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Attorneys for Plaintiff
Epistar Corporation

UNITED STATES DISTRICT COURT

DISTRICT OF NEW JERSEY

Epistar Corporation,	
Plaintiff,	CASE NO.:
v.	*Electronically Filed*
All Star Lighting Supplies, Inc., d/b/a Luxrite,	
Defendant.	

COMPLAINT AND JURY DEMAND

Pursuant to Section 1338 of Title 28 of the United States Code, Plaintiff Epistar Corporation ("Plaintiff" or "Epistar") alleges for its Complaint against All Star Lighting Supplies, Inc., d/b/a Luxrite ("Luxrite" or "Defendant"), on personal knowledge as to Epistar's own actions and on information and belief as to the actions of others, as follows:

NATURE OF THE ACTION

1. This Complaint arises under the patent laws of the United States, Title 35 of the United States Code. This Court has subject matter jurisdiction over this action under 35 U.S.C. § 271 *et seq.,* 28 U.S.C. §§ 1331 and 1338(a).

THE PARTIES

2. Plaintiff Epistar is a Taiwanese corporation with its principal place of business at 21 Li-Hsin Road, Science Park, Hsinchu 300, Taiwan. Epistar is one of the world's leading manufacturers of light-emitting diodes ("LEDs").

3. On information and belief, Defendant Luxrite is a New York corporation having a principal place of business at 33 Randolph Avenue, Avenel, New Jersey 07001-2404.

JURISDICTION AND VENUE

4. The Court may exercise personal jurisdiction over Luxrite because Luxrite has continuous and systematic contacts with the State of New Jersey and, on information and belief, does business in this District.

5. On information and belief, Luxrite maintains its principal place of business in this District at 33 Randolph Avenue, Avenel, New Jersey 07001-2404. *See* Figures 1-2.

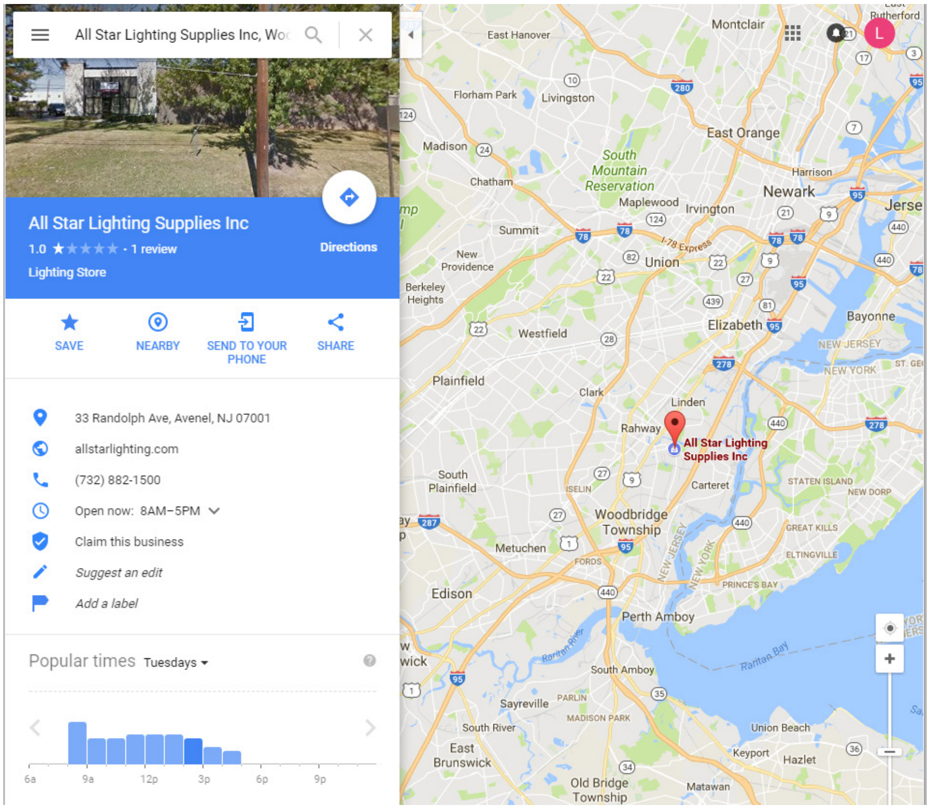

Figure 1.

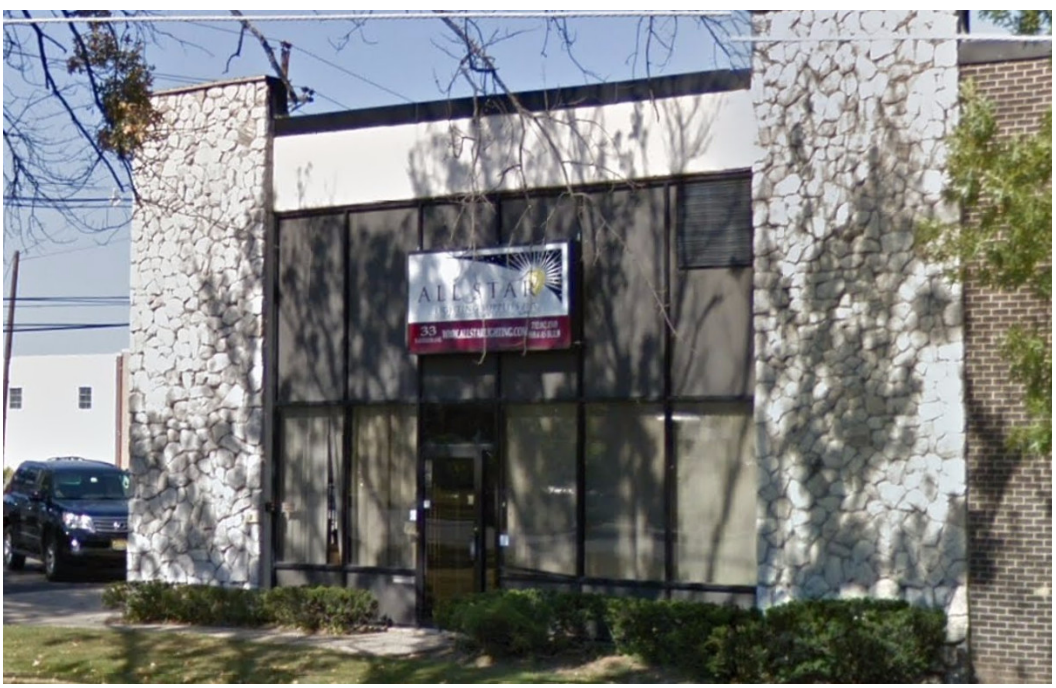

Figure 2.

6. Luxrite conducts business in this District by importing, marketing, offering for sale, and selling its infringing products in this District.

7. Luxrite partners with wholesale distributors and resellers, through Luxrite's website, to sell the infringing LR21205 Light Bulb, Manufacturer Part Number LED4EFC/CL/27K ("the Accused Product") in this District. *See, e.g.*, Figure 3, available at http://www.allstarlighting.com/qquoteadv/index/ (last visited July 25, 2017) ("Please note that All Star Lighting only sells products through wholesale distributors/resalers. If you are not a wholesale distributor or resaler, please send us your quote and we'll direct you to the distributors closest to you.").

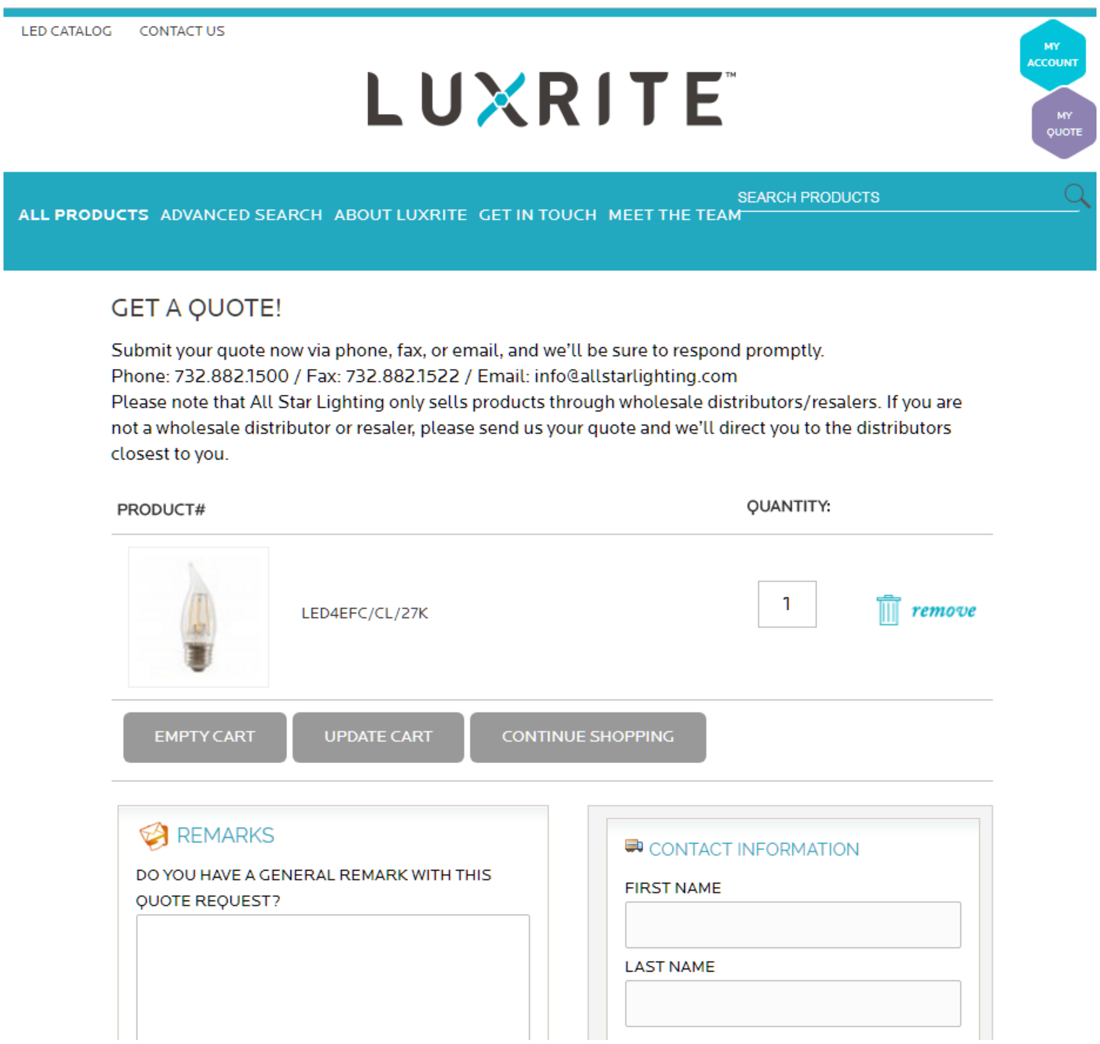

Figure 3.

8. Because Luxrite has availed itself of the privileges of conducting activities in this District, Luxrite is subject to personal jurisdiction in this District.

9. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391(b), (c), (d), and/or 1400(b) because among other things, Luxrite is subject to personal jurisdiction in this District, has committed acts of patent infringement in this District, and continues to commit acts of infringement in this District.

FACTUAL BACKGROUND

10. Epistar brings this action to seek damages arising out of Luxrite's infringement of Epistar's U.S. Patent Nos. 7,355,208; 7,489,068; 7,560,738; 8,791,467; 9,065,022; 9,257,604; 9,488,321; and 9,664,340 (collectively, "the Patents-in-Suit").

Epistar

11. Founded in 1996, Epistar is a worldwide leader in developing, implementing, and providing the technologies behind LED products. Epistar develops and provides a broad range of LED products and services that inject the benefits of solid state lighting into everyday life. Epistar has worked with some of the most well-known brands around the world, popularizing LED applications on cell phone screens, laptops, television, and much more. With approximately 4,100 employees worldwide, Epistar is now one of the largest manufacturers of LEDs in the world.

12. Since its founding, Epistar has been widely recognized as "one of the pioneers in the LED filament industry." *See* http://www.ledinside.com/interview/2016/7/epistar_improves_product_structure_and_profitability_by_specializing_in_niche_led_lighting_applications (last accessed October 12, 2017). During the past two decades, Epistar has invested millions of U.S. dollars, and time and dedication of hundreds of engineers, annually in research and development work, culminating in highly successful LED technologies and ushering in the LED era. Epistar has received numerous industry awards over the years for its innovations in LED technology. Recently, Epistar received an Outstanding Photonics Product Award at the 13^{th} International Nano Exposition for the design of its Flexible LED Lighting System.

13. Epistar LED products are used for a variety of applications, including cell phone screens, laptops, televisions, the automotive industry, and home lighting. Epistar's patented technologies embodied in its LED products inject the benefits of solid state, LED, lighting into everyday life. *See, e.g.*, Figure 4.

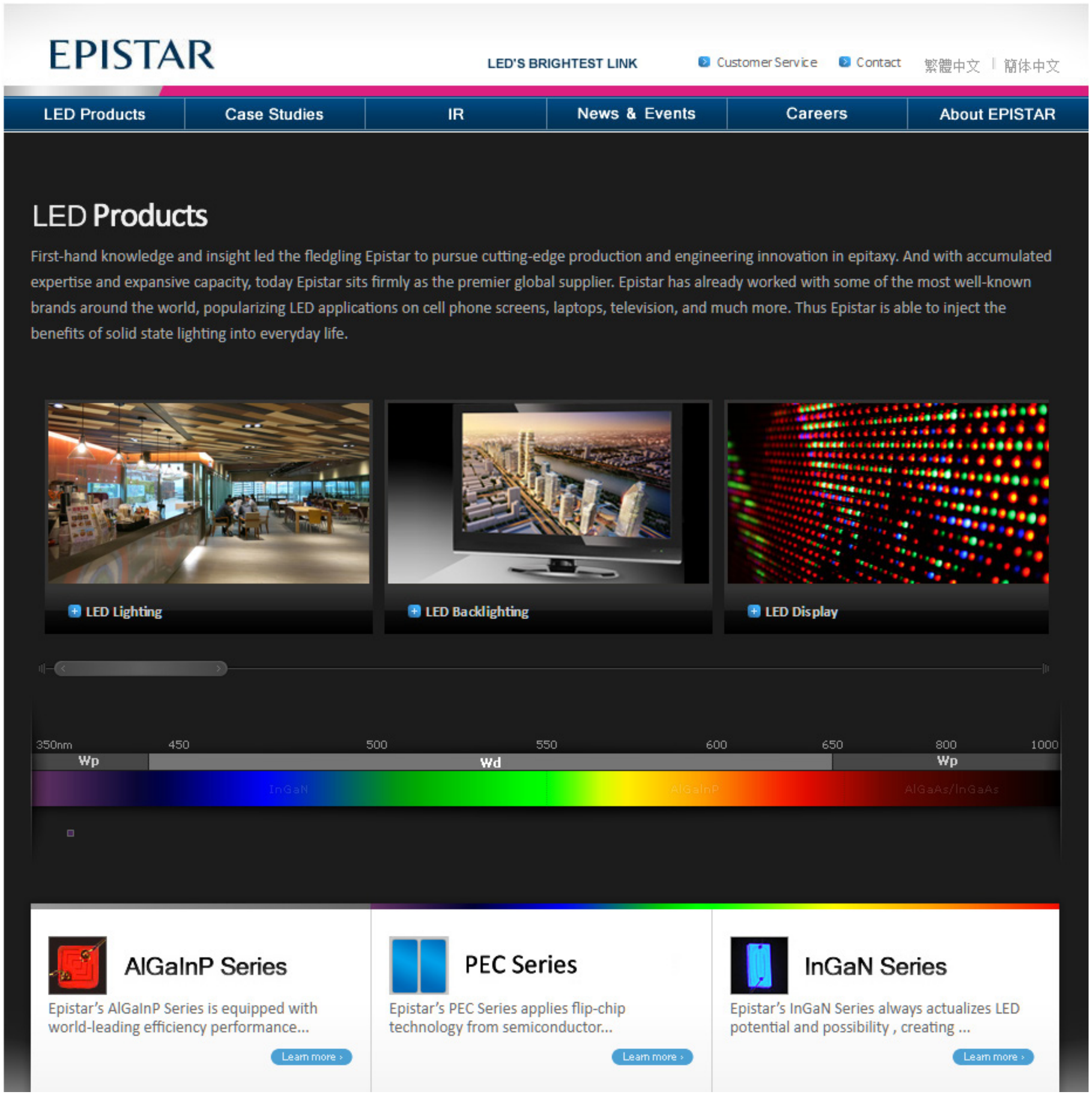

Figure 4.

14. Leading the LED filament evolution, Epistar was one of the earliest companies to acquire related patents including those covering the integration of carrier substrates. To date, Epistar's investment has resulted in over 3,000 patents.

Luxrite

15. On information and belief, Luxrite has its principal place of business in Avenel, New Jersey.

16. On information and belief, Luxrite has and continues to offer for sale and sell infringing LED bulbs since at least as early as May 14, 2015, including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) and similar products ("the Accused Products"). *See, e.g.*, http://www.allstarlighting.com/lr21205.html (last accessed July 25, 2017); *see also* http://www.allstarlighting.com/about-us/ (last accessed October 12, 2017) ("We offer a comprehensive line of energy-efficient LED bulbs, fixtures, and luminaires for every application."); *see also* Figure 5, available at https://web.archive.org/web/20150514055621/http://www.allstarlighting.com:80/led/filament-led.html.

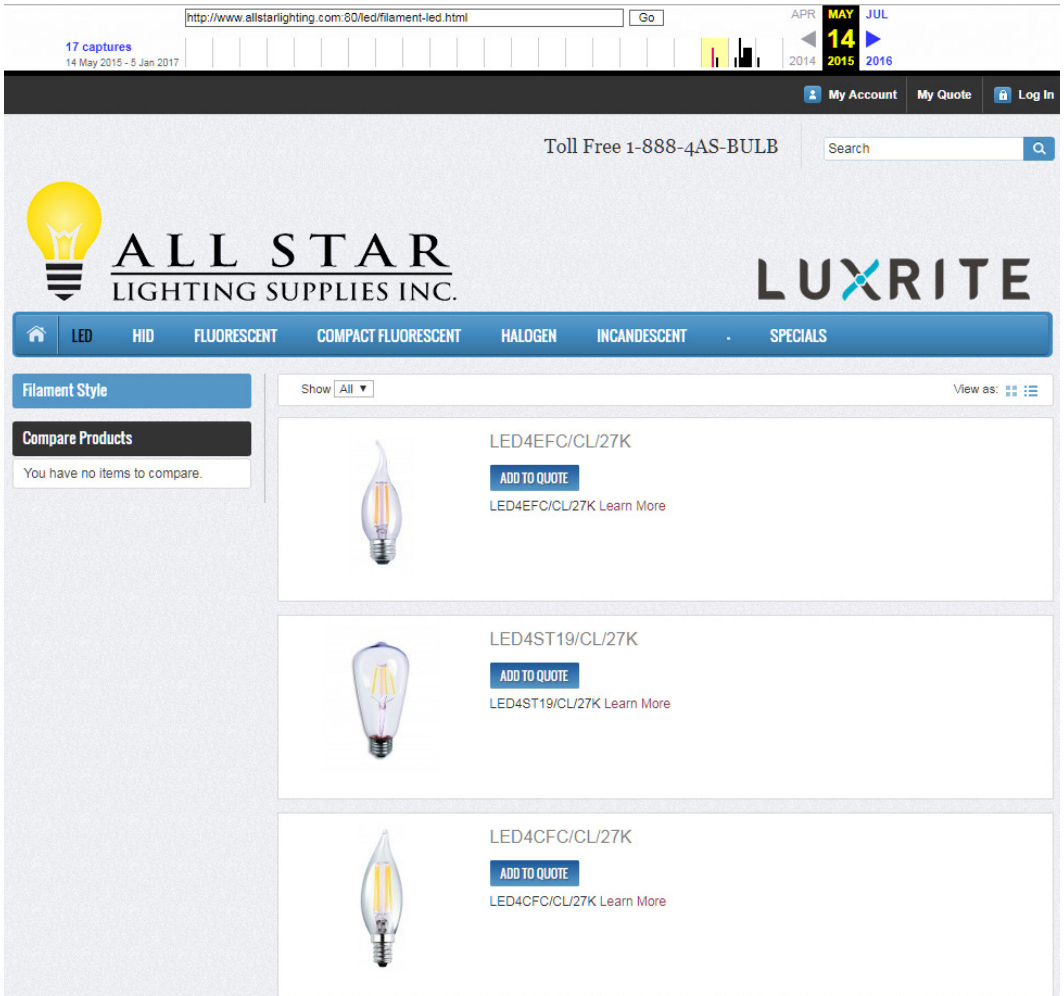

Figure 5.

17. The Accused Products contain a variety of electrical components used to control various aspects of the operation of the LED bulb. The Accused Products are assembled with pre-configured electrical components.

18. As its Amazon web page explains, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb has a "Beautiful Flame Tip LED light bulb that combines the technology of today with the clean decorative look of the past, without producing any heat from the bulb, giving you a nice comfortable atmosphere." *See* https://www.amazon.com/gp/product/B00ZESITM4/ref=ox_sc_act_title_1?smid=A3UAFNSK1EIS6S&psc=1 (last accessed October 12, 2017).

19. The LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb retails for around $7.50 per LED bulb.

The Commercial LED Market

20. With constant innovation in emission efficiency and product design by companies like Epistar, the commercial LED industry is still growing at a promising rate. Industry reports indicate that "LED Lighting market to Worth USD 33.1B as Market Penetration Rate Hit 52% by 2017." *See* http://www.ledinside.com/intelligence/2016/11/ledinside_led_lighting_market_to_worth_usd_33_1b_as_market_penetration_rate_hit_52_by_2017 (last accessed October 12, 2017). "In addition, American major manufacturers are actively developing LED lighting business, with the rising LED lighting penetration rate." *Id.*

The Patents-in-Suit

21. The Patents-in-Suit represent key achievements of Epistar's continuous research and development efforts. These patents enhance the performance of LED filament bulbs and, as a result, help drive demand for Epistar's products.

22. U.S. Patent No. 7,355,208 ("the '208 patent") entitled "Nitride-Based Semiconductor Element and Method of Forming Nitride-Based Semiconductor" issued on April 8, 2008 and lists Masayuki Hata, Tatsuya Kunisato, and Nobuhiko Hayashi as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the '208 patent. A true and correct copy of the '208 patent is attached hereto as Exhibit 1.

23. U.S. Patent No. 7,489,068 ("the '068 patent") entitled "Light Emitting Device" issued on February 10 ,2009 and lists Min-Hsun Hsieh, Ta-Cheng Hsu, Wei-Chih Peng, and Ya-Ju Lee as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the '068 patent. A true and correct copy of the '068 patent is attached hereto as Exhibit 2.

24. U.S. Patent No. 7,560,738 ("the '738 patent") entitled "Light-Emitting Diode Array Having an Adhesive Layer" issued on July 14, 2009 and lists Wen-Huang Liu as inventor. Epistar is the owner and assignee of all right, title, and interest in and to the '738 patent. A true and correct copy of the '738 patent is attached hereto as Exhibit 3.

25. U.S. Patent No. 8,791,467 ("the '467 patent"), entitled "Light Emitting Diode and Method of Making the Same" issued on July 29, 2014 and lists Kuang-Neng Yang as

inventor. Epistar is the owner and assignee of all right, title, and interest in and to the ’467 patent. A true and correct copy of the ’467 patent is attached hereto as Exhibit 4.

26. U.S. Patent No. 9,065,022 (“the ’022 patent”) entitled “Light Emitting Apparatus” issued on June 23, 2015 and lists Chi-Chih Pu, Chen-Hong Lee, Shih-Yu Yeh, Wei-Kang Cheng, Shyi-Ming Pan, Siang-Fu Hong, Chih-Shu Huang, Tzu-Hsiang Wang, Shih-Chieh Tang, and Cheng-Kuang Yang as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the ’022 patent. A true and correct copy of the ’022 patent is attached hereto as Exhibit 5.

27. U.S. Patent No. 9,257,604 (“the ’604 patent”) entitled “Light-Emitting Device Having a Patterned Surface” issued on February 9, 2016 and lists Chen Ou and Chiu-Lin Yao as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the ’604 patent. A true and correct copy of the ’604 patent is attached hereto as Exhibit 6.

28. U.S. Patent No. 9,488,321 (“the ’321 patent”) entitled “Illumination Device with Inclined Light Emitting Element Disposed on a Transparent Substrate” issued on November 8, 2016 and lists Zhi-Ting Ye, Fen-Ren Chien, and Shyi-Ming Pan as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the ’321 patent. A true and correct copy of the ’321 patent is attached hereto as Exhibit 7.

29. U.S. Patent No. 9,664,340 (“the ’340 patent”) entitled “Light Emitting Device” issued on May 30, 2017 and lists Chiu-Lin Yao, Min-Hsun Hsieh, Been-Yu Liaw, Wei-Chiang Hu, Po-Hung Lai, Chun-Hung Liu, Shih-An Liao, Yu-His Sung, and Ming-Chi Hsu as inventors. Epistar is the owner and assignee of all right, title, and interest in and to the ’340 patent. A true and correct copy of the ’340 patent is attached hereto as Exhibit 8.

30. Luxrite has had knowledge of Epistar’s patent portfolio at least as of April 20, 2017. Despite this knowledge, and without making any good-faith efforts to avoid infringing the Patents-in-Suit, Luxrite continues to infringe, and profit from, the Accused Products. Luxrite actively, knowingly, and intentionally sells and offers to sell the Accused Products that infringe on the Patents-in-Suit.

FIRST CAUSE OF ACTION

(Infringement of U.S. Patent No. 7,355,208)

31. Epistar repeats and re-alleges the allegations of paragraphs 1 through 30 in their entirety.

32. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the '208 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the '208 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite's infringement of at least claim 8 of the '208 patent is attached as Exhibit 9. Epistar expects to assert additional claims of the '208 patent.

33. Luxrite has had knowledge of the '208 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '208 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the '208 patent by Luxrite's customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the '208 patent pursuant to 35 U.S.C. § 271(b).

34. Luxrite has had knowledge of the '208 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '208 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '208 patent.

Luxrite has knowingly and intentionally contributorily infringed the ’208 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’208 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’208 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’208 patent pursuant to 35 U.S.C. § 271(c).

35. Unless enjoined by this Court, Luxrite will continue to infringe the ’208 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

36. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’208 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

SECOND CAUSE OF ACTION

(Infringement of U.S. Patent No. 7,489,068)

37. Epistar repeats and re-alleges the allegations of paragraphs 1 through 36 in their entirety.

38. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the ’068 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the ’068 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite’s infringement of at least claim 1 of the ’068 patent is attached as Exhibit 10. Epistar expects to assert additional claims of the ’068 patent.

39. Luxrite has had knowledge of the ’068 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’068 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the ’068 patent by Luxrite’s customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the ’068 patent pursuant to 35 U.S.C. § 271(b).

40. Luxrite has had knowledge of the ’068 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’068 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’068 patent. Luxrite has knowingly and intentionally contributorily infringed the ’068 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’068 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’068 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’068 patent pursuant to 35 U.S.C. § 271(c).

41. Unless enjoined by this Court, Luxrite will continue to infringe the ’068 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

42. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’068 patent,

Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

THIRD CAUSE OF ACTION

(Infringement of U.S. Patent No. 7,560,738)

43. Epistar repeats and re-alleges the allegations of paragraphs 1 through 42 in their entirety.

44. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the ’738 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the ’738 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite’s infringement of at least claim 1 of the ’738 patent is attached as Exhibit 11. Epistar expects to assert additional claims of the ’738 patent.

45. Luxrite has had knowledge of the ’738 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’738 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the ’738 patent by Luxrite’s customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the ’738 patent pursuant to 35 U.S.C. § 271(b).

46. Luxrite has had knowledge of the ’738 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims

of the ’738 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’738 patent. Luxrite has knowingly and intentionally contributorily infringed the ’738 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’738 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’738 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’738 patent pursuant to 35 U.S.C. § 271(c).

47. Unless enjoined by this Court, Luxrite will continue to infringe the ’738 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

48. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’738 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

FOURTH CAUSE OF ACTION

(Infringement of U.S. Patent No. 8,791,467)

49. Epistar repeats and re-alleges the allegations of paragraphs 1 through 48 in their entirety.

50. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the ’467 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the ’467 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite’s

infringement of at least claim 1 of the ’467 patent is attached as Exhibit 12. Epistar expects to assert additional claims of the ’467 patent.

51. Luxrite has had knowledge of the ’467 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’467 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the ’467 patent by Luxrite’s customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the ’467 patent pursuant to 35 U.S.C. § 271(b).

52. Luxrite has had knowledge of the ’467 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’467 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’467 patent. Luxrite has knowingly and intentionally contributorily infringed the ’467 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’467 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’467 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’467 patent pursuant to 35 U.S.C. § 271(c).

53. Unless enjoined by this Court, Luxrite will continue to infringe the ’467 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

54. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite's infringement of the '467 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

FIFTH CAUSE OF ACTION

(Infringement of U.S. Patent No. 9,065,022)

55. Epistar repeats and re-alleges the allegations of paragraphs 1 through 54 in their entirety.

56. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the '022 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the '022 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite's infringement of at least claim 1 of the '022 patent is attached as Exhibit 13. Epistar expects to assert additional claims of the '022 patent.

57. Luxrite has had knowledge of the '022 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '022 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the '022 patent by Luxrite's customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the '022 patent pursuant to 35 U.S.C. § 271(b).

58. Luxrite has had knowledge of the ’022 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’022 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’022 patent. Luxrite has knowingly and intentionally contributorily infringed the ’022 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’022 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’022 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’022 patent pursuant to 35 U.S.C. § 271(c).

59. Unless enjoined by this Court, Luxrite will continue to infringe the ’022 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

60. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’022 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

SIXTH CAUSE OF ACTION

(Infringement of U.S. Patent No. 9,257,604)

61. Epistar repeats and re-alleges the allegations of paragraphs 1 through 60 in their entirety.

62. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the ’604 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb,

without the permission of Epistar. Luxrite is thus liable for direct infringement of the '604 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite's infringement of at least claim 1 of the '604 patent is attached as Exhibit 14. Epistar expects to assert additional claims of the '604 patent.

63. Luxrite has had knowledge of the '604 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '604 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the '604 patent by Luxrite's customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the '604 patent pursuant to 35 U.S.C. § 271(b).

64. Luxrite has had knowledge of the '604 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '604 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '604 patent. Luxrite has knowingly and intentionally contributorily infringed the '604 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the '604 patent, knowing the same to be made or adapted specifically for use in the infringement of the '604 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the '604 patent pursuant to 35 U.S.C. § 271(c).

65. Unless enjoined by this Court, Luxrite will continue to infringe the '604 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at

law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

66. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite's infringement of the '604 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

SEVENTH CAUSE OF ACTION

(Infringement of U.S. Patent No. 9,488,321)

67. Epistar repeats and re-alleges the allegations of paragraphs 1 through 66 in their entirety.

68. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the '321 patent, and continues to infringe in this District, by making, using, selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the '321 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite's infringement of at least claim 1 of the '321 patent is attached as Exhibit 15. Epistar expects to assert additional claims of the '321 patent.

69. Luxrite has had knowledge of the '321 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the '321 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the '321 patent by Luxrite's customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the

infringing technology. Luxrite is therefore liable for indirect infringement of the ’321 patent pursuant to 35 U.S.C. § 271(b).

70. Luxrite has had knowledge of the ’321 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’321 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’321 patent. Luxrite has knowingly and intentionally contributorily infringed the ’321 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’321 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’321 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’321 patent pursuant to 35 U.S.C. § 271(c).

71. Unless enjoined by this Court, Luxrite will continue to infringe the ’321 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

72. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’321 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

EIGHTH CAUSE OF ACTION

(Infringement of U.S. Patent No. 9,664,340)

73. Epistar repeats and re-alleges the allegations of paragraphs 1 through 72 in their entirety.

74. Luxrite has infringed, either literally and/or under the doctrine of equivalents, one or more claims of the ’340 patent, and continues to infringe in this District, by making, using,

selling, offering for sale, and/or importing into the United States products including, but not limited to, the LR21205 40 W Equivalent Incandescent Warm White Chandelier Light Bulb, without the permission of Epistar. Luxrite is thus liable for direct infringement of the ’340 patent pursuant to 35 U.S.C. § 271(a). A representative claim chart detailing Luxrite’s infringement of at least claim 1 of the ’340 patent is attached as Exhibit 16. Epistar expects to assert additional claims of the ’340 patent.

75. Luxrite has had knowledge of the ’340 patent and that the products and systems identified herein infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’340 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has knowingly and intentionally induced and encouraged the direct infringement of the ’340 patent by Luxrite’s customers, resellers, retailers, and end users by intentionally directing them and encouraging them to make, use, sell, and/or offer to sell within the United States and/or to import into the United States one or more devices that embody the patented invention and that incorporate the accused products and systems identified above. On information and belief, Luxrite provides support to instruct its customers on how to use the infringing technology. Luxrite is therefore liable for indirect infringement of the ’340 patent pursuant to 35 U.S.C. § 271(b).

76. Luxrite has had knowledge of the ’340 patent and that the products and systems identified infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’340 patent, at least as of the filing of this complaint and/or has been willfully blind. Luxrite has and continues to contributorily infringe, and will continue to contributorily infringe, either literally and/or under the doctrine of equivalents, one or more claims of the ’340 patent. Luxrite has knowingly and intentionally contributorily infringed the ’340 patent by offering to sell, selling, and/or importing into the United States a component constituting a material part of the invention disclosed in the ’340 patent, knowing the same to be made or adapted specifically for use in the infringement of the ’340 patent, and not a staple article or commodity of commerce suitable for substantial non-infringing use. Luxrite is therefore liable for indirect infringement of the ’340 patent pursuant to 35 U.S.C. § 271(c).

77. Unless enjoined by this Court, Luxrite will continue to infringe the ’340 patent, and Epistar will continue to suffer irreparable harm for which there is no adequate remedy at law. Accordingly, Epistar is entitled to preliminary and permanent injunctive relief against such infringement pursuant to 35 U.S.C. § 283.

78. Luxrite acted in a manner that was willful, malicious, in bad-faith, deliberate, consciously wrongful, or flagrant. As a result of Luxrite’s infringement of the ’340 patent, Epistar has been and continues to be irreparably injured in its business and property rights, and is entitled to recover damages for such injuries pursuant to 35 U.S.C. § 284 in an amount to be determined at trial.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff requests entry of judgment in its favor and against Luxrite as follows:

a. That Luxrite is liable for infringement, contributing to the infringement, and/or inducing the infringement of one or more claims of the Patents-in-Suit, as alleged herein;

b. That such infringement is willful;

c. That Luxrite and its parents, subsidiaries, affiliates, successors, predecessors, assigns, and the officers, directors, agents, servants, and employees of each of the foregoing, customers and/or licensees and those persons acting in concert or participation with any of them, are enjoined and restrained from continued infringement, including but not limited to using, making, importing, offering for sale and/or selling products that infringe, and from contributorily and/or inducing the infringement of the Patents-in-Suit prior to their expiration, including any extensions;

d. An Order directing Luxrite to file with this Court and serve upon Plaintiff’s counsel within 30 days after the entry of the Order of Injunction a report setting forth the manner and form in which Luxrite has complied with the injunction;

e. An award of damages adequate to compensate Plaintiff for the infringement that has occurred, in accordance with 35 U.S.C. § 284, in lost profits, price erosion and/or reasonable royalty, including pre-judgment and post-judgment interest at the highest rates allowed by law;

f. An accounting and/or supplemental damages for all damages occurring after any discovery cutoff and through the Court's decision regarding the imposition of a permanent injunction;

g. An award of attorneys' fees based on this being an exceptional case pursuant to 35 U.S.C. § 285, including prejudgment interest on such fees;

h. Costs and expenses in this action;

i. Such other and further relief, in law and in equity, as this Court may deem just and appropriate.

DEMAND FOR JURY TRIAL

Pursuant to Rule 38(b) of the Federal Rules of Civil Procedure and Civil Rule 38.1 of the District of New Jersey Local Civil Rules, Plaintiff Epistar Corporation demands a trial by jury for any issues so triable.

Respectfully submitted,

Dated: October 13, 2017

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LOCAL CIVIL RULE 11.2 CERTIFICATION

Plaintiff Epistar Corporation hereby certifies that, to its knowledge, the matter in controversy in this action is not the subject of any other pending lawsuit, arbitration, or administrative proceeding.

Respectfully submitted,

Dated: October 13, 2017

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Exhibit 1

US007355208B2

(12) **United States Patent**
Hata et al.

(10) **Patent No.: US 7,355,208 B2**
(45) **Date of Patent: Apr. 8, 2008**

(54) **NITRIDE-BASED SEMICONDUCTOR ELEMENT AND METHOD OF FORMING NITRIDE-BASED SEMICONDUCTOR**

(75) Inventors: **Masayuki Hata**, Kadoma (JP); **Tatsuya Kunisato**, Takatsuki (JP); **Nobuhiko Hayashi**, Osaka (JP)

(73) Assignee: **Sanyo Electric Co., Ltd.**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/195,637**

(22) Filed: **Aug. 3, 2005**

(65) **Prior Publication Data**

US 2005/0263778 A1 Dec. 1, 2005

Related U.S. Application Data

(62) Division of application No. 10/081,180, filed on Feb. 25, 2002, now Pat. No. 6,994,751.

(30) **Foreign Application Priority Data**

Feb. 27, 2001 (JP) 2001-51348

(51) **Int. Cl.**
H01L 27/15 (2006.01)

(52) **U.S. Cl.** **257/79**; 257/618

(58) **Field of Classification Search** 257/79, 257/618

See application file for complete search history.

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Primary Examiner—Mark V. Prenty
(74) *Attorney, Agent, or Firm*—McDermott Will & Emery LLP

(57) **ABSTRACT**

A nitride-based semiconductor element having superior mass productivity and excellent element characteristics is obtained. This nitride-based semiconductor element comprises a substrate comprising a surface having projection portions, a mask layer formed to be in contact with only the projection portions of the surface of the substrate, a first nitride-based semiconductor layer formed on recess portions of the substrate and the mask layer and a nitride-based semiconductor element layer, formed on the first nitride-based semiconductor layer, having an element region. Thus, the first nitride-based semiconductor layer having low dislocation density is readily formed on the projection portions of the substrate and the mask layer through the mask layer serving for selective growth. When the nitride-based semiconductor element layer having the element region is grown on the first nitride-based semiconductor layer having low dislocation density, a nitride-based semiconductor element having excellent element characteristics can be readily obtained. The first nitride-based semiconductor layer is formed through only single growth on the substrate, whereby a nitride-based semiconductor element having excellent mass productivity is obtained.

20 Claims, 14 Drawing Sheets

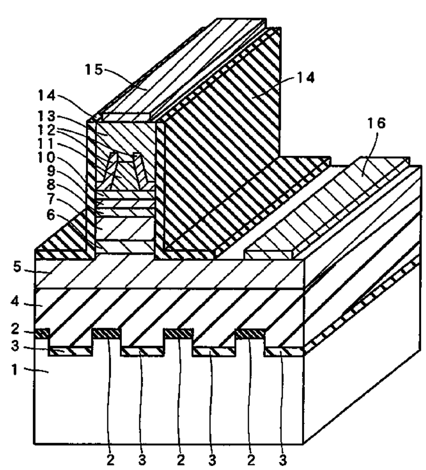

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FIG.1

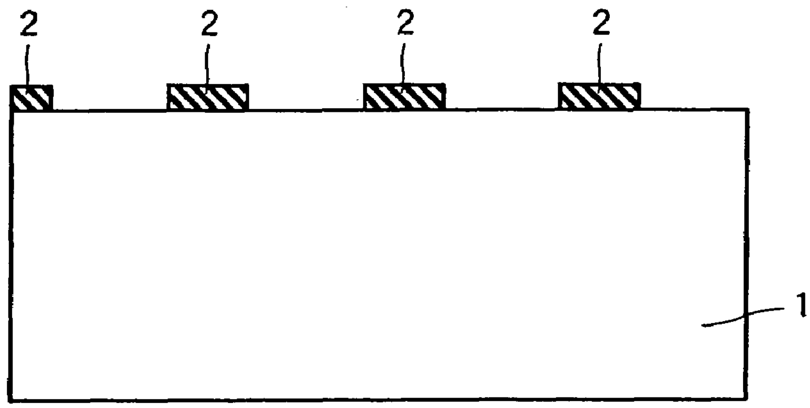


FIG.2

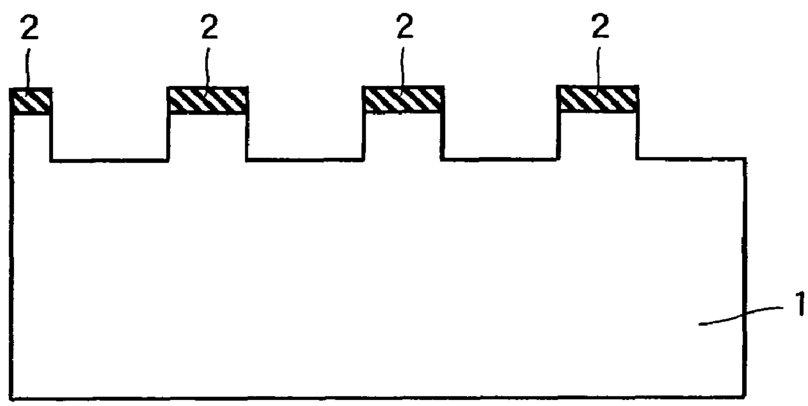


FIG.3

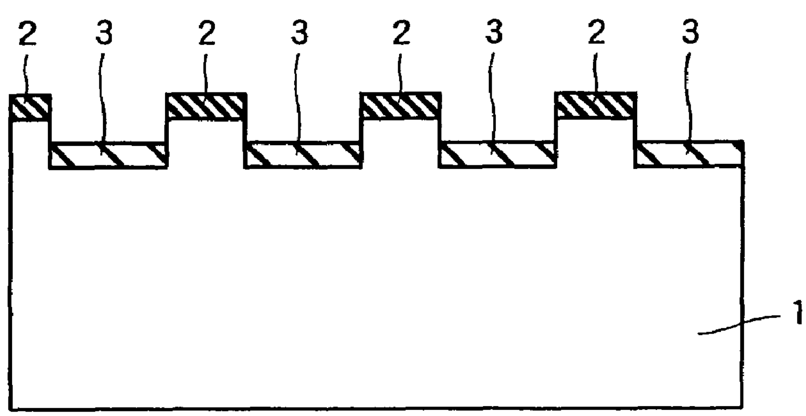


FIG.4

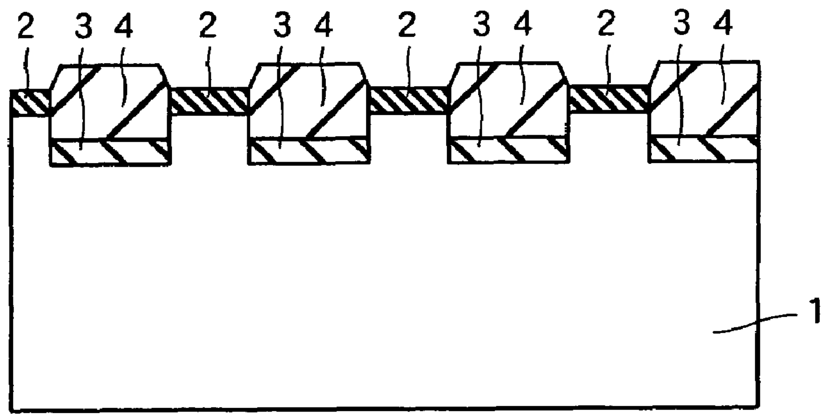


FIG.5

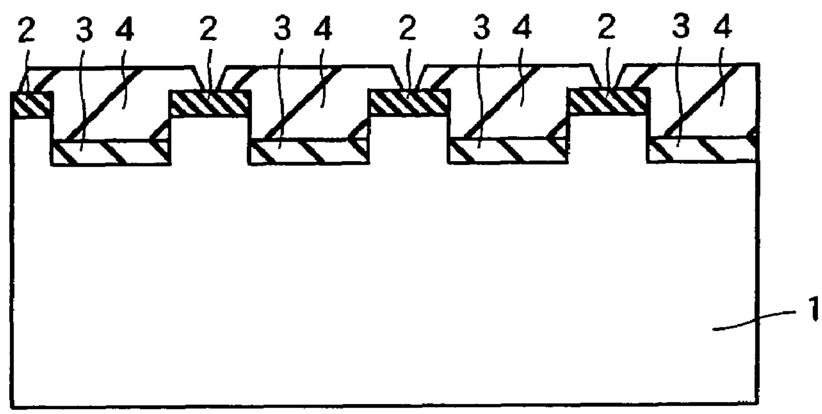


FIG.6

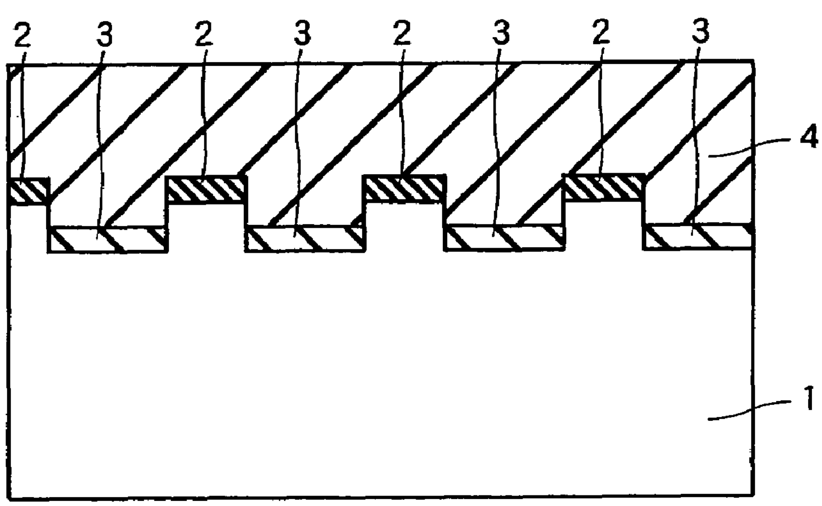


FIG.7

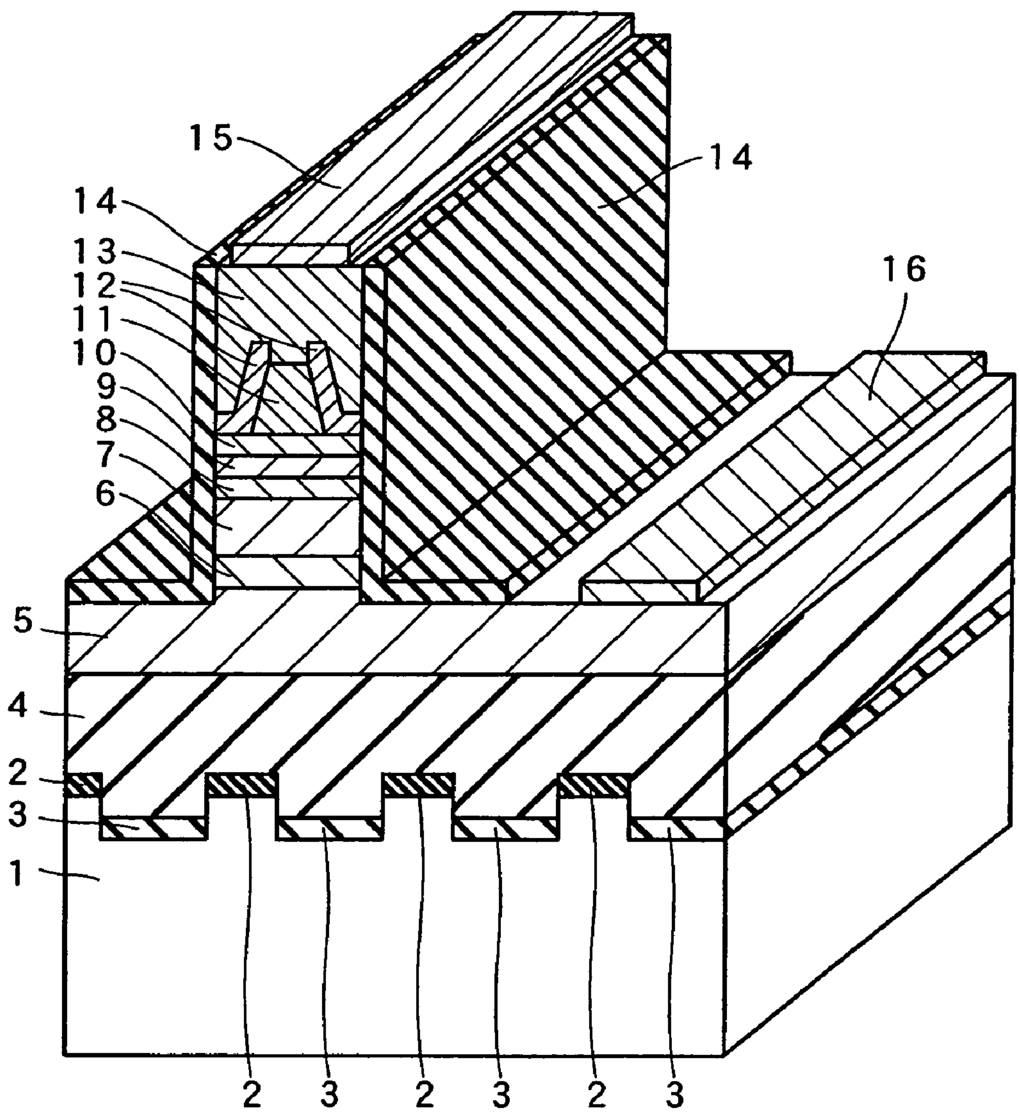


FIG.8

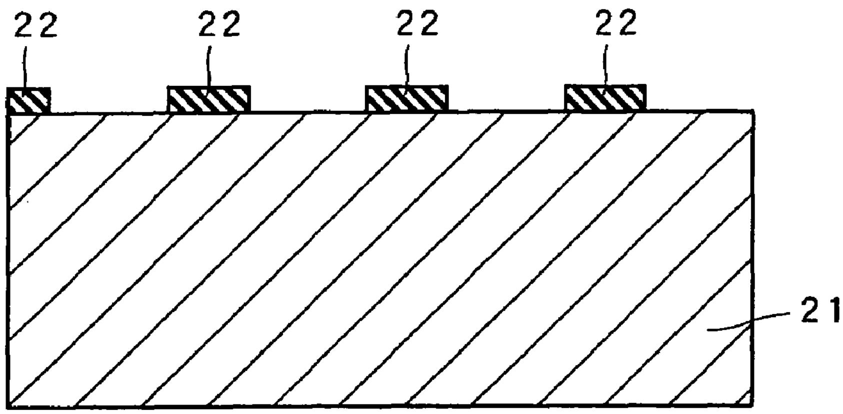


FIG.9

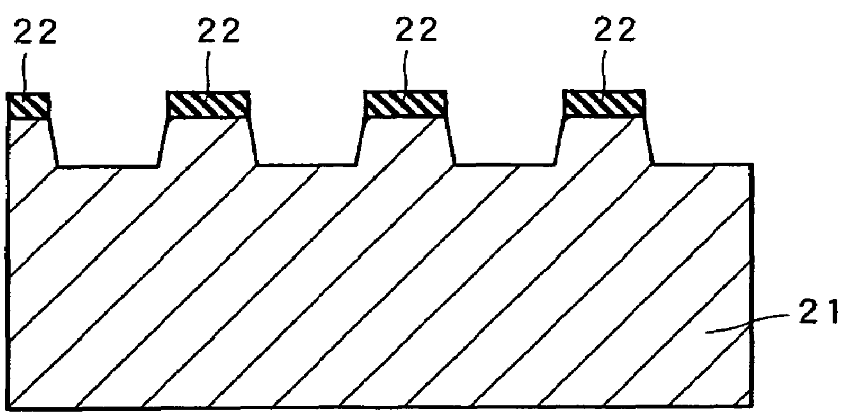


FIG.10

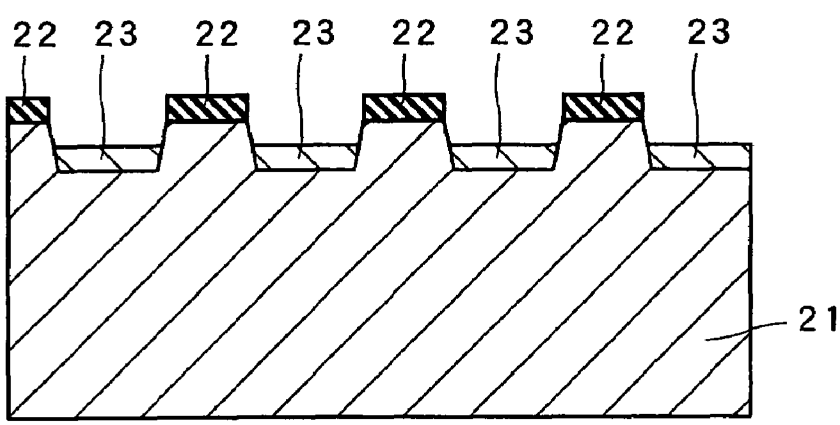


FIG.11

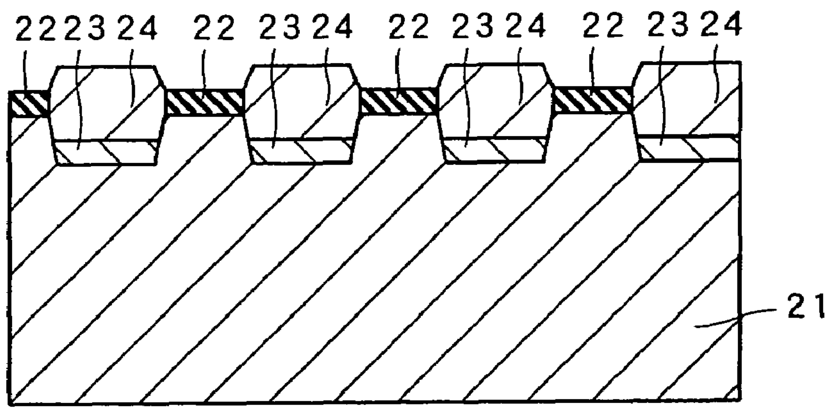


FIG.12

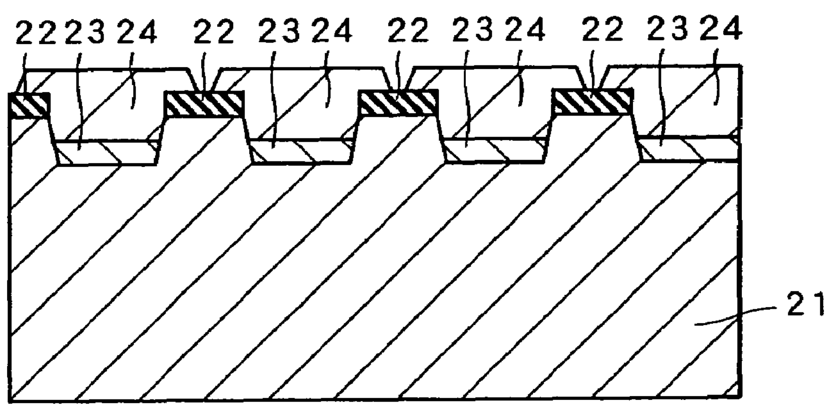


FIG.13

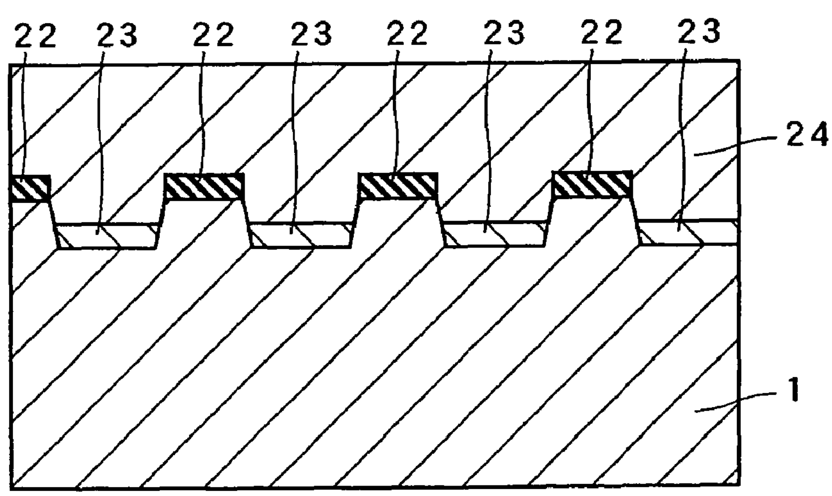


FIG.14

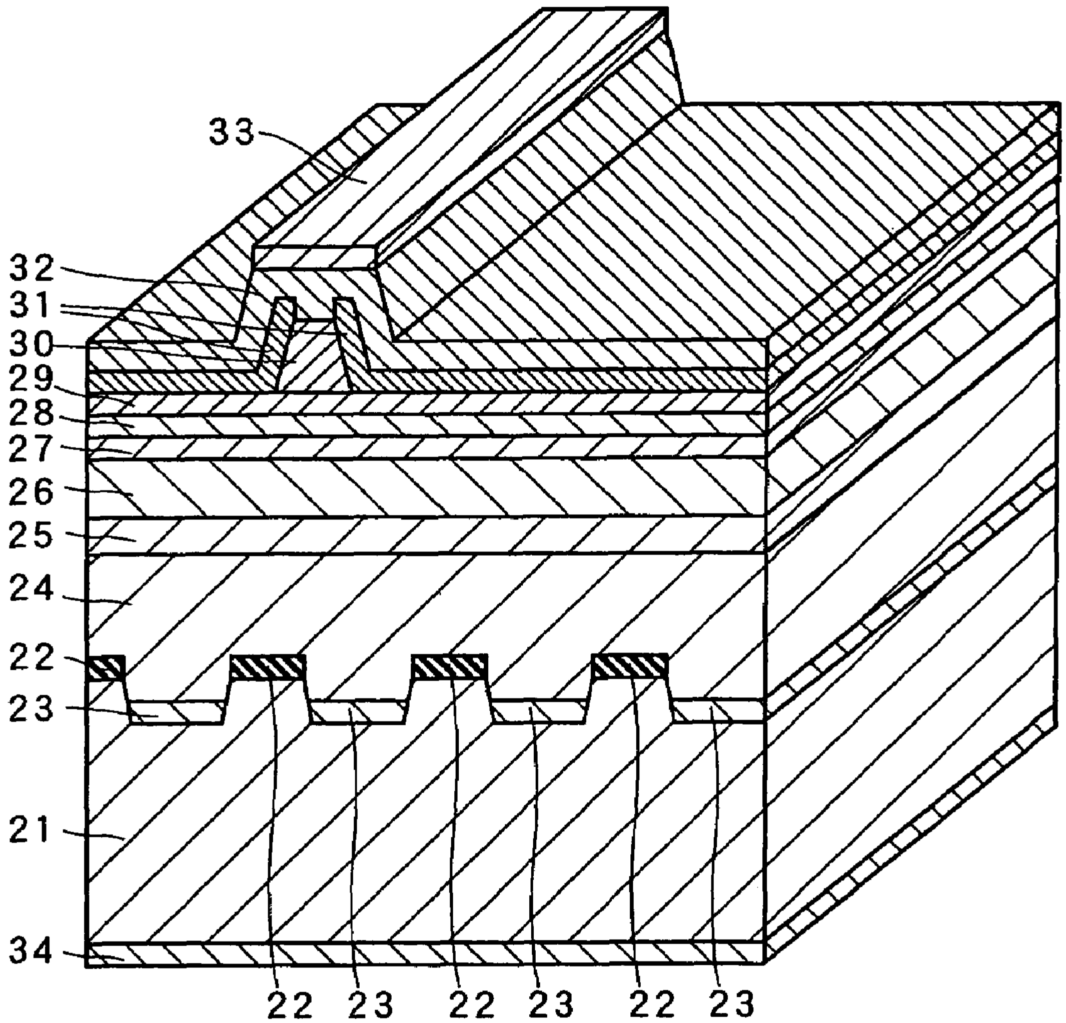


FIG.15

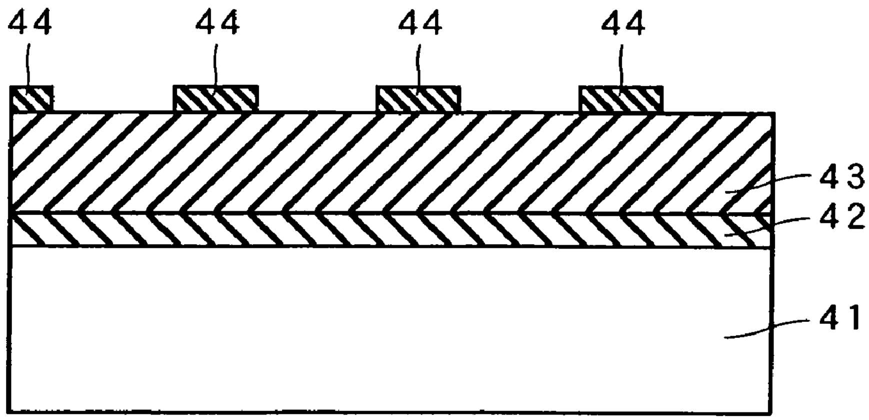


FIG.16

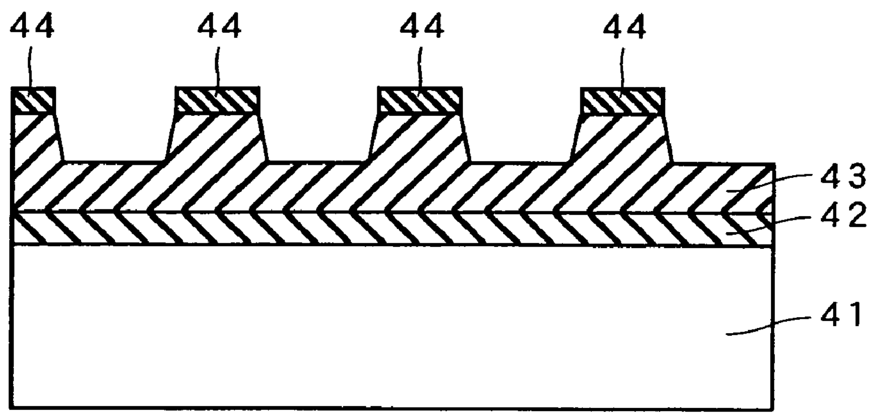


FIG.17

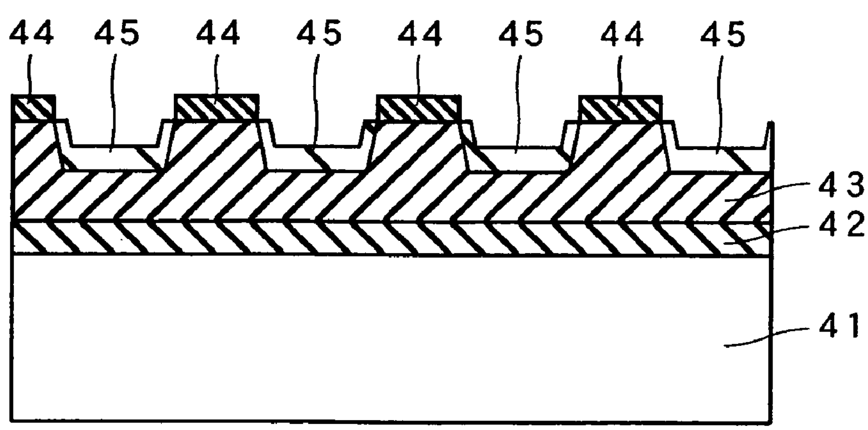


FIG.18

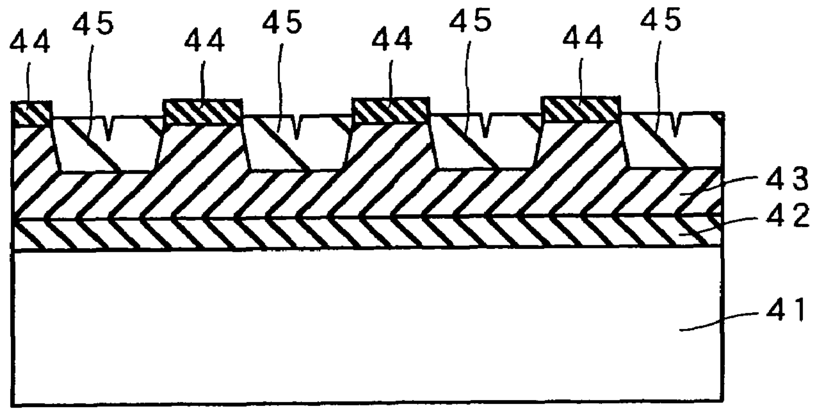


FIG.19

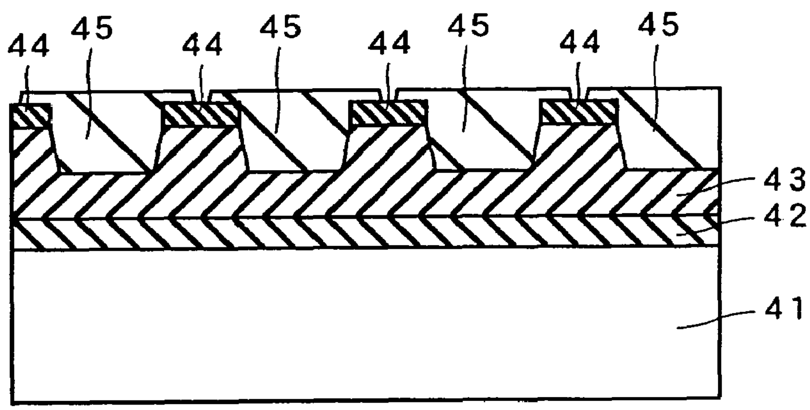


FIG.20

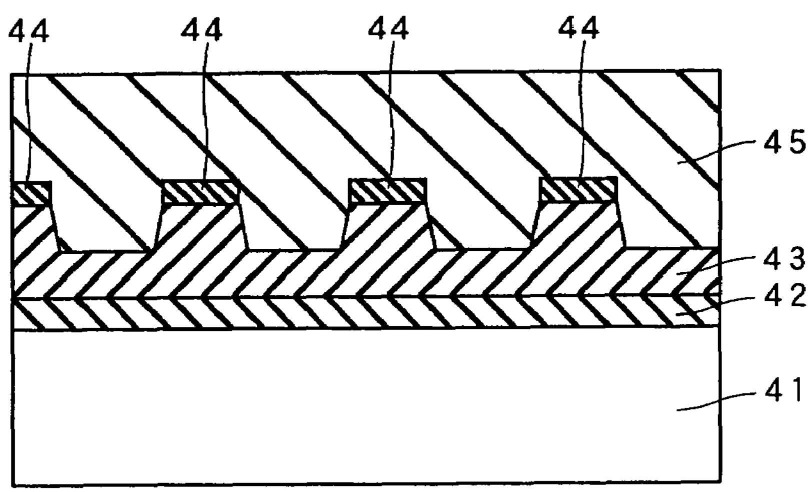


FIG.21

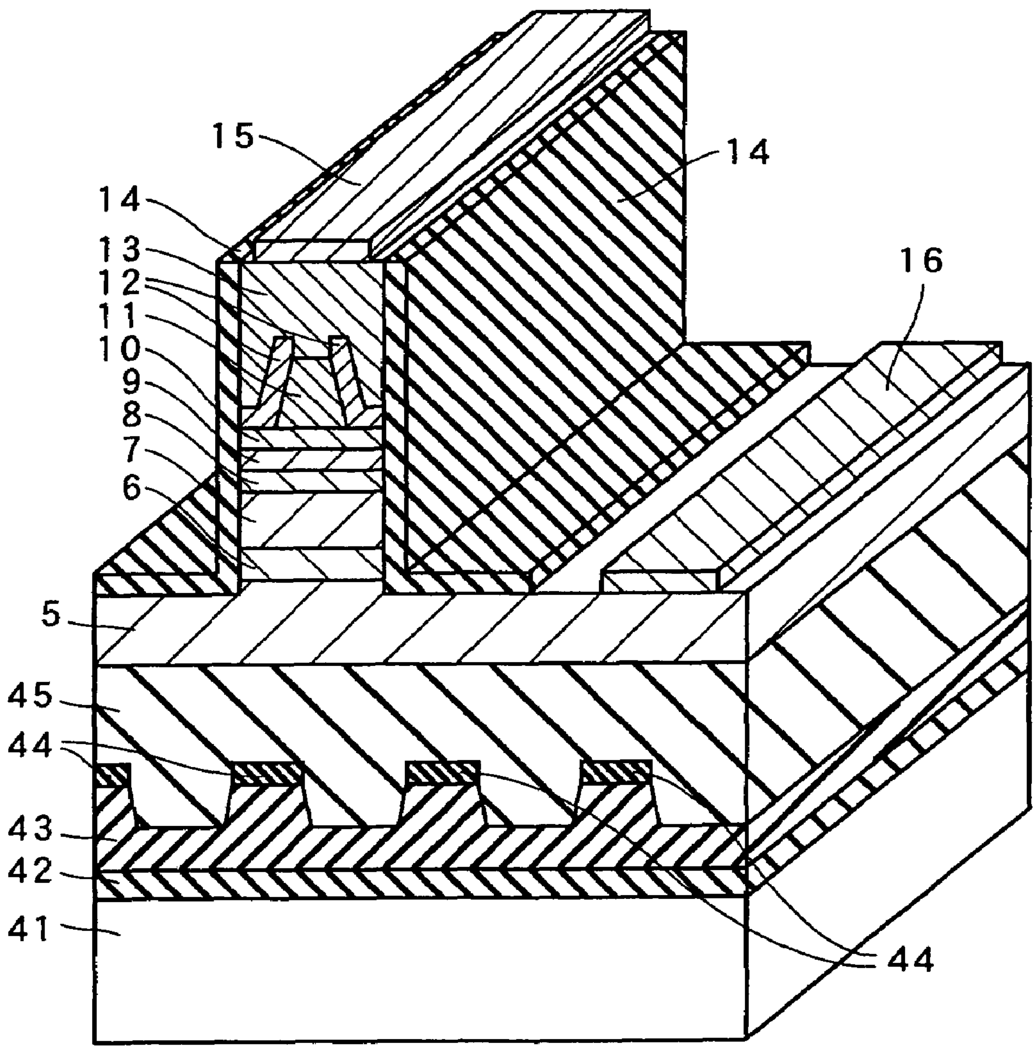


FIG.22

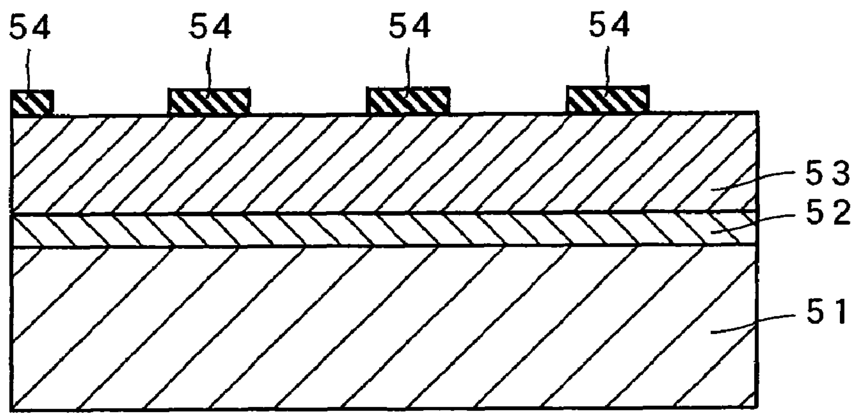


FIG.23

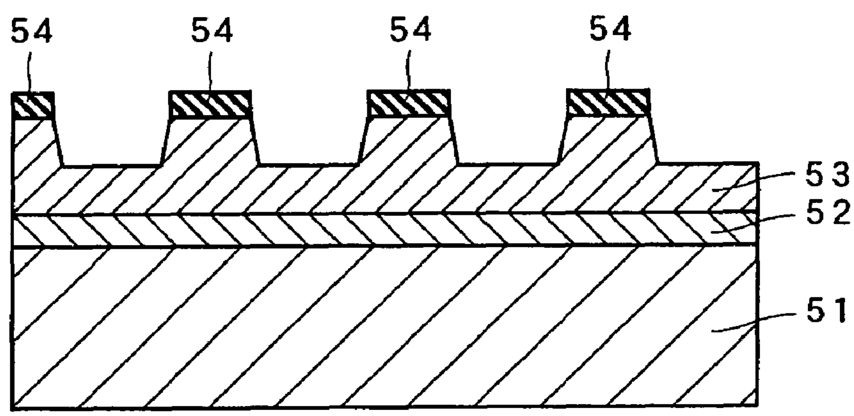


FIG.24

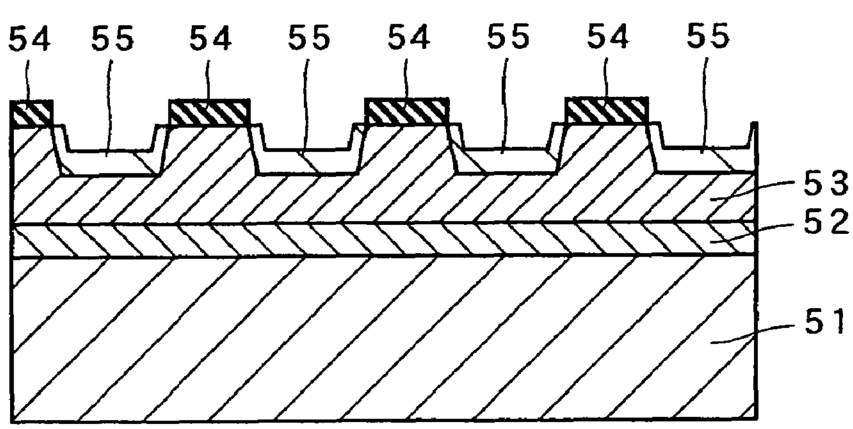


FIG.25

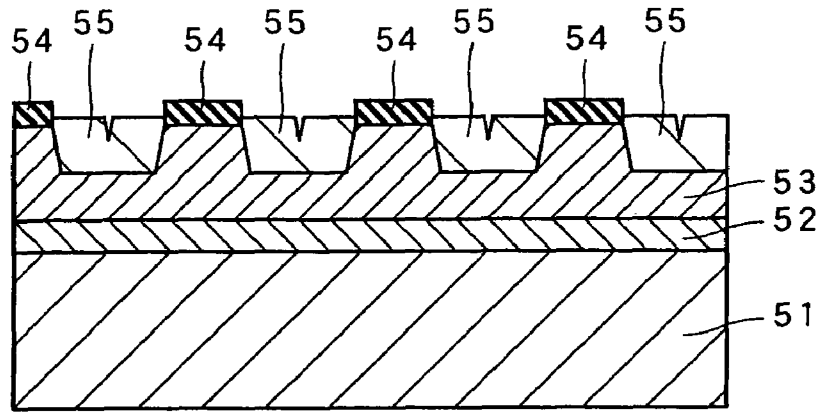


FIG.26

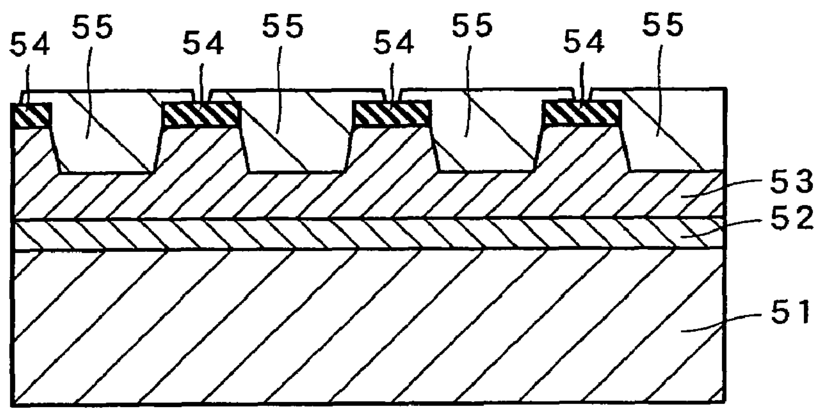


FIG.27

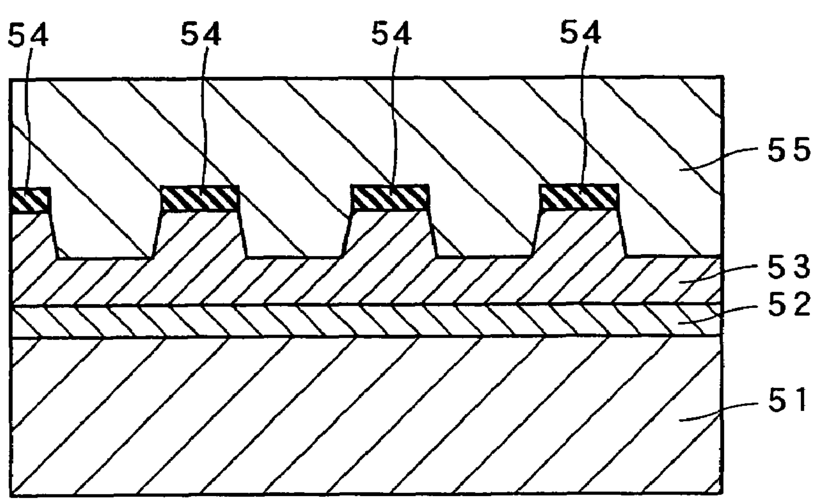


FIG.28

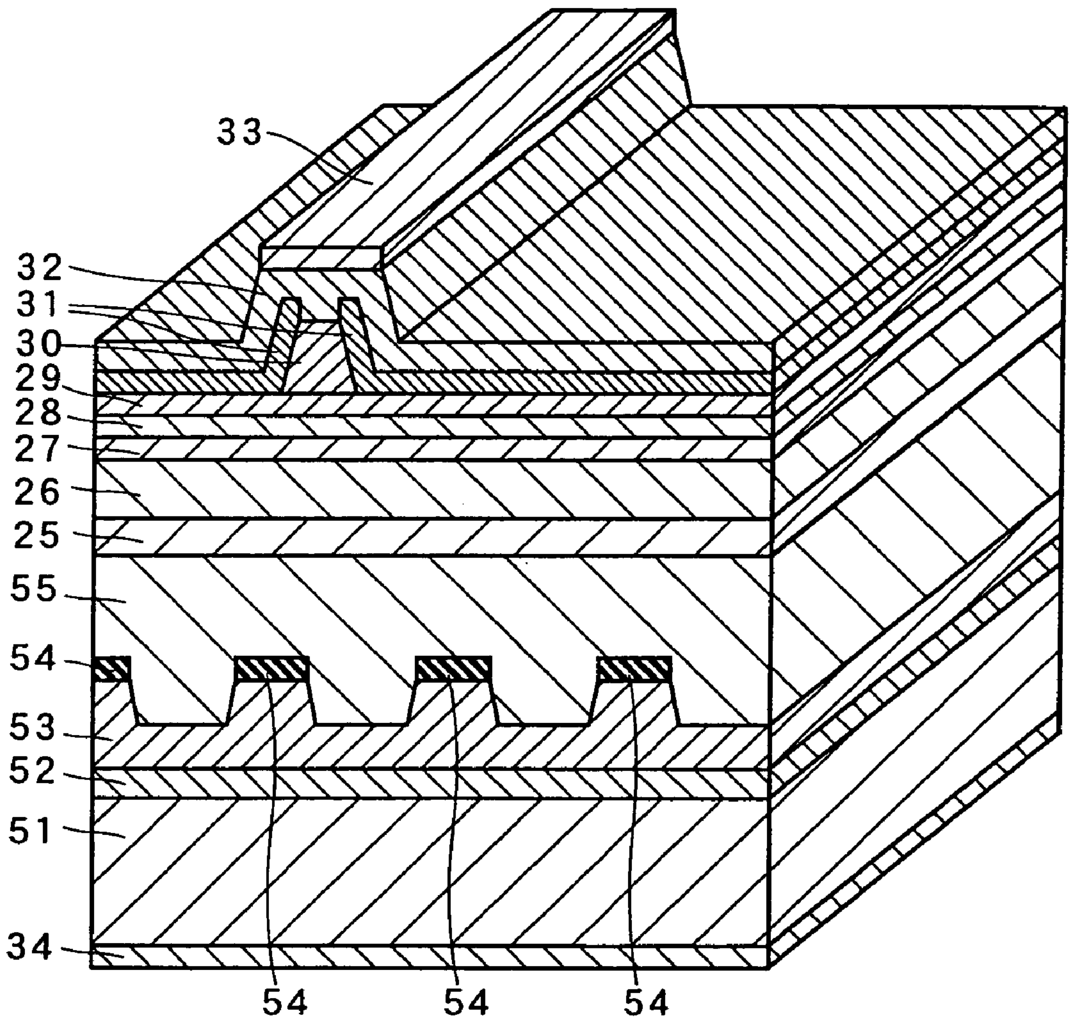


FIG.29 PRIOR ART

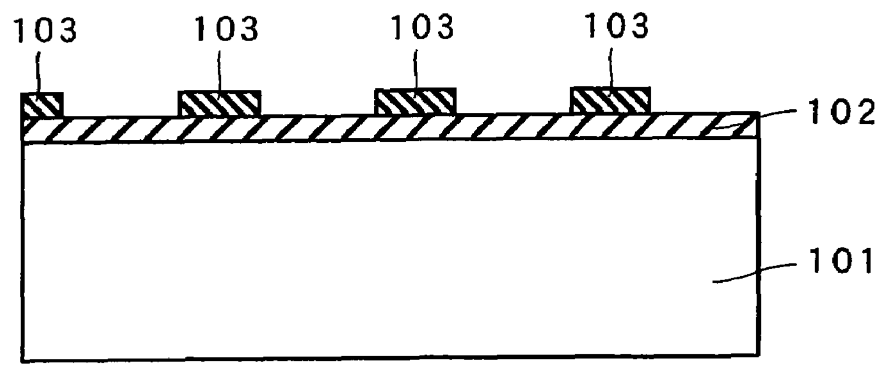


FIG.30 PRIOR ART

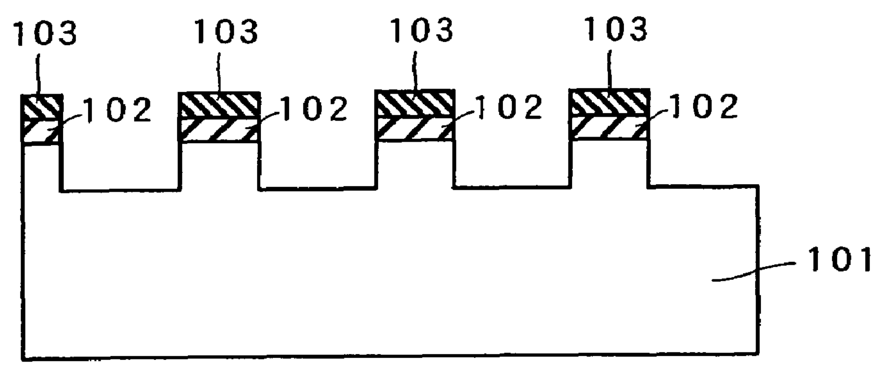


FIG.31 PRIOR ART

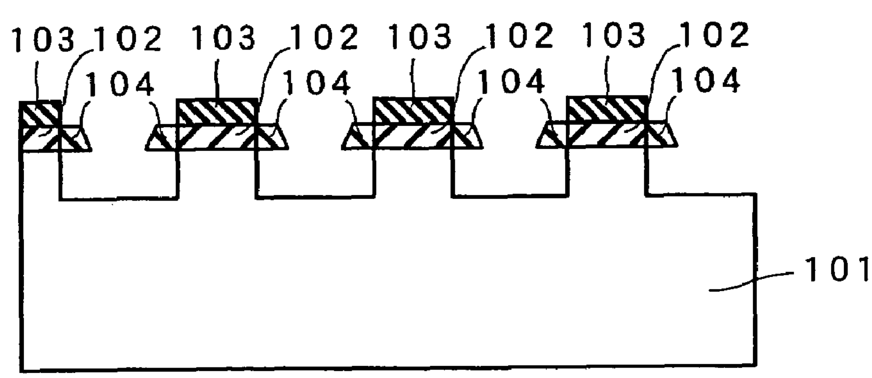


FIG.32 PRIOR ART

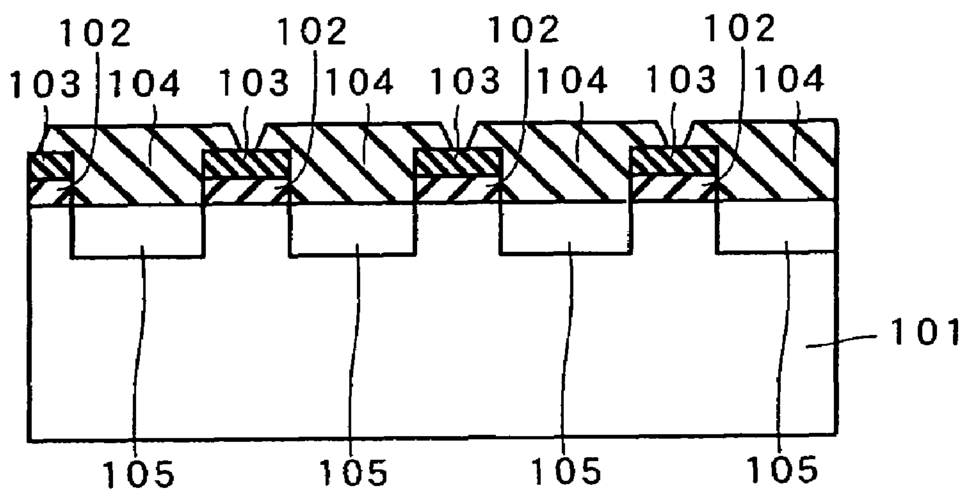
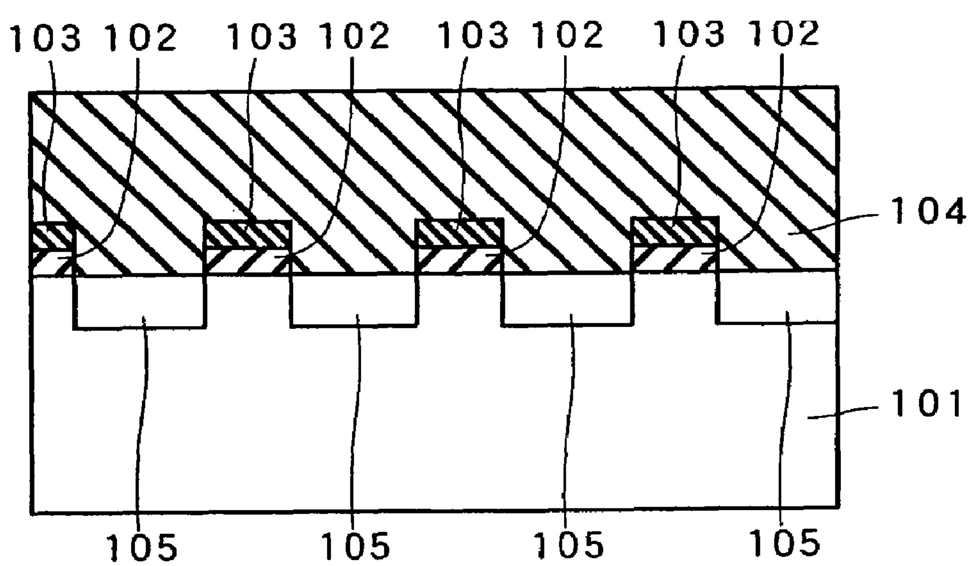


FIG.33 PRIOR ART



NITRIDE-BASED SEMICONDUCTOR ELEMENT AND METHOD OF FORMING NITRIDE-BASED SEMICONDUCTOR

RELATED APPLICATION

This application is a divisional of U.S. application Ser. No. 10/081,180 filed on Feb. 25, 2002 which is U.S. Pat. No. 6,994,751.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a nitride-based semiconductor element and a method of forming a nitride-based semiconductor, and more specifically, it relates to a nitride-based semiconductor element including a nitride-based semiconductor layer formed by epitaxial lateral overgrowth and a method of forming a nitride-based semiconductor.

2. Description of the Prior Art

In recent years, a nitride-based semiconductor element utilizing a group III nitride-based semiconductor is actively developed as a semiconductor element employed for a semiconductor light-emitting device such as a light-emitting diode device or a semiconductor laser device or an electronic device such as a transistor. In order to fabricate such a nitride-based semiconductor element, a nitride-based semiconductor layer is epitaxially grown on a substrate consisting of sapphire or the like.

In this case, the substrate of sapphire or the like and the nitride-based semiconductor layer have different lattice constants and hence the nitride-based semiconductor layer grown on the substrate of sapphire or the like has dislocations (lattice defects) vertically extending from the substrate to the surface of the semiconductor layer. Such dislocations in the nitride-based semiconductor layer result in deterioration of the element characteristics of the semiconductor element and reduction of the reliability thereof.

As a method of reducing the density of the aforementioned dislocations in the nitride-based semiconductor layer, epitaxial lateral growth is generally proposed. This epitaxial lateral growth is disclosed in International Workshop on Nitride Semiconductors—IWN2000—, Nagoya, Japan, 2000, p. 79, for example.

FIGS. **29** to **33** are sectional views for illustrating a conventional method of forming a nitride-based semiconductor employing epitaxial lateral overgrowth. The conventional method of forming a nitride-based semiconductor employing epitaxial lateral overgrowth is now described with reference to FIGS. **29** to **33**.

First, a GaN layer **102** for serving as an underlayer is formed on a substrate **101** consisting of sapphire or SiC, as shown in FIG. **29**. Then, mask layers **103** are formed on prescribed regions of the GaN layer **102**.

Then, portions of the GaN layer **102** located under regions formed with no mask layers **103** are removed by etching while etching the substrate **101** by a thickness in the range not reaching the bottom surface thereof through the mask layers **103** serving for etching in this process. Thus, the substrate **101** is brought into a ridged shape, while stripe-patterned GaN layers **102** to be in contact substantially with the overall upper surfaces of projection potions of the substrate **101**, as shown in FIG. **30**.

Then, undoped GaN layers **104** are re-grown from exposed side surfaces, serving as seed crystals, of the GaN layers **102**, as shown in FIG. **31**. The undoped GaN layers **104** are laterally grown in an initial stage. From the state shown in FIG. **31**, the undoped GaN layers **104** are grown upward while laterally growing on the mask layers **103** serving for selective growth in this process, as shown in FIG. **32**. At this time, voids **105** are formed between the undoped GaN layers **104** and the bottom surfaces of recess portions of the substrate **101**. The undoped GaN layers **104** laterally growing on the mask layers **103** coalesce into a continuous undoped GaN layer **104** having a flattened surface, as shown in FIG. **33**.

In the conventional method of forming a nitride-based semiconductor, as hereinabove described, the undoped GaN layer **102** is formed by epitaxial lateral overgrowth from the exposed side surfaces of the GaN layers **102** serving as seed crystals, whereby lattice defects are scarcely propagated from the GaN layers **102** to a portion around the surface of the undoped GaN layer **104**. Thus, the undoped GaN layer **104** reduced in dislocation density is obtained. When a nitride-based semiconductor element layer (not shown) having an element region is formed on such an undoped GaN layer **104** reduced in dislocation density, a nitride-based semiconductor element having excellent crystallinity can be formed.

In the aforementioned conventional method of forming a nitride-based semiconductor employing epitaxial lateral overgrowth, however, the substrate **101** is brought into the ridged shape by removing the portions of the GaN layers **102** located under the regions formed with no mask layers **103** by etching and thereafter further etching the substrate **101**. In general, therefore, the layers GaN **102**, which are hardly etched nitride-based semiconductor layers, must be etched along the overall thicknesses thereof while the surface of the substrate **101** must also be etched. Thus, the etching time for bringing the substrate **101** into the ridged shape is disadvantageously increased. Consequently, the nitride-based semiconductor is disadvantageously reduced in mass productivity.

In the aforementioned conventional method of forming a nitride-based semiconductor employing epitaxial lateral overgrowth, further, the undoped GaN layer **104** is formed by growing the GaN layers **102** serving as underlayers on the substrate **101** and thereafter epitaxially laterally overgrowing the GaN layers **102**. Therefore, this method requires two crystal growth steps for the GaN layers **102** and the undoped GaN layer **104**. In general, therefore, the nitride-based semiconductor is reduced in mass productivity also in this point.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a nitride-based semiconductor element having superior mass productivity and excellent element characteristics.

Another object of the present invention is to provide a method of forming a nitride-based semiconductor capable of obtaining a nitride-based semiconductor layer having excellent mass productivity and low dislocation density.

A nitride-based semiconductor element according to a first aspect of the present invention comprises a substrate comprising a surface having projection portions, a mask layer formed to be in contact with only the projection portions of the surface of the substrate, a first nitride-based semiconductor layer formed on recess portions of the substrate and the mask layer, and a nitride-based semiconductor element layer, formed on the first nitride-based semiconductor layer, having an element region.

The nitride-based semiconductor element according to the first aspect is provided with the substrate comprising a surface having projection portions and the mask layer formed to be in contact with only the projection portions of the surface of the substrate as hereinabove described, whereby the first nitride-based semiconductor layer having low dislocation density can be readily formed on the recess potions of the substrate and the mask layer through the mask layer serving for selective growth. When the nitride-based semiconductor element layer having the element region is grown on the first nitride-based semiconductor layer having low dislocation density, a nitride-based semiconductor element having excellent element characteristics can be readily obtained. Further, only the surface of the substrate may be etched for forming the projection portions. Thus, the etching time for forming the projection portions can be reduced. According to the first aspect, further, the first nitride-based semiconductor layer can be formed through single growth on the substrate. Consequently, a nitride-based semiconductor element having excellent mass productivity can be obtained.

In the aforementioned nitride-based semiconductor element according to the first aspect, the substrate preferably includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate and a quartz substrate. In this case, the substrate preferably includes a sapphire substrate, while the mask layer and the projection portions of the surface of the substrate are preferably formed in the shape of stripes being parallel to the [1-100] direction of the sapphire substrate. The substrate preferably includes an Si substrate, and the mask layer and the projection portions of the surface of the substrate are preferably formed in the shape of stripes being parallel to the [1-10] direction of the Si substrate.

The aforementioned nitride-based semiconductor element according to the first aspect preferably further comprises a buffer layer formed on the interface between the recess portions of the substrate and the first nitride-based semiconductor layer. According to this structure, the first nitride-based semiconductor layer having lower dislocation density can be formed on the buffer layer.

A nitride-based semiconductor element according to a second aspect of the present invention comprises an underlayer, formed on a substrate, consisting of a nitride-based semiconductor and comprising a surface having projection portions, a mask layer formed to be in contact with only the projection portions of the surface of the underlayer, a first nitride-based semiconductor layer formed on recess portions of the underlayer and the mask layer, and a nitride-based semiconductor element layer, formed on the first nitride-based semiconductor layer, having an element region.

The nitride-based semiconductor element according to the second aspect is provided with the underlayer comprising the surface having the projection portions and the mask layer formed to be in contact with only the projection portions of the surface of the underlayer as described above, whereby the first nitride-based semiconductor layer having low dislocation density can be readily formed on the recess portions of the underlayer and the mask layer through the mask layer serving for selective growth. When the nitride-based semiconductor element layer having the element region is grown on the first nitride-based semiconductor layer having low dislocation density, a nitride-based semiconductor element having excellent element characteristics can be readily obtained. Only the surface of the underlayer consisting of a nitride-based semiconductor may be etched for forming the projection portions on the surface. Thus, the etching time for

forming the projection portions on the surface can be reduced, and a nitride-based semiconductor element having excellent mass productivity can be obtained as a result.

The aforementioned nitride-based semiconductor element according to the second aspect preferably further comprises a buffer layer formed between the substrate and the underlayer. According to this structure, the underlayer consisting of a nitride-based semiconductor having low dislocation density can be readily formed on the buffer layer.

In the aforementioned nitride-based semiconductor element according to the second embodiment, the substrate preferably includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate and a quartz substrate.

In the aforementioned nitride-based semiconductor element according to the second aspect, the underlayer preferably includes a GaN layer, and the mask layer and the projection portions of the surface of the underlayer are preferably formed in the shape of stripes being parallel to the [11-20] direction or the [1-100] direction of the GaN layer.

A method of forming a nitride-based semiconductor according to a third aspect of the present invention comprises steps of forming projection portions on a surface on a substrate, forming a mask layer to be in contact with only the projection portions of the surface of the substrate and growing a first nitride-based semiconductor layer on recess portions of the substrate and the mask layer through the mask layer serving for selective growth.

In the method of forming a nitride-based semiconductor according to the third embodiment, the surface having the projection portions is formed on the substrate while the mask layer is formed to be in contact with only the projection portions of the surface of the substrate, whereby the first nitride-based semiconductor layer having low dislocation density can be readily formed on the recess portions of the substrate and the mask layer when grown through the mask layer serving for selective growth. Further, only the surface of the substrate may be etched for forming the projection portions on the surface. Thus, the etching time for forming the projection portions on the surface can be reduced. According to the third aspect, further, the first nitride-based semiconductor layer can be formed through single growth on the substrate. Consequently, a method of forming a nitride-based semiconductor excellent in mass productivity can be obtained.

The aforementioned method of forming a nitride-based semiconductor according to the third aspect preferably further comprises a step of forming a buffer layer on the recess portions of the substrate in advance of the step of growing the first nitride-based semiconductor layer. According to this structure, the first nitride-based semiconductor layer having lower dislocation density can be formed on the buffer layer.

In the aforementioned method of forming a nitride-based semiconductor according to the third aspect, the steps of forming the projection portions on the surface on the substrate and forming the mask layer preferably include a step of forming the mask layer on the surface of the substrate and thereafter etching the surface of the substrate through the mask layer serving for etching in this step thereby simultaneously forming the projection portions on the surface of the substrate and the mask layer coming into contact with only the projection portions of the surface. According to this method, the mask layer serving for etching simultaneously serves for selective growth, whereby the fabrication process can be simplified.

The aforementioned method of forming a nitride-based semiconductor according to the third aspect preferably further comprises a step of growing a nitride-based semiconductor element layer having an element region on the first nitride-based semiconductor layer. According to this structure, the nitride-based semiconductor element layer having the element region can be grown on the first nitride-based semiconductor layer having low dislocation density, whereby a nitride-based semiconductor element having excellent element characteristics can be readily formed.

In the aforementioned method of forming a nitride-based semiconductor according to the third aspect, the substrate preferably includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate and a quartz substrate. In this case, the substrate preferably includes a sapphire substrate, and the mask layer and the projection portions of the surface of the substrate are preferably formed in the shape of stripes being parallel to the [1-100] direction of the sapphire substrate. Alternatively, the substrate preferably includes an Si substrate, and the mask layer and the projection portions of the surface of the substrate are preferably formed in the shape of stripes being parallel to the [1-10] direction of the Si substrate.

A method of forming a nitride-based semiconductor according to a fourth aspect of the present invention comprises steps of forming an underlayer consisting of a nitride-based semiconductor on a substrate, forming projection portions on a surface on the underlayer, forming a mask layer to be in contact with only the projection portions of the surface of the underlayer and growing a first nitride-based semiconductor layer on recess portions of the underlayer and the mask layer through the mask layer serving for selective growth.

In the method of forming a nitride-based semiconductor according to the fourth aspect, the surface having the projection portions is formed on the underlayer consisting of a nitride-based semiconductor layer provided on the substrate while the mask layer is formed to be in contact with only the projection portions of the surface of the underlayer, whereby the first nitride-based semiconductor layer having low dislocation density can be readily formed on the recess portions of the underlayer and the mask layer when grown through the mask layer serving for selective growth. Further, only the surface of the underlayer consisting of a nitride-based semiconductor may be etched for forming the projection portions on the surface. Thus, the etching time for forming the projection portions on the surface can be reduced, and a method of forming a nitride-based semiconductor having excellent mass productivity can be provided as a result.

The aforementioned method of forming a nitride-based semiconductor according to the fourth aspect preferably further comprises a step of forming a buffer layer on the substrate in advance of the step of forming the underlayer consisting of a nitride-based semiconductor. According to this structure, the underlayer consisting of a nitride-based semiconductor having low dislocation density can be readily formed on the buffer layer.

In the aforementioned method of forming a nitride-based semiconductor according to the fourth aspect, the steps of forming the projection portions on the surface on the underlayer and forming the mask layer preferably include a step of forming the mask layer on the surface of the underlayer and thereafter etching the surface of the underlayer through the mask layer serving for etching in this step thereby simultaneously forming the projection portions on the surface of the underlayer and the mask layer coming into contact with only the projection portions of the surface. According to this method, the mask layer serving for etching simultaneously serves for selective growth, whereby the fabrication process can be simplified.

The aforementioned method of forming a nitride-based semiconductor according to the fourth aspect preferably further comprises a step of growing a nitride-based semiconductor element layer having an element region on the first nitride-based semiconductor layer. According to this structure, the nitride-based semiconductor element layer having the element region can be grown on the first nitride-based semiconductor layer having low dislocation density, whereby a nitride-based semiconductor element having excellent element characteristics can be readily formed.

In the aforementioned method of forming a nitride-based semiconductor according to the fourth aspect, the substrate preferably includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate and a quartz substrate.

In the aforementioned method of forming a nitride-based semiconductor according to the fourth aspect, the underlayer preferably includes a GaN layer, and the mask layer and the projection portions of the surface of the underlayer are preferably formed in the shape of stripes being parallel to the [11-20] direction or the [1-100] direction of the GaN layer.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** to **6** are sectional views for illustrating a method of forming a nitride-based semiconductor according to a first embodiment of the present invention;

FIG. **7** is a perspective view showing a semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the first embodiment of the present invention;

FIGS. **8** to **13** are sectional views for illustrating a method of forming a nitride-based semiconductor according to a second embodiment of the present invention;

FIG. **14** is a perspective view showing a semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the second embodiment of the present invention;

FIGS. **15** to **20** are sectional views for illustrating a method of forming a nitride-based semiconductor according to a third embodiment of the present invention;

FIG. **21** is a perspective view showing a semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the third embodiment of the present invention;

FIGS. **22** to **27** are sectional views for illustrating a method of forming a nitride-based semiconductor according to a fourth embodiment of the present invention;

FIG. **28** is a perspective view showing a semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the fourth embodiment of the present invention; and

FIGS. **29** to **33** are sectional views for illustrating a conventional method of forming a nitride-based semiconductor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention are now described with reference to the drawings.

First Embodiment

A method of forming a nitride-based semiconductor according to a first embodiment of the present invention is described with reference to FIGS. **1** to **6**.

First, striped mask layers **2** of SiO_2 having a thickness of about 0.5 μm are formed on a sapphire (0001) plane substrate **1** (hereinafter referred to as "sapphire substrate **1**"), as shown in FIG. **1**. The stripe patterns of the mask layers **2** are formed in a cycle of about 7 μm so that the width of the mask layers **2** is about 5 μm and the interval between each adjacent pair of mask layers **2** (the width of mask openings) is about 2 μm. The striped mask layers **2** are formed in parallel to the [1-100] direction of the sapphire substrate **1**. The sapphire substrate **1** is an example of the "substrate" according to the present invention.

The mask layers **2** are employed as masks for etching the surface of the sapphire substrate **1** by a thickness of about 1 μm through RIE (reactive ion etching) or the like. Thus, the surface of the sapphire substrate **1** is brought into an uneven shape, as shown in FIG. **2**. The shape of the projection portions varies with etching conditions, such that upper parts of recess portions may be larger or smaller in width than bottom parts thereof. In the following description, side surfaces of the recess portions of the etched sapphire substrate **1** are nearly perpendicular to the upper surface of projection portions of the sapphire substrate **1**. The uneven surface of the sapphire substrate **1** has ridges of a height of about 1 μm and grooves of a terrace width of about 2 μm, and they are formed in parallel to the [1-100] direction of the sapphire substrate **1**.

Then, low-temperature buffer layers **3** of GaN having a thickness of about 15 nm are grown by a crystal growth method such as MOVPE (metal organic vapor phase epitaxy) to be in contact substantially with the overall bottom surfaces of the recess portions of the sapphire substrate **1**, as shown in FIG. **3**. In this case, the low-temperature buffer layers **3** are hardly formed on the mask layers **2** consisting of SiO_2. Alternatively, the low-temperature buffer layers **3** may be formed not only on the bottom surfaces but also on the side surfaces of the recess portions. The low-temperature buffer layers **3** may not be formed on the overall bottom surfaces of the recess portions but may be partially formed on the bottom surfaces of the recess portions. The low-temperature buffer layers **3** are examples of the "buffer layer" according to the present invention.

Then, undoped GaN layers **4** are grown on the low-temperature buffer layers **3** consisting of GaN. In this case, the low-temperature buffer layers **3** and the undoped GaN layers **4** are successively grown without taking the sapphire substrate **1** out of the growth apparatus. In an initial stage, the undoped GaN layers **4** are vertically (upwardly) grown on the low-temperature buffer layers **3**. If the low-temperature buffer layers **3** are formed on the side surfaces of the recess portions, the undoped GaN layers **4** are grown laterally from the low-temperature buffer layers **3** formed on the side surfaces. When this growth is further continued, undoped GaN layers **4** having facets on side surfaces thereof are formed on the recess portions, as shown in FIG. **4**. The undoped GaN layers **4** are examples of the "first nitride-based semiconductor layer" according to the present invention.

From the state shown in FIG. **4**, the undoped GaN layers **4** are laterally grown on the mask layers **2**, as shown in FIG. **5**. The undoped GaN layers **4** laterally grown on the mask layers **2** coalesce into a continuous undoped GaN layer **4** of about 5 μm in thickness having a flattened surface, as shown in FIG. **6**.

In the method of forming a nitride-based semiconductor according to the first embodiment, the undoped GaN layers **4** are grown from the recess portions of the sapphire substrate **1** as hereinabove described, whereby dislocations of the undoped GaN layers **4** are bent in the in-plane direction of the (0001) plane of the undoped GaN layers **4** when the undoped GaN layers **4** are laterally grown from the low-temperature buffer layers **3** formed on the side surfaces of the recess portions or on the mask layers **2**. Thus, the dislocation density can be reduced around the surfaces of the undoped GaN layers **4**.

In the method of forming a nitride-based semiconductor according to the first embodiment, the surface of the sapphire substrate **1** is brought into an uneven shape as hereinabove described, whereby only the surface of the sapphire substrate **1** may be etched through the mask layers **2** serving for etching. Thus, the etching time for forming the projection portions on the surface on the sapphire substrate **1** can be reduced as compared with the conventional process of forming the projection portions on the surface shown in FIG. **30**. Consequently, a method of forming a nitride-based semiconductor having excellent mass productivity can be obtained.

In the method of forming a nitride-based semiconductor according to the first embodiment, growth of the low-temperature buffer layers **3** of GaN formed on the recess portions of the sapphire substrate **1** and selective growth of the undoped GaN layer **4** are successively performed without taking the sapphire substrate **1** out of the growth apparatus, as hereinabove described. Thus, the undoped GaN layer **4** having low dislocation density can be formed through a single growth step. A method of forming a nitride-based semiconductor having excellent mass productivity can be obtained also in this point.

In the method of forming a nitride-based semiconductor according to the first embodiment, further, the undoped GaN layer **4** is grown on the low-temperature buffer layers **3** provided on the sapphire substrate **1**, whereby the undoped GaN layer **4** can be grown in lower dislocation density as compared with that directly grown on the sapphire substrate **1**.

FIG. **7** is a perspective view showing a semiconductor laser device fabricated with the aforementioned method of forming a nitride-based semiconductor according to the first embodiment. The structure of the semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the first embodiment is now described with reference to FIG. **7**.

In the structure of the semiconductor laser device according to the first embodiment, an n-type contact layer **5** of n-type GaN having a thickness of about 4 μm is formed on the undoped GaN layer **4** according to the first embodiment shown in FIG. **6**, as shown in FIG. **7**. An anti-cracking layer **6** of n-type AlGaInN having a thickness of about 0.1 μm, an n-type second cladding layer **7** of n-type AlGaN having a thickness of about 0.45 μm, an n-type first cladding layer **8** of n-type GaN having a thickness of about 50 nm (about 0.05 μm) and a multiple quantum well (MQW) emission layer **9** of GaInN are successively formed on the n-type contact layer **5**. The MQW emission layer **9** is formed by alternately stacking five undoped GaN barrier layers of about 4 nm in thickness and four compressive strain undoped GaInN well layers of about 4 nm in thickness.

A p-type first cladding layer **10** of p-type GaN having a thickness of about 40 nm (about 0.04 μm) is formed on the MQW emission layer **9**. A mesa (trapezoidal) p-type second cladding layer **11** of p-type AlGaN having a height of about 0.45 μm is formed on the p-type first cladding layer **10**. Current blocking layers **12** of n-type GaN having a thickness of about 0.2 μm are formed to cover regions on the p-type first cladding layer **10** other than that formed with the p-type second cladding layer **11** and the side surfaces of the mesa p-type second cladding layer **11** while exposing the upper surface of the p-type second cladding layer **11**. A p-type contact layer **13** of p-type GaN having a thickness of about 3 μm to about 5 μm is formed on the current blocking layers **12** to be in contact with the exposed upper surface of the p-type second cladding layer **11**.

The layers from the p-type contact layer **13** to the n-type contact layer **5** are partially removed. Protective films **14** of an insulator such as SiO_2 or SiN are formed to cover parts of the exposed surface of the n-type contact layer **5** and the exposed side surfaces of the anti-cracking layer **6**, the n-type second cladding layer **7**, the n-type first cladding layer **8**, the MQW emission layer **9**, the p-type first cladding layer **10**, the current blocking layers **12** and the p-type contact layer **13**.

A p-side electrode **15** is formed on the upper surface of the p-type contact layer **13** while an n-side electrode **16** is formed on the partially removed and exposed surface of the n-type contact layer **5**.

The n-type contact layer **5**, the anti-cracking layer **6**, the n-type second cladding layer **7**, the n-type first cladding layer **8**, the MQW emission layer **9**, the p-type first cladding layer **10**, the p-type second cladding layer **11**, the current blocking layers **12** and the n-type contact layer **13** are examples of the "nitride-based semiconductor element layer having an element region" according to the present invention.

In the semiconductor laser device according to the first embodiment, the undoped GaN layer **4** having excellent mass productivity and low dislocation density formed by the method of forming a nitride-based semiconductor according to the first embodiment shown in FIG. **1** to **6** is employed as an underlayer for forming the layers **5** to **13** thereon as hereinabove described, whereby excellent crystallinity can be implemented in the layers **5** to **13**. Consequently, a semiconductor laser device having excellent mass productivity and excellent device characteristics can be obtained according to the first embodiment.

Second Embodiment

Referring to FIGS. **8** to **13**, an n-type Si (111) plane substrate **21** (hereinafter referred to as "Si substrate **21**") having conductivity is employed in a second embodiment of the present invention in place of the insulating sapphire substrate **1** in the first embodiment. A method of forming a nitride-based semiconductor according to the second embodiment is now described with reference to FIGS. **8** to **13**.

According to the second embodiment, striped mask layers **22** of SiO_2 having a thickness of about 0.5 μm are formed on the n-type Si substrate **21**, as shown in FIG. **8**. The stripe patterns of the mask layers **22** are formed in a cycle of about 7 μm, so that the mask layers **22** are about 5 μm in width and the interval between each adjacent pair of mask layers **22** (the width of mask openings) is about 2 μm. The striped mask layers **22** are formed in parallel to the [1-10] direction of the Si substrate **21**. The Si substrate **21** is an example of the "substrate" according to the present invention.

The mask layers **22** are employed as masks for etching the surface of the Si substrate **21** by a thickness of about 1 μm through wet etching or the like. Thus, the surface of the Si substrate **21** is brought into an uneven shape, as shown in FIG. **9**. The shape of the projection portions varies with etching conditions, such that upper parts of recess portions may be larger or smaller in width than bottom parts thereof. In the following description, projection portions of the etched Si substrate **21** are in the form of a mesa (trapezoid). The uneven surface of the Si substrate **21** has ridges of a height of about 1 μm, and they are formed in parallel to the [1-10] direction of the Si substrate **21**.

Then, buffer layers **23** of Si-doped AlGaN having a thickness of about 15 nm are grown by a crystal growth method such as MOVPE to be in contact substantially with the overall bottom surfaces of the recess portions of the Si substrate **21**, as shown in FIG. **10**. In this case, the buffer layers **23** are hardly formed on the mask layers **22** consisting of SiO_2. Alternatively, the buffer layers **23** may be formed not only on the bottom surfaces but also on the side surfaces of the recess portions. The buffer layers **23** may not be formed on the overall bottom surfaces of the recess portions but may be partially formed on the bottom surfaces of the recess portions.

Then, Si-doped GaN layers **24** are grown on the buffer layers **23** consisting of Si-doped AlGaN. In this case, the buffer layers **23** and the Si-doped GaN layers **24** are successively grown without taking the Si substrate **21** out of the growth apparatus. In an initial stage, the Si-doped GaN layers **24** are vertically (upwardly) grown on the buffer layers **23**. If the buffer layers **23** are formed on the side surfaces of the recess portions, the Si-doped GaN layers **24** are grown laterally from the buffer layers **23** formed on the side surfaces. When this growth is further continued, Si-doped GaN layers **24** having facets on side surfaces thereof are formed on the recess portions, as shown in FIG. **11**. The Si-doped GaN layers **24** are examples of the "first nitride-based semiconductor layer" according to the present invention.

From the state shown in FIG. **11**, the Si-doped GaN layers **24** are laterally grown on the mask layers **22**, as shown in FIG. **12**. The Si-doped GaN layers **24** laterally grown on the mask layers **22** coalesce into a continuous Si-doped GaN layer **24** of about 5 μm in thickness having a flattened surface, as shown in FIG. **13**.

In the method of forming a nitride-based semiconductor according to the second embodiment, the Si-doped GaN layers **24** are grown from the recess portions of the Si substrate **21**, whereby dislocations of the Si-doped GaN layers **24** are bent in the in-plane direction of the (0001) plane of the Si-doped GaN layers **24** when the Si-doped GaN layers **24** are laterally grown from the buffer layers **23** formed on the side surfaces of the recess portions or on the mask layers **22**. Thus, the dislocation density can be reduced around the surfaces of the Si-doped GaN layers **24**.

In the method of forming a nitride-based semiconductor according to the second embodiment, the surface of the Si substrate **21** is brought into an uneven shape similarly to the first embodiment, whereby only the surface of the Si substrate **21** may be etched through the mask layers **22** serving for etching. Thus, the etching time for forming the projection portions on the surface on the Si substrate **21** can be reduced as compared with the conventional process of forming the projection portions on the surface shown in FIG. **30**. Consequently, a method of forming a nitride-based semiconductor having excellent mass productivity can be obtained.

In the method of forming a nitride-based semiconductor according to the second embodiment, growth of the buffer layers **23** of Si-doped AlGaN formed on the Si substrate **21** and selective growth of the Si-doped GaN layer **24** are successively performed without taking the Si substrate **21** out of the growth apparatus, similarly to the first embodiment. Thus, the Si-doped GaN layer **24** having low dislocation density can be formed through a single growth step. A method of forming a nitride-based semiconductor having excellent mass productivity can be obtained also in this point.

In the method of forming a nitride-based semiconductor according to the second embodiment, further, the Si-doped GaN layer **24** is grown on the buffer layers **23** provided on the Si substrate **21**, whereby the Si-doped GaN layer **24** can be grown in lower dislocation density as compared with that directly grown on the Si substrate **21**.

FIG. **14** is a perspective view showing a semiconductor laser device fabricated with the aforementioned method of forming a nitride-based semiconductor according to the second embodiment. The structure of the semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the second embodiment is now described with reference to FIG. **14**.

In the structure of the semiconductor laser device according to the second embodiment, an anti-cracking layer **25** of n-type AlGaInN having a thickness of about 0.1 μm, an n-type second cladding layer **26** of n-type AlGaN having a thickness of about 0.45 μm, an n-type first cladding layer **27** of n-type GaN having a thickness of about 50 nm (about 0.05 μm) and a multiple quantum well (MQW) emission layer **28** of GaInN are successively formed on the Si-doped GaN layer **24** according to the second embodiment shown in FIG. **13**, as shown in FIG. **14**. The MQW emission layer **28** is formed by alternately stacking five undoped GaN barrier layers of about 4 nm in thickness and four compressive strain undoped GaInN well layers of about 4 nm in thickness.

A p-type first cladding layer **29** of p-type GaN having a thickness of about 40 nm (about 0.04 μm) is formed on the MQW emission layer **28**. A mesa (trapezoidal) p-type second cladding layer **30** of p-type AlGaN having a height of about 0.45 μm is formed on the p-type first cladding layer **29**. Current blocking layers **31** of n-type GaN having a thickness of about 0.2 μm are formed to cover regions on the p-type first cladding layer **29** other than that formed with the p-type second cladding layer **30** and the side surfaces of the mesa p-type second cladding layer **30** while exposing the upper surface of the p-type second cladding layer **30**. A p-type contact layer **32** of p-type GaN having a thickness of about 3 μm to about 5 μm is formed on the current blocking layers **31** to be in contact with the exposed upper surface of the p-type second cladding layer **30**.

A p-side electrode **33** is formed on a projection portion of the p-type contact layer **32** reflecting the mesa shape of the p-type second cladding layer **30**. According to the second embodiment, the Si substrate **21** has conductivity dissimilarly to the sapphire substrate **1** according to the first embodiment, and hence an n-side electrode **34** is formed on the back surface of the Si substrate **21**.

The anti-cracking layer **25**, the n-type second cladding layer **26**, the n-type first cladding layer **27**, the MQW emission layer **28**, the p-type first cladding layer **29**, the p-type second cladding layer **30**, the current blocking layers **31** and the n-type contact layer **32** are examples of the "nitride-based semiconductor element layer having an element region" according to the present invention.

In the semiconductor laser device according to the second embodiment, the Si-doped GaN layer **24** having excellent mass productivity and low dislocation density formed by the method of forming a nitride-based semiconductor according to the second embodiment shown in FIG. **8** to **13** is employed as an underlayer for forming the layers **25** to **32** thereon as hereinabove described, whereby excellent crystallinity can be implemented in the layers **25** to **32**. Consequently, a semiconductor laser device having excellent mass productivity and excellent device characteristics can be obtained.

While the sapphire substrate **1** and the Si substrate **21** are employed in the aforementioned first and second embodiments respectively, for example, the present invention is not restricted to this but a spinel substrate, an SiC substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate or a quartz substrate may alternatively be employed.

Further alternatively, a GaN substrate may be employed in each of the aforementioned first and second embodiments. In this case, the low-temperature buffer layers **3** or the buffer layers **23** may not necessarily be formed.

Third Embodiment

Referring to FIGS. **15** to **20**, epitaxial lateral overgrowth is performed through an underlayer **43** comprising a surface having projection portions formed on a sapphire (0001) plane substrate **41** (hereinafter referred to as "sapphire substrate **41**") in a third embodiment of the present invention. A method of forming a nitride semiconductor according to the third embodiment is now described in detail with reference to FIGS. **15** to **20**.

First, low-temperature buffer layers **42** of AlGaN having a thickness of about 15 nm and the underlayer **43** of undoped GaN having a thickness of about 2 μm are formed on the sapphire substrate **41** by a crystal growth method such as MOVPE, as shown in FIG. **15**. The sapphire substrate **41** is an example of the "substrate" according to the present invention. The low-temperature buffer layers **42** are examples of the "buffer layer" according to the present invention.

Striped mask layers **44** of SiO_2 having a thickness of about 0.5 μm are formed on the underlayer **43**. The stripe patterns of the mask layers **44** are formed in a cycle of about 6 μm so that the width of the mask layers **44** is about 5 μm and the interval between each adjacent pair of mask layers **44** (the width of mask openings) is about 1 μm. The striped mask layers **44** are formed in parallel to the [11-20] direction of the underlayer **43** consisting of GaN.

The mask layers **44** are employed as masks for etching the surface of the underlayer **43** by a thickness of about 1 μm through RIE or the like. Thus, the surface of the underlayer **43** is brought into an uneven shape, as shown in FIG. **16**. The shape of the projection portions varies with etching conditions, such that upper parts of recess portions may be larger or smaller in width than bottom parts thereof. In the following description, projection portions of the etched underlayer **43** are in the form of a mesa (trapezoid). The uneven surface of the underlayer **43** has ridges of a height of about 1 μm, and they are formed in parallel to the [11-20] direction of the underlayer **43** consisting of undoped GaN.

Then, undoped GaN layers **45** are re-grown from the bottom and side surfaces, serving as seed crystals, of the exposed recess portions of the underlayer **43** consisting of undoped GaN, as shown in FIG. **17**. In an initial stage, the undoped GaN layers **45** are vertically (upwardly) grown from the bottom surfaces of the recess portions of the underlayer **43** and also laterally grown from the side surfaces of the recess portions of the underlayer **43**, as shown in FIGS. **17** and **18**. The undoped GaN layers **45** are examples of the "first nitride-based semiconductor layer" according to the present invention.

From the state shown in FIG. **18**, the undoped GaN layers **45** are laterally grown on the mask layers **44**, as shown in FIG. **19**. The undoped GaN layers **45** laterally grown on the mask layers **44** coalesce into a continuous undoped GaN layer **45** of about 5 μm in thickness having a flattened surface, as shown in FIG. **20**.

In the method of forming a nitride-based semiconductor according to the third embodiment, the undoped GaN layers **45** are grown from the bottom and side surfaces, serving as seed crystals, of the recess portions of the underlayer **43** consisting of undoped GaN as hereinabove described, whereby dislocations of the undoped GaN layers **45** are bent in the in-plane direction of the (0001) plane of the undoped GaN layers **45** when the undoped GaN layers **45** are laterally grown from the side surfaces of the recess portions of the underlayer **43** or on the mask layers **44**. Thus, the dislocation density can be reduced around the surfaces of the undoped GaN layers **45**.

In the method of forming a nitride-based semiconductor according to the third embodiment, the surface of the underlayer **43** is brought into an uneven shape as hereinabove described, whereby only the surface of the underlayer **43** may be etched. Thus, the etching time for forming the projection portions on the surface on the underlayer **43** can be reduced as compared with the conventional process of forming the projection portions on the surface shown in FIG. **30**. Consequently, a method of forming a nitride-based semiconductor having excellent mass productivity can be obtained similarly to the first and second embodiments.

In the method of forming a nitride-based semiconductor according to the third embodiment, the underlayer **43** consisting of undoped GaN is grown after forming the low-temperature buffer layers **42** on the sapphire substrate **41**, whereby the underlayer **43** having low dislocation density can be readily formed.

FIG. **21** is a perspective view showing a semiconductor laser device fabricated with the aforementioned method of forming a nitride-based semiconductor according to the third embodiment. The structure of the semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the third embodiment is now described with reference to FIG. **21**.

In the structure of the semiconductor laser device according to the third embodiment, an n-type contact layer **5**, an anti-cracking layer **6**, an n-type second cladding layer **7**, an n-type first cladding layer **8**, an MQW emission layer **9**, a p-type first cladding layer **10**, a p-type second cladding layer **11**, current blocking layers **12**, a p-type contact layer **13** and protective films **14** are formed on the undoped layer GaN layer **45** shown in FIG. **20**, similarly to the first embodiment. The compositions and thicknesses of the layers **5** to **13** and the protective films **14** are similar to those in the first embodiment.

A p-side electrode **15** is formed on the upper surface of the p-type contact layer **13** while an n-side electrode **16** is formed on a partially removed and exposed surface of the n-type contact layer **5**.

In the semiconductor laser device according to the third embodiment, the undoped GaN layer **45** having excellent mass productivity and low dislocation density formed by the method of forming a nitride-based semiconductor according to the third embodiment shown in FIG. **15** to **20** is employed as an underlayer for forming the layers **5** to **13** thereon as hereinabove described, whereby excellent crystallinity can be implemented in the layers **5** to **13**. Consequently, a semiconductor laser device having excellent mass productivity and excellent device characteristics can be obtained.

Fourth Embodiment

Referring to FIGS. **22** to **27**, an n-type SiC (0001) plane substrate **51** (hereinafter referred to as "SiC substrate **51**") having conductivity is employed in a fourth embodiment of the present invention in place of the insulating sapphire substrate **41** employed in the third embodiment. A method of forming a nitride semiconductor according to the fourth embodiment is now described in detail with reference to FIGS. **22** to **27**.

First, buffer layers **52** of Si-doped AlGaN having a thickness of about 15 nm and an underlayer **53** of Si-doped GaN having a thickness of about 2 μm are formed on the n-type SiC substrate **51** by a crystal growth method such as MOVPE, as shown in FIG. **22**. The SiC substrate **51** is an example of the "substrate" according to the present invention.

Striped mask layers **54** of SiO_2 having a thickness of about 0.5 μm are formed on the underlayer **53**. The stripe patterns of the mask layers **54** are formed in a cycle of about 6 μm so that the width of the mask layers **54** is about 5 μm and the interval between each adjacent pair of mask layers **54** (the width of mask openings) is about 1 μm. The striped mask layers **54** are formed in parallel to the [11-20] direction of the underlayer **53** consisting of Si-doped GaN.

The mask layers **54** are employed as masks for etching the surface of the underlayer **53** by a thickness of about 1 μm through RIE or the like. Thus, the surface of the underlayer **53** is brought into an uneven shape, as shown in FIG. **23**. The shape of the projection portions varies with etching conditions, such that upper parts of recess portions may be larger or smaller in width than bottom parts thereof. In the following description, projection portions of the etched underlayer **53** are in the form of a mesa (trapezoid). The uneven surface of the underlayer **53** has ridges of a height of about 1 μm, and they are formed in parallel to the [11-20] direction of the underlayer **53** consisting of Si-doped GaN.

Then, Si-doped GaN layers **55** are re-grown from the bottom and side surfaces, serving as seed crystals, of the exposed recess portions of the underlayer **53** consisting of Si-doped GaN, as shown in FIG. **24**. In an initial stage, the Si-doped GaN layers **55** are vertically (upwardly) grown from the bottom surfaces of the recess portions of the underlayer **53** and also laterally grown from the side surfaces of the recess portions of the underlayer **53**, as shown in FIGS. **24** and **25**. The Si-doped GaN layers **55** are examples of the "first nitride-based semiconductor layer" according to the present invention.

From the state shown in FIG. **25**, the Si-doped GaN layers **55** are laterally grown on the mask layers **54**, as shown in FIG. **26**. The Si-doped GaN layers **55** laterally grown on the mask layers **54** coalesce into a continuous Si-doped GaN layer **55** of about 5 μm in thickness having a flattened surface, as shown in FIG. **27**.

In the method of forming a nitride-based semiconductor according to the fourth embodiment, the Si-doped GaN layers **55** are grown from the bottom and side surfaces, serving as seed crystals, of the recess portions of the underlayer **43** consisting of Si-doped GaN as hereinabove described, whereby dislocations of the Si-doped GaN layers **55** are bent in the in-plane direction of the (0001) plane of the Si-doped GaN layers **55** when the Si-doped GaN layers **55** are laterally grown from the side surfaces of the recess portions of the underlayer **53** or on the mask layers **54**. Thus, the dislocation density can be reduced around the surfaces of the Si-doped GaN layers **55**.

In the method of forming a nitride-based semiconductor according to the fourth embodiment, the surface of the underlayer **53** is brought into an uneven shape as hereinabove described, whereby only the surface of the underlayer **53** may be etched. Thus, the etching time for forming the projection portions on the surface on the underlayer **53** can be reduced as compared with the conventional process of forming the projection portions on the surface shown in FIG. **30**. Consequently, a method of forming a nitride-based semiconductor having excellent mass productivity can be obtained similarly to the first to third embodiments.

In the method of forming a nitride-based semiconductor according to the fourth embodiment, the underlayer **53** consisting of Si-doped GaN is grown after forming the buffer layers **52** on the SiC substrate **51**, whereby the underlayer **53** having low dislocation density can be readily formed.

FIG. **28** is a perspective view showing a semiconductor laser device fabricated with the aforementioned method of forming a nitride-based semiconductor according to the fourth embodiment. The structure of the semiconductor laser device fabricated with the method of forming a nitride-based semiconductor according to the fourth embodiment is now described with reference to FIG. **28**.

In the structure of the semiconductor laser device according to the fourth embodiment, an anti-cracking layer **25**, an n-type second cladding layer **26**, an n-type first cladding layer **27**, an MQW emission layer **28**, a p-type first cladding layer **29**, a p-type second cladding layer **30**, current blocking layers **31** and a p-type contact layer **32** are formed on the Si-doped layer GaN layer **55** shown in FIG. **27**, similarly to the second embodiment. The compositions and thicknesses of the layers **25** to **32** are similar to those in the second embodiment.

A p-side electrode **33** is formed on a projection portion of the p-type contact layer **32** reflecting the mesa shape of the p-type second cladding layer **30**. The SiC substrate **51** has conductivity, and hence an n-side electrode **34** is formed on the back surface of the SiC substrate **51**.

In the semiconductor laser device according to the fourth embodiment, the Si-doped GaN layer **55** having excellent mass productivity and low dislocation density formed by the method of forming a nitride-based semiconductor according to the fourth embodiment shown in FIG. **22** to **27** is employed as an underlayer for forming the layers **25** to **32** thereon as hereinabove described, whereby excellent crystallinity can be implemented in the layers **25** to **32**. Consequently, a semiconductor laser device having excellent mass productivity and excellent device characteristics can be obtained.

While the sapphire substrate **41** and the SiC substrate **51** are employed in the aforementioned third and fourth embodiments respectively, for example, the present invention is not restricted to this but a spinel substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB_2 substrate or a quartz substrate may alternatively be employed.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

While the recess portions of the surfaces of the sapphire substrate **1**, the Si substrate **21** and the underlayers **43** and **53** are formed in the height of about 1 μm in the aforementioned first to fourth embodiments, the present invention is not restricted to this but the height of the recess portions is preferably set in the range of several nm to several μm not reaching the bottom surfaces of the sapphire substrate **1**, the Si substrate **21** and the underlayers **43** and **53**.

While the striped mask layers **2**, **22**, **44** and **54** are formed in parallel with the [1-100] direction of the sapphire substrate **1**, the [1-10] direction of the Si substrate **21** and the [11-20] directions of the GaN underlayers **43** and **53** in the aforementioned first to fourth embodiments respectively, the present invention is not restricted to this but the striped mask layers may alternatively be formed in a direction different from the aforementioned ones. For example, the mask layers **44** and **45** according to the third and fourth embodiments may be formed in parallel with the [1-100] directions of the GaN underlayers **43** and **53**.

While the projection portions of the surfaces of the sapphire substrate **1**, the Si substrate **21** and the underlayers **43** and **53** are formed in parallel with the [1-100] direction of the sapphire substrate **1**, the [1-10] direction of the Si substrate **21** and the [11-20] directions of the GaN underlayers **43** and **53** in the first to fourth embodiments respectively, the present invention is not restricted to this but the projection portions of the surface may be formed in a direction different from the above. For example, the projection portions of the surfaces of the underlayers **43** and **53** according to the third and fourth embodiments may alternatively be formed in parallel with the [1-100] directions of the GaN underlayers **43** and **53**.

While the mask layers **2**, **22**, **44** and **54** and the openings thereof are formed in a striped shape in the aforementioned first to fourth embodiments, the present invention is not restricted to this but the mask layers may alternatively be formed in a circular, hexagonal or triangular shape, and the openings thereof may also be formed in a circular, hexagonal or triangular shape. When the mask layers and the openings thereof are formed in a hexagonal or triangular shape, the sides of the hexagons or triangles may match with any crystal orientation.

While the recess and projection portions of the surfaces of the sapphire substrate **1**, the Si substrate **21** and the underlayers **43** and **53** are formed in a striped shape in the aforementioned first to fourth embodiments, the present invention is not restricted to this but the recess portions or the projection portions of the surfaces of the sapphire substrate **1**, the Si substrate **21** and the underlayers **43** and **53** may alternatively be formed in a circular, hexagonal or triangular shape. When the recess or projection potions are formed in a hexagonal or triangular shape, the sides of the hexagons or triangles may match with any crystal orientation.

While the nitride-based semiconductors are employed for preparing semiconductor laser devices in the aforementioned first to fourth embodiments, the present invention is not restricted to this but also applicable to another device such as a light emitting diode device or a transistor employing a nitride-based semiconductor.

In each of the aforementioned first to fourth embodiments, the nitride-based semiconductor may have a wurtzite crystal structure or a zinc blende crystal structure.

While crystal growth of each nitride-based semiconductor layer is performed by MOVPE in the aforementioned first to fourth embodiments, the present invention is not restricted to this but crystal growth may alternatively be performed by HVPE or gas source MBE employing TMA1, TMGa, TMIn, NH_3, SiH or Cp_2Mg as source gas.

In each of the first to fourth embodiments, the bottom surfaces of the recess portions of the surface of the sapphire substrate **1**, the Si substrate **21** or the underlayer **43** or **53** are preferably formed in a width within the range of several 100 nm to several 10 μm.

While the n-type first cladding layers **8** or **27** and the p-type first cladding layers **10** or **29** consist of GaN in the aforementioned first to fourth embodiments, the present invention is not restricted to this but the first cladding layers may consist of other materials having a wider bandgap than the MQW emission layer. For example, AlGaN such as $Al_{0.01}Ga_{0.99}N$, InGaN such as $In_{0.01}Ga_{0.99}N$, or AlGaInN such as $Al_{0.01}Ga_{0.98}In_{0.01}N$ may be employed as the materials constituting the first cladding layers.

What is claimed is:

1. A nitride-based semiconductor light-emitting device comprising:

a substrate comprising a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions; and

a nitride-based semiconductor layer formed on said buffer layer, wherein

said buffer layer is formed not to be in contact with upper surfaces of said projection portions.

2. The nitride-based semiconductor light-emitting device according to claim **1**, wherein

said nitride-based semiconductor layer has a flat surface.

3. A nitride-based semiconductor light-emitting device comprising:

a substrate comprising a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions;

a nitride-based semiconductor layer formed on side surfaces of said recess portions; and

an n-type cladding layer, an emission layer and a p-type cladding layer, formed on said nitride-based semiconductor layer; wherein

said recess portions or said projection portions are formed in a circular, hexagonal or triangular shape in a plan view.

4. The nitride-based semiconductor light-emitting device according to claim **1**, wherein

said substrate includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB2 substrate and a quartz substrate.

5. The nitride-based semiconductor light-emitting device according to claim **3**, wherein

said nitride-based semiconductor layer has a flat surface.

6. The nitride-based semiconductor light-emitting device according to claim **3**, wherein

said substrate includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB2 substrate and a quartz substrate.

7. A nitride-based semiconductor light-emitting device comprising:

a substrate comprising a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions;

a nitride-based semiconductor layer formed on side surfaces of said recess portions; and

an n-type layer, an emission layer and a p-type layer, formed on said nitride-based semiconductor layer, wherein

said recess portions or said projection portions are formed in a circular, hexagonal or triangular shape in a plan view.

8. A nitride-based semiconductor light-emitting device comprising:

a substrate including a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions; and

a nitride-based semiconductor layer formed on side surfaces of said recess portions, wherein

said recess portions or said projection portions are formed in a circular, hexagonal or triangular shape in a plan view.

9. A nitride-based semiconductor light-emitting device comprising:

a substrate including a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions; and

a nitride-based semiconductor layer formed on side surfaces of said recess portions, wherein

bottom surfaces of said recess portions are formed in a width within the range of several 100 nm to several 10 μm.

10. The nitride-based semiconductor light-emitting device according to claim **7**, wherein

said nitride-based semiconductor layer has a flat surface.

11. The nitride-based semiconductor light-emitting device according to claim **7**, wherein

said substrate includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB2 substrate and a quartz substrate.

12. The nitride-based semiconductor light-emitting device according to claim **7**, wherein

bottom surfaces of the recess portions are formed in a width within the range of several 100 nm to several 10 μm.

13. The nitride-based semiconductor light-emitting device according to claim **8**, wherein

said nitride-based semiconductor layer has a flat surface.

14. The nitride-based semiconductor light-emitting device according to claim **8**, wherein

said substrate includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB2 substrate and a quartz substrate.

15. The nitride-based semiconductor light-emitting device according to claim **8**, wherein

bottom surfaces of the recess portions are formed in a width within the range of several 100 nm to several 10 μm.

16. The nitride-based semiconductor light-emitting device according to claim **9**, wherein

said nitride-based semiconductor layer has a flat surface.

17. The nitride-based semiconductor light-emitting device according to claim **9**, wherein

said substrate includes a substrate selected from a group consisting of a sapphire substrate, a spinel substrate, an Si substrate, an SiC substrate, a GaN substrate, a GaAs substrate, a GaP substrate, an InP substrate, a ZrB2 substrate and a quartz substrate.

18. The nitride-based semiconductor light-emitting device according to claim **3**, wherein

bottom surfaces of the recess portions are formed in a width within the range of several 100 nm to several 10 μm.

19. A nitride-based semiconductor light-emitting device comprising:

a substrate comprising a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions; and

a nitride-based semiconductor layer formed on side surfaces of said recess portions, wherein

said projection portions are in the form of a mesa.

20. A nitride-based semiconductor light-emitting device comprising:

a substrate comprising a surface having projection portions and recess portions;

a buffer layer formed on bottom surfaces of said recess portions; and

a nitride-based semiconductor layer formed on side surfaces of said recess portions, wherein

upper parts of said recess portions are larger in width than bottom parts of said recess portions.

* * * * *

Exhibit 2

US007489068B2

(12) **United States Patent**
Hsieh et al.

(10) **Patent No.: US 7,489,068 B2**
(45) **Date of Patent: Feb. 10, 2009**

(54) **LIGHT EMITTING DEVICE**

(75) Inventors: **Min-Hsun Hsieh**, Hsinchu (TW); **Ta-Cheng Hsu**, Hsinchu (TW); **Wei-Chih Peng**, Hsinchu (TW); **Ya-Ju Lee**, Hsinchu (TW)

(73) Assignee: **Epistar Corporation**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 491 days.

(21) Appl. No.: **11/326,750**

(22) Filed: **Jan. 6, 2006**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H01J 5/16 (2006.01)

(52) **U.S. Cl.** **313/116**; 313/498; 313/506

(58) **Field of Classification Search** 313/116, 313/498, 506

See application file for complete search history.

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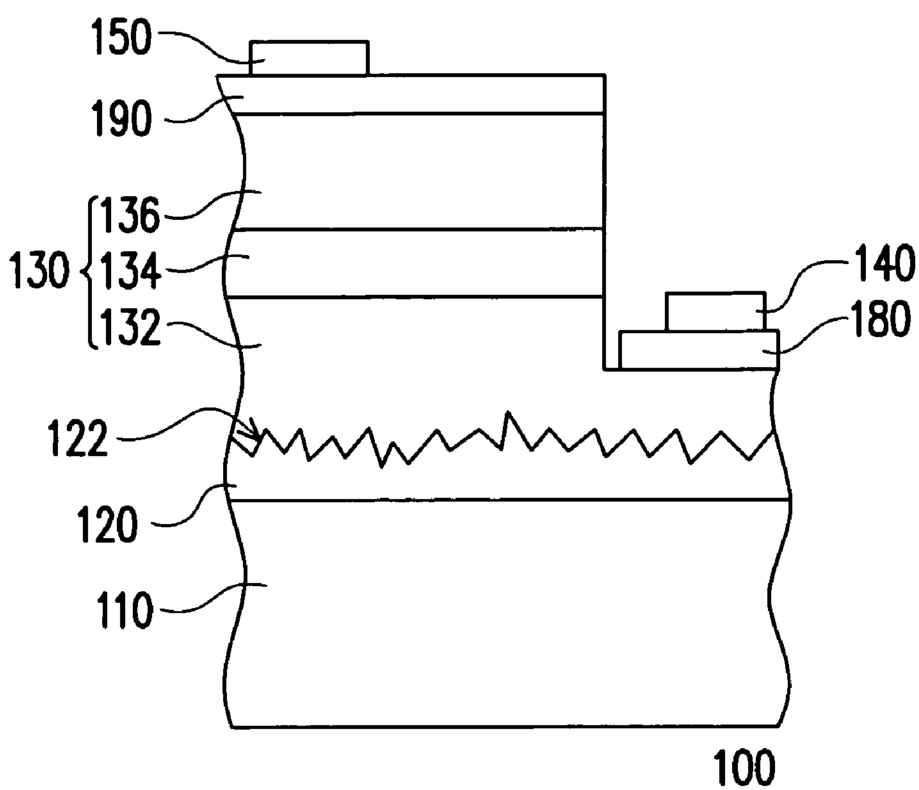
(57) **ABSTRACT**

A light emitting device having a transparent substrate, a light emitting stack, and a transparent adhesive layer is provided. The light emitting stack is disposed above the transparent substrate and comprises a diffusing surface. The transparent adhesive layer is disposed between the transparent substrate and the diffusing surface of the light emitting stack; an index of refraction of the light emitting stack is different from that of the transparent adhesive layer.

28 Claims, 4 Drawing Sheets



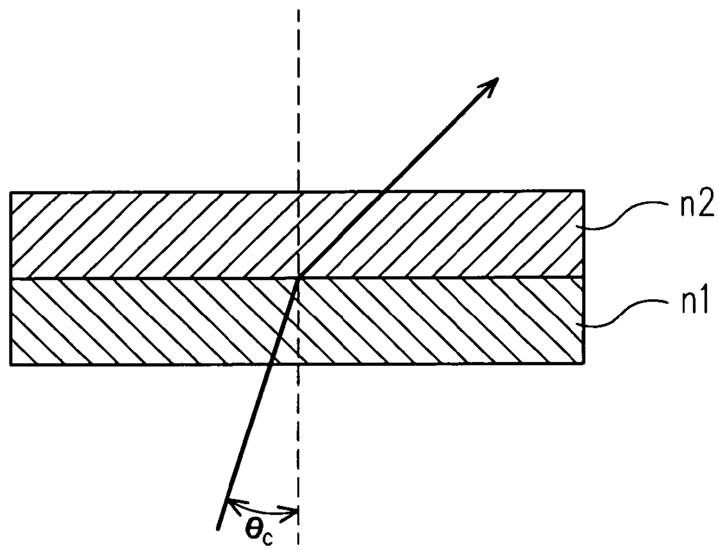


FIG. 1 (PRIOR ART)

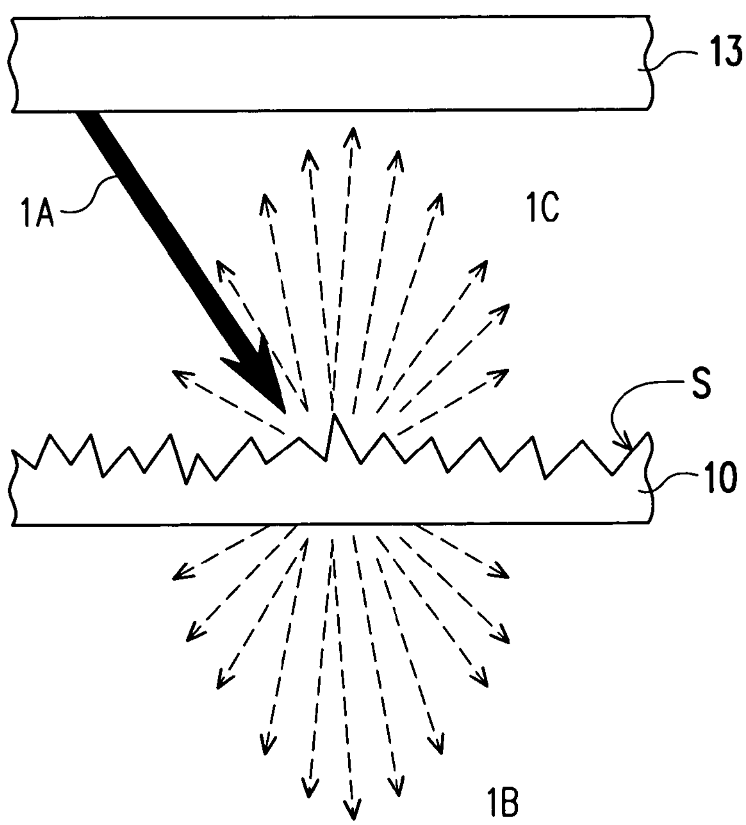


FIG. 2

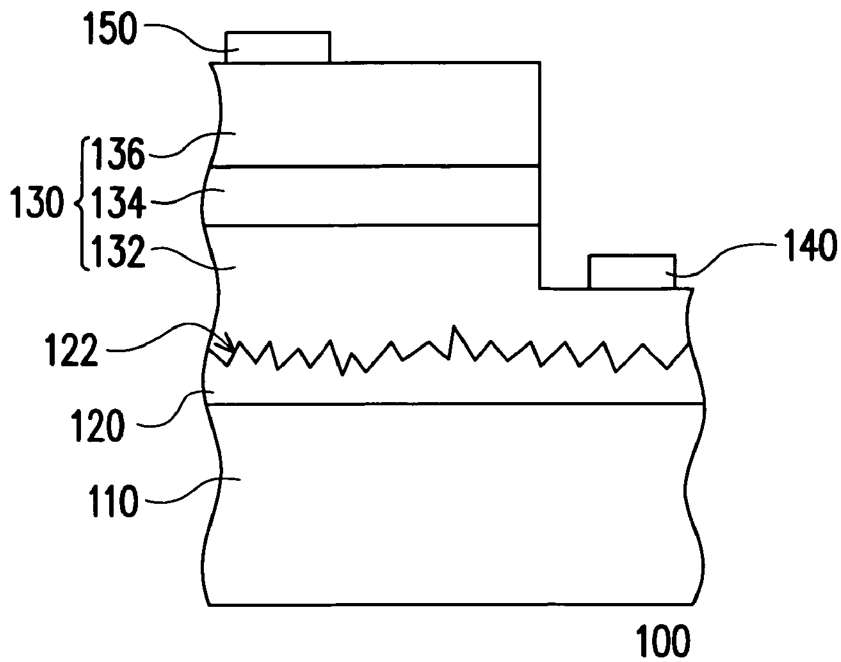

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FIG. 3

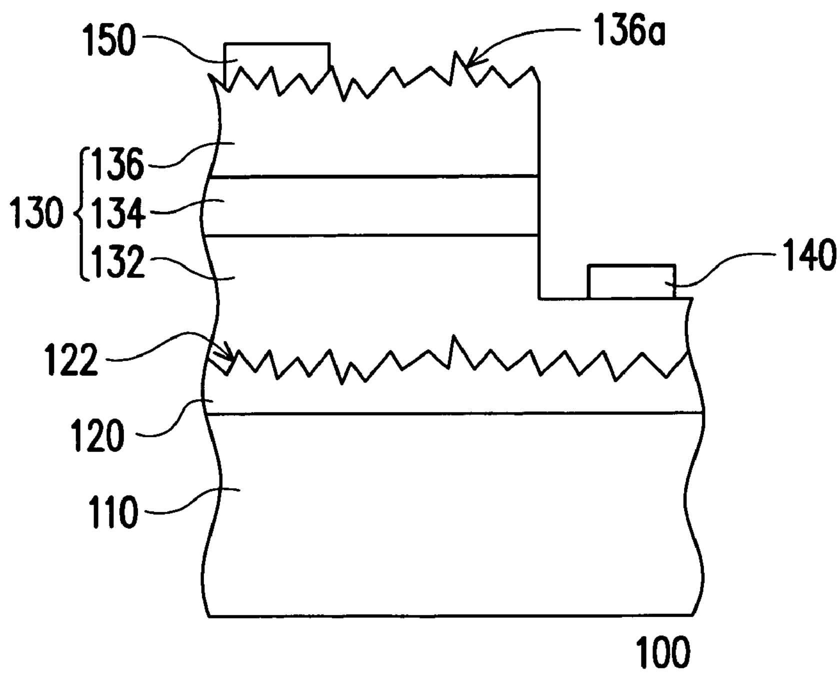
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FIG. 4

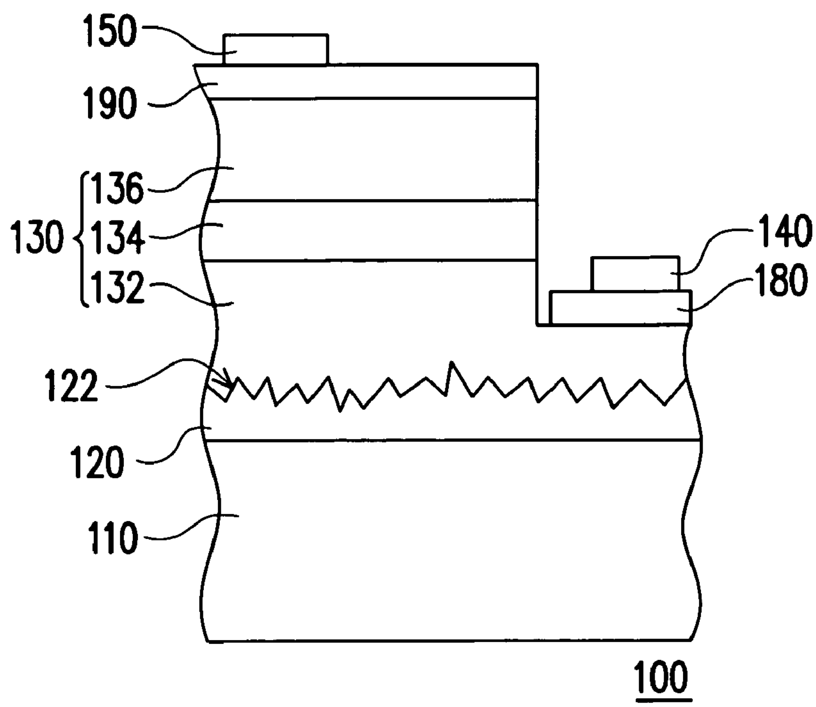
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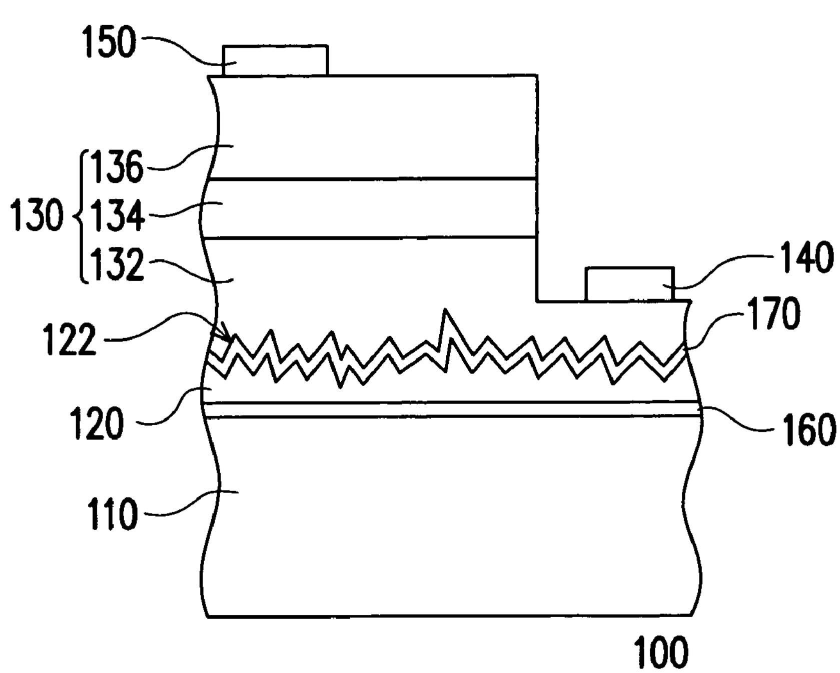
FIG. 5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160
110
100

FIG. 6

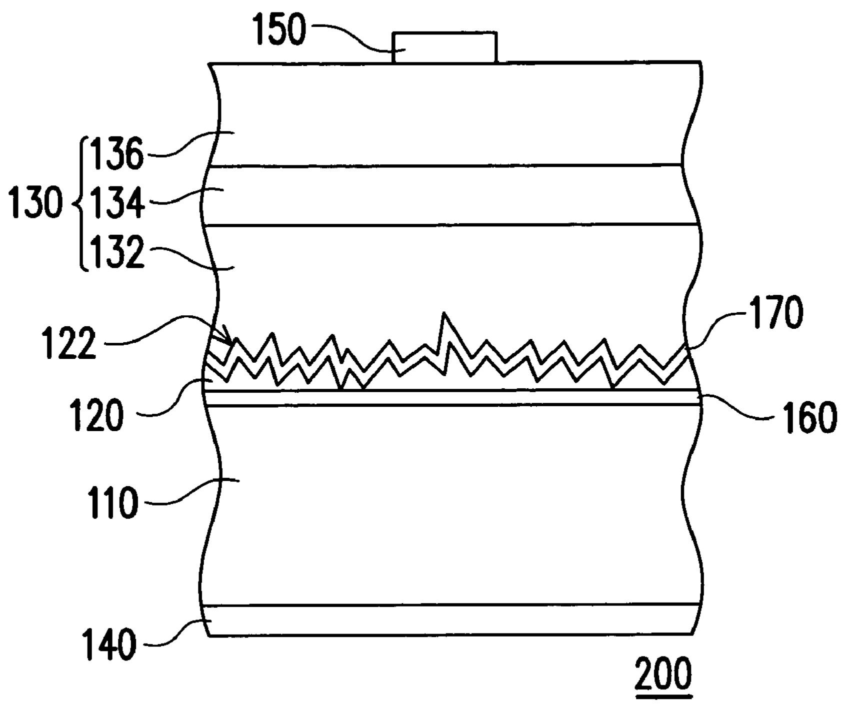
150
136
130
134
132
122
170
120
160
110
140
200

FIG. 7

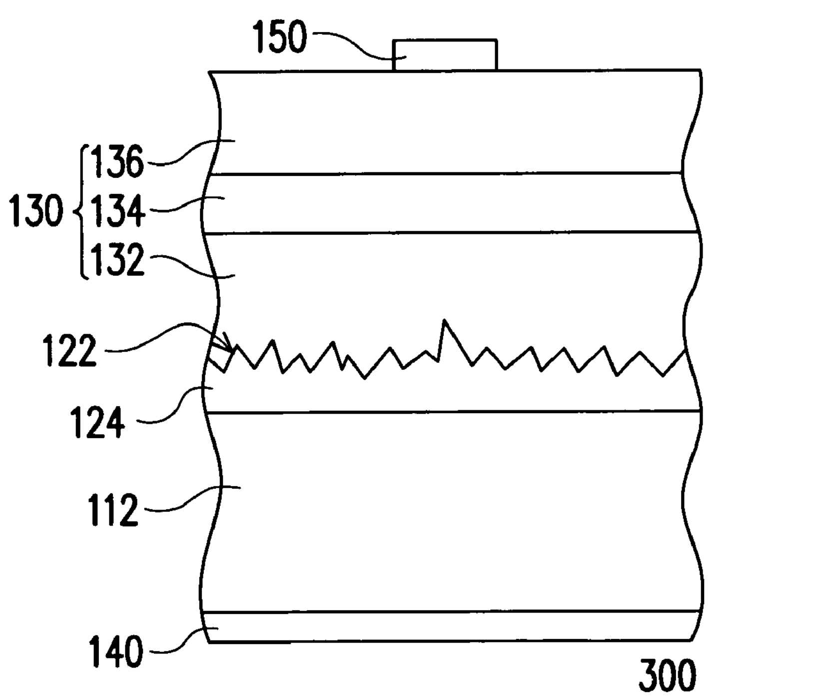
150
136
130
134
132
122
124
112
140
300

FIG. 8

LIGHT EMITTING DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Taiwan application serial no. 94102193, filed on Jan. 25, 2005. All disclosure of the Taiwan application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates to a light emitting device and in particular to a light emitting device having a diffusing surface.

2. Description of the Related Art

Light emitting devices have been employed in a wide variety of applications, including optical displays, traffic lights, data storage apparatus, communication devices, illumination apparatus, and medical treatment equipment. How to improve the light emitting efficiency of light emitting devices is an important issue in this art.

Referring to FIG. **1**, according to Snell's law, when a light is directed from one material with an index of refraction n**1** towards another material with an index of refraction n**2**, the light will be refracted if its incident angle is smaller than a critical angle θ_c. Otherwise, the light will be totally reflected from the interface between the two materials. In other words, when a light beam generated from a light emitting diode (LED) travels across an interface from a material of a higher index of refraction to a material of a lower index of refraction, the angle between the incident light beam and the reflected light beam must be equal or less than $2\theta_c$ for the light to be emitted out. It means that when the light generated from the LED travels from an epitaxial layer having a higher index of refraction to a medium having a lower index of refraction, such as a substrate, air and so on, a portion of the light will be refracted into the medium, and another portion of the light with an incident angle larger than the critical angle will be reflected to the epitaxial layer of the LED. Because the environment surrounding the epitaxial layer of the LED has a lower index of refraction, the reflected light can be reflected for several times inside the LED and finally a certain portion of said reflected light can be absorbed.

In U.S. Patent Publication No. 2002/0017652 entitled "Semiconductor Chip for Optoelectronics", an epitaxial layer of a light-emitting device forming on a non-transparent substrate is etched to form a micro reflective structure having a multiplicity of semi-spheres, pyramids, or cones, then a metal reflective layer is deposited on the epitaxial layer. The top of the micro reflective structure is bonded to a conductive carrier (silicon wafer), and then the non-transparent substrate of the epitaxial layer is removed. All the light generated from the light emitting layer and incident to the micro reflective structure will be reflected back to the epitaxial layer and emitted out of the LED with a direction perpendicular to a light emitting surface. Therefore, the light will not be restricted by the critical angle any more.

SUMMARY

Accordingly, the present invention is directed to a light emitting device utilizing a diffusing surface formed in a light emitting stack of the light emitting device to increase the light extraction efficiency and further improve its light emitting efficiency.

The present invention is directed to a light emitting device to enhance the light extraction efficiency of the light emitting device and further improve the light emitting efficiency.

As embodied and broadly described herein, the present invention provides a light emitting device comprising a transparent substrate, a light emitting stack and a transparent adhesive layer. The light emitting stack is disposed above the transparent substrate and comprises a diffusing surface. The transparent adhesive layer is disposed between the transparent substrate and the diffusing surface of the light emitting stack, wherein an index of refraction of the light emitting stack is different from that of the transparent adhesive layer.

According to one embodiment of the present invention, a material of the transparent substrate is selected from one of the group consisting of GaP, SiC, Al_2O_3 and glass.

According to one embodiment of the present invention, a material of the light emitting stack is selected from one of the group consisting of AlGaInP, AlN, GaN, AlGaN, InGaN and AlInGaN.

According to one embodiment of the present invention, a material of the transparent adhesive layer is selected from one of the group consisting of polyimide, benzocyclobutene (BCB), prefluorocyclobutane (PFCB) and indium tin oxide.

According to one embodiment of the present invention, the diffusing surface is a rough surface.

According to one embodiment of the present invention, the rough surface comprises a plurality of micro protrusions. The shape of the micro protrusions is selected from one of the group consisting of semi-sphere, pyramid, pyramid polygon, and combinations thereof.

According to one embodiment of the present invention, the rough surface is a convex-concave surface.

According to one embodiment of the present invention, the light emitting stack comprises a first semiconductor layer, a light emitting layer and a second semiconductor layer. The first semiconductor layer is disposed above the substrate and has the diffusing surface. The light emitting layer is disposed on a portion of the first semiconductor layer. The second semiconductor layer is disposed on the light emitting layer.

According to one embodiment of the present invention, the second semiconductor layer has another diffusing surface.

According to one embodiment of the present invention, the light emitting device further comprises a first electrode and a second electrode. The first electrode is disposed on the first semiconductor layer where the light emitting layer is not disposed thereon, and the second electrode is disposed on the second semiconductor layer.

According to one embodiment of the present invention, the light emitting device further comprises a first transparent conductive layer disposed between the first electrode and the first semiconductor layer.

According to one embodiment of the present invention, a material of the first transparent conductive layer is selected from one of the group consisting of indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide and zinc tin oxide.

According to one embodiment of the present invention, the light emitting device further comprises a first reaction layer and a second reaction layer. The first reaction layer is disposed between the transparent substrate and the transparent adhesive layer, and the second reaction layer disposed between the transparent adhesive layer and the light emitting stack.

According to one embodiment of the present invention, the first reaction layer is conductive.

According to one embodiment of the present invention, the second reaction layer is conductive.

According to one embodiment of the present invention, a material of the first reaction layer is selected from one of the group consisting of SiNx, Ti and Cr.

According to one embodiment of the present invention, a material of the second reaction layer is selected from one of the group consisting of SiNx, Ti and Cr.

According to one embodiment of the present invention, the second reaction layer is in ohmic contact with the first reaction layer with the existence of the protrusions of the plurality of micro protrusions penetrating through the transparent adhesive layer.

According to one embodiment of the present invention, the second reaction layer is in ohmic contact with the first reaction layer with the existence of the convex part of the convex-concave surface penetrating through the transparent adhesive layer.

According to one embodiment of the present invention, the light emitting stack comprises a first semiconductor layer, a light emitting layer and a second semiconductor layer. The first semiconductor layer is disposed above the substrate and has the diffusing surface. The light emitting layer is disposed on the first semiconductor layer. The second semiconductor layer is disposed on the light emitting layer.

According to one embodiment of the present invention, the transparent substrate is conductive.

According to one embodiment of the present invention, the transparent adhesive layer is a transparent conductive adhesive layer and a material of the transparent conductive adhesive layer is selected from one of the group consisting of intrinsically conductive polymer and polymer having conductive material distributed therein.

According to one embodiment of the present invention, the polymer is selected from one of the group consisting of polyimide, benzocyclobutene (BCB), and prefluorocyclobutane (PFCB).

According to one embodiment of the present invention, the conductive material is selected from one of the group consisting of indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc oxide, zinc tin oxide, Au and Ni/Au.

According to one embodiment of the present invention, the light emitting device further comprises a first electrode and a second electrode. The first electrode is disposed on the second semiconductor layer, and the second electrode is disposed under the transparent substrate.

According to one embodiment of the present invention, the light emitting device further comprises a transparent conductive layer disposed between the second semiconductor layer and the first electrode.

According to one embodiment of the present invention, a material of the transparent conductive layer is selected from one of the group consisting of indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide and zinc tin oxide.

The present invention is to bond the transparent substrate and the light emitting stack having the diffusing surface together by the transparent adhesive layer. The light emitting stack and the transparent adhesive layer have different indices of refraction, such that the possibility of light extraction of the light emitting device is raised, and the light emitting efficiency is improved, too.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. **1** is a schematic diagram illustrating the Snell's law.

FIG. **2** is a schematic diagram showing a light field of the present invention.

FIG. **3** is a schematic cross-sectional view showing a light emitting device according to a preferred embodiment of the present invention.

FIG. **4** is a schematic cross-sectional view showing a light emitting device having two diffusing surfaces according to a preferred embodiment of the present invention.

FIG. **5** is a schematic cross-sectional view showing a light emitting device having transparent conductive layers according to a preferred embodiment of the present invention.

FIG. **6** is a schematic cross-sectional view showing a light emitting device having reaction layers according to a preferred embodiment of the present invention.

FIG. **7** is a schematic cross-sectional view showing a light emitting device according to another preferred embodiment of the present invention.

FIG. **8** is a schematic cross-sectional view showing a light emitting device according to another preferred embodiment of the present invention.

DESCRIPTION OF THE EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

FIG. **2** is a schematic diagram showing a light field of the present invention. Referring to FIG. **2**, when a light **1**A generated from a light emitting layer **13** is directed towards a diffusing surface S, a portion of the light **1**A is refracted to a transparent substrate **10** to form a light field **1**B, and another portion of the light **1**A is diffused by the diffusing surface S to form a light field **1**C. The present invention utilizes the presence of the diffusing surface S to make the light, which is restricted to the critical angle, be reflected to the light emitting layer **13** after diffusion, and the light will be extracted from the front of the light emitting layer **13**, such that the light extraction efficiency will be enhanced. If a portion of the diffused light is totally reflected to the diffusing surface S, it will be diffused again to change its incident angle, thus improving the light extraction efficiency. Therefore, no matter how many times the light experiences the total internal reflection, the light will be diffused by the diffusing surface S, to increase a probability of light extraction and enhance the light emitting efficiency.

FIG. **3** is a schematic cross-sectional view showing a light emitting device according to a preferred embodiment of the present invention. The light emitting device **100** comprises a transparent substrate **110**, a transparent adhesive layer **120**, a light emitting stack **130**, a first electrode **140** and a second electrode **150**. In one embodiment of the present invention, the material of the transparent substrate **110** is selected from one of the group consisting of GaP, SiC, Al_2O_3 and glass. The transparent adhesive layer **120** is formed on the transparent substrate **110**, and the material of the transparent adhesive layer **120** can be polyimide, benzocyclobutene (BCB), prefluorocyclobutane (PFCB) or indium tin oxide. The light emitting stack **130** comprises a first semiconductor layer **132**, a light emitting layer **134** and a second semiconductor layer **136**, and the index of refraction of the light emitting stack **130** is different from that of the transparent adhesive layer **120**.

The first semiconductor layer **132** attaches to the transparent substrate **110** through the transparent adhesive layer **120**, and has a diffusing surface **122** next to the transparent adhesive layer **120**. The material of the first semiconductor layer **132**, the light emitting layer **134** and the second semiconductor layer **136** can be AlGaInP, AlN, GaN, AlGaN, InGaN or AlInGaN. An upper surface of the first semiconductor layer **132** has an epitaxy region and an electrode region. The light emitting layer **134** is formed on the epitaxy region of the first semiconductor layer **132**. The second semiconductor layer **136** is formed on the light emitting layer **134**. The first electrode **140** is formed on the electrode region of the first semiconductor layer **132**. The second electrode **150** is formed on the second semiconductor layer **136**. Referring to FIG. **4**, an upper surface of the second semiconductor layer **136** may further comprise another diffusing surface **136***a*, thereby enhancing the light extraction efficiency.

The way to form the first semiconductor layer **132**, the light emitting layer **134** and the second semiconductor layer **136** on the transparent substrate **110** as shown in FIGS. **3** and **4** is to use an epitaxy method. The diffusing surfaces **122** and **136***a* are rough surfaces, and they can be formed during the exitaxy process. They also can be formed by etching a part of the first semiconductor layer **132** through wet etching or dry etching, such as inductive coupling plasma (ICP), during the epitaxy process. The light emitting diode having the rough surface is attached to the transparent substrate **110** by the transparent adhesive layer **120**.

In another embodiment of the present invention, the diffusing surface **122** of the first semiconductor layer **132** may comprise a plurality of micro protrusions and attaches to the transparent substrate **110** through the transparent adhesive layer **120**. The shape of the micro protrusions can be a semi-sphere, a pyramid or a pyramid polygon. Because of the micro protrusions, the diffusing surface is roughened, and the light extraction efficiency is enhanced.

In one embodiment of the present invention, referring to FIG. **5**, a first transparent conductive layer **180** is selectively disposed between the first electrode **140** and the first semiconductor layer **132**. The material of the first transparent conductive layer **180** comprises indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide or zinc tin oxide. Similarly, a second transparent conductive layer **190** is selectively disposed between the second semiconductor layer **136** and the second electrode **150**. The material of the second transparent conductive layer **190** comprises indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide or zinc tin oxide.

Besides, referring to FIG. **6**, a first reaction layer **160** can be selectively disposed between the transparent substrate **110** and the transparent adhesive layer **120**, and a second reaction layer **170** can be selectively disposed between the transparent adhesive layer **120** and the first semiconductor layer **132**, thereby increasing the adhesion of the transparent adhesive layer **120**. The material of the first reaction layer **160** and the second reaction layer **170** can be SiNx, Ti or Cr.

FIG. **7** is a schematic cross-sectional view showing a vertical structure light emitting device **200** light emitting device according to another preferred embodiment of the present invention. The transparent substrate **110** is a conductive substrate. The first semiconductor layer **132** with the second reaction layer **170** underneath is coupled to a gel-state transparent adhesive layer **120**, and the protrusion part of the second reaction layer **170** penetrates through the transparent adhesive layer **120** and is ohmic contact with the first reaction layer **160** because the first reaction layer **160** and the second reaction layer **170** are both conductive. Then, a first electrode **140** and a second electrode **150** are formed on the lower surface of the transparent substrate **110** and the upper surface of the second semiconductor layer **136** respectively. Similarly, a transparent conductive layer (not shown) is selectively disposed between the second electrode **150** and the second semiconductor layer **136**. The material of the transparent conductive layer comprises indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide or zinc tin oxide.

FIG. **8** is a schematic cross-sectional view showing a light emitting device according to another preferred embodiment of the present invention. Referring to FIG. **8**, the structure of the light emitting device **300** is similar to that of the light emitting device **100** shown in FIG. **3**. The difference between them is that a transparent conductive adhesive layer **124** replaces the transparent adhesive layer **120**, and the transparent substrate **110** is replaced by a transparent conductive substrate **112**, such that the light emitting device **300** is electrically conductive vertically. The transparent conductive adhesive layer **124** is composed of intrinsically conductive polymer or polymer having conductive material distributed therein. The conductive material comprises indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc oxide, zinc tin oxide, Au or Ni/Au. The first electrode **140** is formed under the transparent conductive substrate **112**; the second electrode **150** is formed on the second semiconductor layer **136**.

In one embodiment of the present invention, the light emitting device **300** further comprises a transparent conductive layer (not shown) disposed between the second electrode **150** and the second semiconductor layer **136**. The material of the transparent conductive layer comprises indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminium oxide or zinc tin oxide.

The present invention is to combine the transparent substrate and the light emitting stack together by the transparent adhesive layer having the diffusing surface. The light emitting stack and the transparent adhesive layer have different indices of refraction, such that the possibility of light extraction of the light emitting device is raised, and the light emitting efficiency is improved, too.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structures in accordance with the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A light emitting device, comprising:

a transparent substrate;

a light emitting stack having a first diffusing surface above the transparent substrate; and

a transparent adhesive layer between the transparent substrate and the first diffusing surface, wherein an index of refraction of the light emitting stack is different from that of the transparent adhesive layer.

2. The light emitting device according to claim **1**, wherein the transparent substrate comprises a material selected from the group consisting of GaP, SiC, Al_2O_3, and glass.

3. The light emitting device according to claim **1**, wherein the transparent adhesive layer comprises a material selected from the group consisting of polyimide, benzocyclobutene (BCB), prefluorocyclobutane (PFCB), and indium tin oxide.

4. The light emitting device according to claim **1**, wherein the first diffusing surface comprises a rough surface.

5. The light emitting device according to claim **4**, wherein the rough surface comprises a plurality of micro protrusions.

6. The light-emitting device according to claim **5**, wherein the micro protrusions have a shape selected from the group consisting of semi-sphere, pyramid, pyramid polygon, and combinations thereof.

7. The light emitting device according to claim **4**, wherein the rough surface comprises a convex-concave surface.

8. The light emitting device according to claim **1**, wherein the light emitting stack comprises:

a first semiconductor layer above the substrate and having the first diffusing surface;

a light emitting layer on a portion of the first semiconductor layer; and

a second semiconductor layer on the light emitting layer.

9. The light emitting device according to claim **8**, wherein the second semiconductor layer has a second diffusing surface.

10. The light emitting device according to claim **8**, further comprising a first electrode and a second electrode, wherein the first electrode is on the first semiconductor layer where the tight emitting layer is not disposed thereon, and the second electrode is on the second semiconductor layer.

11. The light emitting device according to claim **10**, further comprising a first transparent conductive layer between the first electrode and the first semiconductor layer.

12. The light emitting device according to claim **11**, wherein the first transparent conductive layer comprises a material selected from the group consisting of indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminum oxide, and zinc tin oxide.

13. The light emitting device according to claim **1**, further comprising a first reaction layer and a second reaction layer, wherein the first reaction layer is between the transparent substrate and the transparent adhesive layer, and the second reaction layer between the transparent adhesive layer and the light emitting stack.

14. The light emitting device according to claim **13**, wherein the first reaction layer comprises a material selected from the group consisting of SiN_x, Ti, and Cr.

15. The light emitting device according to claim **13**, wherein the second reaction layer comprises a material selected from the group consisting of SiN_x, Ti, and Cr.

16. The light emitting device according to claim **13**, wherein at least one of the first reaction layer and the second reaction layer is conductive.

17. The light emitting device according to claim **13**, wherein the first diffusing surface comprises a plurality of micro protrusions, and the second reaction layer is in ohmic contact with the first reaction layer with the existence of the protrusions penetrating through the transparent adhesive layer.

18. The light emitting device according to claim **17**, wherein the micro protrusions have a shape selected from the group consisting of semi-sphere, pyramid, pyramid polygon, and combinations thereof.

19. The light emitting device according to claim **13**, wherein the first diffusing surface comprises a convex-concave surface, and the second reaction layer is in ohmic contact with the first reaction layer with the existence of a convex part of the convex-concave surface penetrating through the transparent adhesive layer.

20. The light emitting device according to claim **1**, wherein the light emitting stack comprises:

a first semiconductor layer above the substrate and having the first diffusing surface;

a light emitting layer on the first semiconductor layer; and

a second semiconductor layer on the light emitting layer.

21. The light-emitting device according to claim **20**, wherein the transparent substrate is conductive.

22. The light emitting device according to claim **20**, wherein the second semiconductor layer has a second diffusing surface.

23. The light emitting device according to claim **20**, wherein the transparent adhesive layer is a conductive adhesive layer and the transparent conductive adhesive layer comprises a material selected from the group consisting of intrinsically conductive polymer and polymer having conductive material distributed therein.

24. The light emitting device according to claim **23**, wherein the polymer having conductive material distributed therein is selected from the group consisting of polyimide, benzocyclobutene (BCB), and prefluorocyclobutane (PFCB).

25. The light emitting device according to claim **23**, wherein the conductive material comprises a material selected from the group consisting of indium tin oxide, cadmium tin oxide, antimony tine oxide, zinc oxide, zinc tin oxide, Au, and Ni/Au.

26. The light emitting device according to claim **20**, further comprising a first electrode and a second electrode, wherein the first electrode is on the second semiconductor layer, and the second electrode is under the transparent substrate.

27. The light emitting device according to claim **26**, further comprising a transparent conductive layer between the second semiconductor layer and the first electrode.

28. The light emitting device according to claim **27**, wherein the transparent conductive layer comprises a material selected from the group consisting of indium tin oxide, cadmium tin oxide, antimony tin oxide, zinc aluminum oxide, and zinc tin oxide.

* * * * *

Exhibit 3

US007560738B2

(12) **United States Patent**
Liu

(10) **Patent No.: US 7,560,738 B2**
(45) **Date of Patent: Jul. 14, 2009**

(54) **LIGHT-EMITTING DIODE ARRAY HAVING AN ADHESIVE LAYER**

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(73) Assignee: **Epistar Corporation**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 440 days.

(21) Appl. No.: **10/906,894**

(22) Filed: **Mar. 11, 2005**

(65) **Prior Publication Data**

US 2005/0224822 A1 Oct. 13, 2005

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/604,245, filed on Jul. 4, 2003, now Pat. No. 6,987,287.

(30) **Foreign Application Priority Data**

Apr. 13, 2004 (TW) .... 93110342 A

(51) **Int. Cl.**
H01L 29/88 (2006.01)

(52) **U.S. Cl.** **257/88**; 257/93; 257/96

(58) **Field of Classification Search** 257/88, 257/93, 96
See application file for complete search history.

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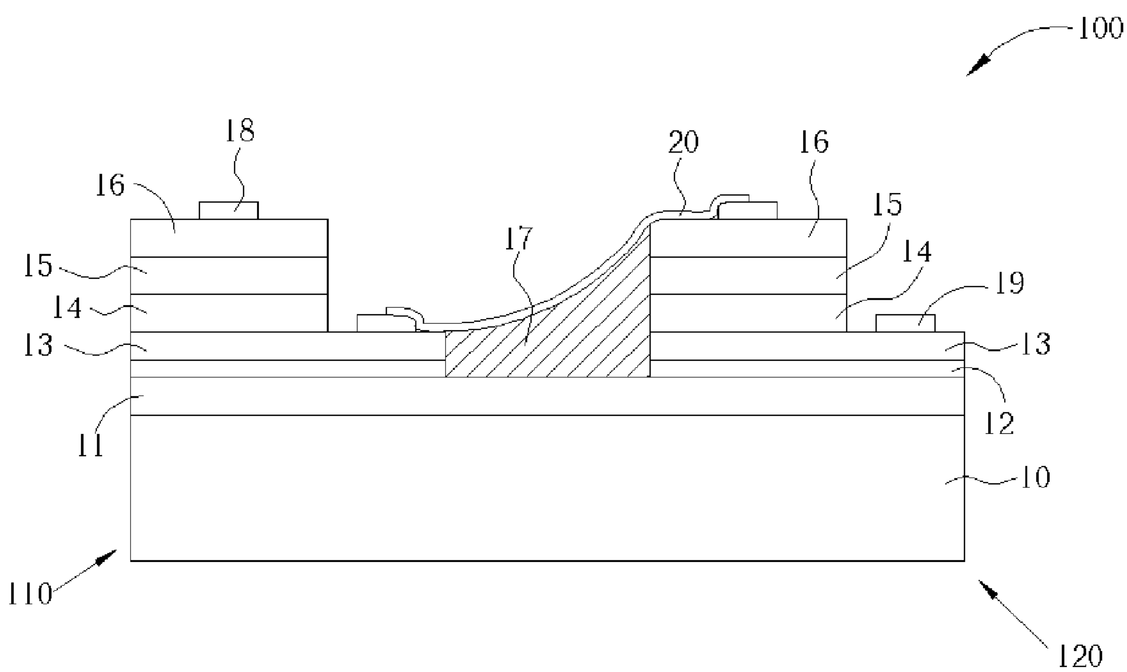
Primary Examiner—Fernando L Toledo
(74) *Attorney, Agent, or Firm*—Quintero Law Office

(57) **ABSTRACT**

A light-emitting diode array includes a substrate, an adhesive layer formed on the substrate, and a plurality of electrically connected epitaxial light-emitting stack layer disposed on the adhesive layer. Each of the epitaxial light-emitting stack layer has a P-contact and an N-contact coplanar to the P-contact. The light-emitting diode array has improved heat ventilation characteristics.

47 Claims, 5 Drawing Sheets



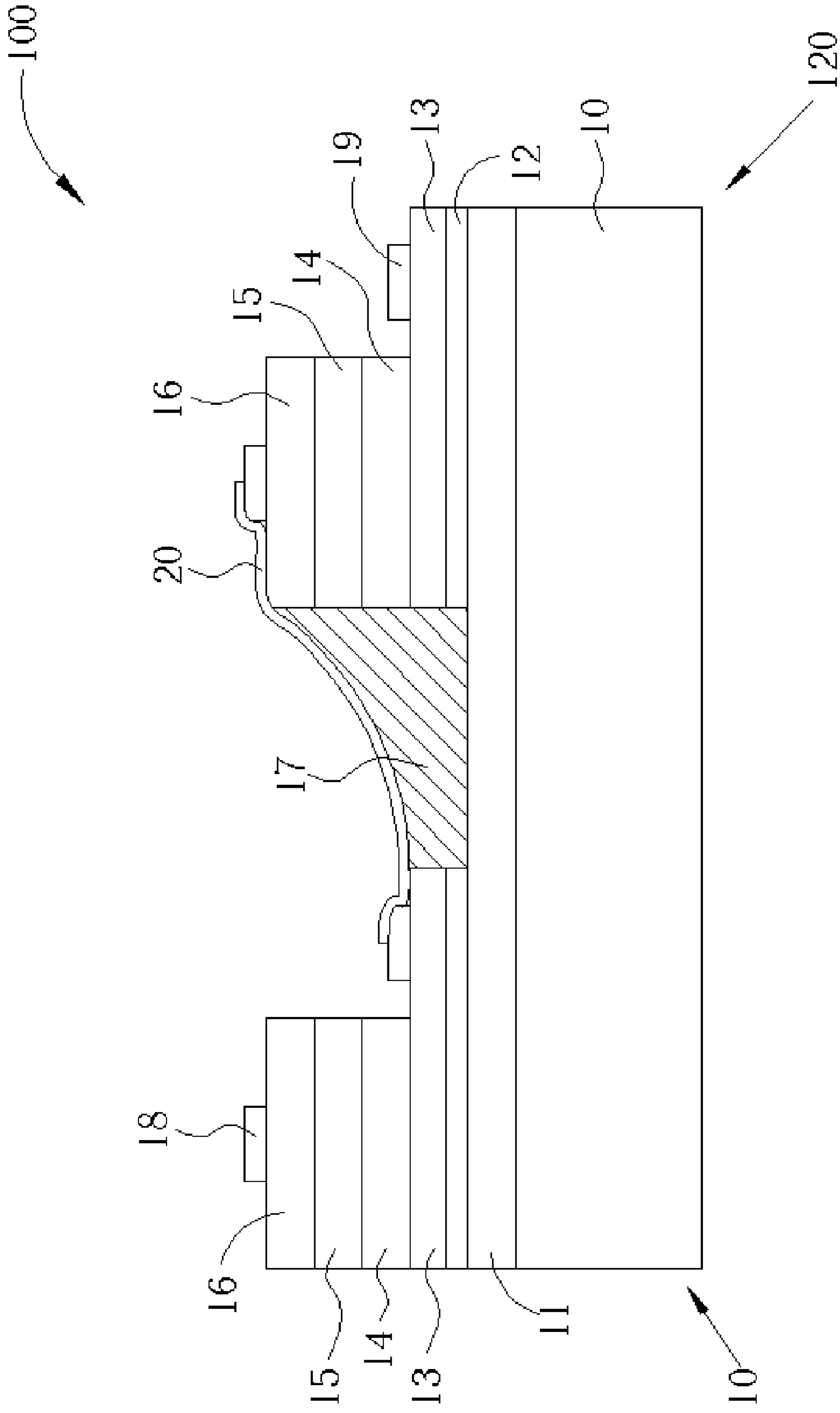


Fig. 1

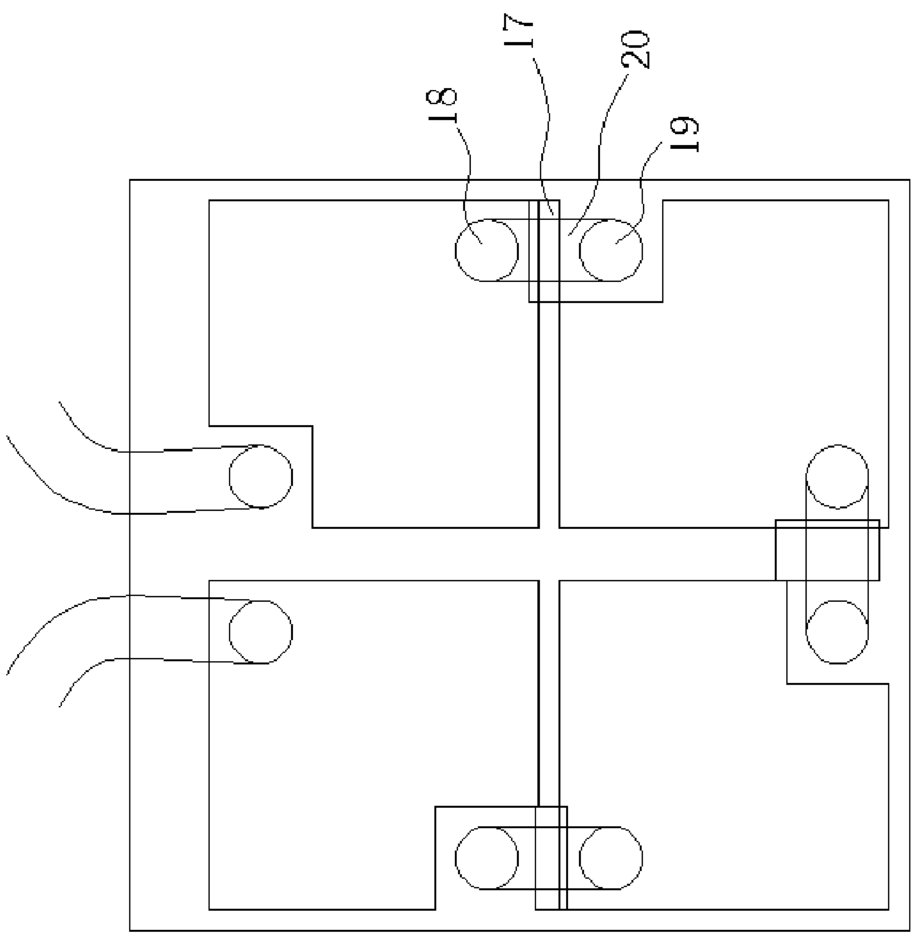


Fig. 2

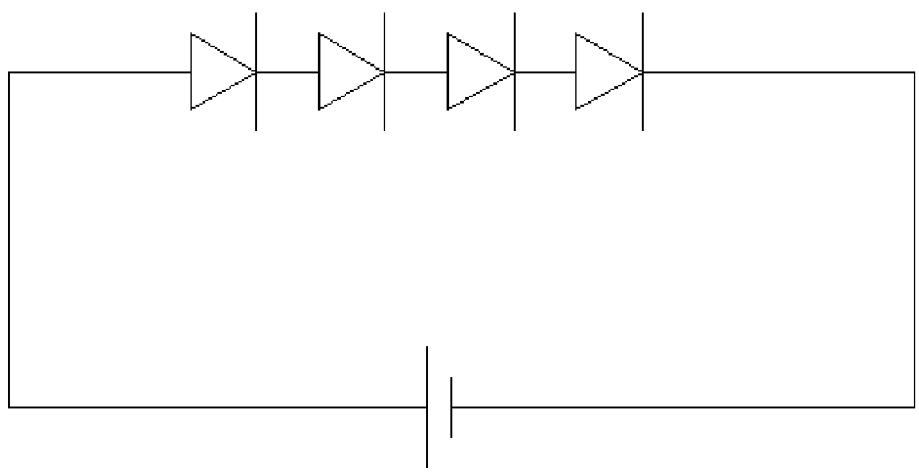


Fig. 3

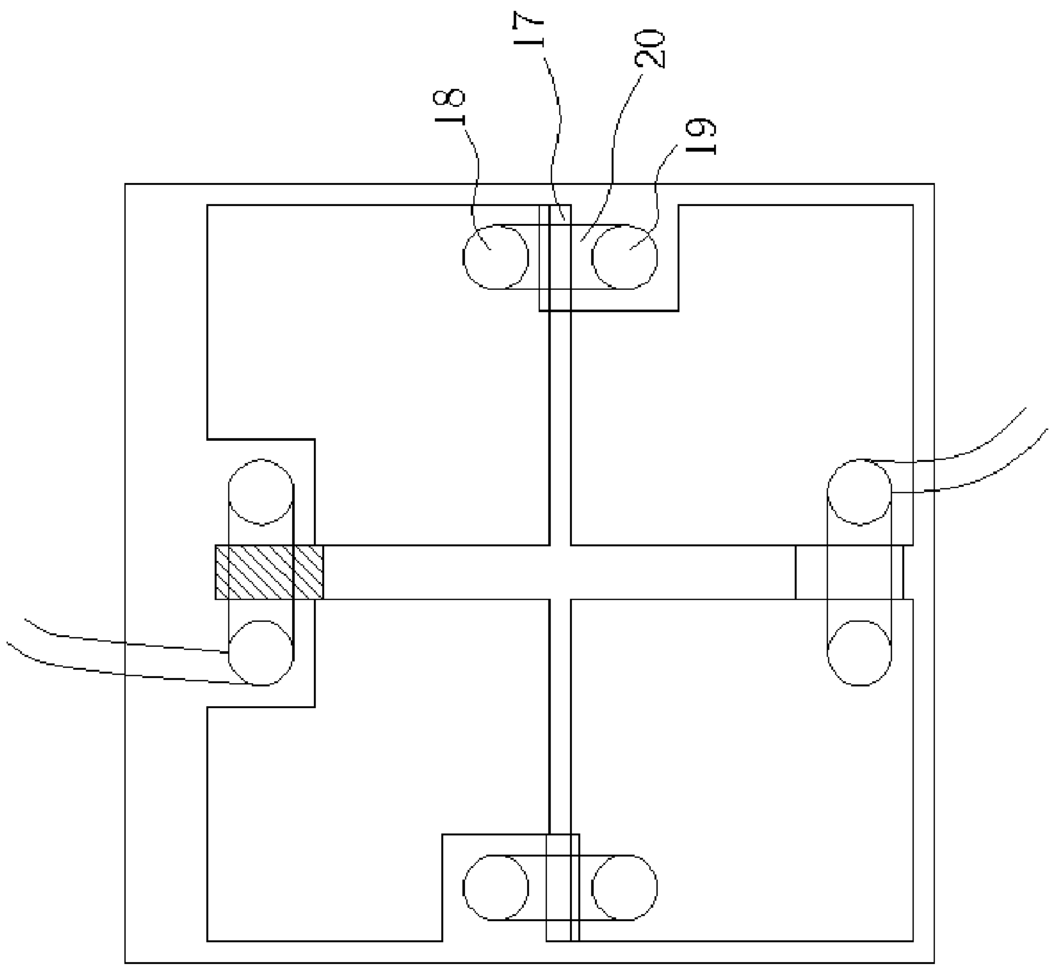


Fig. 4

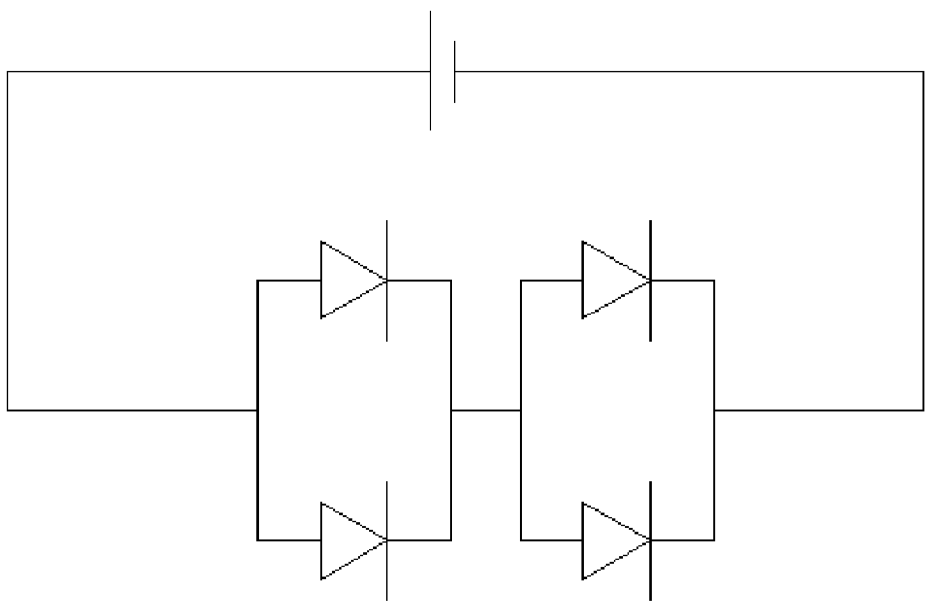


Fig. 5

LIGHT-EMITTING DIODE ARRAY HAVING AN ADHESIVE LAYER

This application is a continuation-in-part of U.S. application Ser. No. 10/604,245, filed Jul. 4, 2003 now U.S. Pat. No. 6,987,287.

BACKGROUND OF INVENTION

1. Field of the Invention

The present invention relates to a light-emitting diode, and more particularly, to a light-emitting diode array having an adhesive layer.

2. Description of the Prior Art

Light-emitting diodes (LEDs) are employed in a wide variety of applications including optical display devices, traffic lights, data storage equipment, communications devices, illumination apparatuses, and medical treatment equipment. One of the most important goals of engineers who design LEDs is to increase the brightness of the light emitted.

U.S. Pat. No. 6,547,249 discloses monolithic serial/parallel LED arrays formed on highly resistive substrates. According to the patent, a Group III-V nitride light-emitting stack layer is formed on an insulating substrate. A portion of the stack layer is etched away to form a trench, and in result to form the LED array, which includes a plurality of light-emitting diodes divided by the trench. Since the insulating substrate is not conductive, both P-contacts and N-contacts for the LED array have to be formed on the same side of the LED array. In use, two LED arrays can be connected either in series or in parallel. However, the LED array disclosed by the patent cannot be applied to a quaternary Al—In—Ga—P light-emitting diode, which comprises a conductive substrate rather than an insulating substrate, P-contacts formed on one side of the conductive substrate, and N-contacts having to be formed on the other side. Therefore, two quaternary Al—In—Ga—P light-emitting diode arrays can be connected neither in series nor in parallel. Moreover, as the size of the LED array become larger, the operating voltage of the LED array becomes higher accordingly, and heat dissipation becomes an important concern for the LED array.

SUMMARY OF INVENTION

It is therefore a primary objective of the claimed invention to provide an LED array having an adhesive layer to overcome the drawbacks of the prior art.

According to the claimed invention, the light-emitting diode array includes a substrate, a reflective layer formed on the substrate, an insulating transparent adhesive layer formed on the reflective layer, a transparent conductive layer formed on the insulating transparent adhesive layer, a first conductive semiconductor stack layer formed on the transparent conductive layer, a light-emitting layer formed on the first conductive semiconductor stack layer, and a second conductive semiconductor stack layer formed on the light-emitting layer.

A trench is formed by etching away a portion of the second conductive semiconductor stack layer, the light-emitting layer, the first conductive semiconductor stack layer, the transparent conductive layer, and the insulating transparent adhesive layer sequentially, and therefore the LED array is divided into a first LED and a second LED, both of which have the substrate in common. Moreover, a transparent conductive layer exposed surface region is formed by etching both of the first LED and the second LED deeply into the transparent conductive layer. The LED array further includes an insulating layer formed surrounding the first LED and the second LED for electrically isolating the first LED from the second LED. First contacts formed on the second conductive semiconductor stack layer of the first LED and the second conductive semiconductor stack layer of the second LED respectively. Second contacts formed on the transparent conductive layer exposed surface region of the first LED and the transparent conductive layer exposed surface region of the second LED respectively, and a conductive line for electrically connecting a second contact of the first LED to a first contact of the second LED.

The substrate comprises at least one material selected from a material group consisting of GaP, GaAs, Si, SiC, Al_2O_3, glass, quartz, GaAsP, AIN, metal, and AlGaAs. The insulating transparent adhesive layer comprises at least one material selected from a material group consisting of polyimide (PI), benzocyclobutene (BCB), and perfluorocyclobutene (PFCB). The reflective layer comprises at least one material selected from a material group consisting of In, Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO). The light-emitting layer comprises at least one material selected from a material group consisting of AlGaInP, GaN, InGaN, AlInGaN, and ZnSe. The transparent conductive layer comprises at least one material selected from a material group consisting of indium-tin oxide (ITO), cadmium-tin oxide (CTO), antimony-tin oxide (ATO), zinc oxide, and zinc-tin oxide. The insulating layer comprises at least one material selected from a material group consisting of SiO_2 and SiN_x. The first semiconductor stack layer comprises at least one material selected from a material group consisting of AlInP, AIN, GaN, InGaN, AlGaN, and AlInGaN. The second semiconductor stack layer comprises at least one material selected from a material group consisting of AlInP, AIN, GaN, InGaN, AlGaN, and AlInGaN.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a cross sectional schematic diagram of a light-emitting diode array having an adhesive layer of the preferred embodiment according to the present invention.

FIG. **2** is a top view of a schematic diagram of a plurality of serially connected LED arrays shown in FIG. **1** according to the present invention.

FIG. **3** is an equivalent circuit diagram of the LED arrays shown in FIG. **2** according to the present invention.

FIG. **4** is a top view of a schematic diagram of a plurality of serially and parallelly connected LED arrays shown in FIG. **1** according to the present invention.

FIG. **5** is an equivalent circuit diagram of the LED arrays shown in FIG. **4** according to the present invention.

DETAILED DESCRIPTION

Please refer to FIG. **1**, which is a cross sectional schematic diagram of a light-emitting diode array **100** of the preferred embodiment according to the present invention. The LED array **100** comprises a substrate **10**, a reflective layer **11** formed on the substrate **10**, an insulating transparent adhesive layer **12** formed on the reflective layer **11**, a transparent conductive layer **13** formed on the insulating transparent adhesive layer **12**, a first conductive semiconductor stack layer **14** formed on the transparent conductive layer **13**, a light-emitting layer **15** formed on the first conductive semiconductor stack layer **14**, a second conductive semiconductor stack layer **16** formed on the light-emitting layer **15**.

A trench is formed by etching away a portion of the second conductive semiconductor stack layer **16**, the light-emitting layer **15**, the first conductive semiconductor stack layer **14**, the transparent conductive layer **13**, and the insulating transparent adhesive layer **12** sequentially, and therefore the LED array **100** is divided into a first LED **110** and a second LED **120**, both of which have the substrate **10** in common. Moreover, a transparent conductive layer exposed surface region is formed by etching both of the first LED **110** and the second LED **120** moderately to the transparent conductive layer **13**. The LED array **100** further comprises an insulating layer **17** formed surrounding the first LED **110** and the second LED **120** for electrically isolating the first LED **110** from the second LED **120**. First contacts **18** formed on the second conductive semiconductor stack layer **16** of the first LED **110** and the second conductive semiconductor stack layer **16** of the second LED **120** respectively. Second contacts **19** formed on the transparent conductive layer exposed surface region of the first LED **110** and the transparent conductive layer exposed surface region of the second LED **120** respectively, and a conductive line **20** for electrically connecting a second contact of the first LED **110** to a first contact of the second LED **120**.

FIG. **2** is a top view of a schematic diagram of a plurality of LED arrays **100** connected in series according to the present invention. FIG. **3** is an equivalent circuit diagram of the LED arrays shown in FIG. **2**. FIG. **4** is a top view of a schematic diagram of a plurality of LED arrays **100** connected in series and in parallel according to the present invention. FIG. **5** is an equivalent circuit diagram of the LED arrays shown in FIG. **4**.

The reflective layer **11** can be also formed between the transparent conductive layer **13** and the adhesive layer **12**. The reflective layer **11** is installed to increase the luminance of the LED array **100** by reflecting light projected onto the substrate **10**. However, the LED array **100** still can operate without the reflective layer **11**.

The insulating transparent adhesive layer **12** is installed to electrically isolate the first LED **110** and the second LED **120** from the substrate **10**. The insulating transparent adhesive layer **12** can be replaced by a conductive adhesive layer made of metal or solder. However, an insulating layer providing electrical isolation has to be installed additionally between the substrate **10** and the conductive adhesive layer **12** or between the conductive adhesive layer **12** and the transparent conductive layer **13** to electrically isolate the first LED **110** and the second LED **120** from the substrate **10**.

The trench together with the insulating layer **17** electrically isolates the first LED **110** from the second LED **120**. However, the LED array **100** can further comprise an ion-implanted region formed between the first LED **110** and the second LED **120** for electrically isolating the first LED **110** from the second LED **120**.

The substrate **10** comprises at least one material selected from a material group consisting of GaP, GaAs, Si, SiC, Al_2O_3, glass, quartz, GaAsP, AlN, metal, and AlGaAs. The insulating transparent adhesive layer **12** comprises at least one material selected from a material group consisting of polyimide (PI), benzocyclobutene (BCB), and perfluorocyclobutene (PFCB). The reflective layer **11** comprises at least one material selected from a material group consisting of In, Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO). The light-emitting layer **15** comprises at least one material selected from a material group consisting of AlGaInP, GaN, InGaN, AlInGaN, and ZnSe. The transparent conductive layer **13** comprises at least

one material selected from a material group consisting of indium-tin oxide (ITO), cadmium-tin oxide (CTO), antimony-tin oxide (ATO), zinc oxide, and zinc-tin oxide. The insulating layer **17** comprises at least one material selected from a material group consisting of SiO_2 and SiN_x. The first conductive semiconductor stack layer **14** comprises at least one material selected from a material group consisting of AlInP, AlN, GaN, InGaN, AlGaN, and AlInGaN. The second conductive semiconductor stack layer **16** comprises at least one material selected from a material group consisting of AlInP, AlN, GaN, InGaN, AlGaN, and AlInGaN.

Since the insulating transparent adhesive layer **12** has a high resistance and is capable of electrically isolating the substrate **10** from the first LED **110** and the second LED **120** when being installed between them, the first LED **110** and the second LED **120** can comprise not only a Group III-V nitride material, but also a quaternary material. Moreover, since the substrate **10** is electrically isolated from the LEDs **110** and **120**, the substrate **10** can be an insulating substrate, a substrate having a high resistance, a conductive substrate, or a substrate having a high thermal conduvtivity, which has a capability to improve the heat-dissipation efficiency of the LED array **100**.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A light-emitting diode array comprising: a substrate; an adhesive layer formed on the substrate; and a plurality of electrically connected epitaxial light-emitting stack layers disposed on the adhesive layer, each of the epitaxial light-emitting stack layers comprising a P-contact and an N-contact, wherein the P-contact and the N-contact are disposed on the same side of the epitaxial light-emitting stack layer.

2. The light-emitting diode array of claim **1**, wherein each of the epitaxial light-emitting stack layers further comprises: a first conductive semiconductor stack layer;

a light-emitting layer formed on the first conductive semiconductor stack layer; and a second conductive semiconductor stack layer formed on the light-emitting layer.

3. The light-emitting diode array of claim **1** further comprising a plurality of insulating regions formed between any two adjacent epitaxial light-emitting stack layers for electrically isolating one of these two adjacent epitaxial light-emitting stack layers from the other.

4. The light-emitting diode array of claim **1** further comprising a reflective layer formed between the substrate and the adhesive layer.

5. The light-emitting diode array of claim **1** further comprising a reflective layer formed between the adhesive layer and the epitaxial light-emitting stack layer.

6. The light-emitting diode array of claim **4**, wherein the reflective layer comprises at least one material selected from a material group consisting of Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO).

7. The light-emitting diode array of claim **5**, wherein the reflective layer comprises at least one material selected from a material group consisting of Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO).

8. The light-emitting diode array of claim **1**, wherein the substrate comprises at least one material selected from a material group consisting of GaP, GaAs, Si, SiC, AI.sub.2O.sub.3, glass, quartz, GaAsP, AIN, metal, and AlGaAs.

9. The light-emitting diode array of claim **1**, wherein the adhesive layer comprises at least one material selected from a material group consisting of polyimide (PI), benzocyclobutene (BCB), and perfluorocyclobutene (PFCB).

10. The light-emitting diode array of claim **1**, wherein the adhesive layer is a metal adhesive layer made of metal.

11. The light-emitting diode array of claim **10** further comprising an insulating layer formed between the metal adhesive layer and the epitaxial light-emitting stack layer.

12. The light-emitting diode array of claim **10** further comprising an insulating layer formed between the metal adhesive layer and the substrate.

13. A light-emitting diode array comprising: a substrate; an adhesive layer formed on the substrate, the adhesive layer comprising a top surface and a plurality of adhesive regions disposed on the top surface; a first light-emitting stack layer formed on a first adhesive region of the plurality of adhesive regions, the first light-emitting stack layer comprising a top surface, a first first-conductivity contact region formed on the top surface, and a first second-conductivity contact region formed on the top surface; a first first-conductivity conductive contact formed on the ffirst first-conductivity contact region; a first second-conductivity conductive contact formed on the first second-conductivity contact region; a second light-emitting stack layer formed on a second adhesive region of the plurality of adhesive regions, the second light-emitting stack layer comprising a top surface, a second first conductive contact region formed on the top surface, and a second second-conductivity contact region formed on the top surface; a second first-conductivity conductive contact formed on the second first-conductivity contact region; a second second-conductivity conductive contact formed on the second second-conductivity contact region; and a first conductive line for electrically connecting either of the conductive contacts of the first light-emitting stack layer to either of the conductive contacts of the second light-emitting stack layer.

14. The light-emitting diode array of claim **13**, wherein the first-conductivity contact region is n-type, and the second-conductivity contact region is p-type.

15. The light-emitting diode array of claim **13**, wherein the first light-emitting stack layer further comprises: a first first-conductivity semiconductor stack layer; a first light-emitting layer formed on the first first-conductivity semiconductor stack layer; and a first second-conductivity semiconductor stack layer formed on the first light-emitting layer.

16. The light-emitting diode array of claim **13**, wherein the second light-emitting stack layer further comprises: a second first-conductivity semiconductor stack layer; a second light-emitting layer formed on the second first-conductivity semiconductor stack layer; and a second second-conductivity semiconductor stack layer formed on the second light-emitting layer.

17. The light-emitting diode array of claim **13** further comprising a insulating region formed between the first light-emitting stack layer and the second light-emitting stack layer for electrically isolating one of these two light-emitting stack layer from the other.

18. The light-emitting diode array of claim **13** further comprising a reflective layer formed between the substrate and the adhesive layer.

19. The light-emitting diode array of claim **13** further comprising a reflective layer formed between the adhesive layer and the first light-emitting stack layer.

20. The light-emitting diode array of claim **13** further comprising a reflective layer formed between the adhesive layer and the second light-emitting stack layer.

21. The light-emitting diode array of claim **17**, wherein the reflective layer comprises at least one material selected from a material group consisting of Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO).

22. The light-emitting diode array of claim **18**, wherein the reflective layer comprises at least one material selected from a material group consisting of Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO).

23. The light-emitting diode array of claim **19**, wherein the reflective layer comprises at least one material selected from a material group consisting of Sn, Al, Au, Pt, Zn, Ge, Ag, Ti, Pb, Pd, Cu, AuBe, AuGe, Ni, PbSn, AuZn, and indium-tin oxide (ITO).

24. The light-emitting diode array of claim **13**, wherein the substrate comprises at least one material selected from a material group consisting of GaP, GaAs, Si, SiC, AI.sub.2O.sub.3, glass, quartz, GaAsP, AIN, metal, and AlGaAs.

25. The light-emitting diode array of claim **13**, wherein the adhesive layer comprises at least one material selected from a material group consisting of polyimide (PI), benzocyclobutene (BCB), and perfluorocyclobutene (PFCB).

26. The light-emitting diode array of claim **13**, wherein the adhesive layer is a metal adhesive layer made of metal.

27. The light-emitting diode array of claim **26** further comprising an insulating layer formed between the metal adhesive layer and the first light-emitting stack layer and between the metal adhesive layer and the second light-emitting stack layer.

28. The light-emitting diode array of claim **26** further comprising an insulating layer formed between the metal adhesive layer and the substrate.

29. The light-emitting diode array of claim **15** further comprising a transparent conductive layer formed between the adhesive layer and the first first-conductivity semiconductor stack layer.

30. The light-emitting diode array of claim **16** further comprising a transparent conductive layer formed between the adhesive layer and the second first-conductivity semiconductor stack layer.

31. The light-emitting diode array of claim **17**, wherein the insulating region is in the form of a trench.

32. The light-emitting diode array of claim **17**, wherein the insulating region is composed of an ion-implanted region.

33. The light-emitting diode array of claim **13** further comprising: a third light-emitting stack layer formed on a third adhesive region of the plurality of adhesive regions, the third light-emitting stack layer comprising a top surface, a third first-conductivity contact region formed on the top surface, and a third second-conductivity contact region formed on the top surface; a third first-conductivity conductive contact formed on the third first-conductivity contact region; a third second-conductivity conductive contact formed on the third second-conductivity contact region;

a fourth light-emitting stack layer formed on a fourth adhesive region of the plurality of adhesive regions, the fourth light-emitting stack layer comprising a top surface, a fourth first-conductivity contact region formed on the top surface, and a fourth second-conductivity contact region formed on the top surface; a fourth first-conductivity conductive contact formed on the fourth first-conductivity contact region; a fourth second-conductivity conductive contact formed on the fourth second-conductivity contact region; and a second conductive line for electrically connecting the first first-conductivity conductive contact to the third second-conductivity conductive contact; a third conductive line for electrically connecting the second first-conductivity conductive contact to the fourth second-conductivity conductive contact; and a fourth conductive line for electrically connecting the third first-conductivity conductive contact to the fourth first-conductivity conductive contact; wherein the first conductive line connects the first second-conductivity conductive contact to the second second-conductivity conductive contact.

34. The light-emitting diode array of claim **33** further comprising an insulating region formed between the third light-emitting stack layer and the second light-emitting stack layer for electrically isolating the third light-emitting stack layer from the second light-emitting stack layer.

35. The light-emitting diode array of claim **33** further comprising an insulating region formed between the third light-emitting stack layer and the fourth light-emitting stack layer for electrically isolating the third light-emitting stack layer from the fourth light-emitting stack layer.

36. The light-emitting diode array of claim **34**, wherein the insulating region is in the form of a trench.

37. The light-emitting diode array of claim **34**, wherein the insulating region is composed of an ion-implanted region.

38. The light-emitting diode array of claim **35**, wherein the insulating region is in the form of a trench.

39. The light-emitting diode array of claim **35**, wherein the insulating region is composed of an ion-implanted region.

40. The light-emitting diode array of claim **33**, wherein the first-conductivity contact region is n-type electro-polarization, and the second-conductivity contact region is p-type electro-polarization.

41. The light-emitting diode array of claim **33**, wherein the third light-emitting stack layer further comprises: a third first-conductivity semiconductor stack layer; a third light-emitting layer formed on the third first-conductivity semiconductor stack layer; and a third second-conductivity semiconductor stack layer formed on the third light-emitting layer.

42. The light-emitting diode array of claim **33**, wherein the fourth light-emitting stack layer further comprises: a fourth first-conductivity semiconductor stack layer; a fourth light-emitting layer formed on the fourth first-conductivity semiconductor stack layer; and a fourth second-conductivity semiconductor stack layer formed on the fourth light-emitting layer.

43. The light-emitting diode array of claim **33** further comprising a reflective layer formed between the substrate and the adhesive layer.

44. The light-emitting diode array of claim **33** further comprising a reflective layer formed between the third light-emitting stack layer and the adhesive layer.

45. The light-emitting diode array of claim **33** further comprising a reflective layer formed between the fourth light-emitting stack layer and the adhesive layer.

46. The light-emitting diode array of claim **41** further comprising a transparent conductive layer formed between the adhesive layer and the third second-conductivity semiconductor stack layer.

47. The light-emitting diode array of claim **42** further comprising a transparent conductive layer formed between the adhesive layer and the fourth second-conductivity semiconductor stack layer.

* * * * *

Exhibit 4

US008791467B2

(12) **United States Patent**
Yang

(10) **Patent No.: US 8,791,467 B2**
(45) **Date of Patent: Jul. 29, 2014**

(54) **LIGHT EMITTING DIODE AND METHOD OF MAKING THE SAME**

(75) Inventor: **Kuang-Neng Yang**, Ping Chen (TW)

(73) Assignee: **Epistar Corporation**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/105,363**

(22) Filed: **May 11, 2011**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Continuation of application No. 12/560,723, filed on Sep. 16, 2009, now Pat. No. 7,951,633, which is a continuation of application No. 11/267,315, filed on Nov. 7, 2005, now Pat. No. 7,615,392, which is a division of application No. 10/142,954, filed on May 13, 2002, now Pat. No. 7,129,527, which is a continuation-in-part of application No. 09/828,060, filed on Apr. 6, 2001, now Pat. No. 6,709,883.

(30) **Foreign Application Priority Data**

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Feb. 15, 2002 (TW) .... 91102629 A

(51) **Int. Cl.**
H01L 33/00 (2010.01)

(52) **U.S. Cl.**
USPC **257/79**; 257/13; 257/E33.001; 438/22; 438/46

(58) **Field of Classification Search**
USPC 257/13, 79, E33.001; 438/22, 46
See application file for complete search history.

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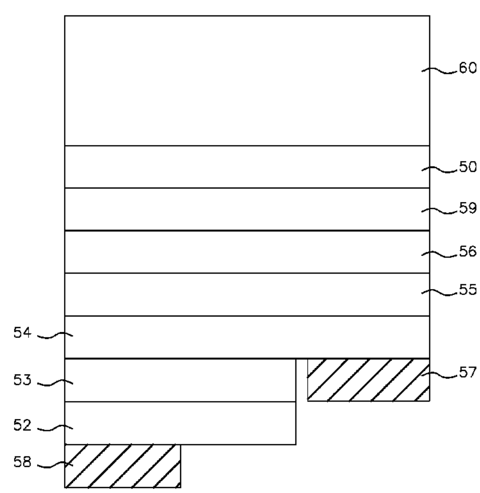
Primary Examiner — Victor A Mandala
(74) *Attorney, Agent, or Firm* — Muncy, Geissler, Olds & Lowe, P.C.

(57) **ABSTRACT**

An embodiment of the present invention discloses a light-emitting structure having a light output power of more than 4mW at 20 mA current. Another embodiment of the present invention discloses a method of making a light-emitting structure having a light output power of more than 4mW at 20 mA current, and a layer with a thickness of 0.5 µm~3µm.

18 Claims, 5 Drawing Sheets



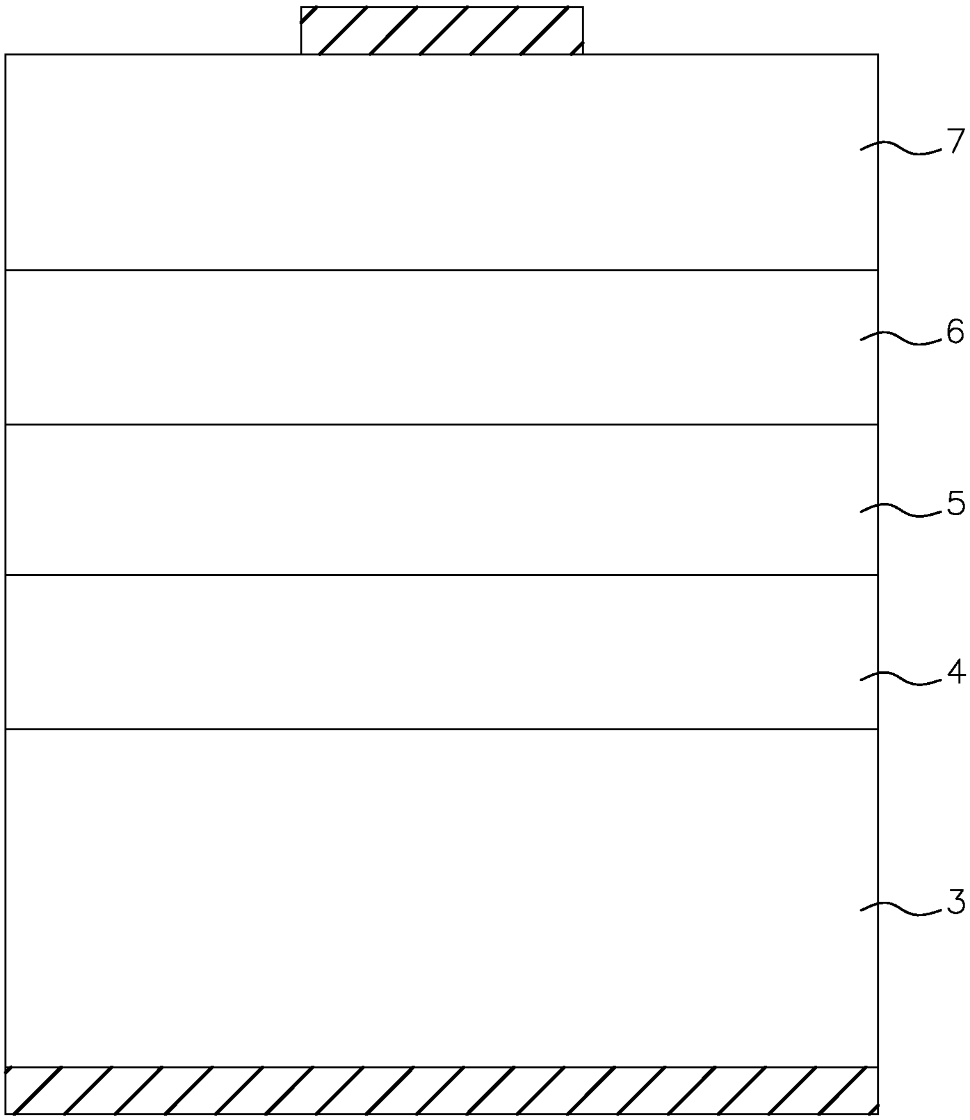


FIG. 1 (PRIOR ART)

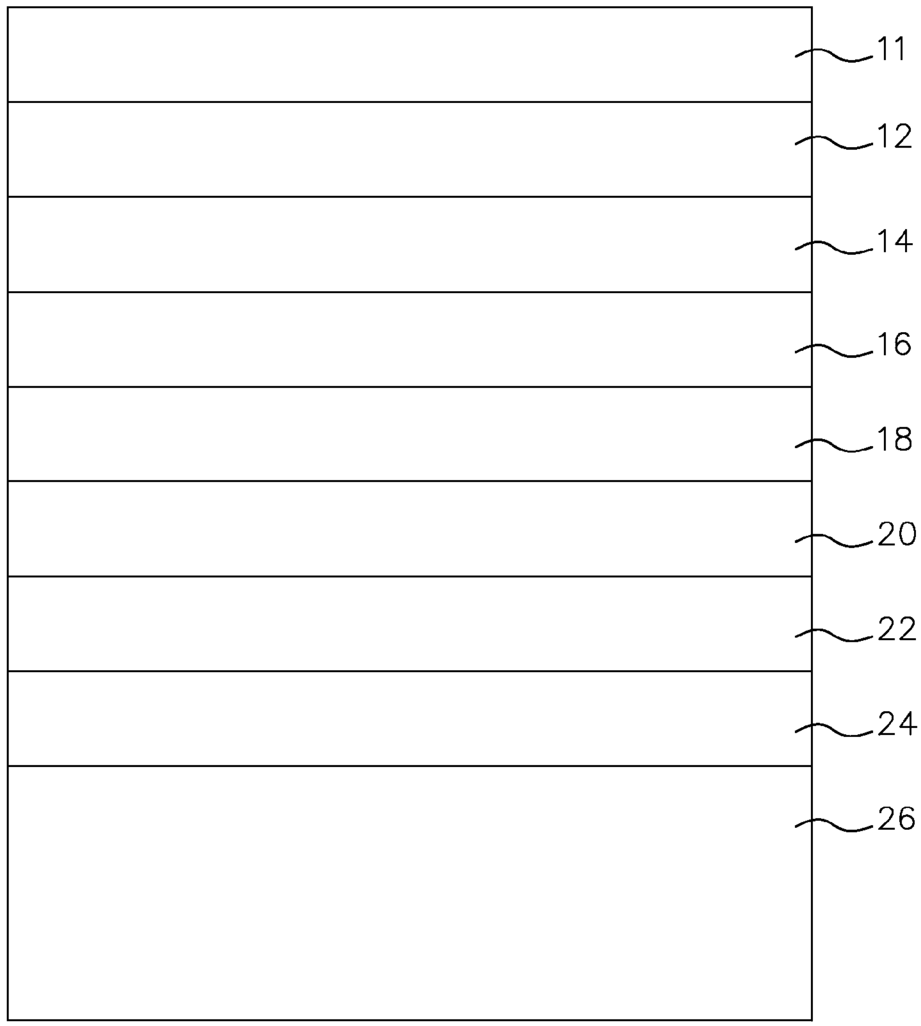


FIG. 2

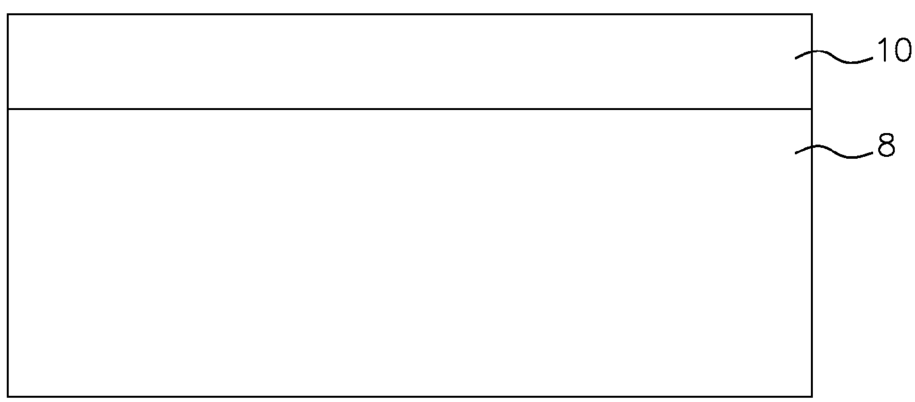


FIG. 3

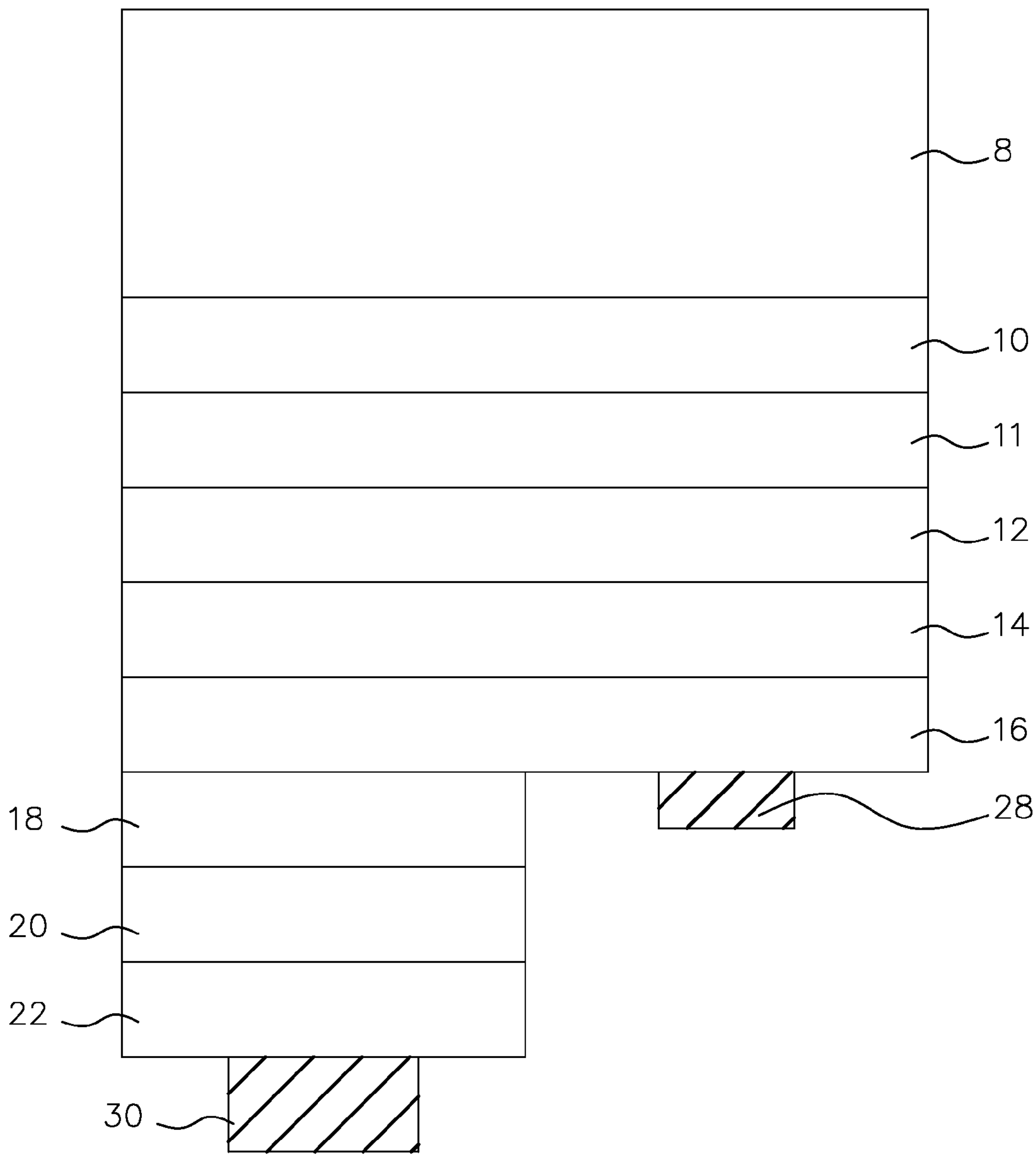


FIG. 4

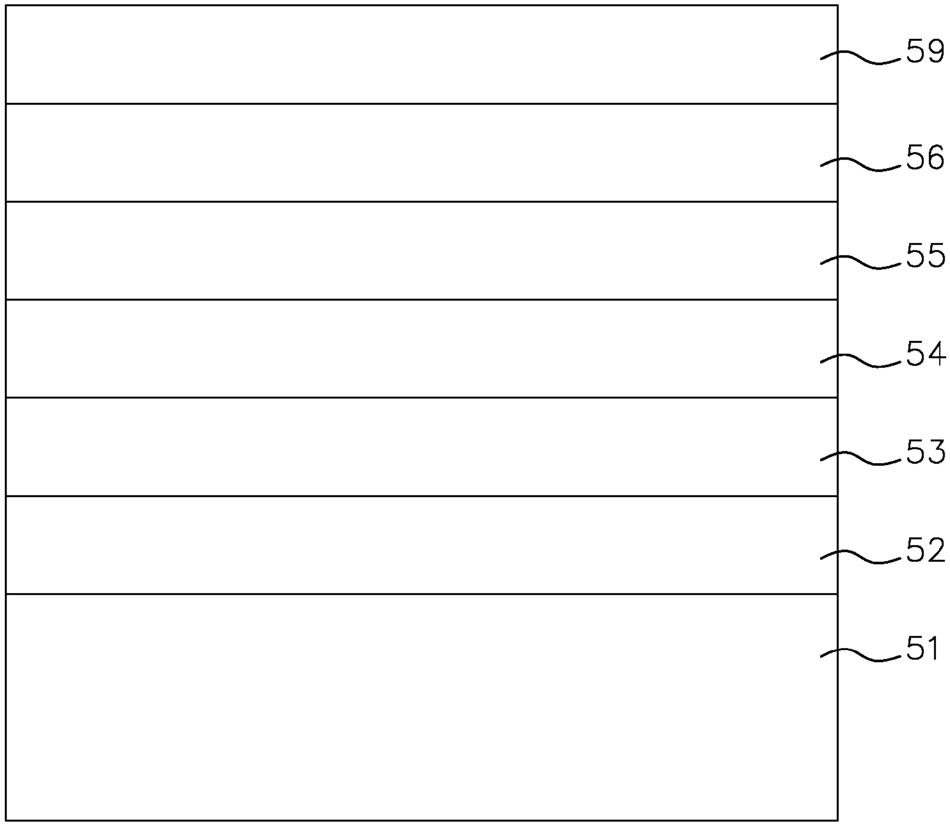


FIG. 5

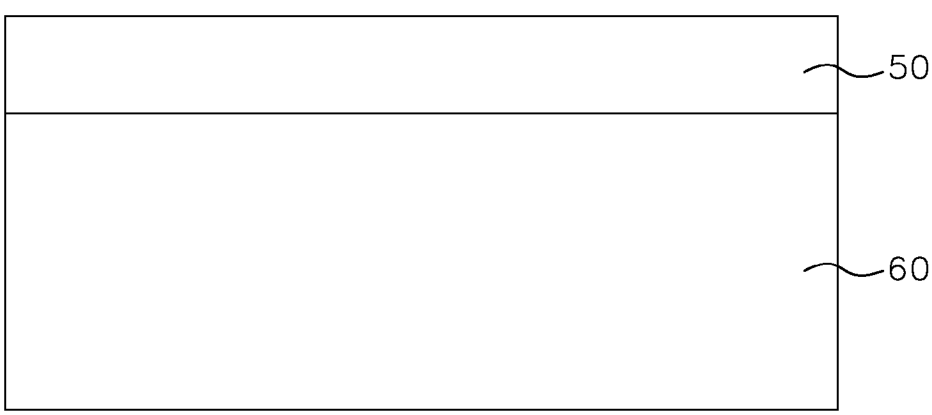


FIG. 6

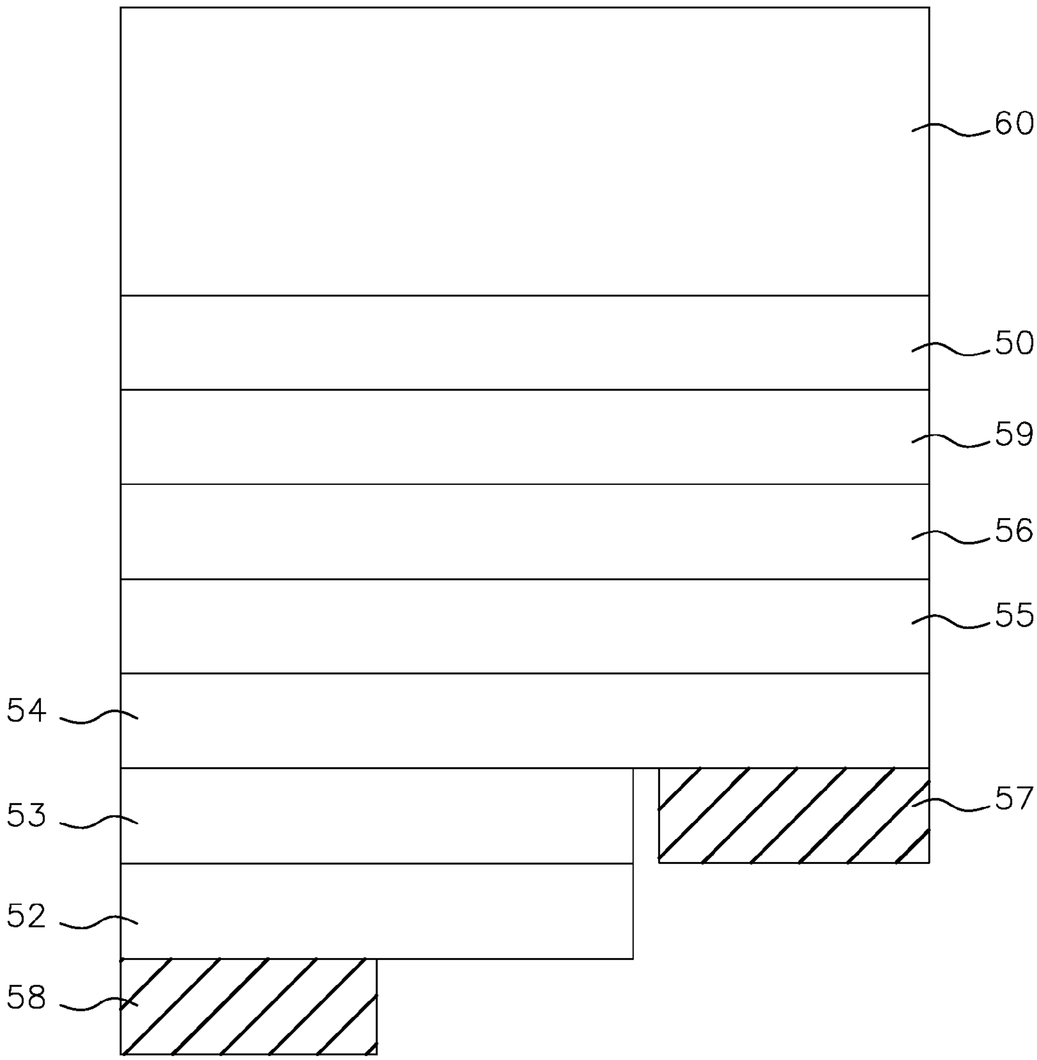


FIG. 7

LIGHT EMITTING DIODE AND METHOD OF MAKING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of U.S. application Ser. No. 12/560,723, filed on Sep. 16, 2009, now U.S. Pat. No. 7,951,633, which is a Continuation of U.S. application Ser. No. 11/267,315, filed on Nov. 7, 2005, now U.S. Pat. No 7,615,392, which is a Divisional of application Ser. No. 10/142,954, filed on May 13, 2002, now U.S. Pat. No. 7,129,527, for which priority is claimed under 35 U.S.C. §120; and this application claims priority of application Ser. No. 091102629 filed in Taiwan, R.O.C. on Feb. 15, 2002 under 35 U.S.C. §119; the entire contents of all of which are hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to a structure and a method of making a light emitting diode (LED) chip, and more particularly to a structure having a specific operating characteristic.

BACKGROUND OF THE INVENTION

The conventional AlGaInP LED, as shown in FIG. **1**, has a double heterostructure (DH), which is consisted of a N-type GaAs substrate **3** and a plurality of layers sequentially formed thereon, wherein the layers are: an N-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ lower cladding layer **4** with an Al composition of about 70%~100%, an $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ active layer **5**, a P-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ upper cladding layer **6** with an Al composition of about 70%~100% and a P-type high energy gap GaAsP, InGaP, AlGaP, GaP, or AlGaAs current spreading layer **7**. The emitting wavelength of the conventional LED structure can be changed by adjusting the composition of the active layer **5** to a wavelength from 650 nm red to 555 nm pure green. One disadvantage of the conventional LED is that, when the light generated by the active layer **5** is emitted downward to the GaAs substrate **3**, the light is absorbed by the GaAs substrate **3** due to a smaller energy gap of the GaAs substrate **3**. Accordingly, the light-output performance of the LED is greatly reduced.

Some conventional LED technologies have been disclosed to prevent the light from being absorbed by the substrate. However, these conventional technologies still have some disadvantages and limitations. For example, Sugawara et al. disclosed a method, which has been published in Appl. Phys. Lett. Vol. 61, 1775-1777 (1992), that adding a distributed Bragg reflector (DBR) layer onto the GaAs substrate so as to reflect the light emitted downward to the GaAs substrate for decreasing the light absorbed by the GaAs substrate. However, because the DBR layer only reflects the light almost normal to the GaAs substrate, its efficiency is not very great.

Kish et al. disclosed a wafer-bonded transparent-substrate (TS) $(Al_xGa_{1-x})_{0.5}In_{0.5}P/GaP$ light emitting diode [Appl. Phys. Lett. Vol. 64, No. 21, 2839 (1994); Very high-efficiency semiconductor wafer-bonded transparent-substrate $(Al_xGa_{1-x})_{0.5}In_{0.5}P/GaP$]. This TS AlGaInP LED is fabricated by growing a very thick (about 50 μm) P-type GaP window layer with the use of hydride vapor phase epitaxy (HVPE). Before bonding, the P-type GaAs substrate is selectively removed by using chemical mechanical polishing and etching techniques. The exposed N-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ cladding layers are subsequently wafer-bonded to 8 mil-10 mil thick N-type GaP substrate. The resulting TS AlGaInP LED exhibits the improvement in light output twice as much as the absorbing substrate (AS) AlGaInP LED. However, the fabrication process of TS AlGaInP LED is too complicated. Therefore, it is difficult to manufacture these TS AlGaInP LEDs in high yield and low cost.

Horng et al. reported a mirror-substrate (MS) AlGaInP/metal/SiO_2/Si LED fabricated by wafer-fused technology [Appl. Phys. Lett. Vol. 75, No. 20, 3054 (1999); AlGaInP light-emitting diodes with mirror substrates fabricated by wafer bonding]. They used AuBe/Au as the adhesive to bond the Si substrate and LED epilayers. However, the luminous intensity of these MS AlGaInP LEDs is about 90 mcd with 20 mA injection current, and is still 50% lower than the luminous intensity of TS AlGaInP LED.

SUMMARY OF THE INVENTION

As described above, the conventional LED has many disadvantages. Therefore, the present invention provides a LED structure and method of making the same to overcome the conventional disadvantages.

A light-emitting structure includes a layer structure, having a first edge, for emitting light; and a carrier substrate, having a second edge, bonded to the layer structure and not being a single crystal wafer; wherein the light-emitting structure has a light output power of more than 4mW at 20 mA current.

A light-emitting structure includes a layer structure for emitting red light and having a first side and a second side; a first Ohmic contact layer formed on the first side; and a substrate formed on the second side: wherein the light-emitting structure has a light output power of more than 4mW at 20 mA current, and the substrate is not a single crystal substrate.

A method of making light-emitting structure includes steps of providing a substrate; forming a layer structure on the substrate; removing the substrate from the layer structure; and injecting current to the layer structure, such that the light-emitting structure has a light output power of more than 4mW at 20 mA current, wherein the step of forming the layer structure on the substrate includes a step of forming a layer having a thickness of 0.5 μm~3 μm.

An advantage of the present invention is to provide a simple LED structure, wherein the adhesion process for forming the LED structure can be performed at a lower temperature to prevent the evaporation problem of V group elements. Moreover, because the light is not absorbed by the substrate, the light emitting efficiency of the LED can be significantly improved.

Another advantage of the present invention is the use of the elastic dielectric adhesive layer to bond the LED and the substrate having high thermal conductivity coefficient. Therefore, an excellent bonding result can be obtained by using the elastic dielectric adhesive layer even if the epitaxial structure has a rough surface.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is a diagram showing the structure of the LED according to the prior art;

FIG. **2**, FIG. **3**, and FIG. **4** are diagrams showing the process of making the LED according to an embodiment of this invention; and

FIG. **5**, FIG. **6**, and FIG. **7** are diagrams showing the process of making the LED according to another embodiment of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention discloses a LED structure and a method of making the same, and will be described in details as follows.

Referring to FIG. **2**, the epitaxial structure of light emitting diode of the present invention is composed of an N-type GaAs substrate **26**, an etching stop layer **24**, an N-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ lower cladding layer **22**, an $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ active layer **20**, a P-type $(AlxGa1\text{-}x)_{0.5}In_{0.5}P$ upper cladding layer **18**, and a P-type ohmic contact epitaxial layer **16**.

Thereafter, a mirror surface protection layer **14** is deposited over the P-type ohmic contact epitaxial layer **16**, wherein the material of the mirror surface protection layer **14** is selected from a group consisting of SiN_x, SiO_2, Al_2O_3, magnesium oxide, zinc oxide, tin oxide, indium oxide, and indium tin oxide.

Thereafter, a metal mirror surface layer **12** is deposited over the mirror surface protection layer **14**, wherein the material of the metal mirror surface layer **12** is selected from a group consisting of Ag, Al, and Au. Then, a mirror surface protection layer **11** is deposited over the metal surface mirror layer **12**, wherein the material of the mirror surface protection layer **11** is selected from a group consisting of SiN_x, SiO_2, Al_2O_3, magnesium oxide, zinc oxide, tin oxide, indium oxide, and indium tin oxide.

In the above description, the material of the P-type ohmic contact epitaxial layer **16** can be AlGaAs, AlGaInP, or GaAsP, as along as the energy gap of the material is larger than that of the active layer **20**, and no light emitted from the active layer **20** is absorbed.

Moreover, the active layer **20** has an Al composition of about $0 \leq x \leq 0.45$, the lower cladding layer **22** has an Al composition of about $0.5 \leq x \leq 1$, and the upper cladding layer **18** has an Al composition of about $0.5 \leq x \leq 1$. If x=0, then the composition of the active layer **20** is $Ga_{0.5}In_{0.5}P$, and the wavelength λd of the LED is 635 nm.

In the above description, the compound ratio in $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ is a preferred embodiment, and the present invention is not limited thereto. Additionally, the structure of the AlGaInP active layer **20** of the present invention can be a homostructure, a single heterostructure, a double heterostructure, or a multiple quantum wells structure. The so-called double heterostructure comprises the N-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ lower cladding layer **22**, the $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ active layer **20** and the P-type $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ upper cladding layer **18**, such as shown in FIG. **2**, wherein the preferred thickness of the lower cladding layer **22**, that of the active layer **20**, and that of the upper cladding layer **18** are about 0.5~3.0 μm, 0.5~2.0 μm, and 0.5~3.0 μm, respectively.

The preferred material of the etching stop layer **24** of the invention can be any III-V compound semiconductor material, provided that the lattice thereof is matched with that of the GaAs substrate **26**, and the etching rate thereof is much smaller than that of the GaAs substrate **26**. For example, InGaP or AlGaAs are suitable for forming the etching stop layer **24**. In addition, the etching rate of the N-type AlGaInP lower cladding layer **22** is also far smaller than that of the GaAs substrate **26**. Therefore, as long as the thickness of the lower cladding layer **22** is sufficient, it is not necessary to form an optional epitaxial layer of different composition as the etching stop layer **24**.

The structure shown in FIG. **3** comprises a dielectric adhesive layer **10**, for example, BCB (B-staged bisbenzocyclobutene) resin and a substrate having high thermal conductivity coefficient **8**. The material of the dielectric adhesive layer **10** is not limited to BCB. Any adhesive material with similar property, such as epoxy resin, polyimide, SOG, or silicone, etc. is also applicable to the present invention. The substrate having high thermal conductivity coefficient **8** can be composed of Si wafer, Cu wafer, or Al wafer, etc. One advantage of the present invention is that the substrate having high thermal conductivity coefficient **8** does not have to be a single crystal wafer. The substrate having high thermal conductivity coefficient **8** is used for mechanically supporting the LED epitaxial layer to prevent the epitaxial layer from breaking during the manufacturing process, and meanwhile is used as a heat sink, and the current does not flow through the substrate having high thermal conductivity coefficient **8** when the LED emits the light. In other words, the polycrystal or amorphous crystal can be used as the carrier substrate. Accordingly, the manufacture cost is significantly decreased.

Thereafter, the epitaxial layer structure shown in FIG. **2** is bonded together with the substrate having high thermal conductivity coefficient **8** shown in FIG. **3** by the dielectric adhesive layer **10**. The adhesion step is performed under high pressure and temperature, such as 250° C., according to the method of the present invention. A layer of adhesion promoter can be coated on the surface of the LED epitaxial structure and the surface of the substrate having high thermal conductivity coefficient **8** to improve the adhesion feature between the LED epitaxial structure and the substrate having high thermal conductivity coefficient **8**. After that, a BCB layer is coated, and then the adhesion between the LED epitaxial structure and the substrate having high thermal conductivity coefficient **8** is completed under high pressure and temperature, such as 250° C. In order to provide better adhesion, the LED epitaxial structure, which is bonded with the substrate having high thermal conductivity coefficient **8** by the dielectric adhesive layer **10**, can be first heated at a lower temperature, for example, 60° C. to 100° C., thereby removing the organic solvent in BCB, and then be heated at the temperature raised to a range between 200° C. and 600° C., so that the LED epitaxial structure, the substrate having high thermal conductivity coefficient **8**, and the dielectric adhesive layer **10** can be tightly bonded. Thereafter, the opaque N-type GaAs substrate **26** is then removed by an etchant, for example, $1NH_4OH$:$1H_2O_2$. However, since the etching stop layer **24**, InGaP or AlGaAs, still absorbs the light emitted from the active layer **20**, it is necessary to remove the etching stop layer **24** completely or with only remaining a portion of the etching stop layer **24** contacting the N-type ohmic contact metal layer **30**, such as shown in FIG. **4**. A dry etching method, for example, RIE (reactive ion etching), is then applied to remove portion of the N-type AlGaInP lower cladding layer **22**, that of the AlGaInP active layer **20**, and that of the P-type AlGaInP upper cladding layer **18** to further expose the P-type ohmic contact epitaxial layer **16**. A P-type ohmic contact metal layer **28** is then formed on the P-type ohmic contact epitaxial layer **16**, and a N-type ohmic contact metal layer **30** is formed on the N-type AlGaInP lower cladding layer **22**, so that a LED structure is formed, wherein the P-type and N-type ohmic contact metal layers formed on the same side, such as shown in FIG. **4**.

According to the present invention, the light output power of the AlGaInP LED having wavelength of 635 nm is more than 4 mW (at 20 mA injection current), and is twice as much as that of the conventional absorbing substrate AlGaInP LED.

The present invention is not limited to the AlGaInP LED having high brightness, and is also suitable for other LED materials, for example, red and infrared-red AlGaAs LED. The epitaxial structure shown on FIG. **5** is a cross-sectional view of the second embodiment of the present invention. The AlGaAs red LED (650 nm) includes a stacked structure of an N-type GaAs substrate **51**, an N-type AlGaAs lower cladding layer **52** with Al composition of about 70~80% and thickness of 0.5 μm~3 μm, an AlGaAs active layer **53** with Al composition of about 35% and thickness of 0.5 μm~2 μm, and a P-type AlGaAs upper cladding layer **54** with Al composition of about 70~80% and thickness of 0.5 μm~3 μm, wherein the AlGaAs active layer **53** can be a homostructure, a single heterostructure, a double heterostructure, or a quantum well structure. Thereafter, a mirror surface protection layer **55**, a metal mirror surface layer **56**, and a mirror surface protection layer **59** are formed on the P-type AlGaAs upper cladding layer **54** in sequence, wherein the material of the mirror surface protection layer **55** and that of the mirror surface protection layer **59** can be selected from a group consisting of SiN_x, SiO_2, Al_2O_3, magnesium oxide, zinc oxide, tin oxide, indium oxide and indium tin oxide, and the material of the metal mirror surface layer **56** could be Ag, Al, or Au.

Referring to FIG. **6**, the structure shown in FIG. **6** comprises a dielectric adhesive layer **50** and a substrate having high thermal conductivity coefficient **60**, wherein the material of the dielectric adhesive layer **50** is BCB resin, for example. The material of the dielectric adhesive layer **50** in the present invention is not limited to BCB. Any adhesive material with similar property, such as epoxy resin, polyimide, SOG, or silicone, etc. is also applicable to the present invention. The substrate having high thermal conductivity coefficient **60** can be composed of Si wafer, Cu wafer, or Al wafer, etc. One advantage of the present invention is that the substrate having high thermal conductivity coefficient **60** does not have to be a single crystal wafer. The substrate having high thermal conductivity coefficient **60** is used for mechanically supporting the LED epitaxial layer to prevent the epitaxial layer from breaking, and is also used as a heat sink, and the current does not flow through the substrate having high thermal conductivity coefficient **60** when the LED emits the light. In other words, the polycrystal or amorphous crystal can be used as the carrier substrate. Accordingly, the manufacture cost is significant decreased.

Referring to FIG. **7**, the above-mentioned AlGaAs red LED structure in FIG. **5** is then bonded to the substrate having high thermal conductivity coefficient **60** by the dielectric adhesive layer **50**. The epitaxial structure is then etched by an etchant, such as $1NH_4OH:1H_2O_2$ to remove the opaque N-type GaAs substrate **51**. Thereafter, a wet etching or a dry etching is applied to remove portion of the N-type AlGaAs lower cladding layer **52** and that of the AlGaAs active layer **53** to further expose the P-type AlGaAs upper cladding layer **54**. Then, a P-type ohmic contact metal layer **57** is formed on the P-type AlGaAs upper cladding layer **54**, and a N-type ohmic contact metal layer **58** is then formed on the N-type AlGaAs lower cladding layer **52**, so that a LED structure is formed, wherein the P-type and N-type ohmic contact metal layers are formed on the same side.

The light output power of the present invention AlGaAs LED with wavelength of about 650 nm is twice as much as that of the conventional absorbing substrate AlGaAs LED under the 20 mA injection current.

The present invention uses the substrate having high thermal conductivity coefficient to enhance the heat dissipation of the chip, thereby increasing the performance stability of the LED, and making the LED applicable at higher currents.

Moreover, the LED of the present invention uses of the elastic property of dielectric adhesive material to bond the substrate having high thermal conductivity coefficient and the multi-layered AlGaInP epitaxial structure. Therefore, an excellent bonding result can be obtained by the use of the elastic property of dielectric adhesive material, even if the epitaxial structure has a rough surface.

As is understood by a person skilled in the art, the foregoing preferred embodiments of the present invention are illustrations of the present invention rather than limitations of the present invention. It is intended to cover various modifications and similar arrangements comprised within the spirit and scope of the appended claims, the scope of which should be accorded the broadest interpretation so as to encompass all such modifications and similar structure.

What is claimed is:

1. A light-emitting structure, comprising:

a layer structure, having a first edge, for emitting light; and

a carrier substrate, having a second edge, bonded to the layer structure and not being a single crystal wafer;

wherein the light-emitting structure has a light output power of more than 4 mW at 20 mA current.

2. The light-emitting structure of claim **1**, further comprising a dielectric adhesive layer between the layer structure and the carrier substrate.

3. The light-emitting structure of claim **1**, further comprising a metal layer between the layer structure and the carrier substrate.

4. The light-emitting structure of claim **1**, further comprising a metal layer having a mirror surface and formed between the layer structure and the carrier substrate.

5. The light-emitting structure of claim **1**, wherein the layer structure comprises a layer having a thickness of 0.5 μm~3 μm.

6. The light-emitting structure of claim **1**, wherein the layer structure comprises a layer with Al composition of about 35% or 70%~80%.

7. The light-emitting structure of claim **1**, wherein the carrier substrate comprises a polycrystal or an amorphous crystal.

8. The light-emitting structure of claim **1**, wherein the first edge and the second edge substantially parallel with each other and have the same length.

9. A light-emitting structure, comprising:

a layer structure for emitting red light and having a first side and a second side;

a first ohmic contact layer formed on the first side; and

a substrate formed on the second side;

wherein the light-emitting structure has a light output power of more than 4 mW at 20 mA current, and

wherein the substrate is not a single crystal substrate.

10. The light-emitting structure of claim **9**, further comprising a second ohmic contact layer formed on the first side.

11. The light-emitting structure of claim **9**, further comprising a dielectric adhesive layer between the layer structure and the substrate.

12. The light-emitting structure of claim **9**, wherein the substrate is bonded to the layer structure.

13. The light-emitting structure of claim **9**, wherein the layer structure comprises a layer with Al composition of about 35% or 70%~80%.

14. A method of making a light-emitting structure, comprising steps of:

providing a substrate;

forming a layer structure on the substrate;

removing the substrate from the layer structure; and injecting current to the layer structure such that the light-emitting structure has a light output power of more than 4 mW at 20 mA current,

wherein said forming the layer structure on the substrate comprises a step of forming a layer having thickness of 0.5 μm~3 μm.

15. The method of claim **14**, further comprising a step of bonding the layer structure to a carrier substrate.

16. The method of claim **15**, further comprising a step of providing a dielectric adhesive layer between the layer structure and the carrier substrate.

17. The method of claim **15**, further comprising a step of providing a metal layer between the layer structure and the carrier substrate.

18. The method of claim **14**, wherein the step of forming the layer structure on the substrate comprises a step of forming a layer with Al composition of about 35% or 70%~80%.

* * * * *

Exhibit 5

US009065022B2

(12) **United States Patent**
Pu et al.

(10) **Patent No.: US 9,065,022 B2**
(45) **Date of Patent: Jun. 23, 2015**

(54) **LIGHT EMITTING APPARATUS**

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(73) Assignee: **Formosa Epitaxy Incorporation**, Taoyuan County (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 176 days.

(21) Appl. No.: **13/845,160**

(22) Filed: **Mar. 18, 2013**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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Jun. 19, 2012	(TW)	....	101121921 A
Jul. 16, 2012	(TW)	....	101125599 A
Aug. 28, 2012	(TW)	....	101131198 A
Aug. 30, 2012	(TW)	....	101131643 A
Sep. 4, 2012	(TW)	....	101132185 A
Sep. 4, 2012	(TW)	....	101132187 A

(51) **Int. Cl.**
F21V 21/00 (2006.01)
H01L 33/50 (2010.01)
F21V 21/14 (2006.01)
H01L 33/48 (2010.01)
H01L 25/075 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 33/50*** (2013.01); ***F21V 21/00*** (2013.01); ***F21V 21/14*** (2013.01); *H01L 25/0753* (2013.01); ***H01L 33/486*** (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/49107* (2013.01); *H01L 2924/3025* (2013.01)

(58) **Field of Classification Search**
CPC F21V 21/00; F21V 24/14
USPC 362/234, 249.01–249.04
See application file for complete search history.

(56) **References Cited**

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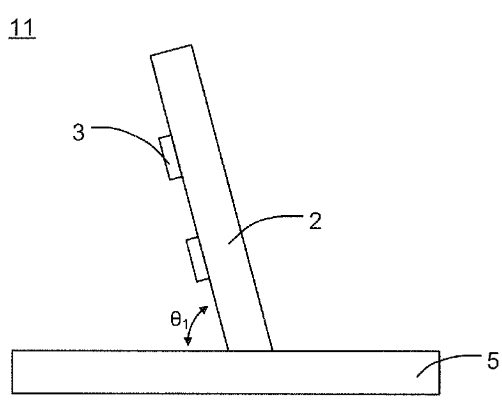
* cited by examiner

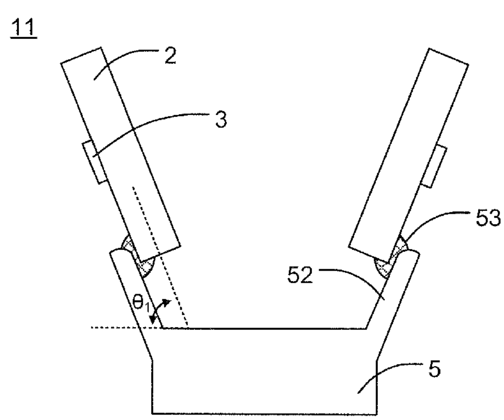
Primary Examiner — Vip Patel
(74) *Attorney, Agent, or Firm* — Rosenberg, Klein & Lee

(57) **ABSTRACT**

The present invention relates to a light emitting apparatus comprising at least one light emitting device and a support mechanism. The light emitting device includes a transparent substrate which light can pass through; at least one LED chip emitting light omni-directionally is disposed on one surface of the substrate, and the light emitted by the LED chip will penetrate into the substrate and at least partially emerge from another surface of the substrate. The support mechanism is coupled to the light emitting device; a first angle is formed between the substrate and the support mechanism. According to the present invention, the light emitting apparatus using LED chips can provide sufficient lighting intensity and uniform lighting performance.

23 Claims, 15 Drawing Sheets





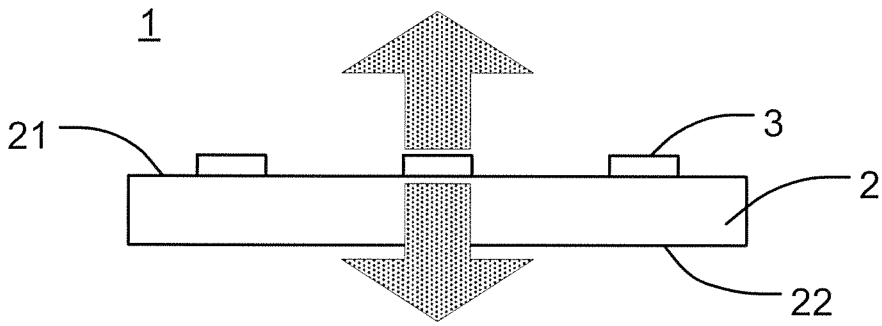


Fig. 1A

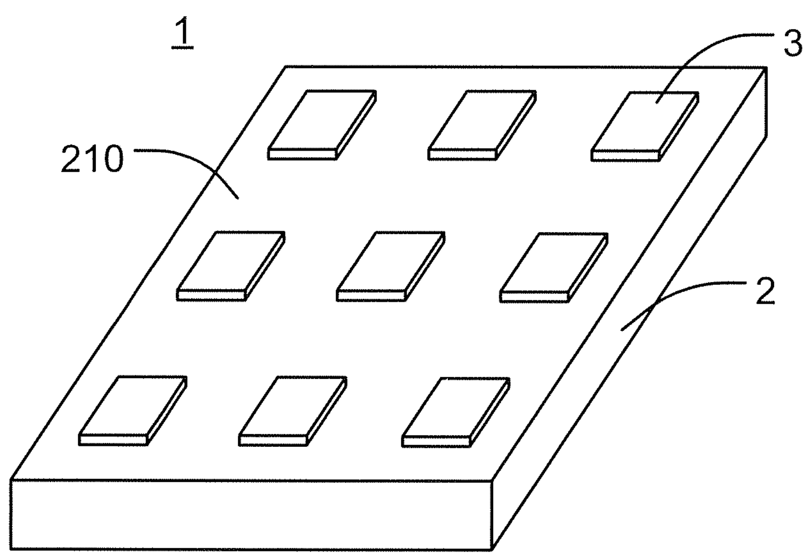


Fig. 1B

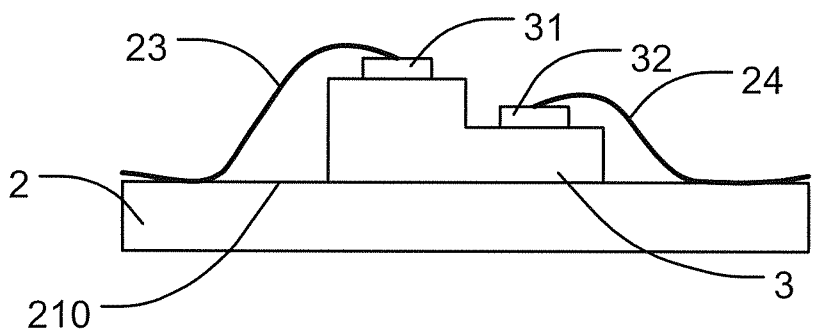


Fig. 2A

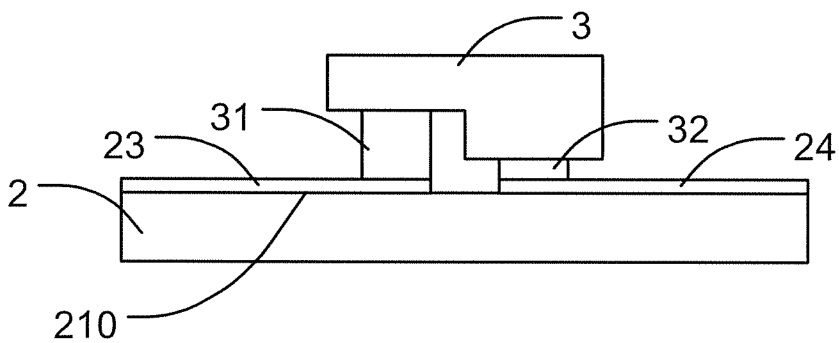


Fig. 2B

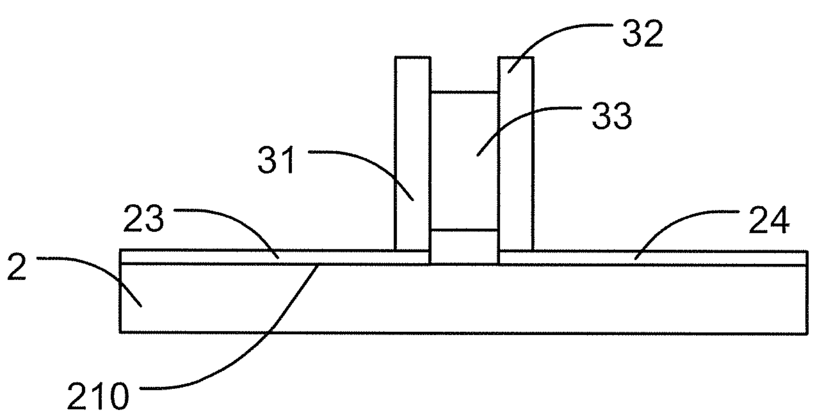


Fig. 2C

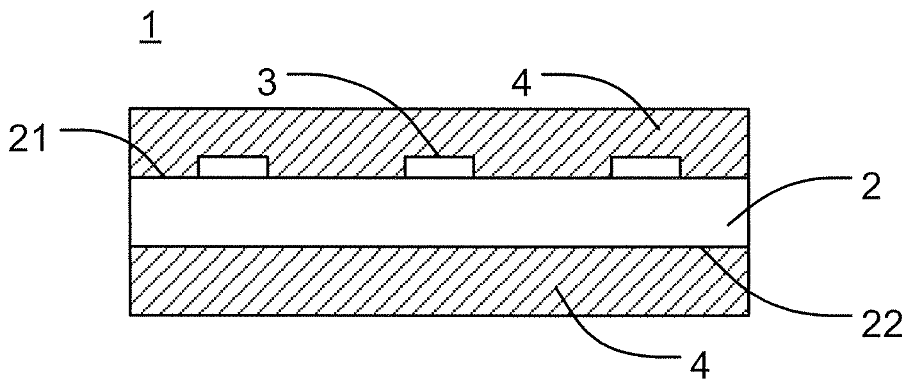


Fig. 3A

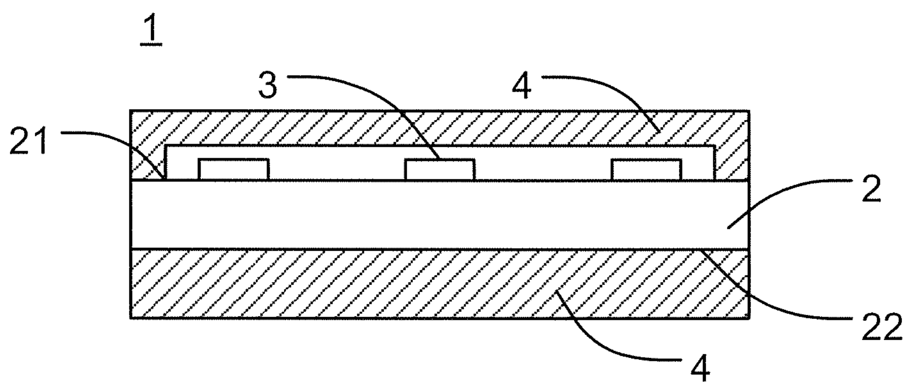


Fig. 3B

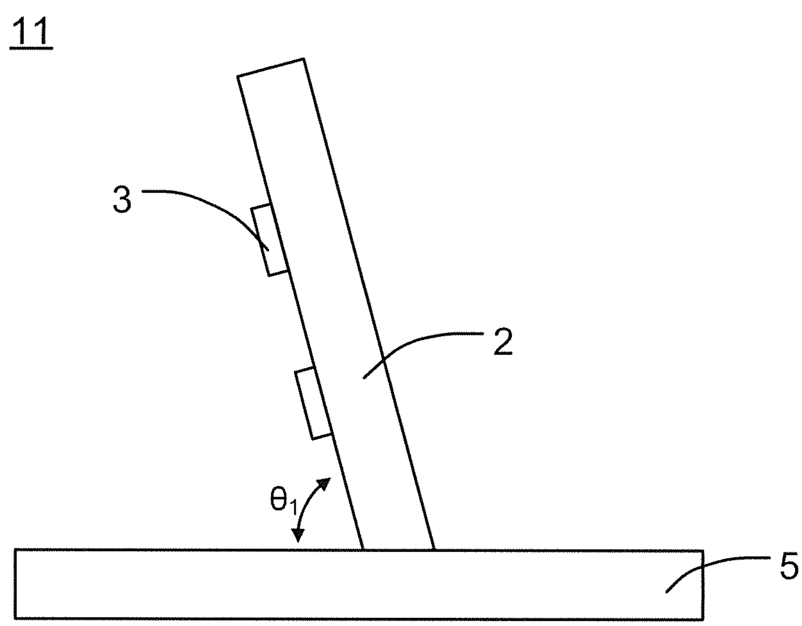


Fig. 4

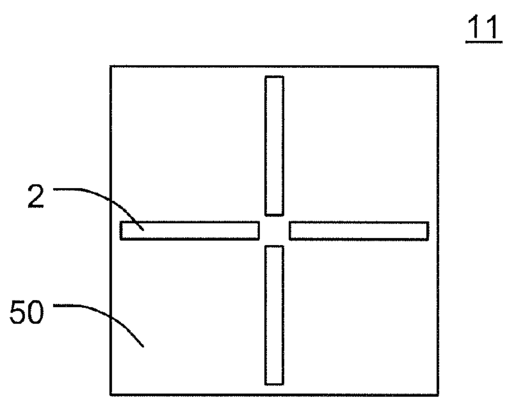


Fig. 5A

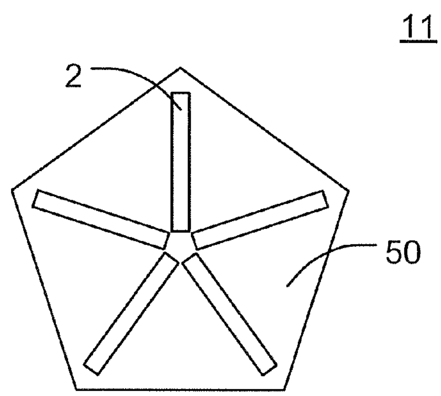


Fig. 5B

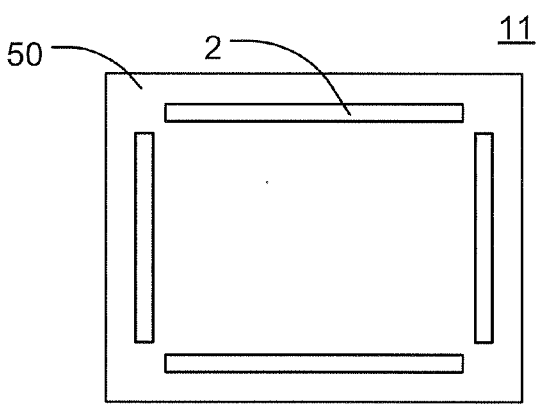


Fig. 5C

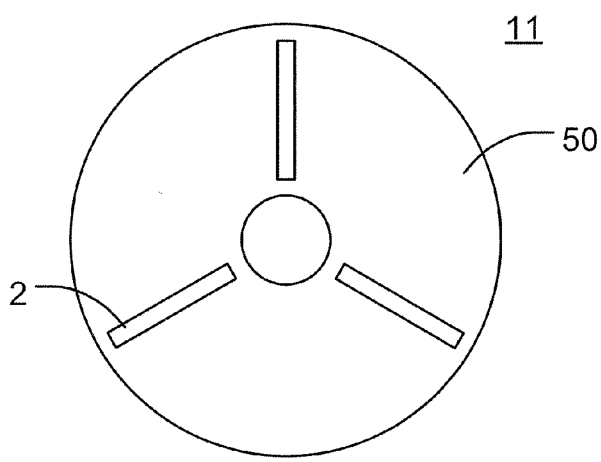


Fig. 5D

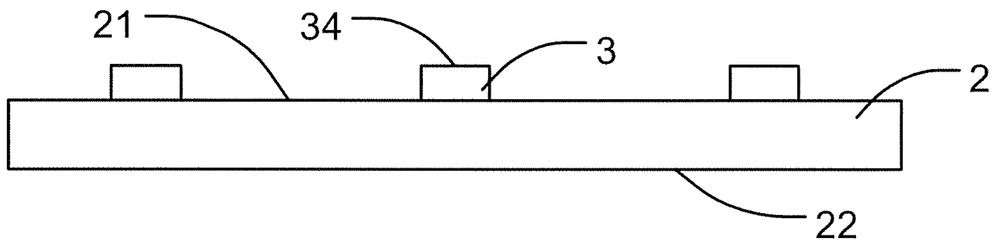


Fig. 6

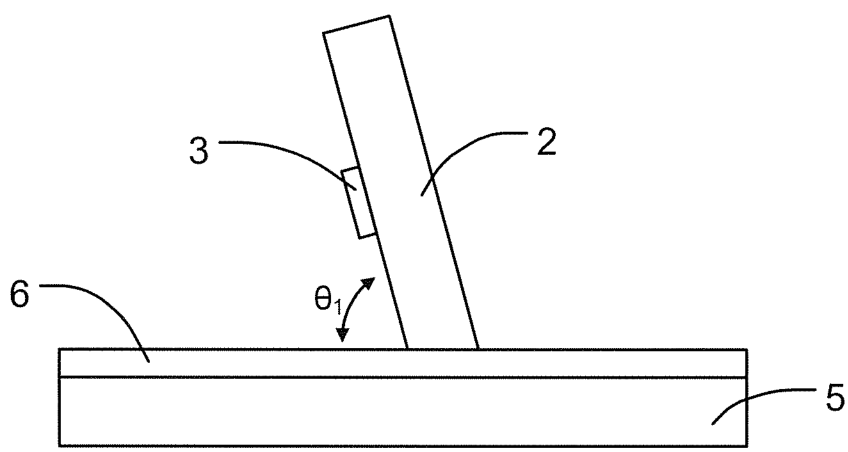


Fig. 7

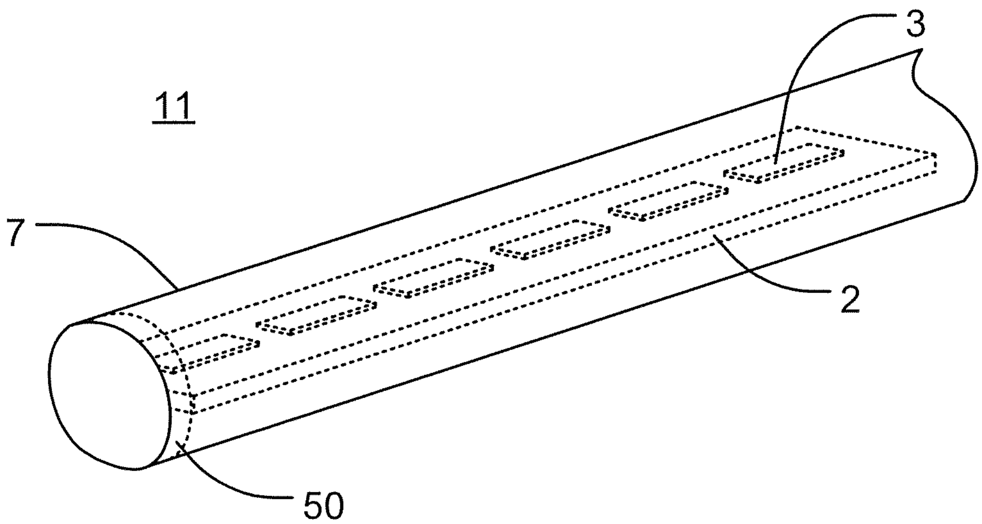


Fig. 8A

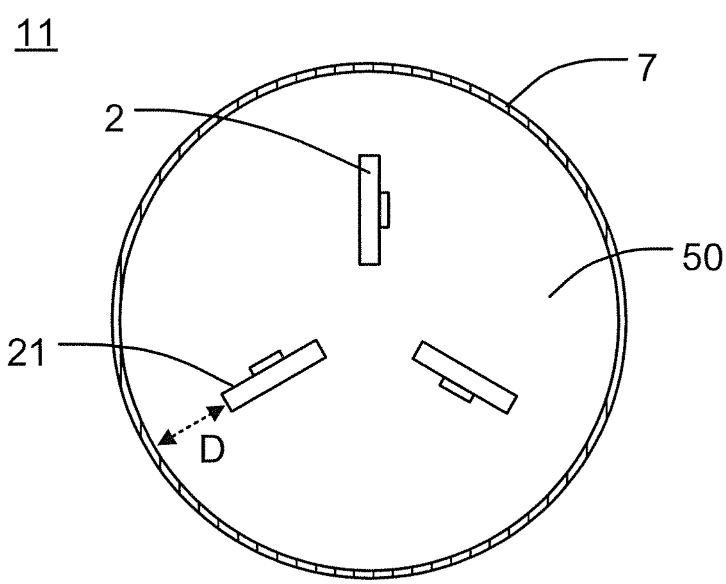


Fig. 8B

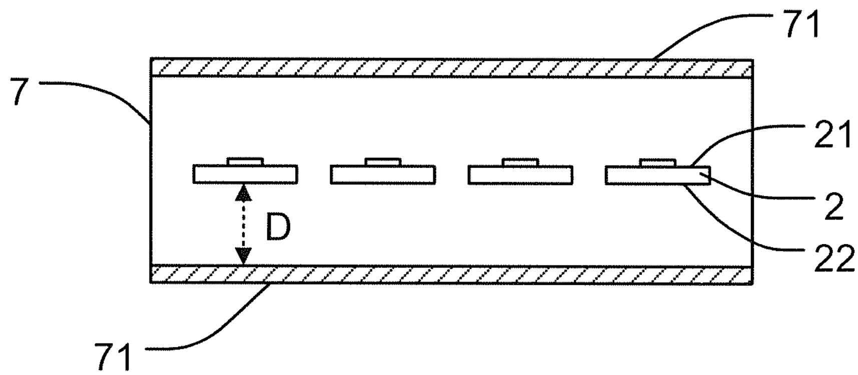


Fig. 9

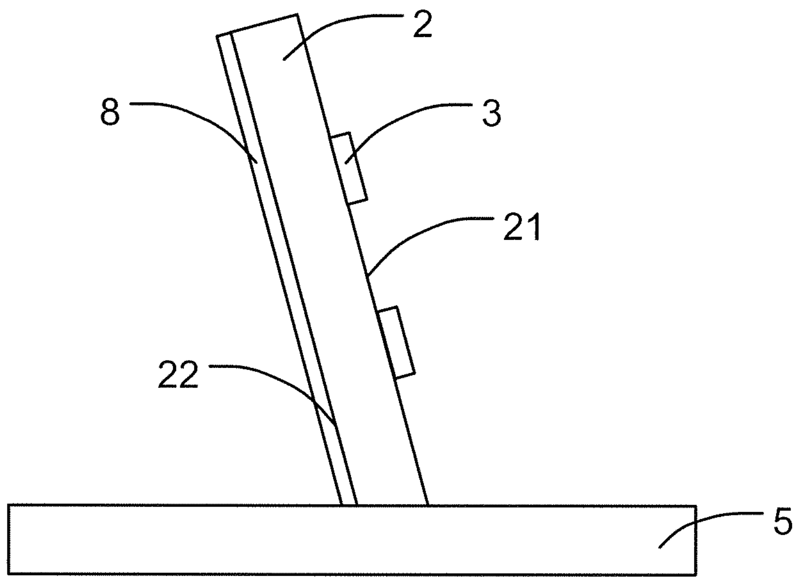


Fig. 10

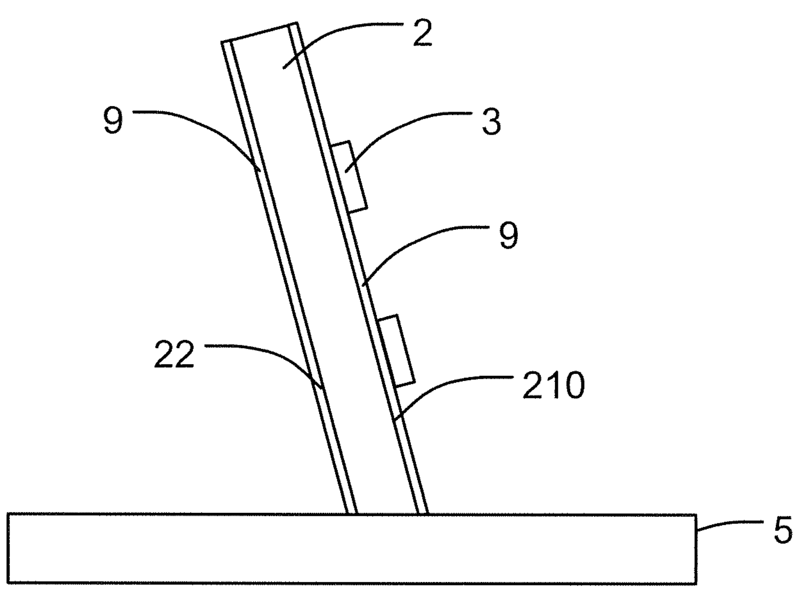


Fig. 11

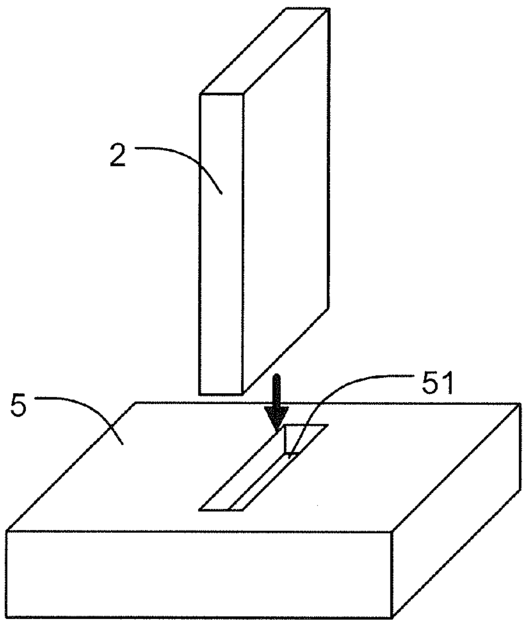


Fig. 12A

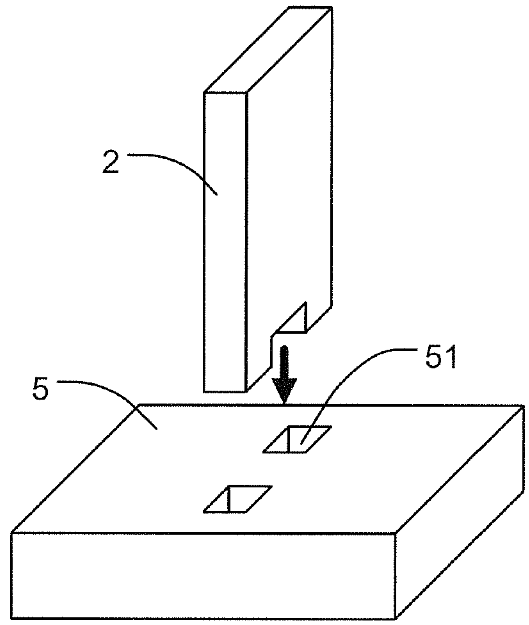


Fig. 12B

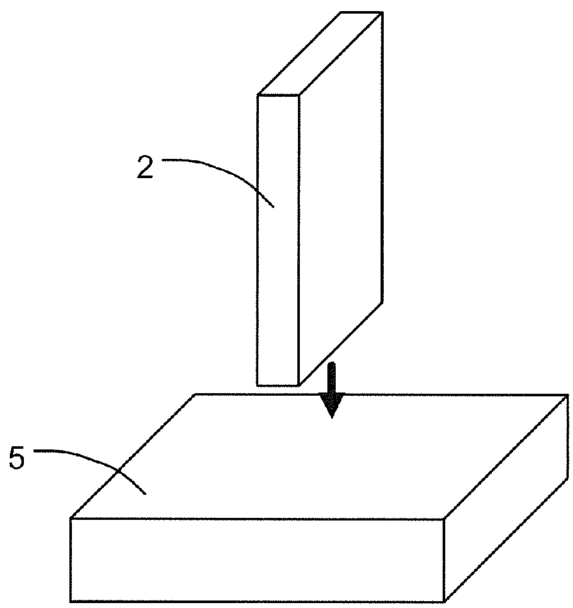


Fig. 12C

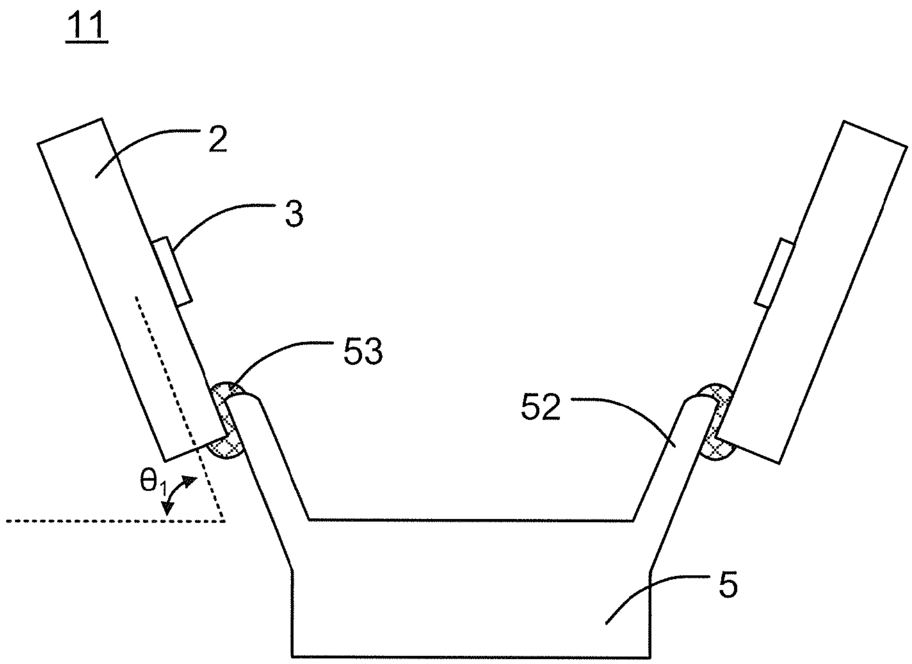


Fig. 13A

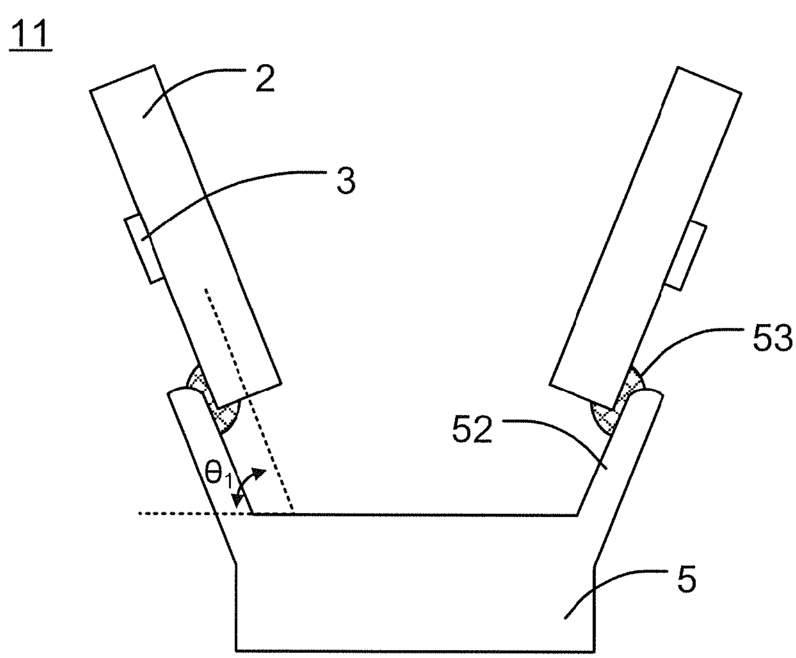


Fig. 13B

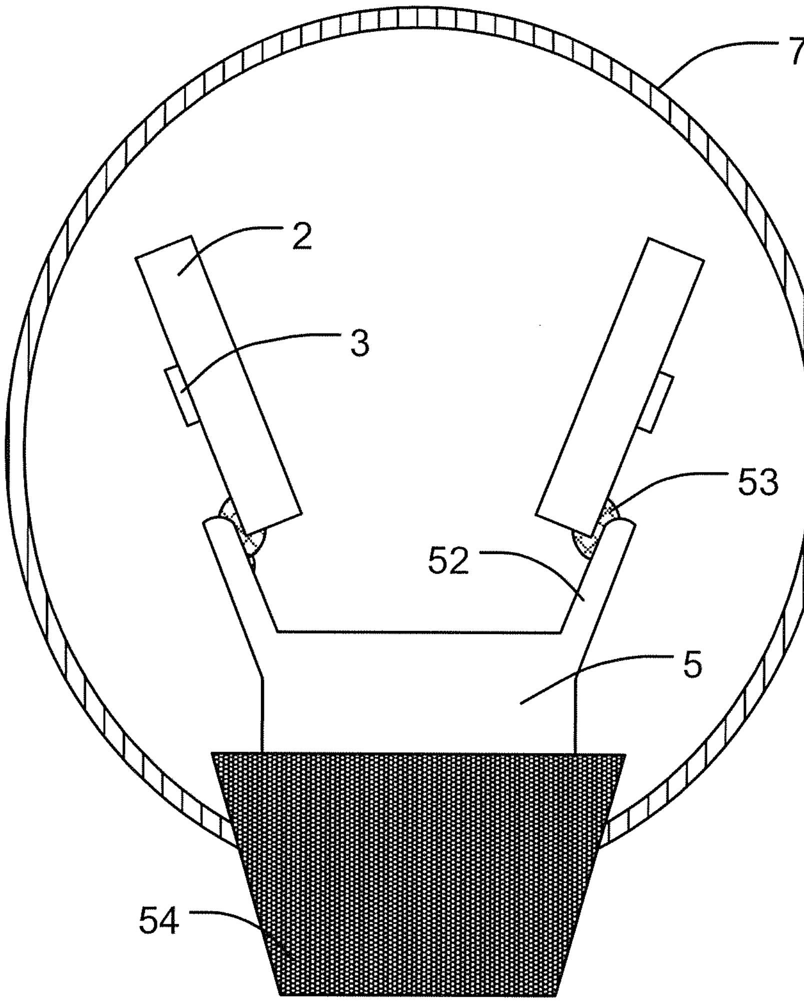


Fig. 14A

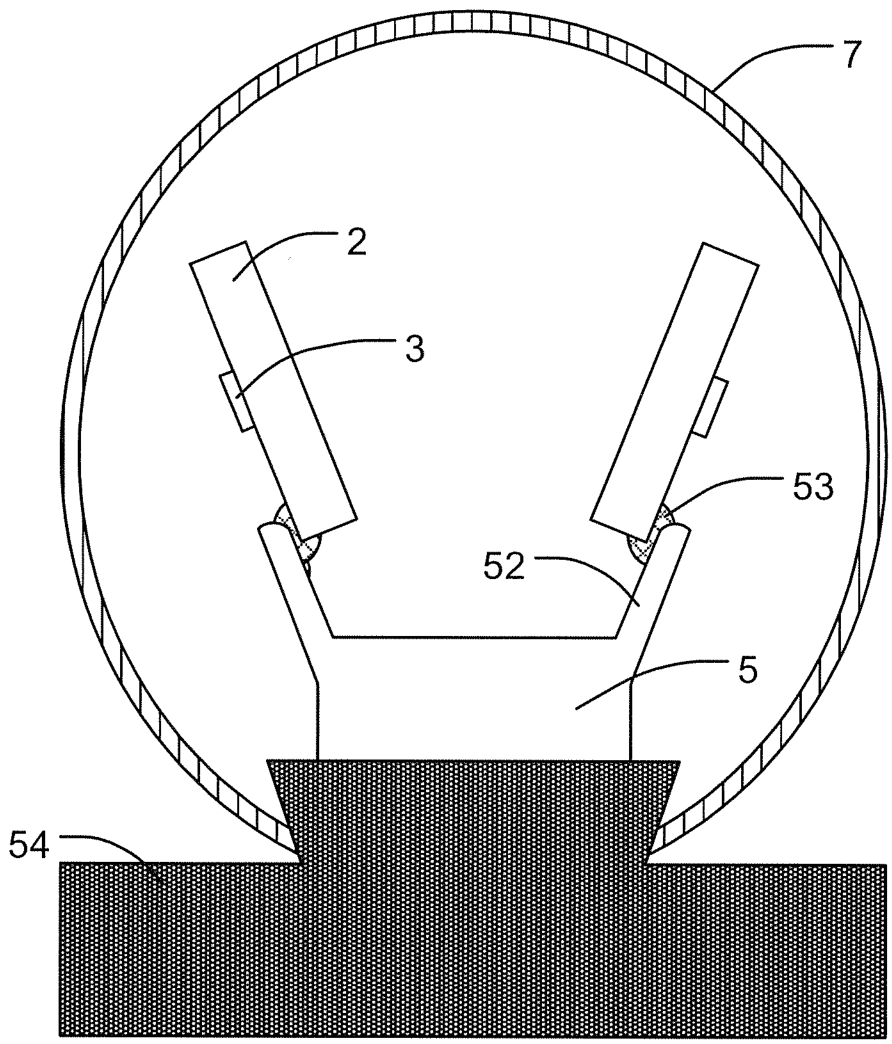


Fig. 14B

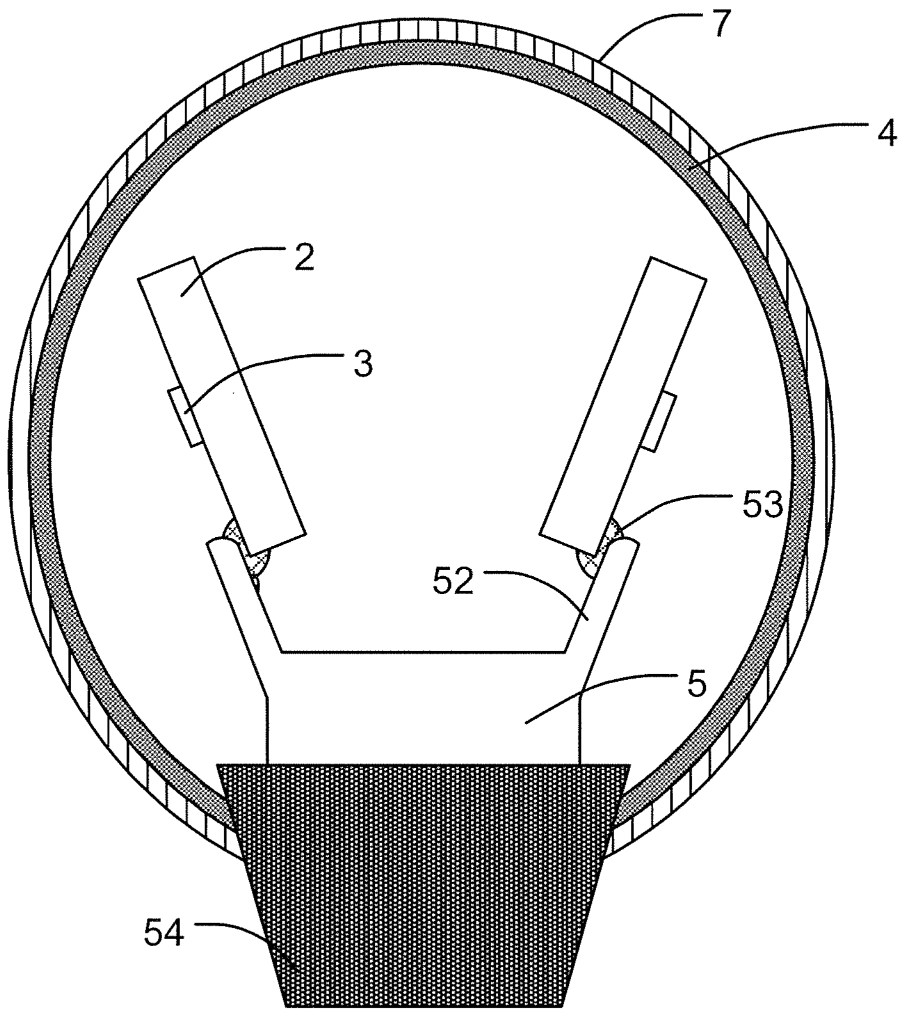


Fig. 14C

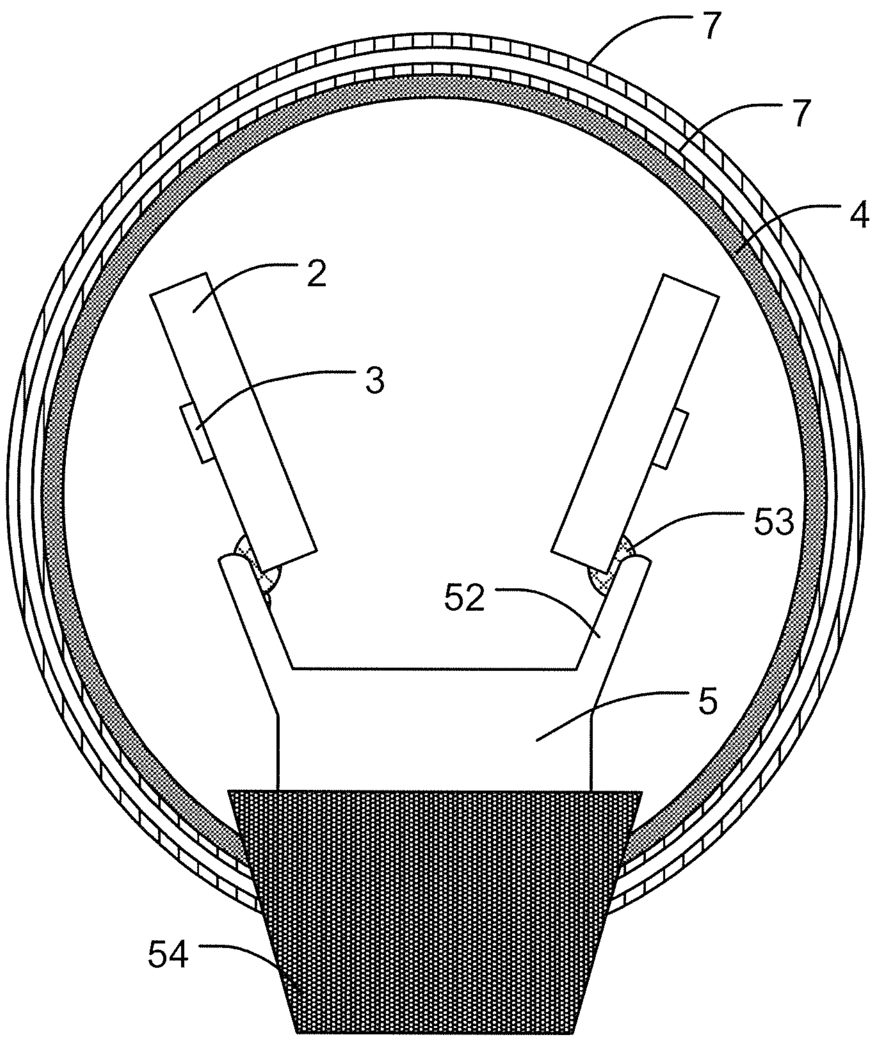


Fig. 14D

LIGHT EMITTING APPARATUS

FIELD OF THE INVENTION

The present invention relates to a light emitting device comprising semiconductor light emitting diode (LED) chips, and particularly to a light emitting device comprising at least one LED chip which emits light omni-directionally, and a light emitting apparatus using same.

BACKGROUND OF THE INVENTION

In the field of lighting technology, the development trends for light sources are low cost, environmental friendliness, and power saving in order to acquire better lighting performance under the condition of consuming less power. These trends make LEDs play an important role in the development.

Practically, there are still limitations and challenges for applying LEDs or similar light emitting units to lamps for lighting. In the past, using LEDs as a light source called for depositing multiple LED chips on a plane and further providing an optical reflection mechanism to guide or broadcast the light emitted from the LED chips emitting light directionally in the beginning.

This kind of arrangement described above was not appropriate to substitute for traditional lamps with wide lighting angles. Because only a portion of light generated by the LED chips propagated in the direction of lighting while the other portions were absorbed or lost during the reflection processes, the lighting efficiency was low and the number of the LED chips must be increased for compensation and meeting the brightness requirement for lighting. Therefore the cost of the tradition LED lamp was high and the benefit for saving energy was insufficient.

Moreover, in traditional LED lamps, the substrates on which LED chips were deposited were planar, firm, and opaque. Thereby, the flexibility of disposing LED chips was limited. For example, when the substrates were non-planar, the light generated by the LED chips deposited on the substrates would be shielded or blocked accordingly, which was unfavorable for reducing power consumption and costs of traditional LED lamps.

SUMMARY

An objective of the present invention is to provide a light emitting device with high reliability, high lighting efficiency, and low cost.

Another objective of the present invention is to provide a light emitting apparatus comprising multiple light emitting devices arranged symmetrically or asymmetrically for enhancing the light intensity of the light emitting apparatus. Meanwhile, the lighting uniformity for various directions can be maintained and the required light shapes can be provided.

Still another objective of the present invention is to provide a light emitting apparatus comprising a lamp housing for applying to lamps, signboards or backlight units.

Accordingly, for achieving the objectives described above, the present invention discloses a light emitting apparatus comprising at least one light emitting device and a support mechanism. The light emitting device includes a transparent substrate which light can pass through and which has a support surface. At least one LED chip comprising multiple light emitting surfaces and emitting light omni-directionally is disposed on the support surface of the substrate, and one of the light emitting surfaces of the LED chip and the support surface form an illuminant first main surface. Because the light emitting angle of the LED chip is wider than 180°, the light emitted by the LED chip will penetrate into the substrate and at least partially emerge from a second main surface corresponding to the first main surface of the substrate. The support mechanism is coupled to the light emitting device; a first angle is formed between the substrate and the support mechanism. According to the present invention, the light emitting apparatus using LED chips can provide sufficient lighting intensity and uniform lighting performance. Additionally, the number and the arrangement of the substrates of the present invention can be modified for adjusting brightness, so the light emitting apparatus has more flexibility for various applications.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A~**1**B show structural schematic diagrams of the light emitting device according to the embodiments of the present invention;

FIGS. **2**A~**2**C show schematic diagrams of the light emitting device comprising the LED chip in various forms coupled to the conductors according to the embodiments of the present invention;

FIGS. **3**A~**3**B show schematic diagrams of the light emitting device comprising the wavelength conversion layer according to the embodiments of the present invention;

FIG. **4** shows a schematic diagram of the light emitting apparatus comprising the support base according to one embodiment of the present invention;

FIGS. **5**A~**5**D show top views of the arrangement of the light emitting device deposited on the support mechanism of the light emitting apparatus point- or line-symmetrically according to the embodiments of the present invention;

FIG. **6** shows a schematic diagram of the light emitting device comprising the LED chips with light emitting surfaces according to one embodiment of the present invention;

FIG. **7** shows a schematic diagram of the light emitting apparatus comprising the circuit board according to one embodiment of the present invention;

FIGS. **8**A~**8**B show schematic diagrams of the light emitting apparatus comprising the lamp housing according to the embodiments of the present invention;

FIG. **9** shows a cross-sectional view of the light emitting apparatus for application according to one embodiment of the present invention;

FIG. **10** shows a schematic diagram of the light emitting apparatus comprising the reflector according to one embodiment of the present invention;

FIG. **11** shows a schematic diagram of the light emitting apparatus comprising diamond-like carbon film according to one embodiment of the present invention;

FIG. **12**A~**12**C show schematic diagrams of the the light emitting apparatus according to the embodiments of the present invention;

FIG. **13**A~**13**B show schematic diagrams of the the light emitting apparatus according to the embodiments of the present invention; and

FIG. **14**A~**14**D show schematic diagrams of the light emitting apparatus for various applications according to the embodiments of the present invention.

DETAILED DESCRIPTION

As shown in FIGS. **1**A and **1**B, the first embodiment of the present invention discloses a light emitting device **1** comprising a transparent substrate **2** which light can pass through, a support surface **210**, a first main surface **21**, a second main surface **22**, and at least one LED chip **3** emitting light omni-directionally.

Wherein the number of the LED chips **3** deposited on the support surface **210** of the sheet-shaped substrate **2** according to the embodiment is 9, and the embodiment arranges the LED chips **3** as a 3×3 matrix. The LED chip **3** comprises multiple light emitting surfaces, and one of the light emitting surfaces **34** and the support surface **210** form the illuminant first main surface **21** of the light emitting device **1**. Because the light emitting angle of the LED chip **3** is wider than 180°, at least a portion of light emitted from the LED chip **3** will penetrate into the substrate **2** from the support surface **210** and pass through the substrate **2**. Then the incident light in the substrate **2** will at least partially emerge from the second main surface **22** and/or the first main surface **21** of the light emitting device **1**.

The material of the substrate **2** can be aluminum oxide, sapphire containing aluminum oxide, glass, plastics, or rubber. According to a preferred embodiment of the present invention, a sapphire substrate is adopted for its essentially single crystal structure and better light transmissivity. In addition, it has superior capability in heat dissipation, which can extend the lifetime of the light emitting device **1**. However, traditional sapphire substrates have the problem of cracking when being assembled with other units of the light emitting apparatus. In order to solve this reliability problem, the thickness of the substrate **2** of the present invention should be greater than or equal to 200 μm as verified by experiments for practical applications.

Moreover, according to the present invention, the difference between color temperatures of the light emerging from the first main surface **21** and the light emerging from the second main surface **22** is set equal to or smaller than 1500K by adjusting the parameters of the substrate **2**, thickness or composition for example, or phosphor deposited thereon. Therefore, the light emitting device **1** of the present invention has an overall consistent lighting performance. According to another embodiment of the present invention, the light transmissivity of the substrate **2** is set greater than or equal to 70% when the range of the wavelength of the incident light is 420~470 nm with the thickness of the substrate **2** being the value described above.

As shown in FIGS. **2**A~**2**C, there are further embodiments of the present invention. For acquiring power for emitting light, an LED chip **3** of a light emitting device according to the present invention includes a first electrode **31** and a second electrode **32** coupled electrically with a first conductor **23** and a second conductor **24** located on the substrate **2** respectively. More particularly, FIG. **2**A shows a lateral type LED chip **3** deposited on the substrate **2** and coupled with the conductors **23**, **24** by wire bonding; FIG. **2**B shows a flip-chip type LED chip **3** deposited on the substrate **2** and coupled with the conductors **23**, **24** by chip bonding wherein the conductors are circuit patterns on the substrate **2**. FIG. **2**C shows an LED chip **3** having the electrodes **31**, **32** disposed on both sides of the epitaxial layers **33** respectively, and the LED chip **3** is vertically deposited on the substrate **2** with the edges of the electrodes **31**, **32** connected to the conductors **23**, **24**.

As shown in FIGS. **3**A~**3**B, there are further embodiments of the present invention. A light emitting device **1** according to the present invention further includes a wavelength conversion layer **4**, which is disposed on a first main surface **21** or/and a second main surface **22** of the light emitting device **1**. Alternatively, the wavelength conversion layer **4** can be disposed on an LED chip **3** directly (not shown in the figures). According to the embodiments of the present invention as

shown in the figures, the wavelength conversion layers **4** including at least one kind of fluorescent powder receive at least a portion of light emitting from the main surfaces **21**, **22** and convert to the light with different wavelength. According to one embodiment shown in FIG. **3**A, one of the wavelength conversion layers **4** encapsulates and contacts the LED chip **3** directly. According to another embodiment shown in FIG. **3**B, one of the wavelength conversion layers **4** covers the LED chip **3** and forms a space between the wavelength conversion layer **4** and the substrate **2** for receiving/converting at least a portion of the light emitted by the LED chip **3** to the light with different wavelength. For example, when the LED chip **3** emits blue light the wavelength conversion layer **4** converts a portion of the blue light to yellow light. Then the light emitting device **1** will eventually emit white light by mixing the blue light and the yellow light. Additionally, the space can be filled with other materials like epoxy, air, phosphor, etc., according to various optics and reliability requirements.

The intensity of the light from the first main surface **21** is slightly different from the intensity of the light from the second main surface **22**. In addition, as described earlier, the further embodiment of the present invention is to set the difference in color temperatures of the emerging light equal to or smaller than 1500K. Additionally, according to a preferred embodiment of the present invention, the ratio of the quantity of the fluorescent powder in the wavelength conversion layer **4** on the first main surface **21** to that on the second main surface **22** is 1:0.5 to 1:3, or other values in order to improve the wavelength conversion efficiency and the light emitting performance of the light emitting device **1**.

As shown in FIG. **4**, a light emitting apparatus of the present invention comprises a light emitting device **1** as described in the previous embodiments and a support base **5**. Wherein the substrate **2** couples to the support base **5** for forming a light emitting apparatus **11**, and there is a first angle θ_1 between the substrate **2** and the support base **5**. The first angle θ_1 is adjustable according to the required light shape of the light emitting apparatus. According to a preferred embodiment, the first angle θ_1 ranges from 30° to 150°.

As shown in FIGS. **5**A~**5**D, a light emitting apparatus **11** according to further embodiments of the present invention further comprises multiple light emitting devices **1** for enhancing the brightness and meeting different light shape requirements. Users can dispose the light emitting devices **1** comprising a plurality of substrates **2** on a support mechanism **50** such as the support base **5** at the same time. The arrangement can be symmetrical or asymmetrical. The preferred arrangement is to dispose the multiple substrates **2** point-symmetrically or line-symmetrically on the support mechanism **50**, so that the light emission of the overall light emitting apparatus **11** can be uniform. (The LED chips **3** are omitted in the figures.) Particularly, the shape of the support mechanism **50** can be a polygon, square, rectangle or regular hexagon for example, or circle or even a hollow circle or a hollow polygon for various applications. According to another embodiment, at least a portion of multiple light emitting devices **1** is disposed concentratively or dispersively in an asymmetrical manner for meeting the requirement in the light shapes of the light emitting apparatus **11** in various applications (not shown in the figures).

In the present invention, the support base **5** or the support mechanism **50** can be a multi-functional base for supporting, supplying power, connecting, and dissipating heat simultaneously. The support base **5** or the support mechanism **50** can comprise such materials as metals, ceramic, glass, plastics, resin or PCB (printed circuit board), just like the base or the socket of a traditional commercial bulb. According to a preferred embodiment, the support base **5** or the support mechanism **50** comprise a flexible metal compound. As shown in FIG. **6**, one of the light emitting surfaces **34** of the LED chip **3** is the exposed surface in the structure essentially parallel to the support surface **210** of the substrate **2**. According to one of the preferred embodiments of the present invention, the area of the first main surface **21** or the second main surface **22** shall be at least five times the total area of the plurality of light emitting surfaces **34** or the single area of the light emitting surface **34**. Then there will be preferred area utilization rate, light emitting and heat dispersion efficiencies of the light emitting device **1**.

As shown in FIG. **7**, the light emitting apparatus **11** of the present invention can further comprise a circuit board **6** on the support base **5** for coupling with an internal or external power supply. The circuit board **6** couples to the first and second conductors **23**, **24** on the substrate **2** (not shown in the figure) for connecting electrically with the LED chips **3** and supplying the power required for emitting light. The circuit board **6** can also be integrated with the support base **5**, therefore the LED chips **3** can be connected electrically with the support base **5** through the first and second conductors **23**, **24** (not shown in the figure). Thereby, power can be directly provided to the LED chips **3** via the support base **5**.

As shown in FIGS. **8**A-**9** and **14**A-**14**D, in order to prevent pollution, corrosion, or wear on the substrate **2** and the LED chips **3** from ambient particles such as dust and moisture, the light emitting apparatus according to further embodiments of the present invention further comprises a lamp housing **7**. The lamp housing **7** couples to the support base **5** or the support mechanism **50** and at least partially covers the substrate **2**, wherein the form of the lamp housing **7** can be a tube, a bulb, or a box. Furthermore, the wavelength conversion layer **4** described above can be disposed optionally on the lamp housing **7**.

FIG. **8**A shows a schematic diagram of a light emitting apparatus **11** according to an embodiment of the present invention. The light emitting apparatus **11** here is a tube, wherein the lamp housing **7** is a transparent tubular structure. Then the light emitting device **1** and the support mechanism **50** are disposed therein. In FIG. **8**A, a single light emitting device **1** is disposed therein. As shown in FIG. **8**B, when two or more light emitting devices **1** are disposed in the lamp housing **7**, the first main surfaces **21** of the plurality of light emitting devices **1** can be arranged as mutually unparallel. In addition, at least a portion of the light emitting device **1** is disposed in the room formed by the lamp housing **7** and not tightly close to the inner walls of the lamp housing **7**. According to a preferred embodiment, there is a distance D greater than 500 μm between the light emitting device **1** and the lamp housing **7**. The lamp housing **7** can also be formed by molding, making the light emitting device **1** at least partially sealed and directly contacted by the lamp housing **7**.

According to another embodiment of the present invention, the light emitting apparatus **11** is a light box as shown in FIG. **9**. The lamp housing **7**, which is used as a signboard in this case, has at least one surface **71** mainly used for printing advertisements. Then the light provided by the first and second main surfaces **21**, **22** of the light emitting device **1** according to the present invention form the backlight for the surface **71**. The light emitting devices **1** can further be inclined or rotatable with a second angle θ_2 relative to the surface **71**, wherein the second angle θ_2 is set between 0° to 45°. (In this case shown in FIG. **9**, θ_2 is 0°, and hence not shown.) According to a preferred embodiment, there is a distance D greater than 500 μm between the light emitting device **1** and the lamp housing **7**. As described above, the lamp housing **7** can also be formed by molding, making the light emitting device **1** at least partially sealed and directly contacted by the lamp housing **7**.

According to still another embodiment of the present invention, as shown in FIG. **10**, the light emitting device **1** further comprises a reflector **8** disposed on the second main surface **22**. The reflector **8** can reflect at least a portion of the light emitted from the second main surface **22** of the substrate **2** and increase the light emitted from the first main surface **21**. This reflector **8** can include, but is not limited to, at least one metal layer or one Bragg reflector comprising stacked multiple layers of dielectric thin films with different refractive indices.

As shown in FIG. **11**, the light emitting device **1** can further comprise diamond-like carbon (DLC) films **9** disposed optionally on the support surface **210** and the second main surface **22** for improving heat conduction and dissipation effects.

As shown in FIGS. **12**A to **14**D, there are some embodiments of the light emitting apparatus **11** according to the present invention. According to embodiments of the present invention shown in FIGS. **12**A and **12**B, the support base **5** can further comprise at least one slot or recess to form a socket or adapter **51**, and correspondingly the substrate **2** can further comprise at least one guide pin or finger connector to connect with the adapter **51** on the support base **5**. Wherein the conductors on the substrate **2** couple with electrodes of the support base **5** correspondingly through the mechanism described above. More particularly, when the substrate **2** comprises dual guide pins as shown in FIG. **12**B, the polarity of the conductor on one of the guide pins can be different from the other conductor on another guide pin. There is also an embodiment as shown in FIG. **12**C that the substrate **2** can be bonded with the support base **5** directly, wherein the bonding material used between the substrate **2** and the support base **5** can be selected from at least one element of the group comprising gold, tin, indium, bismuth, silver, conductive silicone and epoxy resin. Additionally, the substrate **2** and the top surface of the support base **5** form a first angle θ_1 wherein the lighting effect of the light emitting apparatus according to the present invention can be changed accordingly.

According to embodiments of the present invention shown in FIGS. **13**A to **14**B, the support base **5** can further comprise at least one support **52** coupling with at least one light emitting device **1** of the present invention. As shown in FIGS. **13**A and **13**B, there are at least two supports **52** spaced from each other wherein the support **52** can be integrated with the support base **5** or an individual component. Then the substrates **2** are coupled to the supports **52** by bonding layers **53**, therefore the conductors **23**, **24** on the substrate **2** can connect electrically to the power source accordingly. Further more, the substrates **2** can be disposed face-to-face as shown in FIG. **13**A, back-to-back as shown in FIG. **13**B, or face-to-back (not shown) for different lighting effects. Wherein the substrates **2** and the top surface of the support base **5** form the first angle θ_1 wherein the lighting effect of the light emitting apparatus according to the present invention can be changed accordingly. Furthermore, the support **52** can be flexible, retractable, or rotatable therefore the lighting effect of the light emitting apparatus according to the present invention can be adapted to various applications.

As shown in FIGS. **14**A to **14**D, the light emitting apparatus **11** according to the embodiments shown in FIGS. **13**A to **13**B further comprises a lamp housing **7** and a lamp base **54**. Wherein the support base **5** is disposed on the lamp base **54** and covered by the lamp housing **7**, and the lamp housing **7** is connected with the lamp base **54**. Furthermore, the lamp base **54** can be integrated with the support base **5**. More particularly, the lamp base **54** in FIG. **14**A can be connected with socket for traditional bulb so that the light emitting apparatus of the present invention can directly replace the traditional bulb. More particularly, the lamp base **54** in FIG. **14**B can be a board like member of the light emitting apparatus **11** for different applications like a projector, a decoration wall, or an operating lamp according to the present invention. More particularly, the light emitting apparatus **11** according to the embodiment shown in FIG. **14**C further comprises a wavelength conversion layer **4** disposed on the lamp housing **7**, wherein the wavelength conversion layer **4** is disposed on the inner side of the lamp housing **7**. Therefore, at least a portion of the light emitted from the light emitting device **1** can be converted to the light of another wavelength before leaving the lamp housing **7**. More particularly, the light emitting apparatus **11** according to the embodiment shown in FIG. **14**D further comprises an additional lamp housing **7** forming a double-layer lamp housing **7** for changing the decorative patterns and colors conveniently.

The foregoing description is only embodiments of the present invention, not used to limit the scope and range of the present invention. Those equivalent changes or modifications made according to the shape, structure, feature, or spirit described in the claims of the present invention are included in the appended claims of the present invention.

What is claimed is:

1. A light emitting apparatus, comprising:

at least one light emitting device, including:

a substrate, having a support surface; and

at least one light emitting diode chip comprising a plurality of light emitting surfaces, disposed on said support surface of said substrate, one of said light emitting surfaces and said support surface forming a first main surface, wherein a light emitting angle of said light emitting diode chip is wider than 180°, and a portion of light emitted by said light emitting diode chip penetrates into said substrate from said support surface and emerges from a second main surface of said substrate opposing said first main surface; and

a support base, coupled to said light emitting device, and forming a first angle with said substrate.

2. The light emitting apparatus of claim **1**, further comprising a wavelength conversion layer disposed on said first main surface and/or on said second main surface of said light emitting device, wherein said wavelength conversion layer receives at least a portion of the light emitted by said light emitting diode chip and converts the wavelength thereof.

3. The light emitting apparatus of claim **2**, wherein said wavelength conversion layer does not contact said light emitting diode chip.

4. The light emitting apparatus of claim **2**, wherein said wavelength conversion layer is disposed on said first main surface and said second main surface, and the ratio of the fluorescent powder contained in said wavelength conversion layer located on different surfaces ranges from 1:05 to 1:3.

5. The light emitting apparatus of claim **1**, wherein the difference between the color temperature of said first main surface and the color temperature of said second main surface is equal to or less than 1500K.

6. The light emitting apparatus of claim **1**, further comprising a lamp housing, wherein at least a portion of said light emitting device is disposed in the room formed by said lamp housing.

7. The light emitting apparatus of claim **6**, further comprising a wavelength conversion layer disposed on said lamp housing.

8. The light emitting apparatus of claim **6**, wherein said lamp housing is coupled with said support base and at least partially covers said light emitting device.

9. The light emitting apparatus of claim **6**, wherein said lamp housing is a tube, a bulb, or a box.

10. The light emitting apparatus of claim **6**, wherein said lamp housing has at least one surface, and a second angle is formed between said surface and said first main surface or said second main surface of said light emitting device, said second angle ranging from 0° to 45°.

11. The light emitting apparatus of claim **6**, wherein a distance is formed between said lamp housing and said substrate, and said distance is greater than 500 μm.

12. The light emitting apparatus of claim **1**, wherein said first angle ranges from 30° to 150°.

13. The light emitting apparatus of claim **1**, wherein the number of said light emitting device is more than one and the arrangement of said light emitting devices is symmetrical.

14. The light emitting apparatus of claim **13**, wherein said arrangement is point- or line-symmetrical.

15. The light emitting apparatus of claim **1**, and further comprising a circuit board connected electrically to both said light emitting device and said support base.

16. The light emitting apparatus of claim **1**, wherein said support base includes a flexible metal compound.

17. The light emitting apparatus of claim **1**, wherein said support base includes a support member and said light emitting device is disposed on said support member.

18. The light emitting apparatus of claim **17**, further comprising a bonding layer coupling said light emitting device to said support member, wherein the material of said bonding layer is selected from the group consisting of gold, tin, indium, bismuth, silver, silicone, and epoxy resin.

19. The light emitting apparatus of claim **17**, wherein said support member is flexible.

20. The light emitting apparatus of claim **17**, wherein said support member is retractable.

21. The light emitting apparatus of claim **17**, wherein said support member is rotatable.

22. The light emitting apparatus of claim **1**, wherein the material of said substrate is selected from the group consisting of aluminum oxide, sapphire, glass, plastics, and rubber.

23. The light emitting apparatus of claim **1**, wherein the thickness of said substrate is greater than or equal to 200 μm.

* * * * *

Exhibit 6

US009257604B2

(12) **United States Patent**
Ou et al.

(10) **Patent No.: US 9,257,604 B2**
(45) **Date of Patent: Feb. 9, 2016**

(54) **LIGHT-EMITTING DEVICE HAVING A PATTERNED SURFACE**

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(72) Inventors: **Chen Ou**, Hsinchu (TW); **Chiu-Lin Yao**, Hsinchu (TW)

(73) Assignee: **EPISTAR CORPORATION**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/132,819**

(22) Filed: **Dec. 18, 2013**

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Related U.S. Application Data

(63) Continuation of application No. 12/646,553, filed on Dec. 23, 2009, now Pat. No. 8,633,501, and a continuation-in-part of application No. 12/222,548, filed on Aug. 12, 2008, now Pat. No. 8,791,029.

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
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H01L 33/24 (2010.01)

(52) **U.S. Cl.**
CPC ***H01L 33/22*** (2013.01); ***H01L 33/24*** (2013.01); *H01L 2933/0091* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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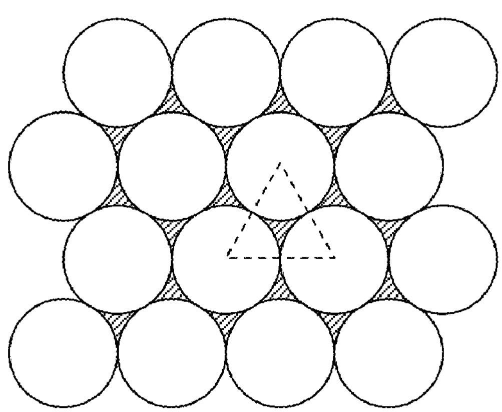
(57) **ABSTRACT**

The disclosure provides a light-emitting device. The light-emitting device comprises: a substrate having a first patterned unit; and a light-emitting stack on the substrate and having an active layer with a first surface; wherein the first patterned unit, protruding in a direction from the substrate to the light-emitting stack, has side surfaces abutting with each other and substantially non-parallel to the first surface in cross-sectional view, and has a non-polygon shape in top view.

16 Claims, 9 Drawing Sheets



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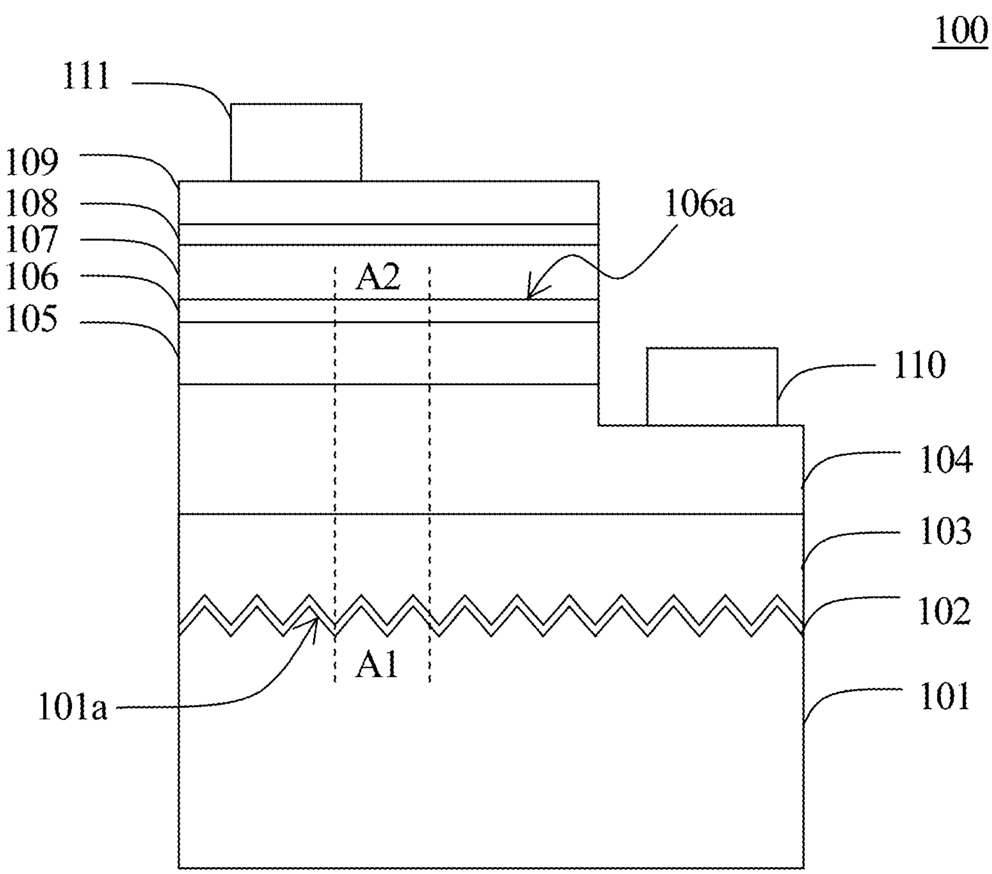

FIG. 1

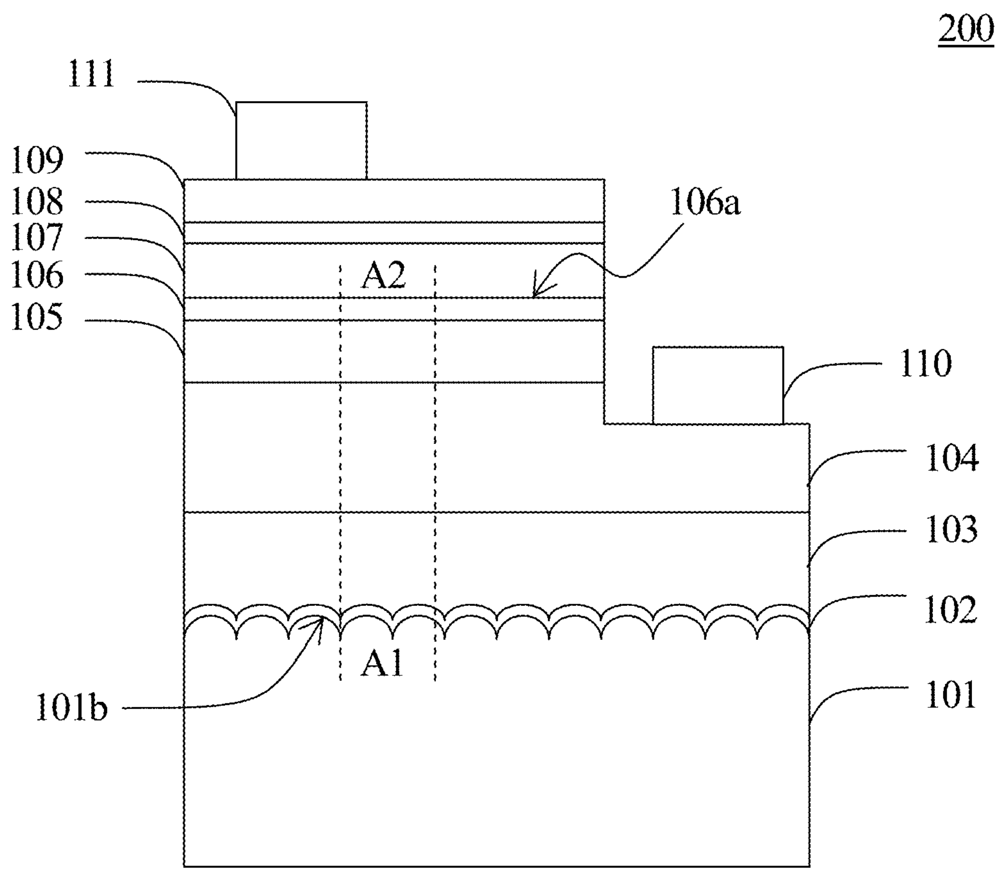

FIG. 2

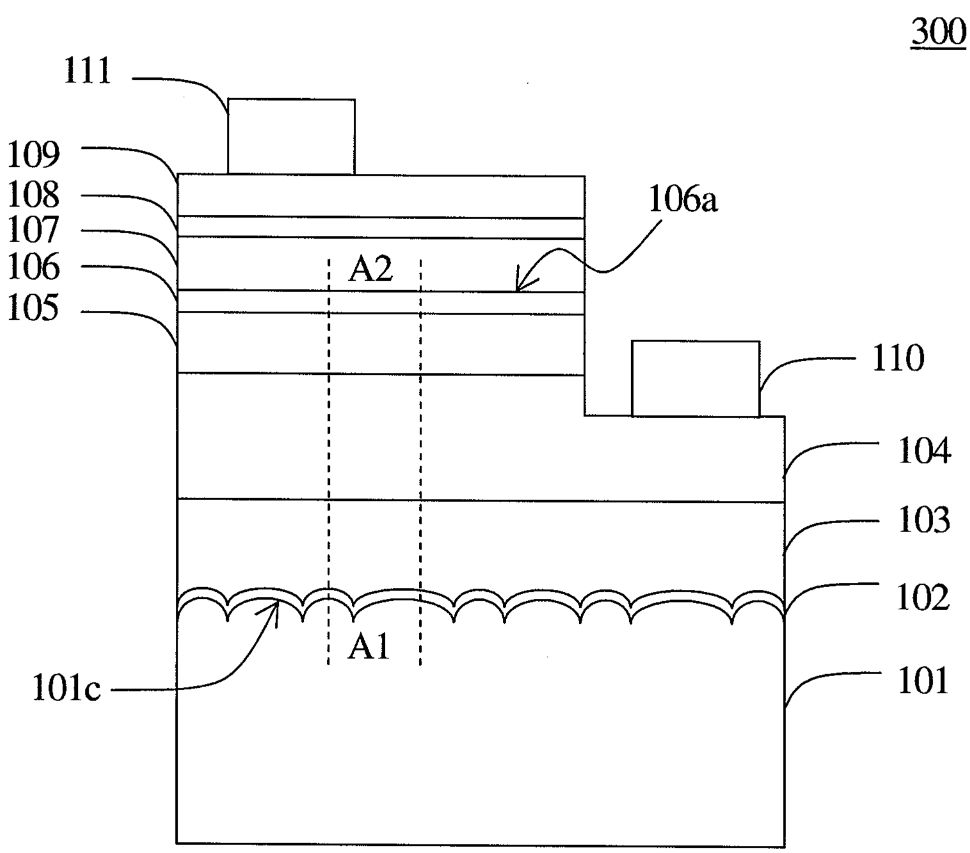

FIG. 3A

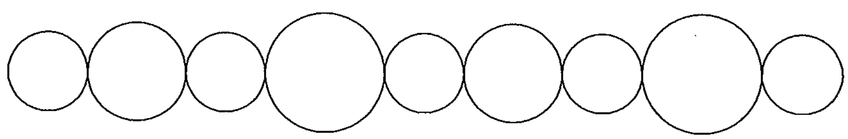

FIG. 3B

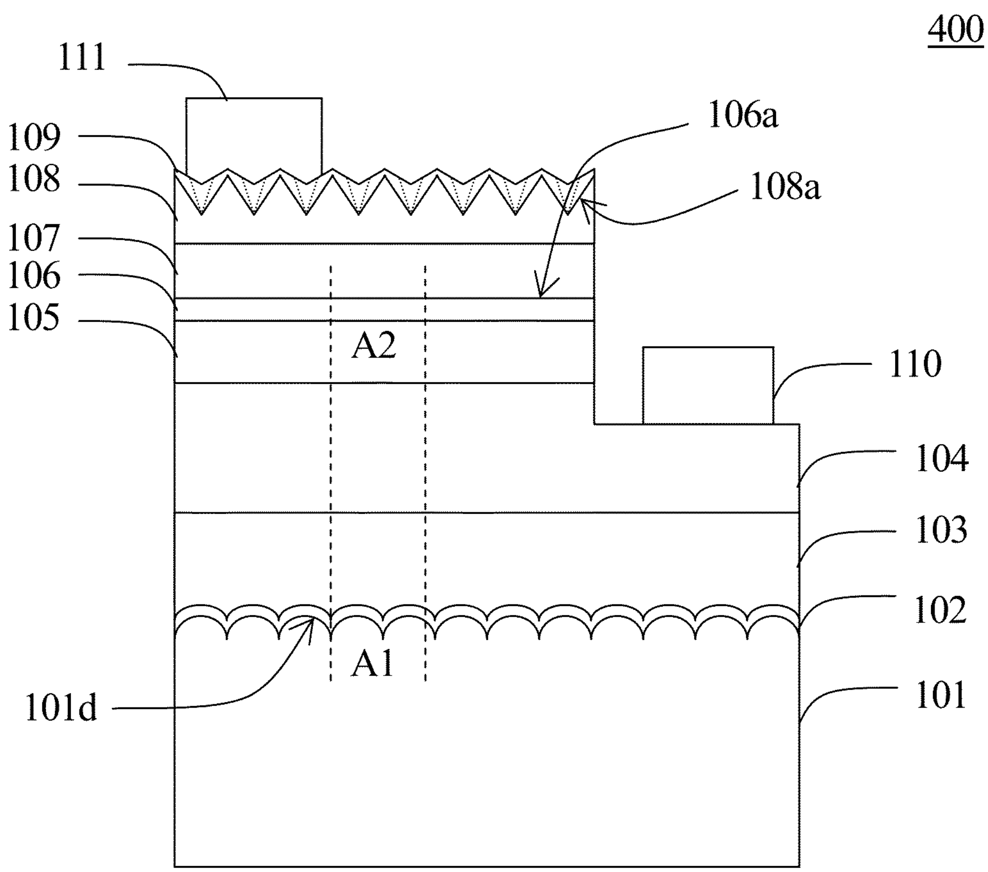
400
111
109
108
107
106
105
106a
108a
A2
110
104
103
102
A1
101d
101

FIG. 4

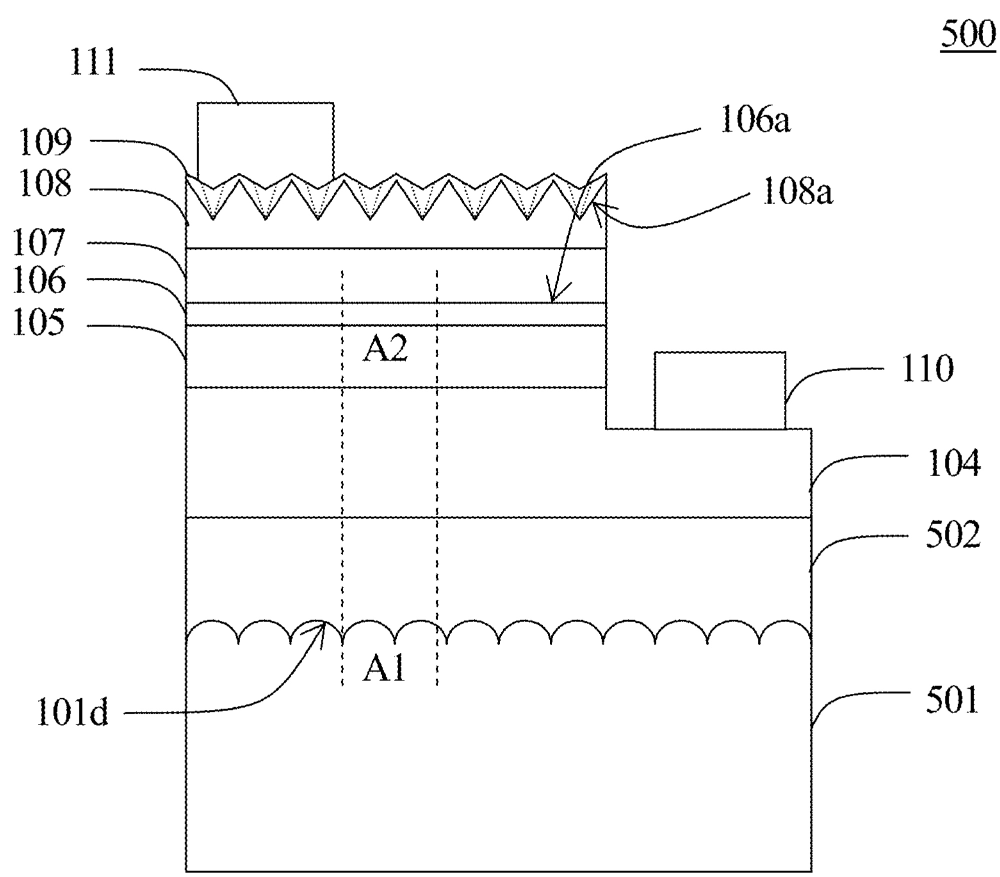

FIG. 5

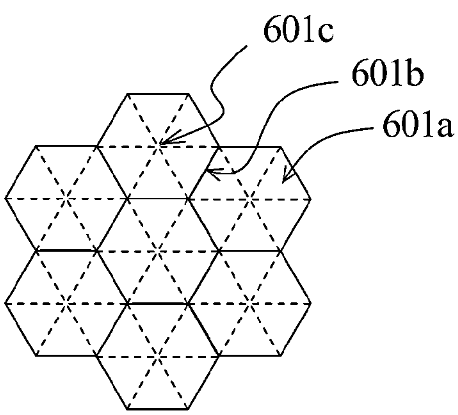

FIG. 6A

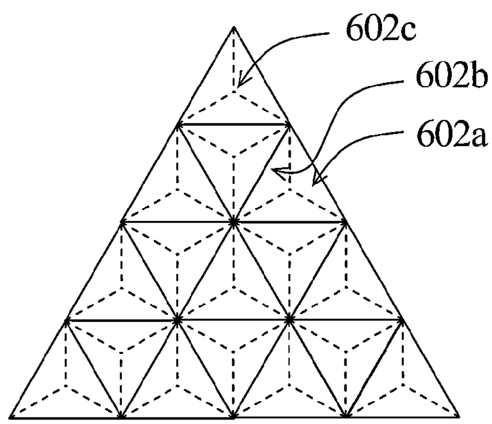

FIG. 6B

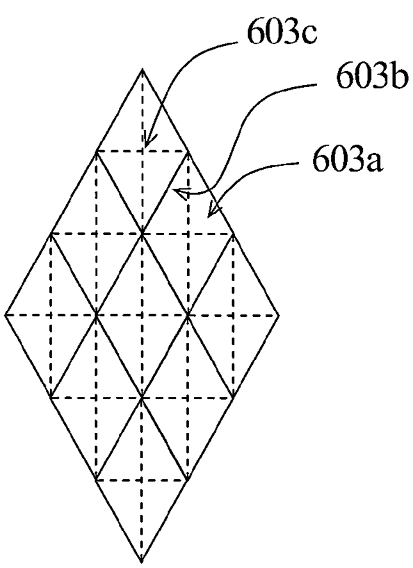

FIG. 6C

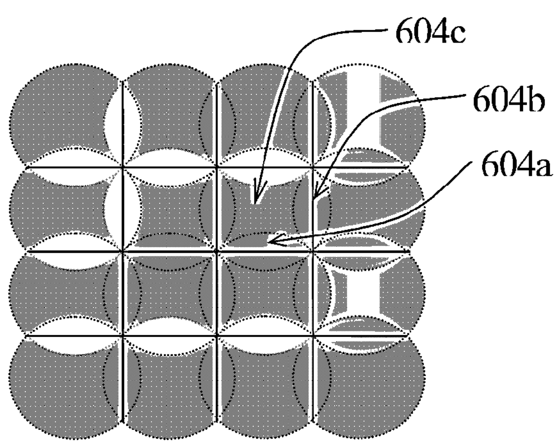

FIG. 6D

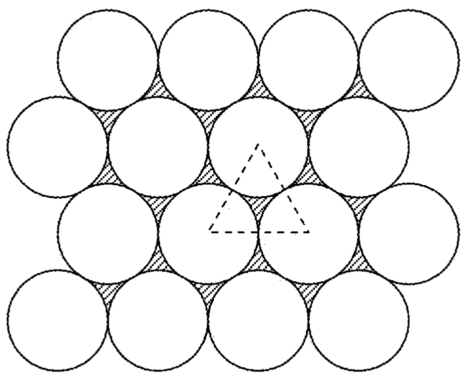

FIG. 6E

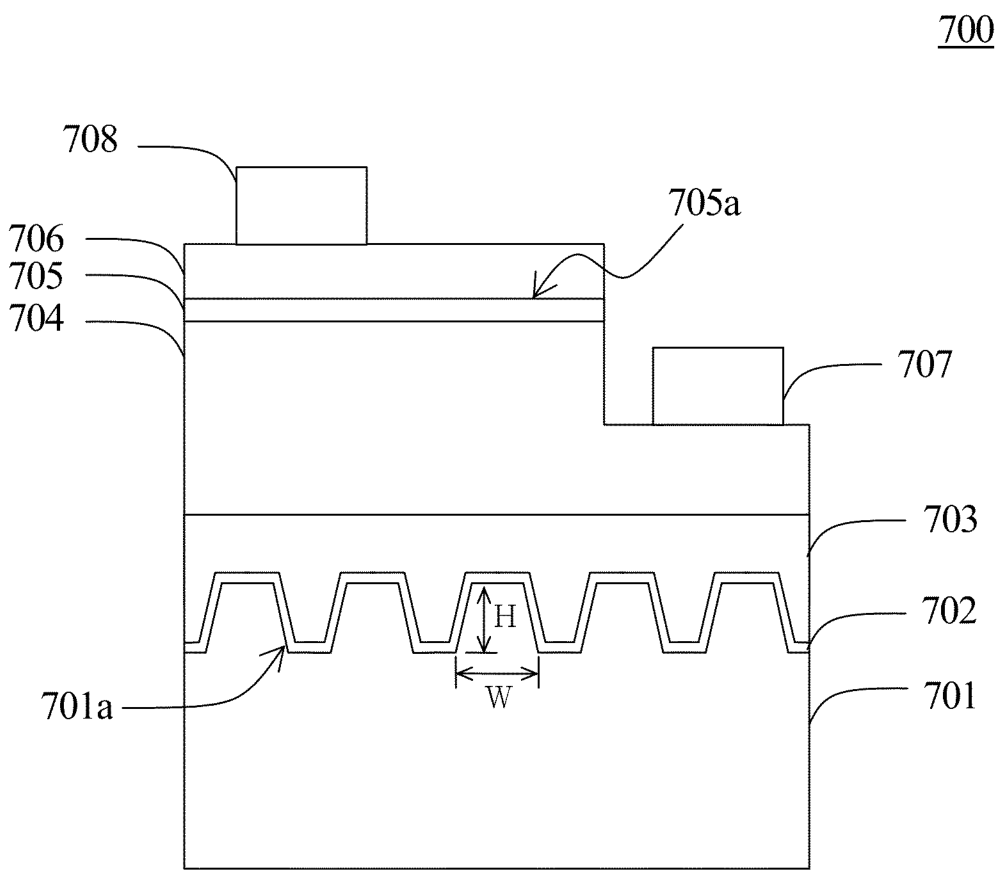

FIG. 7 (PIROR ART)

LIGHT-EMITTING DEVICE HAVING A PATTERNED SURFACE

RELATED APPLICATION

This application is a continuation application of U.S. patent application Ser. No. 12/646,553, entitled "A LIGHT-EMITTING DEVICE HAVING A PATTERNED SURFACE", filed on Dec. 23, 2009, which is a continuation-in-part of U.S. patent application Ser. No. 12/222,548, entitled "Stamp Having Nanoscale Structure And Applications Thereof In Light-Emitting Device", filed on Aug. 12, 2008 claiming the right of priority based on TW application Ser. No. 097150633 filed on Dec. 24, 2008; the contents of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Technical Field

The present disclosure relates to a light-emitting device having a patterned surface.

2. Description of the Related Art

Recently, efforts have been devoted to promote the luminance of the light-emitting diode (LED) in order to implement the device in the lighting domain, and further procure the goal of energy conservation and carbon reduction. There are two major aspects to promote luminance. One is to increase the internal quantum efficiency (IQE) by improving the epitaxy quality to enhance the combination efficiency of electrons and holes. The other is to increase the light extraction efficiency (LEE) that emphasizes on the light which is emitted by the light-emitting layer capable of escaping outside the device, and therefore reducing the light absorbed by the LED structure.

Surface roughening technology is one of the efficient methods to enhance luminance. FIG. **7** shows a known LED **700** having a patterned substrate. LED **700** comprises a growth substrate **701**, an epitaxial stack, a first electrode **707**, and a second electrode **708**. The surface **701***a* of the growth substrate **701** has a plurality of trapezoid depression for improving the light-extraction efficiency. The epitaxial stack comprises a buffer layer **702** grown on the growth substrate, a non-doped semiconductor layer **703** grown on the buffer layer **702**, a first semiconductor layer **704** with first conductivity-type grown on the non-doped semiconductor layer **703**, an active layer **705** grown on the first semiconductor layer **704**, a second semiconductor layer **706** with second conductivity-type grown on the active layer **705**. The first electrode **707** is formed on the exposed first semiconductor layer **704**, and the second electrode **708** is formed on the second semiconductor layer **706**.

The ratio of the pattern width to the width between patterns of the substrate surface **701***a* is generally designed to be around 1. Therefore, a considerable portion of the substrate surface **701***a* is still parallel to the surface of the active layer **705***a*, and the light emitted from the active layer **705** to the parallel substrate surface is easily reflected back to the epitaxial stack because of total internal reflection (TIR) effect and absorbed by the epitaxial stack to generate heat. It worsens both the light extraction efficiency and the heat dissipation problems. Nevertheless, the pattern is usually formed deeper in order to compensate the light loss due to the parallel (unpatterned) region, but the high aspect ratio of the deeper pattern causes difficulty for subsequently epitaxial growth and adversely affects the epitaxial quality.

Another prior technique for roughen surface is to utilize mechanically polishing method to form a randomly distributed rough patterns on the substrate surface. By this method, it is hard to control the roughened dimension, such as the depth or the width. Moreover, the epitaxial quality is not good by growing an epitaxial layer on the randomly rough surface.

SUMMARY OF THE DISCLOSURE

The disclosure provides a light-emitting device. The light-emitting device comprises: a substrate having a first patterned unit; and a light-emitting stack on the substrate and having an active layer with a first surface; wherein the first patterned unit, protruding in a direction from the substrate to the light-emitting stack, has side surfaces abutting with each other and substantially non-parallel to the first surface in cross-sectional view, and has a non-polygon shape in top view.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a light-emitting device in accordance with the first embodiment of the present disclosure.

FIG. **2** shows a light-emitting device in accordance with the second embodiment of the present disclosure.

FIGS. **3**A and **3**B show a light-emitting device in accordance with the third embodiment of the present disclosure.

FIG. **4** shows a light-emitting device in accordance with the fourth embodiment of the present disclosure.

FIG. **5** shows a light-emitting device in accordance with the fifth embodiment of the present disclosure.

FIG. **6**A to **6**E show embodiments of the top views of the patterned surface in accordance with the present disclosure.

FIG. **7** shows a known structure of a light-emitting diode.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. **1** shows a light-emitting device **100** in accordance with a first embodiment of the present disclosure. The light-emitting device **100** comprises a growth substrate **101**, an intermediate layer comprising a buffer layer **102** and/or an undoped semiconductor layer **103** epitaxially grown on the growth substrate **101**, a first contact layer **104** with first conductivity-type epitaxially grown on the intermediate layer, a first cladding layer **105** with first conductivity-type epitaxially grown on the first contact layer **104**, an active layer **106** epitaxially grown on the first cladding layer **105**, a second cladding layer **107** with second conductivity-type epitaxially grown on the acitve layer **106**, a second contact layer **108** with second conductivity-type epitaxially grown on the second cladding layer **107**, a current spreading layer **109** formed on the second contact layer **108** and forming an ohmic contact with the second contact layer **108**, a first electrode **110** formed on the exposed first contact layer **104** by evaporation or sputtering method, and a second electrode **111** formed on the current spreading layer **109** by evaporation or sputtering method; wherein the growth substrate **101** has a patterned surface **101***a* comprising a plurality of ordered pattern units, and each of the plurality of ordered pattern units is compactly disposed, for example, at least one of the plurality of pattern units is substantially contacted with the neighboring units. According to the embodiment, any region of the patterned surface **101***a*, e.g. A**1** region, is substantially not parallel to the corresponding region of the surface of the active layer, e.g. A**2** region. The plurality of the ordered pattern units is disposed in a fixed period, variable period, or quasi-period. The top views of the plurality of pattern units comprise a polygon, or at least one pattern selected from the group consisting of triangle, rectangle, hexagon, and circle. The cross-sections of the plurality of pattern units comprise at least one pattern selected from the group consisting of V-shape, semicircle, arc, and polygon. Each of the plurality of pattern units has a width and a depth, and the depth is preferable less than the width for facilitating the subsequently grown buffer layer **102** and/or the undoped semiconductor layer **103** to fill into the depressed region of the patterned surface **101***a*.

FIG. **2** shows a light-emitting device **200** in accordance with a second embodiment of the present disclosure. In comparison with the light-emitting device **100** shown in FIG. **1**, the cross-section of the patterned surface **101***b* comprises a plurality of ordered patterned units, and each of the patterned units comprises a smooth curve for facilitating the subsequently grown buffer layer **102** and/or the undoped semiconductor layer **103** to fill into the depressed area of the patterned surface **101***b*. The method for forming the cross-section with a smooth curve comprises firstly forming a mask layer of photoresist on a plane substrate, patterning the mask layer by lithographic process, then curing the patterned mask layer in a baking machine under an appropriate temperature to reflow the patterned mask layer of photoresist to form a profile with smooth curve, finally dry-etching or wet-etching the substrate with the patterned mask layer to transfer the smooth curve profile to the substrate to form a patterned surface **101***b* with a smooth curve as shown in FIG. **2**. The top views of the plurality of pattern units comprise polygon, or at least one pattern selected from the group consisting of triangle, rectangle, hexagon, and circle.

FIGS. **3**A and **3**B show a light-emitting device **300** in accordance with a third embodiment of the present disclosure. In comparison with the light-emitting device **200** shown in FIG. **2**, the patterned surface **101***c* of the light-emitting device **300** comprises a plurality of patterned units with variable dimensions or variable patterns disposed in a fixed period, variable period, or quasi-period. The top views of the plurality of the patterned units comprise polygon, or at least one pattern selected from the group consisting of triangle, rectangle, hexagon, and circle. In this embodiment, FIG. **3**A shows the cross-section of the plurality of patterned units comprises at least two curves with different curvatures. FIG. **3**B shows the patterned units have circular shapes with different diameters or different areas in the top view.

FIG. **4** shows a light-emitting device **400** in accordance with a fourth embodiment of the present disclosure. In comparison with the light-emitting device **200** shown in FIG. **2**, the second contact layer **108** of the light-emitting device **400** further comprises an exterior surface **108***a* having the patterned surface as disclosed in the foregoing embodiments for further enhancing the light extraction efficiency, and any region of the patterned surface **108***a* is substantially not parallel to the corresponding region of the upper surface **106***a* of the active layer. The method for forming the exterior surface **108***a* of the second contact layer **108** comprises naturally growing the second contact layer **108** with hexagonal depressions by adjusting the epitaxial growth parameters, such as lowering the growth temperature, or changing the gas concentration ratio of Hydrogen to Nitrogen, or performing a traditional lithographic and etching process to form the patterned surface **108***a* with protrusions and/or depressions. The subsequently formed current spreading layer **109** is conformable with the patterned surface **108***a* and forms a good ohmic contact with the second contact layer **108**.

FIG. **5** shows a light-emitting device **500** in accordance with a fifth embodiment of the present disclosure. In comparison with the light-emitting device **200** shown in FIG. **2**, the intermediate layer **502** of the light-emitting device **500** comprises a bonding layer, e.g. a transparent adhesive layer or a transparent conductive layer. The first contact layer **104** is joined to the second substrate **501** by a bonding technique, e.g. a direct bonding method or a thermo-compression bonding method. According to the present disclosure, the second substrate **501** is not limited to a material for epitaxial growth, and is flexible as long as the material meets the purpose, e.g. a material with high conductivity, a material with high transparency, a conductive material, or a material with high reflectivity.

FIG. **6**A to FIG. **6**D shows the top views of the patterned surface in accordance with the present disclosure. As shown in FIG. **6**A, the patterned surface comprises a plurality of hexagonal pattern units. Each of the pattern units is composed of six inclined surfaces **601***a* depressed or protruded from the substrate. The six inclined surfaces **601***a* are commonly joined at a vertex **601***c*, and mutually joined at six connecting sides **601***b* such that the patterned surface of the substrate is substantially not parallel to the corresponding region of the upper surface **106***a* of the active layer. As shown in FIG. **6**B, the patterned surface comprises a plurality of triangular pattern units. Each of the pattern units is composed of three inclined surfaces **602***a* depressed or protruded from the substrate. The three inclined surfaces **602***a* are commonly joined at a vertex **602***c*, and mutually joined at three connecting sides **602***b* such that the patterned surface of the substrate is substantially not parallel to the corresponding region of the upper surface **106***a* of the active layer. As shown in FIG. **6**C, the patterned surface comprises a plurality of rhombus pattern units. Each of the pattern units is composed of four inclined surfaces **603***a* depressed or protruded from the substrate. The four inclined surfaces **603***a* are commonly joined at a vertex **603***c*, and mutually joined at four connecting sides **603***b* such that the patterned surface of the substrate is substantially not parallel to the corresponding region of the upper surface **106***a* of the active layer. As shown in FIG. **6**D, the patterned surface comprises a plurality of square pattern units defined by overlapped circles. Each of the pattern units is composed of four inclined surfaces **604***a* protruded from the substrate and a rounded top surface **604***c*. The plurality of pattern units are mutually joined at the connecting sides **604***b* such that the patterned surface of the substrate is substantially not parallel to the corresponding region of the upper surface **106***a* of the active layer. The statement of "the patterned surface of the substrate is substantially not parallel to the corresponding region of the upper surface of the active layer" as described in the foregoing embodiments does not exclude the circumstances caused by the various process deviations, such as the photoresist pattern distortion by lithographic deviation or pattern distortion by etching deviation such that portion of the to-be-patterned surface is not patterned or portion of the patterned region still comprises surface parallel to the active layer. For example, the vertices **601***c*, **602***c*, **603***c*, or rounded top surface **604***c* still possibly comprises a small mesa under the various process deviations, but the process deviations are preferred to be controlled to have the total surface area that is parallel to the active layer and the total surface area of the unpatterned surface do not exceed 3% of the total substrate area. As shown in FIG. **6**E, the patterned surface comprises a plurality of circular pattern units. Each of the pattern units is disposed side by side in a tightest disposition such that the patterned surface area of the substrate that is parallel to the corresponding region of the upper surface **106***a* of the active layer is about 9.3% or not over 10% of the total substrate area, i.e. the ratio of the area of the triangular area subtracting the area of the three sectors to the area of the triangular area is about 9.3% or not over 10%.

The pattern units as disclosed in the foregoing embodiments have a relative higher patterned proportion, therefore increase the difficulty to epitaxially grow the subsequently buffer layer and the undoped semiconductor layer. In order to fulfill both light extraction efficiency and internal quantum efficiency, the cross-section of each of the pattern units has a width and a depth smaller than the width, i.e. the ratio of the depth to the width is lower than 1, therefore a pattern unit with a lower aspect ratio is achieved. The subsequently epitaxially grown buffer layer and/or the undoped semiconductor layer are easily filled into the depressed region of the patterned surface to enhance the epitaxial growth quality.

The patterned surface described in the above-mentioned embodiments is not limited to be formed on any surface of any specific structure of the light-emitting device in accordance with the present disclosure. It is still under the scope of the disclosure to form the patterned surface on any structure of the light-emitting device in accordance with the present disclosure. For example, the patterned surface can be formed on the light output surface of the light-emitting device contacting with the surroundings. The neighboring materials neighbored to the patterned structure includes but not limited to any structure of the light-emitting device, the encapsulating material, or the environmental medium having a different refraction index from the patterned structure. The difference of the refraction indexes of the patterned structure and the neighboring material is at least 0.1.

The materials of the buffer layer, the undoped semiconductor layer, the first contact layer, the first cladding layer, the second cladding layer, the second contact layer, and the active layer comprise III-V compound materials, e.g. $Al_pGa_qIn_{(1-p-q)}P$ or $Al_xIn_yGa_{(1-x-y)}N$, wherein, $0 \leq p, q, x, y \leq 1$; $(p+q) \leq 1$; $(x+y) \leq 1$. The first conductivity-type comprises n-type or p-type. The second conductivity-type comprises n-type or p-type and is different to the first conductivity-type. The current spreading layer comprises metal oxide, e.g. ITO, or well-conductive semiconductor layer of phosphide or nitride having high impurity concentration. The growth substrate comprises at least one material selected from the group consisting of GaP, sapphire, SiC, GaN, and AlN. The second substrate comprises a transparent material selected from the group consisting of GaP, sapphire, Sic, GaN, and AlN, or a heat dissipating material selected from the group consisting of diamond, diamond-like-carbon (DLC), ZnO, Au, Ag, Al, and other metals.

It will be apparent to those having ordinary skill in the art that various modifications and variations can be made to the methods in accordance with the present disclosure without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the present disclosure cover modifications and variations of this disclosure provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A light-emitting device comprising:

a substrate having a top surface and a first patterned unit bulged on the top surface; and

a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface;

wherein a base of the first patterned unit has a non-polygon shape in a top view, and in a cross-sectional view the first patterned unit has a vertex, a first inclined line segment, and a second inclined line segment, and the first inclined line segment and the second inclined line segment connect at the vertex.

2. The light-emitting device according to claim **1**, wherein the non-polygon shape is a first circular shape.

3. A light-emitting device comprising:

a substrate having a top surface and a first patterned unit bulged on the top surface; and

a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface,

wherein the first patterned unit has a non-polygon in a top view, and a first inclined line and a second inclined line directly connected to the top surface to form a vertex in a cross-sectional view, and

wherein the first patterned unit is substantially formed in a V-shape in the cross-sectional view.

4. The light-emitting device according to claim **2**, further comprising a second patterned unit, wherein a base of the second patterned unit has a second circular shape in the top view.

5. The light-emitting device according to claim **4**, wherein the second circular shape has an area different from that of the first circular shape.

6. The light-emitting device according to claim **1**, wherein the first patterned unit is between the substrate and the light-emitting stack.

7. The light-emitting device according to claim **6**, further comprising an undoped semiconductor layer formed on the substrate and enclosing the first patterned unit.

8. The light-emitting device according to claim **1**, wherein the first patterned unit has a width and a depth smaller than the width.

9. The light-emitting device according to claim **1**, wherein the substrate comprises GaP, sapphire, GaN, or AlN.

10. The light-emitting device according to claim **1**, wherein the first inclined line segment and second inclined line segment are substantially straight lines.

11. The light-emitting device according to claim **1**, wherein the substrate comprises a non-patterned area parallel to the first surface and not greater than 10% of a total area of the substrate.

12. The light-emitting device according to claim **1**, further comprising a neighboring material with a refraction index different from that of the substrate.

13. The light-emitting device according to claim **4**, wherein the first patterned unit is adjacent to the second patterned unit.

14. A light-emitting device comprising:

a substrate having a top surface and a plurality of first patterned units bulged on the top surface; and

a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface,

wherein each of the plurality of first patterned units has a non-polygon shape in a top view, and a first inclined line and a second inclined line directly connected to the top surface to form a vertex in a cross-sectional view, and

wherein each of the plurality of first patterned units is substantially formed in a V-shape in the cross-sectional view.

15. The light-emitting device according to claim **14**, wherein one of the plurality of first patterned units is adjacent to another one of the plurality of first patterned units.

16. The light-emitting device according to claim **14**, further comprising a plurality of second patterned unit, wherein the plurality of first patterned units and the plurality of second patterned unit are arranged in a row.

* * * * *

Exhibit 7

US009488321B2

(12) **United States Patent**
Ye et al.

(10) **Patent No.: US 9,488,321 B2**
(45) **Date of Patent: *Nov. 8, 2016**

(54) **ILLUMINATION DEVICE WITH INCLINED LIGHT EMITTING ELEMENT DISPOSED ON A TRANSPARENT SUBSTRATE**

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(72) Inventors: **Zhi-Ting Ye**, Tao-Yuan Hsien (TW); **Fen-Ren Chien**, Tao-Yuan Hsien (TW); **Shyi-Ming Pan**, Tao-Yuan Hsien (TW)

(73) Assignee: **Formosa Epitaxy Incorporation**, Tao-Yuan Hsien (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 123 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/218,869**

(22) Filed: **Mar. 18, 2014**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 13/904,038, filed on May 29, 2013, now Pat. No. 9,123,868.

(30) **Foreign Application Priority Data**

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Aug. 28, 2012 (TW) .... 101131198 A
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May 8, 2013 (TW) .... 102116429 A
May 10, 2013 (TW) .... 102116650 A

(51) **Int. Cl.**
F21K 99/00 (2016.01)
H01L 33/44 (2010.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F21K 9/135*** (2013.01); ***H01L 25/0753*** (2013.01); ***H01L 33/44*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC F21K 9/135; F21K 9/13; F21K 9/10; F21Y 2101/02; F21Y 2111/001; F21V 19/001; F21V 19/003
USPC 362/249.02
See application file for complete search history.

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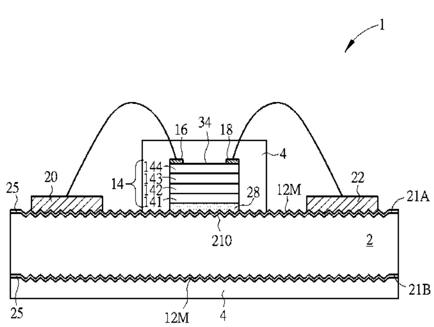
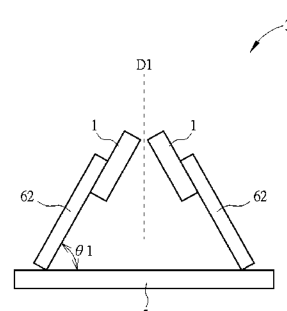
Primary Examiner — Robert May
(74) *Attorney, Agent, or Firm* — Winston Hsu; Scott Margo

(57) **ABSTRACT**

A semiconductor light emitting element includes a transparent substrate and a plurality of light emitting diode (LED) structures. The transparent substrate has a support surface and a second main surface disposed opposite to each other. At least some of the LED structures are disposed on the support surface and form a first main surface where light emitted from with a part of the support surface without the LED structures. Each of the LED structures includes a first electrode and a second electrode. Light emitted from at least one of the LED structures passes through the transparent substrate and emerges from the second main surface. An illumination device includes the semiconductor light emitting element and a supporting base. The semiconductor light emitting element is disposed on the supporting base, and an angle is formed between the semiconductor light emitting element and the supporting base.

9 Claims, 24 Drawing Sheets





(51) **Int. Cl.**

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H01L 33/50	(2010.01)
H01L 33/62	(2010.01)
H01L 23/00	(2006.01)

(52) **U.S. Cl.**

CPC *H01L 24/14* (2013.01); *H01L 24/16* (2013.01); *H01L 24/48* (2013.01); *H01L 24/49* (2013.01); *H01L 33/007* (2013.01); *H01L 33/507* (2013.01); *H01L 33/62* (2013.01); *H01L 2224/14051* (2013.01); *H01L 2224/16225* (2013.01); *H01L 2224/32225* (2013.01); *H01L 2224/45147* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48137* (2013.01); *H01L 2224/49107* (2013.01); *H01L 2224/73204* (2013.01); *H01L 2224/73265* (2013.01); *H01L 2224/83385* (2013.01); *H01L 2224/8592* (2013.01); *H01L 2924/00014* (2013.01); *H01L 2924/01322* (2013.01); *H01L 2924/12041* (2013.01); *H01L 2924/19107* (2013.01); *H01L 2924/3025* (2013.01)

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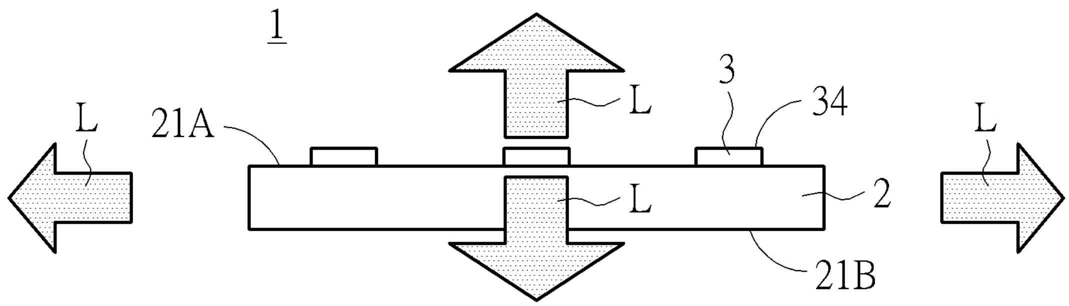


FIG. 1

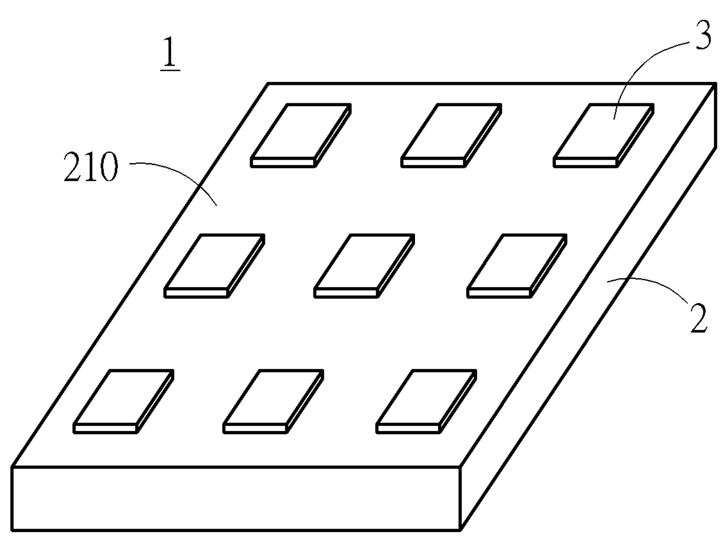


FIG. 2

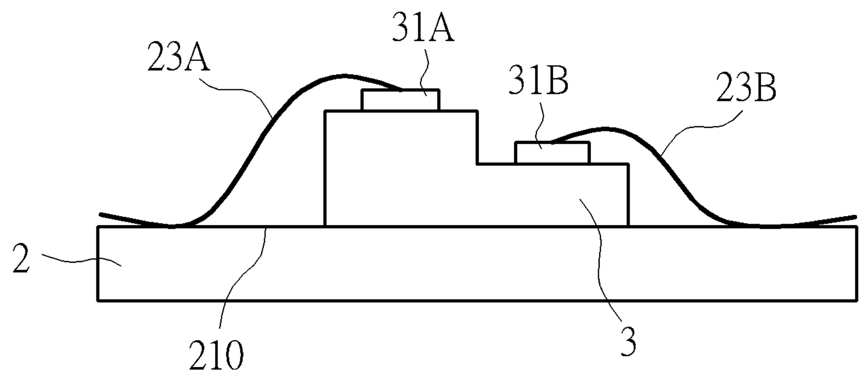


FIG. 3

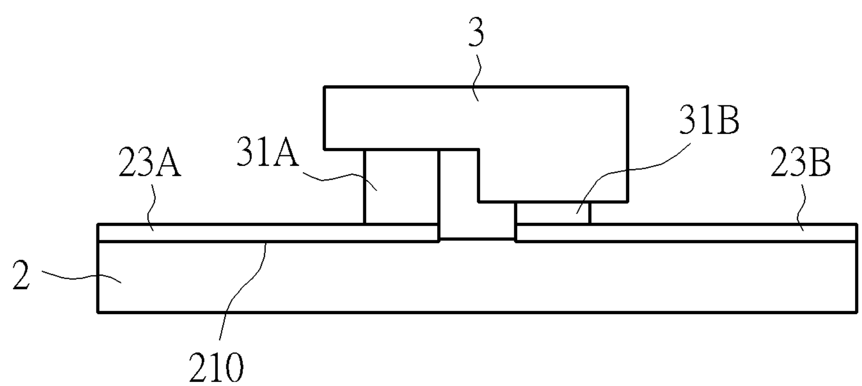


FIG. 4

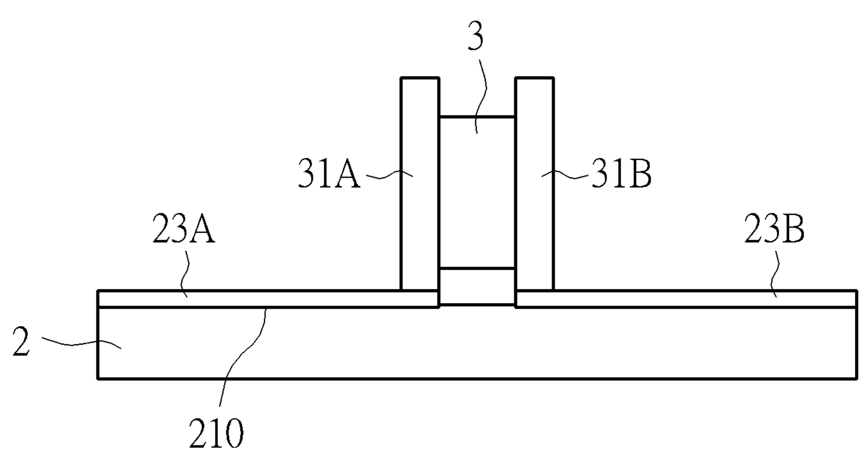


FIG. 5

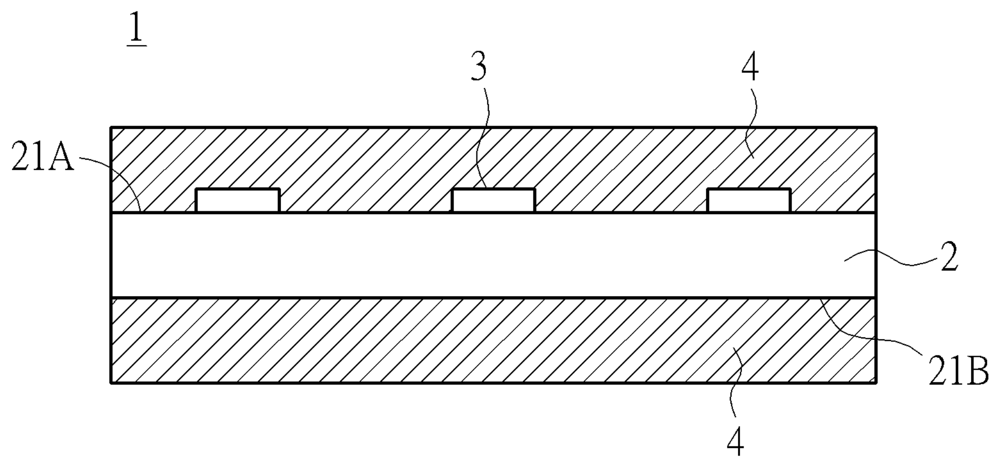


FIG. 6

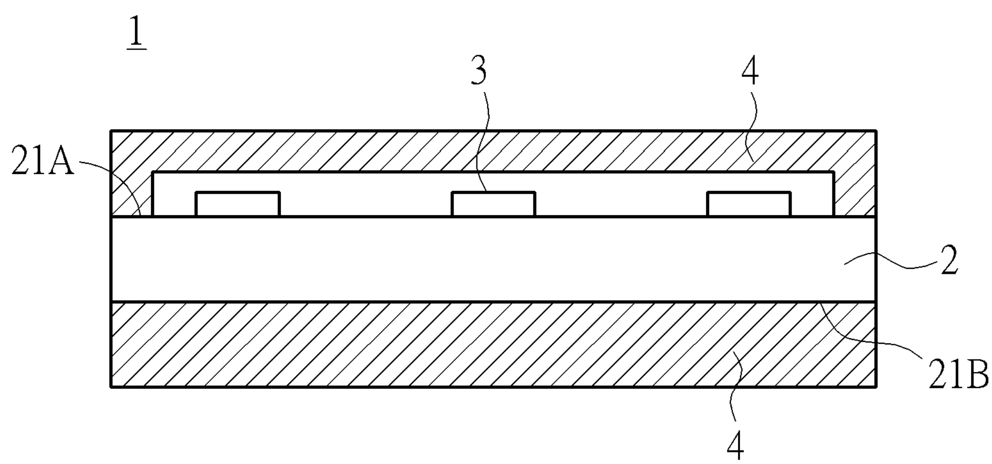


FIG. 7

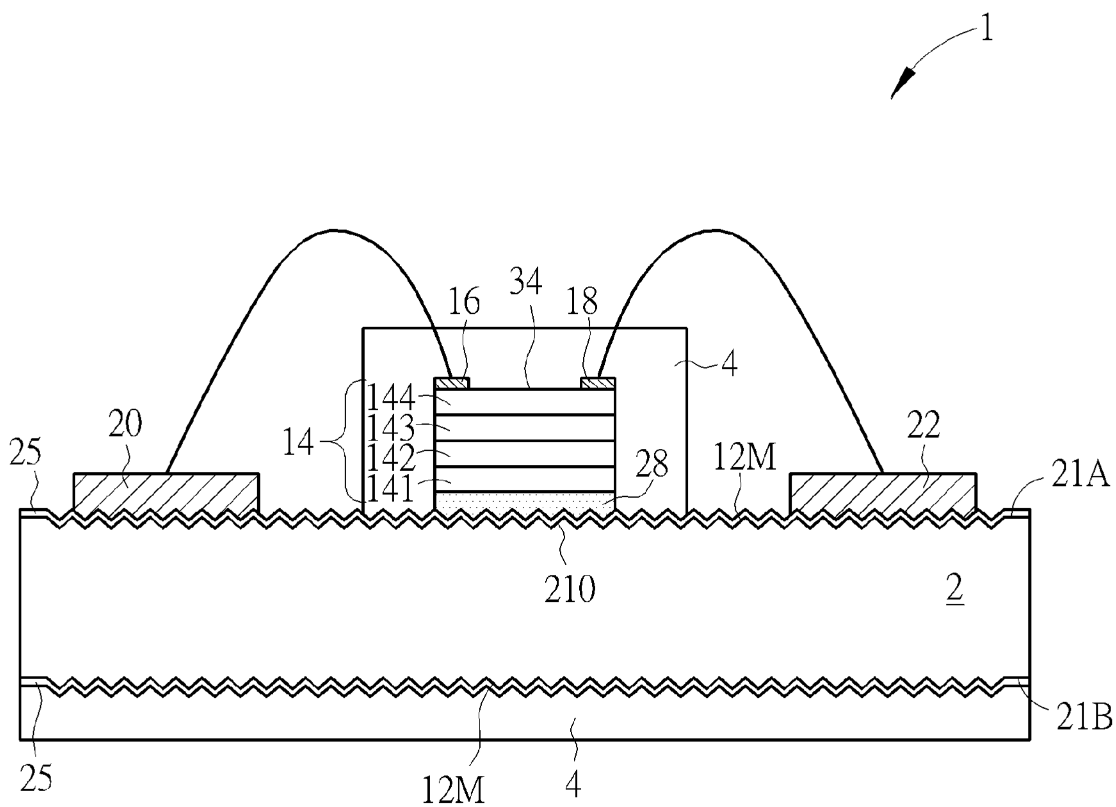
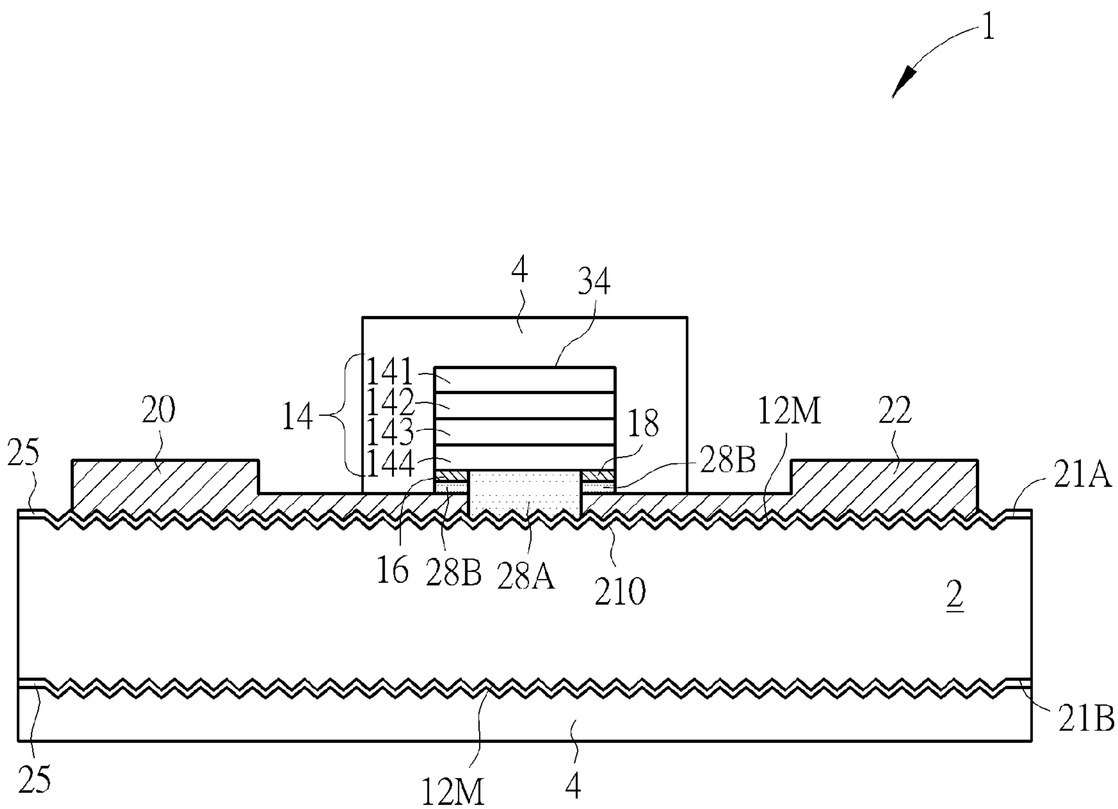


FIG. 8


1
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12M
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28B
21A
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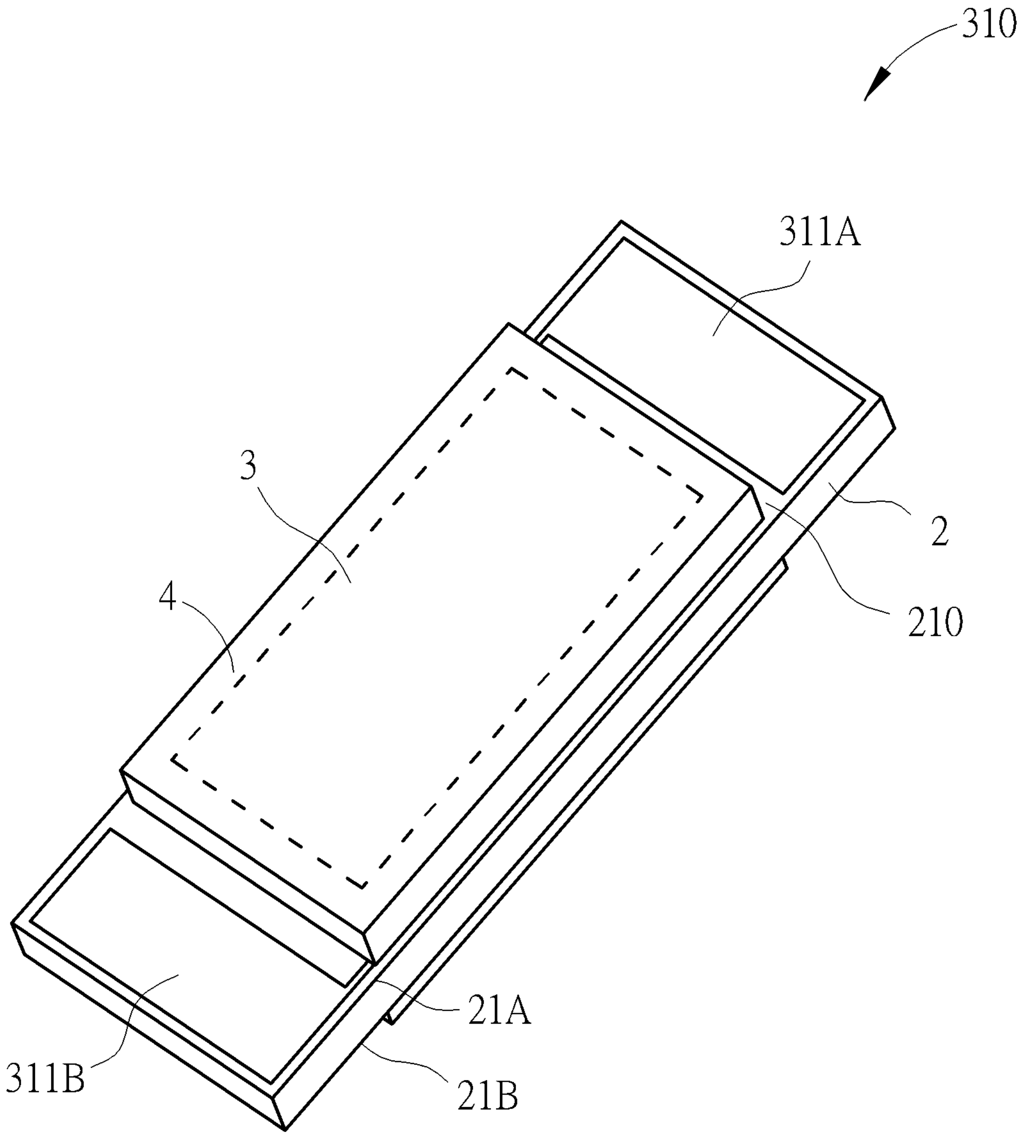
28B
28A
210
2
21B
25
12M
4

FIG. 9



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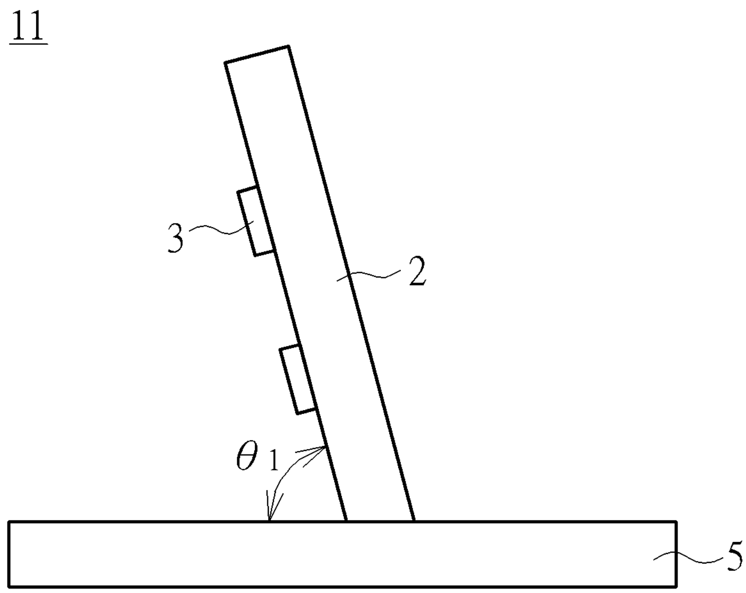


FIG. 11

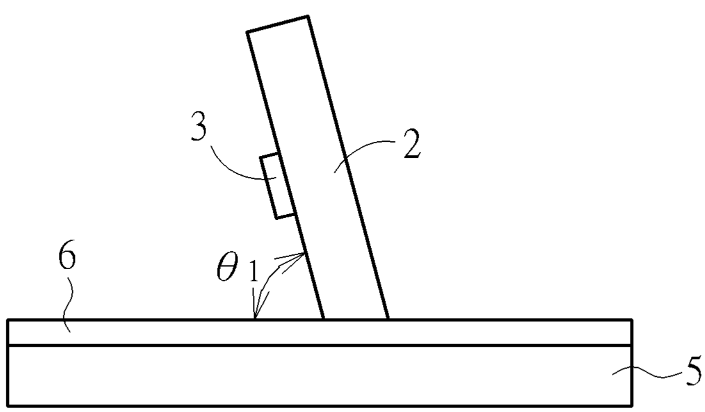


FIG. 12

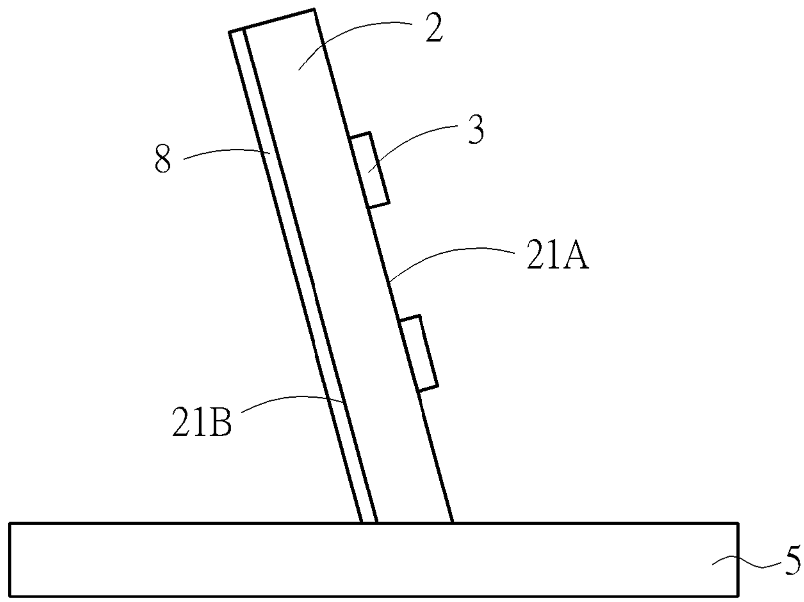


FIG. 13

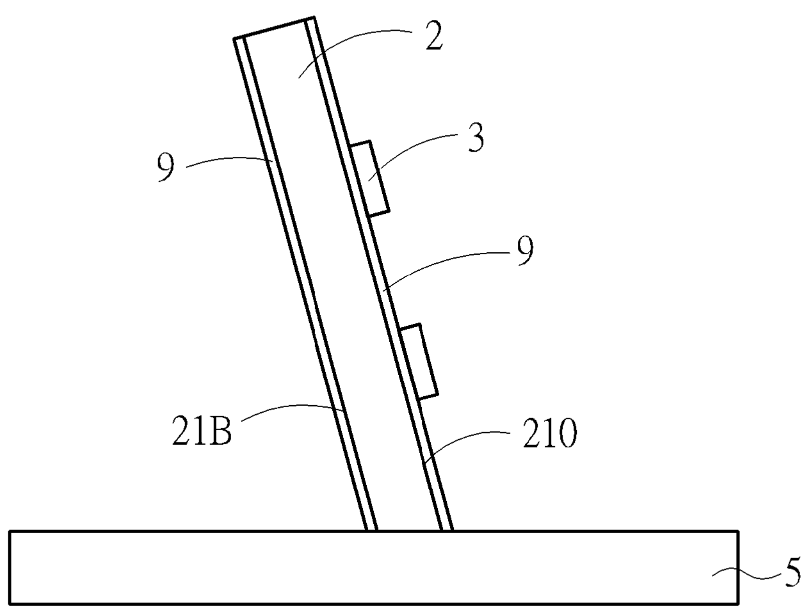


FIG. 14

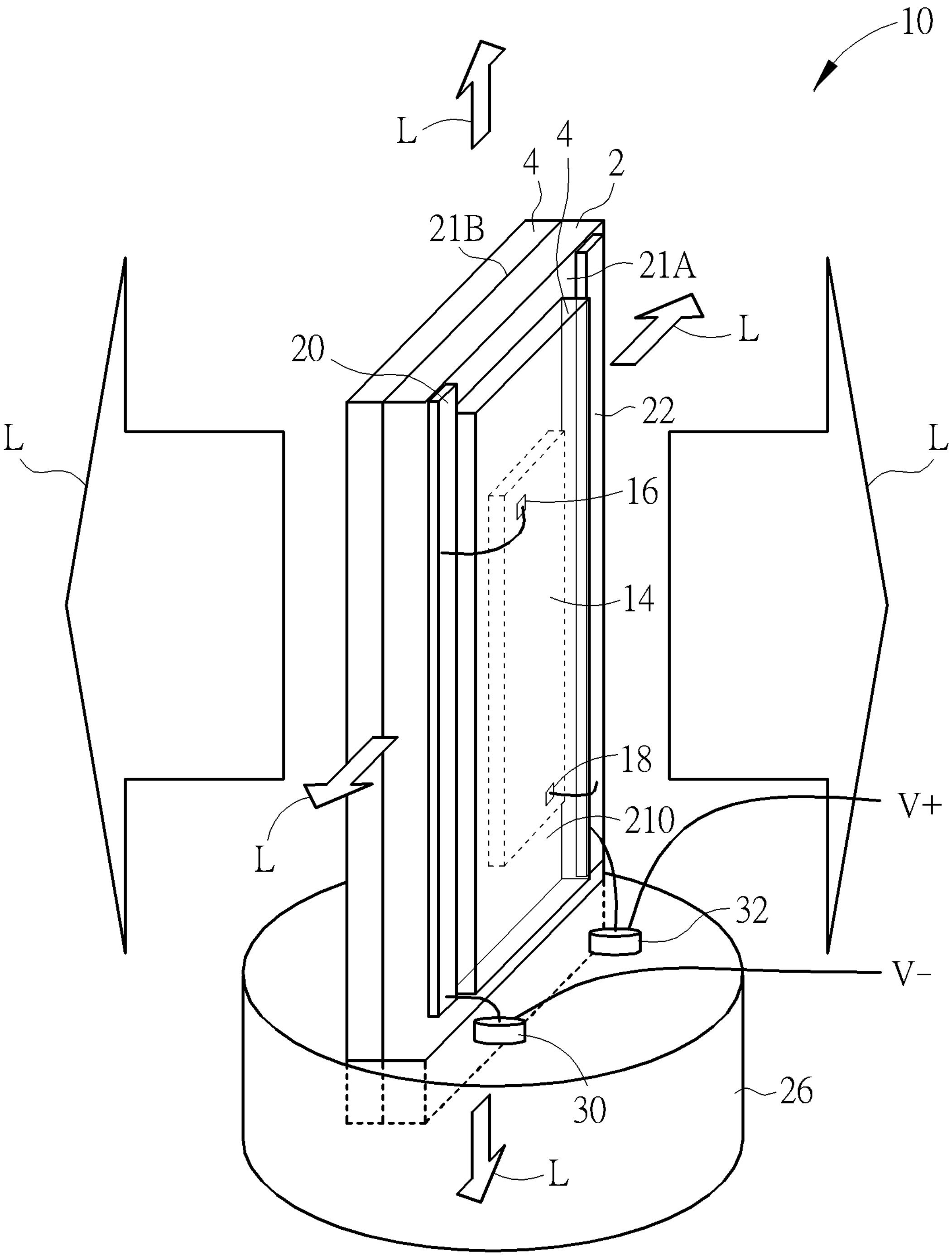


FIG. 15

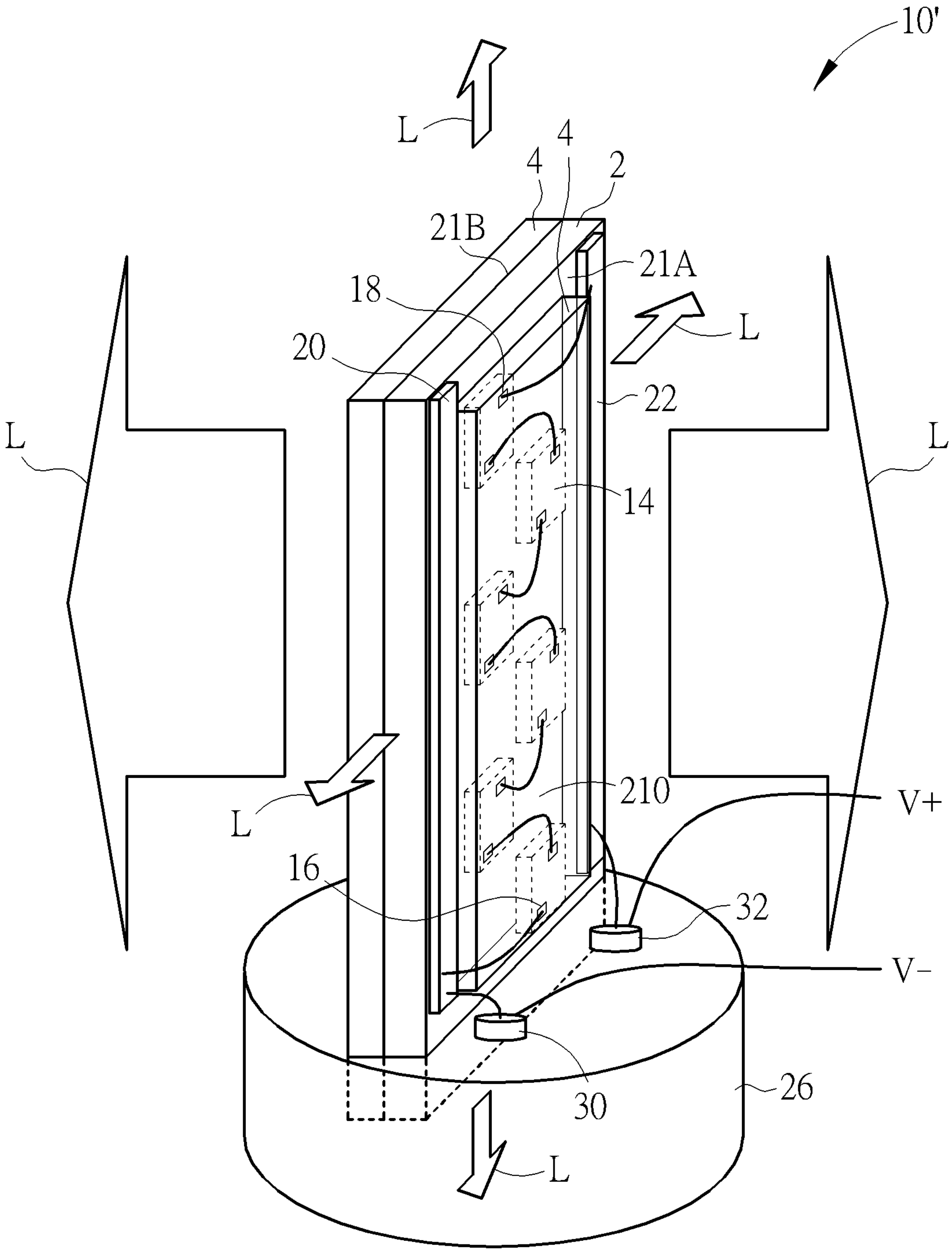


FIG. 16

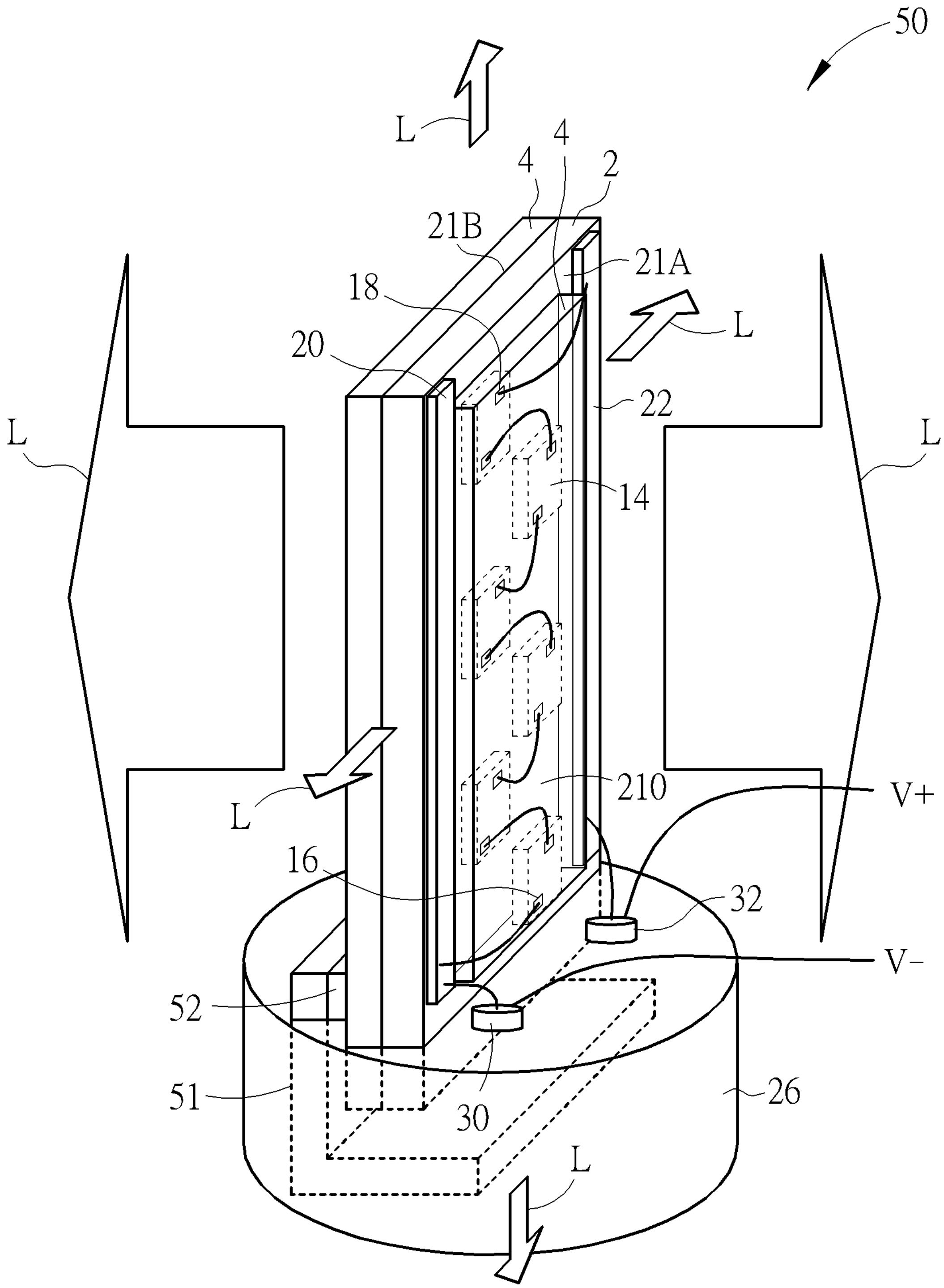


FIG. 17

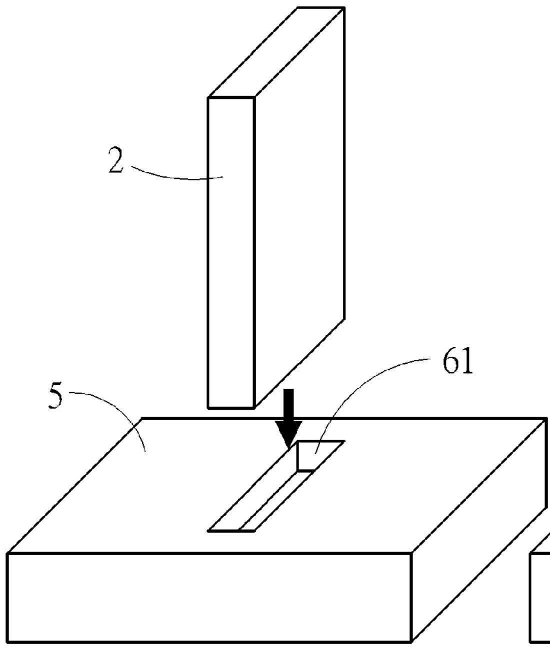


FIG. 18

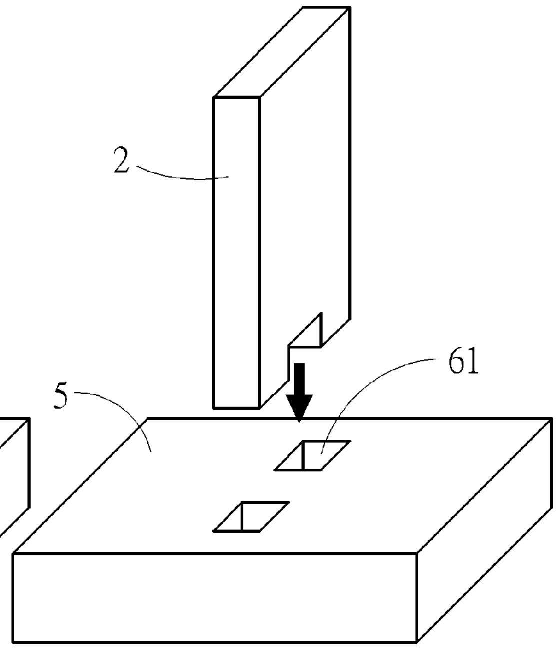


FIG. 19

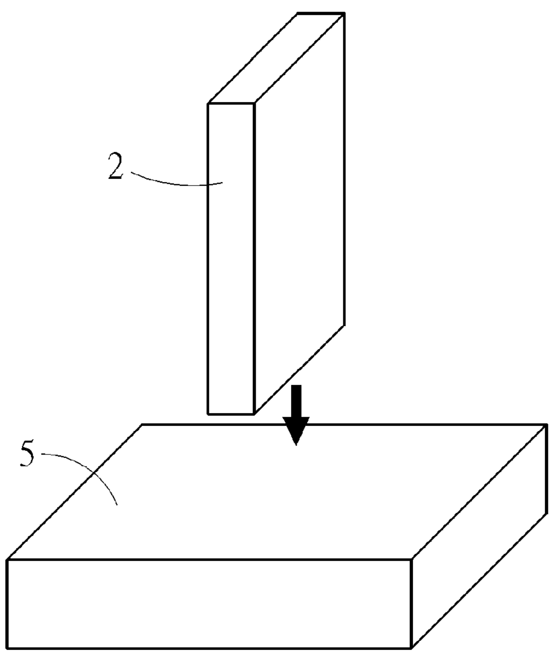


FIG. 20

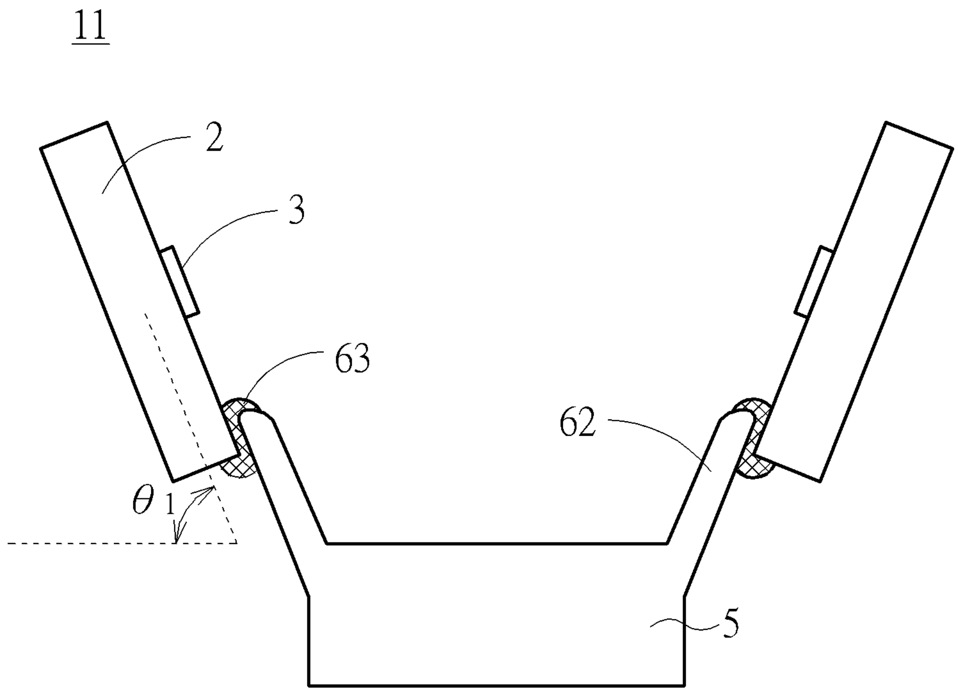


FIG. 21

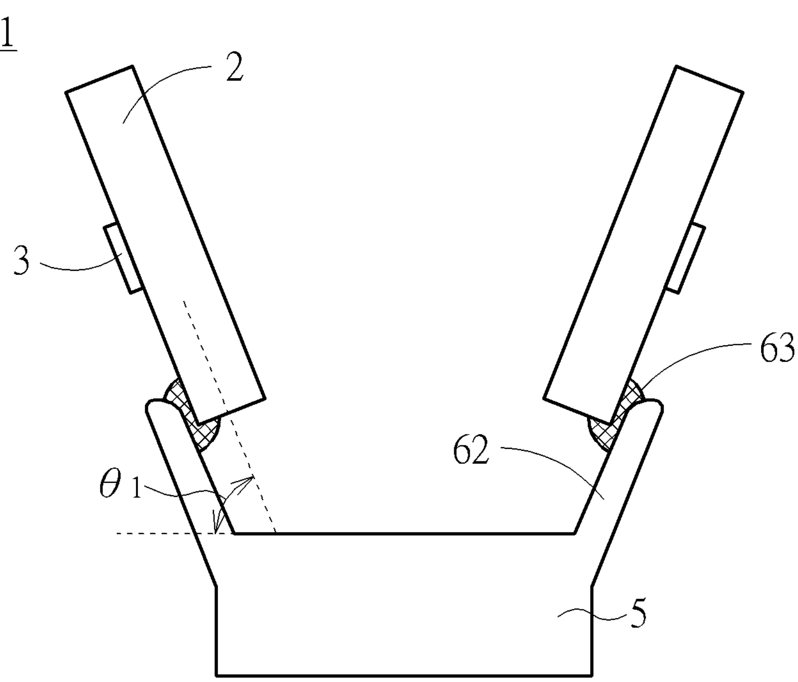


FIG. 22

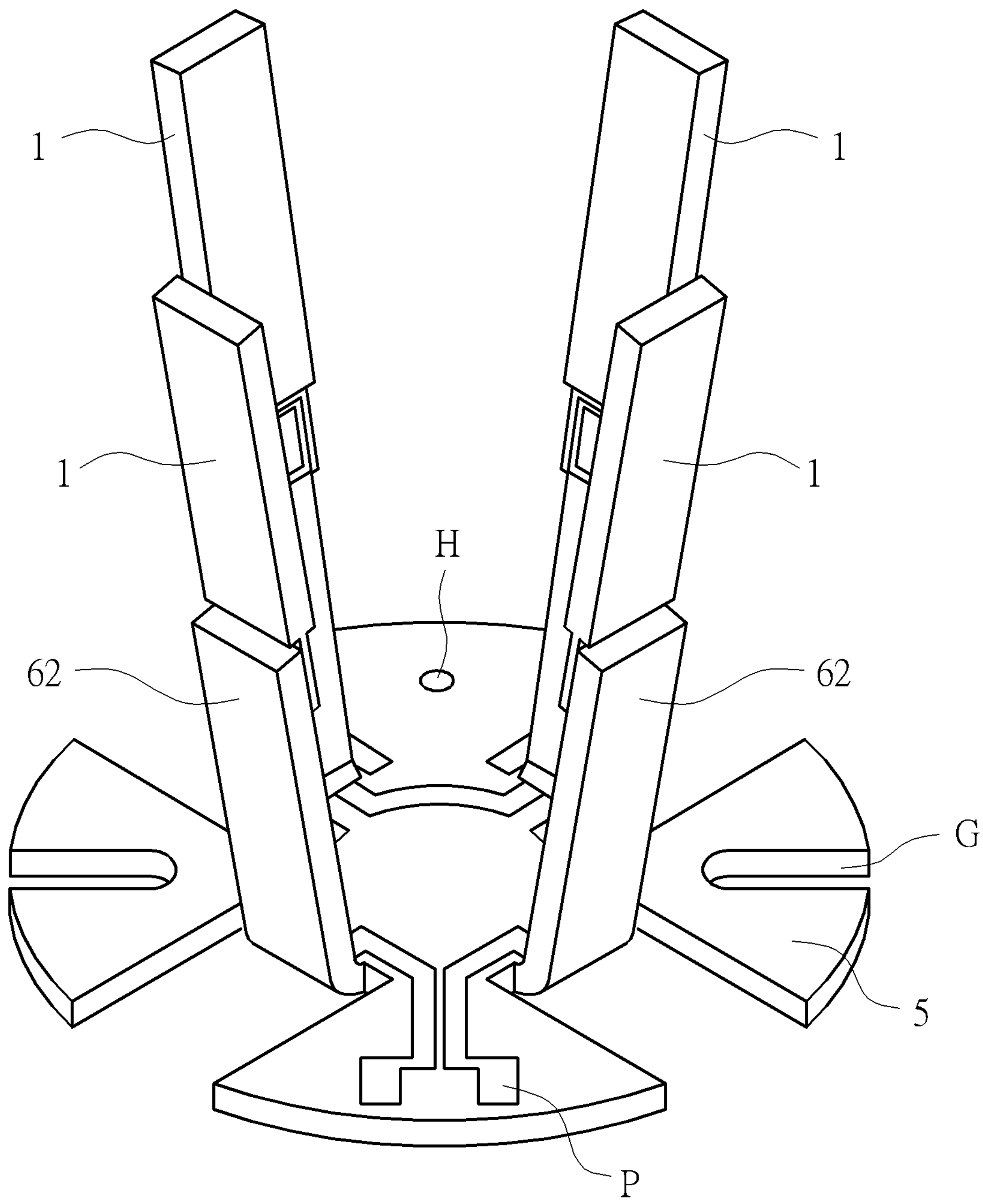


FIG. 23

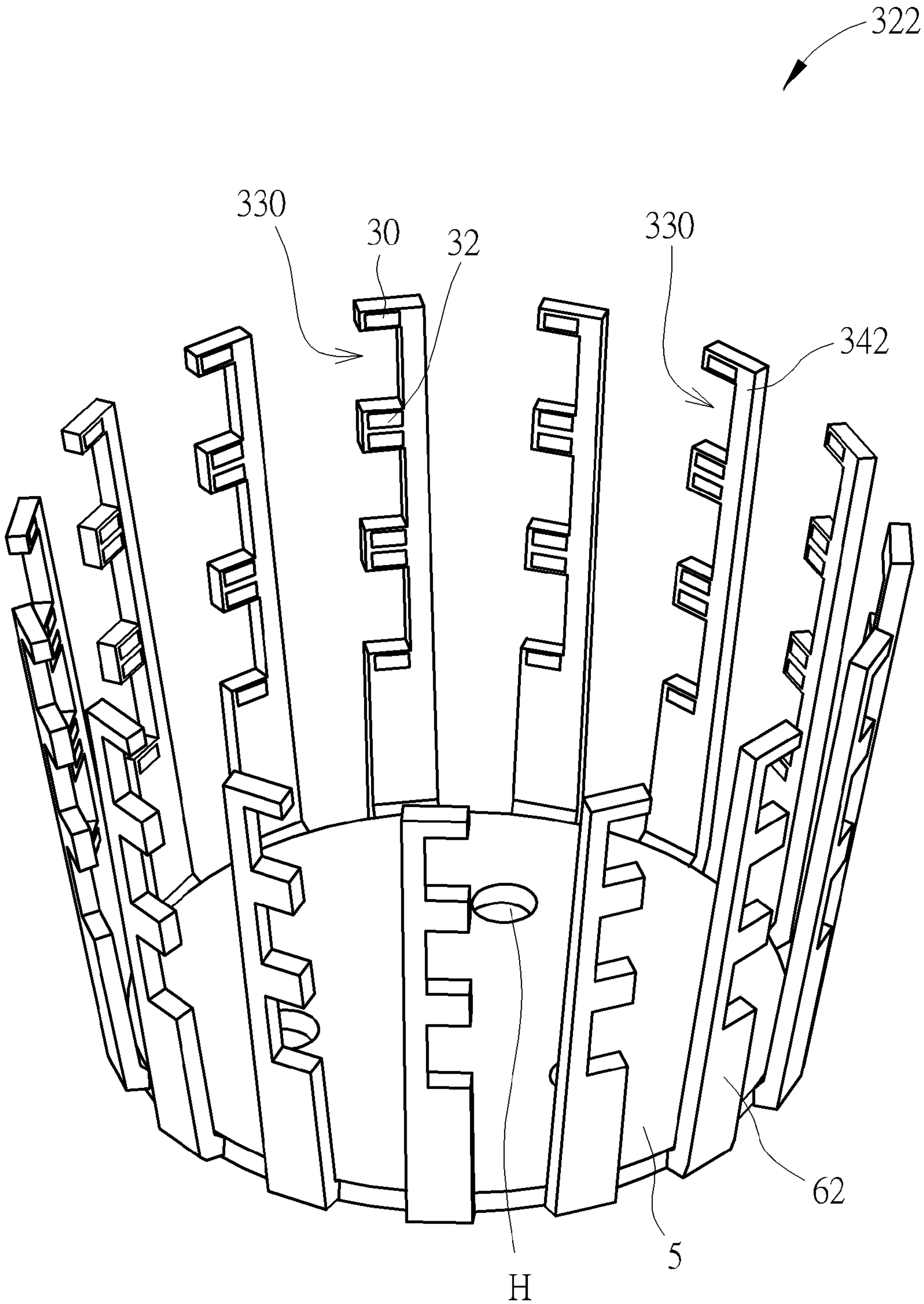
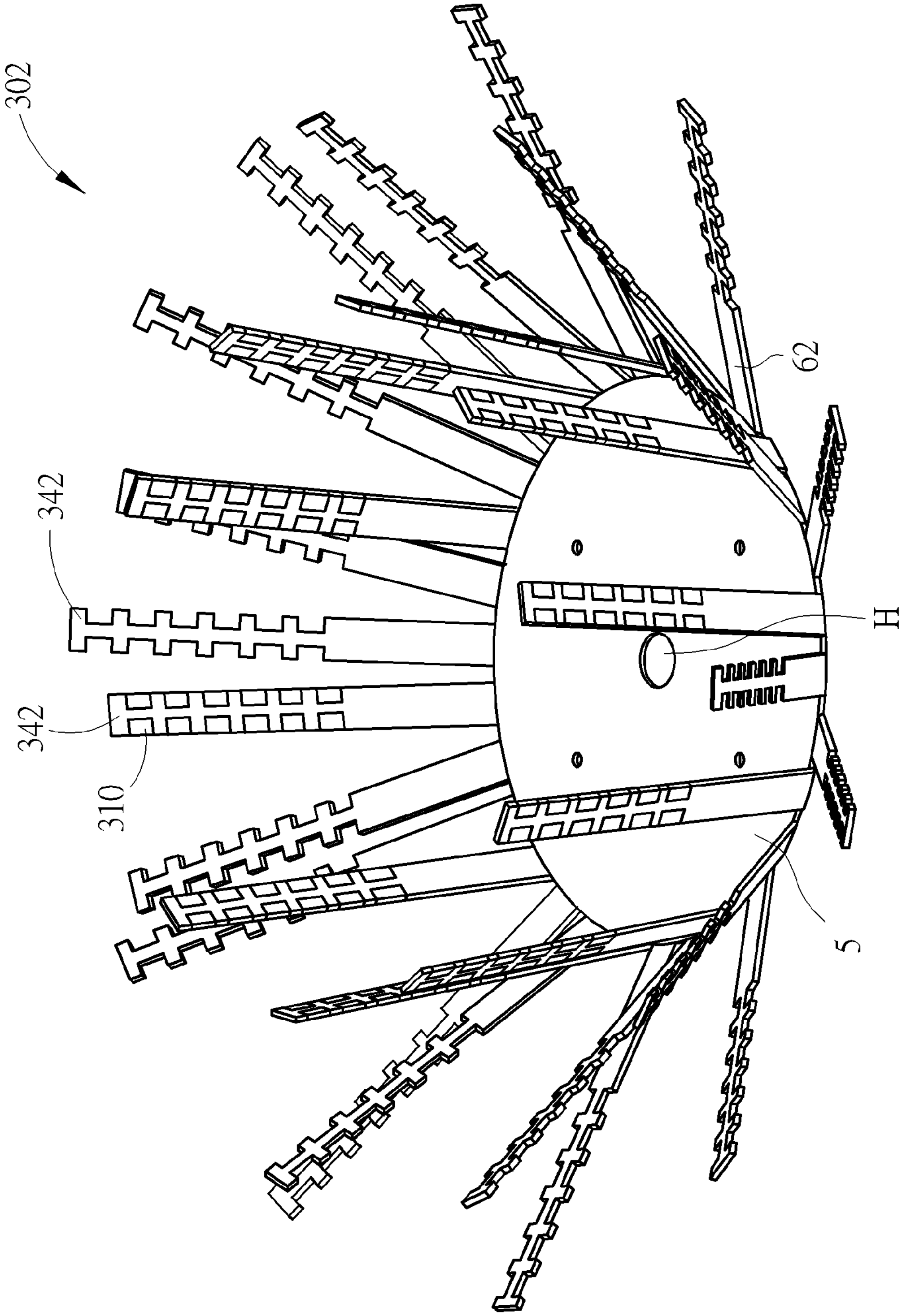


FIG. 24



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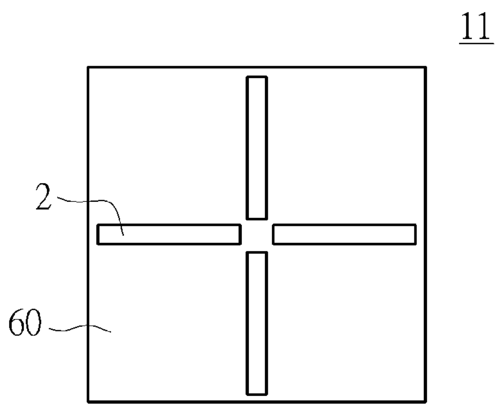

FIG. 26

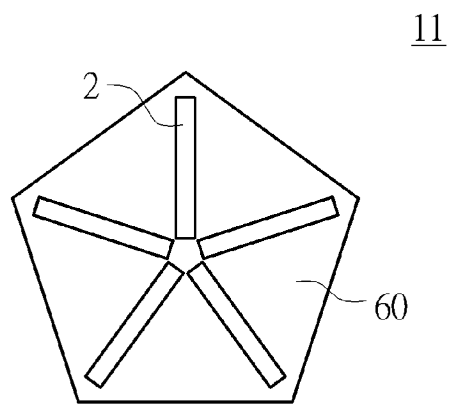

FIG. 27

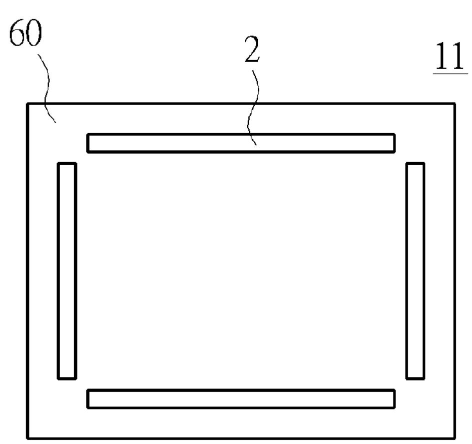

FIG. 28

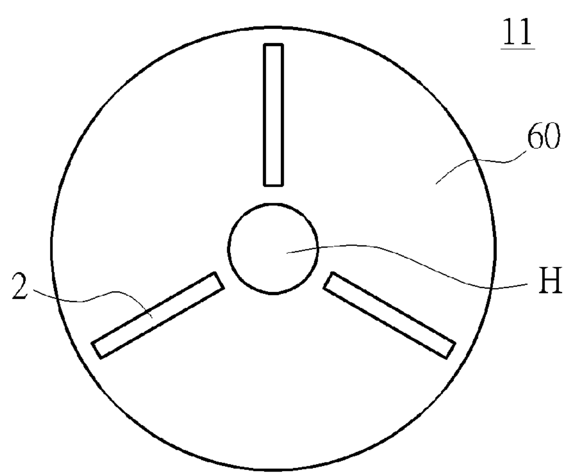

FIG. 29

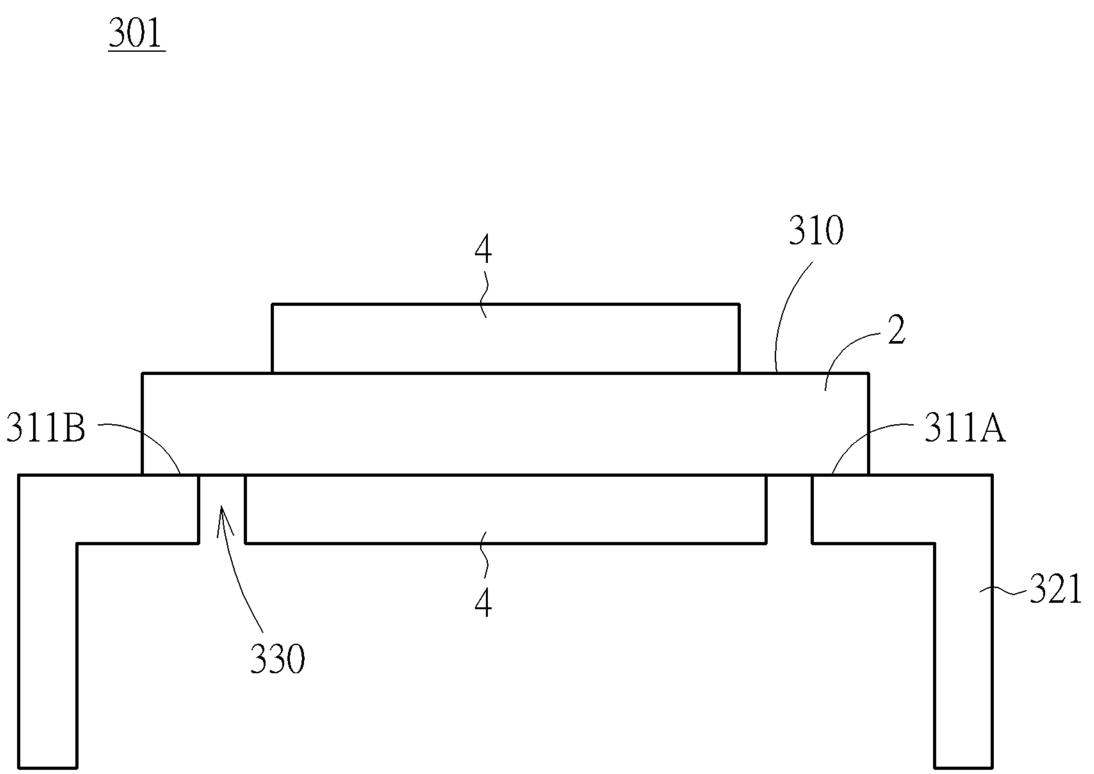

FIG. 30

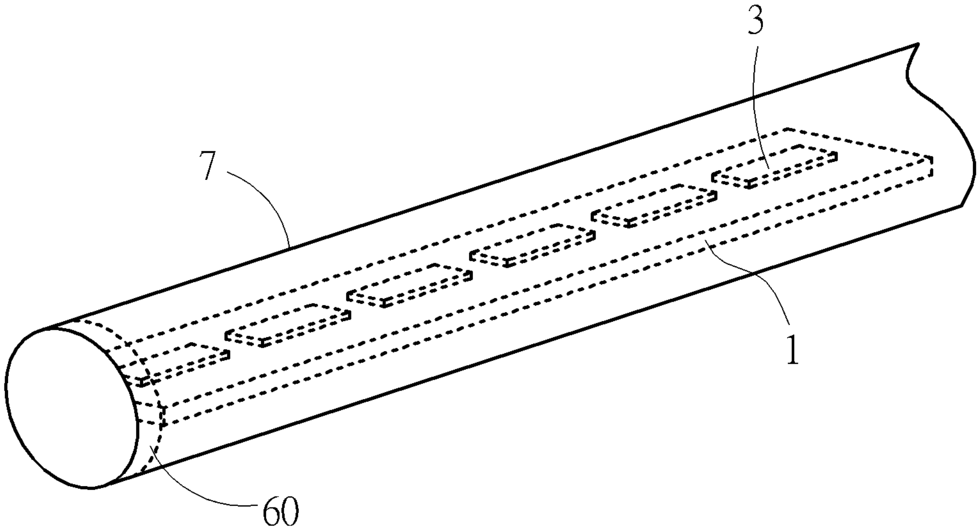

FIG. 31

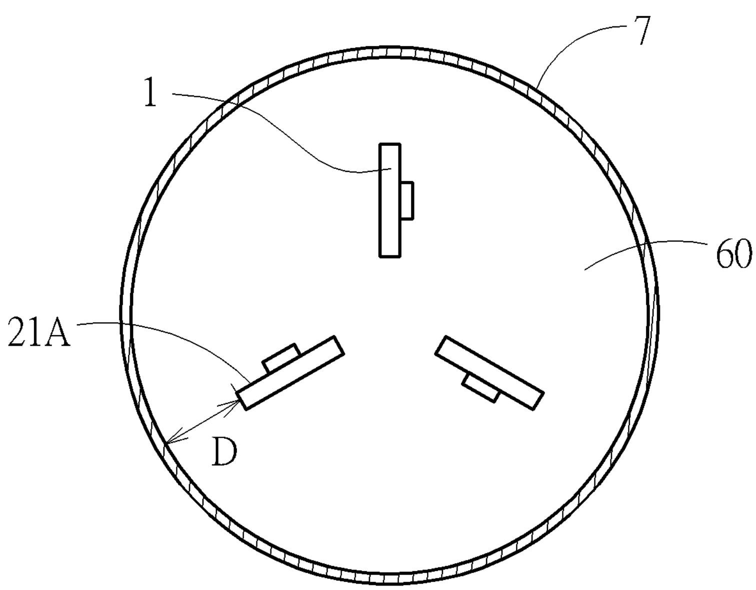

FIG. 32

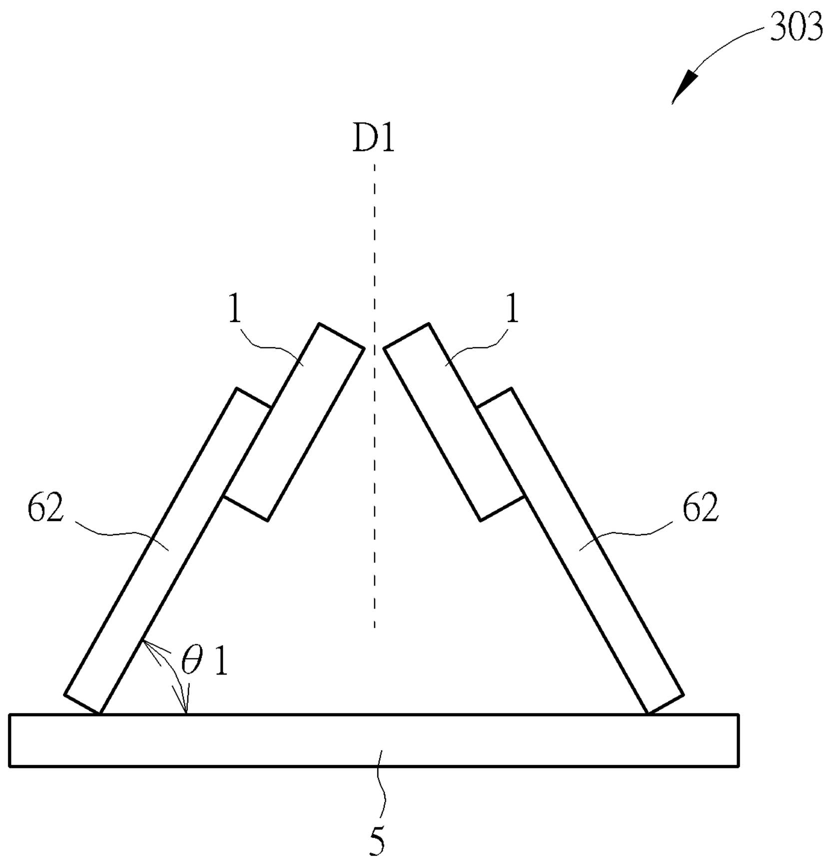

FIG. 33

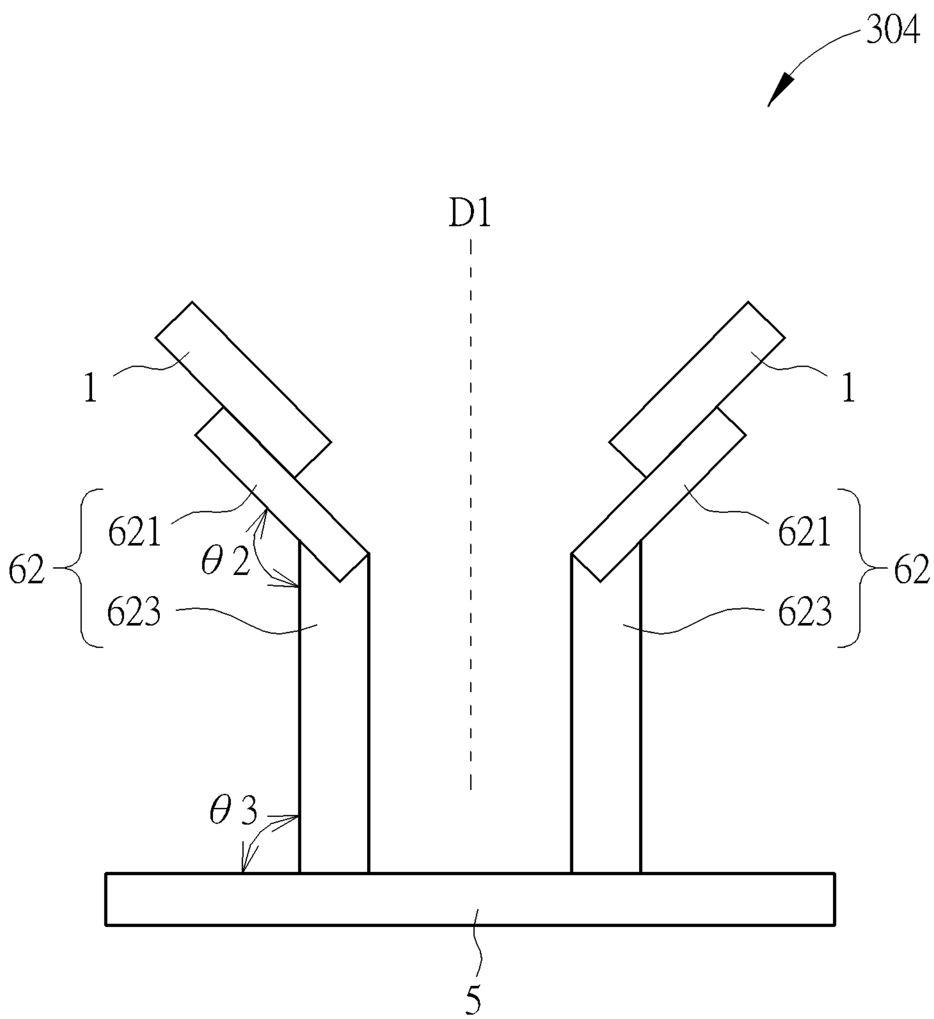

FIG. 34

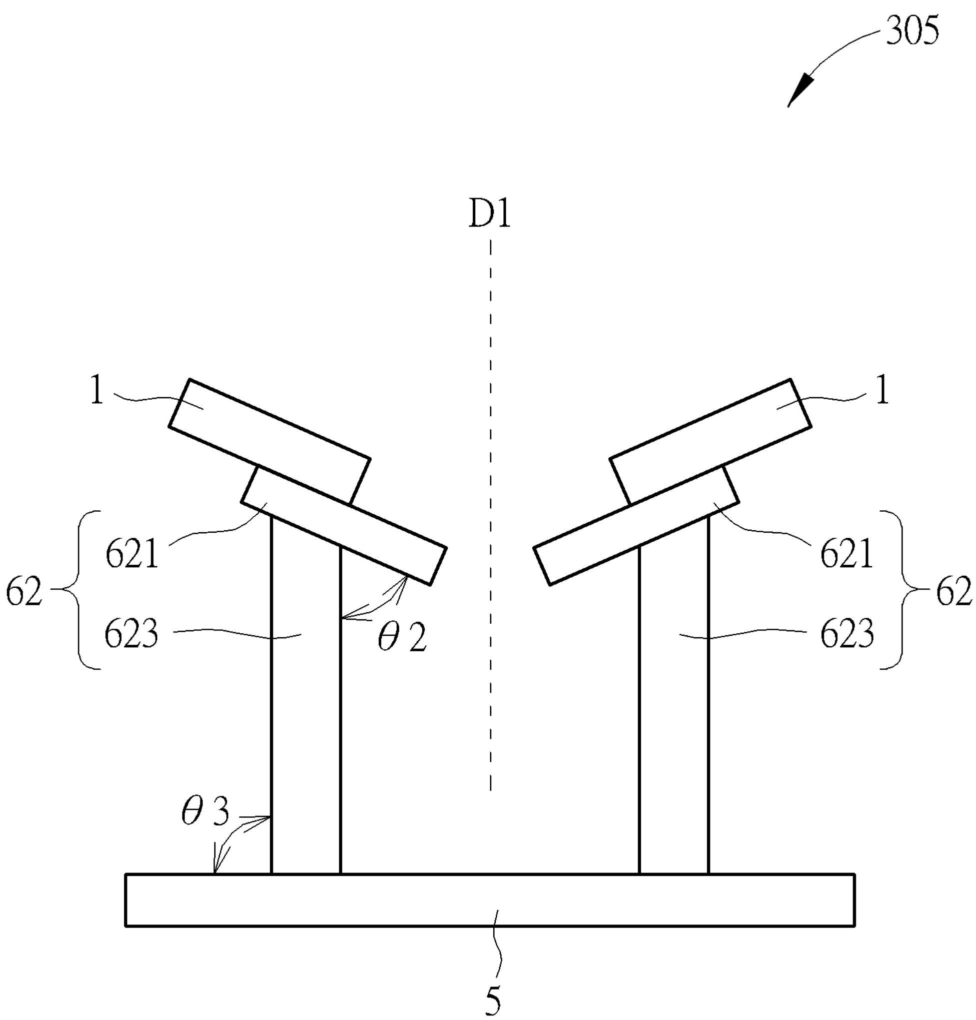

FIG. 35

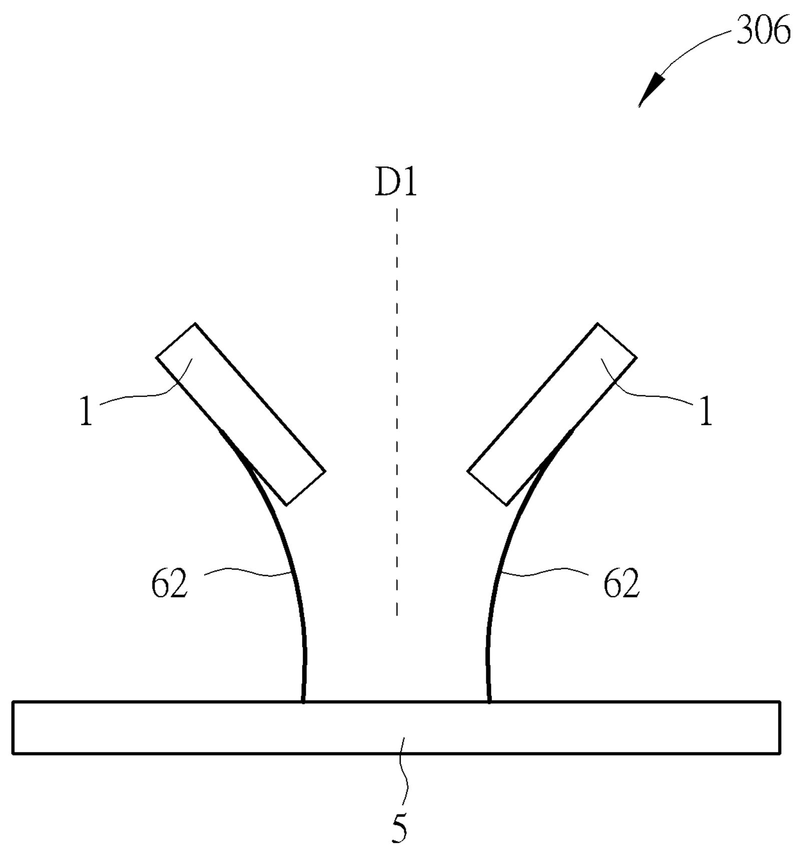

FIG. 36

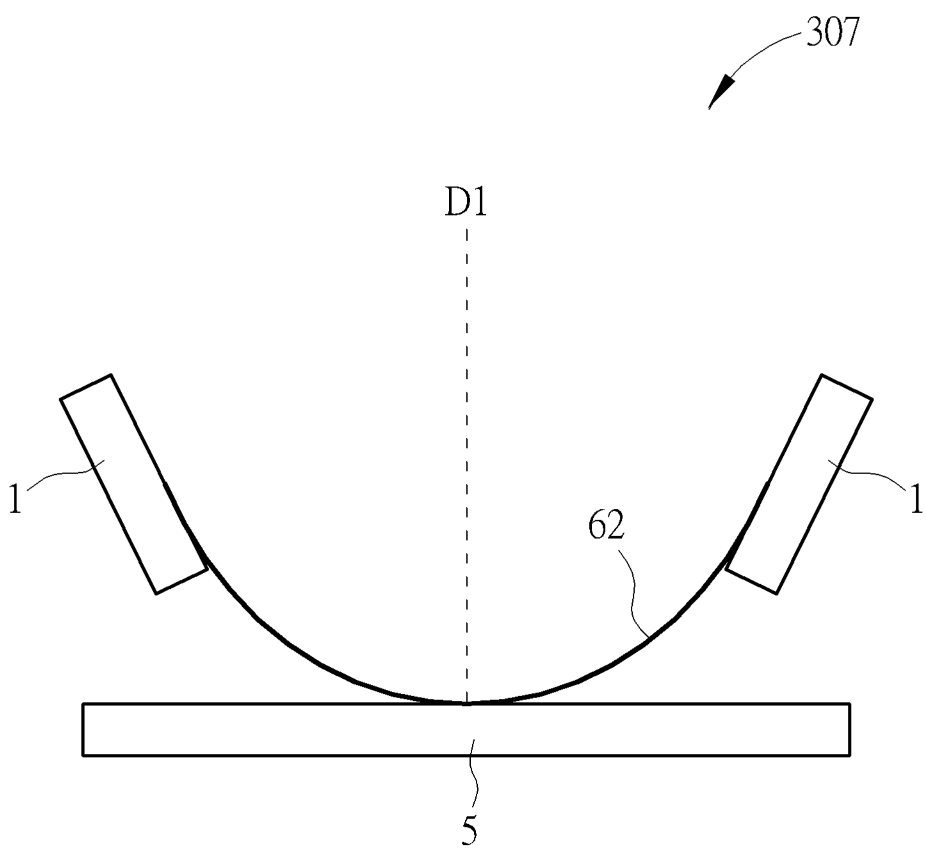

FIG. 37

ILLUMINATION DEVICE WITH INCLINED LIGHT EMITTING ELEMENT DISPOSED ON A TRANSPARENT SUBSTRATE

CROSS REFERENCE TO RELATED APPLICATIONS

This is a Continuation in Part application of Ser. No. 13/904,038, filed on May 29, 2013.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a semiconductor light emitting element and an illumination device thereof, and more particularly, to a semiconductor light emitting element providing light in multi-directions, and an illumination device including the semiconductor light emitting element.

2. Description of the Prior Art

A light beam emitted from a light emitting diode (LED) is a kind of directional light source, which is different from a dispersive light source of a conventional bulb. Accordingly, applications of LED are limited. For instance, the conventional LED cannot or may be hard to provide required lighting effect for indoor and outdoor illumination applications. Additionally, conventional LED illumination devices emit light beams from a single side and luminous efficiency of the conventional LED illumination device is relatively low accordingly.

SUMMARY OF THE INVENTION

It is one of the objectives of the present invention to provide a semiconductor light emitting element providing light in multi-directions, an illumination device including the semiconductor light emitting element, and a device frame of the illumination device. The purposes of luminous efficiency enhancement, light shape improvement, and cost reduction may then be achieved.

A preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate and a plurality of light emitting diode (LED) structures. The transparent substrate has a support surface and a second main surface disposed opposite to each other. At least some of the LED structures are disposed on the support surface and form a first main surface where light emitted from with at least a part of the support surface without the LED structures. Each of the LED structures includes a first electrode and a second electrode. Light emitted from at least one of the LED structures passes through the transparent substrate and emerges from the second main surface.

A preferred embodiment of the present invention provides an illumination device. The illumination device includes at least one semiconductor light emitting element and a supporting base. The semiconductor light emitting element includes a transparent substrate and a plurality of LED structures. The transparent substrate has a support surface and a second main surface disposed opposite to each other. At least some of the LED structures are disposed on the support surface and form a first main surface where light emitted from with at least a part of the support surface without the LED structures. Each of the LED structures includes a first electrode and a second electrode. Light emitted from at least one of the LED structures passes through the transparent substrate and emerges from the second main surface. The semiconductor light emitting element is disposed on the supporting base, and a first angle may exist between the semiconductor light emitting element and the supporting base.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate and at least one LED structure. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure includes a first electrode and a second electrode. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and emerge from the second main surface.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate and at least one LED structure. A material of the transparent substrate includes sapphire, and the transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface The LED structure has a beam angle greater than 180 degrees. At least a part of light beams emitted from the LED structure pass through the transparent substrate and emerge from the second main surface.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate, at least one LED structure and a wavelength conversion layer. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least apart of light beams emitted from the LED structure pass through the transparent substrate and emerge from the second main surface. The wavelength conversion layer is at least disposed on the LED structure or the second main surface. The wavelength conversion layer at least partially absorbs a light beam emitted from the LED structure and coverts the light beam into another light beams having different wavelength range.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate and a plurality of LED structures. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structures are disposed on the support surface. A light emitting surface of each LED structure uncovered by the transparent substrate and at least a part of the support surface without the LED structures form a first main surface where light emitted from. Each of the LED structures has a beam angle greater than 180 degrees. Light emitted from at least one of the LED structures passes through the transparent substrate and emerges from the second main surface. An area of the first main surface or an area of the second main surface is larger than 5 times of a total area formed from at least one of the light emitting surfaces of each LED structure.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate, at least one diamond-like carbon (DLC) film, and at least one LED structure. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The DLC film is disposed on the transparent substrate. The LED structure is disposed on the support surface. A light emitting surface of the LED structure uncovered by the transparent substrate and at least a part of the support surface without the LED structure forma first main surface where light emitted from. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and emerge from the second main surface.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate, at least one LED structure and a reflector. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The reflector is disposed on the second main surface. The LED structure is disposed on the support surface. A light emitting surface of the LED structure uncovered by the transparent substrate and at least a part of the support surface without the LED structure form a first main surface where light emitted from. The LED structure has a beam angle greater than 180 degree.

Another preferred embodiment of the present invention provides a semiconductor light emitting element. The semiconductor light emitting element includes a transparent substrate, at least one LED structure, a first connecting electrode and a second connecting electrode. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and are emitted from the second main surface. The first connecting electrode and the second connecting electrode are respectively disposed on different sides of the transparent substrate. The first connecting electrode and the second connecting electrode are electrically connected to the LED structure.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes a semiconductor light emitting element and a support. The semiconductor light emitting element includes a transparent substrate, at least one LED structure, a first connecting electrode and a second connecting electrode. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and are emitted from the second main surface. The first connecting electrode and the second connecting electrode are respectively disposed on different sides of the transparent substrate. The first connecting electrode and the second connecting electrode are electrically connected to the LED structure. The support includes at least one opening, and the semiconductor light emitting element is disposed correspondingly to the opening.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes a plurality of semiconductor light emitting elements and a device frame. Each of the semiconductor light emitting elements includes a transparent substrate, at least one LED structure, a first connecting electrode and a second connecting electrode. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and are emitted from the second main surface. The first connecting electrode and the second connecting electrode are respectively disposed on different sides of the transparent substrate. The first connecting electrode and the second connecting electrode are electrically connected to the LED structure. The device frame includes a supporting base and a plurality of supports extending outward from the supporting base. Each of the supports includes at least one opening, and the semiconductor light emitting elements are disposed correspondingly to at least some of the openings.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes a plurality of semiconductor light emitting elements and a light bar. Each of the semiconductor light emitting elements includes a transparent substrate, at least one LED structure, a first connecting electrode and a second connecting electrode. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and are emitted from the second main surface. The first connecting electrode and the second connecting electrode are respectively disposed on different sides of the transparent substrate. The first connecting electrode and the second connecting electrode are electrically connected to the LED structure. The light bar includes a plurality of openings. The light bar has an extending direction, and the openings are disposed along the extending direction. The semiconductor light emitting elements are disposed correspondingly to at least some of the openings.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes a plurality of semiconductor light emitting elements and a supporting base. Each of the semiconductor light emitting elements includes a transparent substrate, at least one LED structure, a first connecting electrode and a second connecting electrode. The transparent substrate has a support surface and a second main surface disposed opposite to each other. The LED structure is disposed on the support surface and forms a first main surface where light emitted from with at least a part of the support surface without the LED structure. The LED structure has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure pass through the transparent substrate and are emitted from the second main surface. The first connecting electrode and the second connecting electrode are respectively disposed on different sides of the transparent substrate. The first connecting electrode and the second connecting electrode are electrically connected to the LED structure. The supporting base includes a plurality of openings. The openings are disposed as an array. The semiconductor light emitting elements are disposed correspondingly to at least some of the openings.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes at least one light emitting element, a supporting base and at least one support. The light emitting element is disposed on the support, and the support is coupled to the supporting base. The support is inclined that at least a part of the support is more near to a central axis of the supporting base. At least a part of the support is inclined inward or outward relative to the central axis of the supporting base, and a first angle between the light emitting element and the supporting base may range from 45 degrees to 75 degrees, such that the luminance of the light illumination device near to the central axis of the supporting base is increased.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes at least one light emitting element, a supporting base and at least one support. The support includes a first connected portion and a second connected portion. One end of the second connected portion is disposed on the supporting base, and the other end of the second connected portion is connected to one end of the first connected portion. The light emitting element is disposed on the other end of the first connected portion. The first connected portion extends inward or outward relative to a central axis of the supporting base and is rotatably connected to the second connected portion. The second connected portion is rotatable relative to the supporting base. A second angle exists between the first connected portion and the second connected portion ranges for increasing the luminance near to the central axis. A third angle between the second connected portion and the supporting base ranges from 45 degrees to 85 degrees for increasing the luminance near to the central axis.

Another preferred embodiment of the present invention provides an illumination device. The illumination device includes at least one light emitting element, a supporting base and at least one support. The support is flexible to form an arc-shaped structure, a parabolic structure or an ellipse-shaped structure. The illumination device is a crystal lamp.

Another preferred embodiment of the present invention provides a device frame of an illumination device. The device frame includes a supporting base and a plurality of supports. Each of the supports extends from the supporting base. Each of the supports includes at least one opening and a plurality of electrodes disposed on two sides of the opening.

In the illumination device of the present invention, the LED structure is fixed on the transparent substrate, and the transparent substrate allows the light beam emitted by the LED structure passing through. Accordingly, the illumination device in the present invention can emit light in at least multi-directions or all directions. The luminous efficiency of the illumination device may be accordingly enhanced, and the light shape of the LED illumination device may also be improved.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** and FIG. **2** are schematic structure diagrams illustrating a semiconductor light emitting element according to a preferred embodiment of the present invention.

FIGS. **3-5** are schematic diagrams illustrating different types of electrically coupling approaches between a light emitting diode structure and conductors according to a preferred embodiment of the present invention.

FIG. **6** and FIG. **7** are schematic diagrams illustrating a disposition of a wavelength conversion layer according to a preferred embodiment of the present invention.

FIG. **8** is a cross-sectional diagram illustrating a semiconductor light emitting element according to another preferred embodiment of the present invention.

FIG. **9** is a cross-sectional diagram illustrating a semiconductor light emitting element according to another preferred embodiment of the present invention.

FIG. **10** is a schematic diagram illustrating a semiconductor light emitting element according to another preferred embodiment of the present invention.

FIG. **11** is a schematic diagram illustrating a supporting base according to a preferred embodiment of the present invention.

FIG. **12** is a schematic diagram illustrating a circuit board according to a preferred embodiment of the present invention.

FIG. **13** is a schematic diagram illustrating a reflector according to a preferred embodiment of the present invention.

FIG. **14** is a schematic diagram illustrating a diamond-like carbon film according to a preferred embodiment of the present invention.

FIG. **15** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIG. **16** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIG. **17** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIGS. **18-20** are schematic diagrams illustrating a transparent substrate inserted or bonded to a supporting base according to a preferred embodiment of the present invention.

FIG. **21** and FIG. **22** are schematic diagrams illustrating a transparent substrate bonded to a supporting base with supports according to a preferred embodiment of the present invention.

FIG. **23** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIG. **24** is a schematic diagram illustrating a device frame of an illumination device according to another preferred embodiment of the present invention.

FIG. **25** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIGS. **26-29** are schematic diagrams illustrating transparent substrates point-symmetrically or line-symmetrically disposed on a supporting structure according to a preferred embodiment of the present invention.

FIG. **30** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention.

FIG. **31** and FIG. **32** are schematic diagrams illustrating a lamp housing according to a preferred embodiment of the present invention.

FIGS. **33-37** are schematic diagrams illustrating an illumination device according to different embodiments of the present invention.

DETAILED DESCRIPTION

Please refer to FIG. **1** and FIG. **2**. FIG. **1** and FIG. **2** are schematic structure diagrams illustrating a semiconductor light emitting element according to a preferred embodiment of the present invention. As shown in FIG. **1** and FIG. **2**, a semiconductor light emitting element **1** includes a transparent substrate **2**, a support surface **210**, a first main surface **21**A, a second main surface **21**B and at least one light emitting diode (LED) structure **3** providing light in multi-directions. The transparent substrate **2**, which is a sheet type substrate, has two main surfaces, and one of the surfaces is the support surface **210**. The LED structure **3** capable of emitting light is disposed on the support surface **210**. A light emitting surface **34** of the LED structure **3** uncovered by the transparent substrate **2** and at least a part of the support surface **210** without the LED structure form the first main surface **21**A where light emitted from. The second main surface **21**B is another main surface of the transparent substrate **2** without the LED structures **3**. The disposition described above may also be reversed, or the LED structure **3** may be disposed on the two surfaces of the transparent substrate **2**. In one embodiment, LED structures **3** may be disposed on the support surface **210** of the transparent substrate **2** interlacedly corresponding to other LED structures **3** disposed on the second main surface **21**B, such that light beams emitted from LED structures **3** on one surface of the transparent substrate **2** would not be blocked by other LED structures **3** on another surface of the transparent substrate **2**. The luminance of the semiconductor light emitting element **1** may be increased accordingly. A material of the transparent substrate **2**, such as sapphire, ceramic, glass, plastic, rubber or etc., may comprise one selected from aluminum oxide (Al2O3), magnesium oxide, beryllium oxide, yttrium oxide, thorium dioxide, zirconium dioxide, lead zirconium titanate, gallium arsenide, zinc sulfide, zinc selenide, calcium fluoride, magnesium fluoride, silicon carbide (SiC) or polymer. Preferably, the transparent substrate may be a sapphire substrate in a preferred embodiment of the present invention. The structure of the sapphire substrate is substantially single crystal. The sapphire substrate has properties of higher light transmittance and better heat dissipation capability. The sapphire substrate may be used to increase the life time of the semiconductor light emitting element **1**. However, the conventional sapphire substrate used for growing a conventional light emitting diode may be fragile when applied in the present invention. According to experiment results of the present invention, the transparent substrate **2** of the present invention is preferably a sapphire substrate having a thickness thicker than or equal to 200 micrometers so as to perform better reliability, supporting performance and transparency. For effectively emitting light in multi-directions, including dual-directions or full directions, from the semiconductor light emitting element **1**, the LED structure **3** in this invention preferably has a beam angle greater than 180 degrees. Accordingly, the LED structure **3** disposed on the transparent substrate **2** may emit light beams from the light emitting surface **34** toward a direction away from the transparent substrate **2**, and the LED structure **3** may also emit light beams at least partially entering the transparent substrate **2**. The light beams entering the transparent substrate **2** may emerge from the second main surface **21**B opposite to the first main surface **21**A, and the light beams entering the transparent substrate **2** may also be emitted from a part of the support surface **210** without LED structures **3** or emitted from other surface of the transparent substrate **2**. The semiconductor light emitting element **1** may then be capable of emitting light in multi-directions including dual-directions or full directions. In this invention, an area of the first main surface **21**A or an area of the second main surface **21**B is larger than 5 times of a total area formed from at least one of the light emitting surfaces **34** of each LED structure, and this is a preferred proportion according to the consideration of both the luminous efficiency and the heat dissipation performance.

Additionally, in another preferred embodiment of the present invention, a difference in color temperatures of light beams emitted from the first main surface **21**A and the second main surface **21**B is smaller than or equal to 1500K so as to uniform light emitting effects of the semiconductor light emitting element **1**. In addition, under the thickness condition of the transparent substrate **2** mentioned above, a light transmittance of the transparent substrate **3** is larger than or equal to 70% for light beams having a wavelength range larger than or equal to 420 nanometers, or light beams having a wavelength rage smaller than or equal to 470 nanometers.

The present invention is not limited to the embodiment described above. The following description will detail the different embodiments in the present invention. To simplify the description, similar components in each of the following embodiments are marked with identical symbols. For making it easier to understand the differences between the embodiments, the following description will detail the dissimilarities among different embodiments and the identical features will not be redundantly described.

Please refer to FIGS. **3**-**5**. In the present invention, the LED structure **3** includes a first electrode **31**A and a second electrode **31**B for receiving electricity. The first electrode **31**A and the second electrode **31**B are respectively and electrically connected to a first connecting conductor **23**A and a second connecting conductor **23**B on the transparent substrate **2**. FIGS. **3**-**5** are schematic diagrams illustrating different types of electrically coupling approaches between the light emitting diode structure **3** and the conductors. FIG. **3** illustrates a horizontal type LED structure, the LED structure **3** is formed on the support surface **210** of the transparent substrate **2**, and the electrodes **31**A and **31**B are coupled to the connecting conductors **23**A and **23**B by wire bonding. FIG. **4** illustrates a flip chip type LED structure **3**, and the LED structure **3** is disposed reversely and electrically coupled to the transparent substrate **2** by the first electrode **31**A and the second electrode **31**B. The first electrode **31**A and the second electrode **31**B may be directly coupled to the first connecting conductor **23**A and the second connecting conductor **23**B by welding or adhering. As shown in FIG. **5**, the first electrode **31**A and the second electrode **31**B are disposed on different surfaces of the LED structure **3**, and the LED structure **3** is vertically disposed so as to respectively connect the electrodes **31**A and **31**B to the connecting conductors **23**A and **23**B.

Please refer to FIG. **6** and FIG. **7**. The semiconductor light emitting element **1** in the present invention may further include a wavelength conversion layer **4**. The wavelength conversion layer **4** may be selectively disposed on the first main surface **21**A or/and the second main surface **21**B, or directly on the LED structures **3**. The wavelength conversion layer **4** may directly contact the LED structures **3**, or the wavelength conversion layer **4** may be separated from the LED structures **3** by a distance without directly contact. The wavelength conversion layer **4** contains at least one kind of fluorescent powders such as organic fluorescent powder or inorganic fluorescent powder of garnet series, sulfate series or silicate series. The wavelength conversion layer **4** may then be able to at least partially absorb a light beam emitted from the LED structure **3** and covert the light beam into another light beams having different wavelength range. For example, when blue light beams are emitted from the LED structure **3**, a part of the blue light beams may be converted into yellow light beams by the wavelength conversion layer **4**, and the blue light beams and the yellow light beams may be mixed for presenting white light beams emitted from the semiconductor light emitting element **1**. Additionally, a luminance of the first main surface **21**A is different from a luminance of the second main surface **21**B because a light source of the first main surface **21**A mainly comes from light beams directly emitted from the LED structure **3**, and a light source of the second main surface **21**B comes from light beams passing through the transparent substrate **2**. Therefore, in a semiconductor light emitting element **1** of another preferred embodiment, concentrations of the fluorescent powders in the wavelength conversion layer **4** disposed on the first main surface **21**A and the wavelength conversion layer **4** disposed on the second main surface **21**B are arranged correspondingly. Preferably, a ratio of a fluorescent powder concentration in the wavelength conversion layer **4** disposed on the first main surface **21**A to a fluorescent powder concentration in the wavelength conversion layer **4** disposed on the second main surface **21**B may ranges from 1:0.5 to 1:3, or a ratio of the fluorescent powder concentration in the wavelength conversion layer **4** disposed on the second main surface **21**B to the fluorescent powders in the wavelength conversion layer **4** disposed on the first main surface **21**A may ranges from 1:0.5 to 1:3. The luminance and the lighting effect of the semiconductor light emitting element **1** may become more appropriate for different applications accordingly. A difference in color temperatures of light beams emitted from the first main surface **21**A and the second main surface **21**B may then be controlled to be smaller than or equal to 1500K. A wavelength converting efficiency and light emitting performance of the semiconductor light emitting element **1** may then be enhanced.

Please refer to FIG. **8**. FIG. **8** is a cross-sectional diagram illustrating a semiconductor light emitting element **1** according to another preferred embodiment of the present invention. As shown in FIG. **8**, the semiconductor light emitting element **1** in this embodiment includes a transparent substrate **2** and at least one LED structure **14** providing light in multi-directions. The transparent substrate **2** has a support surface **210** and a second main surface **21**B, or a bottom surface, disposed opposite to each other. The LED structure **14** is disposed on the support surface **210**, or a covered surface of the support surface **210**, of the transparent substrate **2**. The LED structure **14** includes a first electrode **16** and a second electrode **18**. The first electrode **16** and the second electrode **18** are configured to be electrically connected to other devices. A light emitting surface **34** of the LED structure **14** uncovered by the transparent substrate **2** and at least a part of the support surface **210** without the LED structure **14** form a first main surface **21**A, or an uncovered surface, where light emitted from.

The LED structure **14** may include a substrate **141**, an N-typed semiconductor layer **142**, an active layer **143** and a P-typed semiconductor layer **144**. In this embodiment, the substrate **141** of the LED structure **14** may be attached on the transparent substrate **2** by such as a chip bonding layer **28**. Apart from being used to attach the LED structure **14**, a light intensity may also be increased by optimizing the material property of the chip bonding layer **28**. For example, a refractive index of the chip bonding layer **28** is preferably between a refractive index of the substrate **141** and a refractive index of the transparent substrate **2** so as to increase the intensity of light emitted from the LED structure **14**. In addition, the chip bonding layer **28** may be a transparent adhesive or other appropriate bonding material. The first electrode **16** and the second electrode **18** are disposed on the side of the LED structure **14** opposite to the chip bonding layer **28**. The first electrode **16** and the second electrode **18** are electrically connected to the P-typed semiconductor layer **144** and the N-typed semiconductor layer **142** respectively (FIG. **8** does not show the connecting relation between the second electrode **18** and the N-typed semiconductor layer **142**). Horizontal level of an upper surface of the first electrode **16** and an upper surface of the second electrode **18** are substantially the same. The first electrode **16** and the second electrode **18** may be metal electrodes, but not limited thereto. In addition, the semiconductor light emitting element **1** further includes a first connecting conductor **20**, a second connecting conductor **22** and a wavelength conversion layer **4**. The first connecting conductor **20** and the second connecting conductor **22** are disposed on the transparent substrate **2**. The first connecting conductor **20** and the second connecting conductor **22** may be metal wires or other conductive patterns, but not limited thereto. The first electrode **16** and the second electrode **18** are respectively connected to the first connecting conductor **20** and the second connecting conductor **22** electrically by wire bonding or welding, but not limited thereto. The wavelength conversion layer **4** is disposed on the transparent substrate **2**, and the wavelength conversion layer **4** may cover the LED structure **14**. Additionally, the wavelength conversion layer **4** may further cover the second main surface **21**B of the transparent substrate **2**.

In addition, a non-planar structure **12**M may be selectively disposed on the surfaces of the transparent substrate **2** for increasing the intensity of light emitted from the transparent substrate **2** and unifying the distribution of the emitted light. The non-planar structure **12**M may be a convex geometric structure or a concave geometric structure, such as a pyramid, a cone, a hemispheroid, a triangular prism and so forth. The non-planar structures **12**M may be arranged regularly or randomly. Furthermore, a diamond-like carbon (DLC) film **25** may be selectively disposed on the surfaces of the transparent substrate **2** so as to enhance the thermal conductive ability and the heat dissipating performance.

Please refer to FIG. **9**. FIG. **9** is a cross-sectional diagram illustrating a semiconductor light emitting element according to another preferred embodiment of the present invention. Compared with the embodiment shown in FIG. **8**, in the semiconductor light emitting element **1** of this embodiment, the first electrode **16**, the second electrode **18** and a first chip bonding layer **28**A are disposed on the same surface of the LED structure **14**. That the first electrode **16** and the second electrode **18** are electrically connected to the first connecting conductor **20** and the second connecting conductor **22** by flip chip. The first connecting conductor **20** and the second connecting conductor **22** may respectively extend corresponding to the positions of the first electrode **16** and **18**. And the first electrode **16** and the second electrode **18** may be respectively connected to the first connecting conductor **20** and the second connecting conductor **22** electrically through a second chip bonding layer **28**B. The second chip bonding layer **28**B may be a conductive bump such as a gold bump or a solder bump, a conductive glue such as a silver glue, or an eutectic layer such as an Au—Sn alloy eutectic layer or an In—Bi—Sn alloy eutectic layer, but not limited to this. By employing the second chip bonding layer **28**B, the first chip bonding layer **28**A under the LED structure **14** may not be required or may be replaced by the wavelength conversion layer **4**.

Please refer to FIG. **10**. FIG. **10** is a schematic diagram illustrating a semiconductor light emitting element according to another preferred embodiment of the present invention. As shown in FIG. **10**, a semiconductor light emitting element **310** in this invention includes the transparent substrate **2**, at least one LED structure **3**, a first connecting electrode **311**A, a second connecting electrode **311**B and at least one wavelength conversion layer **4**. The LED structure **3** is disposed on the support surface **210** of the transparent substrate **2** and forms a first main surface **21**A where light emitted from. In this embodiment, the LED structure **3** has a beam angle greater than 180 degrees, and at least a part of light beams emitted from the LED structure **3** penetrate into the transparent substrate **2**. At least a part of the penetrating light beams may be emitted from a second main surface **21**B which is opposite to the first main surface **21**A, and the other penetrating light beams may be emitted from other surfaces of the transparent substrate **2**, so as to form the semiconductor light emitting element **310** providing light in multi-directions. The first connecting electrode **311**A and the second connecting electrode **311**B are respectively disposed on different sides of the transparent substrate **2** or on the same side of the transparent substrate **2** (not shown in FIG. **10**). The first connecting electrode **311**A and the second connecting electrode **311**B may be electrodes of the semiconductor light emitting element **310** respectively formed by extension parts of a first connecting conductor and a second connecting conductor on the transparent substrate **2**, and the first connecting electrode **311**A and the second connecting electrode **311**B are electrically connected to the LED structure **3** accordingly. The wavelength conversion layer **4** at least covers the LED structure **3** and exposes at least a part of the first connecting electrode **311**A and the second connecting electrode **311**B. The wavelength conversion layer **4** at least partially absorbs a light beam emitted from the LED structure **3** or/and the transparent substrate **2**, and coverts the light beam into alight beam having another wavelength range. The converted light and the light which are not absorbed by the wavelength conversion layer **4** are mixed to extend the total wavelength range of the light beams emitted from the semiconductor light emitting element **310** and improve the light emitting performance of the semiconductor light emitting element **310**. Because the semiconductor light emitting element **310** in this embodiment includes the first connecting electrode **311**A and the second connecting electrode **311**B respectively disposed on the transparent substrate **2**, traditional LED packaging process may be omitted and the semiconductor light emitting element **310** may be independently manufactured and then combined with an appropriate supporting base. Accordingly, the total manufacturing yield may be improved, the structure may be simplified and applications of the corresponding supporting base may also be increased.

Please refer to FIG. **11**. An illumination device **11** is provided in this embodiment. The illumination device **11** includes a supporting base **5** and the semiconductor light emitting element described above. The transparent substrate **2** of the semiconductor light emitting element may stand on (or lie on) and be electrically coupled to the supporting base **5**. A first angle θ**1** exists between the transparent substrate **2** and the supporting base **5**. The first angle θ**1** may be fixed or be adjusted according to the light shape requirement of the illumination device. Preferably, the first angle θ**1** ranges from 30 degrees to 150 degrees.

Please refer to FIG. **12**. The supporting base **5** of the illumination device **11** in the present invention may further include a circuit board **6** electrically coupled to a power supply. The circuit board **6** is electrically coupled to a first connecting conductor and a second connecting conductor (not shown in FIG. **12**) so as to be electrically connected to the LED structure **3**. The power supply may then provide electricity to the LED ship **3** for emitting light via the circuit board **6**. In other preferred embodiment of the present invention, the LED structure **3** may also be electrically connected to the supporting base directly via the first connecting conductor and the second connecting conductor (not shown in FIG. **12**) without the circuit board **6**, and the power supply may provide electricity to the LED ship **3** via the supporting base **5**.

Please refer to FIG. **13**. The illumination device **11** of the present invention may further include a reflector or filter **8** disposed on the second main surface **21**B or the support surface **210**. The reflector or filter **8** may be used to reflect at least a part of light beams emitted from the LED structure **3** and passing through the transparent substrate **2**. At least apart of the reflected light beams may be changed to be emitted from the first main surface **21**A. The reflector **8** may include at least one metal layer or a Bragg reflector, but not limited thereto. The Bragg reflector may be composed of a plurality of insulating thin films with different refractive indexes disposed in a stack configuration, or the Bragg reflector may be composed of a plurality of insulating thin films with different refractive indexes and a plurality of metal oxide layers disposed in a stack configuration.

Please refer to FIG. **14**. The illumination device **11** of the present invention may further include a diamond-like carbon (DLC) film **9** disposed on the support surface **210** or/and the second main surface **21**B of the transparent substrate **2** so as to enhance the thermal conductive ability and the heat dissipating performance.

Please refer to FIG. **15**. FIG. **15** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention. As shown in FIG. **15**, an illumination device **10** in this embodiment includes a supporting base **26** and the semiconductor light emitting element described in the present invention. The semiconductor light emitting element includes a transparent substrate **2** and at least one LED structure **14**. The semiconductor light emitting element may be at least partially embedded into the supporting base **26**. An electrode **30** and an electrode **32** of the supporting base **26** are electrically connected to the connecting conductors of the semiconductor light emitting element. Driving voltage V+ and V− may be accordingly provided through the electrodes **30** and **32** respectively to the LED structure **14** for emitting the light beam L. The LED structure **14** includes a first electrode **16** and a second electrode **18** respectively and electrically connected to the first connecting conductor **20** and the second connecting conductor **22** by wire bonding, but not limited thereto. Additionally, the LED structure **14** has a beam angle greater than 180 degrees or has a plurality of light emitting surfaces, and then the illumination device **10** may emit light beams from the first main surface **21**A and the second main surface **21**B. Furthermore, because some of the light beams may be emitted directly from the LED structure **14** and/or the other four side surfaces of the transparent substrate **2**, the illumination device **10** may accordingly emit light from multi sides or six sides or in full directions.

The semiconductor light emitting element may further include a wavelength conversion layer **4** selectively disposed on the LED structure **14**, the first main surface **21**A or the second main surface **21**B. The wavelength conversion layer **4** may at least partially absorb a light beam emitted from the LED structure **14** and covert the light beam into another light beam having different wavelength range so as to emit light with specific color or light having a wider wavelength range from the illumination device **10**. For example, when blue light beams are emitted from the LED structure **14**, a part of the blue light beams may be converted into yellow light beams by the wavelength conversion layer **4**, and the blue light beams and the yellow light beams may be mixed for presenting white light beams emitted from the illumination device **10**. Additionally, the transparent substrate **2** may be directly or indirectly fixed on the supporting base **26** in a parallel state or a non-parallel state. For instance, the transparent substrate **2** may be vertically fixed on the supporting base **26** by mounting a side wall of the transparent substrate **2** with the supporting base **26** directly, or the transparent substrate **2** may be horizontally disposed on the supporting base **26**, but not limited thereto. The transparent substrate **2** preferably includes materials with high thermal conductivity, and heat generated from the LED structure **14** may be accordingly dissipated to the supporting base **26** through the transparent substrate **2**, such that the high power LED structures can be applied in the illumination device of the present invention accordingly. However, in a preferred embodiment of the present invention, at the same power consumption of the illumination device, more LED structures with relatively low power are dispersed on the transparent substrate **2** so as to fully utilize the thermal conductivity capability of the transparent substrate **2**. For example, a power of the LED structure in this embodiment may be equal to or lower than 0.2 watt, but not limited thereto.

Please refer to FIG. **16**. FIG. **16** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention. Compared with the illumination shown in FIG. **15**, an illumination device **10'** in this embodiment includes a plurality of LED structures **14**, and at least some of the LED structures **14** are electrically connected to each other in series. Each of the LED structures **14** includes the first electrode **16** and the second electrode **18**. The first electrode **16** of one LED structure **14** disposed on one end of the series is electrically connected to the first connecting conductor **20**, and the second electrode **18** of another LED structure **14** disposed on another end of the series is electrically connected to the second connecting conductor **22**, but not limited thereto. The LED structures **14** may be electrically connected in series or in parallel. The LED structures **14** may be LED structures emitting identical color, such as blue LED structures, or LED structures emitting different colors may also be applied and combined according to different demands. The illumination device **10'** may emit light in much more different colors by further employing the wavelength conversion layer **4** according to the present invention.

Please refer to FIG. **17**. FIG. **17** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention. Compared with the illumination devices shown in FIG. **15** and FIG. **16**, an illumination device **50** in this embodiment further includes a support **51** configured to connect the semiconductor light emitting element and the supporting base **26**. The transparent substrate **2** of the semiconductor light emitting element is fixed on a side of the support **51** by a unit bonding layer **52**, and another side of the support **51** may be disposed on or inserted into the supporting base **26**. Additionally, the support **51** is flexible so as to form an angle between the transparent substrate **2** and the supporting base **26**, and the angle ranges from 30 degrees to 150 degrees. A material of the support **51** may include one selected from aluminum, composite metallic material, copper conductor, electric wire, ceramic substrate, printed circuit board, or other appropriate materials.

Please refer to FIGS. **18-20**. When the transparent substrate **2** in the present invention is disposed on a supporting base **5**, the transparent substrate **2** may be inserted or bonded to the supporting base **5**.

As shown in FIG. **18**. When the transparent substrate **2** is disposed on the supporting base **5**, the transparent substrate **2** is inserted in to a single socket **61** of the supporting base **5**, and the semiconductor light emitting element may be electrically coupled to the single socket **61** via connecting conductors. The LED structures (not shown in FIG. **18**) on the transparent substrate **2** have to be electrically coupled to a power supply from or through the supporting base **5**, and at least part of the conductive pattern or the connecting conductors are extended to an edge of the transparent substrate **2** and integrated in to an connecting finger having a plurality of conductive contact sheets or an electrically connecting port such as the connecting electrodes **311**A and **311**B described above (not shown in FIG. **18**). When the transparent substrate **2** is inserted into the socket **61**, the LED structure (not shown in FIG. **18**) may then receive electricity from or through the supporting base **5**, and the transparent substrate **2** may be fixed by the socket **61** of the supporting base **5** accordingly.

Please refer to FIG. **19**. FIG. **19** is a schematic diagram illustrating the transparent substrate **2** inserted into a multi sockets of the supporting base **5**. In this embodiment, the transparent substrate **2** has a dual-pin structure. One of the pins may be configured as a positive electrode of the device, and another one of the pins may be configured as a negative electrode of the device. Both of the pins have at least one conductive contact sheet respectively so as to act as connecting ports. Accordingly, there are at least two sockets **61** having corresponding shape and size with the pins so as to smoothly insert the transparent substrate **2** into the supporting base **5** and provide electricity to the LED structure.

Please refer to FIG. **20**. The transparent substrate **2** is bonded to the supporting base **5** by the device bonding layer. In the bonding process, metal materials such as gold, tin, indium, bismuth or silver may be used in combining or welding the transparent substrate **2** and the supporting base **5**. Additionally, conductive silica gel or epoxy material may also be used in fixing the transparent substrate **2** on the supporting base **5**. The conductive pattern and the connecting conductors of the semiconductor light emitting element may be electrically connected to the supporting base via the device bonding layer accordingly.

Please refer to FIG. **21** and FIG. **22**. The supporting base **5** of the illumination device **11** described in the present invention may be a substrate comprising one selected from metal such as aluminum, composite metallic material including aluminum, copper conductor, electric wire, ceramic substrate or printed circuit board. There is at least one support **62** on a surface or edge of the supporting base **5**. The support **62** may be separated from the supporting base **5**, or the support **62** and the supporting base **5** are monolithically integrated. The semiconductor light emitting element may be electrically coupled to the support **62** by bonding, and a device bonding layer **63** is used to fix the transparent substrate **2** on the supporting base **5**. The first angle θ1 is maintained between the transparent substrate **2** and a surface of the supporting base **5** without supports. The semiconductor light emitting elements may also be disposed on the surface of the supporting base **5** without supports so as to enhance the light emitting performance of the illumination device **11**. Additionally, the semiconductor light emitting element may also be inserted and connected to the support **62** (not shown in FIG. **21** and FIG. **22**), wherein a connector may be used to connect the semiconductor light emitting element and the support (and/or the support and the supporting base) so as to fix the transparent substrate **2** on the supporting base **5**. Because the supporting base **5** and the support **62** are flexible, it is more convenient to apply the present invention to different applications. Moreover, the color variety of the illumination device **11** may be enhanced for different demands by combining using the semiconductor light emitting elements having different light color.

Please refer to FIG. **23**. As shown in FIG. **23**, an illumination device in this embodiment includes at least one semiconductor light emitting element **1** and a supporting base **5**. The supporting base **5** includes at least one support **62** and at least one circuit pattern P. An end of the transparent substrate of the semiconductor light emitting element **1** is electrically coupled to the support **62** so as to avoid or reduce the shielding influence caused by the support **62** for light emitting from the semiconductor light emitting element **1**. The supporting base **5** may be selected from metal such as aluminum, composite metallic material including aluminum, copper conductor, electric wire, ceramic substrate or printed circuit board. The support **62** may be formed by cutting and bending a part of the supporting base **5** to form an angle (as the first angle θ**1** shown in FIG. **21** and FIG. **22**). The circuit pattern P is disposed on supporting base **5**, and the circuit pattern P has at least one set of electrical port to be electrically connected to a power supply. Another part of the circuit pattern P extends on the support **62** so as to be electrically connected to the semiconductor light emitting element **1**, and the semiconductor light emitting element **1** may than be electrically connected to the power supply via the circuit pattern P of the supporting base **5**. In addition, the supporting base **5** may further include at least one hole H or at least one gap G, and fixing devices such as screws, nails or bolts may be used to combine the supporting base **5** with other device via the hole H or the gap G according to the application conditions of the illumination device. Meanwhile, the hole H or the gap G may also be used to increase the heat radiating area and enhance the heat dissipation capability of the illumination device.

Please refer to FIG. **24**. FIG. **24** is a schematic diagram illustrating a device frame of an illumination device according to another preferred embodiment of the present invention. As shown in FIG. **24**, a device frame **322** in this embodiment includes a supporting base **5** and at least one support **62**. Compared with the embodiment shown in FIG. **23**, the support **62** in this embodiment includes at least one stripe part **342** and an opening **330**. The electrode **30** and the electrode **32** are respectively disposed on two sides of the opening **330**. The stripe part **342** forms at least one wall of the opening **330**. One semiconductor light emitting element described in the present invention is disposed correspondingly to the opening **330** and electrically coupled to the support **62**. The connecting conductors of the semiconductor light emitting element is electrically connected to the electrode **30** and the electrode **32** so as to drive the semiconductor light emitting element by a power supply via the support **62** and the circuit pattern on the supporting base **5**. A size of the opening **330** may not be smaller than a main light emitting surface of the semiconductor light emitting element so as to prevent light beams emitted from the semiconductor light emitting element from being blocked by the support **62**. A connection part between the support **62** and the supporting base **5** may be adjustable so as to adjust the angle between the support **62** and the supporting base **5** as required.

Please refer to FIG. **24** and FIG. **25**. FIG. **25** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention. Compared with the embodiment shown in FIG. **24**, an illumination device **302** shown in FIG. **25** further includes at least one support **62** having a plurality of openings **330**. The openings **330** are respectively disposed on two opposite sides of the support **62**, and the stripe part **342** forms at least one wall of each opening **330**. The semiconductor light emitting element **310** are disposed correspondingly to the openings **330**, and the conductive pattern or the connecting electrodes (not shown in FIG. **25**) of each semiconductor light emitting element **310** are respectively disposed correspondingly and electrically connected to the electrode **30** and **32**. The illumination device **302** in this embodiment may further include a plurality of the supports **62**. The support **62** is disposed between the semiconductor light emitting element **1** and the supporting base **5**. A length of the support **62** may substantially range from 5.8 to 20 um. Angles between the supporting base **5** and the supports **62** with the semiconductor light emitting element disposed on may be modified respectively. In other words, an angle between the supporting base **5** and at least one of the supports **62** may be different from an angle between the supporting base **5** and another one of the supports **62** so as to perform required light emitting effects, but not limited thereto. Additionally, semiconductor light emitting elements emitting light having different wavelength ranges may be disposed on an identical support or on different supports so as to enrich the color effect of the illumination device.

For enhancing the luminance and improving the light emitting effect, in an illumination device of another preferred embodiment of the present invention, a plurality of the semiconductor light emitting elements comprising the transparent substrates are disposed on the supporting bases detailed above or on other supporting structures. A point-symmetric distribution or a line-symmetric distribution may be applied. The semiconductor light emitting elements comprising the transparent substrates may be point-symmetrically disposed on the supporting structure or line-symmetrically disposed on the supporting structure. Please refer to FIGS. **26-29**. In the illumination devices of the embodiments shown in FIGS. **26-29**, the semiconductor light emitting elements are disposed on the supporting structures having different shapes. The light beams emitted from the illumination devices **11** may be uniform because of the point-symmetric distribution or the line-symmetric distribution (the LED structures are not shown in FIGS. **26-29**). The light emitting effects of the illumination devices **11** may be further improved by adjusting the first angle described above. As shown in FIG. **26**, the semiconductor light emitting elements are point-symmetrically arranged and form an angle between each other in 90 degrees. Therefore, at least two of the semiconductor light emitting elements may face any one of the four sides of the illumination device **11**. As shown in FIG. **27**, the angle between the semiconductor light emitting elements is smaller than 90 degrees. As shown in FIG. **29**, the angle between the semiconductor light emitting elements is larger than 90 degrees. In another preferred embodiment of the present invention (not shown), the semiconductor light emitting elements may be asymmetrically disposed and at least apart of the semiconductor light emitting elements may be disposed in a crowd or separately disposed so as to perform required light shape according to different applications of the illumination device.

Please refer to FIG. **30**. FIG. **30** is a schematic diagram illustrating an illumination device according to another preferred embodiment of the present invention. As shown in FIG. **30**, an illumination device **301** includes a semiconductor light emitting element **310** and a support **321**. The support **321** includes an opening **330**, and the semiconductor light emitting element **310** is disposed correspondingly to the opening **330**. In this embodiment, an external part of the support **321** may be work as a pin or be bent to form a connecting pad required in surface mounting so as to be fixed and electrically connected to other electrical circuit units. A light emitting surface of the semiconductor light emitting element **310** is disposed in the opening **330**, and the illumination device **301** may still emit light from multi sides or six sides accordingly whether the support **321** is transparent or not.

Please refer to FIG. **31**. An illumination device is provided in this embodiment of the present invention. The illumination device includes a lamp housing **7** having a tube shape, at least one semiconductor light emitting element **1** and a supporting structure **60**. The semiconductor light emitting element **1** is disposed on the supporting structure **60**, and at least a part of the semiconductor light emitting element **1** is disposed in space formed by the lamp housing **7**. Please refer to FIG. **32**. When more semiconductor light emitting elements **1** are disposed in the lamp housing **7**, the first main surfaces **21**A of the semiconductor light emitting elements **1** are arranged separately and not parallel to one another. Additionally, the semiconductor light emitting elements **1** are at least partially disposed in space formed by the lamp housing **7**, and the semiconductor light emitting elements **1** are not closely adjacent to an inner wall of the lamp housing **7**. Preferably, a distance D between the semiconductor light emitting element **1** and the lamp housing **7** may be equal to or larger than 500 micrometers. However, the lamp housing **7** may also be formed by filling glue, and the lamp housing **7** may at least partially cover and directly contact the semiconductor light emitting element **1**.

Please refer to FIG. **33**. According to another embodiment of the present invention, an illumination device **303** includes at least one light emitting element **1**, a supporting base **5**, and at least one support **62**. The light emitting element **1** is disposed on the support **62** and the support **62** is coupled to the supporting base **5**. In contrast to the embodiment as disclosed in FIG. **21**, the support **62** of this embodiment is inclined that at least a part of the support **62** may be nearer to a central axis D**1** of the supporting base **5**. More specifically to this embodiment, the illumination device **303** includes two supports **62** and two light emitting elements **1** disposed on the two supports **62** respectively. The two supports **62** are connected to the supporting base **5** for better heat conduction. The supports **62** are inclined inward relative to the central axis D**1** of the supporting base **5**, and a first angle θ**1** between the light emitting element **1** and the supporting base **5** as shown in the figure (that is, an angle between the support **62** and the supporting base **5**) may range from 45 degrees to 75 degrees, such that the size of the illumination device **303** can be reduced in contrast to the embodiment as disclosed in FIG. **21**. The luminance of the light illumination device **303** near to the central axis D**1** of the supporting base **5** is increased as well.

Please refer to FIG. **34-37**. In contrast to the above embodiments of the present invention, illumination devices **304/305/306/307** according to different embodiments of the present invention are more flexible for various applications, and illumination devices **304/305/306/307** may be crystal lamps. The illumination device **304** includes at least one light emitting element **1**, a supporting base **5**, and at least one support **62**, as shown in FIG. **34**. The support **62** may further include a first connected portion **621** and a second connected portion **623**. One end of the second connected portion **623** is disposed on the supporting base **5**, and the other end of the second connected portion **623** corresponding to the supporting base **5** is connected to one end of the first connected portion **621**. The light emitting element **1** is disposed on the other end of the first connected portion **621** corresponding to the second connected portion **623**. The first connected portion **621** may further be rotatable relative to the second connected portion **623**. More specifically to this embodiment, the first connected portion **621** extends outward or inward relative to the central axis D**1** of the supporting base **5**, and a second angle θ**2** between the first connected portion **621** and the second connected portion **623** may range from 135 degrees to 175 degrees, such that the luminance near to the central axis D**1** may be increased or decreased for different applications. The second connected portion **623** is perpendicular to the supporting base **5**, but not limited to this. A third angle θ**3** between the second connected portion **623** and the supporting base **5** may range from 45 degrees to 85 degrees according to some other embodiments of the present invention. The second connected portion **623** may further be rotatable relative to the supporting base **5**. According to this embodiment, the luminance near to the central axis D**1** of the supporting base **5** of the illumination device **304** can be higher than the embodiment as disclosed in FIG. **21**, and the size of the illumination device **304** can be reduced.

Please refer to FIG. **35**. In contrast to the embodiment as shown in FIG. **34**, an illumination device **305** may include at least one support **62** including a first connected portion **621** and a second connected portion **623**, wherein a light emitting element **1** is disposed on one end of the first connected portion **621** and the end of the first connected portion **621** is connected to one end of the second connected portion **623**, and the other end of the second connected portion **623** corresponding to the first connected portion **621** is coupled to a supporting base **5**. The other end of the first connected portion **621** corresponding to the second connected portion **623** may extend inward or outward relative to a central axis D**1** of the supporting base **5**, and a second angle θ**2** between the first connected portion **621** and the second connected portion **623** may range from 5 degrees to 45 degrees for increasing the luminance near to the central axis C**1**. The other components of the illumination device **305** may be same as the illumination device **304** and are not reiterated here.

Additionally, please refer to FIG. **36**. A support **62** of an illumination device **306** may be flexibly formed as an arc-shaped structure. A radius of the arc-shaped support **62** ranges from 10 millimeters to 200 millimeters, and a center of the arc-shaped structure may be near to or away from a central axis D**1** of a supporting base **5** of the illumination device **306**. Additionally, according to another embodiment as shown in FIG. **37**, an illumination device **307** includes a support **62** which may be formed as a parabolic structure. Two light emitting elements **1** are disposed on the opposite sides of a central axis D**1** of the parabolic support **62**. Not limited to this, the support **62** can be an ellipse-shaped structure.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. An illumination device, comprising:

a light emitting element, comprising:

a transparent substrate, having an uncovered surface, a covered surface, and a bottom surface opposite to the uncovered surface; and

a plurality of LED structures, disposed on the covered surface without blocking the uncovered surface in a configuration that the uncovered surface and the bottom surface are illuminated when the plurality of LED structures is operated; and

a supporting base associated with the light emitting element; and

a support stacked on the light emitting element, parallel to the transparent substrate, and inwardly inclined against a central axis of the supporting base by a first angle.

2. The illumination device of claim **1**, wherein the first angle ranges from 45 degrees to 75 degrees.

3. The illumination device of claim **1**, wherein the support comprises a first connected portion and a second connected

portion, the second connected portion is disposed on the supporting base, the first connected portion is rotatably connected to the second connected portion, wherein a second angle exists between the first connected portion and the second connected portion.

4. The illumination device of claim **3**, wherein the first connected portion extends outward relative to the central axis of the supporting base and the second angle ranges from 135 degrees to 175 degrees.

5. The illumination device of claim **3**, wherein the first connected portion extends inward relative to the central axis of the supporting base and the second angle ranges from 5 degrees to 45 degrees.

6. The illumination device of claim **3**, wherein a third angle exists between the second connected portion and the supporting base and the third angle ranges from 45 degrees to 85 degrees.

7. The illumination device of claim **1**, wherein the support is an arc-shaped structure.

8. The illumination device of claim **7**, wherein a radius of the arc-shaped support ranges from 10 mm to 200 mm, a center of the arc-shaped structure is near to or away from the central axis of the supporting base.

9. The illumination device of claim **1**, wherein the support is a parabolic structure or an ellipse-shaped structure.

* * * * *

Exhibit 8

US009664340B2

(12) United States Patent
Yao et al.

(10) Patent No.: US 9,664,340 B2
(45) Date of Patent: May 30, 2017

(54) **LIGHT EMITTING DEVICE**

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(72) Inventors: **Chiu-Lin Yao**, Hsinchu (TW); **Min-Hsun Hsieh**, Hsinchu (TW); **Been-Yu Liaw**, Hsinchu (TW); **Wei-Chiang Hu**, Hsinchu (TW); **Po-Hung Lai**, Hsinchu (TW); **Chun-Hung Liu**, Hsinchu (TW); **Shih-An Liao**, Hsinchu (TW); **Yu-His Sung**, Hsinchu (TW); **Ming-Chi Hsu**, Hsinchu (TW)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 262 days.

(21) Appl. No.: **14/301,060**

(22) Filed: **Jun. 10, 2014**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
F21K 99/00 (2016.01)
H01L 25/075 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F21K 9/135*** (2013.01); ***F21K 9/232*** (2016.08); ***H01L 25/0753*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC F21V 23/002; F21V 23/004; F21V 23/005; F21Y 2103/10; F21Y 2105/10; F21Y 2107/90; F21Y 2113/17; G02F 1/1335; H01L 25/0753; H01L 33/52; H01L 33/56; H01L 2224/48137; H01L 2224/97; H01L 23/28; H01L 27/00; H01L 2924/1532;
(Continued)

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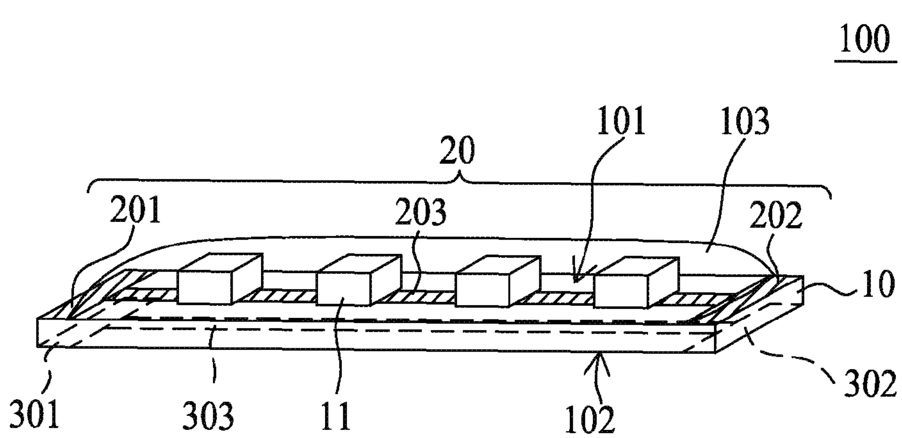
Primary Examiner — Hargobind S Sawhney
(74) *Attorney, Agent, or Firm* — Patterson + Sheridan, LLP

(57) **ABSTRACT**

This disclosure discloses a light-emitting device. The light-emitting device comprises: a first electrode part; a second electrode part; a third electrode part, spaced apart from the first electrode part and the second electrode part; and a light-emitting unit partially covering the first electrode part and the second electrode part and fully covering the second electrode part, the light-emitting unit having a conductive structure contacting the second electrode part.

20 Claims, 25 Drawing Sheets



(51) **Int. Cl.**

F21K 9/232	(2016.01)
H01L 33/54	(2010.01)
H01L 33/62	(2010.01)
F21Y 115/10	(2016.01)
F21Y 107/10	(2016.01)
F21Y 107/30	(2016.01)

(52) **U.S. Cl.**
CPC *F21Y 2107/10* (2016.08); *F21Y 2107/30* (2016.08); *F21Y 2115/10* (2016.08); *H01L 33/54* (2013.01); *H01L 33/62* (2013.01); *H01L 2224/16225* (2013.01); *H01L 2224/32225* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48137* (2013.01); *H01L 2224/48227* (2013.01); *H01L 2224/49107* (2013.01); *H01L 2224/73265* (2013.01)

(58) **Field of Classification Search**
CPC . H01L 2224/48135; H01L 2224/48177; H01L 33/62
See application file for complete search history.

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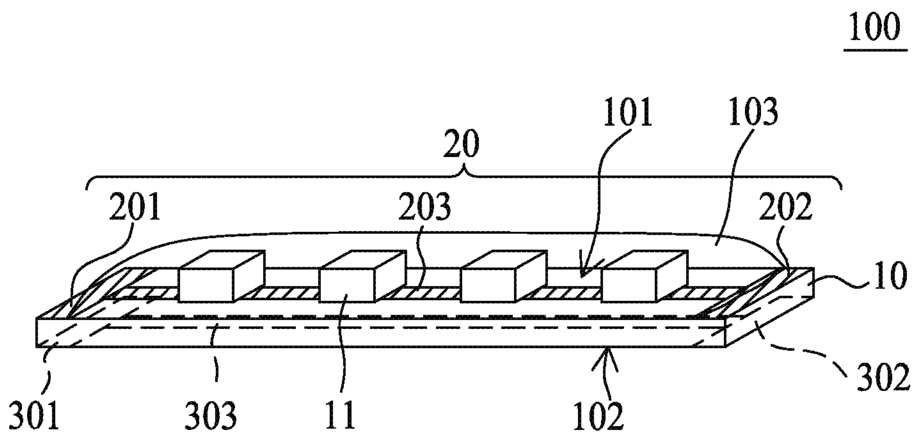


FIG. 1A

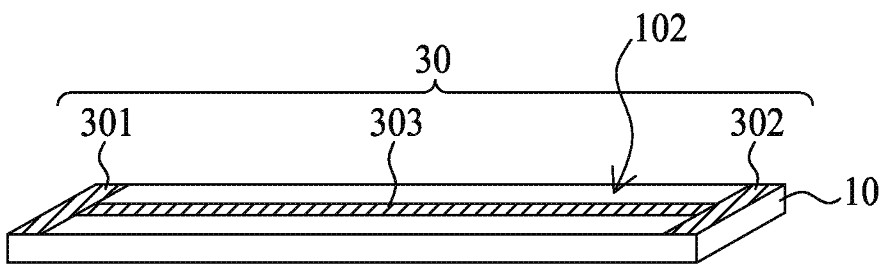


FIG. 1B

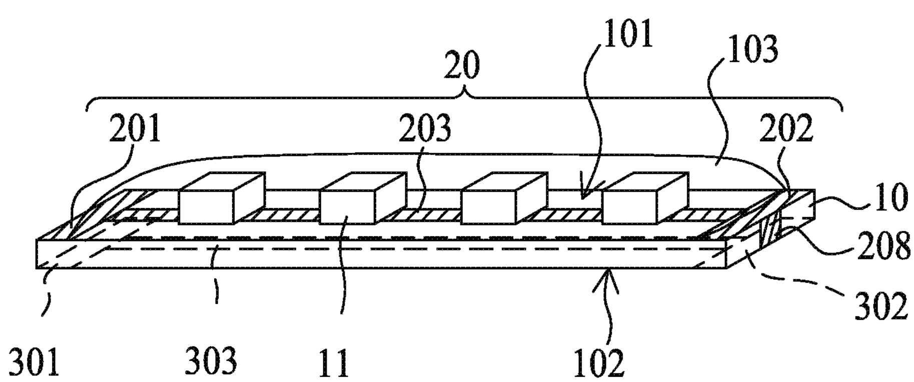


FIG. 1C

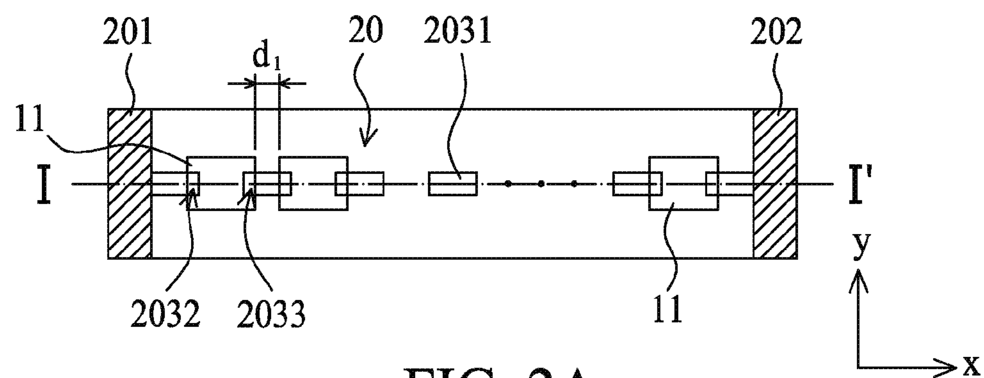

201
d1
20
2031
202
11
I
I'
y
2032
2033
11
x

FIG. 2A

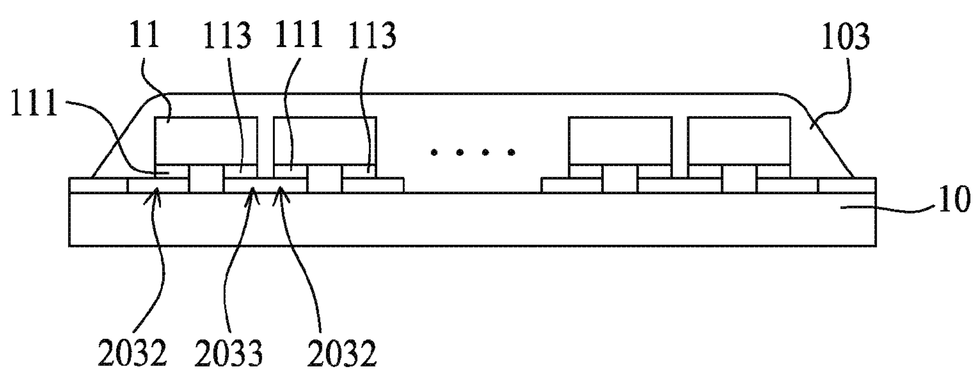
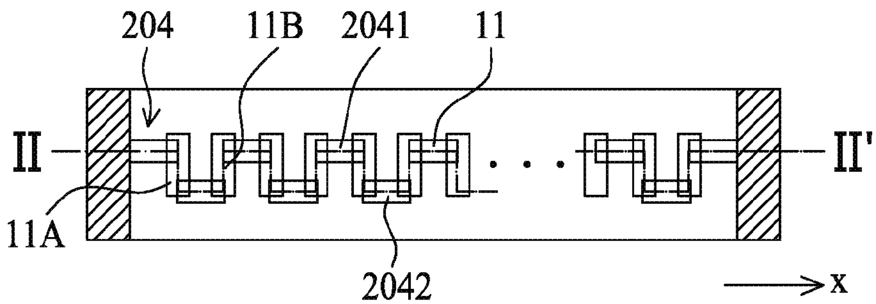
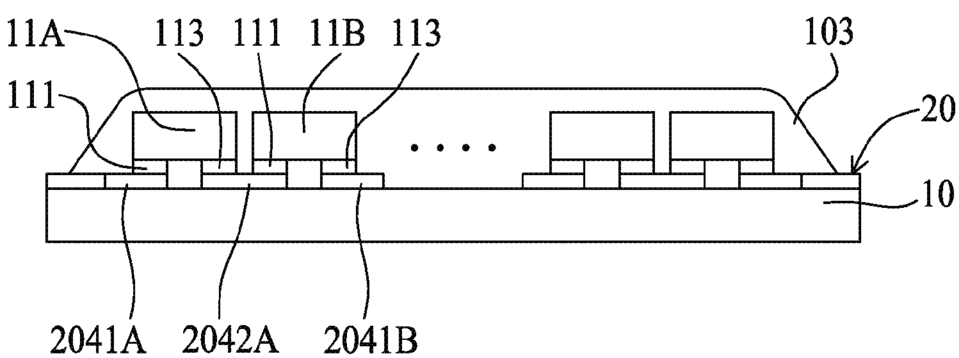

11
113
111
113
103
111
10
2032
2033
2032

FIG. 2B



204
11B
2041
11
II
II'
11A
2042
x

FIG. 3A



11A
113
111
11B
113
103
111
20
10
2041A
2042A
2041B

FIG. 3B

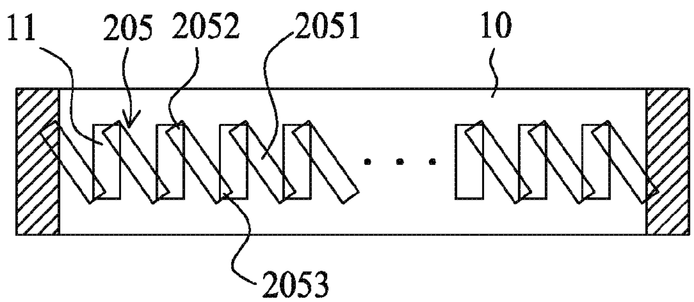


FIG. 4A

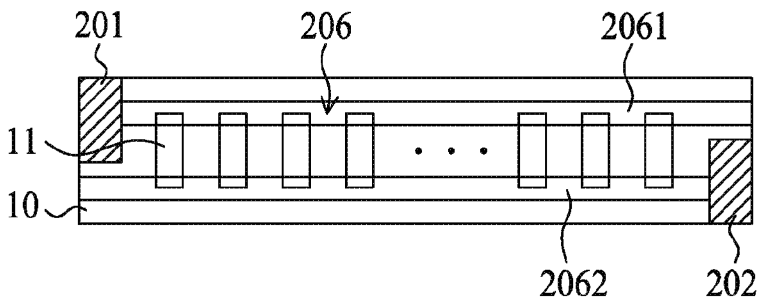


FIG. 4B

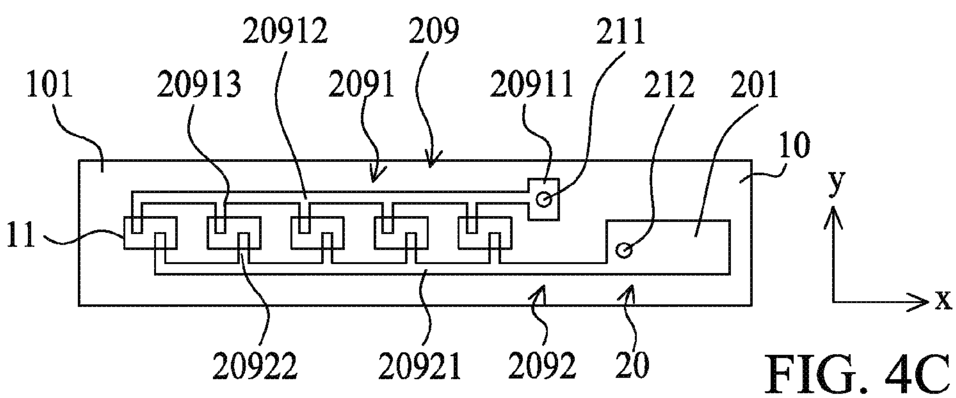


FIG. 4C

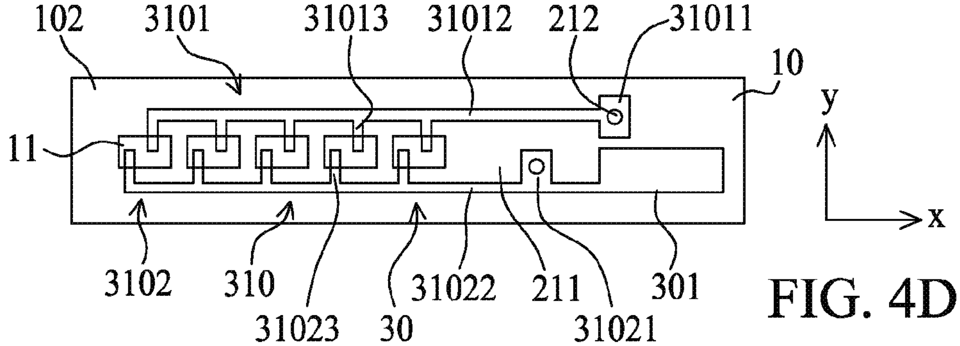


FIG. 4D

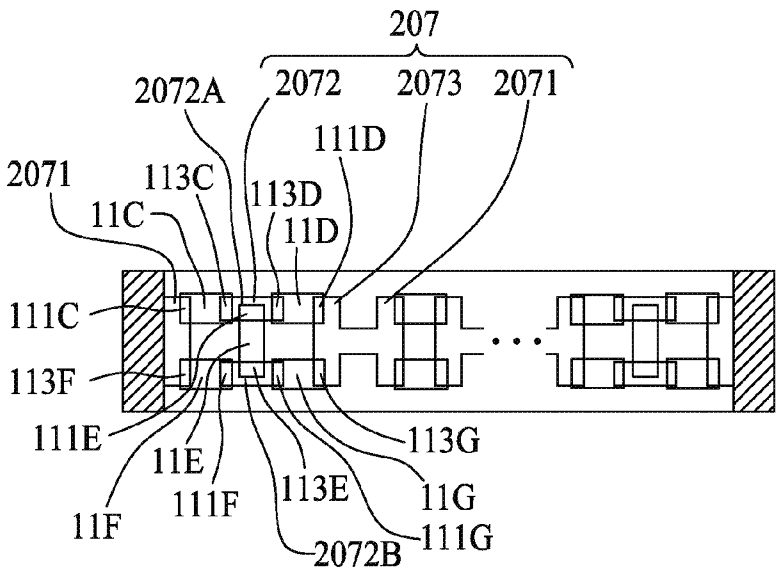


FIG. 4E

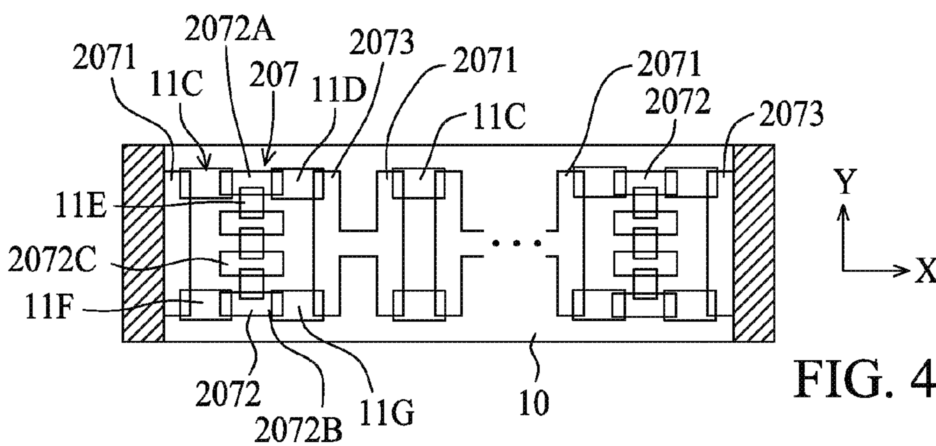


FIG. 4F

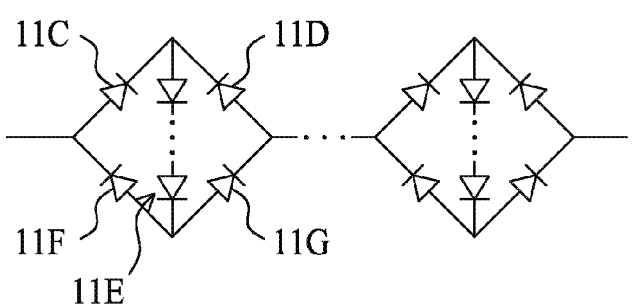


FIG. 4G

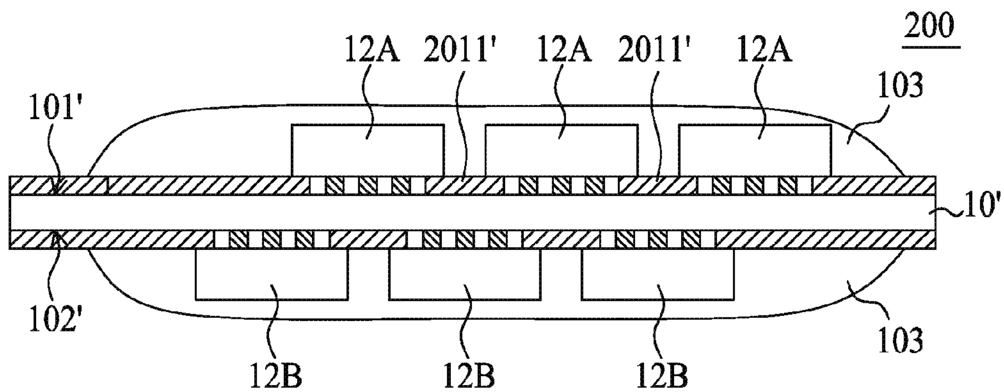


FIG. 5A

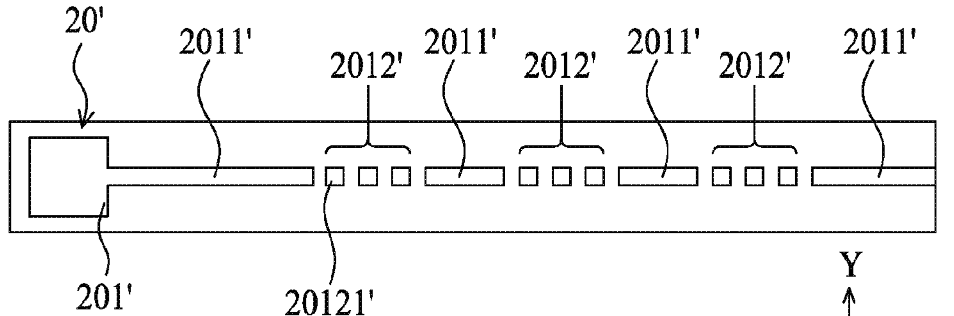


FIG. 5B

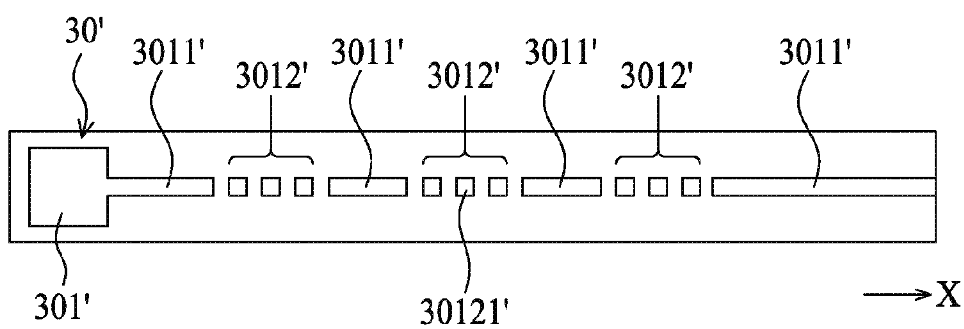
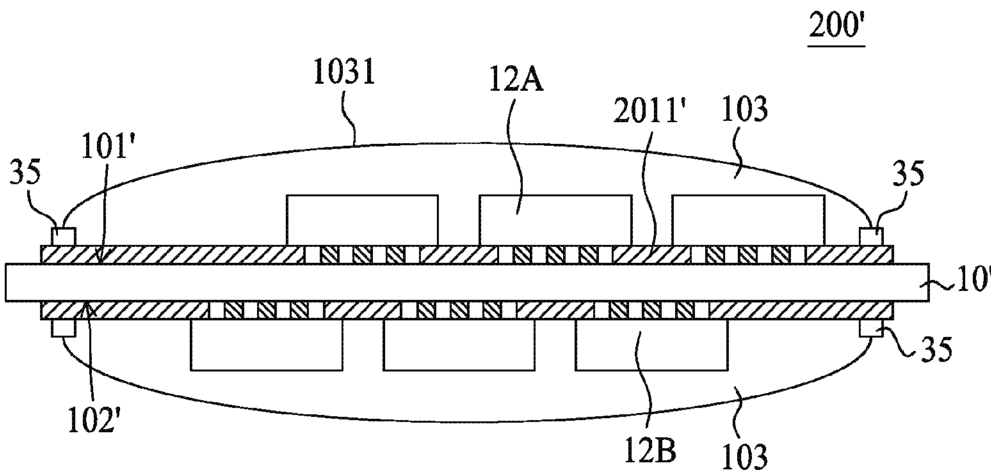


FIG. 5C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1031
12A
2011'
103
101'
35
35
10'
35
102'
12B
103

FIG. 5D

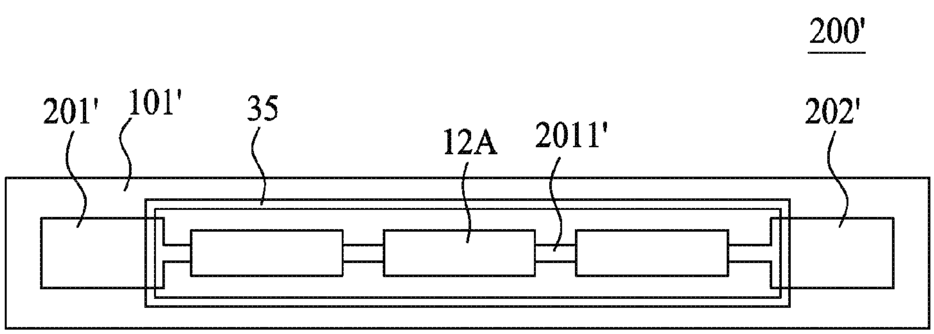

200'
201'
101'
35
12A
2011'
202'

FIG. 5E

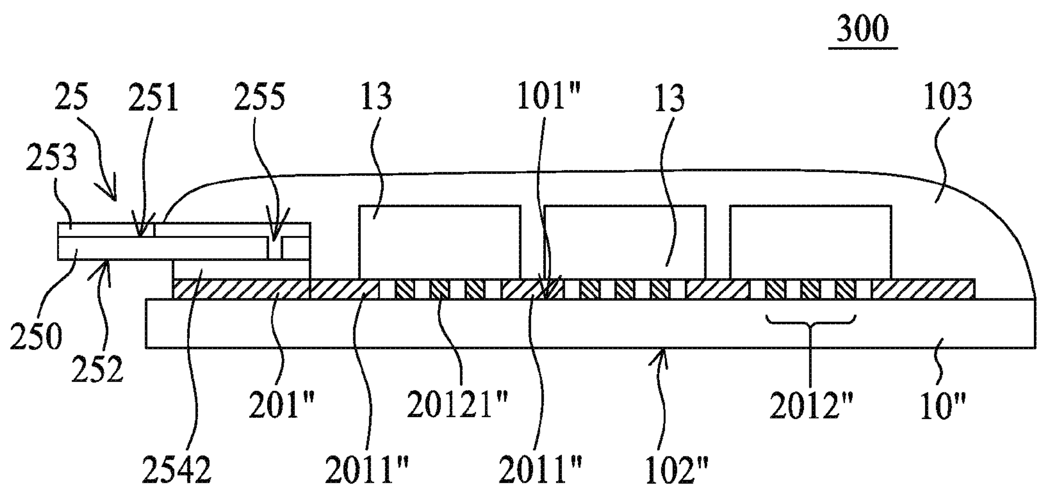

300
25
251
255
13
101"
13
103
253
250
252
201"
20121"
2012"
10"
2542
2011"
2011"
102"

FIG. 6A

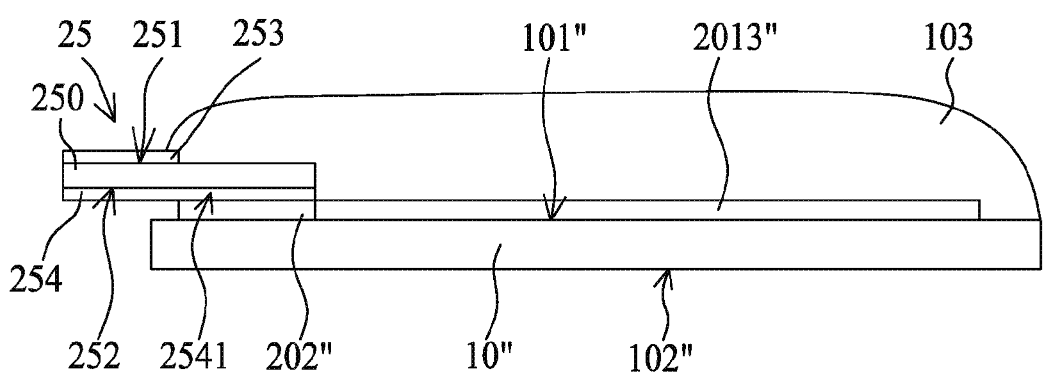

25
251
253
101"
2013"
103
250
254
252
2541
202"
10"
102"

FIG. 6B

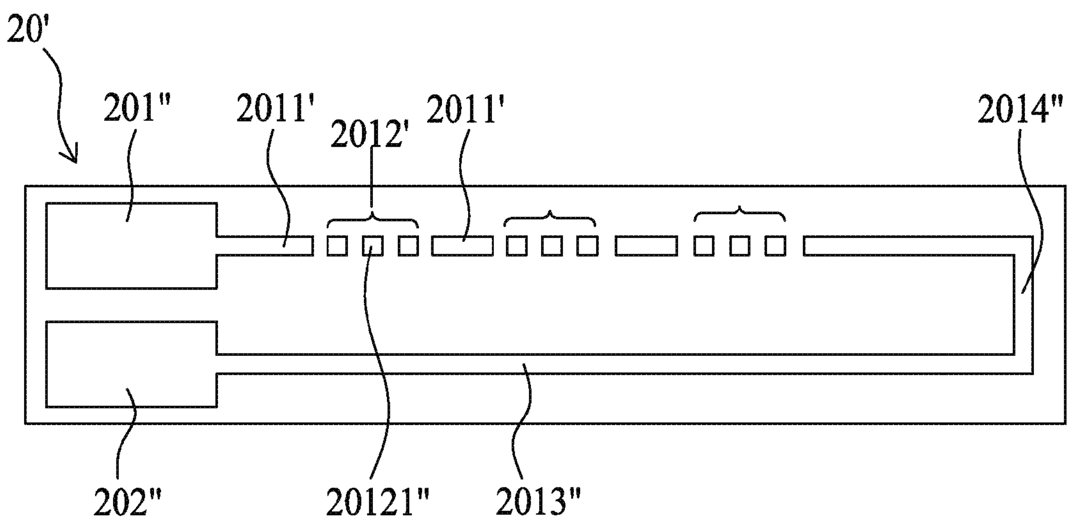


FIG. 6C

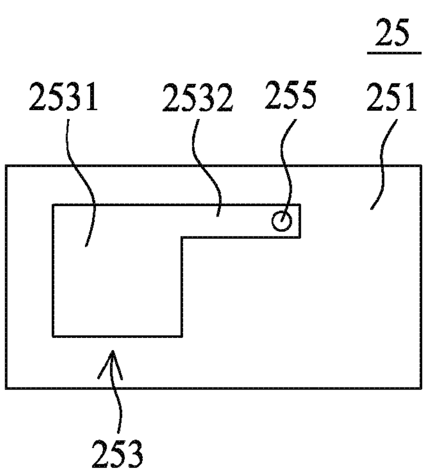


FIG. 6D

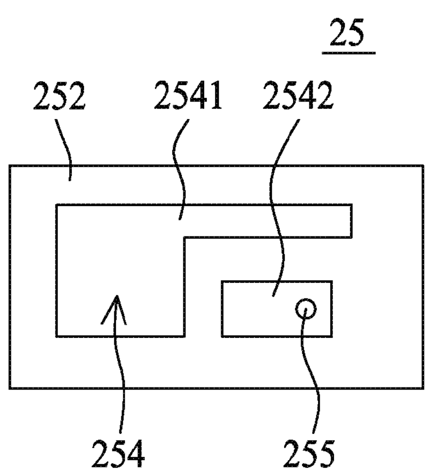


FIG. 6E

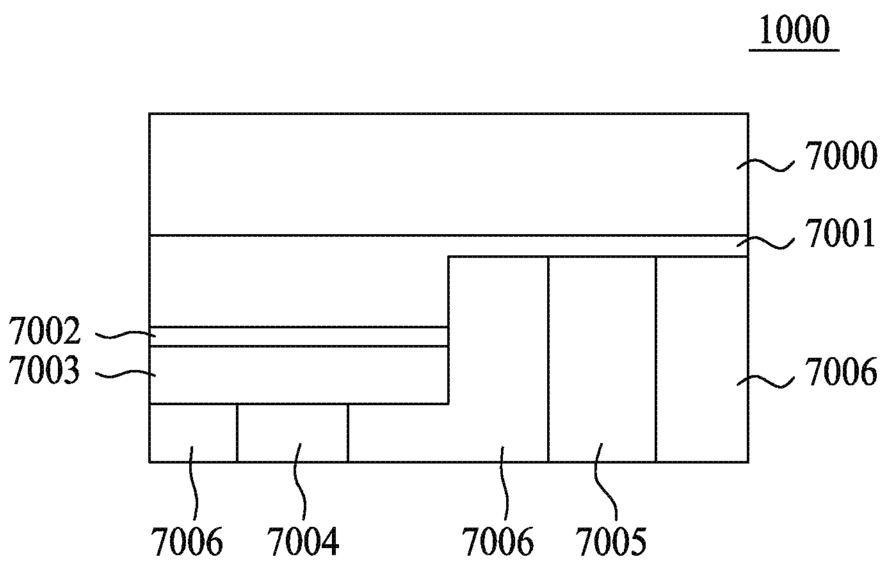

1000
7000
7001
7002
7003
7006
7006
7004
7006
7005

FIG. 7A

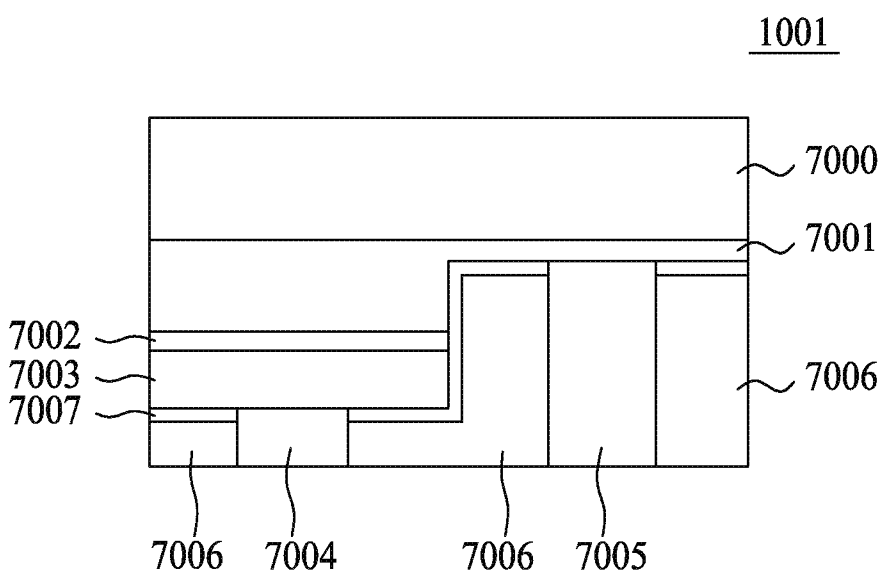

1001
7000
7001
7002
7003
7007
7006
7006
7004
7006
7005

FIG. 7B

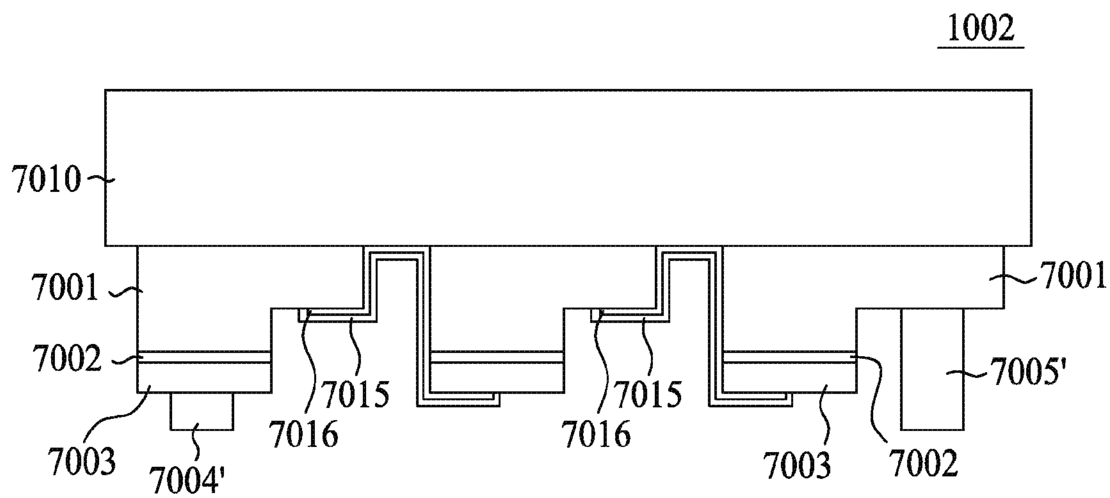

1002
7010
7001
7002
7003
7004'
7016
7015
7016
7015
7003
7002
7001
7005'

FIG. 7C

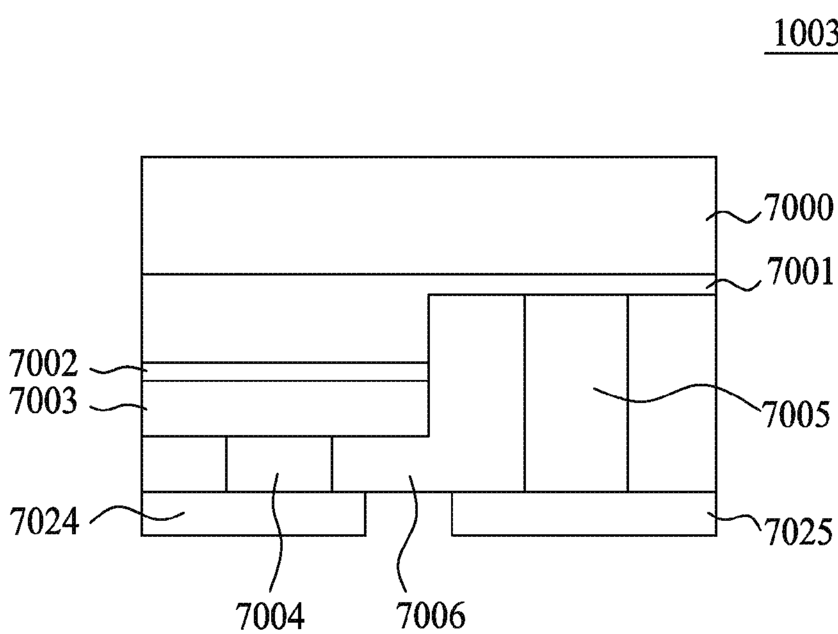
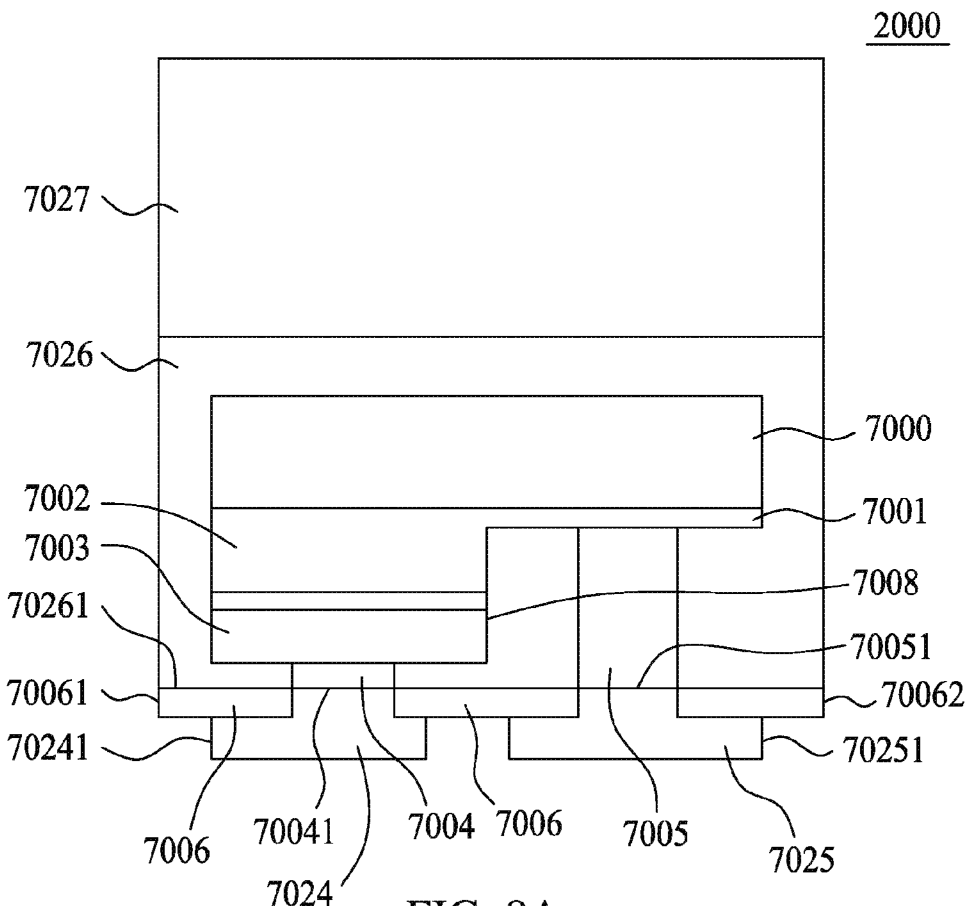

1003
7000
7001
7002
7003
7005
7024
7025
7004
7006

FIG. 7D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7027
7026
7000
7002
7001
7003
7008
70261
70051
70061
70062
70241
70251
7006
70041
7004
7006
7005
7025
7024

FIG. 8A

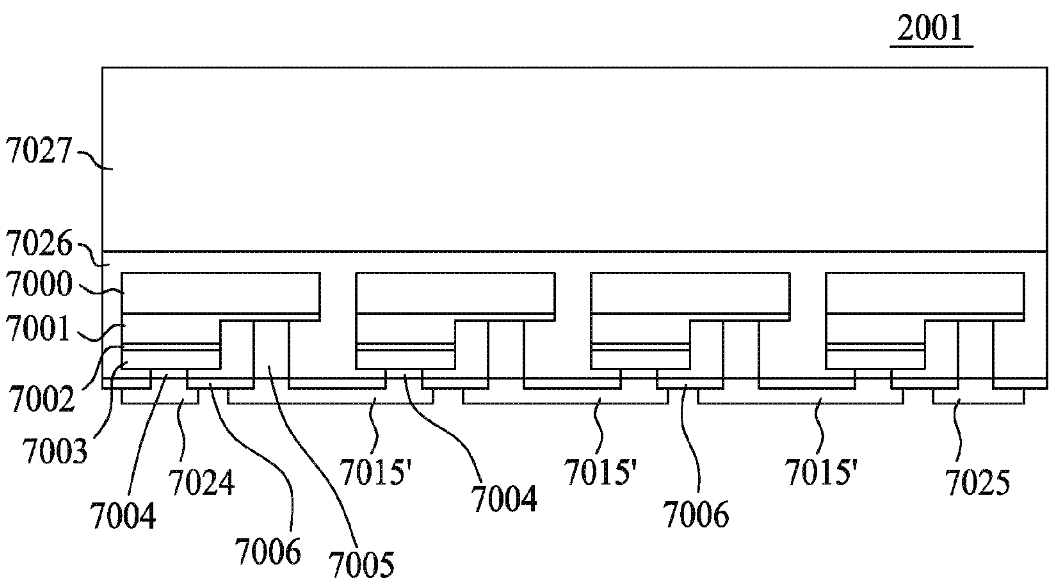

2001
7027
7026
7000
7001
7002
7003
7024
7015'
7004
7015'
7015'
7025
7004
7006
7006
7005

FIG. 8B

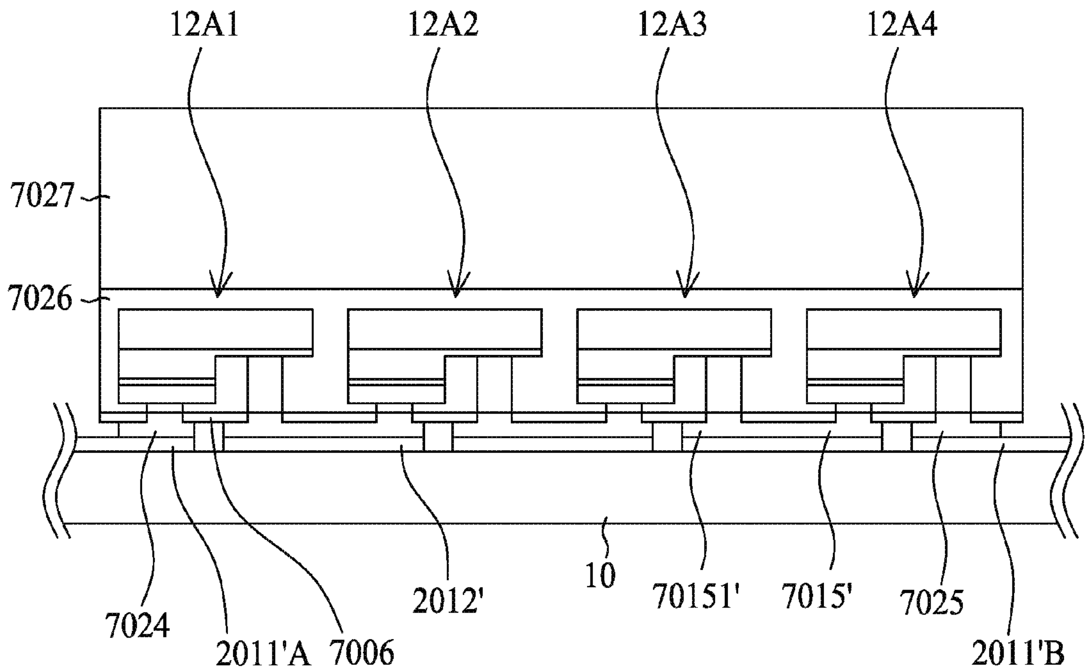

12A1
12A2
12A3
12A4
7027
7026
7024
2011'A
7006
2012'
10
70151'
7015'
7025
2011'B

FIG. 8C

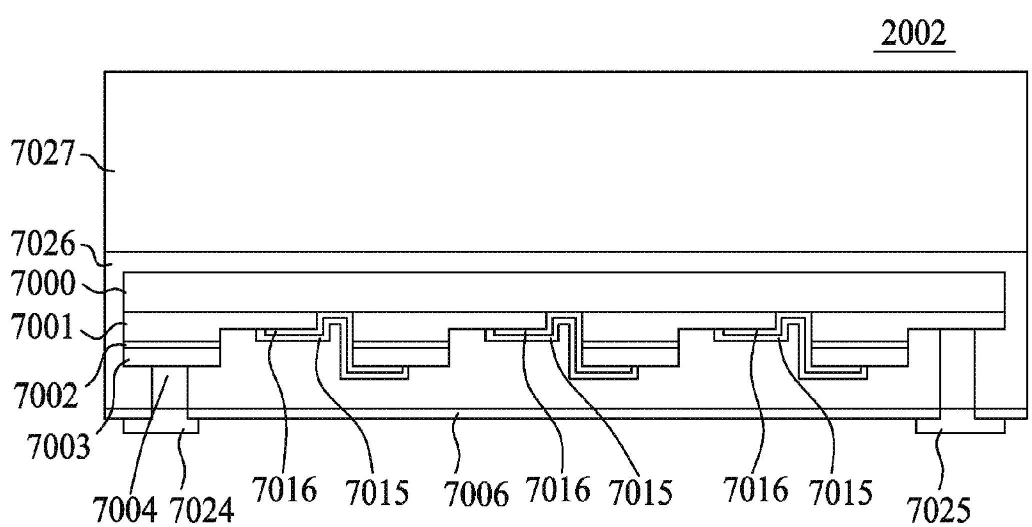

2002
7027
7026
7000
7001
7002
7003
7004
7024
7016
7015
7006
7016
7015
7016
7015
7025

FIG. 8D

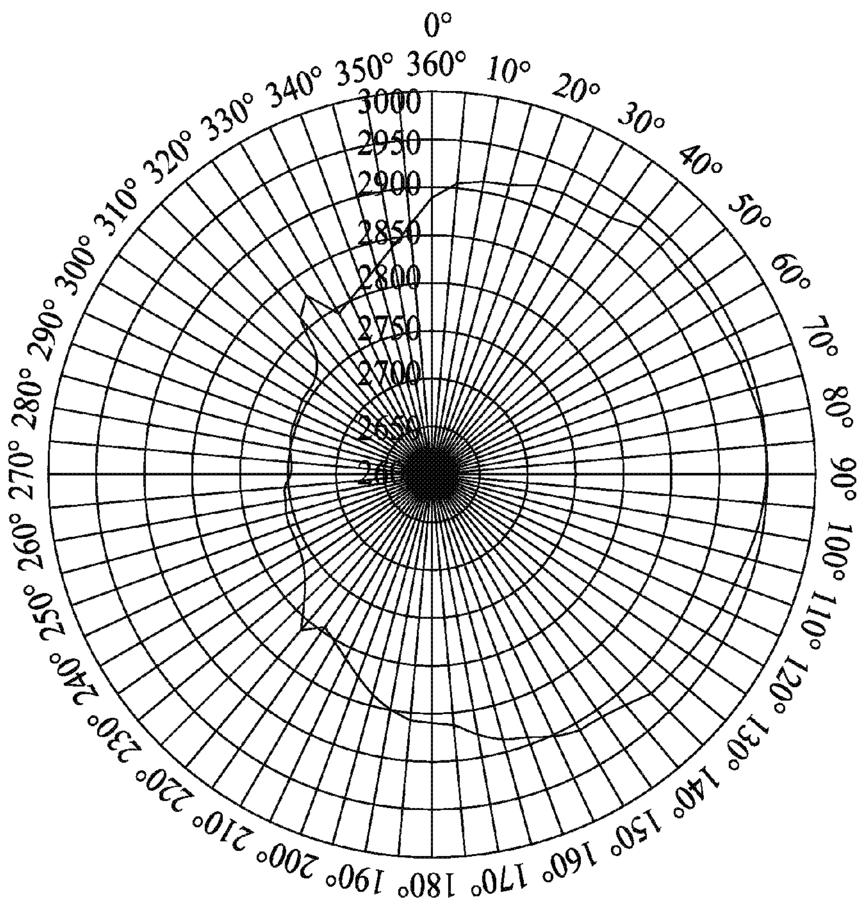

0°
360°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
3000
2950
2900
2850
2800
2750
2700
2650

FIG. 8E

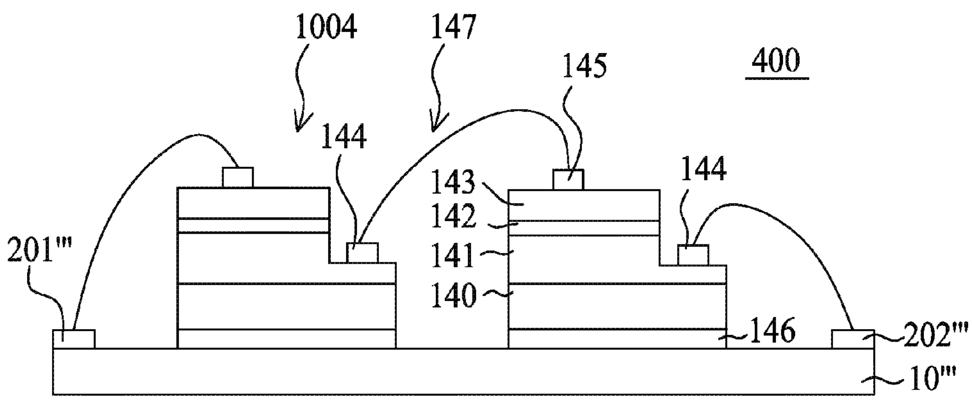

1004
147
145
400
144
143
142
141
140
144
201'''
146
202'''
10'''

FIG. 9

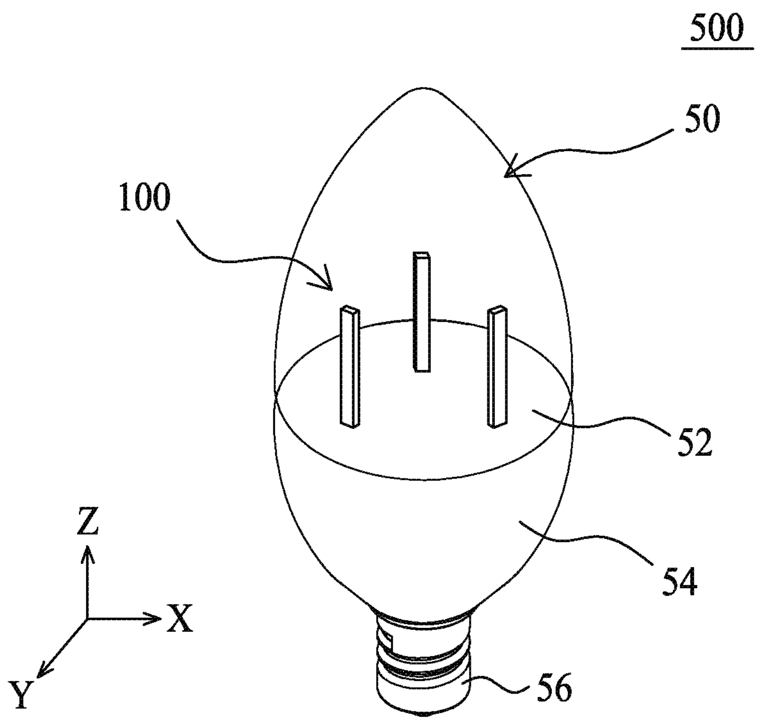


FIG. 10A

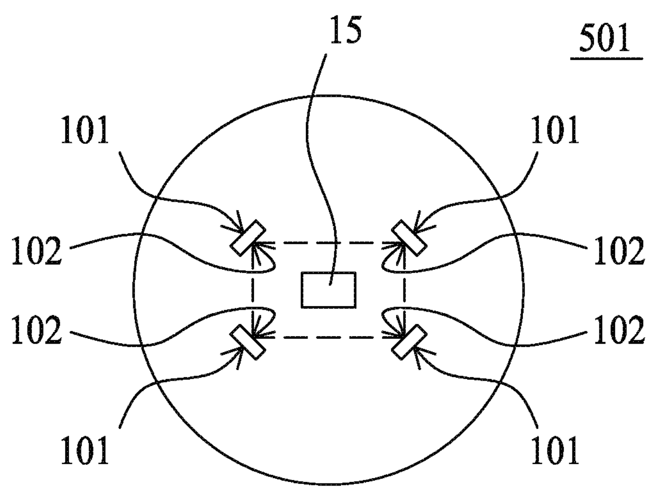


FIG. 10B

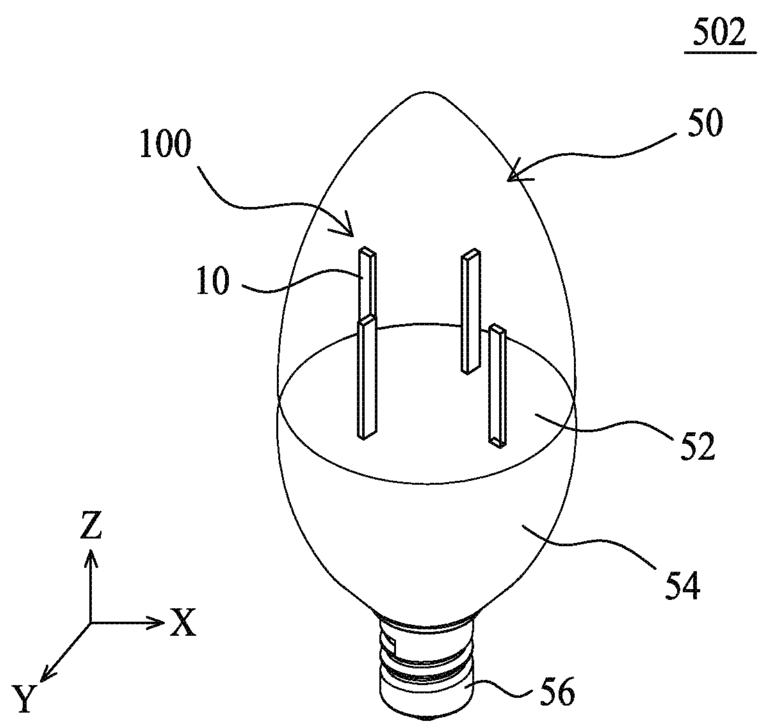


FIG. 11A

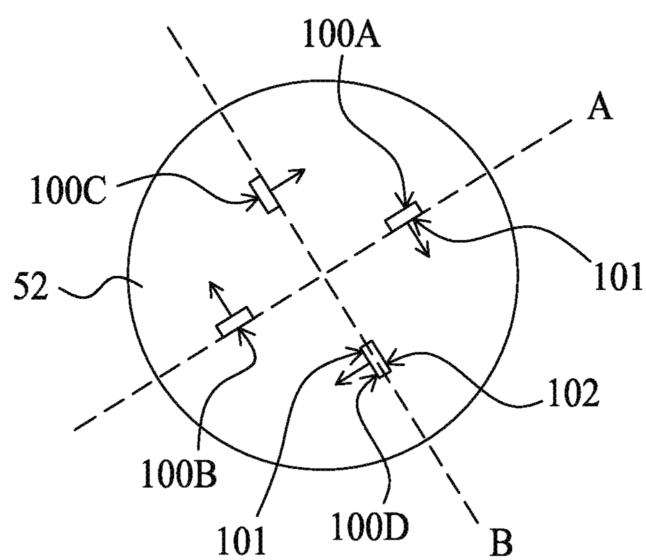


FIG. 11B

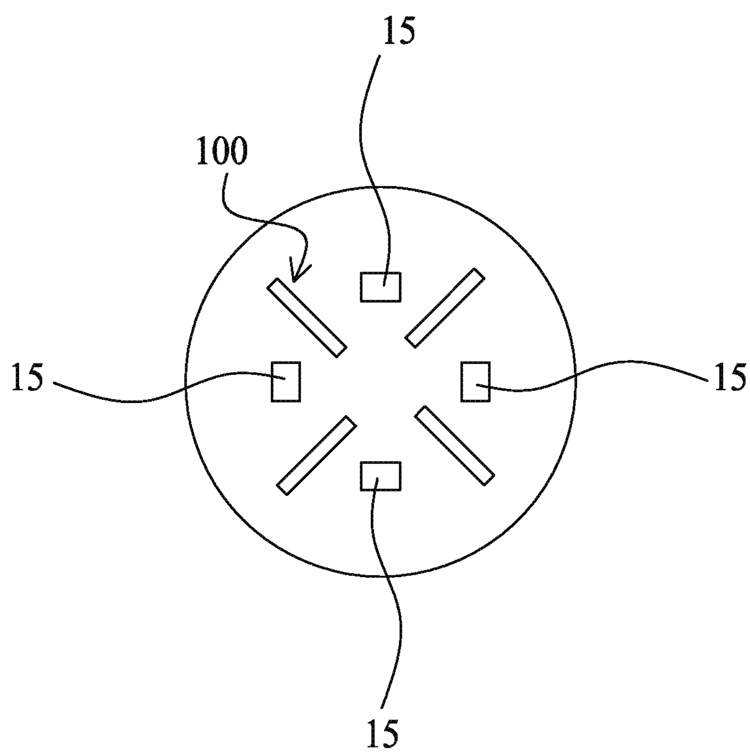


FIG. 11C

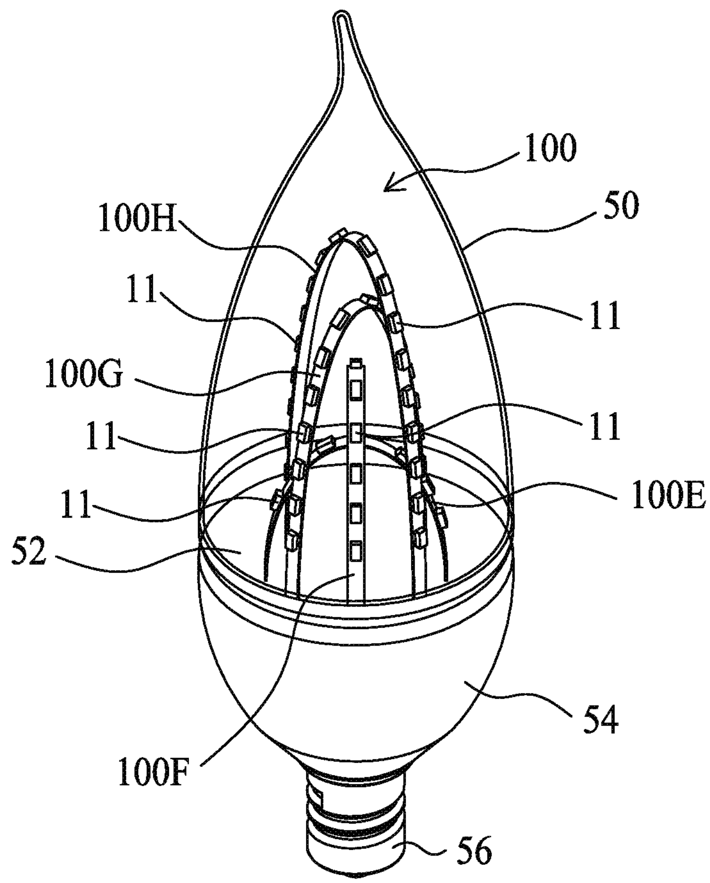


FIG. 11D

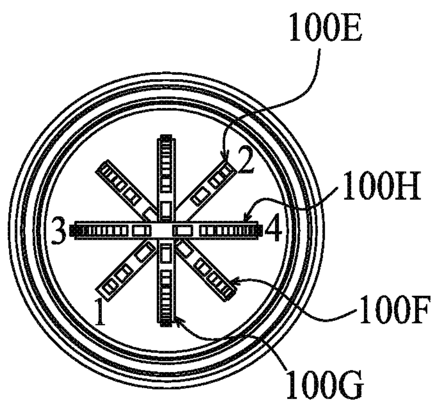


FIG. 11E

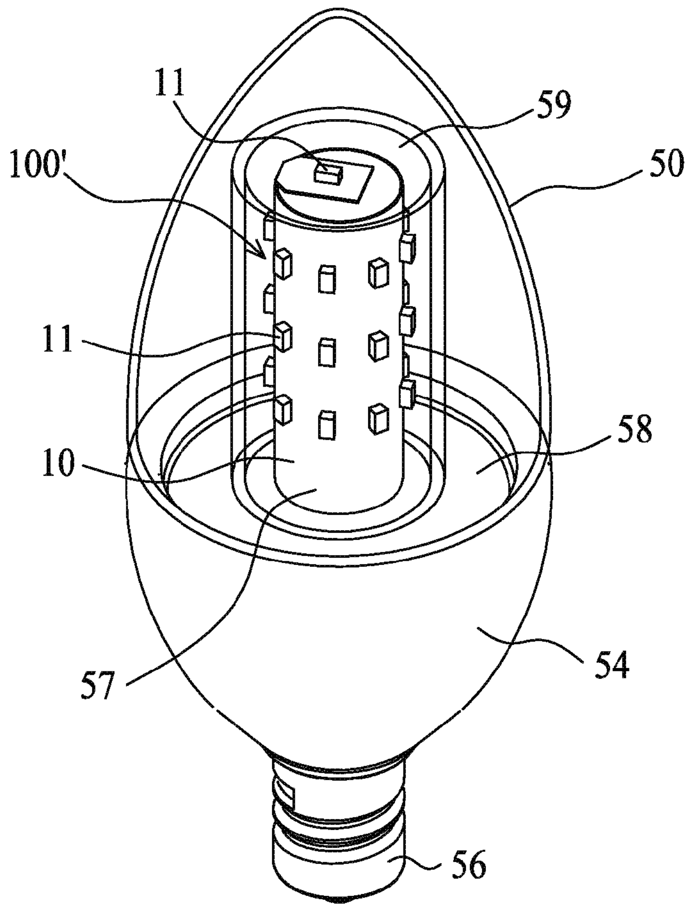


FIG. 11F

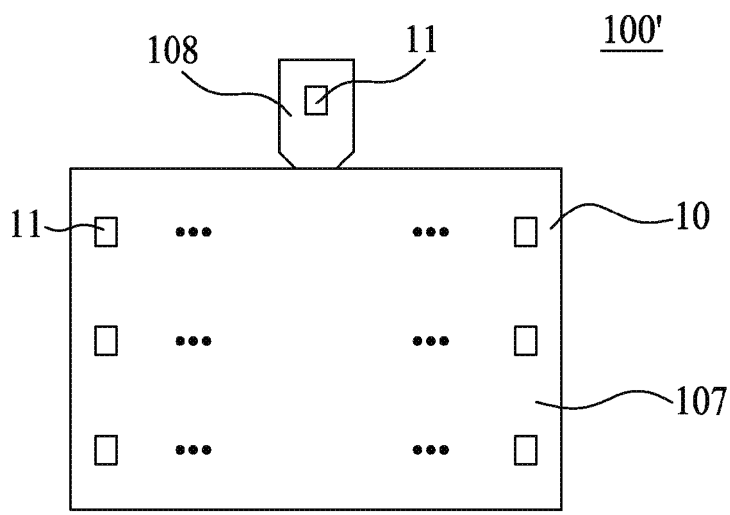


FIG. 11G

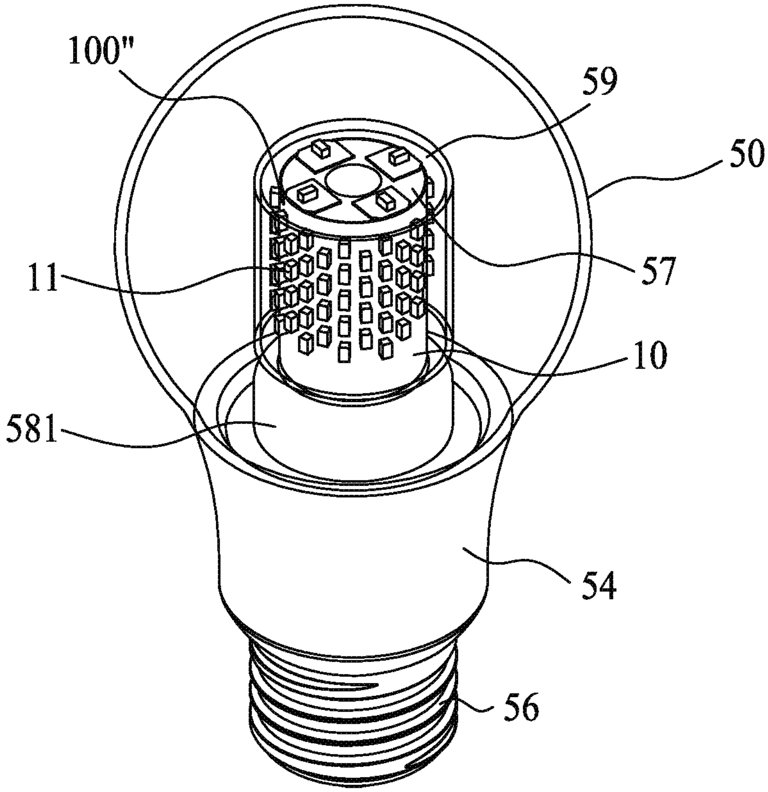


FIG. 11H

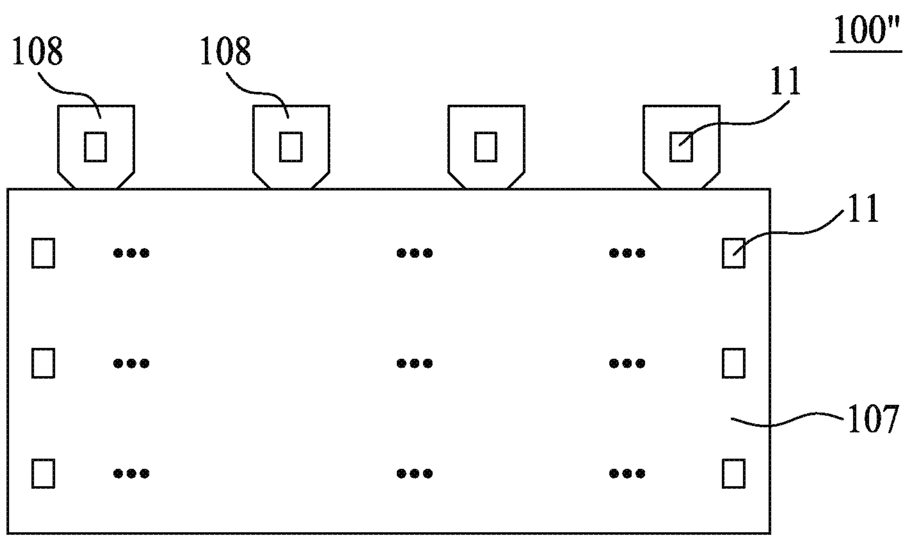


FIG. 11I

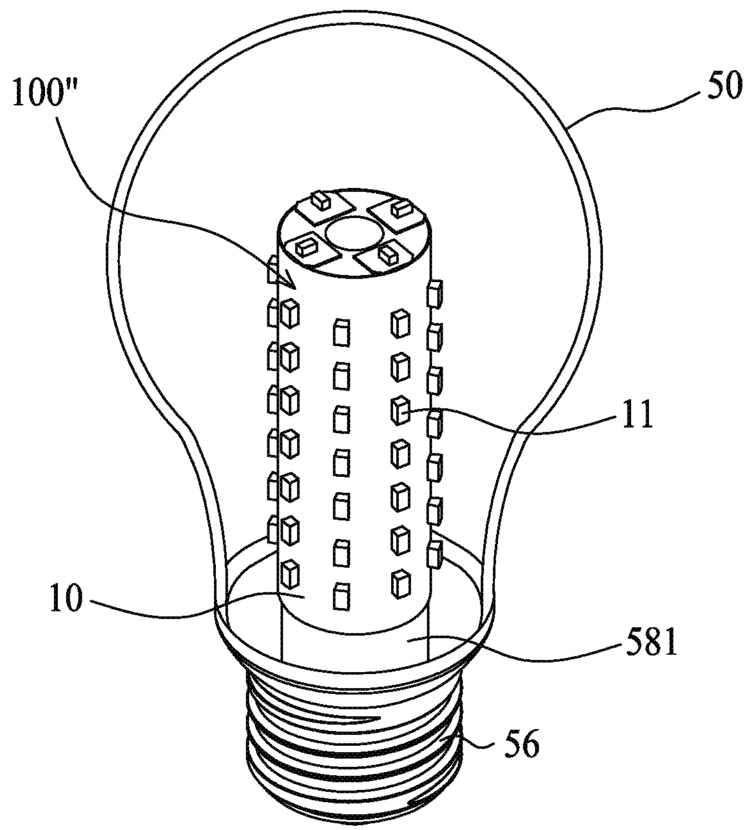


FIG. 11J

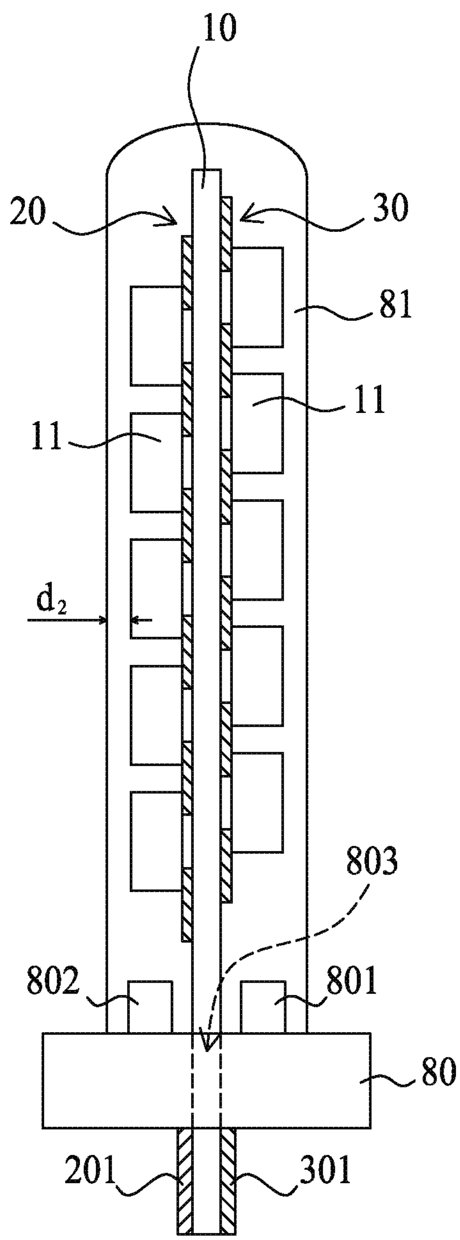


FIG. 12

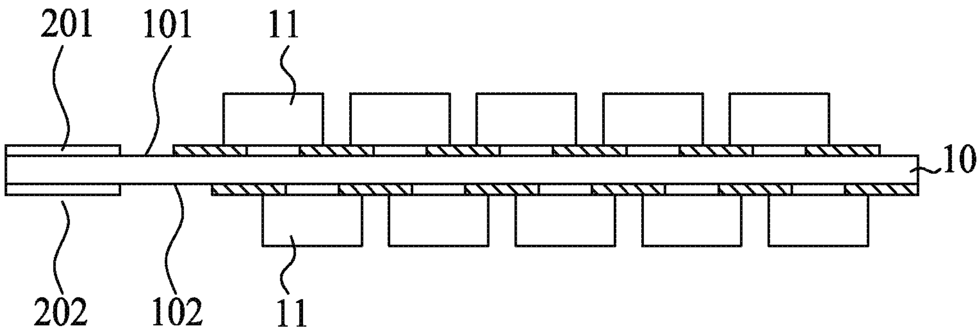


FIG. 12A

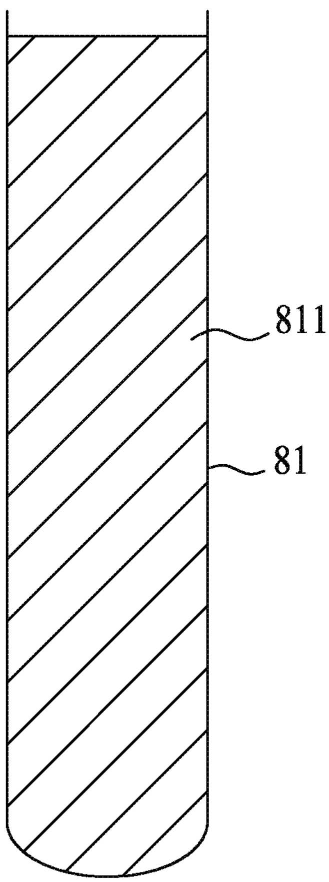


FIG. 12B

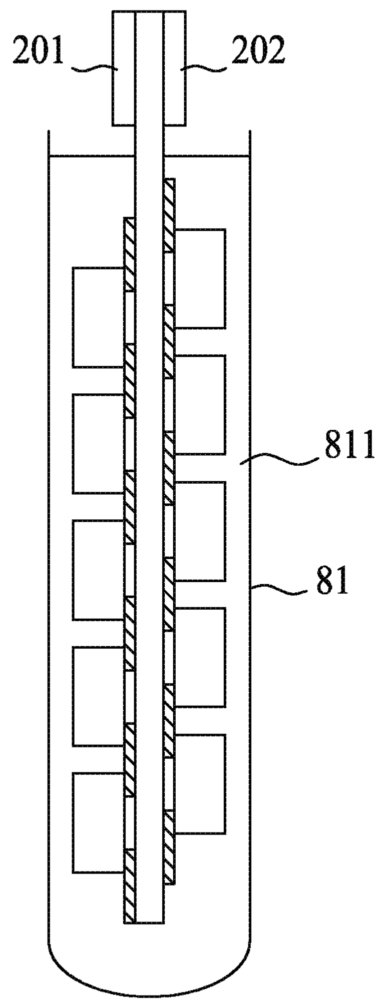


FIG. 12C

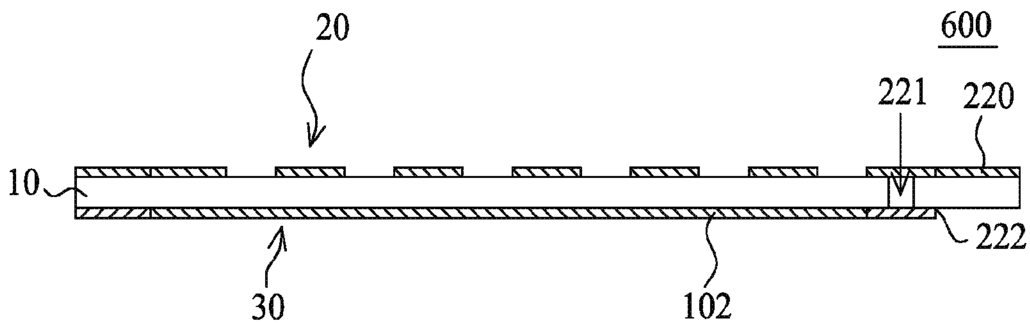


FIG. 13A

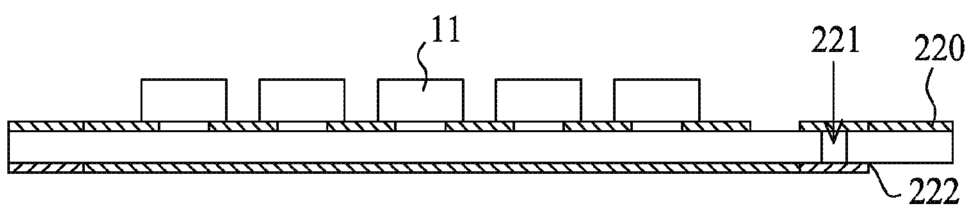


FIG. 13B

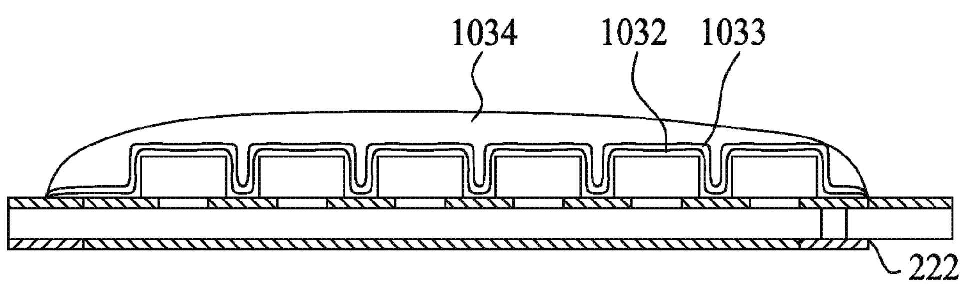


FIG. 13C

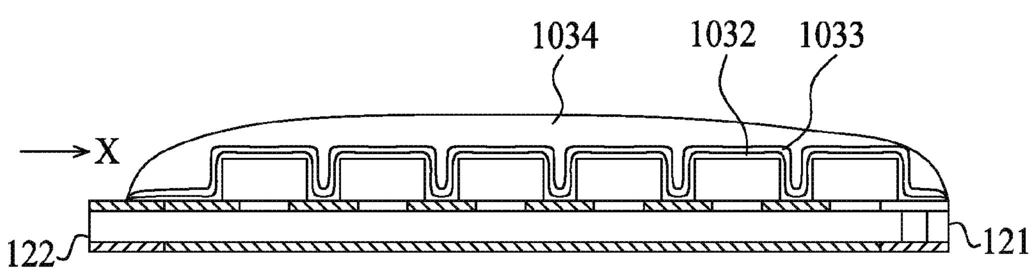


FIG. 13D

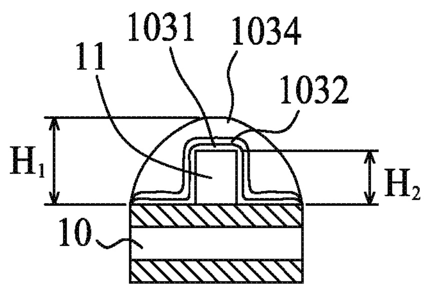


FIG. 13E

LIGHT EMITTING DEVICE

BACKGROUND

Technical Field

The present disclosure relates to a light-emitting device, and in particular to a light-emitting device with an omnidirectional light pattern.

Reference to Related Application

This application claims the right of priority based on TW application Serial No. 102120893, filed on Jun. 11, 2013. The entire content of the application is hereby incorporated by reference.

Description of the Related Art

The light-emitting diodes (LEDs) of the solid-state lighting elements have the characteristics of low power consumption, low heat generation, long operational life, shockproof, small volume, quick response and good opto-electrical property like light emission with a stable wavelength so the LEDs have been widely used in household appliances, indicator light of instruments, and opto-electrical products, etc. As the opto-electrical technology develops, the solid-state lighting elements have great progress in the light efficiency, operation life and the brightness, and LEDs are expected to become the main stream of the lighting devices in the coming future. However, in some application, there is a need to have a light-emitting apparatus with an omnidirectional light pattern which is not available using the conventional light emitting apparatus.

It is noted that the LEDs can be further connected to other components in order to form a light emitting apparatus. For example, the LEDs is disposed on a submount, and then on a carrier. Alternatively, a solder or an adhesive is formed between the LEDs and the carrier to form the light emitting apparatus. In addition, the carrier can further include electrode for electrically connecting to the LEDs.

SUMMARY OF THE DISCLOSURE

The present disclosure provides a light-emitting apparatus with an omnidirectional light pattern.

This disclosure discloses a light-emitting device. The light-emitting device comprises: a first electrode part; a second electrode part; a third electrode part, spaced apart from the first electrode part and the second electrode part; and a light-emitting unit partially covering the first electrode part and the second electrode part and fully covering the second electrode part, the light-emitting unit having a conductive structure contacting the second electrode part.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings are included to provide easy understanding of the application, and are incorporated herein and constitute a part of this specification. The drawings illustrate the embodiments of the application and, together with the description, serve to illustrate the principles of the application.

FIGS. **1**A and **1**B illustrate a perspective view of a light-emitting device in accordance with one embodiment of the present disclosure.

FIG. **1**C illustrates a perspective view of a light-emitting device in accordance with another embodiment of the present disclosure, showing a conductive connecting connector formed on a side of a carrier.

FIG. **2**A illustrates a top view of a light-emitting device in accordance with one embodiment of the present disclosure.

FIG. **2**B illustrates a cross-sectional view taken along from line I-I' of FIG. **2**A.

FIG. **3**A illustrates a top view of a light-emitting device in accordance with one embodiment of the present disclosure.

FIG. **3**B illustrates a cross-sectional view taken along from line II-II' of FIG. **3**A.

FIG. **4**A illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **4**B illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **4**C illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **4**D illustrates a bottom view of the light-emitting device of FIG. **4**C.

FIG. **4**E illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **4**F illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **4**G illustrates an equivalent circuit of the FIG. **4**F.

FIG. **5**A illustrates a cross-sectional view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **5**B illustrates a top view of the light-emitting device of FIG. **5**A.

FIG. **5**C illustrates a bottom view of the light-emitting device of FIG. **5**A.

FIG. **5**D illustrates a cross-sectional view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **5**E illustrates a top view of the light-emitting device of FIG. **5**D.

FIGS. **6**A and **6**B illustrate cross-sectional views of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **6**C illustrates a top view of the light-emitting device of FIGS. **6**A and **6**B.

FIGS. **6**D and **6**E illustrate top and bottom views of an electrical plate embodied in the light-emitting device of FIGS. **6**A and **6**B.

FIG. **7**A illustrates a cross-sectional view of a light-emitting diode unit in accordance with one embodiment of the present disclosure.

FIG. **7**B illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **7**C illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **7**D illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **8**A illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **8**B illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **8**C illustrates a partial cross-sectional view of the light-emitting diode unit of FIG. **8**A embodied in FIG. **5**A.

FIG. **8**D illustrates a cross-sectional view of a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **8**E illustrates a correlated color temperature spatial distribution of light emitted from a light-emitting diode unit in accordance with another embodiment of the present disclosure.

FIG. **9** illustrates a cross-sectional view of a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **10**A illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **10**B illustrates a top view of a circuit board on which a light-emitting device is mounted in accordance with one embodiment of the present disclosure.

FIG. **11**A illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **11**B illustrates a top view of FIG. **11**A.

FIG. **11**C illustrates a top view of a circuit board on which a light-emitting device is mounted in accordance with one embodiment of the present disclosure.

FIG. **11**D illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **11**E illustrates a top view of FIG. **11**D without a cover.

FIG. **11**F illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **11**G illustrates a flexible carrier in a non-bending state.

FIG. **11**H illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **11**I illustrates a flexible carrier in a non-bending state.

FIG. **11**J illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure.

FIG. **12** illustrates a cross-sectional view of an LED tube in accordance with one embodiment of the present disclosure.

FIGS. **12**A~**12**C illustrating a method of making the LED tube of FIG. **12**.

FIGS. **13**A~**13**D are views illustrating a method of making a light-emitting device in accordance with another embodiment of the present disclosure.

FIG. **13**E illustrate a cross-sectional view of a light-emitting device of FIG. **13**D.

DETAILED DESCRIPTION OF THE EMBODIMENTS

To better and concisely explain the disclosure, the same name or the same reference number given or appeared in different paragraphs or figures along the specification should has the same or equivalent meanings while it is once defined anywhere of the disclosure. In addition, these drawings are not necessarily drawn to scale. Likewise, the relative sizes of elements illustrated by the drawings may differ from the relative sizes depicted.

The following shows the description of embodiments of the present disclosure in accordance with the drawings.

FIGS. **1**A and **1**B illustrate a perspective view of a light emitting device **100** in accordance with one embodiment of the present disclosure. The light-emitting device **100** includes an oblong carrier with a top surface **101** and a bottom surface **102** opposite to the top surface **101**, a plurality of light-emitting units **11** disposed on the top surface **101**, a top electrode **20** formed on the top surface **101**, a bottom electrode **30** formed on the bottom surface **102**, and a transparent body **103** covering the top electrode **20** and the light-emitting units **11**. In this embodiment, the carrier **10** has a length of 18 mm~30 mm and a width smaller than 3 mm, and the light-emitting unit **11** has a width of 0.5 mm~1.5 mm and a length of 1 mm~3 mm. Referring to FIG. **1**A, the top electrode **20** includes two top electrode pads **201**, **202** and a top electrode connector **203**. Referring to FIG. **1**B, the bottom electrode **30** is formed on the bottom surface **102** and includes two bottom electrode pads **301**, **302** and a bottom electrode connector **303**. The bottom electrode connector **303** can be a straight line, and is physically and electrically connected to the two electrode pads **301**, **302**. As shown in FIG. **1**C, a conductive connecting connector **208** is optionally formed on a side of the carrier **10** for electrically connecting the top electrode pad **202** with the bottom electrode pad **302**. Alternatively, a via hole (not shown) is formed within and penetrating the carrier **10**, and a conductive material is fully or partly filled with the via hole for electrically connecting the top electrode pad **202** with the bottom electrode pad **302**. In operation, when the light-emitting device **100** is connected to an external source (power supply) and when the conductive connecting connector **208** is not provided, the two top electrode pads **201**, **202** can be respectively connected to a positive node and a negative node of the external source such that the light-emitting units **11** can emit light, that is, the external source is connected to the carrier **10** at the same surface (top surface) but at two opposite sides. In one embodiment, when the conductive connecting connector **208** is further provided for electrically connecting the top electrode pad **202** with the bottom electrode pad **302**, a positive node and a negative node of the external source can be respectively connected to the top electrode pad **201** and the bottom electrode pad **301** such that the light-emitting units **11** can emit light, that is, the external source is connected to the carrier **10** at the different surfaces (top surface and bottom surface) but at the same side. By virtue of the top electrode **20**, the bottom electrode **30** and/or the conductive connecting connector **208**, the light-emitting device **100** can be connected to the external source at the different surfaces but the same side or at the same surface but two opposite sides for different application of the light-emitting device.

The transparent body **103** can includes a single layer or a multilayer structure. When the transparent body **103** is a multilayer structure (not shown), it sequentially includes a first transparent layer, a wavelength conversion layer, and a second transparent layer. The first transparent layer and the second transparent layer can include, e.g. epoxy, polyimide, BCB, PFCB, SU8, acrylic resin, PMMA, PET, PC, polyetherimide, fluorocarbon polymer, glass, Al_2O_3, SINR, SOG, poly(tetrafluoroethene) or combinations thereof. The wavelength conversion layer includes aluminum oxide (such as YAG or TAG), silicate, vanadate, alkaline-earth metal silicate, alkaline-earth metal sulfide, alkaline-earth metal selenide, alkaline-earth metal gallium silicate, metal nitride, metal nitride oxide, a mixture of tungstate and molybdate, a mixture of oxide, or combinations thereof. In this embodiment, the light-emitting unit **11** can emit a blue light with a peak wavelength of 430 nm~480 nm, and some of the blue light is converted by the wavelength conversion layer to emit a yellow light with a peak wavelength of 570 nm~590 nm or a yellowish green light with a peak wavelength of 540 nm~570 nm. Furthermore, the yellow light or the yellowish green light is mixed with the unconverted blue light to produce a white light.

FIG. **2**A is a top view of the light-emitting device as shown in FIG. **1**A without showing the transparent body **103**. Refereeing to FIGS. **1**A and **2**A, the top electrode connector **203** is patterned and includes a plurality of electrode blocks **2031**. In this embodiment, the electrode blocks **2031** are arranged in a straight line along a length direction of the carrier **10** (X) and physically spaced apart from each other. Each of the electrode blocks **2031** includes a first end **2032** and a second end **2033**. In one embodiment, a distance (d_1) between the two adjacent light-emitting units **11** is 0.5 mm~1.2 mm, and each of the distances between the two adjacent light-emitting units **11** can be the same or different depending on actual requirements. FIG. **2**B is a cross-sectional view taken along line I-I' of FIG. **2**A with the transparent body **103** included. Referring to FIG. **2**B, each of the light-emitting units **11** has a first connecting pad **111** (for example, p pad) and a second connecting pad **113** (for example, n pad). The first connecting pad **111** and the second connecting pad **113** are at positions corresponding to the first end **2032** of one electrode block **2031** and the second end **2033** of adjacent one electrode block **2031** for physically and electrically connecting therebetween. Accordingly, the light-emitting units **11** are electrically connected in series with each other on the carrier **10**. The transparent body **103** is provided to cover portions of the top electrode **20** and the light-emitting units **11**.

FIG. **3**A is a top view of a light-emitting device in accordance with another embodiment of the present disclosure, but without showing the transparent body. FIG. **3**B is a cross-sectional view taken along line II-II' of FIG. **3**A with the transparent body included. Referring to FIGS. **3**A and **3**B, a top electrode connector **204** includes a first electrode region **2041** and a second electrode region **2042**. The first electrode region **2041** and the second electrode region **2042** are parallelly and alternately arranged along the length direction of the carrier **10** (X) and physically spaced apart from each other. The light-emitting units **11** are arranged along the length direction of the carrier **10** (X), and the first connecting pad **111** and the second connecting pad **113** are at positions corresponding to the first electrode region **2041** and the second electrode region **2042** for physically and electrically connecting therebetween. For example, the first connecting pad **111** of the light-emitting unit **11**A is corresponding to the first electrode region **2041**A and the second connecting pad **113** of the light-emitting unit **11**A is corresponding to the second electrode region **2042**A; the first connecting pad **111** of the light-emitting unit **11**B is corresponding to the second electrode region **2042**A and the second connecting pad **113** of the light-emitting unit **11**B is corresponding to the first electrode region **2041**B. The second connecting pad **113** of the light-emitting unit **11**A and the first connecting pad **111** of the light-emitting unit **11**B are both disposed on the second electrode region **2042**A for electrically connecting therebetween. Accordingly, the light-emitting units **11** are electrically connected in series with each other on the carrier **10**. In this embodiment, the second connecting pad **113** of the light-emitting units **11**A and the first connecting pad **111** of the light-emitting units **11**B are at the same side of the carrier **10**; the first connecting pad **111** of the light-emitting units **11**A and the second connecting pad **113** of the light-emitting units **11**B are at another side of the carrier **10**. The light-emitting device further includes a transparent body **103** covering the top electrode **20** and the light-emitting units **11**.

FIG. **4**A is a top view of a light-emitting device in accordance with another embodiment of the present disclosure. Referring to FIG. **4**A, a top electrode connector **205** includes a plurality of electrode zones **2051** arranged along the length direction of the carrier **10** at a first oblique angle to the length direction. Each of the electrode zones **2051** has a first end **2052** and a second end **2053**. The light-emitting units **11** are arranged along the length direction of the carrier **10** and at a second oblique angle with respect to the electrode zones **2051**. The first oblique angle can be the same or different from the second oblique angle. Each of the light-emitting units **11** has a first connecting pad (not shown) and a second connecting pad (not shown). The first connecting pad and the second connecting pad are respectively at positions corresponding to the first end **2052** of one electrode zone **2051** and the second end **2053** of adjacent one electrode zone **2051** for physically and electrically connecting therebetween. Accordingly, the light-emitting units **11** are electrically connected in series with each other on the carrier **10**. In this embodiment, all the second connecting pads of the light-emitting units **11** are at the same side of the carrier **10** and all the first connecting pads of the light-emitting units **11** are at another side of the carrier **10**.

FIG. **4**B is a top view of a light-emitting device in accordance with another embodiment of the present disclosure. Referring to FIG. **4**B, a top electrode connector **206** includes a first electrode bar **2061** and a second electrode bar **2062**. The top electrode pad **201** is merely connected to the first electrode bar **2061** and the top electrode pad **202** is merely connected to the second electrode bar **2062**. Each of the light-emitting units **11** has a first connecting pad (not shown) and a second connecting pad (not shown). The first connecting pad and the second connecting pad are respectively at positions corresponding to the first electrode bar **2061** and second electrode bar **2062** for physically and electrically connecting therebetween. Accordingly, the light-emitting units **11** are electrically connected in parallel with each other on the carrier **10**.

FIG. **4**C is a top view of a light-emitting device in accordance with another embodiment of the present disclosure. Referring to FIG. **4**C, the top electrode **20** includes a top electrode pad **201** and a top electrode connector **209** formed on the top surface **101** of the carrier **10**. The top electrode connector **209** includes a first electrode strip **2091** and the second electrode stripe **2092**. The first electrode stripe **2091** and the second electrode stripe **2092** are physically spaced apart from each other. The first electrode stripe **2091** includes a first region **20911**, a first stripe **20912** electrically connecting to and extending from the first region **20911** along the length direction of the carrier **10** (−X), and a plurality of first branches **20913** electrically connecting to and extending from the first stripe **20912** along the width direction of the carrier **10** (−Y). The second electrode stripe **2092** includes a second stripe **20921** electrically connecting to and extending from the top electrode pad **201** along the length direction of the carrier **10** (−X); and a plurality of second branches **20922** electrically connecting to and extending from the second stripe **20921** along the width direction of the carrier **10** (Y). The first stripe **20912** and the second stripe **20921** are parallel with each other; and the first branches **20913** and the second branches **20922** are alternately and parallelly arranged with each other. Each of the light-emitting units **11** has a first connecting pad (not shown) and a second connecting pad (not shown) which are at positions respectively corresponding to the first branches **20913** and the second branches **20922** for electrically connecting therebetween.

FIG. **4**D illustrates a bottom view of the light-emitting device in FIG. **4**C. The bottom electrode **30** includes a bottom electrode pad **301** and a bottom electrode connector **310** formed on the bottom surface **102** of the carrier **10**. The bottom electrode line **310** includes a third electrode stripe **3101** and the fourth electrode stripe **3102**. The third electrode stripe **3101** and the fourth electrode stripe **3102** are physically spaced apart from each other. The third electrode stripe **3101** includes a second region **31011**, a third stripe **31012** electrically connecting to and extending from the second region **31011** along the length direction of the carrier **10** (−X), and a plurality of third branches **31013** electrically connecting to and extending from the third stripe **31012** along the width direction of the carrier **10** (−Y). The fourth electrode stripe **3102** includes a third region **31021**, a fourth stripe **31022** electrically connecting to and extending from the bottom electrode pad **301** along the length direction of the carrier **10** (−X); and a plurality of fourth branches **31023** extending from and electrically connecting to the fourth stripe **31022** along the width direction of the carrier **10** (Y). The third stripe **31012** and the fourth stripe **31022** are parallel with each other; and the third branches **31013** and the fourth branches **31023** are alternately and parallelly arranged with each other. Each of the light-emitting units **11** has a first connecting pad (not shown) and a second connecting pad (not shown) which are at positions respectively corresponding to the fourth branches **31023** and the third branches **31013** for electrically connecting therebetween. Referring to FIGS. **4**C and **4**D, the first region **20911** is at the position corresponding to the third region **31021** and a hole **211** penetrates through the carrier **10** at the first region **20911** and the third region **31021**; the second region **31011** is at the position corresponding to the top electrode pad **201** and a hole **212** penetrates through the carrier **10** at the second region **31011** and the top electrode pad **201**. The holes **211**, **212** can include a conductive material fully or partly filled therewithin for electrically connecting the opposite surfaces of the carrier **10** with each other. To be more specific, when a positive node and a negative node of the external source are electrically connected to the top electrode pad **201** and the bottom electrode pad **301**, respectively, the top electrode pad **201** is electrically connected to the second region **31011** through the hole **212** for further electrically connecting to the third stripe **31012** and the third branches **31013**. In other words, the top electrode pad **201**, the second electrode stripe **2092** and the third electrode stripe **3101** are electrically connected to the positive node of the external source. Likewise, the first region **20911** is electrically connected to the third region **31021** through the hole **211**. Since the third region **31021** is electrically connected to the bottom electrode pad **301**, the bottom electrode pad **301** can be electrically connected to the first stripe **20912** and the first branches **20913**. In other words, the bottom electrode pad **301**, the first electrode strip **2091** and the fourth electrode stripe **3102** are electrically connected to the negative node of the external source. Accordingly, the light-emitting units **11** on the top surface **101** and the bottom surface **102** are all electrically connected in parallel with each other for emitting light. In this embodiment, with the hole **211**, the first stripe **20912** and the fourth stripe **31022** are electrically connected to each other. In other embodiment, instead of forming the first stripe **20912**, the first regions **20911** and the hole **211**, a plurality of individual holes is formed corresponding to each the first branch **20913** for electrically connecting the first branch **20913** with the fourth stripe **31022**.

FIG. **4**E illustrates a top view of the light-emitting device in accordance with another embodiment of the present disclosure. The top electrode connector **207** includes a first electrode region **2071**, a second electrode region **2072**, and a third electrode region **2073**. The first electrode region **2071**, the second electrode region **2072**, and the third electrode region **2073** are all rectangle. The long sides of the first electrode region **2071** and the third electrode region **2073** are parallel with the short side (width) of the carrier; the short side of the second electrode region **2072** is parallel with the long side (length) of the carrier. A plurality of the light-emitting units is disposed on the carrier **10** and electrically connected to each other in a bridge configuration by the arrangement of the top electrode connector **207**. The light-emitting units have the first connecting pad and the second connecting pad. It is noted that from the top view of FIG. **4**E, the first connecting pad and the second connecting pad cannot be clearly viewed. However, for clarifying this embodiment the first connecting pad and the second connecting pad are labeled in FIG. **4**E. To be more specific, the first connecting pad **111**C of the light-emitting unit **11**C is at the first electrode region **2071** for electrically connecting therebetween; the second connecting pad **113**C of the light-emitting unit **11**C is at the second electrode region **2072**A for electrically connecting therebetween; the first connecting pad **111**D of the light-emitting unit **11**D is at the third electrode region **2073** for electrically connecting therebetween; the second connecting pad **113**D of the light-emitting unit **11**D is at the second electrode region **2072**A for electrically connecting therebetween; the first connecting pad **111**E of the light-emitting unit **11**E is at the second electrode region **2072**A for electrically connecting therebetween; the second connecting pad **113**E of the light-emitting unit **11**E is at the second electrode region **2072**B for electrically connecting therebetween; the first connecting pad **111**F of the light-emitting unit **11**F is at the second electrode region **2072**B for electrically connecting therebetween; the second connecting pad **113**F of the light-emitting unit **11**F is at the first electrode region **2071** for electrically connecting therebetween; and the first connecting pad **111**G of the light-emitting unit **11**G is at the second electrode region **2072**B for electrically connecting therebetween; the second connecting pad **113**G of the light-emitting unit **11**G is at the third electrode region **2073** for electrically connecting therebetween such that the light-emitting units **11**C, **11**D, **11**E, **11**F, **11**G are electrically connected to each other in the bridge configuration. Therefore, the light-emitting device can be directly connected to an alternately current (AC) power supply. FIG. **4**G is an equivalent circuit of FIG. **4**E. In the positive cycle of the alternately current power supply, a positive-cycle current passes through the light-emitting units **11**C, **11**E, **11**G; and in the negative cycle of the alternately current power supply, a negative-cycle current passes through the light-emitting units **11**D, **11**E, **11**F. In this embodiment, only one bridge configuration is described, however, there can be a plurality of bridge configurations formed on the carrier **10** for electrically connecting to each other. In addition, the quantity of the bridge configurations is adjustable depending on a desired voltage (for example, 110V, 120V, 220V or 240V). FIG. **4**F illustrates a top view of a light-emitting device in accordance with another embodiment of the present disclosure. The light-emitting device in FIG. **4**F is similar with that in FIG. **4**E, except that the second electrode region **2072** can includes a plurality of sub electrode regions **2072**C between the sub electrode regions **2072**A, **2072**B. A plurality of light-emitting units **11**E is arranged on the sub electrode regions **2072**A, **2072**C,

2072B for electrically connecting in series to each other. In other embodiment, the light-emitting units **11**E can be connected to each other in parallel or in series-parallel.

FIG. **5**A illustrates a cross-sectional view of the light-emitting device **200** in accordance with another embodiment of the present disclosure. FIGS. **5**B and **5**C are a top view and a bottom view without showing the light-emitting units, respectively. Referring to FIGS. **5**A~**5**C, the light-emitting device **200** includes a carrier **10'** having a top surface **101'** and a bottom surface **102'** opposite to the top surface **101'**, a plurality of light-emitting units **12**A, **12**B respectively disposed on the top surface **101'** and the bottom surface **102'**, a top electrode **20'** on the top surface **101'**, a bottom electrode **30'** formed on the bottom surface **102'**, and a transparent body **103** covering the top electrode **20'**, the bottom electrode **30'**, and the light-emitting units **12**A, **12**B. As shown in FIG. **5**B, the top electrode **20'** includes a top electrode pad **201'**, a plurality of first electrode parts **2011'** and a plurality of second electrode parts **2012'**. The first electrode part **2011'** and the second electrode part **2012'** are arranged in a straight line along a length direction of the carrier **10'** (X), and physically and alternately spaced apart from each other. The second electrode part **2012'** includes a plurality of sub electrode part **20121'** spaced apart from each other. In this embodiment, the first electrode part **2011'** between two adjacent second electrode parts **2012'** has a length smaller than that of the second electrode part **2012'**. A distance between two adjacent light-emitting units is smaller than a length of one of the light-emitting units. In this embodiment, the second electrode part **2012'** includes three sub electrode parts **20121'** which are spaced apart from each other by a distance. Referring to FIGS. **5**A and **5**B, the light-emitting unit **12**A has a first connecting pad (not shown) at a position corresponding to the first electrode part **2011'** for electrically connecting therebetween, and the light-emitting unit **12**A has a second connecting pad (not shown) at a position corresponding to adjacent one first electrode part **2011'** for electrically connecting therebetween, such that the light-emitting unit **12**A partially covers the first electrode part **2011'** and the adjacent first electrode part **2011'**, and fully covers the second electrode part **2012'**. The second electrode part **2012'** contacts the light-emitting unit **12**A but is not electrically connected to the light-emitting unit **12**A for dissipating heat from the light-emitting unit **12**A to the ambient (air). It is noted that the "contact" means directly contact or indirectly contact. The indirectly contact indicates a conductive material (for example: solder) or a non-conductive material (for example: adhesive) formed between the light-emitting unit **12**A and the second electrode part **2012'**. In another embodiment, the second electrode part **2012'** can also be electrically connected to the light-emitting unit **12**A. Referring to FIG. **5**C, the bottom electrode **30'** includes a bottom electrode pad **301'**, a plurality of third electrode parts **3011'** and a plurality of fourth electrode parts **3012'**. The bottom electrode **30'** has a pattern similar with that of the top electrode **20'**. The third electrode parts **3011'** and the fourth electrode parts **3012'** are arranged in a straight line along a length direction of the carrier **10'** (X), and physically and alternately spaced apart from each other. The fourth electrode part **3012'** includes three sub electrode parts **30121'** spaced apart from each other. Referring to FIGS. **5**A and **5**C, the light-emitting unit **12**B has a first connecting pad (not shown) at a position corresponding to the third electrode part **3011'** for electrically connecting therebetween, and the light-emitting unit **12**B has a second connecting pad (not shown) at a position corresponding to adjacent third electrode part **3011'** for electrically connecting therebetween. The fourth electrode part **3012'** contacts the light-emitting unit **12**B but is not electrically connected to the light-emitting unit **12**B for dissipating heat from the light-emitting unit **12**B to the ambient (air). In another embodiment, the fourth electrode part **3012'** can also be electrically connected to the light-emitting unit **12**B. It is noted that the first electrode part **2011'** and the fourth electrode part **3012'** are respectively formed on the top surface **101'** and the bottom surface **102'** at the position corresponding to each other, and the second electrode part **2012'** and the third electrode part **3011'** are respectively formed on the top surface **101'** and the bottom surface **102'** at the position corresponding to each other. Accordingly, the light-emitting units **12**A on the top surface **101'** and the light-emitting units **12**B on the bottom surface **102'** are alternately arranged, and the light-emitting units **12**A does not fully overlap the light-emitting units **12**B. The quantity, the shape, and the length of the sub electrode parts can be varied. The distance between the sub electrode parts can also be varied. Moreover, the quantity, the shape, and the length of the first electrode part **2011'**, the second electrode part **2012'**, the third electrode part **3011'**, the fourth electrode part **3012'** can also be varied. In this embodiment, like FIG. **1**C, a conductive connecting connector **208** is optionally formed on a side of the carrier **10'** for electrically connecting the first electrode part **2011'** at the end position with the third electrode part **3011'** at the end position. Alternatively, a hole (not shown) is optionally formed to penetrate through the carrier **10'** and a conductive material is fully or partly filled with the hole for electrically connecting the first electrode part **2011'** with the third electrode part **3011'**. Therefore, in operation, when the light-emitting device is connected to the external source, a positive node and a negative node of the external source can be electrically connected to the top electrode pad **201'** and the bottom electrode pad **301'** such that the light-emitting units **12**A, **12**B are electrically connected in series to each other for emitting light, that is, the external source is connected to the carrier **10** at the different surfaces (top surface and bottom surface) but at the same side.

FIG. **5**D illustrates a cross-sectional view of the light-emitting device **200'** in accordance with another embodiment of the present disclosure. FIG. **5**E illustrates a cross-sectional view of the light-emitting device **200'** in accordance with another embodiment of the present disclosure. The light-emitting device **200'** has a structure similar with the light-emitting device **200**. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting device **200'** further includes a dam **35** formed on the top surface **101'** and/or the bottom surface **102'** to surround the light-emitting units **12**A, **12**B (as shown in FIG. **5**E). Subsequently, a transparent body **103** is formed on the light-emitting units **12**A, **12**B and the dam **35**. In this embodiment, the dam **35** has a height (0.3 mm~0.75 mm) lower than that of the light-emitting units **12**A, **12**B (0.8 mm~1 mm), thereby a coverage range of the transparent body **103** can be substantially limited by the dam **35**. Using the same amount of transparent body **103**, compared to the light-emitting device without the dam **35**, the transparent body **103** of the light-emitting device with the dam **35** has a smooth top surface for improving a uniformity of the emitting angle of the light-emitting device. The dam **35** is made of a material the same or different from the transparent body **103** and including silicone, epoxy, polyimide, BCB, PFCB, SU8, acrylic resin, PMMA, PET, PC, polyetherimide, fluorocarbon polymer, glass, Al_2O_3, SINR, SOG, Poly(tetrafluoroethene) or combinations thereof.

FIGS. **6**A and **6**B illustrate cross-sectional views of the light-emitting device **300** in accordance with another embodiment of the present disclosure. FIG. **6**C illustrates a top view of the light-emitting device **300** without showing an electrical plate **25**. The light-emitting device **300** includes a carrier **10"** having a top surface **101"** and a bottom surface **102"** opposite to the top surface **101"**, a plurality of light-emitting units **13** disposed on the top surface **101"**, a top electrode **20"** on the top surface **101"**, an electrical plate **25**, and a transparent body **103** covering the top electrode **20"**, the light-emitting units **13** and part of the electrical plate **25**. As shown in FIG. **6**C, the top electrode **20"** includes a first electrode pad **201"**, a second electrode pad **202"**, a plurality of first electrode parts **2011"**, a plurality of second electrode parts **2012"**, and a third electrode part **2013"**. The first electrode pad **201"** and the second electrode pad **202"** are arranged at the same side and the same surface (the top surface). The first electrode part **2011"** and the second electrode part **2012"** are arranged in a straight line along a length direction of the carrier **10"** (X), and physically and alternately spaced apart from each other. The third electrode part **2013"** is a straight line and parallel with the first electrode part **2011"** and the second electrode part **2012"**. The top electrode **20"** further includes a bended part **2014"** which has an end arranged in a straight line with and spaced apart from the second electrode part **2012"** while the other end is physically and electrically connected to the third electrode part **2013"**. The second electrode part **2012"** includes a plurality of sub electrode part **20121"** spaced apart from each other. In this embodiment, the second electrode part **2012"** includes three sub electrode parts **20121"** spaced apart from each other by a distance. Referring to FIG. **6**A, the light-emitting unit **13** has a first connecting pad (not shown) at a position corresponding to the first electrode part **2011"** for electrically connecting therebetween, and the light-emitting unit **13** has a second connecting pad (not shown) at a position corresponding to adjacent first electrode part **2011'** for electrically connecting therebetween. The second electrode part **2012"** contacts the light-emitting unit **13** but is not electrically connected to the light-emitting unit **13** for dissipating heat from the light-emitting unit **13** to the ambient (air). In another embodiment, the second electrode part **2012"** can also be electrically connected to the light-emitting unit **13**. As shown in FIGS. **6**A, **6**B, **6**D, and **6**E, the electrical plate **25** includes a board **250** having a top surface **251** and a bottom surface **252** opposite to the top surface **251**, a first electrode block **253** formed on the top surface **251** and a second electrode block **254** formed on the bottom surface **252**. Referring to FIG. **6**D, the first electrode block **253** has a first section **2531** and a second section **2532** connecting to the first section **2531**. Referring FIG. **6**E, the second electrode block **254** has a third section **2541**, and a fourth section **2542** without physically connecting to the third section **2541**. The second section **2532** and the fourth section **2542** are respectively formed on the top surface **251** and the bottom surface **252** at the position corresponding to each other. A hole **255** penetrates through the board **250** at the second section **2532** and the fourth section **2542** (as shown in FIG. **6**A), and a conductive material can be fully or partly filled within the hole **255** for electrically connecting the second section **2532** with the fourth section **2542**. The electrical plate **25** is disposed at a position corresponding to the top electrode **20"** of the carrier **10"**, the fourth section **2542** is physically and electrically connected to the first electrode pad **201"**, the third section **2541** is physically and electrically connected to the second electrode pad **202"**, and the fourth section **2542**

is electrically connected to the first electrode block **253** through the conductive material filled within the hole **255**. In operation, a positive node and a negative node of the external source can be electrically connected to the first section **2531** of the first electrode block **253** and the third section **2541** of the second electrode block **254** such that the light-emitting units **13** can emit light. Specifically, the first electrode block **253** is electrically connected to the fourth section **2542** through the conductive material filled within the hole **255**, and the fourth section **2542** is physically and electrically connected to the first electrode pad **201"**, thus the positive node of the external source can be electrically connected to the first electrode pad **201"**. Likewise, the negative node of the external source can be electrically connected to the second electrode pad **202"** through the third section **2541**. Since the positive node and the negative node of the external source can be electrically connected to the first electrode block **253** and the second electrode block **254**, respectively, and the first electrode block **253** and the second electrode block **254** are respectively arranged on the top surface **251** and the bottom surface **252** of the electrical plate **25**, the external source is connected to the electrical plate **25** at the different surfaces (top surface **251** and bottom surface **252**) but at the same side. By virtue of the hole **255**, the first section **253** is connected to the first electrode pad **201"** such that the positive node and the negative node of the external source can be electrically connected to the first electrode pad **201"** and the second electrode pad **202"**, respectively, and the first electrode pad **201"** and the second electrode pad **202"** are formed on the top surface **101"** of the carrier **10"**, therefore, the external source is connected to the carrier **10"** at the same surface (top surface **101"**) and at the same side. In another embodiment, the first electrode block and the second electrode block can be designed to form on the top surface of the electrical plate and a hole is formed at the first electrode block and the second electrode block. With the conductive material filled within the hole, the first electrode block and the second electrode block are electrically connected to the first electrode pad and the second electrode pad, respectively, therefore, the external source is connected to the electrical plate at the same surface (top surface **101**) and at the same side.

It is noted that the sub electrode parts described in FIG. **5**A can also be formed in FIGS. **2**A, **3**A **4**A~**4**E. In other words, there are sub electrode parts formed between the electrode blocks **2031** in FIG. **2**A; there are sub electrode parts formed between the first electrode region **2041** and the second electrode region **2042** in FIG. **3**A; there are sub electrode parts formed between the electrode zones **2051** in FIG. **4**A; there are sub electrode parts formed between the first electrode bar **2061** and the second electrode bar **2062** in FIG. **4**B; there are sub electrode parts formed between the first branch **20913** and the second branch **20922** in FIG. **4**C; there are sub electrode parts formed between the third branch **31013** and the fourth branch **31023** in FIG. **4**D; and there are sub electrode parts formed between the first electrode region **2071**, the second electrode region **2072**, and the third electrode region **2073**. The sub electrode parts contacts the light-emitting unit but is not electrically connected to the light-emitting unit for dissipating heat from the light-emitting unit to the ambient (air). In another embodiment, the sub electrode parts can also be electrically connected to the light-emitting unit.

FIG. **7**A illustrates a cross-sectional view of a light-emitting diode unit **1000** in accordance with one embodiment of the present disclosure, which can be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, 4A~4F, **5**A, **5**D, and **6**A. The light-emitting diode unit **1000** includes a substrate **7000**, a first-type semiconductor layer **7001**, an active layer **7002**, and a second-type semiconductor layer **7003**. The first-type semiconductor layer **7001** and the second-type semiconductor layer **7003**, for example a cladding layer or a confinement layer, respectively provide electrons and holes such that electrons and holes can be combined in the active layer **7002** to emit light. A first conductive portion **7004** and a second conductive portion **7005** are formed on the second-type semiconductor layer **7003** and the first-type semiconductor layer **7001**, respectively. The light-emitting diode unit **1000** is a flip-chip light-emitting diode unit. In another embodiment, the light-emitting diode unit **1000** can further includes a wavelength conversion material (not shown) formed on the substrate **7000** to convert light emitted by the active layer **7002**. In another embodiment, the light-emitting diode unit **1000** is a thin-film light-emitting diode structure without the substrate **7000**. Therefore, a wavelength conversion material (not shown) is directly formed on the first-type semiconductor layer **7001**. It is noted that when the light-emitting diode unit **1000** is used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A, the first conductive portion **7004** acts as the previously described first connecting pad or the second connecting pad, and the second conductive portion **7005** acts as the previously described second connecting pad or the first connecting pad. Accordingly, a connection configuration between the first conductive portion **7004**, the second conductive portion **7005**, the top electrode or/and the bottom electrode is the same as the connection configuration between the first (second) connecting pad, the second (first) connecting pad, the top electrode or/and the bottom electrode. The light-emitting diode unit **1000** further includes a protective layer **7006** made of a transparent insulation material with a high thermal conductivity coefficient (for example, diamond like carbon) and formed to cover the first-type semiconductor layer **7001**, the second-type semiconductor layer **7003**, and the active layer **7002**. Therefore, when the light-emitting diode unit **1000** is used as the light-emitting units **12**A, **12**B, **13** in FIGS. **5**A and **6**A, the protective layer **7006** can contact the electrode part **2012'**, **3012'**, **2012"** for dissipating heat from the light-emitting diode unit **1000** to the ambient (air). Furthermore, the protective layer **7006** can also include a reflective material therein (for example, TiO_2, SiO_2, Al_2O_3, ZrO_2, ZnS, ZnO, or MgO).

FIG. **7**B illustrates a cross-sectional view of a light-emitting diode unit **1001** in accordance with one embodiment of the present disclosure. The light-emitting diode unit **1001** has a structure similar with the light-emitting diode unit **1000**, and can also be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, and **6**A. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **1001** further includes a reflective layer **7007** to cover the first-type semiconductor **7001**, the second-type semiconductor **7003**, and the active layer **7002**. Accordingly, the light emitted from the active layer **7002** is able to be reflected toward the substrate **7000**. The light-emitting diode unit **1001** can also include a protective layer **7006** formed on the reflective layer **7007** that is made of a transparent insulation material with a high thermal conductivity coefficient (for example, diamond like carbon). When the light-emitting diode unit **1001** is used as the light-emitting units **12**A, **12**B, **13** in FIGS. **5**A and **6**A, the protective layer **7006** can contact the electrode part **2012'**, **3012'**, **2012"** for dissipating heat from the light-emitting diode unit **1001** to the ambient (air). The reflective layer **7007** comprises insulating material, such as SiO_x, Al_2O_3, TiO_2 or combinations thereof.

FIG. **7**C illustrates a cross-sectional view of a light-emitting diode unit **1002** in accordance with one embodiment of the present disclosure. The light-emitting diode unit **1002** has a structure similar with the light-emitting diode unit **1000** and can also be used as any one of the light-emitting unit **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, and **6**A. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **1000** merely includes a light-emitting diode; however, the light-emitting diode unit **1002** includes a plurality of light-emitting diodes commonly formed on a common substrate **7010**. The light-emitting diodes are physically spaced apart from each other on the common substrate **7010** and a conductive structure **7015** is provided to electrically connect the light-emitting diodes with each other in series, in parallel or in series-parallel such that the light-emitting diode unit **1002** is capable of operating in a high voltage (an operating voltage (such as 6V, 12V, 24V, 36V, or 45V) is larger than the forward voltage of a light-emitting diode (about 3V)). In this embodiment, the light-emitting diode unit **1002** includes three light-emitting diodes and has an operating voltage of about 9V (3V*3=9V). An insulation layer **7016** formed between the light-emitting diodes and the conductive structure **7015** for avoiding an undesired electrical path. In another embodiment, as shown in FIGS. **7**A and **7**B, the light-emitting diode unit **1002** con includes a protective layer (not shown) for covering the first-type semiconductor **7001**, the second-type semiconductor **7003**, the active layer **7002** and the conductive structure **7015**. Alternatively, a reflective layer (not shown) is provided to cover the first-type semiconductor **7001**, the second-type semiconductor **7003**, and the active layer **7002**. Accordingly, the light emitted from the active layer **7002** is able to be reflected toward the substrate **7000**. Likewise, when the light-emitting diode unit **1002** is used as the light-emitting unit **12**A, **12**B, **13** in FIGS. **5**A and **6**A, the protective layer **7006** can contact the electrode part **2012'**, **3012'**, **2012"** for dissipating heat from the light-emitting diode unit **1002** to the ambient (air). It is noted that the light-emitting diode unit **1002** merely has one first conductive portion **7004'** formed on the second-type semiconductor layer **7003** of one light-emitting diode and one second conductive portion **7005'** are formed on the first-type semiconductor layer **7001** of another light-emitting diode. When the light-emitting diode unit **1002** is used as the light-emitting unit **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A, the first conductive portion **7004'** acts as the previously described first connecting pad or the second connecting pad, and the second conductive portion **7005'** acts as the previously described second connecting pad or the first connecting pad. Accordingly, a connection configuration between the first conductive portion **7004'**, the second conductive portion **7005'**, the top electrode or/and the bottom electrode is the same as the connection configuration between the first (second) connecting pad, the second (first) connecting pad, the top electrode or/and the bottom electrode. By connecting the first conductive portion **7004'** and the second conductive portion **7005'** to the external source, all the light-emitting diodes can emit light. The reflective layer **7007** includes an insulating material, such as SiO_x, Al_2O_3, TiO_2 or combinations thereof.

FIG. **7**D illustrates a cross-sectional view of a light-emitting diode unit **1003** in accordance with one embodiment of the present disclosure. The light-emitting diode unit

1003 has a structure similar with the light-emitting diode unit **1000** and can also be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, and **6**A. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **1003** further includes a first expansion electrode portion **7024** that is physically and electrically connected to the first conductive portion **7004**, and that has an area greater than that of the first conductive portion **7004**; and a second expansion electrode portion **7025** that is physically and electrically connected to the second conductive portion **7005** and that has an area greater than that of the second conductive portion **7005**. Likewise, when the light-emitting diode unit **1003** is used as the any one of light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A, the first expansion electrode portion **7024** acts as the previously described first (second) connecting pad), and the second expansion electrode portion **7025** acts as the previously described second (first) connecting pad. Accordingly, a connection configuration between the first expansion electrode portion **7024**, the second expansion electrode portion **7025**, the top electrode or/and the bottom electrode is the same as the connection configuration between the first (second) connecting pad, the second (first) connecting pad, the top electrode or/and the bottom electrode. In this embodiment, the first expansion electrode portion **7024** and the second expansion electrode portion **7025** are provided for facilitating a subsequent alignment process.

FIG. **8**A illustrates a cross-sectional view of a light-emitting diode unit **2000** in accordance with one embodiment of the present disclosure, which can be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A. The light-emitting diode unit **2000** has a structure similar with the light-emitting diode unit **1003**. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **2000** includes a substrate **7000**, a first-type semiconductor layer **7001**, an active layer **7002** and a second-type semiconductor layer **7003**. The first-type semiconductor layer **7001** and the second-type semiconductor layer **7003**, for example a cladding layer or a confinement layer, respectively provide electrons and holes such that electrons and holes can be combined in the active layer **7002** to emit light. A first conductive portion **7004** and a second conductive portion **7005** are formed on the second-type semiconductor layer **7003** and the first-type semiconductor layer **7001**, respectively. The light-emitting diode unit **2000** is a flip-chip light-emitting diode unit. A space **7008** is formed between the first conductive portion **7004** and the second conductive portion **7005**. The first conductive portion **7004** has a contact surface **70041** and the second conductive portion **7005** has a contact surface **70051** substantially coplanar with the contact surface **70041**. A transparent substance covers the substrate **7000**, the first-type semiconductor layer **7001**, the active layer **7002** and the second-type semiconductor layer **7003** and further fully fills into the space **7008** to form a first transparent structure **7026**. In another embodiment, the transparent substance does not fully fill the space **7008**, and there may have air between the first conductive portion **7004** and the second conductive portion **7005**. The first transparent structure **7026** has a surface **70261** substantially coplanar with the contact surface **70041**, **70051**. Subsequently, the protective layer **7006** formed on a surface of the first transparent structure **7026** to expose the first conductive portion **7004** and the second conductive portion **7005**. A first

expansion electrode portion **7024** and a second expansion electrode portion **7025** formed on and electrically connected to the first conductive portion **7004** and the second conductive portion **7005**, respectively, and further formed on the protective layer **7006**. In this embodiment, the first expansion electrode portion **7024** has a sidewall **70241** not coplanar with a sidewall **70061** of the protective layer **7006**; the second expansion electrode portion **7025** has a sidewall **70251** not coplanar with another sidewall **70062** of the protective layer **7006**. In other embodiment, the sidewall **70241** of the first expansion electrode portion **7024** can be coplanar with a sidewall **70061** of the protective layer **7006**; the sidewall **70251** of the second expansion electrode portion **7025** can be coplanar with the another sidewall **70062** of the protective layer **7006**. The light-emitting diode unit **2000** further includes a second transparent structure **7027** formed on the first transparent structure **7026**. The first transparent structure **7026** includes silicone, epoxy, polyimide (PI), BCB, perfluorocyclobutane (PFCB), SU8, acrylic resin, polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), polycarbonate (PC), polyetherimide, fluorocarbon polymer, Al_2O_3, SINR, or spin-on-glass (SOG). The second transparent structure **7027** can include sapphire, diamond, glass, epoxy, quartz, acryl resin, SiO_x, Al_2O_3, ZnO, silicone, and/or any combination thereof.

FIG. **8**B illustrates a cross-sectional view of a light-emitting diode unit **2001** in accordance with one embodiment of the present disclosure, which can be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A. The light-emitting diode unit **2001** has a structure similar with the light-emitting diode unit **2000**. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **2000** merely includes a light-emitting diode; however, the light-emitting diode unit **2001** includes a plurality of light-emitting diodes. In this embodiment, each of the light-emitting diodes has a respective substrate, but in another embodiment, as shown in FIG. **7**C, the light-emitting diodes can be commonly formed on a substrate. The light-emitting diodes are electrically connected to each other (in series, in parallel or in series-parallel) through a conductive structure **7015'**. In this embodiment, the conductive structure **7015'** physically and electrically connects the second conductive portion **7005** of one light-emitting diode with the first conductive portion **7004** of adjacent light-emitting diode in series. The transparent structure **7026** covers the light-emitting units. It is noted that when the light-emitting diode unit **2001** is used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A, the first expansion electrode portion **7024** acts as the previously described first (second) connecting pad, and the second expansion electrode portion **7025** acts as the previously described second (first) connecting pad. Accordingly, a connection configuration between the first expansion electrode portion **7024**, the second expansion electrode portion **7025**, the top electrode or/and the bottom electrode is the same as the connection configuration between the first (second) connecting pad, the second (first) connecting pad, the top electrode or/and the bottom electrode. By connecting the first expansion electrode portion **7024** and the second expansion electrode portion **7025** to the external source, the light-emitting diodes can emit light. FIG. **8**C is a partially cross-sectional view where the light-emitting diode unit **2001** is applied in the light-emitting device of FIG. **5**. In this embodiment, only one light-emitting diode unit **2001** is shown to be disposed on the carrier **10**. The light-emitting diode unit **2001** includes four light-emitting diodes **12**A**1**, **12**A**2**, **12**A**3**, **12**A**4**. The first expansion electrode portion **7024** merely covers partial of the first electrode part **2011'**A and the second expansion electrode portion **7025** and merely cover partial of the first electrode part **2011'**B. The conductive structure **7015'** includes a plurality of sub conductive structures **70151'** which all are not physically connected to the first electrode parts **2011'**A, **2011'**B. The first electrode part **2011'**A is merely physically connected to the light-emitting diodes **12**A**1**, the second electrode part **2012'** is physically connected to the light-emitting diodes **12**A**1**, **12**A**2**, **12**A**3**, **12**A**4**, and the first electrode part **2011'**B is merely physically connected to the light-emitting diodes **12**A**4**. The first transparent structure **7026** merely cover partial of the first electrode part **2011'**A, **2011'**B but cover full of the second electrode part **2012'**. A protective layer **7006** is formed between the conductive structure **7015'** and the first transparent structure **7026**. The conductive structure **7015'** can be physically connected to the electrode part **2012'** (**3012'**) for dissipating heat from the light-emitting diode unit **2001** to the ambient (air). Similarly, the light-emitting diode unit **2001** can also be used as the light-emitting unit **13** in FIG. **6**A. Alternatively, when the light-emitting device of the aforesaid embodiments further has sub electrode parts, the light-emitting diode unit **2001** can still be used as any one of the light-emitting unit of these light-emitting devices. In this embodiment, the conductive structure **7015'** includes Au, Al, Cu, or Pt, and is electrically connected to the electrode part **2012'** (**3012'**, **2012"**). The conductive structure **7015'** has a shape or area as the same as that of the electrode part **2012'** (**3012'**, **2012"**). Referring to FIGS. **5**A, **8**C (**6**A), the electrode part **2012'** (**3012'**, **2012"**) has three sub electrode parts **20121'** (**30121'**, **20121"**) and the conductive structure **7015'** has three sub conductive structures **70151'**, that is, the amount of the sub electrode parts is equal to (corresponding to) the sub conductive structures. In other embodiment, the sub conductive structure **70151'** has an area smaller than that of the corresponding sub electrode part.

FIG. **8**D illustrates a cross-sectional view of a light-emitting diode unit **2002** in accordance with one embodiment of the present disclosure, which can be used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting diode unit **2001** includes a plurality of light-emitting diodes commonly formed on a common substrate **7000**. The light-emitting diodes are physically spaced apart from each other on the common substrate **7000** and a conductive structure **7015** is provided to electrically connect the light-emitting diodes with each other in series, in parallel or in series-parallel such that the light-emitting diode unit **2002** is capable of operating in a high voltage (an operating voltage (such as 6V, 12V, 24V, 36V, or 45V) larger than the forward voltage of a light-emitting diode (about 3V)). In this embodiment, the light-emitting diode unit **2002** includes four light-emitting diodes and has an operating voltage of about 12V (3V*4=12V). An insulation layer **7016** is formed between the light-emitting diodes and the conductive structure **7015** for avoiding an undesired electrical path. It is noted that the light-emitting diode unit **2002** merely has one first conductive portion **7004** formed on the second-type semiconductor layer **7003** of one light-emitting diode and one second conductive portion **7005** formed on the first-type semiconductor layer **7001** of another light-emitting diode. When the light-emitting diode unit **2002** is used as any one of the light-emitting units **11**, **12**A, **12**B, **13** in FIGS. **1**A, **3**A, **4**A~**4**F, **5**A, **5**D, and **6**A, the first conductive portion **7004** acts as the previously described first connecting pad or the second connecting pad, and the second conductive portion **7005** acts as the previously described second connecting pad or the first connecting pad. Accordingly, a connection configuration between the first conductive portion **7004**, the second conductive portion **7005**, the top electrode or/and the bottom electrode is the same as the connection configuration between the first (second) connecting pad, the second (first) connecting pad, the top electrode or/and the bottom electrode. By connecting the first conductive portion **7004** and the second conductive portion **7005** to the external source, all the light-emitting diodes can emit light. The first transparent structure **7026** covers all the light-emitting units.

The aforesaid light-emitting diode units **1000**, **1001**, **1002**, **2000**, **2001**, **2002** having the protective layer or/and the reflective layer can emit light from the light-emitting diode unit toward the substrate which is substantially defined as a five-surface light-emitting diode unit. When the light-emitting units **11**, **13** are merely arranged on the top surface **101**, **101"** of the carrier **10**, **10"** (shown in FIGS. **1**A, **3**A, **4**A~**4**F, **6**A) and includes a transparent body **103** having the wavelength conversion layer dispersed in and formed on the light-emitting units **11**, **13** and portion of the carrier, portion of the light (ex. blue light) emitted from the light-emitting unit is converted to another light (ex. yellow or yellowish-green light) by the wavelength conversion layer. The blue light is mixed with the yellow light (or yellowish-green light) to form a white light. In other embodiment, the light-emitting diode unit includes a wavelength conversion material for converting the light emitted by the active layer, thus the transparent body **103** does not includes the wavelength conversion layer. In this embodiment, the carrier is a transparent or semi-transparent. Portions of the white light can be scattered or reflected by the particles within the wavelength conversion layer (or the wavelength conversion material) to be incident on the transparent or semi-transparent carrier such that the white light not only emits outwardly through a side (top surface) of the transparent carrier on which the light-emitting unit is arranged, but also emits outwardly through a side surface and a bottom surface of the transparent carrier, which indicates the white light can emit outwardly through all surfaces of the carrier (defined as a six-surface light-emitting device). In addition, a diffusing powder (ex. TiO_2) is optionally added into the wavelength conversion layer (or the wavelength conversion material) for increasing the possibility in which the white light progresses downward. In short, in this embodiment, an approximately uniform light distribution (can be seen from a six-surface light-emitting device) can be achieved by using a non-uniform light source (such as five-surface light-emitting diode). Furthermore, the white light at the side of the transparent carrier on which the light-emitting unit is arranged (top surface) has a first average correlated color temperature (CCT); the white light at another side of the transparent carrier (bottom surface) has a second average correlated color temperature less than the first average correlated color temperature. A difference of the first average correlated color temperature and the second average correlated color temperature is not smaller than 50K and not greater than 300K. To be specific, the light-emitting device is disposed on a black base with the top surface facing upward and is electrically connected to the external source. When the light-emitting device emits light, a Chroma Meter (for example, UPRtek, MK350) is used to measure the correlated color temperature to obtain the first average correlated color temperature. Hereinafter, the light-emitting device is provided with its bottom surface facing upward and is electrically connected to the external source. When the light-emitting device emits light, the second average correlated color temperature is measured. Alternatively, a goniophotometer is used to obtain the correlated color temperature of the white light at any point in a space. For example, the light-emitting device is viewed as a central point, and a correlated color temperature spatial distribution of the light emitted from the light-emitting device is shown in FIG. **8**E (0°~360°). The spatial angle at the top surface of the carrier (with the light-emitting unit) is defined as 0°~180° and the spatial angle at the bottom surface of the carrier (without the light-emitting unit) is defined as 180°~360°. In the range of 0°~180°, the correlated color temperature at any angle is measured to obtain a first correlated color temperature; in the range of 180°~360°, the correlated color temperature at any angle is measured to obtain a second correlated color temperature; the first correlated color temperature is greater than the second correlated color temperature and a different of the first correlated color temperature and the second correlated color temperature is not smaller than 50K and not greater than 300K. As shown in FIG. **8**E, within the range of 180°~360°, the correlated color temperature in the range of 210°~225° and 315°~300° is higher. In addition, the average correlated color temperature at the top surface (0°~180°) is greater than that at the bottom surface (180°~360°).

FIG. **9** illustrates a cross-sectional view of a light-emitting device **400** in accordance with another embodiment of the present disclosure. The light-emitting device **400** includes a transparent carrier **10'''**, a plurality of light-emitting diode units **1004** disposed on the transparent carrier **10'''**, a first electrode pad **201'''** and a second electrode pad **202'''**. The light-emitting diode unit **1004** includes a substrate **140**, a first-type semiconductor layer **141**, an active layer **142** and a second-type semiconductor layer **143**. The first-type semiconductor layer **141** and the second-type semiconductor layer **143**, for example a cladding layer or a confinement layer, respectively provide electrons and holes such that electrons and holes can be combined in the active layer **142** to emit light. The light-emitting diode unit **1004** further includes a first bonding pad **144** formed on the first-type semiconductor layer **141** and a second bonding pad **145** formed on the second-type semiconductor layer **143**. The light-emitting diode unit **1004** includes a reflective structure **146** formed between the substrate **140** and the carrier **10'''** for reflecting the light from the light-emitting diode unit **1004** toward the bonding pad, which is substantially defined as a five-surface light-emitting diode unit. A wire **147** connects the first bonding pad **144** of one light-emitting diode unit **1004** with the second bonding pad **145** of adjacent light-emitting diode unit **1004** in series. Moreover, the wire **147** further connects the light-emitting diode unit **1004** with the first electrode pad **201'''** and the second electrode pad **202'''**. When the light-emitting device **400** is connected to the external source (power supply), a positive node and a negative node of the external source is electrically connected to the first electrode pad **201'''** and the second electrode pad **202'''**, respectively, such that the light-emitting diode unit **1004** can emit light. Similarly, since a transparent body **103** including a wavelength conversion layer (not shown) can be formed on the light-emitting diode unit **1004** and portions of the transparent carrier **10'''**. Portion of the light (ex. blue light) emitted from the light-emitting diode unit **1004** is converted to another light (ex. yellow or yellowish-green light) by the wavelength conversion layer. The blue light is mixed with the yellow light (or yellowish-green light) to form a white light. Portions of the white light can be scattered or reflected by the particles within the wavelength conversion layer to be incident on the transparent carrier such that the white light not only emits outwardly through a side (top surface) of the transparent carrier on which the light-emitting unit is arranged, but also emits outwardly through side surface and a bottom surface of the transparent carrier, which indicates the white light can emit outwardly through all surfaces (defined as a six-surface light-emitting device). In addition, a diffusing powder (ex. TiO_2) is optionally added into the wavelength conversion layer (or the wavelength conversion material) for increasing the possibility in which the white light progresses downward. In short, in this embodiment, an approximately uniform light distribution (can be seen from a six-surface light-emitting device) can be achieved by using a non-uniform light source (such as five-surface light-emitting diode). In other embodiment, a wavelength conversion material is directly formed on the second-type semiconductor layer **143** for converting the light emitted by the active layer, thus the transparent body **103** does not includes the wavelength conversion layer. The reflective layer can be a single layer or a multilayer structure made of one or more conductive material or insulating material. The conductive material includes Ag, Al, Ni. Cu, Au, Ti, or combinations thereof. The insulating material includes epoxy, SiO_x, Al_2O_3, TiO_2, silicone, resin or combinations thereof.

It is noted that the carrier **10**, **10'**, or **10'''** is transparent or non-transparent to the light emitted by the light-emitting units **11**, **12**A, **12**B, **13** depending on actual requirements. When the carrier is transparent, it can be glass (n (refractive index)=1.4~1.7), SiC, diamond, epoxy, quartz, acryl resin, SiO_x, Al_2O_3, ZnO, silicone or combinations thereof. The glass can include Soda-Lime Glass, Alumino Silicate Glass, or low alkaline glass. When the carrier is non-transparent, it can be circuit board with a core board made of a metal, a thermoplastic material, a thermosetting material or a ceramic material. The metal includes Al or Cu. The thermosetting material includes phonetic, epoxy, bismaleimide triazine, or combinations thereof. The thermoplastic material includes polyimide resin, or polytetrafluorethylene. The ceramic material includes Al_2O_3, AlN, or AlSiC. The top electrode and the bottom electrode can include Au, Al, Cu, Ag or combinations thereof. In another embodiment, the carrier is made of a flexible material such as polyimide. The transparent body **103** is transparent or semi-transparent to the light emitted by the light-emitting units **11**, **12**A, **12**B, **13**.

FIG. **10**A illustrates a perspective view of an LED bulb **500** in accordance with an embodiment of the present disclosure. The LED bulb **500** includes a cover **50**, a light-emitting device **100**, a circuit board **52**, a heat sink **54**, and an electrical connector **56**. The light-emitting device **100** can be replaced by the light-emitting device **200**, **300** and the light-emitting device **200**, **300** can be applied in the light-emitting bulb **500**. The light-emitting device **100** can be viewed as a light filament. When the light-emitting device **100** is mounted on the circuit board **52**, the carrier **10** is connected to the circuit board **52** through the same side but different surfaces (see FIG. **1**C) thereof. Alternatively, by the electrical plate **25**, the external source is connected to the carrier **10** at the same surface but at two opposite sides (see FIGS. **6**A~**6**E). The circuit board **52** is mounted on the heat sink **54** for dissipating heat generated by the light-emitting device **100** away therefrom in a conduction, convection or radiation method. The electrical connector **56** is connected to the heat sink **54**, and also connected to the external source.

In this embodiment, the light-emitting devices are substantially disposed on the circuit board **52** in a vertical direction (Z) and arranged in a triangular pattern (from the top view). In other embodiment, the light-emitting devices can be arranged in a rectangular pattern, a polygonal pattern or an approximate circle pattern. FIG. **10**B illustrates a top view of a circuit board on which the light-emitting devices are mounted in accordance with an embodiment of the present disclosure. The light-emitting devices **100** are arranged in a quadrangular pattern while the top surfaces **101** of each carrier (with the light-emitting units) face outwardly and the bottom surfaces of each carrier (without the light-emitting units) face each other. The LED bulb **501** further includes a light-emitting unit **15** disposed in an interior space defined by the quadrangular pattern and surrounding by the light-emitting devices **100**. The light-emitting unit **15** substantially emits light along the Z direction (see FIG. **10**A). It is noted that the light-emitting device **100** emits white light and the light-emitting unit **15** emits red light so this configuration can improve the color rendering (CRI≥90) or the Color Quality Scale (CQS≥85). Any one of the light-emitting diode unit **1000**, **1001**, **1002**, **1003**, **2000**, **2001**, **2002** can be used as the light-emitting unit **15**.

FIG. **11**A illustrates a perspective view of an LED bulb **502** in accordance with another embodiment of the present disclosure. FIG. **11**B illustrates a top view of FIG. **11**A. The LED bulb **502** is similar with the LED bulb **501**. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. The light-emitting devices **100** are substantially disposed on the circuit board **52** in a vertical direction (Z) and arranged in a quadrangular pattern (from the top view). The light-emitting device **200**, **300** can also be applied in this embodiment. In other embodiment, the light-emitting devices can be arranged in a rectangular pattern, a polygonal pattern or an approximate circle pattern. Referring to FIG. **11**B, the light-emitting devices **100**A, **100**B are arranged along the first direction (A) in a straight line with a width direction parallel with the first direction. The light-emitting devices **100**C, **100**D are arranged along the second direction (B) in a straight line with a width direction parallel with the second direction. The first direction is, but not limited to, substantially perpendicular to the second direction. An angle between the first direction and the second direction can be 30°, 45° or 60°. Each top surface **101** (with the light-emitting unit) of the light-emitting units **100**A, **100**B has a normal vector perpendicular to the first direction (A) and the two normal vectors point in opposite directions from each other (see arrow). Likewise, each top surface **101** (with the light-emitting unit) of the light-emitting units **100**C, **100**D has a normal vector perpendicular to the second direction (B) and the two normal vectors point in opposite directions from each other (see the arrow). Furthermore, the emitting direction (see the arrow) of the light-emitting devices **100**A, **100**B, **100**C, **100**D can be viewed in a clockwise direction (or anticlockwise). The top surface **101** of the light-emitting device **100**A faces the bottom surface **102** of the light-emitting device **100**D. FIG. **11**C illustrates a top view of a circuit board on which the light-emitting devices are mounted in accordance with an embodiment of the present disclosure. It is different from that of FIG. **11**B that a light-emitting unit **15** is further disposed in a space between two adjacent light-emitting devices **100**. The light-emitting unit **15** substantially emits light along the Z direction (see FIG. **10**A). It is noted that the light-emitting device **100** emits white light and the light-emitting unit **15** emits red light so this configuration can improve the color rendering (CRI≥90) or the Color Quality Scale (CQS≥85).

FIG. **11**D illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure. The LED bulb includes a cover **50**, four light-emitting devices **100**, a circuit board **52**, a heat sink **54**, and an electrical connector **56**. The detail structure of the light-emitting device **100** can be referred to the aforesaid embodiments. In this embodiment, the carrier of each of the light-emitting devices **100** is made of a flexible material, such as polyimide. The four light-emitting devices **100** are alternately arranged over each other on the circuit board **52**. Specifically, the carrier of the bottom light-emitting device **100**E is bent to have an arc shape and the top surface of the carrier faces outwardly so the light-emitting units **11** emit outwardly. Similarly, the carrier of each of the first middle light-emitting device **100**F, the second middle light-emitting device **100**G and the top light-emitting device **100**H is bent to have an arc shape and the top surface of the carrier faces outwardly so the light-emitting units **11** emit outwardly[??]. By this configuration, light can emit toward different directions such that an LED bulb with an omnidirectional direction light pattern can be obtained. FIG. **11**E illustrates a top view of FIG. **11**D without the cover **50**. Each of the light-emitting devices **100**E~**100**H extends in different directions (for example, the bottom light-emitting device **100**E extends from point **1** to point **2**; the top light-emitting device **100**H from point **3** to point **4**).

FIG. **11**F illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure. The LED bulb includes a cover **50**, a post **57**, a light-emitting device **100'**, a circuit board **58**, a heat sink **54**, and an electrical connector **56**. The light-emitting device **100'** includes a flexible carrier **10** and a plurality of light-emitting units **11** on the carrier **10**. In this embodiment, the post **57** is a solid cylinder and has a circuit for electrically connecting to the light-emitting units **11**. Alternatively, the post **57** can be a hollow cylinder. FIG. **11**G illustrates the flexible carrier **10** in a non-bending state. The flexible carrier **10** has a first portion **107** and a second portion **108**. In this embodiment, a plurality of light-emitting units **11** is arranged on the first portion **107** in an array and one light-emitting unit **11** is arranged on the second portion **108**. When the flexible carrier **10** is attached to the post **57**, the first portion **107** is bent to wind along the contour of a side surface of the post **57**. Subsequently, the second portion **108** is bent in a direction toward a center of the post **57**. After winding on the post **57**, the second portion **108** is substantially perpendicular to the first portion **107**. By this configuration, the light-emitting units **11** on the first portion **107** emit light toward a side direction and the light-emitting unit **11** on the second portion **108** emits light in an upward direction, thereby an LED bulb with an omnidirectional direction light pattern can be obtained. In addition, an enclosing structure **59** is optionally provided to fully enclose the light-emitting device **100'** and the post **57**. The enclosing structure **59** is transparent and can be made of a material like silicone or epoxy.

FIG. **11**H illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure. The LED bulb of FIG. **11**H has a structure similar to that of FIG. **11**F. The LED bulb is a type A bulb and includes a cover **50**, a pedestal **581**, a post **57**, a light-emitting device **100"**, a heat sink **54**, and an electrical connector **56**. The light-emitting device **100"** includes a flexible carrier **10** and a plurality of light-emitting units **11** on the carrier **10**. In this embodiment, the post **57** is a hollow cylinder and has a circuit for electrically connecting to the light-emitting units **11**. FIG. **11**I illustrates the flexible carrier **10** in a non-bending state. Different from the light-emitting device **100'**, the light-emitting device **100"** includes four second portions **108** each of which has one light-emitting unit **11** is arranged thereon[??]. By this configuration, the light-emitting units **11** on the first portion **107** emit light toward a side direction and the light-emitting units **11** on the second portions **108** emit light in an upward direction, thereby an LED bulb with an omnidirectional direction light pattern can be obtained.

FIG. **11**J illustrates a perspective view of an LED bulb in accordance with one embodiment of the present disclosure. The LED bulb of FIG. **11**J has a structure similar to that of FIG. **11**H. In this embodiment, the LED bulb does not include a heat sink and the cover **50** is directly connected to the electrical connector **56**. The LED bulb is also the light-emitting bulb with an omnidirectional direction light pattern. It is noted that the aforesaid "omnidirectional direction light pattern" means the light pattern complying with the definition by Energy Star.

FIG. **12** illustrates a cross-sectional view of a light-emitting tube in accordance with one embodiment of the present disclosure. The light-emitting tube includes a light-emitting device, a holder **80** and a cover **81**. The aforesaid light-emitting devices can be combined with each other to apply in this light-emitting tube. In another embodiment, the cover **81** can be made of a flexible material such as polyimide (PI). In this embodiment, taking the light-emitting device of FIGS. **4**A and **4**B for example, the holder **80** includes a first clamp portion **801**, a second clamp portion **802**, and a penetrating hole **803**. The first clamp portion **801** and the second clamp portion **802** are spaced apart from each other and define a space therebetween. The light-emitting device has a part passing through the space and further through the penetrating hole **803** to expose the top electrode pad **201** and the bottom electrode pad **301** for electrically connecting to the external source. With the clamp portions **801**, **802** tightly clamping the light-emitting device, the light-emitting device can be mounted on the holder **80**. In another embodiment, the space between the clamp portions **801**, **802** is larger than a width of the light-emitting device and does not directly contact the light-emitting device so an adhesive substance (not shown) is filled within the space between the clamp portions **801**, **802** for firmly mounting the light-emitting device on the holder. The holder **82** substantially divides the light-emitting device into two sides wherein one is with the light-emitting units **11** and the other is with the top electrode pad **201** and the bottom electrode pad **301**. The cover **81** merely covers the side with light-emitting units **11** but does not cover the side with top electrode pad **201** and the bottom electrode pad **301**. In addition, the cover **81** is spaced apart from the light-emitting device by a shortest distance (d**2**) smaller than 2 mm for efficiently dissipating heat from the light-emitting device to ambient (air) through the cover. Alternatively, a filler can be filled between the cover **81** and the light-emitting device and includes a transparent substance, a wavelength conversion layer or a diffusing layer (not shown). The filler directly contact the light-emitting device for conducting heat from the light-emitting device to ambient (air) therethrough. Moreover, because of the filler, the light-emitting device has a better hot/cold ratio. To be more specific, when the light-emitting device is connected to the external source, in an initial state, a cold-state lighting efficiency (light output (lumen)/watt) is measured, hereinafter, in every period of time (ex. 30 ms), the lighting efficiency is measured. When a difference between the adjacent measured light emitting efficiencies is smaller than 0.5%, the latter light efficiency is defined as a hot-state lighting efficiency. The hot/cold ratio is a ratio of the hot-state lighting efficiency to the cold-state lighting efficiency. In this embodiment, when the filler is filled between the light-emitting device and the cover, the hot/cold ratio of the light-emitting device is R_1, and when the filler is not filled between the light-emitting device and the cover, the hot/cold ratio of the light-emitting device is R_2, wherein a difference of R_1 and R_2 is larger than 20%. The adhesive substance can be made of a material the same as the transparent substance. The cover **81** includes diamond, glass, epoxy, quartz, acrylic resin, SiO_x, Al_2O_3, ZnO or silicone. The transparent substance includes silicone, epoxy, polyimide (PI), BCB, perfluorocyclobutane (PFCB), SU8, acrylic resin, polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), polycarbonate (PC), polyetherimide, fluorocarbon polymer, Al_2O_3, SINR, spin-on-glass (SOG).

FIGS. **12**A~**12**C illustrate drawings of a method making the light-emitting tube of FIG. **12**. Referring to FIG. **12**A, a carrier **10** is provided and a plurality of light-emitting units **11** disposed on the top surface **101** and the bottom surface **102** of the carrier **10** to form a light-emitting device. Referring to FIG. **12**B, a hollow cover **81** is provided and has an open end and a closed end. A transparent substance **811** (which can include a wavelength conversion material and/or a diffusing powder) is filled into the cover **81** from the open end. Referring to FIG. **12**C, a portion of the light-emitting device is embedded into the transparent substance **811** such that the top electrode pad **201** and the bottom electrode pad **301** are exposed from the open end. It is noted that, in the embedded step, gas (air, bubble) may be generated, and a degas step can be performed to remove the gas. Alternatively, the gas is not entirely removed so there is gas existing in the transparent substance **811**. Subsequently, the transparent substance **811** can be solidified by heating or lighting. Optionally, before the solidification, a holder is provided and the light-emitting device passes through the penetrating hole of the holder and is mounted on the holder (as shown in FIG. **12**) such that the side with the light-emitting units is fully sealed by the cover to expose the top electrode pad **201** and the bottom electrode pad **301** for electrically connecting to the external source.

FIGS. **13**A~**13**D illustrate drawings of a method making the light-emitting device **600** in accordance with one embodiment of the present disclosure. The light-emitting device **600** is similar with the light-emitting device **100**. The devices, elements or steps with similar or the same symbols represent those with the same or similar functions. Referring to FIG. **13**A and FIG. **13**B, a carrier **10** is provided and the top electrode **20**, the bottom electrode **30** and a temporary electrode **220** are formed on the carrier **10** using printing. A hole **221** is formed and a conductive material is fully or partly filled with the hole **221** for electrically connecting the top electrode **20** with the bottom electrode **30**. The temporary electrode **220** can be electrically connected to the top electrode **20**. Furthermore, a scribe line **222** is formed on the bottom surface **102** of the carrier at a position corresponding to the temporary electrode **220**. The light-emitting units **11** are mounted on the top electrode **20** (or/and the bottom electrode, as shown in FIG. **5**A) of the carrier **10** by surface mounted technology or wiring bonding. Referring to FIGS. **13**C and **13**D, a first transparent layer **1032** is formed to cover the light-emitting units **11** along its contour; a wavelength conversion layer **1033** is formed to cover the first transparent layer **1032** along its contour; and a second transparent layer **1034** is formed to cover the wavelength conversion layer **1033** without having the same contour as the wavelength conversion layer **1033**. During test, the positive node and the negative node of the external source are connected to the top electrode **20** and the temporary electrode **220**, respectively, so the light-emitting units **11** emit light. Hereinafter, the temporary electrode **220** and portions of the carrier **10** are removed along the scribe line **222**. In this embodiment, the temporary electrode **220** is removed using breaking, laser dicing, or diamond dicing that such methods can cause a side **121** of the carrier **10** with a rough, unsmooth, or irregular surface. On the contrary, another side **122** of the carrier has a smooth surface. Therefore, the side **121** and another side **122** have different roughness. The wavelength conversion layer can be a single layer or a multilayer structure. FIG. **13**E is a cross-sectional view of FIG. **13**D (along X direction). The light-emitting unit **11** has a height (H_2), a maximum distance between the second transparent layer **1034** and the carrier is H_1; $H_2 \geq 0.5 H_1$. It is noted that when the light-emitting unit **11** includes the first transparent structure (the light-emitting diode units **2000**, **2001** or **2002** in FIG. **8**A, FIG. **8**B to FIG. **8**D), and the first transparent structure **7026** is made of a material the same as the first transparent layer **1032**, an interface formed therebetween is vague under the electrical microscopy or the interface does not exist between the first transparent structure **7026** and the first transparent layer **1032**.

While the aforesaid light-emitting device is applied in an alternating current (AC) power supply or a direct current (DC) power supply with a root mean square voltage of 120V, the light-emitting device can be designed to have an operating voltage of 140V±10%; while the light-emitting device is applied in an alternating current (AC) power supply or a direct current (DC) power supply with a root mean square voltage of 100V, the light-emitting device can be designed to have an operating voltage of 115V±10%; while the light-emitting device is supplied with an alternating current (AC) power supply or a direct current (DC) power supply with a root mean square voltage of 220V, the light-emitting device can be designed to have an operating voltage of 280V±10%. The alternating current (AC) power supply is rectified to a direct current (DC) power supply. Furthermore, the light-emitting device can also be supplied with a direct current power supply with a substantially constant voltage (ex. battery) and the light-emitting device can be designed to have an operating voltage smaller than 15V. In addition, a plurality of light-emitting devices is disposed in a support and the light-emitting devices are electrically connected to each other in series, in parallel, in series-parallel for increasing the applications. Moreover, the aforesaid light-emitting device or light tube can also be applied in U-shape lamp, spiral lamp, bulb, and candle lamp.

It is noted that, besides the light-emitting diode unit (FIGS. **7**A~7D, **8**A~**8**B and **8**D) described in the present disclosure can be used as any one of the light-emitting units. However, the conventional package structure (for example, 3014 or 5630 package) can be used as any one of the light-emitting units.

It is noted that the foregoing description has been directed to the specific embodiments of this invention. It will be apparent to those having ordinary skill in the art that other alternatives and modifications can be made to the devices in accordance with the present disclosure without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the present disclosure covers modifications and variations of this disclosure provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A light-emitting device, comprising:

a carrier having a top surface and a bottom surface;

a first electrode having a first part formed on the top surface, and a second part formed on the bottom surface;

a second electrode having a third part formed on the top surface, wherein the first part and the third part are arranged at two opposite sides of the carrier;

a first light-emitting unit disposed on the top surface and electrically connected to the first electrode; and

a transparent body covering the first part, the second part, the third part and the first light-emitting unit.

2. The light-emitting device of claim **1**, wherein the first part overlaps the second part.

3. The light-emitting device of claim **1**, wherein the carrier comprises a transparent material or a non-transparent material.

4. The light-emitting device of claim **1**, wherein the carrier has a side surface and the first part extends beyond the side surface.

5. The light-emitting device of claim **1**, wherein the first part and the third part are electrically separated from each other when the first light-emitting unit is not disposed on the top surface.

6. The light-emitting device of claim **1**, wherein the second electrode has a fourth part formed on the bottom surface and electrically connected to the third part.

7. The light-emitting device of claim **6**, wherein the transparent body covers the third part and fourth part.

8. The light-emitting device of claim **1**, further comprising a connector electrically and physically connected to the first part and the second part.

9. The light-emitting device of claim **8**, wherein the connector covers a side surface of the carrier.

10. The light-emitting device of claim **8**, wherein the connector is shorter than the first part.

11. The light-emitting device of claim **1**, further comprising a second light-emitting unit, wherein the second light-emitting unit and the first electrode are arranged on opposite sides of the first light-emitting unit.

12. The light-emitting device of claim **1**, wherein the carrier is made of a flexible material.

13. The light-emitting device of claim **1**, wherein the first light-emitting unit comprises a plurality of connecting pads, the plurality of connecting pads is formed on a same side of the first light-emitting unit.

14. The light-emitting device of claim **1**, wherein the first electrode fully covers an end portion of the carrier in a top view.

15. The light-emitting device of claim **1**, wherein the transparent body comprises a wavelength conversion layer.

16. The light-emitting device of claim **1**, wherein the carrier has a side surface devoid of the transparent body.

17. The light-emitting device of claim **1**, wherein when the light-emitting device emits light, the light has a first average correlated color temperature over the top surface and a second average correlated color temperature below the bottom surface, the first average correlated color temperature is larger than the second average correlated color temperature.

18. The light-emitting device of claim **17**, wherein the first average correlated color temperature and the second average correlated color temperature have a difference of not smaller than 50K and not greater than 300K.

19. A light-emitting device, comprising:

a carrier having a top surface and a bottom surface;

a first electrode having a first part formed on the top surface and a second part formed on the bottom surface;

a second electrode having a third part formed on the top surface, wherein the first part and the third part are arranged at two opposite sides of the carrier;

a plurality of light-emitting units disposed on the top surface and electrically connected to the first electrode; and

a wavelength conversion layer covering the first part, the second part, the third part and the plurality of light-emitting units.

20. The light-emitting device of claim of **19**, further comprising a connector electrically and physically connected to the first part and the second part.

* * * * *

Exhibit 9

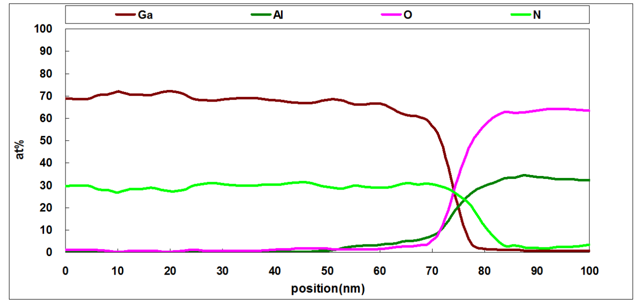
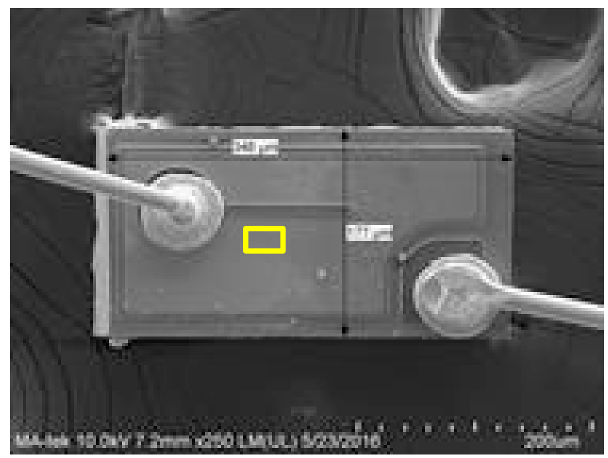
Exhibit 9: Infringement Claim Chart for U.S. Patent No. 7,355,208

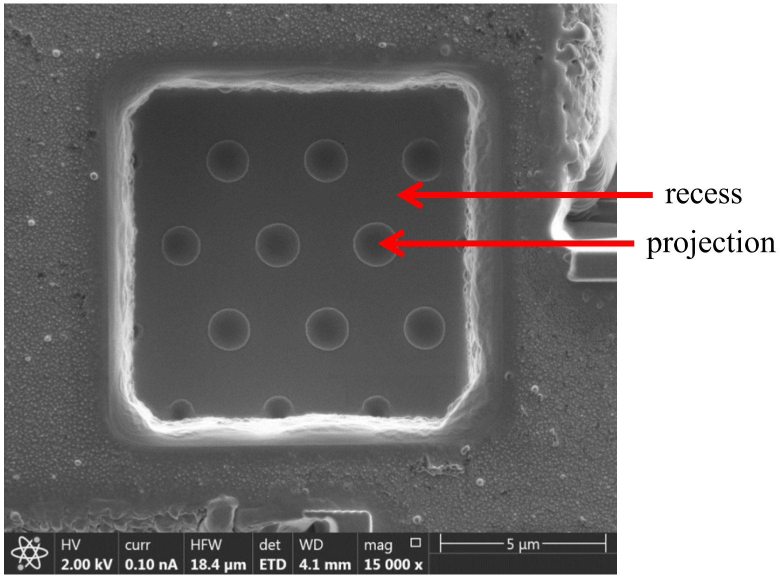
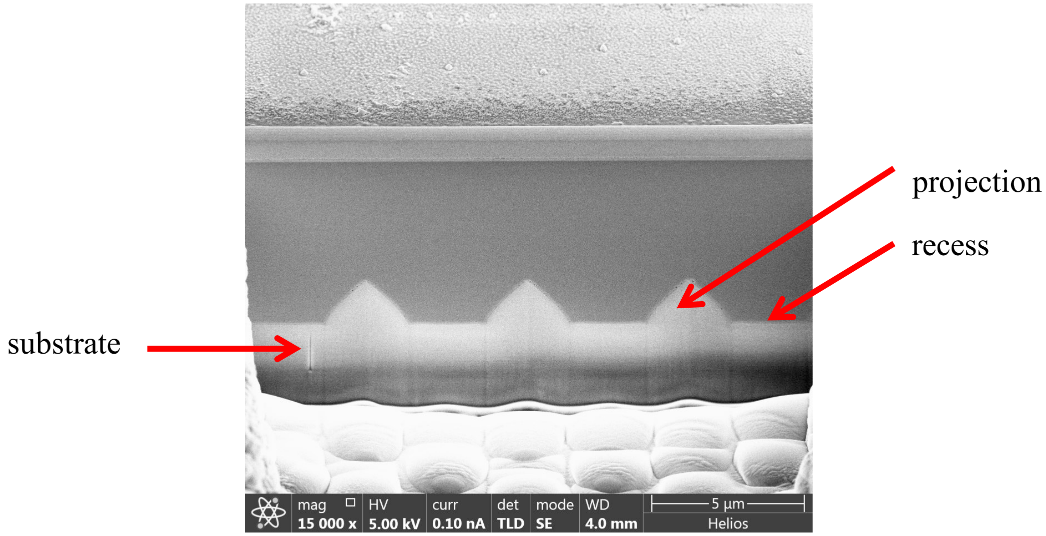
The Defendant infringes U.S. Patent No. 7,355,208 ("the '208 Patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

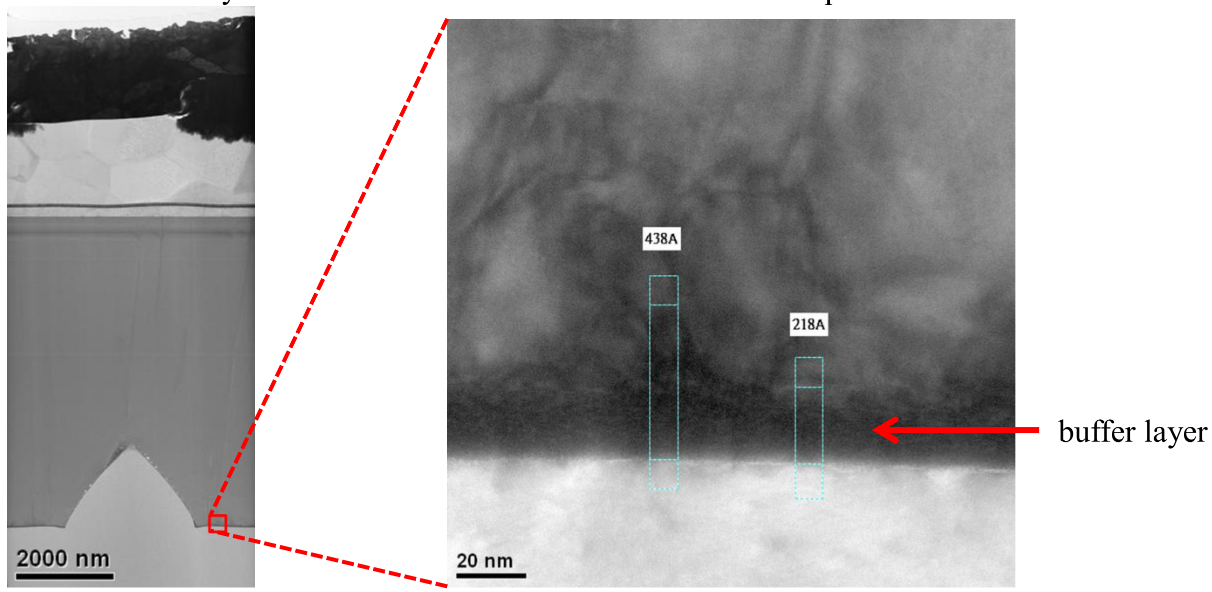
The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

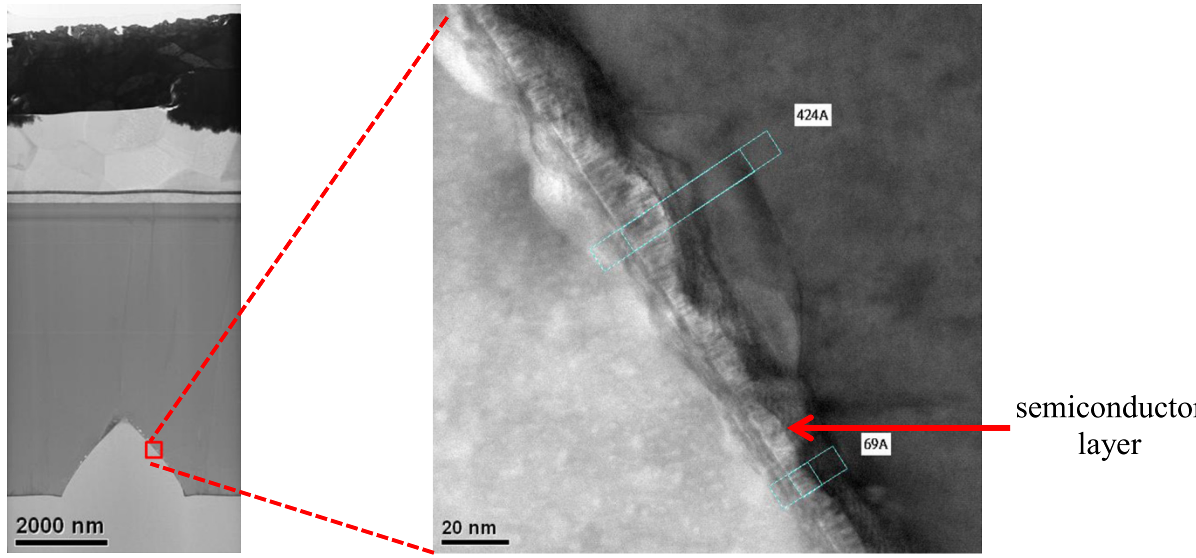
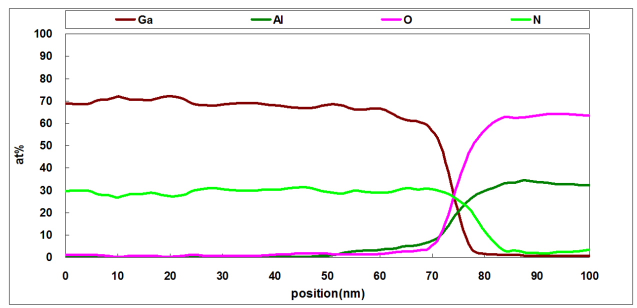
As one non-limiting example, at least the **Luxrite LR21205** includes the features cited in the chart below:

Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
8. A nitride-based semiconductor light-emitting device comprising:	The Luxrite **LR21205** includes a nitride based semiconductor light-emitting device. For example, as shown in the image below, the Luxrite LR21205 is a 4W LED Filament Light Bulb that includes a light-emitting device.   A tranmission electron microscopy analysis shows that this device is a nitride-based semiconductor (GaN).

Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
	
a substrate including a surface having projection portions and recess portions;	The Luxrite **LR21205** includes a substrate including a surface having projection portions and recess portions. For example, as shown in the microscopic photographs below, the light emitting device of the Luxrite LR21205 has a plurality of LED chips.  (top view of chip)

Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
	The LED chips have a substrate that includes a surface with projection portions and recess portions.  (top view of chip; expanded view of area under yellow rectangle in figure above) 

Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
a buffer layer formed on bottom surfaces of said recess portions; and	The Luxrite **LR21205** includes a buffer layer formed on bottom surfaces of said recess portions. For example, as shown in the microscopic photographs below, the Luxrite LED4EFC/CL/27K includes a buffer layer formed on the bottom surface of the recess portions. 
a nitride-based semiconductor layer formed on side surfaces of said recess portions, wherein	The Luxrite **LR21205** includes a nitride-based semiconductor layer formed on side surfaces of said recess portions. For example, as shown in the microscopic photographs below, the Luxrite LED4EFC/CL/27K includes a semiconductor layer formed on the bottom surface of the recess portions.

Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
	 A tranmission electron microscopy analysis shows that the semiconductor layer is nitride-based (GaN).. 
said recess portions or said projection portions are formed in a circular, hexagonal or triangular shape in a plan view.	The Luxrite **LR21205** includes said recess portions or said projection portions that are formed in a circular, hexagonal or triangular shape in a plan view. For example, as shown in the microscopic photographs below, the Luxrite LED4EFC/CL/27K recess portions or projection portions are formed in a circular, hexagonal or triangular shape in a plan view.

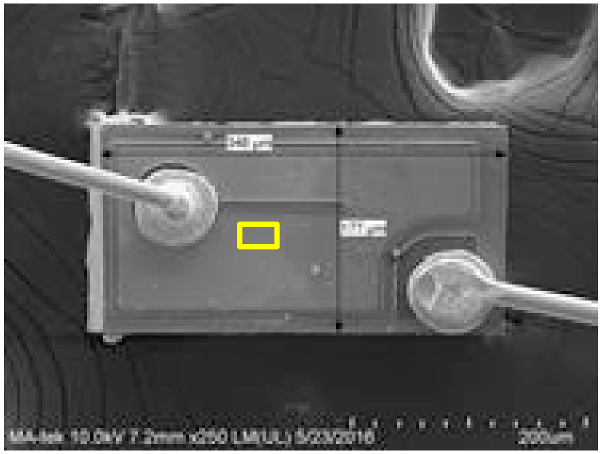
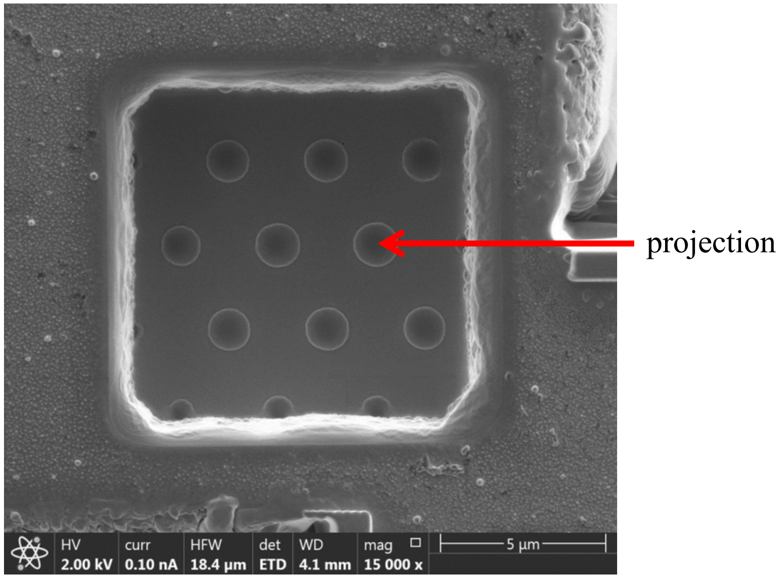
Claim	Exemplary Disclosures of Technical Features for Luxrite LR21205
	 (top view of chip)  (top view of chip; expanded view of area under yellow rectangle in figure above)

Exhibit 10

Exhibit 10: Infringement Claim Chart for U.S. Patent No. 7,489,068

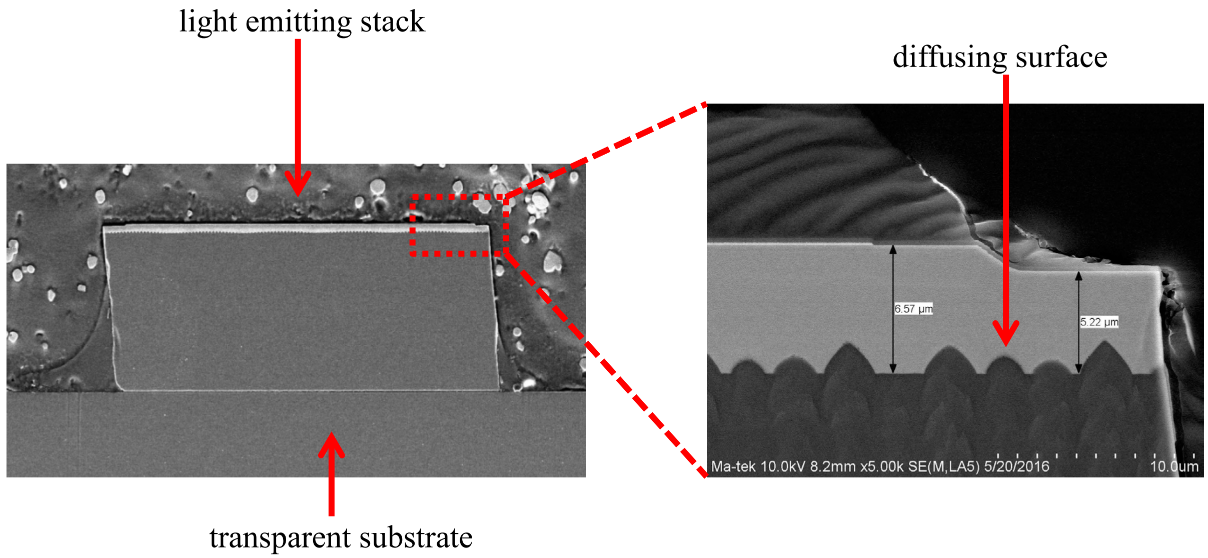
The Defendant infringes U.S. Patent No. 7,489,068 (the "'068 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light emitting device, comprising:	The Luxrite LED4EFC/CL/27K includes a light emitting device. For example, as shown in the images below, the Luxrite LED4EFC/CL/27K contains a light emitting device. 

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a transparent substrate;	The Luxrite LED4EFC/CL/27K includes a transparent substrate. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K includes a transparent substrate. 

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a light emitting stack having a first diffusing surface above the transparent substrate; and	The Luxrite LED4EFC/CL/27K includes a light emitting stack having a first diffusing surface above the transparent substrate. For example, as shown in the microscopic photographs below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a light emitting stack having a first diffusing surface above the transparent substrate. 
a transparent adhesive layer between the transparent substrate and the first diffusing surface, wherein an index of refraction of the light emitting stack is different from that of the transparent adhesive layer.	The Luxrite LED4EFC/CL/27K includes a transparent adhesive layer between the transparent substrate and the first diffusing surface, wherein an index of refraction of the light emitting stack is different from that of the transparent adhesive layer. For example, as shown in the microscopic photographs below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a transparent adhesive layer between the transparent substrate and the first diffusing surface, wherein an index of refraction of the light emitting stack is different from that of the transparent adhesive layer.

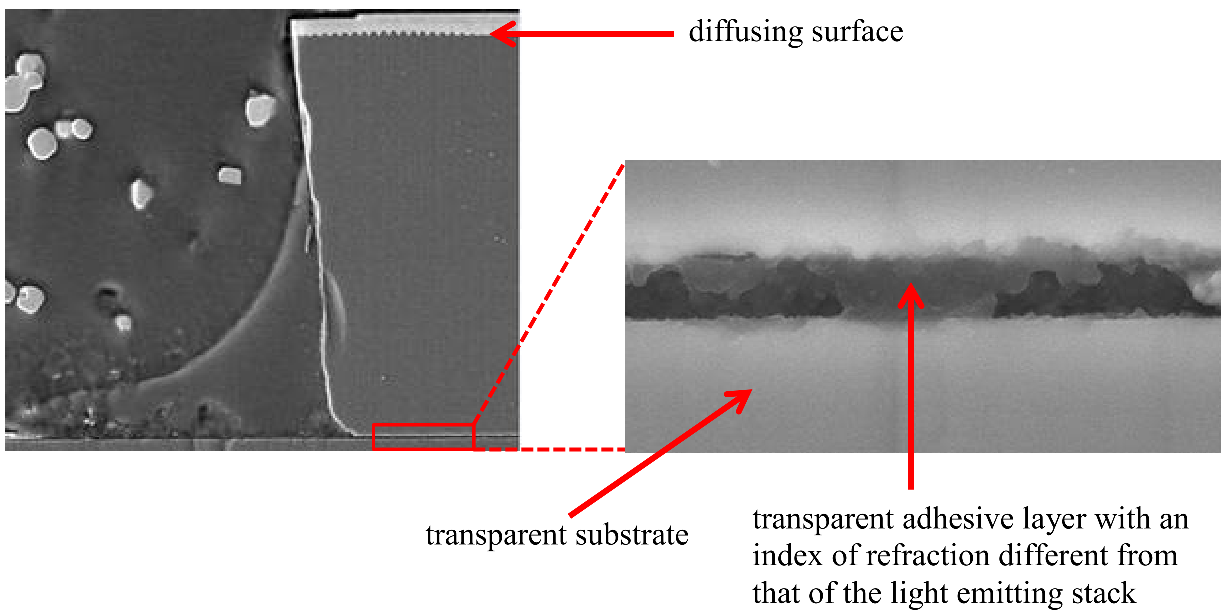
Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	

Exhibit 11

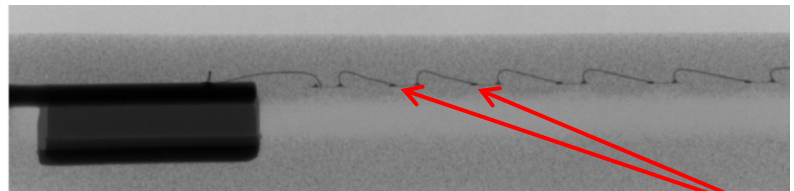
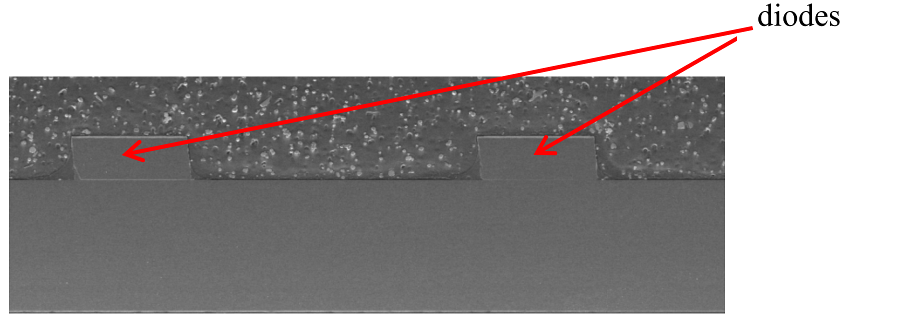
Exhibit 11: Infringement Claim Chart for U.S. Patent No. 7,560,738

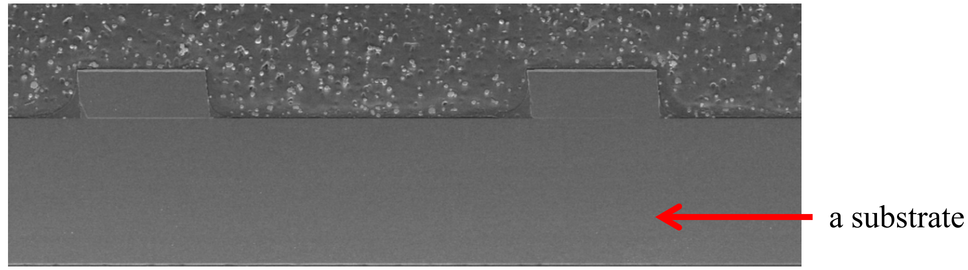
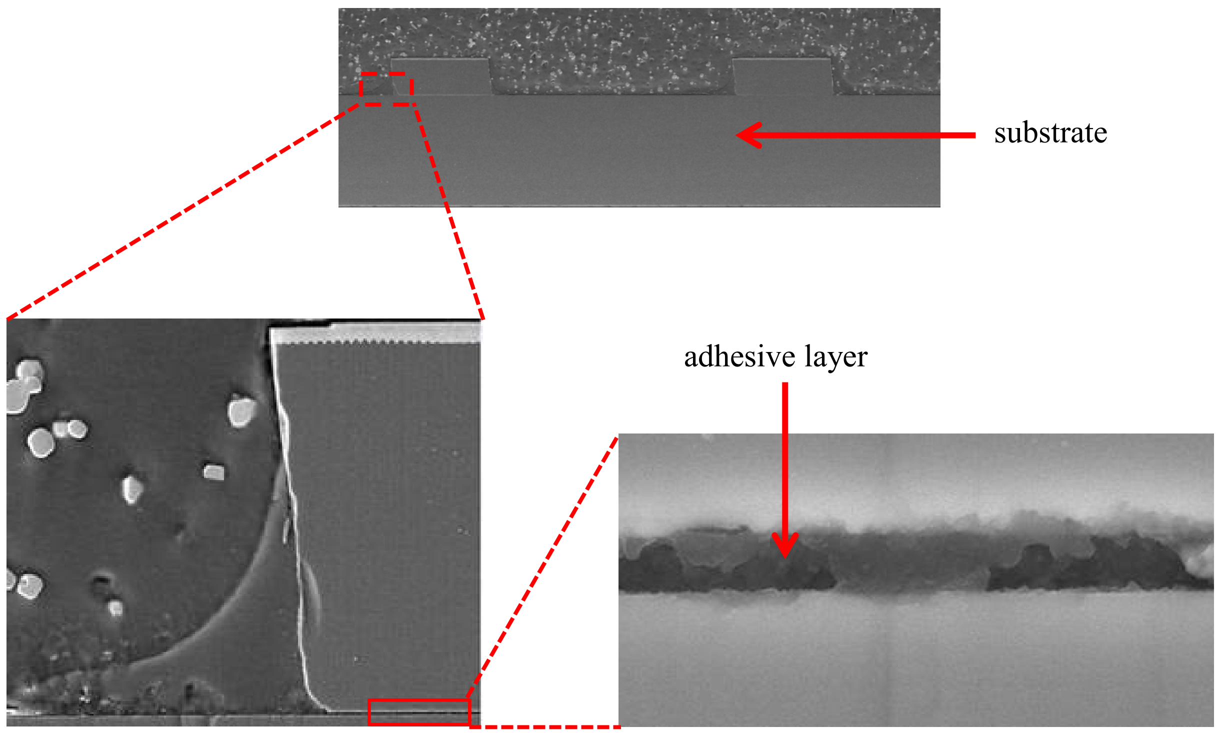
The Defendant infringes U.S. Patent No. 7,560,738 (the "'738 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

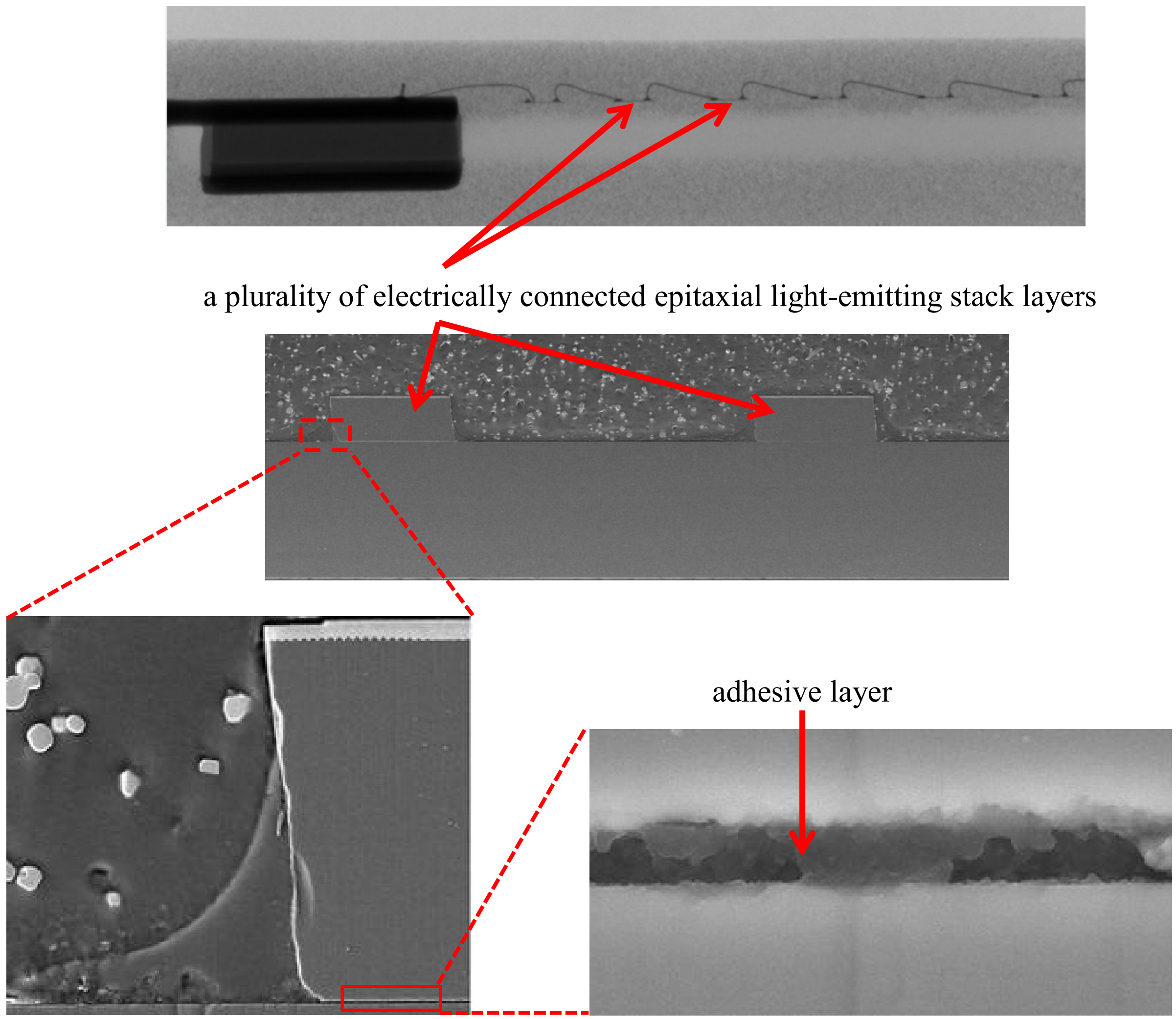
The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light-emitting diode array comprising:	The Luxrite LED4EFC/CL/27K includes a light-emitting diode array. For example, as shown in the images below, the Luxrite LED4EFC/CL/27K contains a light-emitting filament that includes a light-emitting diode array. 

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	 As shown below in the microscopic images taken of the Luxrite LED4EFC/CL/27K filament, there is a light-emitting diode array with a plurality of electrically-connected light-emitting diodes.  
a substrate;	The Luxrite LED4EFC/CL/27K includes a substrate. For example, as shown in the microscopic image below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a substrate.

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	
an adhesive layer formed on the substrate; and	The Luxrite LED4EFC/CL/27K includes an adhesive layer formed on the substrate. For example, as shown in the microscopic photographs below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes an adhesive layer formed on the substrate. 

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a plurality of electrically connected epitaxial light-emitting stack layers disposed on the adhesive layer,	The Luxrite LED4EFC/CL/27K includes a plurality of electrically connected epitaxial light-emitting stack layers disposed on the adhesive layer. For example, as shown in the microscopic photographs below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a plurality of electrically connected epitaxial light-emitting stack layers disposed on the adhesive layer. 

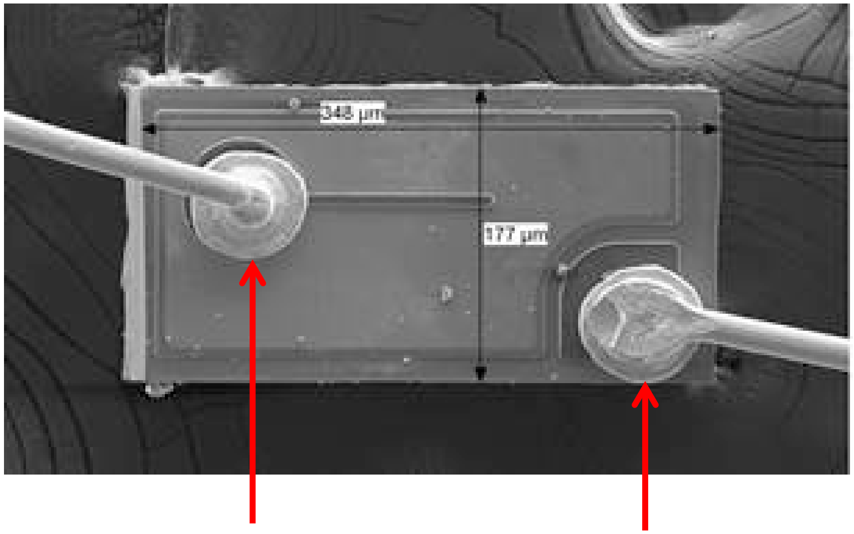
Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
each of the epitaxial light-emitting stack layers comprising a P-contact and an N-contact, wherein the P-contact and the N-contact are disposed on the same side of the epitaxial light-emitting stack layer.	The Luxrite LED4EFC/CL/27K includes epitaxial light-emitting stack layers comprising a P-contact and an N-contact, wherein the P-contact and the N-contact are disposed on the same side of the epitaxial light-emitting stack layer. For example, as shown in the microscopic photograph of a top view of an LED below, the Luxrite LED4EFC/CL/27K includes epitaxial light-emitting stack layers comprising a P-contact and an N-contact, wherein the P-contact and the N-contact are disposed on the same side of the epitaxial light-emitting stack layer. 

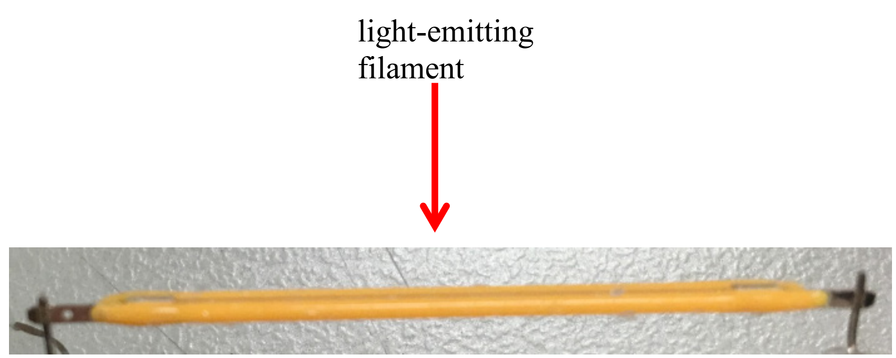
Exhibit 12

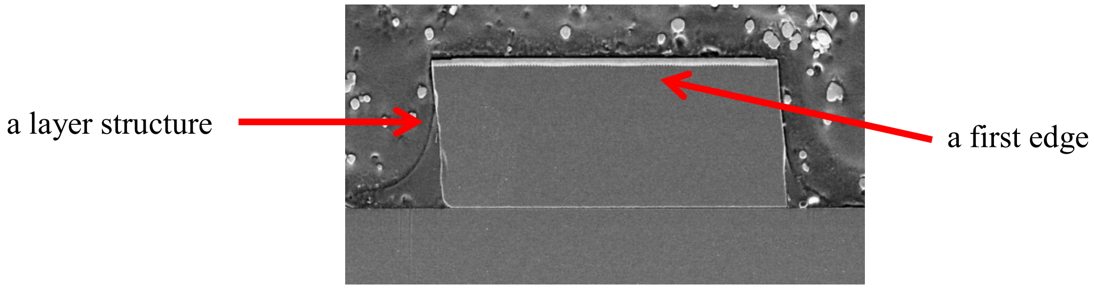
Exhibit 12: Infringement Claim Chart for U.S. Patent No. 8,791,467

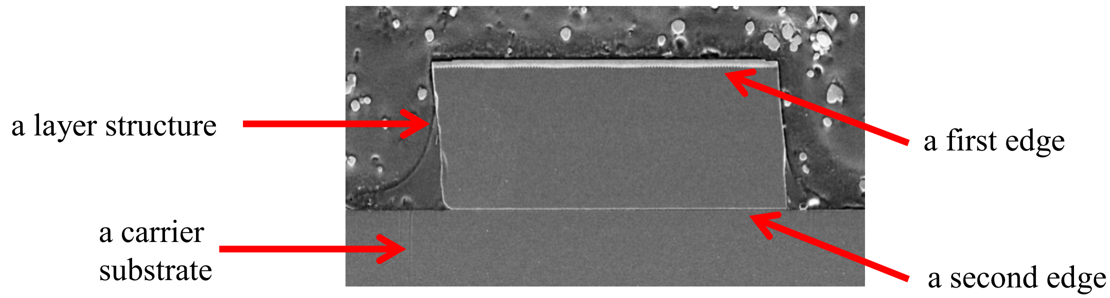
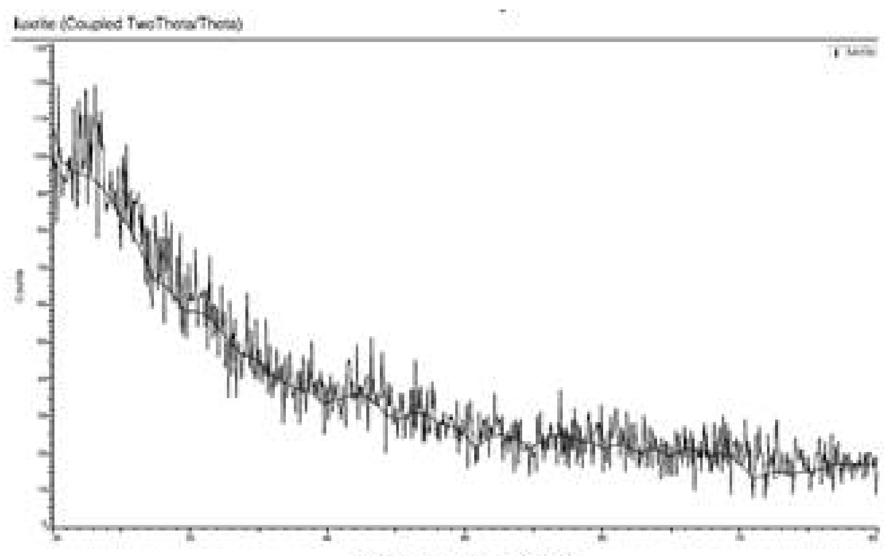
The Defendant infringes U.S. Patent No. 8,791,467 (the "'467 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light-emitting structure, comprising:	The Luxrite LED4EFC/CL/27K is a light-emitting structure. For example, as shown in the images below, the Luxrite LED4EFC/CL/27K includes a light-emitting structure. Specifically, the Accused Product is an LED bulb that includes light-emitting filaments.  

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a layer structure, having a first edge, for emitting light; and	The Luxrite LED4EFC/CL/27K includes a layer structure, having a first edge, for emitting light. For example, as shown in the microscopic image below, the Luxrite LED4EFC/CL/27K includes a layer structure, having a first edge, for emitting light. 

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a carrier substrate, having a second edge, bonded to the layer structure and not being a single crystal wafer;	The Luxrite LED4EFC/CL/27K includes a carrier substrate, having a second edge, bonded to the layer structure and not being a single crystal wafer. For example, as shown in the images and XRD ("X-Ray Diffraction") analysis below, the Luxrite LED4EFC/CL/27K includes a carrier substrate, having a second edge, bonded to the layer structure and not being a single crystal wafer. The XRD analysis indicates that the substrate is amorphous and not a single crystal wafer.   **XRD Analysis**

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
wherein the light-emitting structure has a light output power of more than 4 mW at 20 mA current.	The Luxrite LED4EFC/CL/27K includes a light-emitting structure that has a light output power of more than 4 mW at 20 mA current. For example, based on an illumination analysis, a light-emitting filament of the Luxrite LED4EFC/CL/27K can have a light output power of 639.3 mW at 20 mA operation current. <table><tr><th>Radiant flux (mW)</th><th>Operating current (mA)</th></tr><tr><td>639.3</td><td>20</td></tr></table>

Exhibit 13

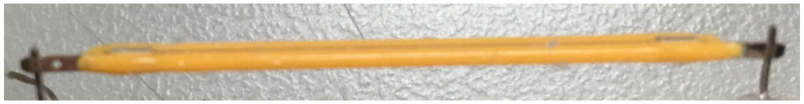
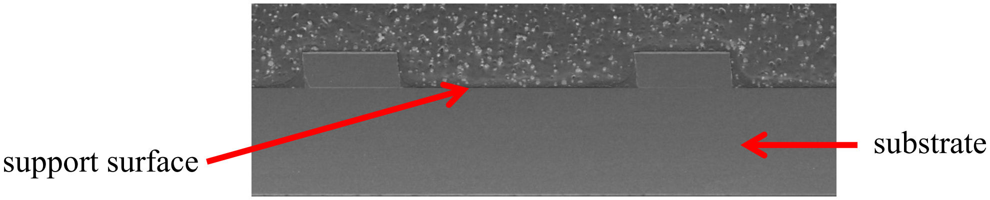
Exhibit 13: Infringement Claim Chart for U.S. Patent No. 9,065,022

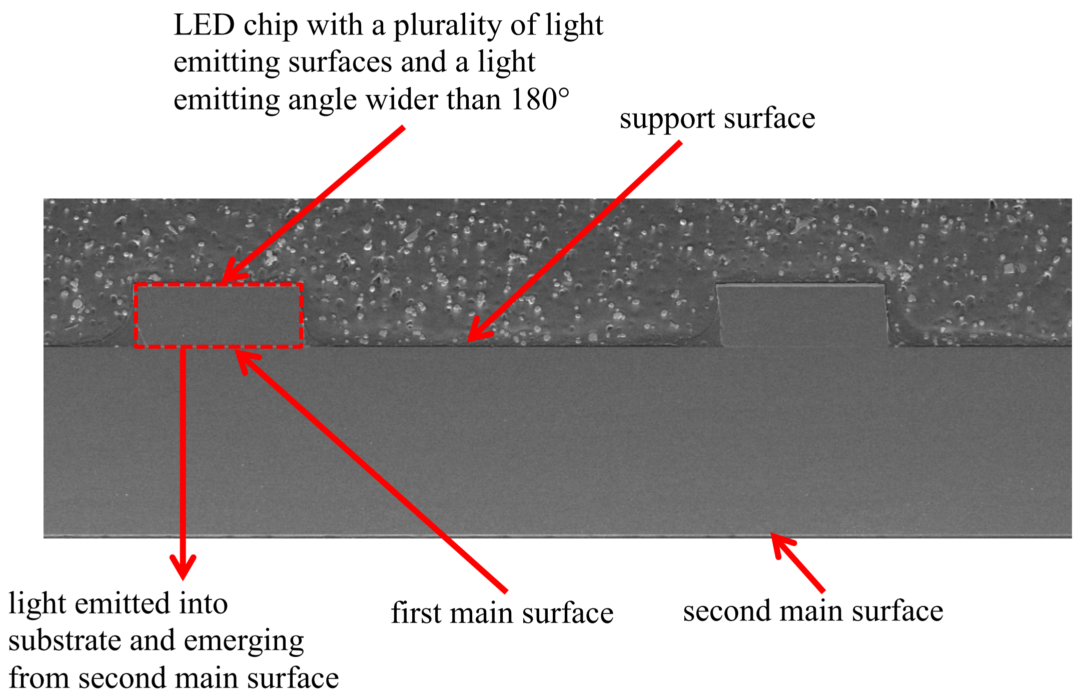
The Defendant infringes U.S. Patent No. 9,065,022 (the "'022 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light emitting apparatus, comprising:	The Luxrite LED4EFC/CL/27K includes a light emitting apparatus. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K contains a light emitting apparatus. 

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
at least one light emitting device, including:	The Luxrite LED4EFC/CL/27K includes at least one light emitting device. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K includes at least one light emitting device. 
a substrate, having a support surface; and	The Luxrite LED4EFC/CL/27K includes a substrate, having a support surface. For example, as shown in the photographs below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a substrate, having a support surface.  
at least one light emitting diode chip comprising a plurality of light emitting surfaces, disposed	The Luxrite LED4EFC/CL/27K includes at least one light emitting diode chip comprising a plurality of light emitting surfaces, disposed on said support surface of said substrate, one of said light emitting surfaces and said support surface forming a first main surface, wherein a light

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
on said support surface of said substrate, one of said light emitting surfaces and said support surface forming a first main surface, wherein a light emitting angle of said light emitting diode chip is wider than 180°, and a portion of light emitted by said light emitting diode chip penetrates into said substrate from said support surface and emerges from a second main surface of said substrate opposing said first main surface; and	emitting angle of said light emitting diode chip is wider than 180°, and a portion of light emitted by said light emitting diode chip penetrates into said substrate from said support surface and emerges from a second main surface of said substrate opposing said first main surface. For example, as shown in the microscopic photograph below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes at least one light emitting diode chip comprising a plurality of light emitting surfaces, disposed on said support surface of said substrate, one of said light emitting surfaces and said support surface forming a first main surface, wherein a light emitting angle of said light emitting diode chip is wider than 180°, and a portion of light emitted by said light emitting diode chip penetrates into said substrate from said support surface and emerges from a second main surface of said substrate opposing said first main surface. 
a support base, coupled to said light emitting device, and forming a first angle with said substrate.	The Luxrite LED4EFC/CL/27K includes a support base, coupled to said light emitting device, and forming a first angle with said substrate.

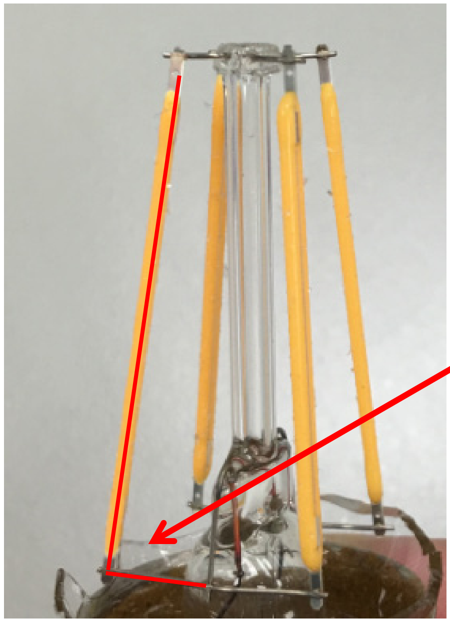
Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	For example, as shown in the photograph below, the Luxrite LED4EFC/CL/27K includes a support base, coupled to said light emitting device, and forming a first angle with said substrate. 

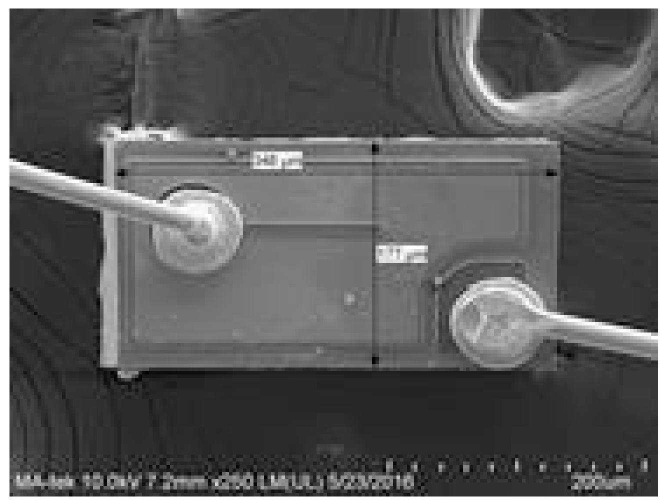
Exhibit 14

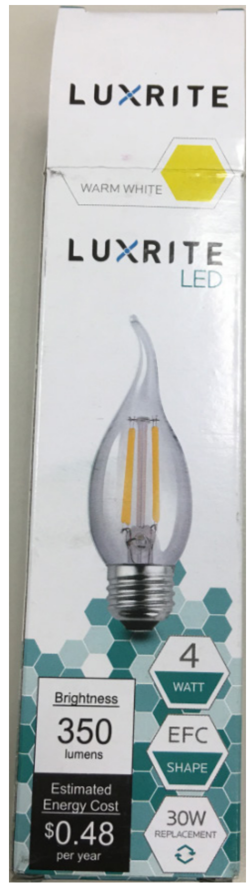
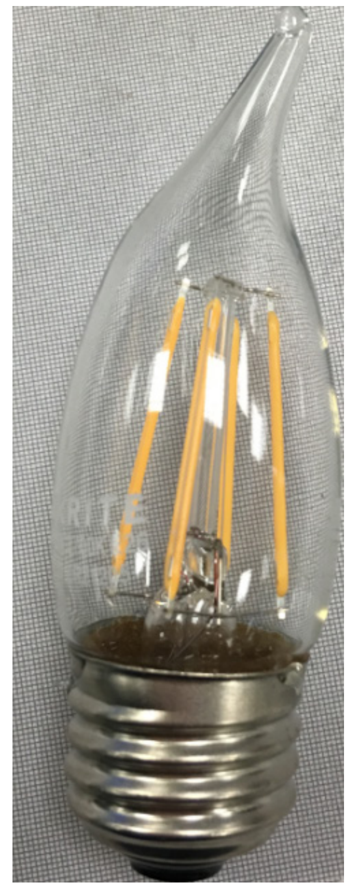
Exhibit 14: Infringement Claim Chart for U.S. Patent No. 9,257,604

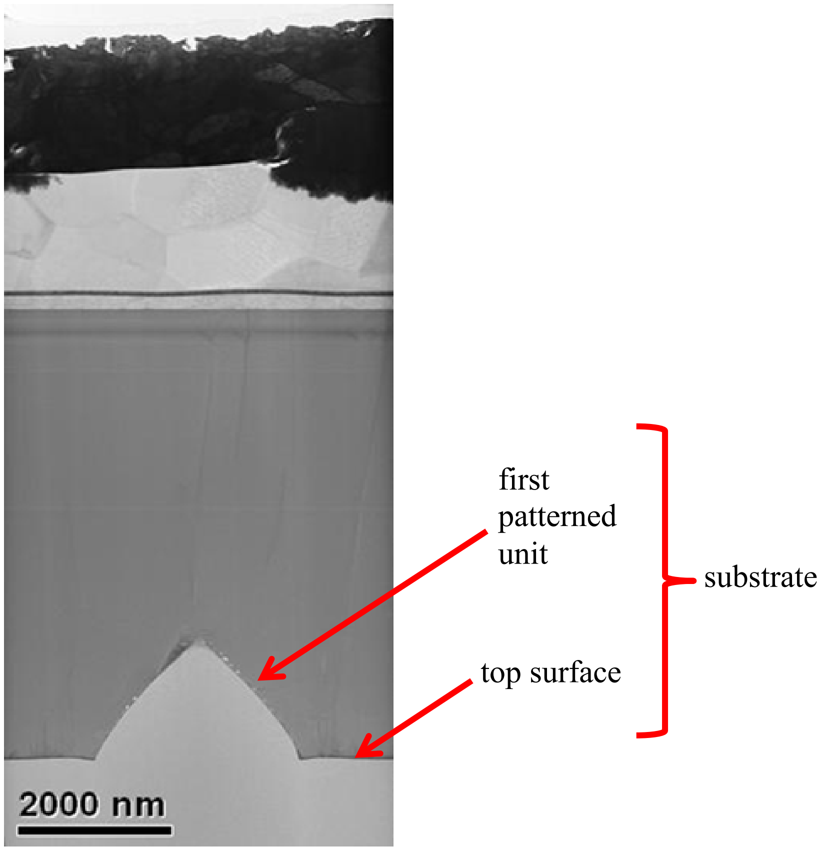
The Defendant infringes U.S. Patent No. 9,257,604 (the "'604 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

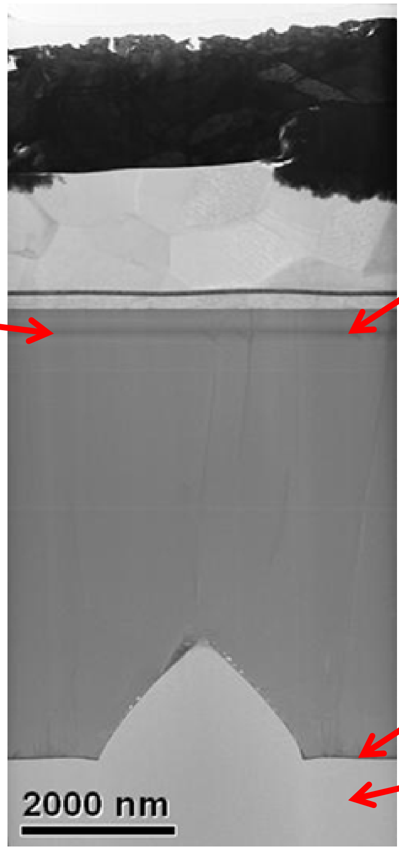
As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light-emitting device comprising:	The Luxrite LED4EFC/CL/27K includes a light-emitting device. For example, as shown in the microscopic photograph below, the Luxrite LED4EFC/CL/27K includes a light-emitting device. 

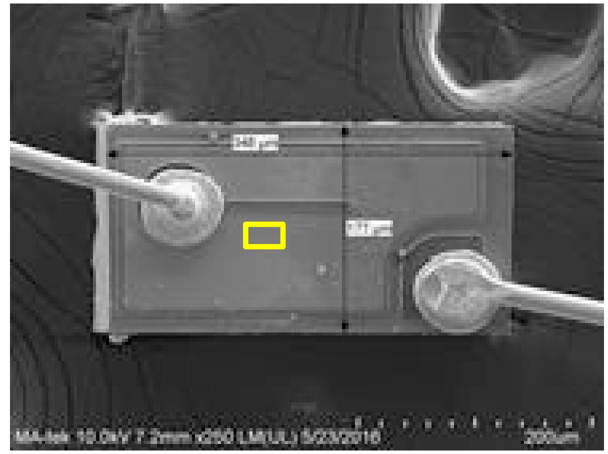
Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a substrate having a top surface and a first patterned unit bulged on the top surface; and	The Luxrite LED4EFC/CL/27K includes a substrate having a top surface and a first patterned unit bulged on the top surface. For example, as shown in the images and microscopic photographs below, the Luxrite LED4EFC/CL/27K includes a substrate having a top surface and a first patterned unit bulged on the top surface.  

<table>
<tr><th>Claim</th><th>Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td>a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface;</td><td>The Luxrite LED4EFC/CL/27K includes a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface.

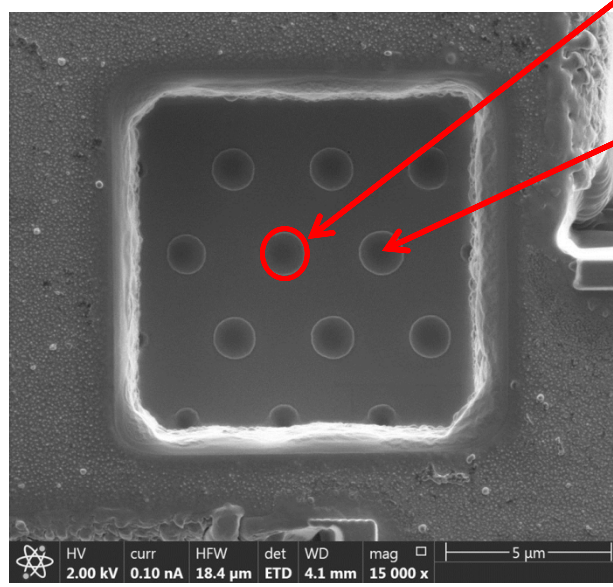
For example, as shown in the microscopic photographs below, the Luxrite LED4EFC/CL/27K includes a light-emitting stack formed on the substrate and having an active layer with a first surface substantially parallel to the top surface.</td></tr>
</table>

Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	
wherein a base of the first patterned unit has a non-polygon shape in a top view, and in a cross-sectional view the first patterned unit has a vertex, a first inclined line segment, and a second inclined line segment, and the first inclined line segment and the second inclined line segment connect at the vertex.	The Luxrite LED4EFC/CL/27K includes a base of the first patterned unit has a non-polygon shape in a top view, and in a cross-sectional view the first patterned unit has a vertex, a first inclined line segment, and a second inclined line segment, and the first inclined line segment and the second inclined line segment connect at the vertex. For example, as shown in the microscopic photographs below, theLuxrite LED4EFC/CL/27K includes a base of the first patterned unit has a non-polygon shape in a top view, and in a cross-sectional view the first patterned unit has a vertex, a first inclined line segment, and a second inclined line segment, and the first inclined line segment and the second inclined line segment connect at the vertex.

<table>
<tr><th>Claim</th><th>Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K</th></tr>
<tr><td></td><td>



(top view of chip)



(top view of chip; expanded view of area under yellow rectangle in figure above)

</td></tr>
</table>

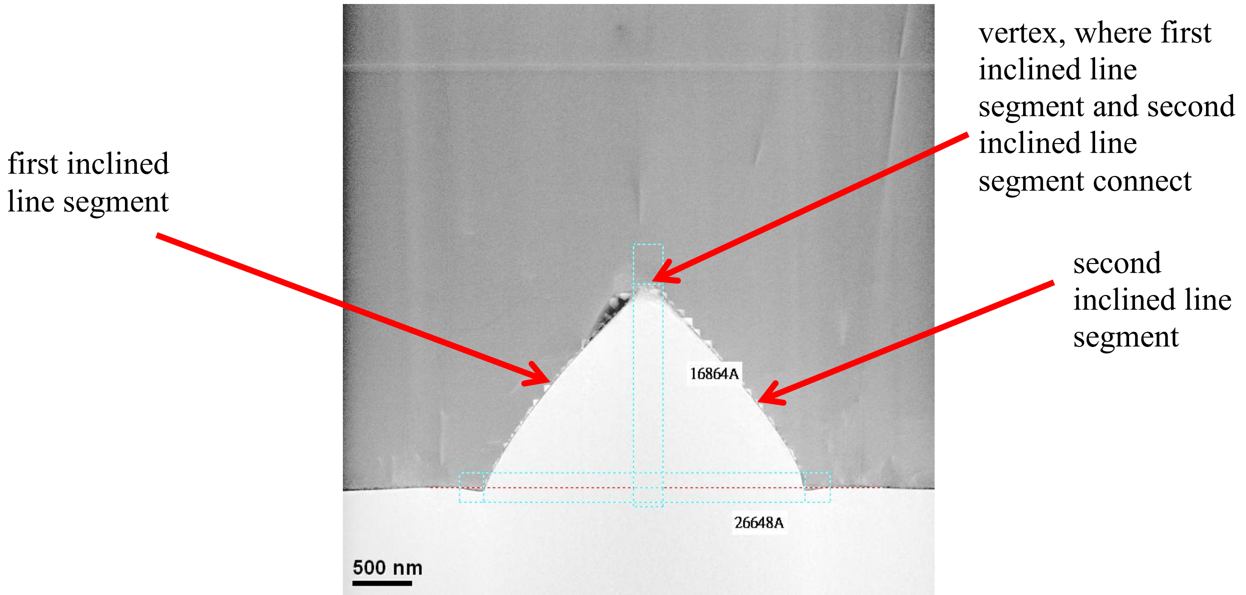
Claim	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	 (cross-sectional view of first patterned unit)

Exhibit 15

Exhibit 15: Infringement Claim Chart for U.S. Patent No. 9,488,321

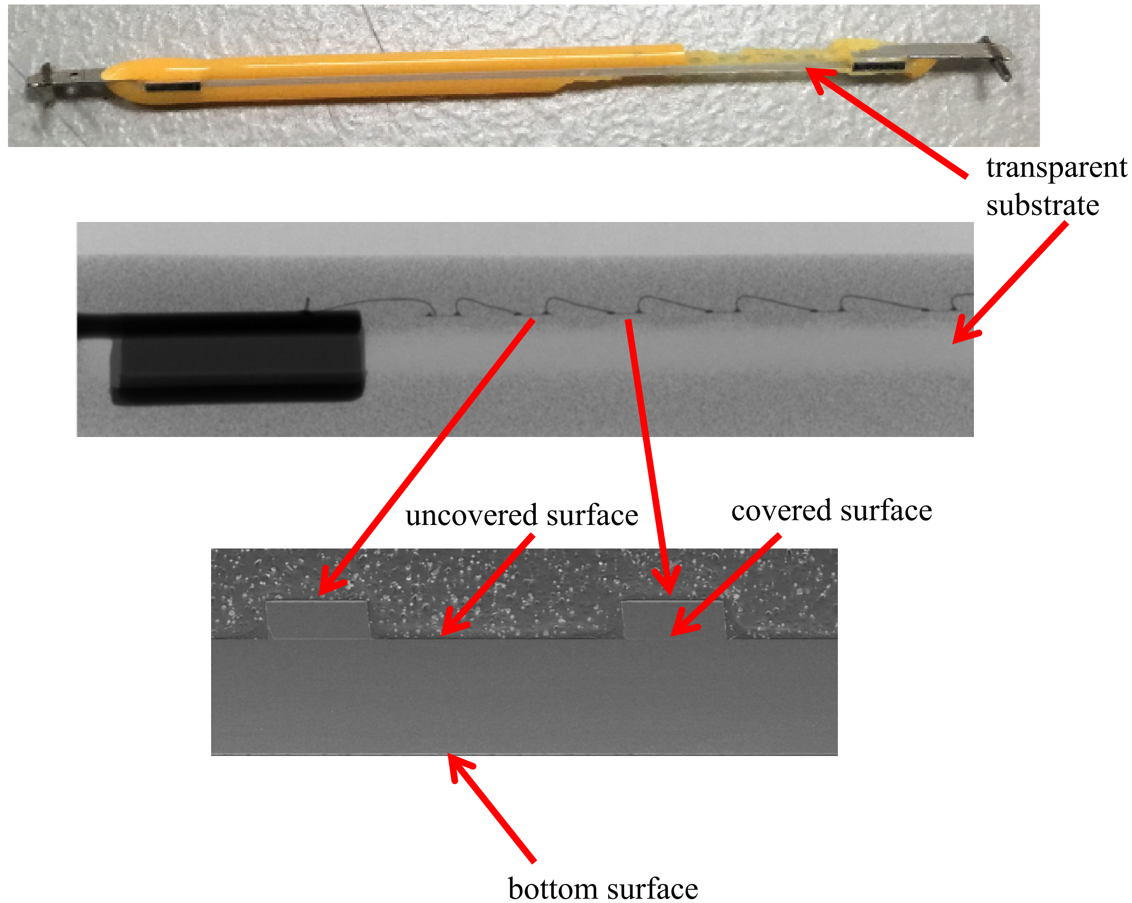
The Defendant infringes U.S. Patent No. 9,488,321 (the "'321 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

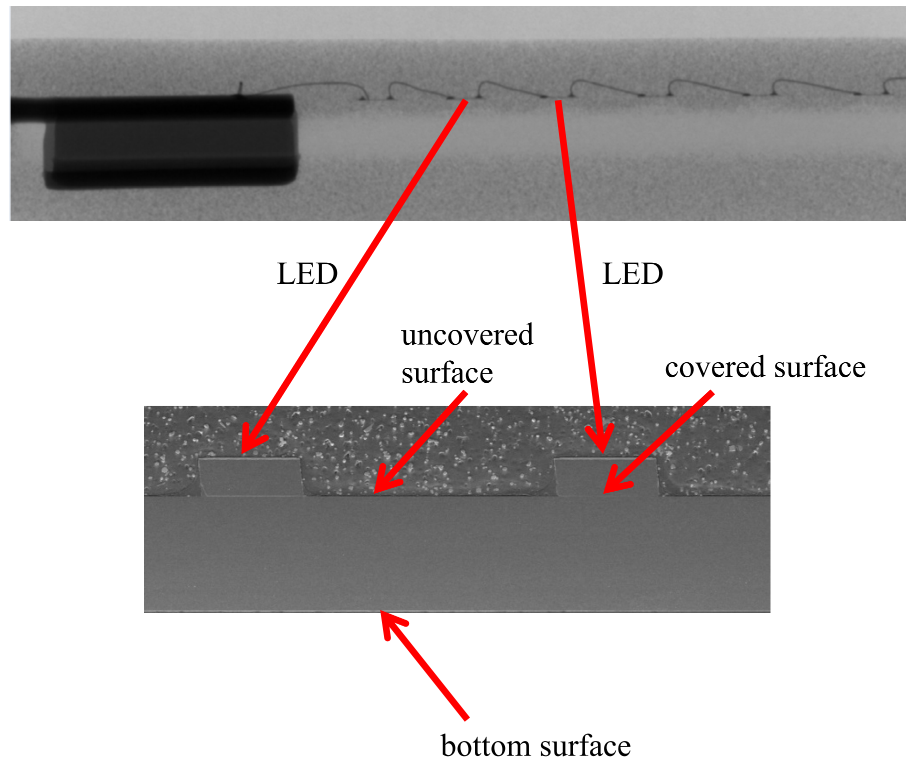
The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

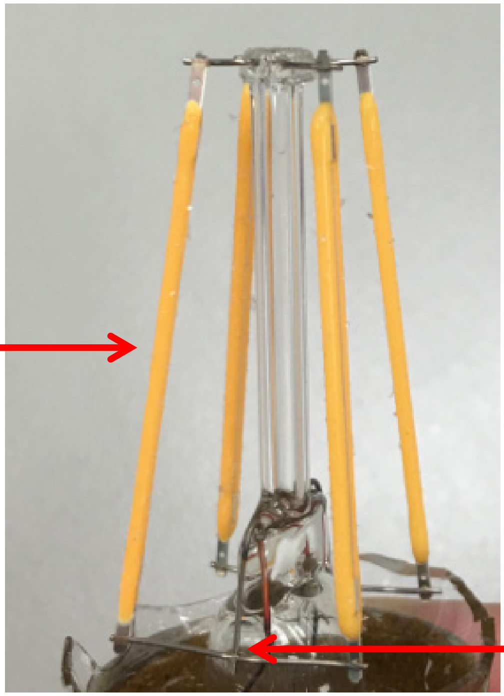
As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. An illumination device, comprising:	The Luxrite LED4EFC/CL/27K is an illumination device. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K includes an illumination device. Specifically, the Accused Product is an LED bulb that includes light-emitting filaments. 

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a light emitting element, comprising:	The Luxrite LED4EFC/CL/27K includes a light emitting element. For example, as shown in the images below, the Luxrite LED4EFC/CL/27K includes a light emitting element, such as a light-emitting filament.  
a transparent substrate, having an uncovered surface, a covered surface, and a bottom surface opposite to the uncovered surface; and	The Luxrite LED4EFC/CL/27K includes a transparent substrate, having an uncovered surface, a covered surface, and a bottom surface opposite to the uncovered surface. For example, as shown in the images and analysis below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a transparent substrate, having an uncovered surface, a covered surface, and a bottom surface opposite to the uncovered surface.

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	
a plurality of LED structures, disposed on the covered surface without blocking the uncovered surface in a configuration that the	The Luxrite LED4EFC/CL/27K includes a plurality of LED structures, disposed on the covered surface without blocking the uncovered surface in a configuration that the uncovered surface and the bottom surface are illuminated when the plurality of LED structures is operated.

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
uncovered surface and the bottom surface are illuminated when the plurality of LED structures is operated; and	For example, as shown in the microscopic images and analysis below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a plurality of LED structures, disposed on the covered surface without blocking the uncovered surface in a configuration that the uncovered surface and the bottom surface are illuminated when the plurality of LED structures is operated. 
a supporting base associated with the light emitting element; and	The Luxrite LED4EFC/CL/27K includes a supporting base associated with the light emitting element. For example, as shown in the images and analysis below, the Luxrite LED4EFC/CL/27K includes a supporting base associated with the light emitting element.

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	
a support stacked on the light emitting element, parallel to the transparent substrate, and inwardly inclined against a central axis of the supporting base by a first angle.	The Luxrite LED4EFC/CL/27K includes a support stacked on the light emitting element, parallel to the transparent substrate, and inwardly inclined against a central axis of the supporting base by a first angle. For example, as shown in the images and analysis below, the Luxrite LED4EFC/CL/27K includes a support stacked on the light emitting element, parallel to the transparent substrate, and inwardly inclined against a central axis of the supporting base by a first angle.

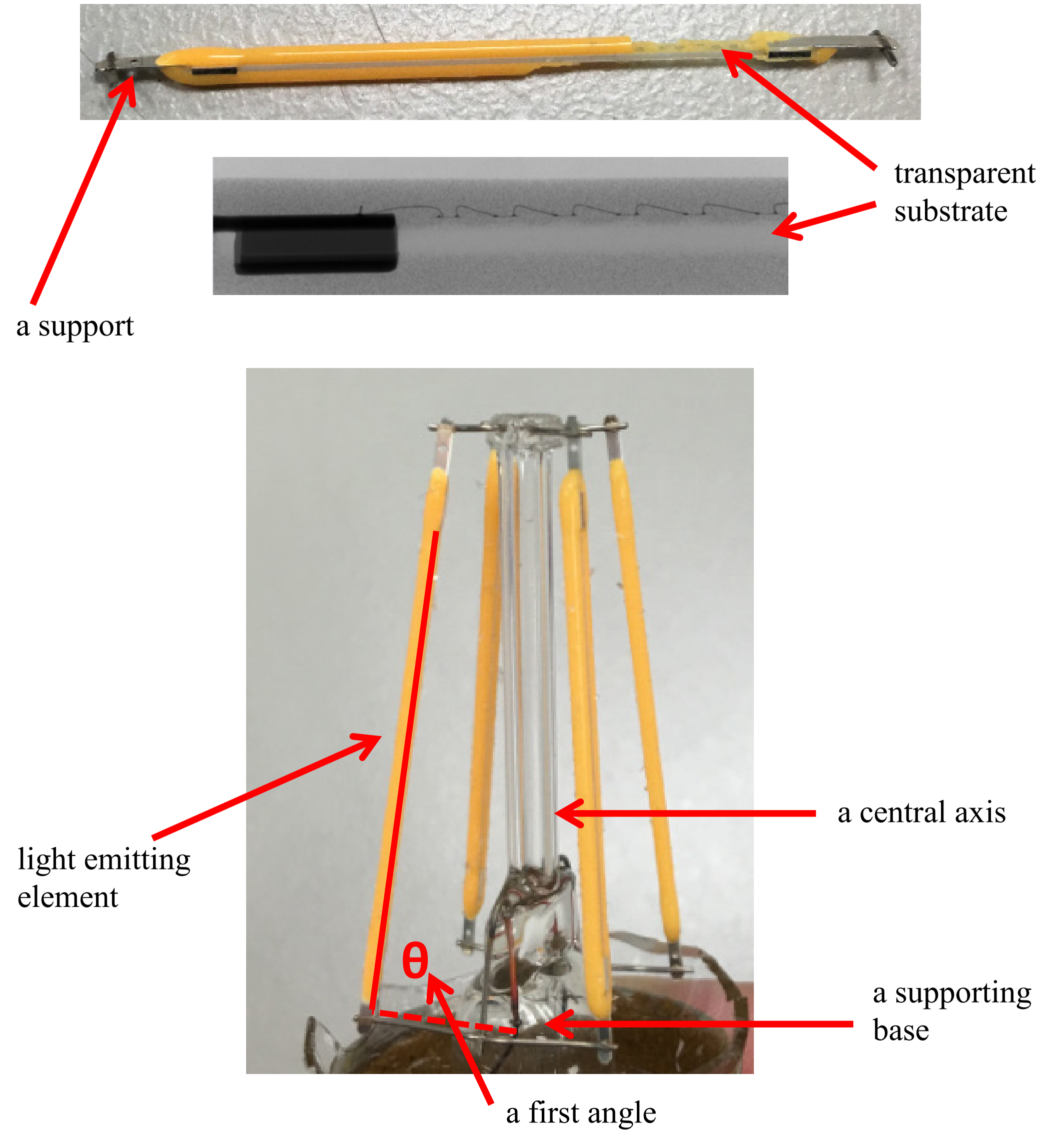
Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
	

Exhibit 16

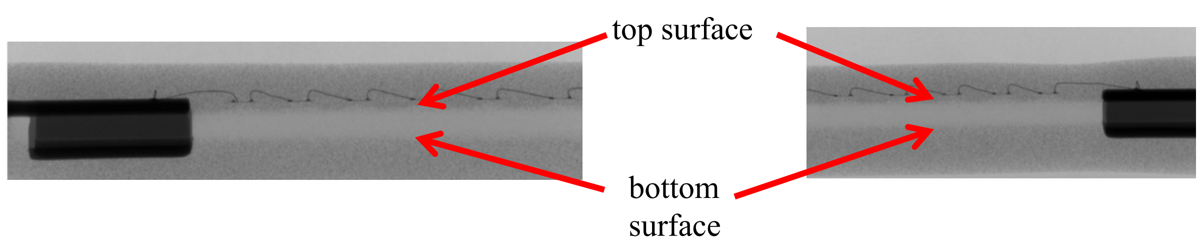
Exhibit 16: Infringement Claim Chart for U.S. Patent No. 9,664,340

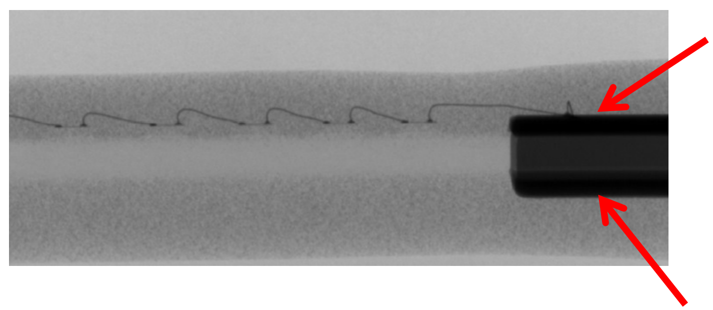
The Defendant infringes U.S. Patent No. 9,664,340 (the "'340 patent") by making, using, selling, offering for sale, and importing at least the Luxrite LR21205 Light Bulb (Manufacturer Part Number: LED4EFC/CL/27K) (the "Accused Product").

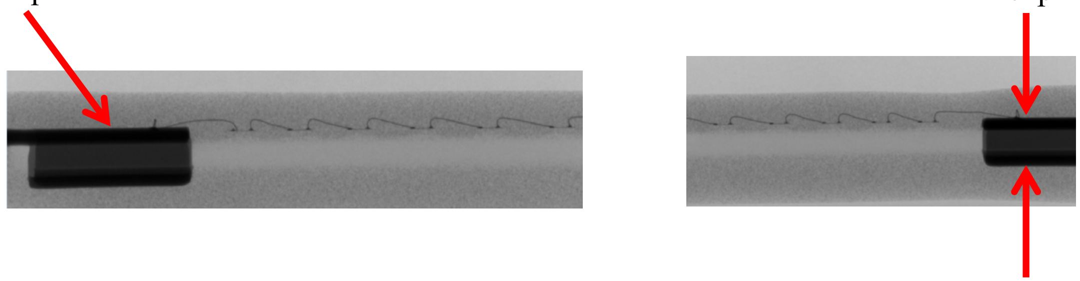
The asserted claims include elements that are implemented, at least in part, by proprietary hardware in the Accused Product. Plaintiff has provided these contentions based on analyzing the Accused Product as well as a review of the publicly available materials regarding the Accused Product. The chart is merely exemplary and may not show the functionality in its entirety. Furthermore, Plaintiff reserves the right to revise these contentions as discovery in the case progresses, in view of the Court's final claim construction in this action and in connection with expert reports.

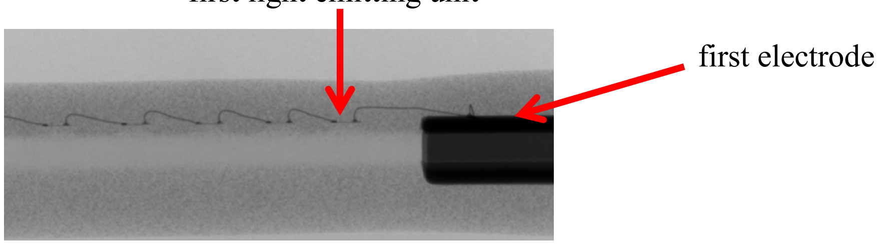
As one non-limiting example, at least the **Luxrite LED4EFC/CL/27K** includes the features cited in the chart below:

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
1. A light-emitting device, comprising:	The Luxrite LED4EFC/CL/27K is a light-emitting device. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K includes a light-emitting device. Specifically, the Accused Product is an LED bulb that includes light-emitting filaments. 

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a carrier having a top surface and a bottom surface;	The Luxrite LED4EFC/CL/27K includes a carrier having a top surface and a bottom surface. For example, as shown in the images below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a carrier having a top surface and a bottom surface.   

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a first electrode having a first part formed on the top surface, and a second part formed on the bottom surface;	The Luxrite LED4EFC/CL/27K includes a first electrode having a first part formed on the top surface, and a second part formed on the bottom surface. For example, as shown in the images and analysis below, the light-emitting filament of the Luxrite LED4EFC/CL/27K includes a first electrode having a first part formed on the top surface, and a second part formed on the bottom surface.   

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a second electrode having a third part formed on the top surface, wherein the first part and the third part are arranged at two opposite sides of the carrier;	The Luxrite LED4EFC/CL/27K includes a second electrode having a third part formed on the top surface, wherein the first part and the third part are arranged at two opposite sides of the carrier. For example, as shown in the images and analysis below, the Luxrite LED4EFC/CL/27K includes a second electrode having a third part formed on the top surface, wherein the first part and the third part are arranged at two opposite sides of the carrier.  

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a first light-emitting unit disposed on the top surface and electrically connected to the first electrode; and	The Luxrite LED4EFC/CL/27K includes a first light-emitting unit disposed on the top surface and electrically connected to the first electrode. For example, as shown in the image below, the Luxrite LED4EFC/CL/27K includes a first light-emitting unit disposed on the top surface and electrically connected to the first electrode. 

Claims	Exemplary Disclosures of Technical Features for Luxrite LED4EFC/CL/27K
a transparent body covering the first part, the second part, the third part and the first light-emitting unit.	The Luxrite LED4EFC/CL/27K includes a transparent body covering the first part, the second part, the third part and the first light-emitting unit. For example, as shown in the images and analysis below, the Luxrite LED4EFC/CL/27K includes a transparent body covering the first part, the second part, the third part and the first light-emitting unit.