IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

OSRAM GMBH and OSRAM OPTO SEMICONDUCTORS GMBH	)	
Plaintiffs.	)	C.A. No. 06-710-SLR
v.	)	
CITIZEN WATCH CO., LTD. CITIZEN ELECTRONICS CO., LTD. And CECOL, INC.	)	
Defendants.	)	

FIRST AMENDED ANSWERS AND COUNTERCLAIMS OF CITIZEN ELECTRONICS CO., LTD. AND CECOL, INC, TO PLAINTIFFS' FIRST SUPPLEMENTAL COMPLAINT

Defendants Citizen Electronics Co., Ltd. (hereinafter "CE"), and Cecol, Inc. (collectively, "Citizen"), by and through the undersigned attorneys, hereby respond to the similarly numbered paragraphs within the First Supplemental Complaint of Osram GmbH and Osram Opto Semiconductors GmbH (collectively, "Osram").

I. ANSWERS TO COMPLAINT

NATURE OF THE ACTION

1. Citizen admits this is a civil action asserting patent infringement arising under the patent laws of the United States, Title 35, United States Code, and that Osram seeks damages, injunctive relief and other relief in connection thereto. Citizen denies the remaining allegations.

PARTIES

2. Admitted.

3. Admitted.

4. Admitted.

5. Admitted.

6. Admitted.

JURISDICTION AND VENUE

7. Admitted that this court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331 and 1338(a). Otherwise denied.

8. Admitted that Cecol, Inc. is a Delaware corporation, otherwise denied.

9. Admitted that this Court has personal jurisdiction over Cecol, Inc., by virtue of Cecol, Inc. being a Delaware corporation. Admitted that CE is the parent corporation of Cecol, Inc., and that Citizen Watch Co., Ltd. is the parent corporation of CE. Citizen denies all remaining allegations.

10. Admitted that CE filed two declaratory judgment actions against Osram, and that both of its actions have been dismissed. Admitted that in January 2005 CE filed its first declaratory judgment action, seeking a declaration that several Osram patents were invalid and/or not infringed. Admitted that Osram successfully moved the trial court to dismiss CE's first declaratory judgment action for lack of subject matter jurisdiction. Admitted that on July 29, 2005, the trial court issued its final order dismissing CE's first declaratory judgment action, and that CE filed a second declaratory judgment action against Osram a few days later. Otherwise denied.

11. Admitted that the trial court dismissed CE's second declaratory judgment action. Otherwise denied.

12. Citizen denies all allegations.

PATENTS-IN-SUIT

13. Admit to the title of the '259 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '259 patent is attached to the complaint as Exhibit A.

14. Admit to the title of the '301 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '301 patent is attached to the complaint as Exhibit B.

15. Admit to the title of the '780 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '780 patent is attached to the complaint as Exhibit C.

16. Admit to the title of the '247 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '247 patent is attached to the complaint as Exhibit D.

17. Admit to the title of the '500 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '500 patent is attached to the complaint as Exhibit E.

18. Admit to the title of the '162 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '162 patent is attached to the complaint as Exhibit F.

19. Admit to the title of the '283 patent, the purported inventors listed thereon, and issue date, and that what appears to be a true copy of the '283 patent is attached to the complaint as Exhibit G.

20. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 20, and therefore denies them.

COUNT I – ALLEGED INFRINGEMENT OF THE '259 PATENT

21. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

22. Denied.

23. Denied.

24. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 24, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

25. Denied.

26. Denied.

27. Denied.

COUNT II – ALLEGED INFRINGEMENT OF THE '301 PATENT

28. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

29. Denied.

30. Denied.

31. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 31, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

32. Denied.

33. Denied.

34. Denied.

COUNT III – ALLEGED INFRINGEMENT OF THE '780 PATENT

35. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

36. Denied.

37. Denied.

38. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 38, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

39. Denied.

40. Denied.

41. Denied.

COUNT IV – ALLEGED INFRINGEMENT OF THE '247 PATENT

42. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

43. Denied.

44. Denied.

45. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 45, because the statement is indefinite as to any

timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

46. Denied.

47. Denied.

48. Denied.

COUNT V – ALLEGED INFRINGEMENT OF THE '500 PATENT

49. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

50. Denied.

51. Denied.

52. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 52, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

53. Denied.

54. Denied.

55. Denied.

COUNT VI – ALLEGED INFRINGEMENT OF THE '162 PATENT

56. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

57. Denied.

58. Denied.

59. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 59, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

60. Denied.

61. Denied.

62. Denied.

COUNT VII – ALLEGED INFRINGEMENT OF THE '283 PATENT

63. Citizen incorporates by reference its responses to each of the foregoing paragraphs 1-20.

64. Denied.

65. Denied.

66. Citizen lacks information sufficient to form a belief as to the truth of the allegations set forth in paragraph 66, because the statement is indefinite as to any timeframe or the basis for and meaning of the term "actual knowledge." Therefore, denied.

67. Denied.

68. Denied.

69. Denied.

II. DEFENSES TO OSRAM'S COMPLAINT

1. The claims of the '259 patent, '301 patent, '780 patent, '247 patent, '500 patent, '162 patent and '283 patent are invalid for failure to meet the requirements of the

United States patent laws, 35 U.S.C. §§ 101 et seq., including, but not limited to §§ 102, 103, and 112.

2. Neither Citizen nor Citizen's white light LED products or processes infringe, contribute to the infringement of, or induce the infringement of any valid and enforceable claim of the above patents.

3. Osram's claim for damages, if any, against Citizen is statutorily limited by 35 U.S.C. § 286 and/or § 287.

4. Prosecution history estoppel bars Osram's assertion of any interpretation of any of the claims of the above patents that would cover any of Citizen's white light LEDs.

5. For the reasons set forth in greater detail in counterclaim paragraph nos. 26 – 150 below, the '259 patent, '301 patent, '780 patent, '247 patent, '500 patent, '162 patent, and '283 patent are unenforceable due to inequitable conduct.

III. EXCEPTIONAL CASE

This is an exceptional case under 35 U.S.C. § 285 and, as such, Citizen is entitled to recover from Osram the attorneys fees and costs incurred by Citizen in connection with this action.

IV. COUNTERCLAIMS BY CITIZEN ELECTRONICS, LTD. AND CECOL, INC.

Counterclaim-Plaintiffs Citizen Electronics Company, Ltd. ("CE") and Cecol, Inc. ("Cecol"), (collectively, "Citizen") by and through the undersigned attorneys, bring these

counterclaims against counterclaim-defendants OSRAM GmbH and OSRAM Opto Semiconductors GmbH (collectively "OSRAM") as follows:

PARTIES

1. CE is a Japanese company having a principal place of business at 1-23-1 Kamikurechi, Fujiyoshida-shi, Yamanashi-ken 403-0001, Japan.

2. Cecol is a Delaware corporation with its principal place of business at 951 North Plum Grove Road, Suite D, Schaumburg, IL 60173.

3. On information and belief, OSRAM GmbH is a German company with a principal place of business at Hellabrunner Strasse 1, 81543 Munich, Germany.

4. On information and belief, OSRAM Opto Semiconductors GmbH is a German company with a principal place of business at Wernerwerkstrasse 2, 93049 Regensburg Germany, and it is a subsidiary of OSRAM GmbH.

NATURE OF THE COUNTERCLAIMS

5. These are counterclaims for declaratory judgment that neither Citizen nor Citizen's white light LED products or processes infringe, contribute to the infringement of, or induce the infringement of Osram's intellectual property rights in the patents-in-suit and that such intellectual property rights are invalid and/or unenforceable due to inequitable conduct.

JURISDICTION AND VENUE

6. This Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331, 1338, 2201, and 2202. Venue is proper in this judicial district under 28 U.S.C. § 1391(c).

7. This court has personal jurisdiction over counterclaim-defendants.

ADDITIONAL PATENTS IN SUIT

8. In addition to the '301, '247, '259, '780, '500, '162, and '283 patents already at issue in this case, Citizen's counterclaims also involve U.S. Patent Nos. 6,066,861 and 6,576,930. Hereinafter, all of the patents in the preceding sentence are referenced by the term "patents-in-suit."

9. United States Patent 6,066,861 ("the '861 patent") entitled WAVELENGTH-CONVERTING CASTING COMPOSITION AND ITS USE to Klaus Hohn of Taufkirchen, Germany, Alexandra Debray of Regensburg, Germany, Peter Schlotter of Freiburg, Germany, Ralf Schmidt of Vorstetten, Germany, and Jurgen Schneider of Kirchzarten, Germany issued on May 23, 2000 to Siemens Aktiengesellschaft (Ex. A attached hereto).

10. United States Patent 6,576,930 ("the '930 patent") entitled LIGHT-RADIATING SEMICONDUCTOR COMPONENT WITH A LUMINESCENCE CONVERSION ELEMENT to Ulrike Reeh of Munchen, Germany, Klaus Hohn of Taufkirchen, Germany, Norbert Stath of Regensburg, Germany, Gunter Waitl of Regensburg, Germany, Peter Schlotter of Freiburg, Germany, Jurgen Schneider of Kirchzarten, Germany, and Ralf Schmidt of Vorstetten, Germany issued on June 10, 2003 to Osram Opto Semiconductors GmbH (Ex. B attached hereto).

BACKGROUND

11. CE and Cecol have imported, offered for sale, and/or sold white light emitting diodes (LEDs) in the United States, and CE and Cecol continue to import, offer for sale, and sell white light emitting diodes in the United States.

12. Commencing in 2003, OSRAM asserted to CE that its white LEDs imported, offered for sale, and sold in the United States infringe several of the patents-in-suit. Throughout 2003, CE and OSRAM exchanged correspondence and discussed the alleged infringement of several of the patents-in-suit, but the parties reached no agreement.

13. OSRAM's January 28, 2003, letter to CE stated that "Citizen manufactures, markets, and sells white LED products . . . which makes use of our Particle Size Patents" and that OSRAM further believes "that your products . . . are offered for sale, sold, and used in countries where our Particle Size Patents are in force."

14. OSRAM's October 29, 2003 letter to CE stated :

> Finally it has to be emphasized that it is still our position that specifically white LED components of CITIZEN make unauthorized use of and infringe OSRAM patent rights directed to luminescence conversion particle size and principle of conversion LED. Your argument that the scope of U.S. 6,576,930 B2 is weak and not persuasive."

15. On or around March 14, 2005, OSRAM filed a patent infringement action against CE and CE's German distributor, before the Düsseldorf Regional Court in Germany.

16. OSRAM's German complaint asserts that CE's white LEDs infringe OSRAM's European Patent no. EP 0862794, and OSRAM's German utility model nos. DE-GM 297 24 847, DE-GM 297 24 382, and DE-GM 297 24 848.

17. Each of the patent documents asserted by OSRAM in its German complaint against CE is a member of the same family of international patent documents that includes the instant patents-in-suit. That is, all of the patents-in-suit are U.S. counterparts of patents upon which Osram brought suit against CE in Germany, and all of these U.S. and German patents claim an origin to the same German applications.

18. Through its complaint filed on November 27, 2006, and its supplemental pleading filed February 1, 2007, before this Court, Osram asserts infringement of the '301, '247, '259, '780 particle size patents, and the '500, '162, and '283 conversion patents due to the making, using, offering to sell, and/or selling by CE or Cecol of white light emitting LEDs.

19. The '861 patent that is added to these counterclaims is a member of Osram's particle size patent family, and indeed is one of the parent patents to which all of the other particle size patents claim priority. The '930 patent that is added to these counterclaims is a member of Osram's conversion patent family, and it ultimately claims priority to the same foreign applications as Osram's other conversion family members.

20. OSRAM's actions and the facts recited above create a true case and controversy between CE/Cecol and Osram as to the patents-in-suit.

COUNTERCLAIM COUNT I
Non-Infringement of the Patents-in-suit

21. CE/Cecol repeat the allegations of counterclaim paragraphs 1 through 20, and paragraphs 23-150 below, as if fully set forth herein.

22. There is an actual case or controversy as to infringement of the patents-in-suit. CE's/Cecol's white light emitting LED products and processes do not and would not infringe, contribute to the infringement of, or induce the infringement of any valid and enforceable claim of the patents-in-suit.

COUNTERCLAIM COUNT II
Invalidity of the Patents-in-suit

23. CE/Cecol repeat the allegations of counterclaim paragraphs 1 through 22, and paragraphs 25-150 below, as if fully set forth herein.

24. There is an actual case or controversy as to the validity of claims in each of the patents-in-suit. Claims within each of the patents-in-suit are invalid for failure to satisfy one or more of the requirements of 35 U.S.C. §§ 101, et seq., including, but not limited to §§ 102, 103, and 112.

COUNTERCLAIM COUNT III
Unenforceability of the Patents-in-suit

25. CE/Cecol repeat the allegations of counterclaim paragraphs 1 through 24, as if fully set forth herein.

26. Under 37 C.F.R. § 1.56, all individuals associated with the preparation, filing, and prosecution of a patent application have an uncompromising duty of candor and good faith in dealing with the PTO. That duty requires such individuals, *inter alia*, to disclose to the PTO all information known by them to be material to patentability.

27. Among those individuals subject to this "duty of disclosure" are the inventors named in a patent application, attorneys, agents, and any others associated or substantively involved with preparing and prosecuting the patent application (hereinafter collectively referred to as "Osram").

28. The duty of candor before the PTO, in particular, 37 CFR 1.56(b)(2) requires applicants to disclose any information that "refutes, or is inconsistent with, a position the applicant takes...."

29. The patents-in-suit can be divided into two families. Each family has a common "parent" application or patent, to which younger members of that family can trace their lineage.

30. One family can be characterized as the "particle size patents," due to the presence of a particle size distribution limitation in each claim of the '861, '301, '247, '259, and '780 patents (hereinafter, "the particle size patents"). U.S. Patent No. 6,066,861 is the "parent" patent of these "particle size patents."

31. The other family can be characterized as the "conversion" patents due to the presence in the claims of the '930, '500, '162, and '283 patents of an element that converts primary radiation emitted by a semiconductor component (hereinafter, the "conversion patents"). U.S. Patent No. 7,078,732 is the "parent" patent to these "conversion patents."

32. The '301, '247, '259, '780, '930, '500, '162, and '283 patents are unenforceable because Osram made misleading statements and withheld material information or did not bring material information to the attention of the patent examiner. This inequitable conduct was pervasive throughout both patent families, and includes conduct during prosecution not only of the conversion patents, but also other patents in the same conversion family that are not asserted by Osram in this action. These additional omissions and commissions in the non-asserted patents reinforce the inequitable conduct in the patents-in-suit, and confirm that Osram fraudulently procured their patents through multiple patterns of intentional misconduct, and not isolated incidents or mistakes.

A. Inequitable Conduct Regarding the Conversion Patents

Osram Failed to Properly Disclose an Adverse Interference Judgment that Prohibited its Entitlement to the '500, '162, and '283 Patents

33. Osram initiated an interference dispute with Nichia Corporation (hereafter, "Nichia"), and subsequently received an adverse judgment that precluded Osram from obtaining the same claims or claims of obvious scope to those lost in the interference. However, Osram did just that, and prosecuted claims as if it had won, rather than lost the interference. Indeed, although Osram was required to bring the existence and materiality of this interference to the attention of those members of the U.S. Patent and Trademark Office ("PTO") examining Osram's conversion patents, Osram failed to do either, or it did so in a manner that mischaracterized and misled patent examiners to believe that Osram was entitled to the patents. But for Osram's fraudulent actions, the '500, '283, and '162 patents, would not have issued in their present form.

Background Regarding the Osram-Nichia Interference

34. On April 9, 2001, Osram filed application 09/828,727 ("the '727 application"). This '727 application relates to applications that matured into Osram's '930, '500, '162, and '283 patents, since all of them claim priority to the same parent application, namely no. 09/221,789. This parent application matured into the "parent" patent, U.S. 7,078,732.

35. Simultaneously with its April 9, 2001 filing of the '727 application, Osram requested the PTO to initiate an interference proceeding between Osram's '727 application and U.S. Patent No. 6,069,440, which had issued on May 30, 2000 to Nichia (hereafter, "Nichia's '440 patent").

36. An interference proceeding before the PTO determines which party first invented an invention, so that only one patent exists or will exist for any given invention, and that only one entity owns that particular invention. In this case, Nichia's '440 patent had already claimed the subject matter claimed in Osram's '727 application.

37. On page 2 of its April 9, 2001 request for interference, Osram argued that claims 34 and 40 of its '727 application were claims defining the subject matter of the interference with Nichia's '440 patent.

38. Claim 40 of Osram's '727 application recited:

> 40. A light emitting device comprising:
>
> a light emitting component capable of emitting blue light, and
> a coating member covering said light emitting component and
> containing a phosphor capable of absorbing a part of blue light emitted by said light emitting component and emitting light of wavelength different from that of the absorbed light,
> wherein the color of said phosphor is yellow and
> said coating member contains light diffusing particles.

39. Claim 34 of Osram's '727 application was identical to claim 40, except instead of reciting that its "phosphor is yellow and said coating member contains light diffusing particles," it stated that its "phosphor is yellow and said coating member is colored opal by containing a dispersant."

40. Claim 34 directly copied, and therefore was identical to claim 1 of Nichia's '440 patent.

41. On pages 3 and 7 of its April 9, 2001, request for interference, Osram indicated that the "coating member" mentioned in claim 34 and 40 of the '727 application corresponded to "luminescence conversion elements" both in the form of an encapsulation and conversion layer.

42. All claims corresponding to the subject matter of the interference included the use of diffusers (referred to alternatively as "dispersants") within the coating layer/luminescence converting element.

43. On page 2 of its April 9, 2001 request for interference, Osram stated that claims 3-8 of Nichia's '440 patent, including claim 5 that recites the use of a silicon resin, "would be obvious in light of the respective independent claims on which they depend."

44. On June 28, 2002, the PTO declared an interference (no. 104,846) between Osram's '727 application and Nichia's '440 patent. It defined the "count," i.e., subject-matter of the interference to be either of claims 34 and 40 of Osram's '727 application, or claim 1 of Nichia's '440 patent, and it defined all claims within Osram's '727 application to correspond to, or fall within the subject matter of the interference.

45. On or around June 24, 2002, Osram issued a press release stating "[A] patent dispute that Osram Opto Semiconductor GmbH and Nichia Corporation had been conducting in Japan, the United States, and Europe was resolved with the signing of a patent cross-licensing agreement....The matter in question is the basic technology for the industrial manufacture of light emitting diodes (LEDs) and lasers made from GN/InGaN-based semiconductors and also the use of phosphor converters to generate white light in particular."

46. On or around June 25, 2002, Nichia issued a press release announcing that Osram and Nichia were entering a patent cross-license agreement and that this "agreement resolves all pending patent disputes between Nichia and Osram...."

47. On August 9, 2002, instead of filing its list of preliminary motions in the interference, Osram filed a document stating "that [it] is not planning to file preliminary motions, inasmuch as the parties are planning to settle this interference."

48. In a document dated December 5, 2002, Osram filed a request for adverse judgment to be entered against Osram, upon the grounds that it was abandoning the interference contest. That is, Osram filed a paper voluntarily surrendering the interference.

49. Osram's request for adverse judgment was granted December 16, 2002. The judgment of the U.S. Board of Patent Appeals and Interferences stated:

> ORDERED that judgment on priority as to Count 1… is awarded against [Osram].
>
> FURTHER ORDERED that [Osram] is not entitled to a patent containing claims 34-45 (corresponding to Count 1 respectively) of application 09/828,727, filed April 9, 2001.
>
> …
>
> FURTHER ORDERED that if there is a settlement agreement, attention is directed to 35 U.S.C. § 135(c) and 37 CFR §1.661.
>
> (Emphasis added).

50. Due to the Judgment dated December 16, 2002, Nichia retained its '440 patent, and Osram was not entitled to a patent on any of its claims in its '727 application or claims corresponding (i.e., obvious) to claim 1 of Nichia's '440 patent.

51. Furthermore, as stated in the U.S. Patent Office's Manual of Patent Examining Procedure in section 2308.03, Osram, as "a losing party, is barred on the merits from seeking a claim that would have been anticipated or rendered obvious by the subject matter of the lost count." When the interference was declared, it defined all of Osram's claims within the '727 application as corresponding to the subject matter of the interference. Therefore, Osram was not entitled to any claim in any patent that would

have been anticipated or rendered obvious by any of the claims in its '727 application (all of which corresponded to the lost count in the interference).

The Interference that Osram Lost is Material to the '500 Patent, and Yet Osram Never Disclosed it to the U.S. Patent Office

52. On December 6, 2000, Osram filed the application that matured into the '500 patent.

53. Osram's '500 patent contains claims very similar to, and, indeed, are anticipated by or obvious over the subject matter of Osram's '727 application that was lost in the interference. For example, just like the claims in Osram's '727 lost interference application, claim 3 of the '500 patent covers a light emitting device that emits blue light, with a luminescence conversion layer containing light diffusing particles and phosphor that converts only part of the light emitted from the semiconductor into radiation of a different wavelength.

54. Importantly, pages 3 and 7 of Osram's April 9, 2001 request for interference stated that the luminescence conversion layer or encapsulation described in their '727 interference application (which is identical to the luminescence conversion layer or encapsulation described in the '500 patent, due to the fact that the '727 and '500 patent are related) is the "coating member" recited in the '727 application's claims. That is, Osram admitted that the luminescence conversion layer or encapsulation of the type described in the '500 patent is identical to the "coating member" in the '727 application's claims that Osram lost in the interference. Since Osram is not entitled to patent claims that are anticipated or obvious in view of Osram's claims from its lost '727 interference application, the interference highly material to the '500 patent.

55. The prosecution of claims reciting diffusers or light diffusing particles in the '500 Patent further demonstrates the materiality of the interference proceedings and Osram's inequitable conduct in withholding this highly material information from the examiner.

56. The '500 patent claims 3 and 4 were allowed by the PTO Examiner due to the recitation that the resin layer or encapsulation includes "light-diffusing particles." In the application that matured into the '500 patent, Osram initially attempted to obtain broader patent claims. However, the Examiner rejected all of the original claims, except for dependent application claims 13, 25, and 26. As to these dependent claims, the Examiner indicated that they would be allowable if they were rewritten in independent form. Dependent application claims 25 and 26 read as follows (emphasis added):

> 25. The semiconductor component according to claim 1, wherein said luminescence conversion element includes ***light-diffusing particles***.
>
> 26. The semiconductor component according to claim 1, which comprises a transparent encapsulation with ***light-diffusing particles***.

57. Thus, the Examiner did not consider the subject matter of independent claim 1 allowable, but did consider the subject matter of claims 25 and 26 patentable, due to the recitation of light-diffusing particles. Osram then rewrote application claims 25 and 26 in independent form, and they became claims 3 and 4 of the '500 patent.

58. However, in the prosecution proceedings for the '500 patent, Osram failed to inform the PTO Examiner that through the PTO interference dispute with Nichia that Osram lost, Osram knew that Nichia already had its '440 patent with claims directed to light-diffusing particles.

59. Conversely, in the prosecution proceedings for the '500 patent, Osram failed to inform the PTO Examiner that Osram's '727 application, which was lost in the interference, likewise had claims directed to light diffusing particles, and that the interference judgment prohibited Osram from obtaining claims that are obvious to or anticipated by the '727 application claims lost in the interference.

60. By requesting the claims that ultimately issued in the '500 Patent, Osram was "recapturing" subject matter in the '500 patent that Osram had lost in its interference with Nichia.

61. The interference is further relevant and material to Osram's '500 patent through the '500 patent's claim 5, which recites that the luminescence conversion element includes a specific resin (silicone).

62. On page 2 of Osram's Request for Interference, Osram conceded that the use of silicone was obvious. In particular, Osram requested that the independent claims involved in the interference should be considered as the "count" (i.e., the subject matter of the interference dispute), while the dependent claims of the Nichia patent and corresponding claims by Osram were considered to be "obvious":

> Applicants [i.e., Osram] identify claims 1-8 [of Nichia's USP 6,069,440] as corresponding to the proposed count. Independent claims 1, 2 correspond exactly to the proposed count. The remaining claims correspond substantially to the proposed count because they describe subject matter that would be obvious in light of the respective independent claims on which they depend.

63. Dependent claim 5 of Nichia's '440 patent recited the use of silicone:

> 5. A light emitting device according to claim 2; wherein said molding member are made of the material selected from the group consisting of epoxy resin, urea resin and ***silicone resin***.

(Emphasis added).

64. Yet, in proceedings before the Examiner in the '500 patent, Osram repeatedly argued that its claims were patentable *by virtue of the recitation of silicone as the particular resin of the luminescence conversion element*. Indeed, with respect to many references initially relied upon by the Examiner to reject the '500 patent's claims, the use of silicone for the conversion element was the only distinction pointed to by Osram.

65. For example, on page 18 of its response dated April 17, 2003, after the '500 patent's claims were initially rejected, Osram argued to the PTO Examiner:

> Stevenson shows a GaN semiconductor and mentions using phosphors to change the frequency of light, but does not describe how the phosphors would be employed and [Stevenson] ***does not disclose*** a luminescence conversion layer or encapsulation ***of silicone*** as required by claims 1 and 52, respectively.
>
> Tadatsu JP 5152609 has gallium nitride semiconductor (with emitting peaks of 430 nm and 370 nm) and a dome-shaped molded resin encapsulation with a fluorescent dye 5 or pigment dispersed in the resin. ***Tadatsu thus does not disclose*** a luminescence conversion layer or encapsulation of ***silicone*** as required by claims 1 and 72, respectively. (Emphasis added).

66. Immediately after submission of the arguments above, the Examiner allowed the application that became the '500 patent, and application claim 52 (which Osram distinguished based upon the use of silicone) became claim 5 of the '500 patent.

67. Accordingly, the materiality of Osram's interference with Nichia is irrefutable, given Osram's additional admission during the interference that the use of silicone was obvious, which directly contradicts the opposite argument by Osram during

the '500 patent's prosecution that the use of silicone rendered the examined claims patentable.

68. In addition to the use of silicone, the '500 patent's claim 5 also specifies a particular type of luminescent material (or phosphor), which is met by a YAG (or yttrium aluminum garnet) fluorescent material.

69. Osram also acknowledged that the use of a YAG phosphor was obvious in its interference dispute with Nichia. Specifically, Osram conceded that the dependent claims of Nichia's '440 patent were obvious, and dependent claim 7 is directed to particular types of phosphors, including garnet fluorescent materials (a YAG phosphor is a type of garnet fluorescent material):

> 7. A light emitting device according to claim 2; wherein said light emitting component has a nitride compound semiconductor and said phosphor contains a ***garnet fluorescent material*** comprising 1) at least one element selected from the group consisting of ***Y***, Lu, Se, La, Gd and Sm, and 2) at least one element selected from the group consisting of ***Al***, Ga and In.
> (Emphasis added).

70. Despite the high materiality of the interference to the claims to the '500 patent, including, but not limited to:

a) the fact that the lost interference prohibited Osram from prosecuting claims of equal or obvious scope to its '727 applications' claims (or the count) lost in the interference, including *inter alia*, the use of diffusers or dispersants;

b) Osram's statements regarding the obvious use of Silicone or YAG phosphors during the interference and its contrary

statements made during prosecution of the '500 patent to gain allowance of the claims; and

c) Osram's admission during its request for interference that the subject matter of the interference would include luminescence conversion elements in the form of both encapsulations and layers,

Osram failed to bring to the examiner's attention in any way in the '500 patent's prosecution proceedings the existence, subject matter, or relevance of Osram's interference with Nichia, including, *inter alia*, the contrary positions Osram had taken during the interference or the subject matter of the interference for which Osram was barred from obtaining a patent. Indeed, Osram obtained claims in the '500 patent based on subject matter clearly within that barred by the interference, including diffusers (or dispersants) and the use of silicone.

71. Osram had more than ample time and adequate opportunity in the '500 patent's prosecution proceedings to bring the Osram-Nichia interference to the Patent Examiner's attention. The application that matured into the '500 patent was filed December 6, 2000, and issued as a patent on November 2, 2004, more than 22 months after the December 16, 2002 judgment that concluded the Osram-Nichia interference.

72. Within the 22 months after the December 16, 2002 judgment that concluded the interference, Osram filed in the '500 patent's prosecution proceedings three separate sets of Information Disclosure Statements on June 5, 2003, July 3, 2003, and January 15, 2004. Although these disclosures identified various references, no mention was made of the Osram-Nichia interference, the contradictory positions Osram had taken during the

interference, or the subject matter that was barred to Osram as a result of losing the interference.

73. Further, the same individual who served as lead counsel for Osram during the Osram-Nichia interference also represented Osram throughout the prosecution of the '500 patent. These facts establish that Osram knew of the materiality of the interference, and intentionally failed to call it to the Examiner's attention in an effort to mislead the Patent Office into issuing the '500 patent. Indeed, the interference and other disputes between Osram and Nichia were of such a high profile to Osram that upon resolution of its disputes, Osram issued a press release to announce their resolution. Yet, Osram misled the examiner during prosecution of the '500 patent by withholding highly material information concerning the interference.

74. Osram knew that it was not entitled to a patent on the subject matter of the interference – subject matter that Osram recaptured in the '500 patent. By recapturing this subject matter, Osram accomplished exactly what the interference was structured to avoid; namely, both Nichia and Osram possessing patents with overlapping subject matter, such that a company (e.g., CE) would need to obtain license agreements from both Nichia and Osram for the same white light emitting LED technology.

75. Through its press release dated October 5, 2004, Osram appreciates its position of requiring licenses from the public, even when the public has already licensed white LED technology from Nichia:

> However, [the Managing Director of Osram Opto] also pointed out that in view of the patent exchange agreement between Osram and Nichia, companies that have received a license from Nichia are not automatically entitled to use Osram patents.

The Interference that Osram Lost is Also Material to Osram's '283 and '162 Conversion Patents, and Yet Osram did not Properly Bring Highly Material Information Relating to the Interference to the PTO's Attention during Prosecution

76. On November 2, 2004, Osram filed application number 10/979,778 which matured into the '283 patent.

77. Each of the claims in the '283 patent require at least one luminescence conversion layer applied directly to a semiconductor. Furthermore, claim 34 of the '283 patent requires the conversion layer to be made of silicone.

78. Page 3 of Osram's April 9, 2001 request for interference stated that the luminescence conversion layer described in their '727 interference application (which is identical to the luminescence conversion layer described in the '283 patent, due to the fact that the '727 application and '283 patent are related) is the "coating member" recited in the '727 application's claims. That is, Osram admitted that the luminescence conversion layer of the type described in the '283 patent is identical to the "coating member" in the '727 application's claims that Osram lost in the interference. Since Osram is not entitled to patent claims that are anticipated or obvious in view of the lost count or Osram's claims from its 727 interference application, the interference is highly material to the '283 patent.

79. On page 2 of Osram's Request for Interference, Osram conceded that the use of silicone was obvious. In particular, Osram requested that the independent claims involved in the interference were considered as the "count" (i.e., the subject matter of the interference dispute), while the dependent claims of the Nichia patent and corresponding claims by Osram were considered to be "obvious":

> Applicants [i.e., Osram] identify claims 1-8 [of Nichia's USP 6,069,440] as corresponding to the proposed count. Independent claims 1, 2 correspond exactly to the proposed count. The remaining claims correspond substantially to the proposed count because they describe subject matter that would be obvious in light of the respective independent claims on which they depend.

80. Dependent claim 5 in the interference recited the use of silicone:

> 5. A light emitting device according to claim 2; wherein said molding member are made of the material selected from the group consisting of epoxy resin, urea resin and ***silicone resin***.
> (Emphasis added).

81. In the prosecution proceedings of the '283 patent, Osram did not provide any suggestion to the PTO regarding the existence of its lost interference with Nichia, until September 12, 2005, nearly 33 months after the December 16, 2002, judgment terminated the interference against Osram.

82. When Osram did barely mention the interference to the PTO, Osram did so in a manner that did not bring highly material information relating to the PTO's attention.

83. Instead, Osram barely provided a passing reference to the interference within a list of many other applications in a PTO submission dated September 12, 2005. Moreover, the September 12, 2005 submission discussed other subjects and cited numerous documents (some 62) to the PTO. However, nowhere did Osram disclose highly material information relating to the interference including, *inter alia*, the subject matter that was barred to Osram as a result of losing the interference. Pages 2-3 of Osram's September 12, 2005 submission merely mention in passing:

> Finally, we note that there are a number of applications related to the present application. Specifically, the present application claims priority to U.S. patent application serial number 09/731,220, now issued as U.S.

> Patent No. 6,812,500, and U.S. Patent Application Serial No. 09/221,789, filed December 28, 1998 (hereinafter "the original application"). Furthermore, the following applications claim priority to the original application: U.S. patent serial number 09/731,452, now issued as U.S. Patent No.6,576,930 (i.e., the '930 patent), U.S. patent application serial number 09/828,727, now abandoned following a decision by the Board of Patent Appeals and Interferences; U.S. patent application 11/080,786, now published as U.S. Patent Publication No. 2005-0161694, and U.S. patent application serial number 11/150,916.

84. In this paragraph which Osram indicates is simply to recite related applications, Osram lists "U.S. patent application serial number 09/828,727, now abandoned following a decision of the Board of Patent Appeals and Interferences." This is incomplete, misleading, and fails to bring highly material information to the attention of the examiner. Osram's characterization does not even explicitly state that Osram lost the interference. Instead, Osram's statement is sufficiently vague to imply that Osram's '727 application may have gone abandoned during *ex parte* patent prosecution after Osram won the interference. Moreover, this vague passing reference clearly failed to inform the examiner of the subject matter that was barred to Osram as a result of the interference.

85. Osram knew that it lost the interference and that the abandonment of the '727 application was highly material because Osram could not obtain claims that are anticipated by or obvious in view of the claims or count lost in the interference. Furthermore, as a result of the interference, another party, in this case, Nichia, had been awarded the subject matter of the interference. The mere passing reference to the interference in the middle of a paragraph listing a series of other applications is insufficient to bring this highly material information to the examiner's attention. This

recitation supports an inference that Osram intentionally misled the PTO and that the '283 patent is therefore unenforceable due to inequitable conduct.

86. On March 15, 2005 Osram filed application number 11/080,786 which matured into the '162 patent.

87. Page 3 of Osram's April 9, 2001 request for interference stated that the luminescence conversion layer and the luminescence encapsulation described in their '727 interference application (which is identical to the luminescence conversion layer described in the '162 patent, due to the fact that the '727 application and '162 patent are related) are the "coating member" recited in the '727 application's claims. That is, Osram admitted that the luminescence conversion layer of the type described in the '162 patent is identical to the "coating member" in the '727 application's claims that Osram lost in the interference. Since Osram is not entitled to patent claims that are anticipated or obvious in view of the lost count or Osram's claims from its 727 interference application, the interference is highly material to the '162 patent.

88. In the prosecution proceedings of the '162 patent, Osram did not provide any suggestion to the PTO regarding the existence of its lost interference with Nichia, until September 12, 2005, nearly 33 months after the December 16, 2002 judgment terminated the interference against Osram. In Osram's fourth Information Disclosure Statement ("IDS"), a reference to the interference was buried in the seventh paragraph of the IDS.

89. When Osram did barely mention the interference to the PTO, Osram did so in a manner that did not bring highly material information relating to the PTO's attention.

90. Instead, Osram barely provided a passing reference to the interference within a list of many other applications in a PTO submission dated September 12, 2005.

Moreover, the September 12, 2005 submission discussed other subjects and cited numerous documents (some 62) to the PTO. However, nowhere did Osram disclose highly material information relating to the interference including, *inter alia*, the subject matter that was barred to Osram as a result of losing the interference. Pages 2-3 of Osram's September 12, 2005 submission merely mention in passing:

> Finally, we note that there are a number of applications related to the present application. Specifically, the present application claims priority to U.S. Patent Application Serial No. 09/221,789, filed December 28, 1998 (hereinafter "the original application"), and the following applications claim priority to the original application: U.S. patent application serial number 731,220, now issued as U.S. Patent No. 6,812,500, and U.S. Patent Application Serial No. 09/221,789, filed December 28, 1998 (hereinafter "the original application"). Furthermore, the following applications claim priority to the original application: U.S. patent serial number 09/731,452, now issued as U.S. Patent No.6,576,930 (i.e., the '930 patent), U.S. patent application serial number 09/828,727, now abandoned following a decision by the Board of Patent Appeals and Interferences; U.S. patent application 10/979,778, now published 080,786, now published as U.S. Patent Publication No. 2005-0127385, and U.S. patent application serial number 11/150,916.

91. But in this paragraph, which Osram indicates is simply to recite related applications, Osram lists "U.S. patent application serial number 09/828,727, now abandoned following a decision of the Board of Patent Appeals and Interferences." This is incomplete, misleading, and fails to bring highly material information to the attention of the examiner. Osram's characterization does not even explicitly state that Osram lost the interference. Instead, Osram's statement is sufficiently vague to imply that Osram's '727 application may have gone abandoned during *ex parte* patent prosecution after Osram won the interference. Moreover, this vague passing reference clearly failed to inform the examiner of the subject matter that was barred to Osram as a result of the interference.

92. Osram knew that it lost the interference and that the abandonment of the '727 interference application was highly material because Osram could not obtain claims that are anticipated by or obvious in view of its claims or count lost in the interference. Furthermore, as a result of the interference, another party, in this case, Nichia, had been awarded the subject matter of the interference.

93. The mere passing reference to the interference in the middle of a paragraph listing a series of other applications is insufficient to bring the highly material information to a patent examiner's attention. This recitation supports an inference that Osram intentionally misled the PTO and that the '162 patent is therefore unenforceable due to inequitable conduct.

Osram Failed to File The Settlement Agreement that related to the Termination of the Osram-Nichia Interference

94. As stated in the December 16, 2002, judgment terminating the interference, 35 U.S.C.135(c) requires the filing of any settlement agreement made in connection with the termination of the interference. Failure to file such an agreement can render the settlement agreement unenforceable, and also render unenforceable any involved patents or patents maturing from applications that were involved in an interference.

95. 35 U.S.C. 135(c) was enacted to prevent anticompetitive agreements under the protective cover of patent interference proceedings.

96. 35 U.S.C. 135(c) states:

> Any agreement or understanding between parties to an interference, including any collateral agreements referred to therein, made in connection with or in contemplation of the termination of the interference, shall be in writing and a true copy thereof filed in the Patent and Trademark Office before the termination of the interference....Failure to

> file the copy of such agreement or understanding shall render permanently unenforceable such agreement or understanding and any patent of such parties involved in the interference or any patent subsequently issued on any application of such parties so involved. (Emphasis added.)

97. The *per se* unenforceability of patents and agreements that automatically accompanies the failure to file understandings or agreements made in connection with the termination of an interference underscores the high degree of materiality of information relating to interferences.

98. Despite the reminder within the final judgment to file all agreements and understandings relating to the termination of the interference, Osram did not file any such agreement or understanding.

99. The failure of Osram to file its settlement agreement relating to the termination of its interference proceeding, as required by 35 U.S.C. 135(c), represents an additional act within Osram's pattern of misconduct in deceiving the Patent Office on matters relating to its interference with Nichia.

Osram Mischaracterized or Failed to Cite Material Information relating to the ITC Proceedings and the '930 Patent

100. On or around May 6, 2004, Osram filed a complaint before the International Trade Commission (hereinafter, "ITC") requesting the exclusion from entry into the United States of white LEDs and products incorporating white LEDs that are manufactured, imported, or sold by three corporations (not including Citizen).

101. Osram asserted its U.S. Patent No. 6,576,930 ('the '930 patent) in the ITC litigation. The conversion element in the '930 patent is formed such that semiconductor

emitted radiation passes through the conversion element along a plurality of paths having "a substantially equal path length."

102. During the '930 patent's prosecution, the examiner issued a rejection citing Japanese patent 5-152609 to Tadatsu ("Tadatsu") which teaches emission of multiple wavelengths with phosphor conversion to enable white light emission. Osram distinguished its application from Tadatsu because, according to Osram, Tadatsu discloses a dome-shaped molded resin encapsulation where the resin is taller than it is wide "such that there is a longer path for the light through the resin upward than to the sides. Tadatsu thus does not teach substantially equal thickness, as required by claims 1 and 54." Thus, Osram surrendered the encapsulation embodiment and limited its conversion element to one having "substantially equal thickness."

103. In the ITC action, Osram argued that the "path length" limitation of the '930 patent meant that the device produces homogenous white light, and it therefore covered conversion elements in the form of an encapsulation as well as those in the form of an equal thickness layer.

104. Specifically, in its opening arguments on December 6, 2004 in the ITC action, OSRAM referred to the '930 patent as the "homogenous light patent," and it stated:

> We can tell what happened in the device based on the color that's emitted. If it's all white, it was substantially equal path length, because all the way across, it encountered the same number of phosphor particles, substantially so.

105. When comparing chromaticity data of Osram's and the alleged infringer's devices, Osram continued:

> The issue comes back to substantially equal path length. What does that mean?
>
> The evidence of infringement is undisputed, that everybody has homogeneous white light.

106. In the prosecution proceedings for the '930 patent, Osram did not disclose to the PTO examiner that Osram was interpreting the limitation "substantially equal path length" so broadly that claims of the '930 patent would encompass LEDs emitting homogenous white light. This was a material omission because interpreting the claim limitation so broadly would have placed additional prior art at issue, and increased the relevance of the prior art that was cited.

107. Given the high materiality of Osram's failure to disclose the broad claim interpretation of the "substantially equal path length" limitation, an intent to deceive the Patent Office can be inferred.

108. The ITC rejected Osram's assertion that the '930 patent covered encapsulations, since encapsulations were disclosed in the prior art. The ITC construed the "equal path length" limitation in the '930 claims to mean a luminescence conversion element of uniform thickness, just as Osram had argued during prosecution of the '930 patent.

109. Statements above regarding the ITC decision and statements concerning the '930 patent's prosecution history are relevant and material to the '500, '162, and '283 conversion patents because those statements show that the only way Osram distinguished the prior art Tadatsu reference was to limit its conversion element to one having "substantially equal thickness." When Osram dropped this limitation from its conversion patents, it was material to call these earlier statements regarding the Tadatsu reference to

an examiner's attention, since the '930 patent's limitation was the only reason Osram overcame the prior art.

110. Nonetheless, Osram completely failed to disclose the ITC litigation in connection with the '500 patent. PTO rules require applicants to disclose when the subject matter for which a patent is being sought is or has been involved in a litigation. See, MPEP § 2001.06(c). Osram's failure to disclose the ITC litigation, which was pending during the prosecution of the '500 patent constitutes inequitable conduct.

111. In connection with the '283 patent, Osram disclosed the ITC litigation involving the '930 patent in its September 12, 2005 IDS. However, the disclosure only discussed the fact that the ITC had declined to hold the '930 patent invalid. Osram did not disclose that the ITC rejected Osram's argument that the '930 covered encapsulations, instead construing the "equal path length" limitation in the '930 claims to mean a luminescence conversion element of uniform thickness. The ITC came to this conclusion because encapsulation was disclosed in the prior art. The ITC's finding is information that "refutes, or is inconsistent with, a position the applicant [took]…." Osram's failure to call the PTO's attention to the ITC's finding violated its duty of candor and constitutes inequitable conduct.

112. These above-recited acts and omissions render the '283 patent unenforceable.

113. During prosecution of the '162 patent, Osram did disclose Tadatsu, the reference that caused Osram to limit the conversion element to substantially equal thickness, during prosecution of the '930 patent. However, this Tadatsu reference was not disclosed until the second IDS among a total of over 400 references cited during

prosecution. Osram made no attempt to draw the examiner's attention to the relevance of the Tadatsu patent. Prosecution of the '162 patent proceeded as if Osram had surrendered no subject matter during the '930 patent prosecution. By failing to disclose this information, Osram violated 37 CFR 1.56(b)(2) which required, at all relevant times, an applicant to disclose any information that "refutes, or is inconsistent with, a position the applicant [took]…."

114. During prosecution of the '162 patent, Osram disclosed the ITC litigation involving the '930 patent in its September 12, 2005 IDS. However, the disclosure only discussed the fact that the ITC had declined to hold the '930 patent invalid. Osram did not disclose that the ITC rejected Osram's argument that the '930 covered conversion elements in the form of an encapsulation, instead construing the "equal path length" limitation in the '930 claims to mean a luminescence conversion element of uniform thickness. The ITC came to this conclusion because encapsulation was disclosed in the prior art. The ITC's finding is information that "refutes, or is inconsistent with, a position the applicant [took]…" Osram's failure to discuss the finding violated its duty of candor.

115. During prosecution of the '500, '283, and '162 patents, Osram failed to bring highly material information to the attention of the PTO, including the relevance of Tadatsu and other prior art, and the fact that during prosecution of the '930 patent the only reason Osram distinguished over prior art was the equal path length limitation that was not present in claims being pursued in applications for the '500, '283, and '162 patents. Further, Osram did not disclose that this limitation was also a basis the ITC relied upon to uphold the validity of the '930 patent. In addition, Osram knew of the

importance of this limitation, because this limitation was also the reason the ITC found no infringement of the '930 patent. However, in the related applications, Osram did not include the equal path length limitations in all claim limitations and Osram obtained the '500, '283 and '162 patents while withholding or misleading the examiner as to highly material information concerning the '930 patent, the ITC proceedings, and the prior art.

Osram Mischaracterized or Failed to Cite its "Demand for Trial"

116. On March 3, 2000 Osram filed a "Demand for Trial" in the Japanese Patent Office seeking a trial to invalidate Japanese patent no. 2927279 on the basis of, *inter alia*, obviousness. Japanese patent 2927279 claimed, generally, an LED with a light-emitting gallium nitride semiconductor chip in a mount-lead cup, an inner lead connected with the chip by an electrically conductive wire, coated with a transparent resin of fluorescent material which emits light when hit by light from the LED chip, and a mold member covering the coating member, LED chip, and conductive wire. Osram's Demand for Trial laid out detailed arguments, with prior art, as to what subject matter was obvious and why.

117. The subject matter that Osram argued was obvious in Japanese patent 2927279 included the same subject matter that Osram pursued during prosecution of its US conversion patents. For example, each of Osram's conversion patents has claims regarding the use of diffuser particles in their conversion element. However, in the Demand for Trial submitted by Osram in its dispute with Nichia, Osram acknowledged:

> Claim 2 recites the feature that the mold member is shaped to have a lens effect and ***contains a diffusing member*** . . . [the prior art] discloses the feature of using a polycarbonate transparent resin as the resin for the cylindrical body 3 and mixing a ***light diffusing agent*** 7 . . . ***The Invention***

> ***according to Claim 2, therefore is known from [the prior art] . . .***

at pp. 30-31. (Emphasis added).

118. The '500 patent claims 3 and 4 were allowed by the PTO Examiner due to the recitation that the resin layer or encapsulation includes "light-diffusing particles." In the application that matured into the '500 patent, Osram initially attempted to obtain broader patent claims. However, the Examiner rejected all of the original claims, except for dependent application claims 13, 25, and 26. As to these dependent claims, the Examiner indicated that they would be allowable if they were rewritten in independent form. Dependent application claims 25 and 26 read as follows (emphasis added):

> 25. The semiconductor component according to claim 1, wherein said luminescence conversion element includes ***light-diffusing particles***.
>
> 26. The semiconductor component according to claim 1, which comprises a transparent encapsulation with ***light-diffusing particles***.

119. Thus, the Examiner did not consider the subject matter of independent claim 1 allowable, but did consider the subject matter of claims 25 and 26 patentable, due to the recitation of light-diffusing particles. Osram then rewrote application claims 25 and 26 in independent form, and they became claims 3 and 4 of the '500 patent.

120. However, Osram failed to inform the PTO Examiner that in its Demand for Trial, Osram had taken the position that the use of light diffusing agents in connection with a conversion element was known and disclosed in the prior art.

121. Similarly claims 2 and 3 of the '930 patent were allowed by the PTO Examiner due to the recitation that the conversion element or encapsulation includes

"light-diffusing particles." In the application that matured into the '930 patent, Osram initially attempted to obtain broader patent claims. However, the Examiner rejected all initial claims, except for dependent application claims 13, 25, 26, and 52. As to these dependent claims, the Examiner indicated on page 3 of his Office action mailed July 15, 2002, that they would be allowable if they were rewritten in independent form:

> Claims 13, 25, 26, 52 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claims and any intervening claims.
>
> Claims reciting diffusing particles mixed in with the fluorescent particles or the luminescent layer directly contacting the semiconductor device are not fairly obvious in view of Lowery.

122. Dependent application claims 25 and 26 read as follows (emphasis added):

> 25. The semiconductor component according to claim 1, wherein said luminescence conversion element includes ***light-diffusing particles***.
>
> 26. The semiconductor component according to claim 1, which comprises a transparent encapsulation with ***light-diffusing particles***.

123. Thus, the Examiner did not consider the subject matter of independent claim 1 allowable, but did consider the subject matter of claims 25 and 26 patentable, due to the recitation of light-diffusing particles. Osram then rewrote application claims 25 and 26 in independent form, and they became claims 2 and 3 of the '930 patent.

124. However, during prosecution of the '930 patent, Osram failed to inform the '930 patent's PTO Examiner of the existence of Osram's Demand for Trial, and that Osram had taken the position that the use of light diffusing agents in connection with a conversion element was known and disclosed in the prior art.

125. Additionally,, several of Osram's conversion patents have claims to the use of a YAG phosphor. Within its Demand for Trial, Osram stated:

> It is generally known to convert the emission from the LED chip to different wavelengths by the fluorescent material in the mold resin. It is also common knowledge to a skilled person that the fluorescent material includes the fluorescent pigment formed by inorganic material and/or organic material and the fluorescent dye consisting of organic material, as recognized in A-18, page 18, line 10 to last line of page 9. The fluorescent material is also well-known which uses the wavelength emitted by the light source as the excitation light. It is a matter of design for a person skilled in the art to use the known inorganic fluorescent material as the material for the fluorescent material. ***The feature of using the yttrium aluminum garnet [YAG] fluorescent material is well-known in the art*** (See A-19, page 2).
> pp. 28 (Emphasis added).

126. Despite the related subject matter, during prosecution of the '500 patent, Osram identified the existence and purpose behind its Demand for Trial, but did not specifically cite to the materiality of this document, or explain its relevance within the sea of some 400+ references cited during the '500 patent's prosecution:

> The assignee of this application [Osram] filed a Demand for Trial in Japan seeking to invalidate Japanese Patent No. 2927279 on March 3, 2000. That Japanese patent claims priority from three of the five Japanese applications just noted and includes claims that are directed to a light emitting diode including a fluorescent material having the general formula $(RE_{1-x}\ Sm_x)_3(Al_yGa\ 1\text{-}y)O_{12}$:Ce. (See claim language at pages 2-5 of the Demand for Trial.) In that Demand for Trial, it is asserted that the Japanese Patent No. 2927279 is invalid under Japanese law on the basis of prior art and other reasons.

127. In the '162 patent and the '283 patent, Osram did not even explain its Demand for Trial at all, and merely listed it together with the more than 400 other references in an Information Disclosure Statement.

128. Given the high materiality of Osram's Demand for Trial, and Osram's failure to properly bring the Demand for Trial and Osram's contradictory statements therein to the examiner's attention, intent to deceive the patent Office can be inferred. Moreover, the egregiousness of Osram's conduct concerning Osram's own statements in the Demand for Trial is particularly apparent when considered in conjunction with Osram's other acts of misleading statements or failure to disclose highly material information, such as Osram's conduct with regard to the interference.

Osram Failed to call the PTO's Attention to the Materiality of the Prior Art That Caused Osram's to remove all References in its European Patent to Conversion Elements in a Form other than a Constant Thickness Layer

129. Osram prosecuted patent EP 0907969, the European equivalent to the '930 patent, before the European Patent Office. During prosecution of the European patent in early 2003, the examiner informed Osram that the only difference between the application and reference JP 8-7614 (hereinafter, the "Shimizu reference") was "the constant layer thickness of the luminescence-converting layer." In response, Osram restricted its claim to require a conversion element in the form of a uniform thickness layer. Based on the EPO's requirements, Osram was required to delete the unclaimed subject matter, which included all drawing figures with a conversion element in the form of an encapsulation, retaining only those drawings with a conversion element in the form of an equal or uniform thickness layer. This European rejection and citation of the Shimizu reference put Osram on notice that this reference is highly material to any claim that could cover more than a uniform thickness conversion layer.

130. Although Osram did cite the Shimizu reference in an IDS submitted in each of the '500, '162, and '283 patents, Osram failed to bring to the PTO examiner's attention

highly material information concerning the Shimizu reference. The European Office action rejection based on the Shimizu reference is information that "refutes, or is inconsistent with, a position the applicant [took]...."

131. Osram's failure to apprise the examiner of the importance of this reference, and to submit the reference merely as one among several hundred references, violated Osram's duty of candor.

Osram Falsely Claimed Priority With the '162 Patent

132. The '162 patent application claims priority to German Applications Serial Nos. 196 25 622.4, ("DE '622") filed June 26, 1996 and 196 38 667.5 ("DE 667") filed September 20, 1996. DE '622 discloses a wavelength conversion element having a "luminescent dye" dispersed in epoxy resin. DE '622 repeatedly refers to the luminescent dye as an organic dye. Thus, the concept of using an inorganic luminescent dye is supported only by the later DE '667 document. Likewise, the disclosure in the '162 patent of encapsulating luminescent material with mutual different refractive indices is not supported by the DE '622 priority document. Rather, as with the inorganic luminescent materials, this disclosure is only found in the DE '667 priority application. Osram has therefore incorrectly claimed priority with regard to the '162 patent.

133. Upon information and belief, Osram was aware that the '162 patent could not claim priority, in all respects, to DE '622, and its recurring efforts to incorrectly claim priority provide an inference of intent to mislead the U.S. Patent Office.

134. These acts and omissions, together with Osram's other misconduct cited above, render the '162 patent unenforceable.

Osram's Non-asserted Conversion Patents contain similar Prosecution Records that confirm the Pattern of Misconduct Perpetrated by Osram on the Patent Office

135. U.S. Patent no. 7,078,732 ("the '732 patent) is the "parent" patent in the United States to the '930, '500, '162, and '283 conversion patents.

136. During the prosecution leading to the '732 patent, Osram did not make any mention of the interference between Osram and Nichia until September 12, 2005 – 2 ½ years after the interference judgment and as part of the sixth IDS filed in the '732 patent's prosecution after the conclusion of the interference. Like in the '162 and '283 prosecution histories, the reference to the interference was a fleeting reference buried in the list of applications cited as relating to the present application. The IDS mentioning the interference was filed a mere 10 days prior to the issuance of a Notice of Allowance.

137. Osram's incomplete and misleading disclosure further evidences Osram's patent of misconduct and intent to deceive the patent office.

B. Unenforceability of the '301, '247, '259, and '780 Particle Size Patents

138. The '301 patent is unenforceable because the inventors and/or Osram, or others acting for or on their behalf, violated their duty of disclosure to the PTO during the prosecution of the '301 patent by misrepresenting a material fact in stating that Osram's German priority document DE 19638667 supported claim limitations regarding particle size distributions, when in fact the German priority document offered no such support.

139. On page 4 of its response dated February 12, 2001, Osram amended all claims in the '301 patent to require that "luminous substance pigments have grain sizes $\leq$ 20 μm and a mean grain diameter d50 $\leq$ 5 μm." Osram further stated, "The sole reference cited for disclosure of this feature was the PCT publication for the above-

captioned application [co-pending application 09/650,932]. Inasmuch as the Examiner should now agree that applicant is entitled to the earlier filing, that publication cannot be considered as prior art, and the claims are patentable."

140. Osram's German priority document DE 19638667 in fact does not support a limitation requiring grain sizes $\leq$ 20 μm and a mean grain diameter d50 $\leq$ 5 μm, because the only reference to particle size in the priority document refers to grain sizes of 4μm – 13 μm.

141. On information and belief the inventors and/or Osram, or others acting for or on their behalf, knew that the misrepresentations regarding the alleged support in DE 19638667 for the claimed particle size distribution were incorrect, and that such statements were material to the prosecution of the '301 patent.

142. The high materiality of the misrepresentation is confirmed by the fact that the examiner had rejected the application prior to the misrepresentation, and then allowed the application that matured into the '301 patent following the misrepresentation.

143. Despite the high materiality of the misstatements regarding support in the German priority document, no one having the duty of disclosure – i.e., the inventors, its attorneys, and any other individual substantively involved in prosecuting the application that matured into the '301 patent and associated with the inventor or assignee – disclosed or corrected this material misstatement to the PTO during prosecution of the '301 patent.

144. The misstatement to the PTO, in view of the fact that on information and belief, the inventors, and/or others having a duty to disclose were aware of the misstatement and its materiality to one or more of the claims during the prosecution of

the '301 patent, demonstrates an intent to mislead and deceive the PTO in obtaining the '301 patent.

145. The making of and failure to correct this material misstatement with deceptive intent renders the '301 patent unenforceable due to inequitable conduct before the PTO.

146. For the same reasons as stated above, Osram further perpetuated this misrepresentation in the '247, '259, and '780 patents, upon information and belief, by continuing to assert, with deceptive intent, that each of the '247, '259, and '780 were entitled to the benefit of the German priority document D19638667.

147. The making of and failure to correct these material misstatement with deceptive intent likewise renders the '247, '259, and '780 patents unenforceable due to inequitable conduct before the PTO.

148. For all of the reasons set forth above, each of the '301, '247, '259, '780, '930, '500, '162, and '283 patents is unenforceable, due to inequitable conduct. Osram's intent to deceive the PTO is evidenced in these patents not only by the high materiality of the various misrepresentations, but also by the repeated pattern of Osram's conduct in misleading, misinforming, or simply hiding material facts from the PTO.

149. Moreover, intent to deceive the PTO in connection with the these patents is further evidenced by the fact that Osram regards the prosecution of the patent rights in the white LED field to be of immense commercial importance and a matter of high profile. It is therefore highly unlikely that the misrepresentations and failure to inform the PTO of material facts were mere administrative or unintentional oversights. The commercial importance of this technology to Osram is evidenced by:

a. Osram's numerous patent conflicts with Nichia, both in interferences before the PTO, and in various opposition proceedings throughout the world;

b. The various license negotiations, litigations, and ITC proceedings that Osram has commenced against its opponents;

c. The press releases issued by Osram reporting on its licensing and litigation developments; and

d. Osram's comprehensive patent efforts in the United States and worldwide, as evidenced by the fact that Osram has filed at least fifteen U.S. applications within just the particle size and conversion families.

150. There is an actual case or controversy as to the enforceability of the patents-in-suit. The '301, '247, '259, '780, '930, '500, '162, and '283 patents are unenforceable due to inequitable conduct.

PRAYER FOR RELIEF

WHEREFORE, Citizen respectfully requests that the Court enter judgment:

a. Declaring that Plaintiffs take nothing in this Action;

b. Dismissing Plaintiffs' claims in their entirety and with prejudice;

c. Declaring that Plaintiff's patents-in-suit are invalid;

d. Declaring that CE's/Cecol's white light emitting LED products and processes do not and would not infringe, contribute to the infringement of, or induce the infringement of any valid and enforceable claim of the patents-in-suit;

e. Declaring that the '301, '247, '259, '780, '930, '500, '162, and '283 patents are unenforceable, due to Osram's inequitable conduct;

f. Declaring this case "exceptional" under 35 U.S.C. §285 and awarding Citizen its attorneys' fees, costs, and expenses incurred in this action, and

g. Such other relief as the Court deems just and proper.

JURY DEMAND

Citizen demands a trial by jury on all issues so triable.

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Dated: May 4, 2007

Attorneys for Defendants Citizen Electronics Co., Ltd., and Cecol, Inc.

793442 / 31008

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CERTIFICATE OF SERVICE

I, David E. Moore, hereby certify that on May 4, 2007, the attached document was hand delivered to the following persons and was electronically filed with the Clerk of the Court using CM/ECF which will send notification to the registered attorney(s) of record that the document has been filed and is available for viewing and downloading:

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776067 / 31008

EXHIBIT A

US006066861A

United States Patent [19]

Höhn et al.

[11] Patent Number: 6,066,861

[45] Date of Patent: May 23, 2000

[54] **WAVELENGTH-CONVERTING CASTING COMPOSITION AND ITS USE**

[75] Inventors: **Klaus Höhn**, Taufkirchen; **Alexandra Debray**, Regensburg; **Peter Schlotter**, Freiburg; **Ralf Schmidt**, Vörstetten; **Jürgen Schneider**, Kirchzarten, all of Germany

[73] Assignee: **Siemens Aktiengesellschaft**, Munich, Germany

[21] Appl. No.: **09/082,205**

[22] Filed: **May 20, 1998**

Related U.S. Application Data

[63] Continuation of application No. PCT/DE97/02139, Sep. 22, 1997.

[51] **Int. Cl.**[7] **H01L 33/00**; H01J 63/04; C09K 11/02

[52] **U.S. Cl.** ..... **257/99**; 257/98; 257/100; 313/486; 313/467; 252/301.6 P

[58] **Field of Search** ..... 257/81, 89, 98, 257/99, 100; 313/486, 467, 468; 252/301.6 P, 301.4 R

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

0039017B1	11/1981	European Pat. Off. .
2642465	3/1978	Germany .
3804293A1	8/1989	Germany .
9013615	1/1991	Germany .
7176794	7/1995	Japan .

Primary Examiner—Minh Loan Tran
Attorney, Agent, or Firm—Herbert L. Lerner; Laurence A. Greenberg; Werner H. Stemer

[57] **ABSTRACT**

The wavelength-converting casting composition is based on a transparent epoxy casting resin with a luminous substance admixed. The composition is used in an electroluminescent component having a body that emits ultraviolet, blue or green light. An inorganic luminous substance pigment powder with luminous substance pigments is dispersed in the transparent epoxy casting resin. The luminous substance is a phosphorous group of the general formula $A_3B_5X_{12}$:M, and the luminous substance pigments have particle sizes<20 μm and a mean grain diameter d_{50}<5 μm.

14 Claims, 4 Drawing Sheets

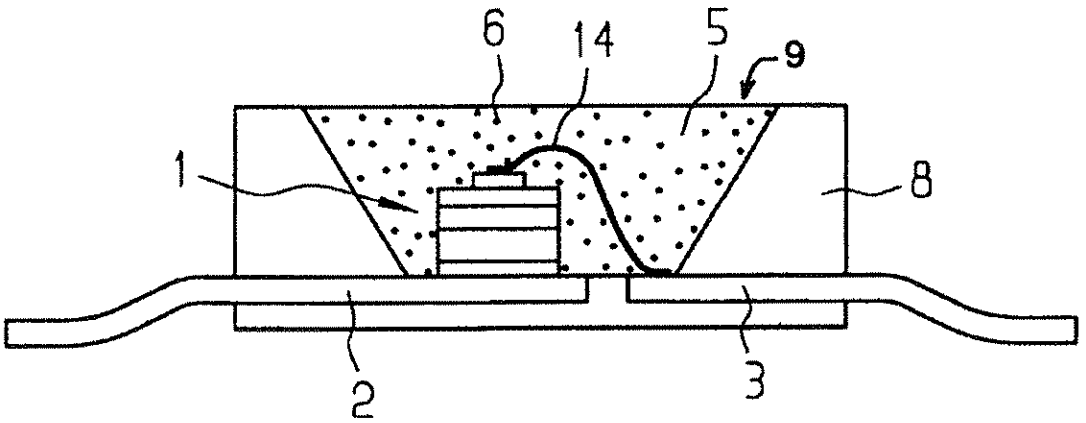


FIG 1

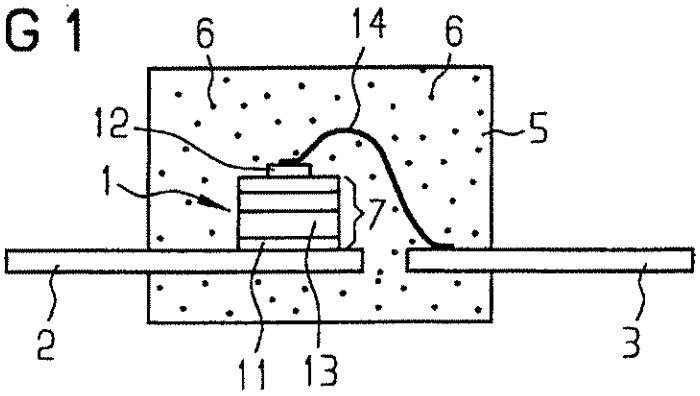


FIG 2

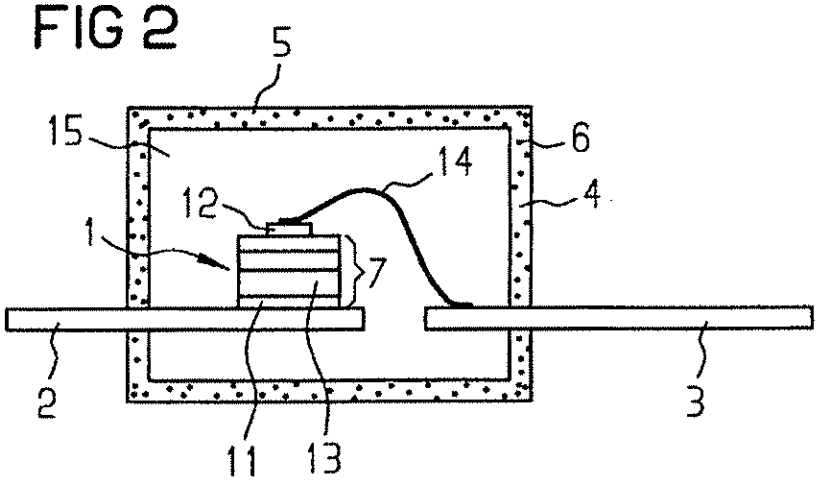


FIG 3

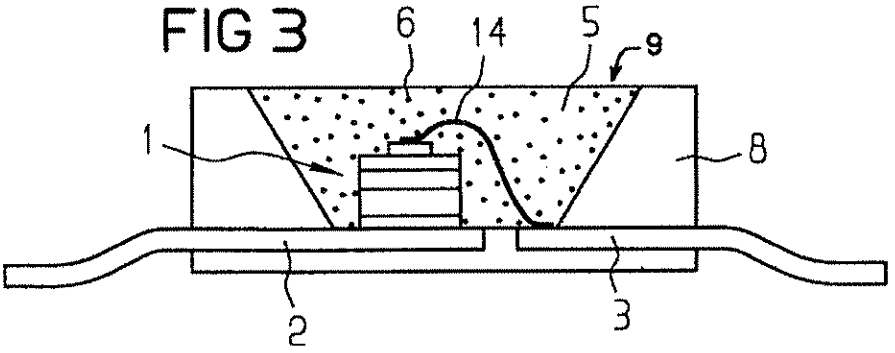


FIG 4

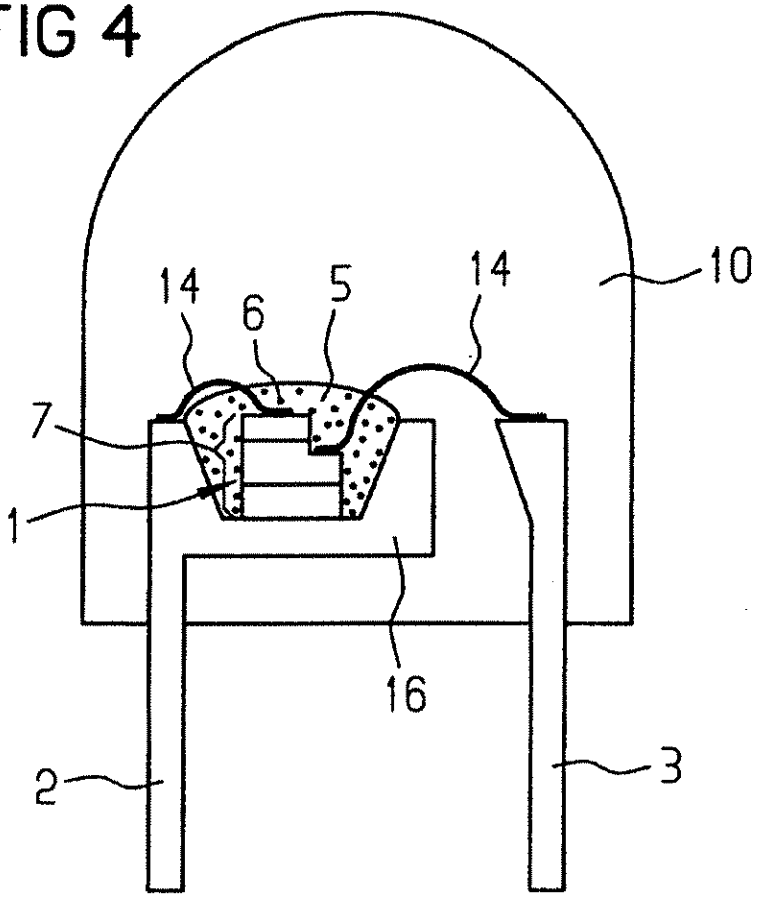


FIG 5

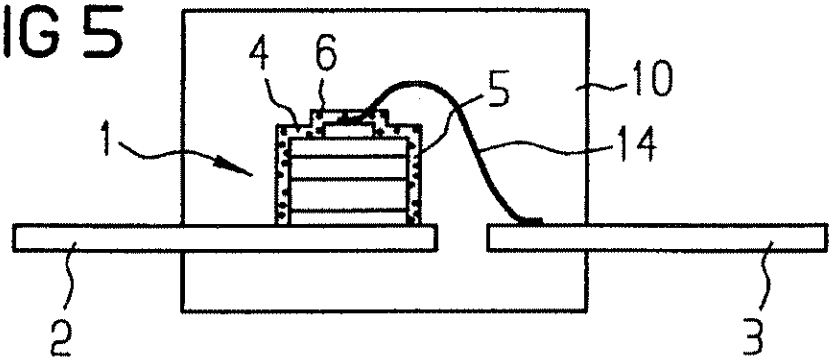


FIG 6

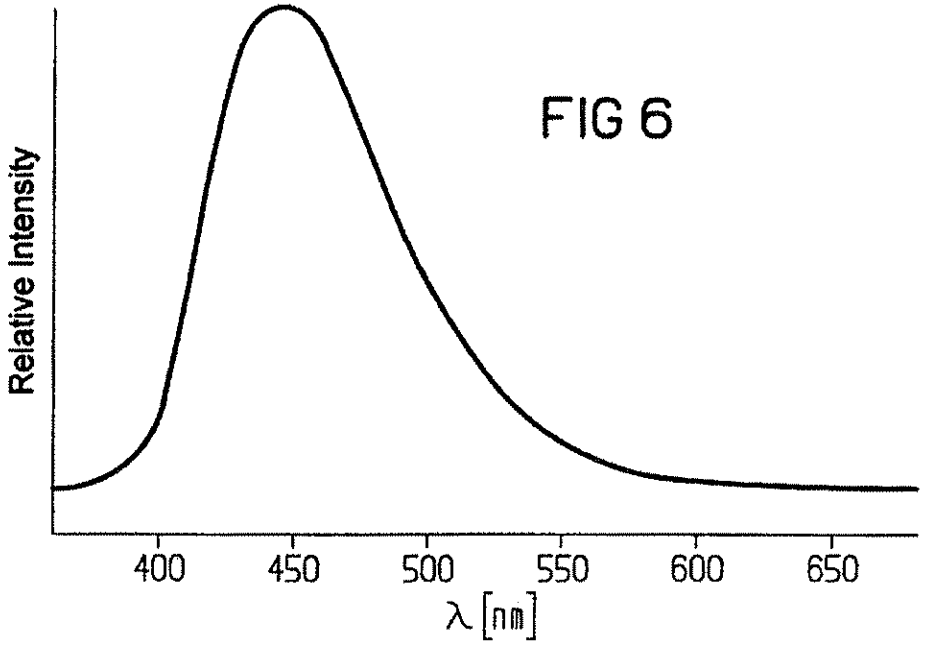

Relative Intensity
400
450
500
550
600
650
λ[nm]

FIG 7

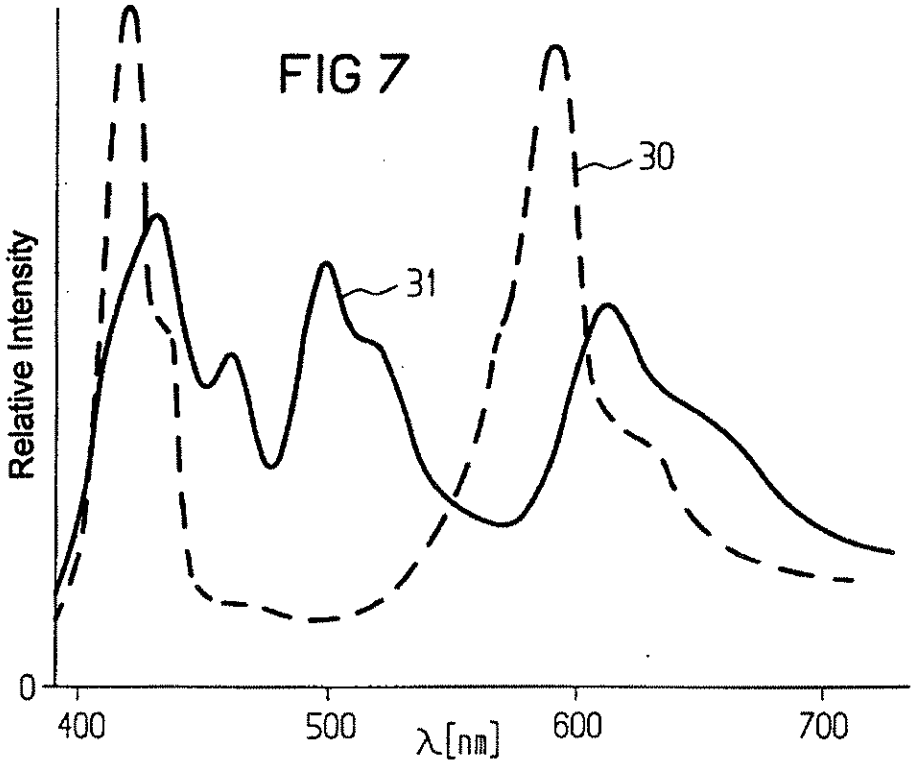
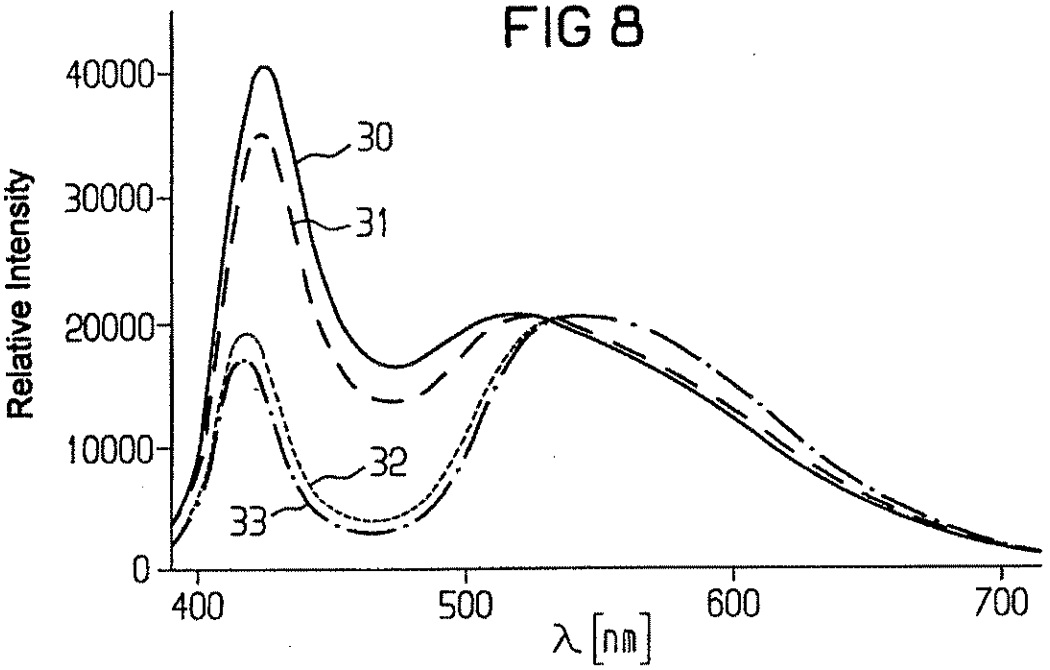

30
31
Relative Intensity
0
400
500
λ[nm]
600
700

FIG 8


Relative Intensity
40000
30000
20000
10000
0
400
500
600
700
λ [nm]
30
31
32
33

WAVELENGTH-CONVERTING CASTING COMPOSITION AND ITS USE

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation of copending international application PCT/DE97/02139, filed Sep. 22, 1997, which designated the United States.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a wavelength-converting casting composition based on a transparent epoxy casting resin which is mixed with a luminous substance, for an electroluminescent component having a body that emits ultraviolet, blue or green light.

2. Description of the Related Art

A component of that type has become known, for instance, from German published, non-prosecuted patent application DE 38 04 293. The reference describes an arrangement with an electroluminescent diode or laser diode, in which the emissions spectrum emitted by the diode is shifted toward longer wavelengths, by means of a plastic element mixed with a fluorescing, light-converting, organic colorant. The light emitted by the arrangement as a result has a different color from what the light emitting diode emitted. Depending on the type of colorant added to the plastic, it is possible to produce LED arrays that light up in different colors with one and the same type of light-emitting diode (LED).

In many potential applications for LEDs, such as in display elements in motor vehicle dashboards, illumination in aircraft and automobiles, and in LED displays capable of showing full color, there is an increasing demand for LED arrays with which mixed color light and in particular white light can be generated.

However, the prior art casting compositions of the type referred to at the outset with organic luminous substances exhibit a shift in the color location, that is, the color of the light emitted by the electroluminescent component, under temperature and temperature/humidity stresses.

Japanese patent disclosure JP-07 176 794-A describes a white-light-emitting planar light source, in which two diodes that emit blue light are disposed on one face end of a transparent plate and emit light into the transparent plate. The transparent plate is coated on one of the two opposed main sides with a fluorescing substance that emits light when it is excited with the blue light of the diodes. The light emitted by the fluorescing substance has a different wavelength from the blue light emitted by the diodes. In this known component, it is especially difficult to apply the fluorescing substance in such a way that the light source emits homogeneous white light. Moreover, replicability and mass production presents major problems, because even slight fluctuations in the layer thickness of the fluorescing layer, for instance from irregularities of the surface of the transparent plate, cause a change in the white of the light emitted.

SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide a wavelength-converting casting mass, which overcomes the above-mentioned disadvantages of the prior art devices and methods of this general type and with which electroluminescent components can be produced that emit homogeneous mixed-colored light, and which enables mass production at reasonable engineering effort and expense and with maximally replicable component characteristics. The emitted light should be color-stable even under temperature and temperature/humidity stresses. It is a further object to specify a use for the casting mass and a method for producing the composition.

With the foregoing and other objects in view there is provided, in accordance with the invention, a wavelength-converting casting composition, for converting a wavelength of ultraviolet, blue or green light emitted by an electroluminescent component, comprising:

a transparent epoxy casting resin;

an inorganic luminous substance pigment powder dispersed in the transparent epoxy resin, the pigment powder comprising luminous substance pigments from a phosphorus group having the general formula $A_3B_5X_{12}$:M;

the luminous substance pigments having grain sizes $\leqq 20$ μm and a mean grain diameter $d_{50} \leqq 5$ μm.

In accordance with an added feature of the invention, the mean grain diameter d_{50} of the luminous substance pigments is between one and two micrometers.

Inorganic/mineral luminous substances are extremely stable with regard to temperature and temperature/humidity stresses.

In accordance with an additional feature of the invention, the composition includes the following parts:

a) epoxy casting resin $\geqq 60\%$ by weight;

b) luminous substance pigments>0 and $\leqq 25\%$ by weight;

c) thixotropic agent>0 and $\leqq 10\%$ by weight;

d) mineral diffusor>0 and $\leqq 10\%$ by weight;

e) processing adjuvant>0 and $\leqq 3\%$ by weight;

f) hydrophobic agent>0 and $\leqq 3\%$ by weight; and

g) adhesion promoters>0 and $\leqq 2\%$ by weight.

Suitable epoxy casting resins are described for instance in German published, non-prosecuted patent application 26 42 465 (pp. 4–9, in particular examples 1–4), and in European patent disclosure EP 0 039 017 (pp. 2–5, in particular examples 1–8). The disclosures of those documents are hereby expressly incorporated by reference.

Pyrogenic silicic acid is for instance used as the thixotropic agent. The thixotropic agent is used to thicken the epoxy casting resin, so as to reduce the sedimentation of the luminous substance pigment powder. The flow and wetting properties are also adjusted for processing the casting resin.

CaF_2 is preferably used as a mineral diffusor for optimizing the luminous pattern of the component.

Glycol ether is for instance suitable as a processing adjuvant. It improves the compatibility between the epoxy casting resin and the luminous substance pigment powder and is thus used to stabilize the dispersion of luminous substance pigment powder and epoxy casting resin. To that end, surface modifiers based on silicone can also be employed.

The hydrophobic agent, such as liquid silicone wax, is also used to modify the pigment surface; in particular, the compatibility and wettability of the inorganic pigment surface is improved with the organic resin.

The adhesion promoter, such as functional alkoxysiloxane, improves the adhesion between the pigments and the epoxy resin in the cured state of the casting composition. As a result it is attained that the boundary face between the epoxy resin and the pigments will not rupture, for instance in response to temperature fluctuations. Gaps

between the epoxy resin and the pigments would cause light losses in the component.

The epoxy casting resin, preferably with a reactive triple oxiran ring, preferably includes a monofunctional and/or multifunctional epoxy casting resin system (≧80% by weight, such as bisphenol-A-diglycidyl ether), a reactive diluent (≦10% by weight, such as aromatic monoglycidyl ether), a multifunctional alcohol (≦5% by weight), a degassing agent based on silicone (≦1% by weight), and a decolorizing component to adjust the color number (≦1% by weight).

In accordance with another feature of the invention, the luminous substance pigments are substantially spherical particles or flakelike particles. The tendency to clumping of such pigments is advantageously very slight. The H_2O content is below 2%.

In the production and processing of epoxy casting resin components with inorganic luminous substance pigment powders, in general not only wetting but also sedimentation problems occur. Especially luminous substance pigment powders with d_{50}≦5 μm have a strong tendency to clumping. In the last-named composition of the casting composition, the luminous substance pigments, with the above-indicated particle size, can advantageously be substantially free of clumps and can be dispersed homogeneously in the epoxy casting resin. This dispersion is stable even under long-term storage of the casting composition. Essentially no problems of wetting and/or sedimentation occur.

In accordance with a further feature of the invention, the luminous substance pigments are particles of Ce-doped garnets, such as, particularly, YAG:Ce particles. An advantageous dopant concentration is 1%, for example, and an advantageous luminous substance concentration is 12%, for example. The preferred high-purity luminous substance pigment powder also advantageously has an iron content of ≦5 ppm. A high iron content leads to high light losses in the component. The luminous substance pigment powder is highly abrasive. The iron content in the casting composition can therefore rise considerably during production. Iron contents in the casting composition<20 ppm are advantageous.

The inorganic luminous substance YAG:Ce has the particular advantage, among others, that this involves insoluble color pigments with an index of refraction of approximately 1.84. As a result, along with the wavelength conversion, dispersion and scattering effects occur that lead to good mixing of blue diode emissions with yellow converter radiation.

It is also especially advantageous that the luminous substance concentration in the epoxy resin when inorganic luminous substance pigments are used is not limited by the solubility, as is the case for organic colorants.

For further reduction of clumping, the luminous substance pigments may advantageously be provided with a silicone coating.

With the above and other objects in view there is also provided, in accordance with the invention, a method of producing a wavelength-converting casting composition, for converting a wavelength of ultraviolet, blue or green light emitted by an electroluminescent component, the method which comprises:

providing a base of transparent epoxy casting resin;

providing a luminous substance pigment powder of luminous substance pigments from a phosphorus group having the general formula $A_3B_5X_{12}$:M;

tempering the luminous substance pigment powder at a temperature of ≧200° C. and subsequently mixing the tempered pigment powder with the epoxy casting resin.

Tempering is preferably effected for approximately ten hours. As a result, again the tendency to clumping can be reduced.

As an alternative or in addition for this purpose, the luminous substance pigment powder, before being mixed with the epoxy casting resin, can be slurried in a higher-boiling alcohol and subsequently dried. A further possibility for reducing clumping is to add a hydrophobic silicone wax to the luminous substance pigment powder before the powder is mixed with the epoxy casting resin. Surface stabilization of the phosphors by heating the pigments in the presence of glycol ethers, for instance for 16 hours at T>60° C., is especially advantageous.

To avoid problematic contamination upon dispersal of the luminous substance pigments, caused by abrasion, reaction vessels, agitators and dispersing devices as well as rolling mechanisms of glass, corundum, carbide and nitride materials as well as especially hardened types of steel are used. Clump-free luminous substance dispersions are also obtained by ultrasonic methods or by the use of screens and glass ceramic frits.

An especially preferred inorganic luminous substance for producing optoelectronic components that light up white is the phosphorous YAG:Ce ($Y_3Al_5O_{12}:Ce^{3+}$). This phosphorous can be especially simply mixed with transparent epoxy casting resins conventionally used in LED technology. Also conceivable as luminous substances are other garnets, doped with rare earths, such as $Y_3Ga_5O_{12}:Ce^{3+}$, $Y(Al,Ga)_5O_{12}:Ce^{3+}$, and $Y(Al,Ga)_5O_{12}:Tb^{3+}$.

To generate mixed-colored light, the thiogallates doped with rare earths are moreover especially suitable, examples being $CaGa_2S_4:Ce^{3+}$ and $SrGa_2S_5:Ce^{3+}$. Once again, the use of aluminates doped with rare earths, such as $YAlO_3:Ce^{3+}$, $YGaO_3:Ce^{3+}$, $Y(Al,Ga)O_3:Ce^{3+}$, and orthosilicates doped with rare earths, $M_2SiO_5:Ce^{3+}$ (M:Sc,Y,Sc), such as $Y_2SiO_5:Ce^{3+}$ is conceivable. In all the yttrium compounds, the yttrium can in principle also be replaced with scandium or lanthanum.

Therefore, in the phosphorous group $A_3B_5X_{12}$:M, the variables may stand for the following exemplary elements: A=Y, Ca, Sr; B =Al, Ga, Si; X=O, S; and M=Ce^{3+}, Tb^{3+}.

Preferably, the casting composition according to the invention is used in a radiation-emitting semiconductor body, in particular with an active semiconductor layer or semiconductor layer sequence of $Ga_xIn_{1-x}N$ or $Ga_xAl_{1-x}N$, which in operation emits an electromagnetic radiation of the ultraviolet, blue and/or green spectral range. The luminous substance particles in the casting composition convert some of the radiation originating in this spectral range into radiation with a longer wavelength, in such a way that the semiconductor component emits mixed radiation, and in particular mixed-colored light comprising this radiation as well as radiation from the ultraviolet, blue and/or green spectral range. This means for instance that the luminous substance particles spectrally selectively absorb some of the radiation emitted by the semiconductor body and emit in the longer-wave range. Preferably, the radiation emitted by the semiconductor body has a relative maximum intensity at a wavelength lambda λ≦520 nm, and the wavelength range spectrally selectively absorbed by the luminous substance particles is outside this maximum intensity.

It is also advantageously possible for a plurality of different kinds of luminous substance particles, which emit at different wavelengths, to be dispersed in the casting composition. This is preferably achieved by means of different doping in different host lattices. This advantageously makes it possible to generate manifold color mixtures and

color temperatures of the light emitted by the component. This is especially of interest for LEDs capable of emitting full color.

In a preferred use of the casting composition of the invention, a radiation-emitting semiconductor body (such as an LED chip) is at least partly enclosed by the casting composition. The casting composition is preferably simultaneously used as a component envelope (housing). The advantage of a semiconductor component in accordance with this embodiment is essentially that conventional production lines used to make conventional LEDs (such as radial LEDs) can be used to produce it. For the component envelope, instead of the transparent plastic used for this purpose in conventional LEDs, the casting composition can simply be employed.

With the casting composition of the invention, it is possible in a simple way, with a single colored light source, particularly an LED with a single semiconductor body that emits blue light, to create mixed-colored and in particular white light. For instance to generate white light with a semiconductor body that emits blue light, some of the radiation emitted by the semiconductor body is converted out of the blue spectral range into the yellow spectral range, which is complementary in color to blue, by means of inorganic luminous substance particles.

The color temperature or color location of the white light can be varied by a suitable choice of the luminous substance, its particle size, and its concentration. In addition, luminous substance mixtures can also be employed, and as a result advantageously the desired tonality of the color of the emitted light can be adjusted very precisely.

Especially preferably, the casting composition is used in a radiation-emitting semiconductor body in which the emitted radiation spectrum has a maximum intensity at a wavelength between 420 nm and 460 nm, and in particular at 430 nm (examples being semiconductor bodies based on $Ga_xAl_{1-x}N$) or 450 nm (such as semiconductor bodies based on $Ga_xIn_{1-x}N$). With such a semiconductor component, nearly all the colors and mixed colors in the CIE chromaticity diagram can advantageously be generated.

Instead of the radiation-emitting semiconductor body of electroluminescing semiconductor material, however, some other electroluminescing material may be used, such as polymer material.

With the objects of the invention is view there is further provided, in accordance with the invention, a light-emitting semiconductor component, comprising:

- a semiconductor body formed of a semiconductor layer sequence and being capable, during an operation of the semiconductor component, of emitting electromagnetic radiation in at least one of an ultraviolet, blue, and green spectral range;
- a wavelength-converting casting composition disposed in a vicinity of the semiconductor body, the casting composition being formed of a transparent epoxy casting resin and an inorganic luminous substance pigment powder dispersed in the transparent epoxy resin, the pigment powder comprising luminous substance pigments from a phosphorus group having the general formula $A_3B_5X_{12}$:M and having grain sizes $\leqq 20$ μm and a mean grain diameter $d_{50} \leqq 5$ μm;
- the luminous substance pigments converting a portion of the radiation originating from the ultraviolet, blue and green spectral range into radiation of a higher wavelength, such that the semiconductor component emits mixed radiation including the higher-wavelength radiation and radiation from at least one of the ultraviolet, blue and green spectral range.

In other words, the casting composition is especially suitable for a light-emitting semiconductor component (for instance an LED), in which the electroluminescing semiconductor body is disposed in a recess of a prefabricated housing, optionally already provided with a leadframe, and the recess is provided with the casting composition. This kind of semiconductor component can be produced in great numbers on conventional production lines. All that is needed, after mounting of the semiconductor body in the housing, is to fill the recess with the casting composition.

A semiconductor component that emits white light can be produced with the casting composition according to the invention advantageously by choosing the luminous substance in such a way that a blue radiation emitted by the semiconductor body is converted into complementary wavelength ranges, in particular blue and yellow, or additive color triads, such as blue, green and red. The yellow or green and red light is generated via the luminous substances. The color tonality (color location in the CIE chromaticity diagram) of the white light thus produced can then be varied by means of a suitable choice of the luminous substance or luminous substances in terms of their mixture and concentration.

To improve the mixing of the radiation emitted by an electroluminescing semiconductor body with the radiation converted by the luminous substance and thus to improve the homogeneity of color of the light emitted by the component, in an advantageous feature of the casting composition according to the invention a blue-luminescing colorant, which attenuates a so-called directional characteristic of the radiation emitted by the semiconductor body. The term "directional characteristic" is understood to mean that the radiation emitted by the semiconductor body has a preferential emission direction.

A semiconductor component according to the invention that emits white light, with an electroluminescing semiconductor body emitting blue light, can be especially preferably achieved by admixing the inorganic luminous substance YAG:Ce ($Y_3Al_5O_{12}:Ce^{3+}$) with the epoxy resin used for the casting composition. Some of the blue radiation emitted by the semiconductor body is shifted by the inorganic luminous substance ($Y_3Al_5O_{12}:Ce^{3+}$) into the yellow spectral range and thus into a wavelength range that is complementary in color to the color blue. The color tonality (color location in the CIE chromaticity diagram) of the white light can then be varied by means of a suitable choice of the colorant concentration.

In addition, light-scattering particles, so-called diffusers, can be added to the casting composition. As a result, the color impression and the emission characteristics of the semiconductor component can advantageously be still further optimized.

With the casting composition of the invention, advantageously an ultraviolet radiation emitted by an electroluminescing semiconductor body along with the visible radiation can advantageously be converted into visible light. This markedly increases the brightness of the light emitted by the semiconductor body.

A particular advantage of semiconductor components according to the invention that emit white light, and in which YAG:Ce is used in particular as the luminescence-converting colorant, is that this luminous substance on excitation with blue light causes a spectral shift of approximately 100 nm between absorption and emission. This leads to a substantial reduction and reabsorption of the light emitted by the luminous substance and thus to a higher light yield. Moreover, YAG:Ce advantageously has high thermal and photochemical (such as UV) stability (substantially

higher than organic luminous substances) so that even white-emitting diodes for outdoor use and/or high temperature ranges can be produced.

YAG:Ce has by now proved itself to be the best-suitable luminous substance in terms of reabsorption, light yield, thermal and photochemical stability, and processability. However, the use of other Ce-doped phosphors, in particular Ce-doped types of garnet, is also conceivable.

The wavelength conversion of the primary radiation is determined by the crystal field cleavage of the active transition metal centers in the host lattice. By substituting Gd and/or Lu for Y, or Ga for Al in the $Y_3Al_5O_{12}$ garnet lattice, the emission wavelengths can be shifted in various ways, and this can also be done by the type of doping. By substituting Eu^{3+} and/or Cr^{3+} for Ce^{3+} centers, corresponding shifts can be brought about. Corresponding dopings with Nd^{3+} and Er^{3+} even make it possible, because of the greater ion radii and thus reduced crystal field cleavage, to make components that emit infrared (IR) light. Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a wavelength-converting casting composition, its use, and method for its production, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic sectional view of a first semiconductor component with a casting composition according to the invention;

FIG. **2** is a schematic sectional view of a second semiconductor component with a casting composition according to the invention;

FIG. **3** is a schematic sectional view of a third semiconductor component with a casting composition according to the invention;

FIG. **4** is a schematic sectional view of a fourth semiconductor component with a casting composition according to the invention;

FIG. **5** is a schematic sectional view of a fifth semiconductor component with a casting composition according to the invention;

FIG. **6** is a graph of an emission spectrum of a semiconductor body that emits blue light, with a layer sequence on the basis of GaN;

FIG. **7** is a graph of the emissions spectra of two semiconductor components with a casting composition according to the invention, which emit white light; and

FIG. **8** is a graph of the emissions spectra of further semiconductor components that emit white light.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is now had to the figures of the drawing in which elements that are identical or that function identically are identified by the same reference numerals throughout. In the light-emitting semiconductor component of FIG. **1**, the semiconductor body **1** is secured by its back-side contact **11** to a first electrical terminal **2** by means of an electrically conductive joining means such as a metal solder or an adhesive. The front-side contact **12** is joined to a second electrical terminal **3** by means of a bond wire **14**.

The free surfaces of the semiconductor body **1** and portions of the electrical terminals **2** and **3** are enclosed directly by a hardened, wavelength-converting casting or potting composition **5**. The casting composition preferably has the following: epoxy casting resin 80 to 90% by weight, luminous substance pigments (YAG:Ce)≦15% by weight, diethylene glycol monomethyl ether≦2% by weight, Tegopren 6875-45≦2% by weight, Aerosil 200≦5% by weight.

The exemplary embodiment of a semiconductor component according to the invention shown in FIG. **2** differs from that of FIG. **1** in that the semiconductor body **1** in portions of the electrical terminals **2** and **3** are enclosed not by a wavelength-converting potting mass but by a transparent envelope **15**. The transparent envelope **15** does not cause any change in the wavelength of the radiation emitted by the semiconductor body **1** and for instance comprises an epoxy, silicone or acrylate resin conventionally used in LED technology, or some other suitable radiation-permeable material, such as inorganic glass.

A layer **4** is applied to the transparent envelope **15**. The layer **4** comprises a wavelength-converting casting composition and, as shown in FIG. **2**, covers the entire surface of the envelope **15**. It is equally conceivable for the layer **4** to cover only a portion of the surface. The layer **4** for instance comprises a transparent epoxy resin which is mixed with luminous substance particles **6**. Once again, for a semiconductor component that emits white light, YAG:Ce is preferred as the luminous substance.

FIG. **3** illustrates a particularly advantageous and preferred embodiment of the invention. The first and second electrical terminals **2**, **3** are embedded in an opaque, and optionally prefabricated, basic housing **8** that has a recess **9**. The term "prefabricated" is understood to mean that the basic housing **8** is already finished at the terminals **2**, **3**, for instance by means of injection molding, before the semiconductor body is mounted on the terminal **2**. The basic housing **8**, by way of example, is formed of opaque plastic, and in terms of its form the recess **9** is embodied as a reflector **17** for the radiation emitted by the semiconductor body in operation (the reflection optionally being achieved by means of suitable coating of the inside walls of the recess **9**). Such basic housings **8** are used in particular for LEDs that are surface-mounted on printed circuit boards. They are applied, before mounting of the semiconductor body, to a conductor strip (lead frame) that has the electrical terminals **2**, **3**, the application for instance being done by injection molding.

The recess **9** is filled with a casting composition **5**, whose composition is equivalent to that given above in conjunction with the description of FIG. **1**.

FIG. **4** shows a so-called radial diode. Here, the electroluminescing semiconductor body **1** is secured, for instance by soldering or adhesive bonding, in a part **16**, embodied as a reflector, of the first electrical terminal **2**. Such housing constructions are known in LED technology and therefore require no further description here. The free surfaces of the semiconductor body **1** are covered directly by a casting composition **5** containing luminous substance particles **6**, and the casting composition in turn is surrounded by a further transparent housing envelope **10**.

It will be appreciated by those skilled in the art that, in the construction of FIG. **4** as well, analogously to the component of FIG. **1**, an integral envelope comprising hardened casting composition **5** with luminous substance particles **6**, may also be used.

In the exemplary embodiment of FIG. **5**, a layer **4** (see the list of materials given above) is coated directly on the semiconductor body **1**. The semiconductor body **1** and portions of the electrical terminals **2**, **3** are enclosed by a further transparent housing envelope **10**. The latter causes no change in wavelength of the radiation that has passed through the layer **4**, and it is made for instance from a transparent epoxy resin that is usable in LED technology, or from glass.

Such semiconductor bodies **1** provided with a layer **4** and without an envelope can naturally advantageously be used in all the housing constructions known from LED technology (such as SMD housings, and radial housings; see FIG. **4**).

In all the components described above, in order to optimize the color impression of the light emitted and to adapt the emission characteristics, the casting composition **5**, optionally the transparent envelope **15**, and/or optionally the further transparent envelope **10** may have light-scattering particles, advantageously so-called diffusers. Examples of such diffusers are mineral fillers, in particular CaF_2, TiO_2, Sio_2, $CaCO_3$, or $BaSO_4$, or organic pigments. These materials can easily be added to epoxy resins.

FIGS. **6–8** illustrate emissions spectra. FIG. **6** refers to a semiconductor body that emits blue light (luminescence maximum at λ~430 nm) and FIGS. **7** and **8** refer to semiconductor components that emit white light. In each case, the wavelength λ is plotted in nm on the abscissa, and a relative electroluminescence (EL) intensity is plotted on the ordinate.

Of the radiation emitted by the semiconductor body in FIG. **6**, only some is converted into a longer-wavelength range, so that white light is created as the mixed color. The dashed line **30** in FIG. **7** represents an emissions spectrum of a semiconductor component which emits radiation comprising two complementary wavelength ranges (blue and yellow) and thus emits combined white light. The emissions spectrum here has one maximum each at wavelengths between approximately 400 and approximately 430 nm (blue) and between approximately 550 and 580 nm (yellow). The solid line **31** represents the emissions spectrum of a semiconductor component that mixes the color white from three wavelength ranges (additive color triad comprising blue, green and red). The emissions spectrum here has one maximum each for the wavelengths of approximately 430 nm (blue), approximately 500 nm (green) and approximately 615 nm (red).

FIG. **8** shows an emissions spectrum of a white-emitting semiconductor component, which is provided with a semiconductor body that transmits an emissions spectrum as shown in FIG. **6** and in which TAG:Ce is used as the luminous substance. Of the radiation shown in FIG. **6** emitted by the semiconductor body, only some is converted into a longer-wavelength range, so that white light is created as a mixed color. The variously dashed lines **32–33** of FIG. **8** represent emissions spectra of semiconductor components according to the invention, in which the epoxy resin of the casting composition **5** has different YAG:Ce concentrations. Each emissions spectrum has one maximum intensity between lambda=420 nm and lambda=430 nm (i.e., in the blue spectrum), and between lambda=520 nm and lambda=545 nm (i.e., in the green spectrum). The emission bands having the longer-wavelength maximum intensity are predominantly located in the yellow spectral range. The graph of FIG. **8** shows that in the semiconductor component of the invention, the CIE color location of the white light can be varied in a simple way by varying the luminous substance concentration in the epoxy resin.

While the foregoing specification refers specifically to a semiconductor body, for example LED chips or laser diode chips, the invention is not in the least restricted to these embodiments. The term may also be understood to mean a polymer LED, for instance, that emits an equivalent radiation spectrum.

We claim:

1. A wavelength-converting casting composition, for converting a wavelength of ultraviolet, blue or green light emitted by an electroluminescent component, comprising:

a transparent epoxy casting resin;

an inorganic luminous substance pigment powder dispersed in said transparent epoxy resin, said pigment powder comprising luminous substance pigments from a phosphorus group having the general formula $A_3B_5X_{12}$:M, where A is an element selected from the group consisting of Y, Ca, Sr; B is an element selected from the group consisting of Al, Ga, Si; X is an element selected from the group consisting of O and S; M is an element selected from the group consisting of Ce and Tb;

said luminous substance pigments having grain sizes≦20 μm and a mean grain diameter d_{50}≦5 μm.

2. The casting composition according to claim **1**, wherein said luminous substance pigments are substantially spherical particles.

3. The casting composition according to claim **1**, wherein said luminous substance pigments are flakelike particles.

4. The casting composition according to claim **1**, wherein the mean grain diameter d_{50} of said luminous substance pigments is between one and two micrometers.

5. The casting composition according to claim **1**, which comprises the following components:

a) epoxy casting resin≧60% by weight;

b) luminous substance pigments>0 and ≦25% by weight;

c) thixotropic agent>0 and ≦10% by weight;

d) mineral diffusor>0 and ≦10% by weight;

e) processing adjuvant>0 and ≦3% by weight;

f) hydrophobic agent>0 and ≦3% by weight; and

g) adhesion promoters>0 and ≦2% by weight.

6. The casting composition according to claim **1**, wherein said luminous substance pigments are particles of Ce-doped garnets.

7. The casting composition according to claim **6**, wherein said luminous substance pigments are YAG:Ce particles.

8. The casting composition according to claim **1**, which comprises a content of iron≦20 ppm.

9. The casting composition according to claim **1**, wherein said luminous substance pigments are formed with a silicon coating.

10. A light-emitting semiconductor component, comprising:

a semiconductor body formed of a semiconductor layer sequence and being capable, during an operation of the semiconductor component, of emitting electromagnetic radiation in at least one of an ultraviolet, blue, and green spectral range;

a wavelength-converting casting composition disposed in a vicinity of said semiconductor body, said casting

composition being formed of a transparent epoxy casting resin and an inorganic luminous substance pigment powder dispersed in said transparent epoxy resin, said pigment powder comprising luminous substance pigments from a phosphorus group having the general formula $A_3B_5X_{12}$:M, where A is an element selected from the group consisting of Y, Ca, Sr; B is an element selected from the group consisting of Al, Ga, Si; X is an element selected from the group consisting of O and S; M is an element selected from the group consisting of Ce and Tb, and having grain sizes$\leqq$20 μm and a mean grain diameter $d_{50}\leqq 5$ μm;

said luminous substance pigments converting a portion of the radiation originating from the ultraviolet, blue and green spectral range into radiation of a higher wavelength, such that the semiconductor component emits mixed radiation including the higher-wavelength radiation and radiation from at least one of the ultraviolet, blue and green spectral range.

11. The light-emitting semiconductor component according to claim **10**, wherein said casting composition encloses at least a part of said semiconductor body.

12. The light-emitting semiconductor component according to claim **10**, wherein said semiconductor body is adapted to emit radiation in a blue spectral range having a maximum luminescence intensity at λ=430 nm or at λ=450 nm.

13. The light-emitting semiconductor component according to claim **10**, which further comprises an opaque base housing having a recess formed therein, said semiconductor body being disposed in said recess and said recess being at least partially filled with said casting composition.

14. The light-emitting semiconductor component according to claim **10**, wherein said casting composition is provided with various kinds of luminous substance pigments in respect to a host lattice distribution and a type and extent of doping.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,066,861 Page 1 of 1
DATED : May 23, 2000
INVENTOR(S) : Klaus Höhn, Elexandra Debray, Peter Schlotter, Ralf Schmidt and Jürgen Schneider

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Insert -- [30] **Foreign Application Priority Data**
September 20, 1996 (DE).....196 38 667.5 --

Signed and Sealed this

Eleventh Day of June, 2002

Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

EXHIBIT B

US006576930B2

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

(10) **Patent No.: US 6,576,930 B2**
(45) **Date of Patent: Jun. 10, 2003**

(54) **LIGHT-RADIATING SEMICONDUCTOR COMPONENT WITH A LUMINESCENCE CONVERSION ELEMENT**

(75) Inventors: **Ulrike Reeh**, München (DE); **Klaus Höhn**, Taufkirchen (DE); **Norbert Stath**, Regensburg (DE); **Günter Waitl**, Regensburg (DE); **Peter Schlotter**, Freiburg (DE); **Jürgen Schneider**, Kirchzarten (DE); **Ralf Schmidt**, Vörstetten (DE)

(73) Assignee: **Osram Opto Semiconductors GmbH**, Regensburg (DE)

(*) 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.: **09/731,452**

(22) Filed: **Dec. 7, 2000**

(65) **Prior Publication Data**

US 2001/0002049 A1 May 31, 2001

Related U.S. Application Data

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(30) **Foreign Application Priority Data**

Jun. 26, 1996 (DE) 196 25 622
Sep. 20, 1996 (DE) 196 38 667

(51) **Int. Cl.**[7] **H01L 33/00**
(52) **U.S. Cl.** **257/98**; 257/99; 257/100
(58) **Field of Search** 257/98, 99, 100

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,096,693 A 10/1937 Cox 313/485
2,192,869 A 3/1940 Pearce 313/485
3,593,055 A 7/1971 Geusie 257/98
3,602,758 A 8/1971 Thornton 313/485
3,691,482 A 9/1972 Pinnow 330/108

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

DE	2 347 289	4/1974
DE	33 15 675 A1	11/1983
DE	38 04 293 A1	8/1989
EP	0 486 052 A1	5/1992
EP	97 933 047.9	7/1997
JP	46-7462	12/1971

(List continued on next page.)

OTHER PUBLICATIONS

English Translation of Japanese 01175103 A, Jul. 11, 1989.
English Translation of Japanese 01260707 A, Oct. 18, 1989.
Phosphor Handbook, English Translation of (BAT).
"Phosphor Handbook", Ohm 1987, pp. 172–174, 188–189, 270, 275–276, 383–385.
Nakamura, Shuji et al., Candela–class high–brightness InGan/AlGaN double–heterostructure blue–light–emitting diodes, App. Phys. Lett 64 (13) Mar. 28, 1994, pp. 1687–1689.

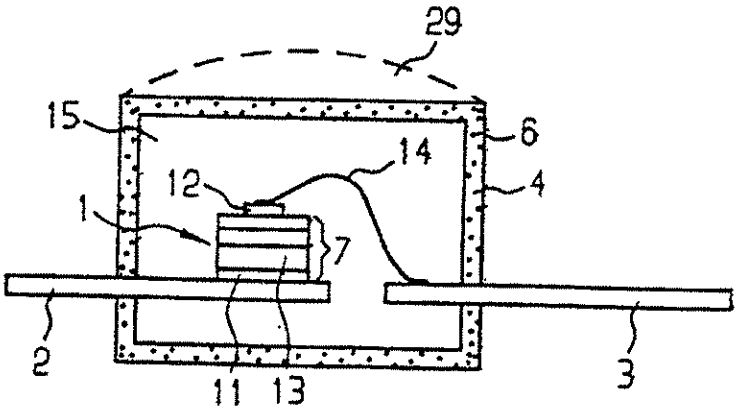
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Primary Examiner—Jerome Jackson
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

The light-radiating semiconductor component has a radiation-emitting semiconductor body and a luminescence conversion element. The semiconductor body emits radiation in the ultraviolet, blue and/or green spectral region and the luminescence conversion element converts a portion of the radiation into radiation of a longer wavelength. This makes it possible to produce light-emitting diodes which radiate polychromatic light, in particular white light, with only a single light-emitting semiconductor body. A particularly preferred luminescence conversion dye is YAG:Ce.

4 Claims, 6 Drawing Sheets



U.S. PATENT DOCUMENTS

3,696,478	A	10/1972	Pinnow et al.	
3,819,974	A	6/1974	Stevenson et al.	
3,932,881	A	1/1976	Mita et al.	257/98
5,019,746	A	5/1991	Merg	
5,126,214	A	6/1992	Tokailin	313/503
5,535,230	A	7/1996	Abe	257/98
5,959,316	A	9/1999	Lowery	257/98
5,998,925	A	12/1999	Shimizu et al.	
6,069,440	A	5/2000	Shimizu et al.	313/486

FOREIGN PATENT DOCUMENTS

JP	50-43913	4/1975
JP	52-40959	10/1977
JP	2-91980	9/1988
JP	5-152609	6/1993
JP	6-69546	3/1994
JP	7-99345	4/1995
JP	7-176794	7/1995
JP	198585/1996	7/1996
JP	244339/1996	9/1996
JP	245381/1996	9/1996
JP	359004/1996	12/1996
JP	9-73807	3/1997
JP	081010/1997	3/1997
JP	11-220174	8/1999

OTHER PUBLICATIONS

Nakamuri, T, "Nichia Chemical starts the sample shipment of white light Emitting Diode", Nikkei Electronics, Sep. 23, 1996 (No. 671), pp. 15–16.
English translation of (BAV).
Schlotter, P. et al., "Luminescence conversion of blue light emitting diodes", Applied Physics A, Springer Verlag (publ.), Apr. 1997, vol. 4, pp. 417–418.
Material Safety Data Sheet, pp. 1 and 2, and Lamp Phosphor Data Sheet of Phosphor NP–204 of Nichia Corporation.
"Phosphor and Emitter", Osram GmbH, Jun. 1997.
Proceedings of 264th Institute of Phosphor Society, "Development and Application of high bright white LED Lamps", Nov. 29, 1996, pp. 5–14.
English Translation of (BAAA).
English Translation of Japanese Patent Application No. 245381, Filed Sep. 18, 1996, Nichia Chemical Industries Ltd.
English Translation of Japanese Patent Application No. 359004, Filed Dec. 27, 1996, Nichia Chemical Industries Ltd.
English Translation of Japanese Patent Application No. 198585, Filed Jul. 29, 1996, Nichia Chemical Industries Ltd.
English Translation of Japanese Patent Application No. 018010, Filed Mar. 31, 1997, Nichia Chemical Industries Ltd.
Nikkei Sangyo Shimbun (Nikkei Industrial Newspaper), Sep. 13, 1996.
English Abstract of Japanese 7–99345, Apr. 11, 1995.
B.M. J. Smets, "Phosphors Based On Rare–Earths, A New Era in Fluorescent Lighting", Materials Chemistry and Physics, 16 (1987), pp. 283–299.
Chao et al., *Jour Solid State Chemistry*, "White Light Emitting Glass", p. 17–29.
D.J. Robbins, "The Effects of Crystal Field and Temperature on the Photoluminescence Excitation of Ce^{3+} in YAG", J. Electrochem. Soc.; Solid State Science and Technology, Sep. 1979, vol. 126, No. 9, pp. 1550–1555.
Frank Möllmer et al., "Siemens SMT–TOPLED für die Oberflächenmontage", [Siemens SMT–TOPLEDS for surface mounting], Siemens Components 29, 1991, No. 4, pp. 147–149.
G. Blasse et al., "A New Phosphor For Flying–Spot Ray Tubes For Color Television; Yellow–Emitting $Y_3Al_5O_{12}Ce^{3+}$", Applied Physics Letter, vol. 11, No. 2, Jul. 15, 1967, pp. 53, 54.
German Utility Model G 90 12 615.2., dated Jan. 24, 1991, electroluminescent or laser diode.
Glen A. Slack et al., "Optical Absorption of $Y_3Al_5O_{12}$ from 10–to 55000–cm^{-1} Wave Numbers", Physical review, vol. 177, No. 3, Jan. 15, 1969, pp. 1308–1314.
Japanese Patent Abstract 07176794 A (Yoshinori), dated Jul. 14, 1995.
Japanese Patent Abstract 08007614 (Yoshinori), dated Jan. 12, 1996.
Japanese Patent Abstract No. 5–152609 (Tdatatsu), dated Jun. 18, 1993.
Mary V. Hoffman, "Improved color rendition in high pressure mercury vapor lamps", Journal of IES, Jan. 1977, pp. 89–91.
S.N. Mohammad et al., "Emerging Gallium Nitride Based Devices", Proceedings of the IEEE, vol. 83, No. 10, Oct. 1995, pp. 1306–1355.
Sato et al., "Full–Color . . . Diode", Jpn. J. Appl. Phys., vol. 24 (1996), pp. L838–L839, 7/96.
Shuji Nakamura et al., "The blue laser diode; GaN based light emitters and lasers", Springer Verlag, Berlin, 1997, 99. 216–219, 328.
Siemens Forsch.–u. Entwickl.–Ber Bd 5 (1977) No. 3, p. 162 [Siemens research and development reports, vol., 6].
Thomas Jüstel et al., "Neue Entwickungen auf dm Gebiet luminesziererender Materialien für Beleuchtungs–und Displayanwendungen" [new developments in the field of luminescent material for lighting and display applications], Angew. Chem., 1998, 110, pp. 3250–3271.
White LED Lamp by Nichia, copy of a Japanese Newspaper, dated Sep. 1996.

FIG 1

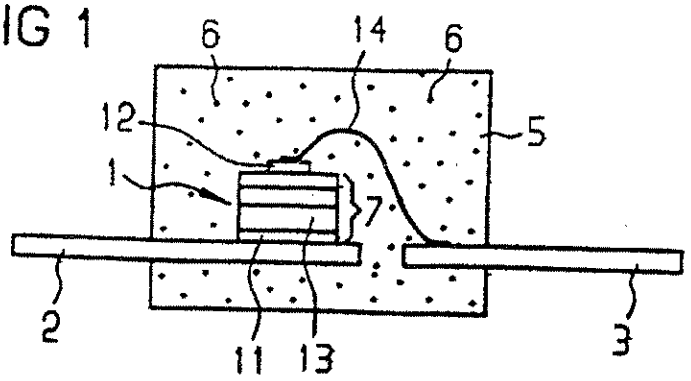


FIG 2

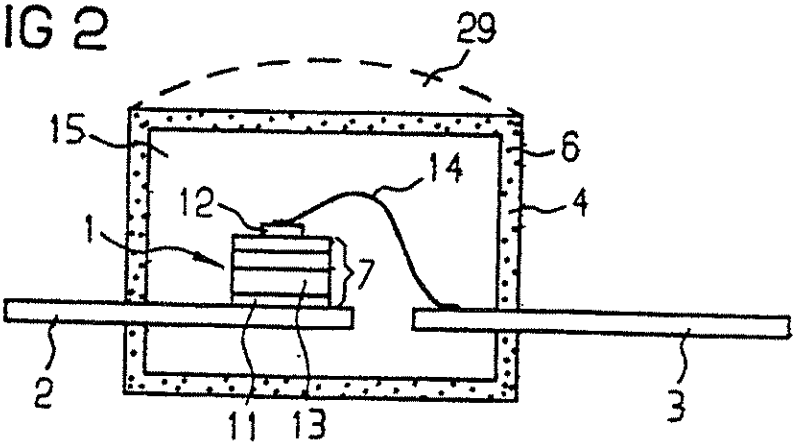


FIG 3

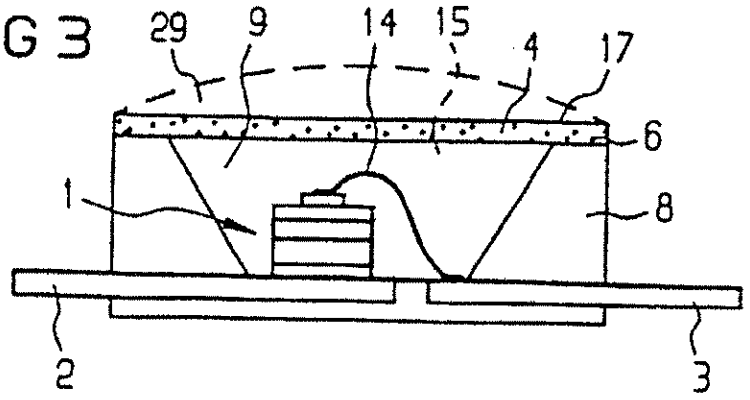


FIG 4

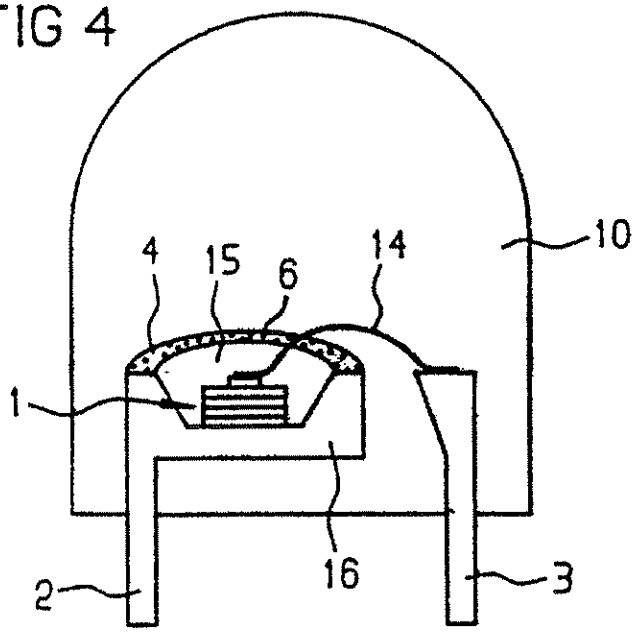


FIG 5

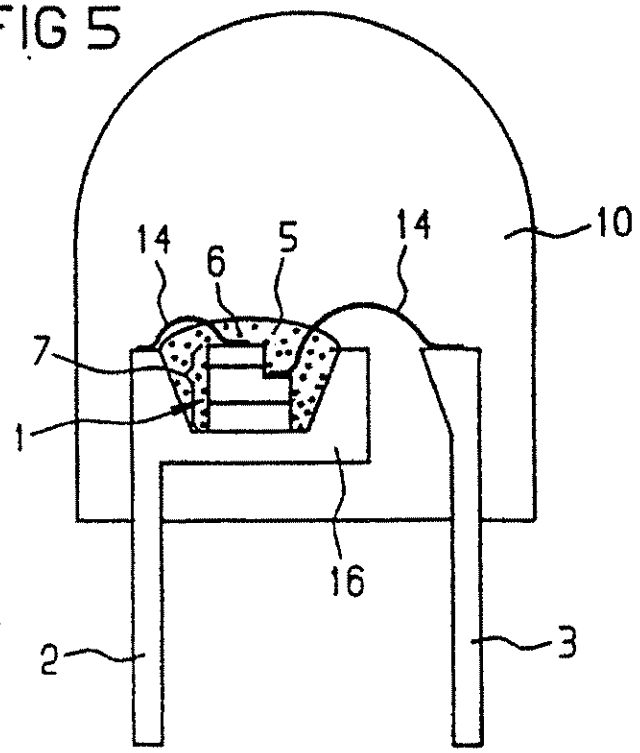


FIG 6

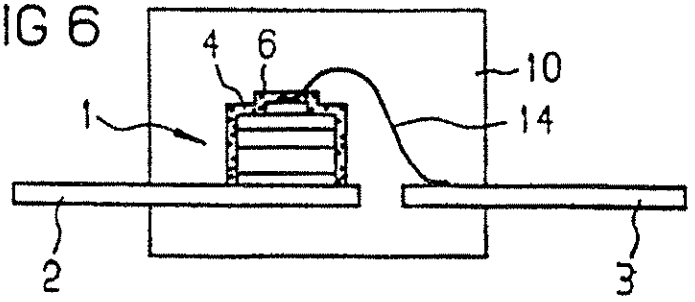


FIG 9

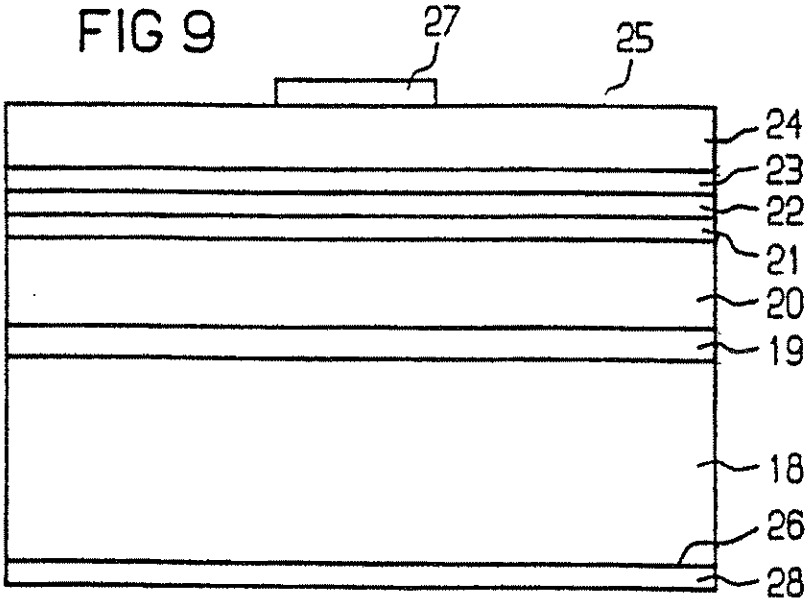


FIG 10

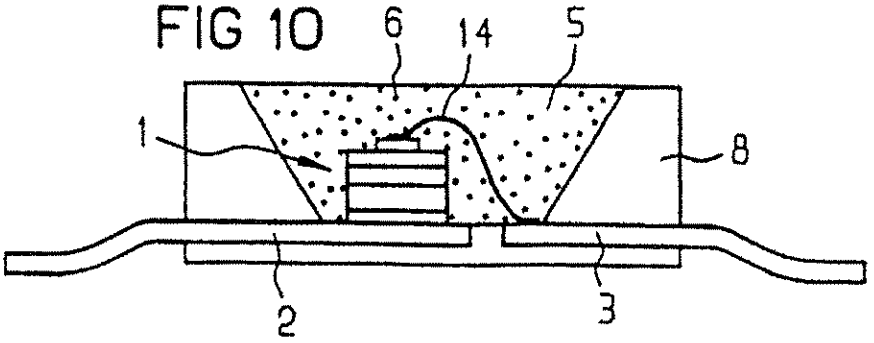


FIG 7

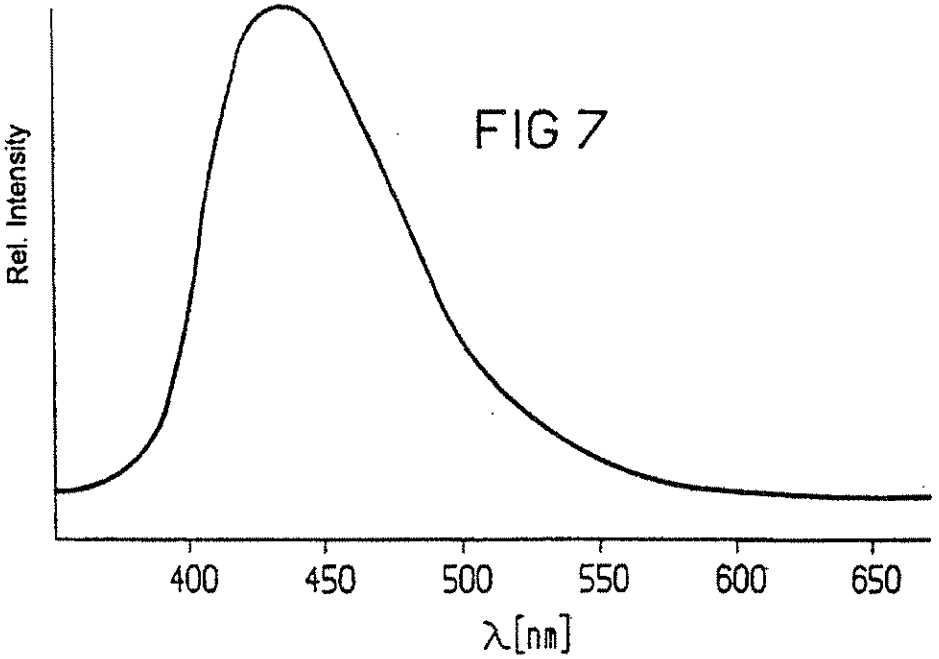

Rel. Intensity
400
450
500
550
600
650
λ[nm]

FIG 8

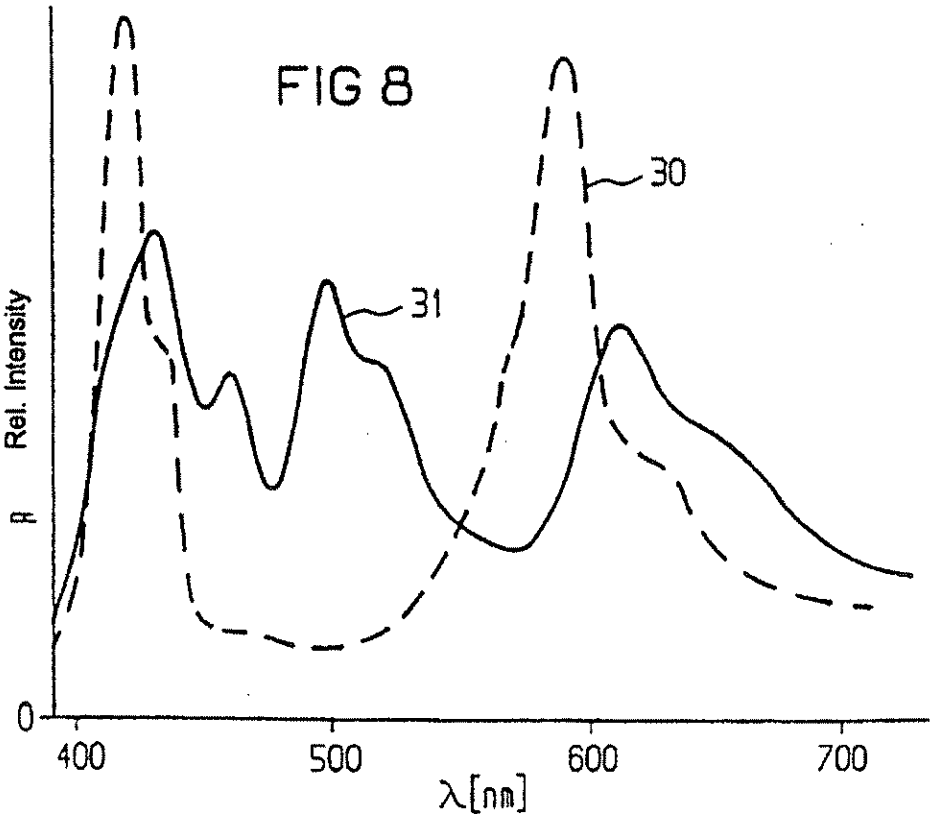

30
31
Rel. Intensity
1
0
400
500
600
700
λ[nm]

FIG 11

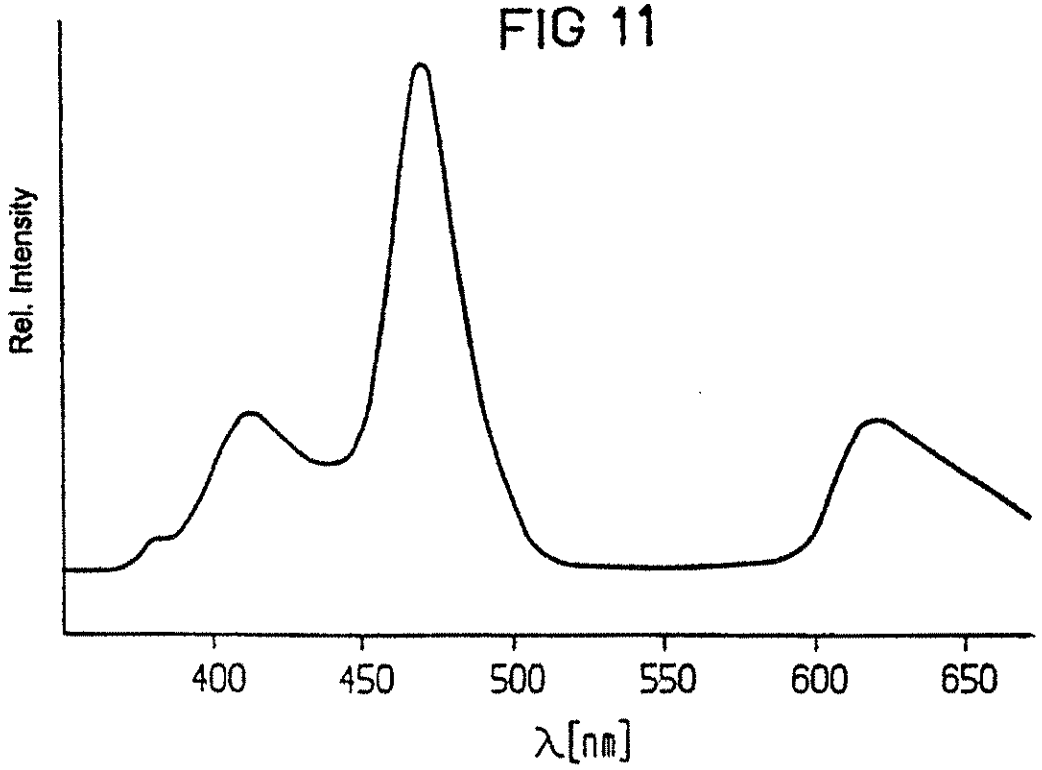

Rel. Intensity
400
450
500
550
600
650
λ[nm]

FIG 12

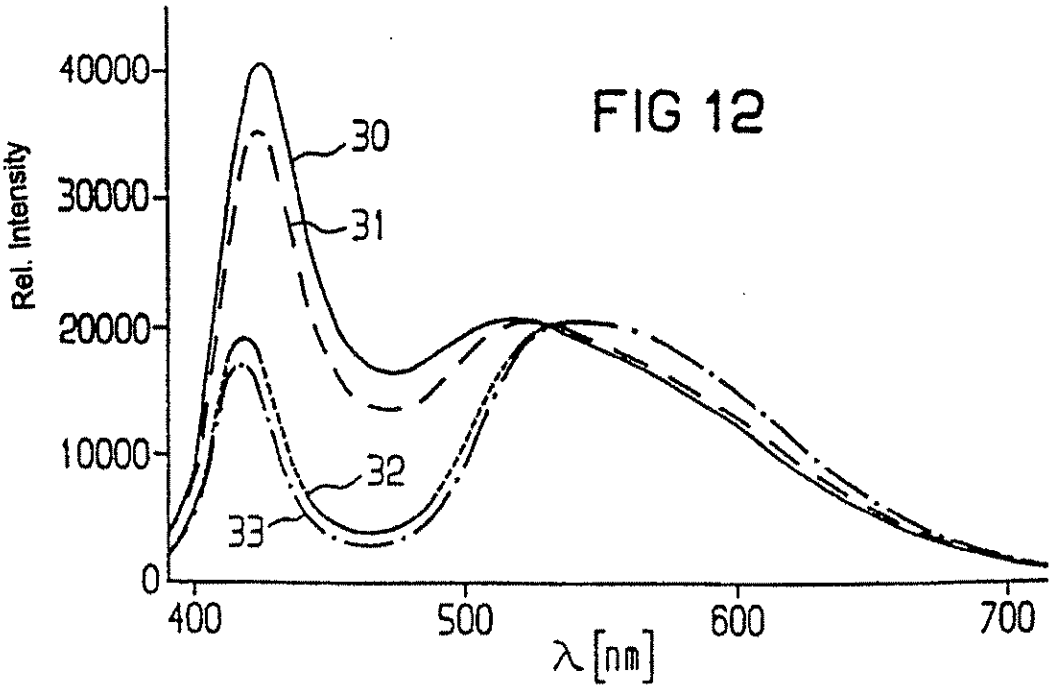

Rel. Intensity
40000
30000
20000
10000
0
30
31
32
33
400
500
600
700
λ [nm]

FIG 13

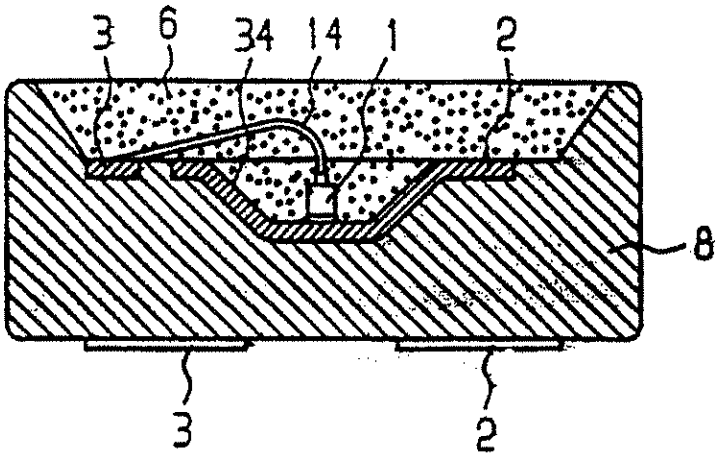
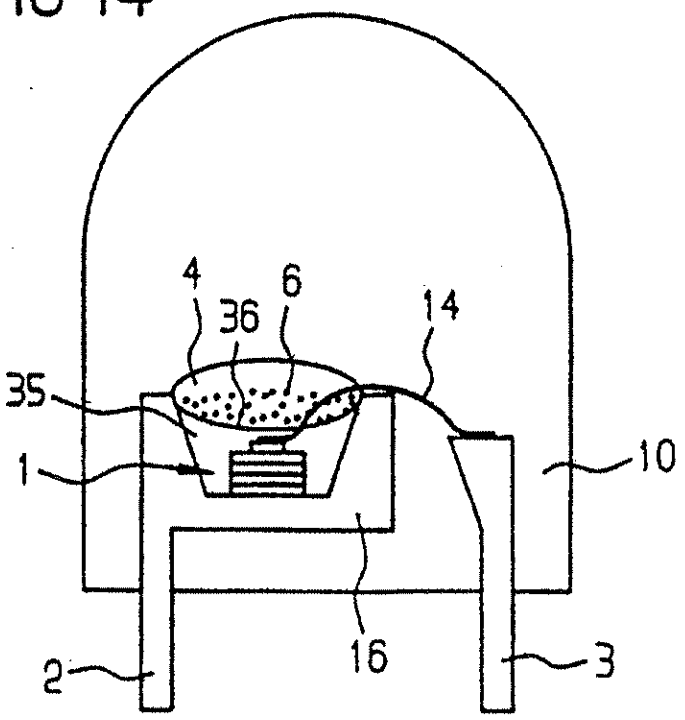


FIG 14



LIGHT-RADIATING SEMICONDUCTOR COMPONENT WITH A LUMINESCENCE CONVERSION ELEMENT

CROSS-REFERENCE TO RELATED APPLICATION

This is a divisional of U.S. application Ser. No. 09/221,789, filed Dec. 28, 1998, which is a continuation of International Application PCT/DE97/01337, filed Jun. 26, 1997, which designated the United States.

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to a light-radiating semiconductor component with a semiconductor body that emits electromagnetic radiation during operation of the semiconductor component. The component has at least one first and at least one second electrical terminal, which are electrically connected to the semiconductor body. The component further has a luminescence conversion element with at least one luminescent material.

A semiconductor component of that type is disclosed, for example, in German published patent application DE 38 04 293. There, an arrangement having an electroluminescent or laser diode in which the entire emission spectrum radiated by the diode is shifted toward greater wavelengths by means of a plastic element that is treated with a fluorescent, light-converting organic dye. The light radiated by the arrangement consequently has a different color from the light emitted by the light-emitting diode. Depending on the nature of the dye added to the plastic, light-emitting diode arrangements which emit light in different colors can be produced using one and the same type of light-emitting diode.

German published patent application DE 23 47 289 discloses an infrared (IR) solid-state lamp in which luminescent material is applied on the edge of an IR diode and converts the IR radiation that is radiated there into visible light. The aim of this measure is, for supervisory purposes, to convert a smallest possible part of the IR radiation emitted by the diode into visible light in conjunction with the smallest possible reduction of the intensity of the emitted IR radiation.

Furthermore, European patent application EP 486 052 discloses a light-emitting diode in which at least one semiconductor photoluminescent layer is arranged between the substrate and an active electroluminescent layer. The semiconductor photoluminescent layer converts the light of a first wavelength range—the light emitted by the active layer in the direction of the substrate—into light of a second wavelength range, with the result that, altogether, the light-emitting diode emits light of different wavelength ranges.

In many potential areas of application for light-emitting diodes, such as, for example, in display elements in motor vehicle dashboards, lighting in aircraft and automobiles, and in full-color LED displays, there is increasingly a demand for light-emitting diode arrangements with which polychromatic light, in particular white light, can be produced.

Japanese patent application JP-07 176 794-A describes a white-light-emitting, planar light source in which two blue-light-emitting diodes are arranged at an end of a transparent plate. The diodes emit light into the transparent plate. The transparent plate is coated with a fluorescent substance on one of the two mutually opposite main surfaces. The fluorescent substance emits light when it is excited by the blue

light of the diodes. The light emitted by the fluorescent substance has a different wavelength from that of the blue light emitted by the diodes. In that prior art component, it is particularly difficult to apply the fluorescent substance in such a manner that the light source radiates homogeneous white light. Furthermore, the question of reproducibility in mass production also poses major problems because even slight fluctuations in the thickness of the fluorescent layer, for example on account of unevenness of the surface of the transparent plate, cause a change in the shade of white of the radiated light.

SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide a light-radiating semiconductor component, which overcomes the above-mentioned disadvantages of the heretofore-known devices and methods of this general type and which radiates homogeneous polychromatic light and ensures technically simple mass production with component characteristics that are reproducible to the greatest possible extent.

With the foregoing and other objects in view there is provided, in accordance with the invention, a light-radiating semiconductor component, comprising:

a semiconductor body emitting electromagnetic radiation during an operation of the semiconductor component, the semiconductor body having a semiconductor layer sequence suitable for emitting electromagnetic radiation of a first wavelength range selected from a spectral region consisting of ultraviolet, blue, and green;

a first electrical terminal and a second electrical terminal each electrically conductively connected to the semiconductor body; and

a luminescence conversion element with at least one luminescent material, the luminescence conversion element converting a radiation originating in the first wavelength range into radiation of a second wavelength range different from the first wavelength range, such that the semiconductor component emits polychromatic radiation comprising radiation of the first wavelength range and radiation of the second wavelength range.

The invention provides for the radiation-emitting semiconductor body to have a layer sequence, in particular a layer sequence with an active semiconductor layer made of $Ga_xIn_{1-x}N$ or $Ga_xAl_{1-x}N$, which emits an electromagnetic radiation of a first wavelength range from the ultraviolet, blue and/or green spectral region during operation of the semiconductor component. The luminescence conversion element converts part of the radiation originating from the first wavelength range into radiation of a second wavelength range, in such a way that the semiconductor component emits polychromatic radiation, in particular polychromatic light, comprising radiation of the first wavelength range and radiation of the second wavelength range. This means, for example, that the luminescence conversion element spectrally selectively absorbs part of the radiation emitted by the semiconductor body, preferably only over a spectral subregion of the first wavelength range, and emits it in the region of longer wavelength (in the second wavelength range). Preferably, the radiation emitted by the semiconductor body has a relative intensity maximum at a wavelength $\lambda \leqq 520$ nm and the wavelength range which is spectrally selectively absorbed by the luminescence conversion element lies outside this intensity maximum.

In accordance with an added feature of the invention, the luminescence conversion element converts radiation of the first wavelength range into radiation of a plurality of second

wavelength ranges from mutually different spectral subregions, such that the semiconductor component emits polychromatic radiation comprising radiation of the first wavelength range and radiation of the plurality of second wavelength ranges. In other words, the invention advantageously makes it possible also to convert a number (one or more) of first spectral subregions originating from the first wavelength range into a plurality of second wavelength ranges. As a result, it is possible to produce diverse color mixtures and color temperatures.

The semiconductor component according to the invention has the particular advantage that the wavelength spectrum generated by way of luminescence conversion and hence the color of the radiated light do not depend on the level of the operating current intensity through the semiconductor body. This has great significance particularly when the ambient temperature of the semiconductor component and, consequently, as is known, also the operating current intensity greatly fluctuate. Especially light-emitting diodes having a semiconductor body based on GaN are very sensitive in this respect.

In addition, the semiconductor component according to the invention requires only a single driving voltage and, as a result, also only a single driving circuit configuration, whereby the outlay on devices for the driving circuit of the semiconductor component can be kept very low.

In accordance with an additional feature of the invention, the semiconductor component has a defined main radiating direction, and the luminescence conversion element is disposed substantially downstream of the semiconductor body in the main radiating direction of the semiconductor component.

In accordance with another feature of the invention, the luminescence conversion element is at least one luminescence conversion layer disposed in a vicinity of the semiconductor body. In this particularly preferred embodiment of the invention, a partially transparent luminescence conversion layer, that is to say one which is partially transparent to the radiation emitted by the radiation-emitting semiconductor body, is provided as the luminescence conversion element above or on the semiconductor body. In order to ensure a uniform color of the radiated light, the luminescence conversion layer is advantageously designed in such a way that it has a constant thickness throughout. This has the particular advantage that the path length of the light radiated by the semiconductor body through the luminescence conversion layer is virtually constant for all radiation directions. The effect that can be achieved as a result of this is that the semiconductor component radiates light of the same color in all directions. A further particular advantage of a semiconductor component according to the invention in accordance with this development consists in the fact that a high degree of reproducibility can be obtained in a simple manner, which is of considerable significance for efficient mass production. A resist or resin layer treated with luminescent material may be provided, for example, as the luminescence conversion layer.

In accordance with a further feature of the invention, the luminescence conversion element is a luminescence conversion encapsulation enclosing at least a part of the semiconductor body and partial regions of the first and second electrical terminals. The encapsulation is partially transparent and encloses at least part of the semiconductor body (and possibly partial regions of the electrical terminals) and can simultaneously be utilized as component encapsulation (housing). The advantage of a semiconductor component in accordance with this embodiment consists essentially in the fact that conventional production lines used for the production of conventional light-emitting diodes (for example radial light-emitting diodes) can be utilized for its production. The material of the luminescence conversion encapsulation is used for the component encapsulation instead of the transparent plastic which is used for this purpose in conventional light-emitting diodes.

In further advantageous embodiments of the semiconductor component according to the invention and of the two preferred embodiments mentioned above, the luminescence conversion layer or the luminescence conversion encapsulation is composed of a transparent material, for example plastic, preferably epoxy resin, which is provided with at least one luminescent material (examples of preferred plastics and luminescent materials will be found further below). In this way, it is possible to produce luminescence conversion elements in a particularly cost-effective manner. Specifically, the requisite process steps can be integrated in conventional production lines for light-emitting diodes with no major outlay.

In accordance with again an added feature of the invention, the second wavelength range includes wavelengths at least some of which are longer than wavelengths of the first wavelength range.

In accordance with again an additional feature of the invention, the semiconductor body is adapted to emit ultraviolet radiation during operation of the semiconductor component, and the luminescence conversion element converts at least a portion of the ultraviolet radiation into visible light.

In accordance with again another feature of the invention, the first wavelength range and the second wavelength range of the polychromatic radiation lie at least partially in mutually complementary-color spectral regions, and a combination of radiation from the first and second wavelength range results in white light.

When the second spectral subregion of the first wavelength range and a second wavelength range are complementary to one another, it is possible to produce polychromatic, in particular white, light from a single colored light source, in particular a light-emitting diode having a single blue-light-radiating semiconductor body. In order, for example, to produce white light with a blue-light-emitting semiconductor body, part of the radiation from the blue spectral region emitted by the semiconductor body is converted into the yellow spectral region, which is complementarily colored with respect to blue. The color temperature or color locus of the white light can in this case be varied by a suitable choice of the luminescence conversion element, in particular by a suitable choice of the luminescent material, its particle size and its concentration. Furthermore, these arrangements also advantageously afford the possibility of using luminescent material mixtures, as a result of which, advantageously, the desired hue can be set very accurately. Likewise, it is possible to configure luminescence conversion elements inhomogeneously, for example by means of inhomogeneous luminescent material distribution. Different path lengths of the light through the luminescence conversion element can advantageously be compensated for as a result of this.

In accordance with again a further feature of the invention, the first wavelength range emitted by the semiconductor body and two second wavelength ranges produce an additive color triad, such that white light is radiated by the semiconductor component during operation thereof.

In a further preferred embodiment of the semiconductor component according to the invention, the luminescence conversion element or another constituent of a component encapsulation has, for the purpose of color matching, one or more dyes which do not effect wavelength conversion. For this purpose, it is possible to use the dyes which are used for the production of conventional light-emitting diodes, such as, for example, azo, anthraquinone or perinone dyes.

In order to protect the luminescence conversion element against an excessively high radiation load, in an advantageous development or in the above-mentioned preferred embodiments of the semiconductor component according to the invention, at least part of the surface of the semiconductor body is surrounded by a first, transparent casing composed, for example, of a plastic, on which casing the luminescence conversion layer is applied. This reduces the radiation density in the luminescence conversion element and, consequently, the radiation load thereof, which, depending on the materials used, has a positive effect on the life of the luminescence conversion element.

In accordance with yet an added feature of the invention, the radiation emitted by the semiconductor body has a luminescence intensity maximum in a blue spectral region at a wavelength selected from the group consisting of λ=430 nm and λ=450 nm. The preferred radiation-emitting semiconductor body has a radiation spectrum with an intensity maximum at a wavelength of between 420 nm and 460 nm, in particular at 430 nm (for example semiconductor body based on $Ga_xAl_{1-x}N$) or 450 nm (for example semiconductor body based on $Ga_xIn_{1-x}N$). It is advantageous that virtually all colors and mixed colors of the C.I.E. chromaticity diagram can be produced by such a semiconductor component according to the invention. In this case, as specified above, the radiation-emitting semiconductor body may essentially be composed of electroluminescent semiconductor material, but also of a different electroluminescent material, such as polymer material, for example.

In accordance with yet an additional feature of the invention, an opaque base housing is formed with a recess, and wherein the semiconductor body is disposed in the recess of the base housing, and including a covering layer having a luminescence conversion layer on the recess. Alternatively, the recess is at least partially filled with the luminescence conversion element.

In accordance with yet another feature of the invention, the luminescence conversion element comprises a plurality of layers with mutually different wavelength conversion properties.

In accordance with yet a further feature of the invention, the luminescence conversion element includes organic dye molecules in a plastic matrix, such as in a matrix of silicone, thermoplastic material, or thermosetting plastic material. The luminescence conversion element may also have organic dye molecules in an epoxy resin matrix or a polymethyl methacrylate matrix.

In accordance with yet again an added feature of the invention, the luminescence conversion element has at least one inorganic luminescence material selected from the group of phosphors. The inorganic luminescent material is preferably from the group of Ce-doped garnets, such as YAG:Ce.

In accordance with yet again an additional feature of the invention, the inorganic luminescent material is embedded in an epoxy resin matrix. It may also be embedded in a matrix formed of inorganic glass with a relatively low melting point.

Preferably, the inorganic luminescent material has a mean particle size of approximately 10 μm.

In accordance with yet again another feature of the invention, the luminescence conversion element is provided with a plurality of mutually different materials selected from the group consisting of organic and inorganic luminescent materials. The luminescence conversion element may include organic or inorganic dye molecules partly with and partly without a wavelength conversion effect.

In accordance with yet again a further feature of the invention, the luminescence conversion element includes light-diffusing particles. The component may also have a transparent encapsulation with light-diffusing particles.

In accordance with again an added feature of the invention, the luminescence conversion element comprises at least one luminescent 4f-organometallic compound.

A blue output radiation is obtained if, in accordance with the invention, the luminescence conversion element includes a luminescent material that is luminescent in a blue region. The encapsulation may thereby be transparent with a blue luminescent material.

As noted, the luminescence conversion encapsulation or the luminescence conversion layer may be produced from a resist or from a plastic, for example from a silicone, thermoplastic or thermosetting plastic material (epoxy and acrylate resins) used for the encapsulation of optoelectronic components. Furthermore, covering elements fabricated from thermoplastic materials, for example, can be used as the luminescence conversion encapsulation. All the above-mentioned materials can be treated with one or more luminescent materials in a simple manner.

A semiconductor component according to the invention can be realized in a particularly simple manner when the semiconductor body is arranged in a recess in an optionally prefabricated housing and the recess is provided with a covering element having the luminescence conversion layer. A semiconductor component of this type can be produced in large numbers in conventional production lines. For this purpose, all that is necessary, after the mounting of the semiconductor body in the housing, is to apply the covering element, for example a resist or casting resin layer or a prefabricated covering plate made of thermoplastic material, to the housing. Optionally, the recess in the housing may be filled with a transparent material, for example a transparent plastic, which does not alter in particular the wavelength of the light emitted by the semiconductor body or, however, if desired, may already be designed such that it effects luminescence conversion.

In a development of the semiconductor component according to the invention which is particularly preferred on account of the fact that it can be realized in a particularly simple manner, the semiconductor body is arranged in a recess in a housing which is optionally prefabricated and may already be provided with a lead frame and the recess is filled with an at least partially transparent casting resin, to which the luminescent material has already been added prior to the recess being sealed by casting. In this case, the luminescence conversion element is consequently provided by the potting of the semiconductor body that is provided with luminescent material.

A particularly preferred material for the production of the luminescence conversion element is epoxy resin, to which one or more luminescent materials are added. However, it is also possible to use polymethyl methacrylate (PMMA) instead of epoxy resin.

PMMA can be treated with organic dye molecules in a simple manner. Perylene-based dye molecules, for example,

can be used to produce green-, yellow- and red-light-emitting semiconductor components according to the invention. Semiconductor components which emit light in the UV, visible or infrared region can also be produced by admixture of 4f-organometallic compounds. In particular, red-light-emitting semiconductor components according to the invention can be realized for example by admixture of Eu^{3+}-based organometallic chelates ($\lambda \approx 620$ nm). Infrared-radiating semiconductor components according to the invention, in particular having blue-light-emitting semiconductor bodies, can be produced by admixture of 4f-chelates or of Ti^{3+}-doped sapphire.

A white-light-radiating semiconductor component according to the invention can advantageously be produced by choosing the luminescent material such that a blue radiation emitted by the semiconductor body is converted into complementary wavelength ranges, in particular blue and yellow, or to form additive color triads, for example blue, green and red. In this case, the yellow or the green and red light is produced by means of the luminescent materials. The hue (color locus in the CIE chromaticity diagram) of the white light thereby produced can in this case be varied by a suitable choice of the dye/s in respect of mixture and concentration.

Suitable organic luminescent materials for a white-light-radiating semiconductor component according to the invention are perylene luminescent materials, such as, for example, BASF Lumogen F 083 for green luminescence, BASF Lumogen F 240 for yellow luminescence and BASF Lumogen F 300 for red luminescence. These dyes can be added to transparent epoxy resin, for example, in a simple manner.

A preferred method for producing a green-light-emitting semiconductor component using a blue-light-radiating semiconductor body consists in using UO_2^{++}-substituted borosilicate glass for the luminescence conversion element.

In a further preferred development of a semiconductor component according to the invention and of the advantageous embodiments specified above, light-diffusing particles, so-called diffusers, are additionally added to the luminescence conversion element or to another radiation-transmissive component of the component encapsulation. The color perception and the radiation characteristics of the semiconductor component can advantageously be optimized by this means.

In a particularly advantageous embodiment of the semiconductor component according to the invention, the luminescence conversion element is at least partially composed of a transparent epoxy resin provided with an inorganic luminescent material. Specifically, it is advantageous that inorganic luminescent materials can be bound in epoxy resin in a simple manner. A particularly preferred inorganic luminescent material for the production of white-light-emitting semiconductor components according to the invention is the phosphor YAG:Ce ($Y_3Al_5O_{12}:Ce^{3+}$). The latter can be mixed in a particularly simple manner in transparent epoxy resins which are conventionally used in LED technology. Other conceivable luminescent materials are further garnets doped with rare earths, such as, for example, $Y_3Ga_5O_{12}:Ce^{3+}$, $Y(Al,Ga)_5O_{12}:Ce^{3+}$ and $Y(Al,Ga)_5O_{12}:Tb^{3+}$, as well as alkaline earth metal sulfides doped with rare earths, such as, for example, $SrS:Ce^{3+}$, Na, $SrS:Ce^{3+}$, Cl, Srs:$CeCl_3$, $CaS:Ce^{3+}$ and $SrSe:Ce^{3+}$.

Furthermore, the thiogallates doped with rare earths, such as, for example, $CaGa_2S_4:Ce^{3+}$ and $SrGa_2S_4:Ce^{3+}$, are particularly suitable for the purpose of producing differently polychromatic light. The use of aluminates doped with rare earths, such as, for example, $YAlO_3:Ce^{3+}$, $YGaO_3:Ce^{3+}$, $Y(Al,Ga)O_3:Ce^{3+}$, and orthosilicates $M_2SiO_5:Ce^{3+}$ (M:Sc, Y, Sc) doped with rare earths, such as, for example, $Y_2SiO_5:Ce^{3+}$, is likewise conceivable for this purpose. In all of the yttrium compounds, the yttrium can, in principle, also be replaced by scandium or lanthanum.

In a further possible embodiment of the semiconductor component according to the invention, at least all those components of the encapsulation through which light is radiated, that is to say including the luminescence conversion encapsulation or layer, are composed of purely inorganic materials. Consequently, the luminescence conversion element is composed of an inorganic luminescent material which is embedded in a thermally stable, transparent or partially transparent inorganic material. In particular, the luminescence conversion element is composed of an inorganic phosphor, which is embedded in an inorganic glass advantageously of low melting point (for example silicate glass). A preferred procedure for producing a luminescence conversion layer of this type is the sol gel technique, by means of which the entire luminescence conversion layer, hat is to say both the inorganic luminescent material and the embedding material, can be produced in one work operation.

In order to improve the thorough mixing of the radiation of the first wavelength range that is emitted by the semiconductor body with the luminescence-converted radiation of the second wavelength range and hence the color homogeneity of the radiated light, in an advantageous refinement of the semiconductor component according to the invention, a dye which emits light in the blue region is additionally added to the luminescence encapsulation or the luminescence conversion layer and/or to another component of the component encapsulation, which dye attenuates a so-called directional characteristic of the radiation radiated by the semiconductor body. Directional characteristic is to be understood to mean that the radiation emitted by the semiconductor body has a preferred radiation direction.

In a preferred refinement of the semiconductor component according to the invention, the inorganic luminescent material is used in powder form for the above-mentioned purpose of thorough mixing of the emitted radiation, the luminescent material particles not dissolving in the substance (matrix) encapsulating them. In addition, the inorganic luminescent material and the substance encapsulating it have mutually different refractive indices. This advantageously leads to a portion of the light which is not absorbed by the luminescent material being scattered, in a manner dependent on the particle size of the luminescent material. The directional characteristic of the radiation radiated by the semiconductor body is thereby efficiently attenuated, with the result that the unabsorbed radiation and the luminescence-converted radiation are homogeneously mixed, which leads to a spatially homogeneous color perception.

A white-light-radiating semiconductor component according to the invention can particularly preferably be realized by admixing the inorganic luminescent material YAG:Ce ($Y_3Al_5O_{12}:Ce^{3+}$) with an epoxy resin used to produce the luminescence conversion encapsulation or layer. Part of a blue radiation emitted by the semiconductor body is shifted by the inorganic luminescent material $Y_3Al_5O_{12}:Ce^{3+}$ into the yellow spectral region and, consequently, into a wavelength range which is complementarily colored with respect to the color blue. The hue (color locus in the CIE chromaticity diagram) of the white light can in this case be varied by a suitable choice of the dye mixture and concentration.

The inorganic luminescent material YAG:Ce has, inter alia, the particular advantage that insoluble coloring pigments (particle size in the region of 10 nm) having a refractive index of approximately 1.84 are involved in this case. Consequently, not only does the wavelength conversion occur but also a scattering effect which leads to good mixing together of blue diode radiation and yellow converter radiation.

In a further preferred development of a semiconductor component according to the invention and of the advantageous embodiments specified above, light-diffusing particles, so-called diffusers, are additionally added to the luminescence conversion element or to another radiation-transmissive component of the component encapsulation. The color perception and the radiation characteristic of the semiconductor component can advantageously be further improved by this means.

It is particularly advantageous that the luminous efficiency of white-light-emitting semiconductor components according to the invention and their above-mentioned embodiments having a blue-light-emitting semiconductor body produced essentially on the basis of GaN is comparable with the luminous efficiency of an incandescent bulb. The reason for this is that, on the one hand, the external quantum efficiency of such semiconductor bodies is a few percent and, on the other hand, the luminescence efficiency of organic dye molecules is often established at more than 90%. Furthermore, the semiconductor component according to the invention is distinguished by an extremely long life, greater robustness and a smaller operating voltage in comparison with the incandescent bulb.

It is advantageous, moreover, that the luminosity of the semiconductor component according to the invention that is perceptible to the human eye can be distinctly increased by comparison with a semiconductor component which is not equipped with the luminescence conversion element but is otherwise identical, since the sensitivity of the eye increases in the direction of a higher wavelength.

Furthermore, the principle according to the invention can advantageously be used also to convert an ultraviolet radiation which is emitted by the semiconductor body in addition to the visible radiation into visible light. The luminosity of the light emitted by the semiconductor body is thereby distinctly increased.

The concept, presented here, of luminescence conversion with blue light from a semiconductor body can advantageously be extended to multistage luminescence conversion elements as well, in accordance with the scheme ultraviolet→blue→green→yellow→red. In this case, a plurality of spectrally selectively emitting luminescence conversion elements are arranged one after the other relative to the semiconductor body.

Likewise, it is advantageously possible for a plurality of differently spectrally selectively emitting dye molecules to be jointly embedded in a transparent plastic of a luminescence conversion element. A very broad color spectrum can be produced by this means.

A particular advantage of white-light-radiating semiconductor components according to the invention in which YAG:Ce, in particular, is used as the luminescence conversion dye consists in the fact that this luminescent material, upon excitation by blue light, effects a spectral shift of approximately 100 nm between absorption and emission. This leads to a significant reduction in the reabsorption of the light emitted by the luminescent material and hence to a higher luminous efficiency. In addition, YAG:Ce advantageously has high thermal and photochemical (for example UV) stability (significantly higher than organic luminescent materials), with the result that it is even possible to produce white-light-emitting diodes for outdoor use and/or high temperature ranges.

YAG:Ce has, to date, proved to be the best-suited luminescent material in respect of reabsorption, luminous efficiency, thermal and photochemical stability and processability. However, the use of other Ce-doped phosphors is also conceivable, in particular of Ce-doped garnets.

In a particularly advantageous manner, semiconductor components according to the invention can be used, in particular on account of their low power consumption, in full-color LED displays for the lighting of motor vehicle interiors or of aircraft cabins as well as for the illumination of display devices such as motor vehicle dashboards or liquid crystal displays.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a light-radiating semiconductor component having a luminescence conversion element, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic sectional side view of a first exemplary embodiment of a semiconductor component according to the invention;

FIG. **2** is a diagrammatic sectional side view of a second exemplary embodiment of the semiconductor component according to the invention;

FIG. **3** is a diagrammatic sectional side view of a third exemplary embodiment of the semiconductor component according to the invention;

FIG. **4** is a diagrammatic sectional side view of a fourth exemplary embodiment of the semiconductor component according to the invention;

FIG. **5** is a diagrammatic sectional side view of a fifth exemplary embodiment of the semiconductor component according to the invention;

FIG. **6** is a diagrammatic sectional side view of a sixth exemplary embodiment of the semiconductor component according to the invention;

FIG. **7** is a graph of an emission spectrum of a blue-light-radiating semiconductor body with a layer sequence based on GaN;

FIG. **8** is a graph of the emission spectra of two semiconductor components according to the invention which radiate white light;

FIG. **9** is a diagrammatic sectional view taken through a semiconductor body which emits blue light;

FIG. **10** is a diagrammatic sectional side view of a seventh exemplary embodiment of the semiconductor component according to the invention;

FIG. **11** is a graph of an emission spectrum of a semiconductor component according to the invention which radiates polychromatic red light;

FIG. **12** is a graph of the emission spectra of further semiconductor components according to the invention which radiate white light;

FIG. **13** is a diagrammatic sectional side view of an eighth exemplary embodiment of the semiconductor component according to the invention; and

FIG. **14** is a diagrammatic sectional side view of a ninth exemplary embodiment of the semiconductor component according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be had to the figures of the drawing in detail, in which identical or functionally identical parts are designated by the same reference symbols throughout, and first, particularly, to FIG. **1** thereof.

The light-emitting semiconductor component illustrated in FIG. **1**, a semiconductor body **1** has a back-side contact **11**, a front-side contact **12** and a layer sequence **7**, which is composed of a number of different layers and has at least one active zone which emits a radiation (for example ultraviolet, blue or green) during the operation of the semiconductor component.

An example of a suitable layer sequence **7** for this and for all of the exemplary embodiments described below is shown in FIG. **9**. There, a layer sequence made of an AlN or GaN layer **19**, an n-conducting GaN layer **20**, an n-conducting $Ga_xAl_{1-x}N$ or $Ga_xIn_{1-x}N$ layer **21**, a further n-conducting GaN or a $Ga_xIn_{1-x}N$ layer **22**, a p-conducting $Ga_xAl_{1-x}N$ layer or $Ga_xIn_{1-x}N$ layer **23** and a p-conducting GaN layer **24** is applied on a substrate **18** composed of SiC, for example. A respective contact metallization layer **27**, **28** is applied on a main surface **25** of the p-conducting GaN layer **24** and a main surface **26** of the substrate **18**, said contact metallization layer being composed of a material which is conventionally used for electrical contacts in opto-semiconductor technology.

However, it is also possible to use any other semiconductor body deemed to be suitable by those skilled in this art for the semiconductor component according to the invention. This likewise applies to all of the exemplary embodiments described below.

In the exemplary embodiment of FIG. **1**, the semiconductor body **1** is fixed by its back-side contact **11** on a first electrical terminal **2** by means of an electrically conductive bonding agent, for example a metallic solder of an adhesive. The front-side contact **12** is connected to a second electrical terminal **3** by means of a bonding wire **14**.

The free surfaces of the semiconductor body **1** and partial regions of the electrical terminals **2** and **3** are directly enclosed by a luminescence conversion encapsulation **5**. The latter is preferably composed of a transparent plastic (preferably epoxy resin or else polymethyl methacrylate) which can be used for transparent light-emitting diode encapsulations and is treated with luminescent material **6**, preferably inorganic luminescent material, for white-light-emitting components, preferably $Y_3Al_5O_{12}:Ce^{3+}$ (YAG:Ce).

The exemplary embodiment of a semiconductor component according to the invention which is illustrated in FIG. **2** differs from that of FIG. **1** by the fact that the semiconductor body **1** and partial regions of the electrical terminals **2** and **3** are enclosed by a transparent encapsulation **15** instead of by a luminescence conversion encapsulation. This transparent encapsulation **15** does not effect any wavelength change in the radiation emitted by the semiconductor body **1** and is composed, for example, of an epoxy, silicone or acrylate resin which is conventionally used in light-emitting diode technology, or of another suitable radiation-transmissive material, such as inorganic glass, for example.

A luminescence conversion layer **4** is applied to the transparent encapsulation **15** and, as illustrated in FIG. **2**, covers the entire surface of the encapsulation **15**. It is likewise conceivable for the luminescence conversion layer **4** to cover only a partial region of this surface. The luminescence conversion layer **4** is composed, for example, once again of a transparent plastic (for example epoxy resin, resist or polymethyl methacrylate) which is treated with a luminescent material **6**. In this case, too, YAG:Ce is preferably suitable as luminescent material for a white-light-emitting semiconductor component.

This exemplary embodiment has the particular advantage that the path length through the luminescence conversion element is approximately the same size for all of the radiation emitted by the semiconductor body. This is important particularly when, as is often the case, the exact hue of the light radiated by the semiconductor component depends on this path length.

For improved output coupling of the light from the luminescence conversion layer **4** of FIG. **2**, a covering **29** (depicted by a broken line) in the form of a lens can be provided on a side surface of the component, which covering reduces total reflection of the radiation within the luminescence conversion layer **4**. This covering **29** in the form of a lens may be composed of transparent plastic or glass and be bonded, for example, onto the luminescence conversion layer **4** or be designed directly as the component part of the luminescence conversion layer **4**.

In the exemplary embodiment illustrated in FIG. **3**, the first and second electrical terminals **2**, **3** are embedded in an opaque, possibly prefabricated base housing **8** having a recess **9**. "Prefabricated" is to be understood to mean that the base housing **8** is already preconstructed on the connections **2**, **3**, for example by means of injection molding, before the semiconductor body is mounted on to the connection **2**. The base housing **8** is composed for example of an opaque plastic and the recess **9** is designed, in respect of its shape, as a reflector **17** for the radiation emitted by the semiconductor body during operation (if appropriate by suitable coating of the inner walls of the recess **9**). Such base housings **8** are used in particular in the case of light-emitting diodes which can be surface-mounted on printed circuit boards. They are applied to a lead frame having the electrical terminals **2**, **3**, for example by means of injection molding, prior to the mounting of the semiconductor bodies.

The recess **9** is covered by a luminescence conversion layer **4**, for example a separately produced covering plate **17** made of plastic which is fixed on the base housing **8**. Suitable materials for the luminescence conversion layer **4** are once again, as mentioned further above in the general part of the description, the plastics or inorganic glass in conjunction with the luminescent materials mentioned there. The recess **9** may either be filled with a transparent plastic, with an inorganic glass or with gas or else be provided with a vacuum.

As in the case of the exemplary embodiment according to FIG. **2**, a covering **29** (depicted by a broken line) in the form of a lens can be provided on the luminescence conversion layer **4** in this case as well, for improved output coupling of the light from said luminescence conversion layer, which covering reduces total reflection of the radiation within the luminescence conversion layer **4**. This covering **29** may be

composed of transparent plastic and be bonded, for example, onto the luminescence conversion layer **4** or be designed integrally together with the luminescence conversion layer **4**.

In a particularly preferred embodiment, the recess **9** is filled, as shown in FIG. **10**, with an epoxy resin provided with luminescent material, that is to say with a luminescence encapsulation **5** which forms the luminescence conversion element. A covering plate **17** and/or a covering **29** in the form of a lens can then be omitted as well. Furthermore, as illustrated in FIG. **13**, the first electrical terminal **2** is optionally designed as a reflector well **34** for example by embossing in the region of the semiconductor body **1**, which reflector well is filled with a luminescence conversion encapsulation **5**.

In FIG. **4**, a so-called radial diode is illustrated as a further exemplary embodiment. In this case, the semiconductor body **1** is fixed in a part **16**, designed as a reflector, of the first electrical terminal **2** by means of soldering or bonding, for example. Such housing designs are known in light-emitting diode technology and, therefore, need not be explained in any further detail.

In the exemplary embodiment of FIG. **4**, the semiconductor body **1** is surrounded by a transparent encapsulation **15** which, as in the case of the second exemplary embodiment mentioned (FIG. **2**), does not effect any wavelength change in the radiation emitted by the semiconductor body **1** and may be composed, for example, of a transparent epoxy resin which is conventionally used in light-emitting diode technology or of organic glass.

A luminescence conversion layer **4** is applied on this transparent encapsulation **15**. Suitable materials for this are, for example, once again, as referred to in connection with the above-mentioned exemplary embodiments, the plastics or inorganic glass in conjunction with the dyes mentioned there.

The entire structure, comprising semiconductor body **1**, partial regions of the electrical terminals **2**, **3**, transparent encapsulation **15** and luminescence conversion layer **4**, is directly enclosed by a further transparent encapsulation **10**, which does not effect any wavelength change in the radiation which has passed through the luminescence conversion layer **4**. It is composed, for example, once again of a transparent epoxy resin which is conventionally used in light-emitting diode technology or of inorganic glass.

The exemplary embodiment shown in FIG. **5** differs from that of FIG. **4** essentially by the fact that the free surfaces of the semiconductor body **1** are directly covered by a luminescence conversion encapsulation **5**, which is again surrounded by a further transparent encapsulation **10**. FIG. **5** illustrates, moreover, by way of example, a semiconductor body **1** in which, instead of the underside contacts, a further contact is provided on the semiconductor layer sequence **7**, which further contact is connected to the associated electrical terminal **2** or **3** by means of a second bonding wire **14**. It goes without saying that such semiconductor bodies **1** can also be used in all the other exemplary embodiments described herein. Conversely, of course, a semiconductor body **1** in accordance with the above-mentioned exemplary embodiments can also be used in the exemplary embodiment of FIG. **5**.

For the sake of completeness, let it be noted at this point that an integral luminescence conversion encapsulation **5**, which then replaces the combination of luminescence conversion encapsulation **5** and further transparent encapsulation **10**, can, of course, also be used in the design according to FIG. **5** in an analogous manner to the exemplary embodiment according to FIG. **1**.

In the case of the exemplary embodiment of FIG. **6**, a luminescence conversion layer **4** (possible materials as specified above) is applied directly to the semiconductor body **1**. The latter and partial regions of the electrical terminals **2**, **3** are enclosed by a further transparent encapsulation **10**, which does not effect any wavelength change in the radiation which has passed through the luminescence conversion layer **4**, and is fabricated for example from a transparent epoxy resin which can be used in light-emitting diode technology or from glass.

Such semiconductor bodies **1** provided with a luminescence conversion layer **4** and not having an encapsulation can, of course, advantageously be used in all housing designs known from light-emitting diode technology (for example SMD housings, radial housings (cf. FIG. **5**)).

In the case of the exemplary embodiment of a semiconductor component according to the invention which is illustrated in FIG. **14**, a transparent well part **35** is arranged on the semiconductor body **1** and has a well **36** above the semiconductor body **1**. The well part **35** is composed for example of transparent epoxy resin or of inorganic glass and is fabricated for example by means of injection-molding encapsulation of the electrical terminals **2**, **3** including semiconductor body **1**. Arranged in this well **36** is a luminescence conversion layer **4**, which, for example, is once again fabricated from epoxy resin or inorganic glass in which are bound particles **37**, composed of one of the above-mentioned inorganic luminescent materials. In the case of this design, it is advantageously ensured in a very simple manner that the luminescent material accumulates at unintended locations, for example next to the semiconductor body, during the production of the semiconductor component. Of course, the well part **35** can also be produced separately and be fixed in a different way, for example on a housing part, above the semiconductor body **1**.

In all of the exemplary embodiments described above, it is possible, in order to optimize the color perception of the radiated light and also in order to adapt the radiation characteristic, for the luminescence conversion element (luminescence conversion encapsulation **5** or luminescence conversion layer **4**), if appropriate the transparent encapsulation **15**, and/or if appropriate the further transparent encapsulation **10** to have light-diffusing particles, advantageously so-called diffusers. Examples of such diffusers are mineral fillers, in particular CaF_2, TiO_2, SiO_2, $CaCO_3$ or $BaSO_4$ or else organic pigments. These materials can be added in a simple manner to the above-mentioned plastics.

FIGS. **7**, **8** and **12** respectively show emission spectra of a blue-light-radiating semiconductor body (FIG. **7**) (luminescence maximum at λ=430 nm) and of white-light-emitting semiconductor components according to the invention which are produced by means of such a semiconductor body (FIGS. **8** and **12**). The wavelength l in nm is plotted in each case on the abscissa and a relative electroluminescence (EL) intensity is in each case plotted on the ordinate.

Only part of the radiation emitted by the semiconductor body according to FIG. **7** is converted into a wavelength range of longer wavelength, with the result that white light is produced as mixed color. The dashed line **30** in FIG. **8** represents an emission spectrum of a semiconductor component according to the invention which emits radiation from two complementary wavelength ranges (blue and yellow) and hence white light overall. In this case, the emission spectrum has a respective maximum at wave-

lengths of between approximately 400 and approximately 430 nm (blue) and of between approximately 550 and approximately 580 nm (yellow). The solid line **31** represents the emission spectrum of a semiconductor component according to the invention which mixes the color white from three wavelength ranges (additive color triad formed from blue, green and red). In this case, the emission spectrum has a respective maximum for example at the wavelengths of approximately 430 nm (blue), approximately 500 nm (green) and approximately 615 nm (red).

Furthermore, FIG. **11** illustrates an emission spectrum of a semiconductor component according to the invention which radiates polychromatic light comprising blue light (maximum at a wavelength of approximately 470 nm) and red light (maximum at a wavelength of approximately 620 nm). The overall color perception of the radiated light for the human eye is magenta. The emission spectrum radiated by the semiconductor body in this case corresponds once again to that of FIG. **7**.

FIG. **12** shows a white-light-emitting semiconductor component according to the invention which is provided with a semiconductor body emitting an emission spectrum in accordance with FIG. **7** and in which YAG:Ce is used as the luminescence material. Only part of the radiation emitted by the semiconductor body in accordance with FIG. **7** is converted into a wavelength range of longer wavelength, with the result that white light is produced as the mixed color. The differently dashed lines **30** to **33** of FIG. **12** represent emission spectra of semiconductor components according to the invention in which the luminescence conversion element, in this case a luminescence conversion encapsulation made of epoxy resin, has different YAG:Ce concentrations. Each emission spectrum has a respective intensity maximum between λ=420 nm and λ=430 nm, that is to say in the blue spectral region and between λ=520 nm and λ=545 nm, that is to say in the green spectral region, the emission bands having the longer-wavelength intensity maximum largely lying in the yellow spectral region. The diagram of FIG. **12** makes it clear that in the semiconductor component according to the invention, the CIE color locus of the white light can be altered in a simple manner by alteration of the luminescent material concentration in the epoxy resin.

Furthermore, it is possible to apply inorganic luminescent materials based on Ce-doped garnets, thiogallates, alkaline earth metal sulfides and aluminates directly to the semiconductor body, without dispersing them in epoxy resin or glass.

A further particular advantage of the above-mentioned inorganic luminescent materials results from the fact that, unlike in the case of organic dyes, the luminescent material concentration e.g. in the epoxy resin is not limited by the solubility. As a result, large thicknesses of luminescence conversion elements are not necessary.

The explanation of the semiconductor component according to the invention using the exemplary embodiments described above ought not, of course, to be regarded as a restriction of the invention thereto. For example, a polymer LED emitting a corresponding radiation spectrum may also be understood as semiconductor body, such as, for example, light-emitting diode chips or laser diode chips.

We claim:

1. A light-radiating semiconductor component, comprising:

a semiconductor body emitting electromagnetic radiation during an operation of the semiconductor component, said semiconductor body having a semiconductor layer sequence suitable for emitting electromagnetic radiation of a first wavelength range selected from a spectral region consisting of ultraviolet, blue, and green;

a first electrical terminal and a second electrical terminal each electrically conductively connected to said semiconductor body;

a luminescence conversion element with at least one luminescent material, said luminescence conversion element being deposited on said semiconductor body, said luminescence conversion element converting a radiation originating in the first wavelength range into radiation of a second wavelength range different from the first wavelength range, such that the semiconductor component emits polychromatic visible light comprising radiation of the first wavelength range and radiation of the second wavelength range; and

said luminescence conversion element being formed such that the radiation of the first wavelength range passes through said luminescence conversion element along a plurality of paths, the plurality of paths having a substantially equal path length inside said luminescence conversion element, and said luminescence conversion element emitting a substantial portion of the radiation of the first wavelength range and the radiation of the second wavelength range,

wherein said luminescence conversion element comprises a plurality of layers with mutually different wavelength conversion properties.

2. A light-radiating semiconductor component, comprising:

a semiconductor body emitting electromagnetic radiation during an operation of the semiconductor component, said semiconductor body having a semiconductor layer sequence suitable for emitting electromagnetic radiation of a first wavelength range selected from a spectral region consisting of ultraviolet, blue, and green;

a first electrical terminal and a second electrical terminal each electrically conductively connected to said semiconductor body;

a luminescence conversion element with at least one luminescent material, said luminescence conversion element being deposited on said semiconductor body, said luminescence conversion element converting a radiation originating in the first wavelength range into radiation of a second wavelength range different from the first wavelength range, such that the semiconductor component emits polychromatic visible light comprising radiation of the first wavelength range and radiation of the second wavelength range; and

said luminescence conversion element being formed such that the radiation of the first wavelength range passes through said luminescence conversion element along a plurality of paths, the plurality of paths having a substantially equal path length inside said luminescence conversion element, and said luminescence conversion element emitting a substantial portion of the radiation of the first wavelength range and the radiation of the second wavelength range,

wherein said luminescence conversion element includes light-diffusing particles.

3. A light-radiating semiconductor component, comprising:

a semiconductor body emitting electromagnetic radiation during an operation of the semiconductor component, said semiconductor body having a semiconductor layer

sequence suitable for emitting electromagnetic radiation of a first wavelength range selected from a spectral region consisting of ultraviolet, blue, and green;

a first electrical terminal and a second electrical terminal each electrically conductively connected to said semiconductor body;

a luminescence conversion element with at least one luminescent material, said luminescence conversion element being deposited on said semiconductor body, said luminescence conversion element converting a radiation originating in the first wavelength range into radiation of a second wavelength range different from the first wavelength range, such that the semiconductor component emits polychromatic visible light comprising radiation of the first wavelength range and radiation of the second wavelength range; and

said luminescence conversion element being formed such that the radiation of the first wavelength range passes through said luminescence conversion element along a plurality of paths, the plurality of paths having a substantially equal path length inside said luminescence conversion element, and said luminescence conversion element emitting a substantial portion of the radiation of the first wavelength range and the radiation of the second wavelength range,

which comprises a transparent encapsulation with light-diffusing particles.

4. A light-radiating semiconductor component, comprising:

a semiconductor body emitting electromagnetic radiation during an operation of the semiconductor component, said semiconductor body having a semiconductor layer sequence suitable for emitting electromagnetic radiation of a first wavelength range selected from a spectral region consisting of ultraviolet, blue, and green;

a first electrical terminal and a second electrical terminal each electrically conductively connected to said semiconductor body;

a luminescence conversion element with at least one luminescent material, said luminescence conversion element being deposited on said semiconductor body, said luminescence conversion element converting a radiation originating in the first wavelength range into radiation of a second wavelength range different from the first wavelength range, such that the semiconductor component emits polychromatic visible light comprising radiation of the first wavelength range and radiation of the second wavelength range; and

said luminescence conversion element being formed such that the radiation of the first wavelength range passes through said luminescence conversion element along a plurality of paths, the plurality of paths having a substantially equal path length inside said luminescence conversion element, and said luminescence conversion element emitting a substantial portion of the radiation of the first wavelength range and the radiation of the second wavelength range,

wherein said luminescence conversion element is directly deposited on said semiconductor body.

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