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(54) **SEMICONDUCTOR LIGHT-EMITTING DEVICE**

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(73) Assignee: **PANASONIC CORPORATION**, Osaka (JP)

(21) Appl. No.: **13/025,758**

(22) Filed: **Feb. 11, 2011**

Related U.S. Application Data

(63) Continuation of application No. 11/995,924, filed on Jan. 16, 2008, now Pat. No. 7,910,940, filed as application No. PCT/JP2006/314844 on Jul. 27, 2006.

(30) **Foreign Application Priority Data**

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Publication Classification

(51) **Int. Cl.**
H01L 33/60 (2010.01)

(52) **U.S. Cl.** **257/98**; 257/E33.072; 257/E33.059

(57) **ABSTRACT**

A semiconductor light-emitting device **10** has a semiconductor chip **12** for emitting light having a wavelength in blue to ultraviolet regions, and a sealing portion **16** formed in at least a partial region on a passage path on which the light is passed. The sealing portion **16** includes a sealing material **16***d* which is a composite material including a matrix material **16***a* made of a resin, nano-particles **16***b* made of an inorganic material which are distributed in the matrix material **16***a*, the nano-particle **16***b* having an effective particle size which is ¼ or less of the wavelength of the light in the matrix material **16***a*, and a fluorescent material **16***c*.

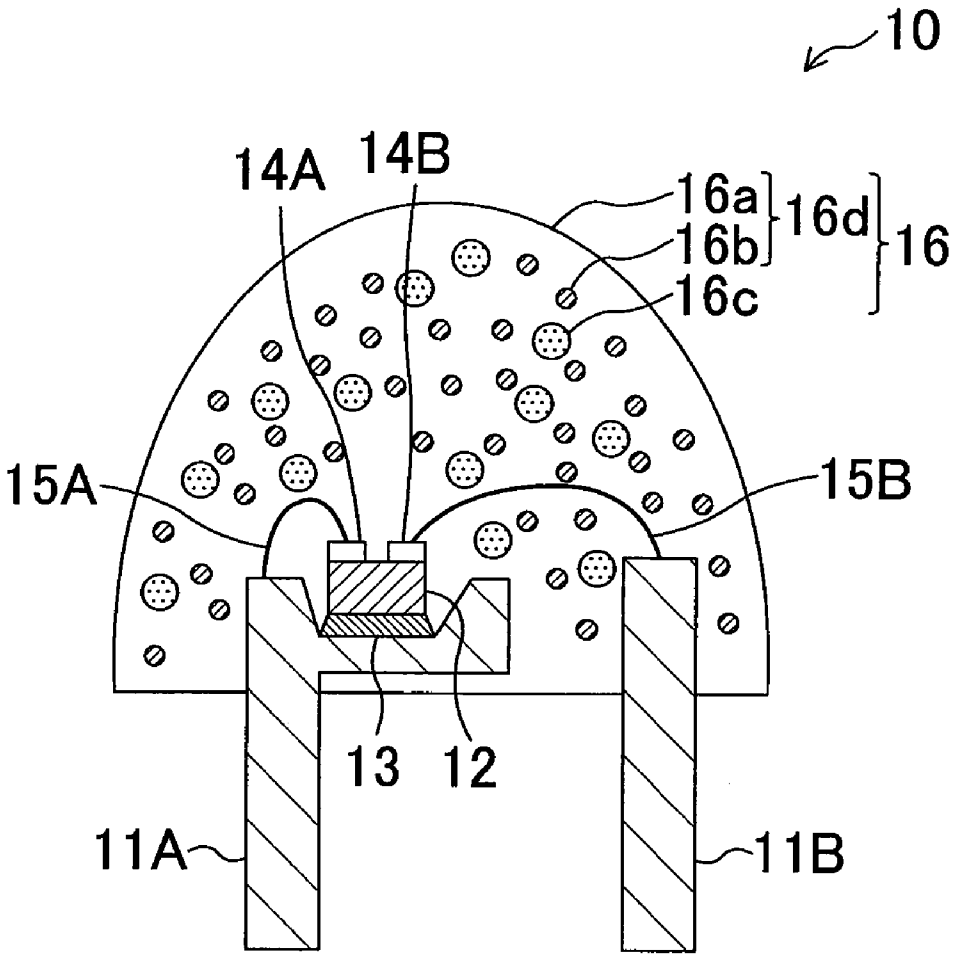


FIG. 1

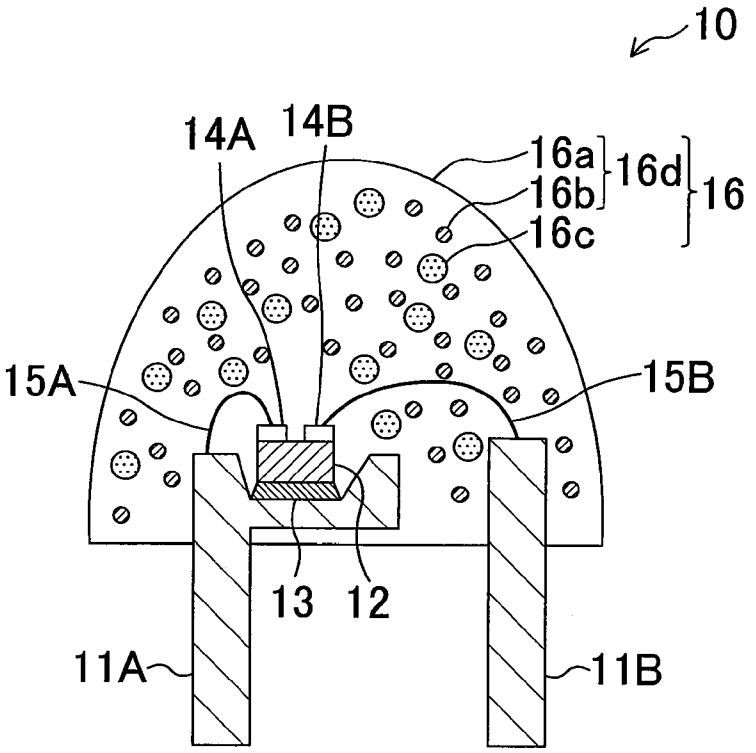

10
14A
14B
16a
16b
16d
16
16c
15A
15B
13
12
11A
11B

FIG. 2

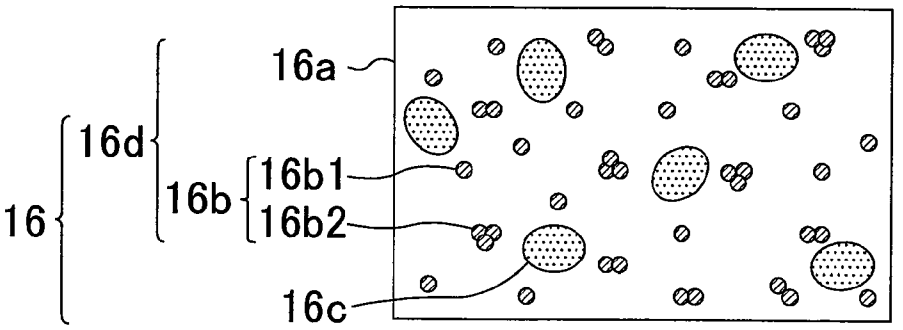

16a
16d
16b
16b1
16b2
16
16c

FIG. 3

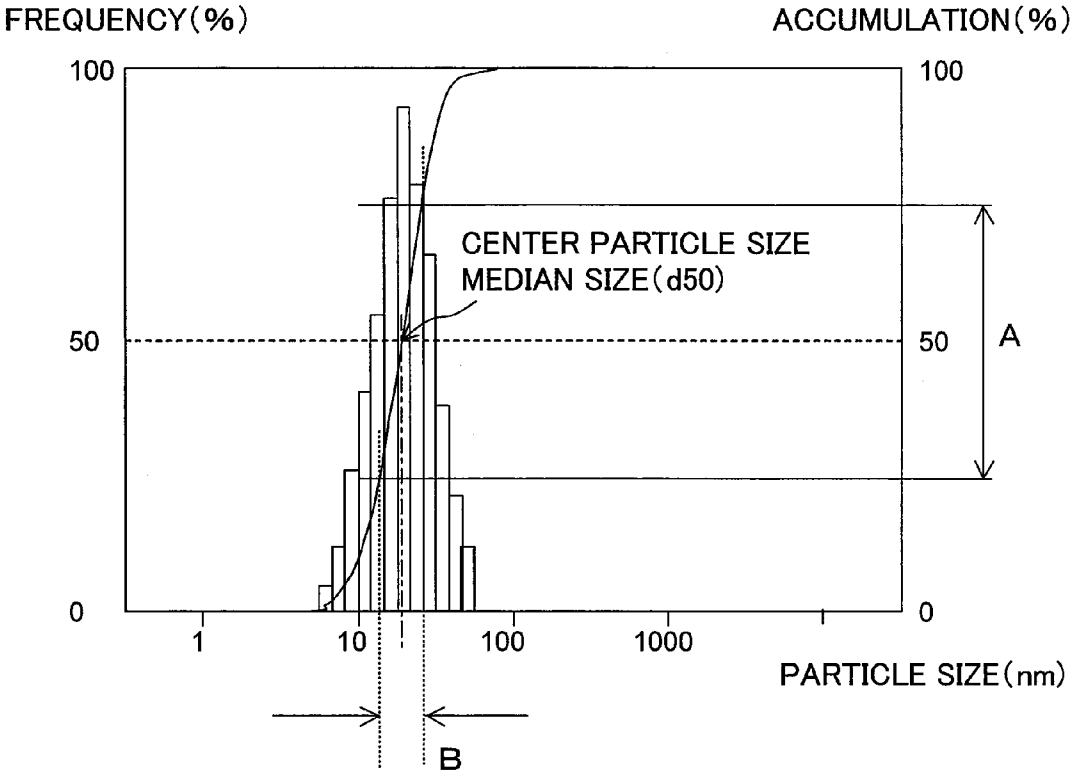

FREQUENCY(%)
ACCUMULATION(%)
100
50
0
100
50
0
CENTER PARTICLE SIZE
MEDIAN SIZE(d50)
A
B
1
10
100
1000
PARTICLE SIZE(nm)

FIG. 4

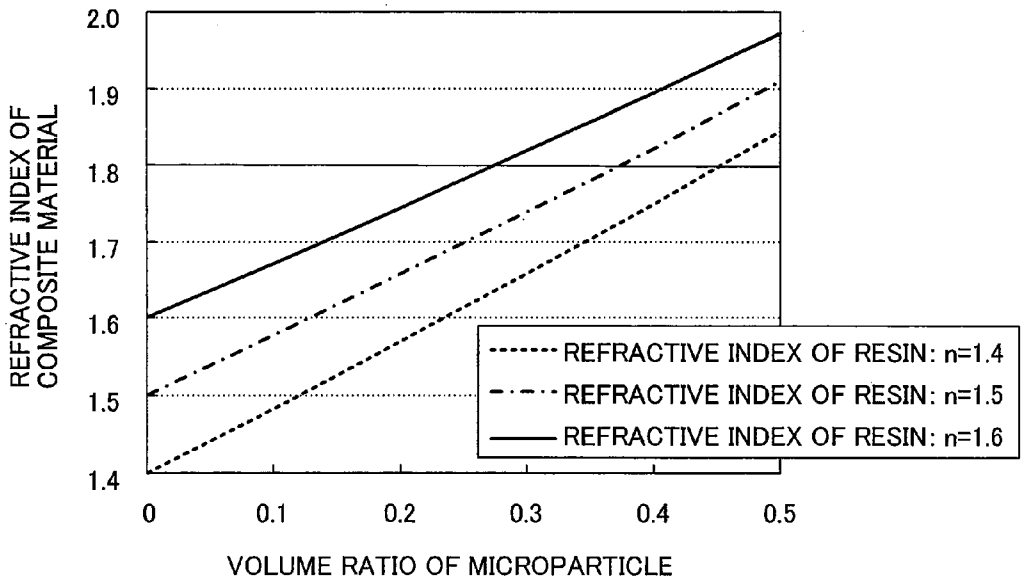

REFRACTIVE INDEX OF COMPOSITE MATERIAL
2.0
1.9
1.8
1.7
1.6
1.5
1.4
0
0.1
0.2
0.3
0.4
0.5
VOLUME RATIO OF MICROPARTICLE
REFRACTIVE INDEX OF RESIN: n=1.4
REFRACTIVE INDEX OF RESIN: n=1.5
REFRACTIVE INDEX OF RESIN: n=1.6

FIG. 5

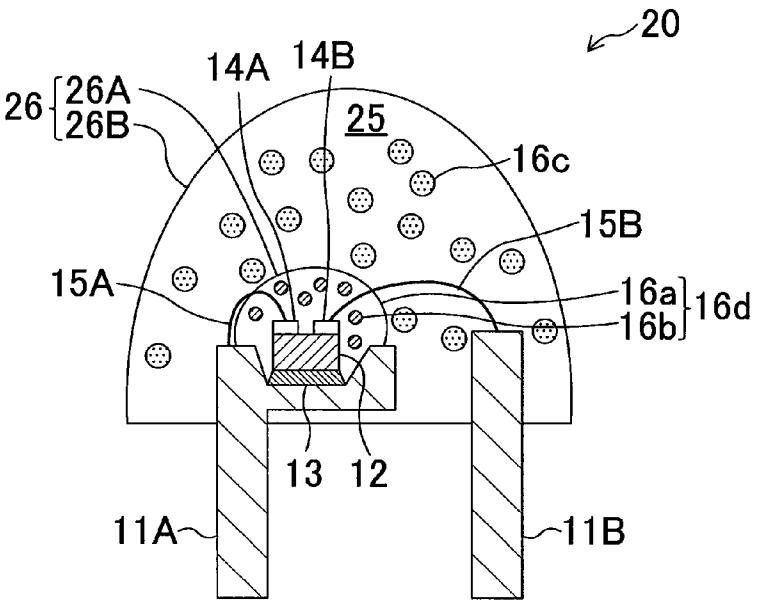

20
14A
14B
26
26A
26B
25
16c
15B
15A
16a
16b
16d
13
12
11A
11B

FIG. 6

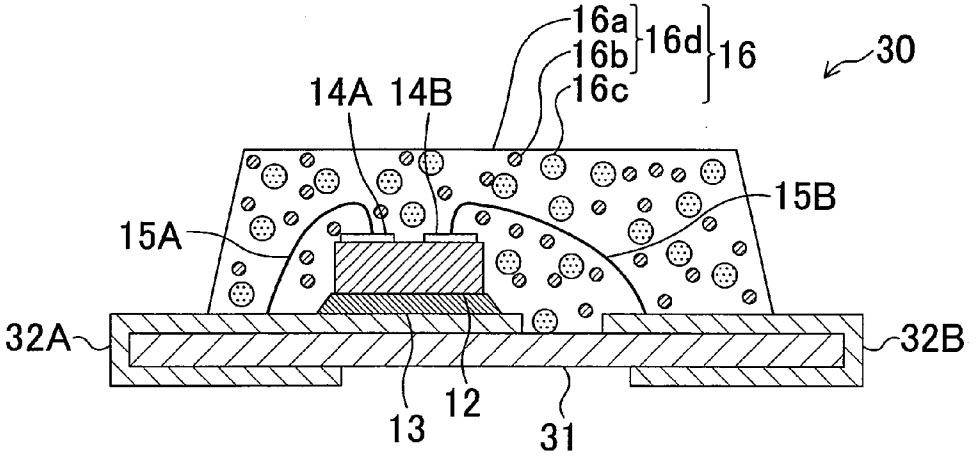

16a
16b
16d
16
30
14A
14B
16c
15B
15A
32A
32B
13
12
31

FIG. 7

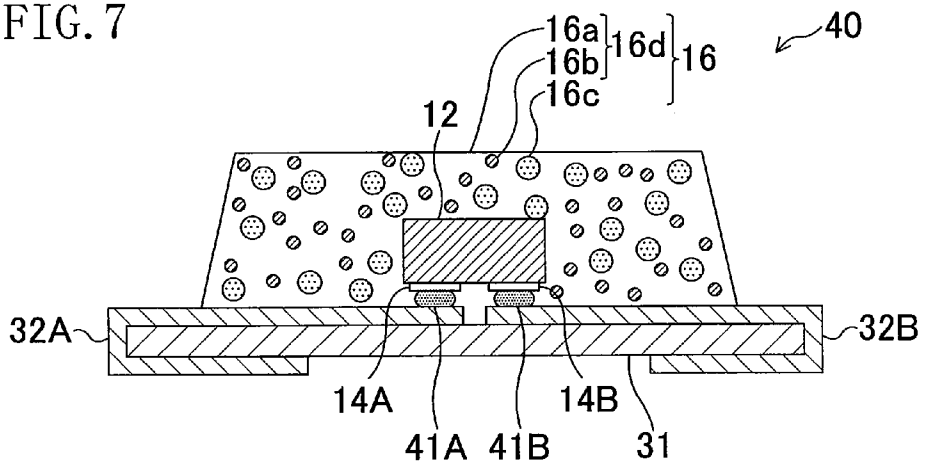

16a
16b
16c
16d
16
40
12
32A
32B
14A
14B
41A
41B
31

FIG. 8

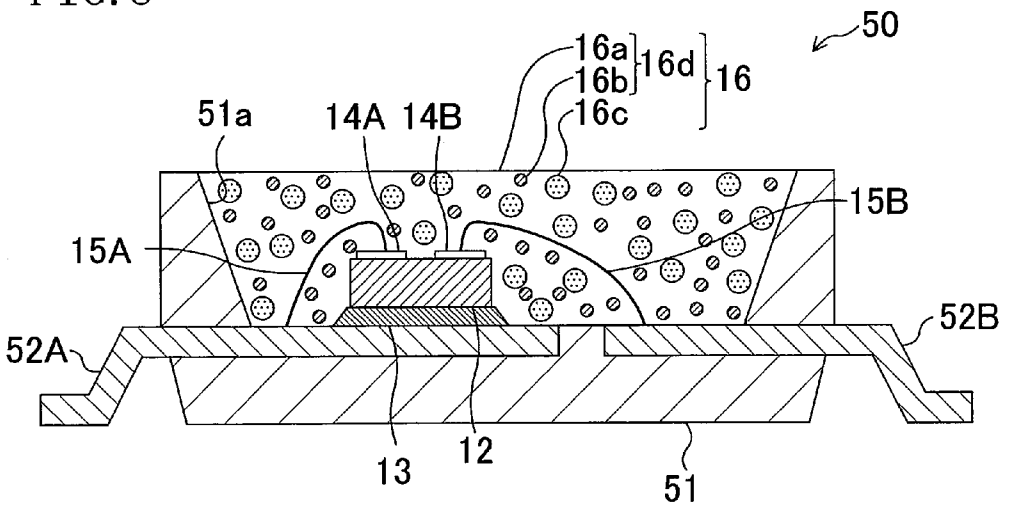
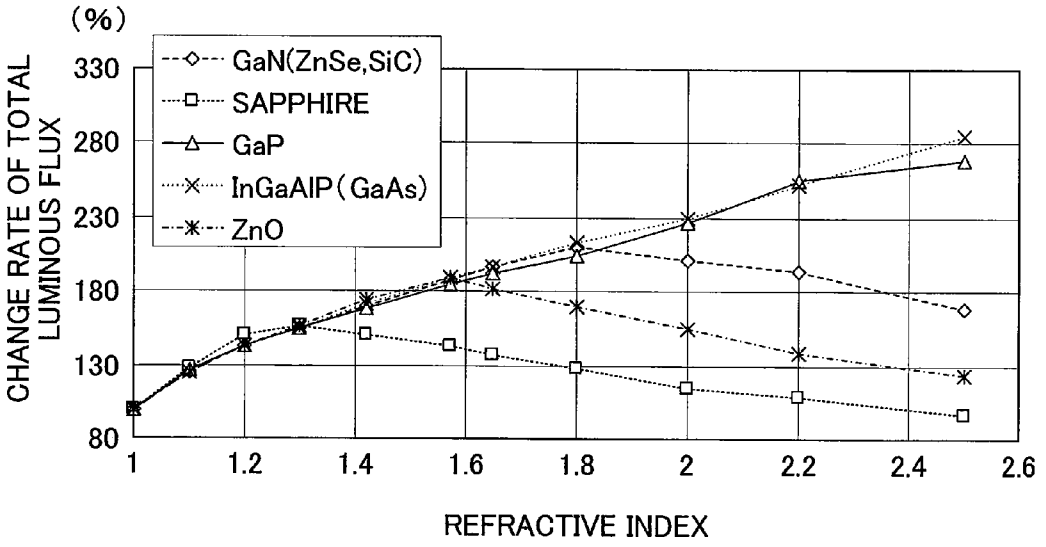

50
16a
16b
16c
16d
16
51a
14A
14B
15A
15B
52A
52B
13
12
51

FIG. 9

(a)


(%)
CHANGE RATE OF TOTAL LUMINOUS FLUX
330
280
230
180
130
80
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
REFRACTIVE INDEX
GaN(ZnSe,SiC)
SAPPHIRE
GaP
InGaAlP(GaAs)
ZnO

(b)

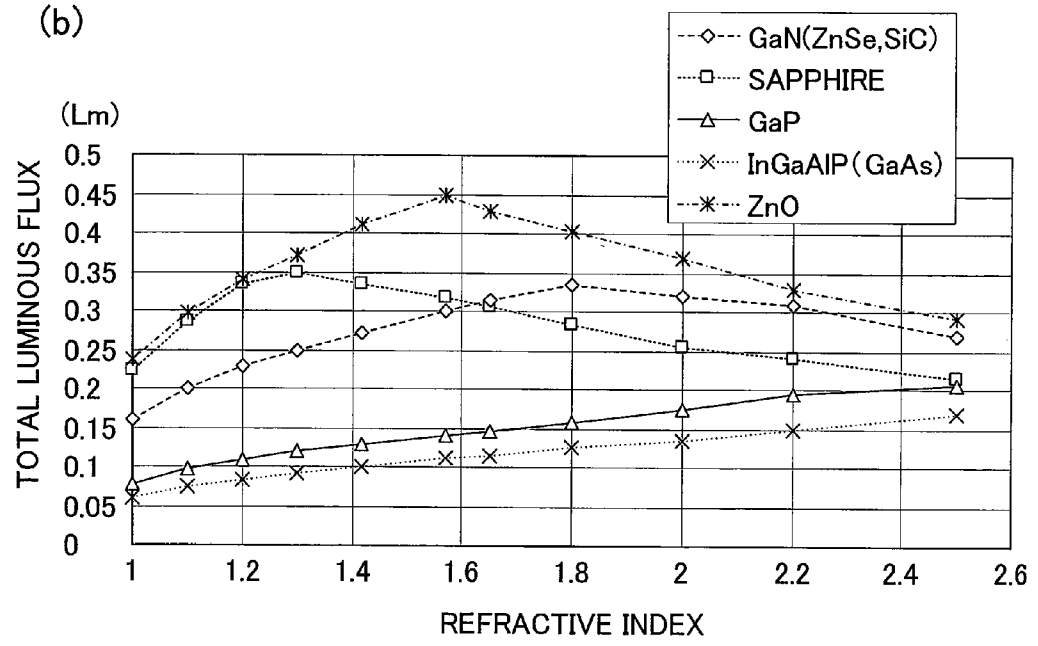

(Lm)
TOTAL LUMINOUS FLUX
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
REFRACTIVE INDEX
GaN(ZnSe,SiC)
SAPPHIRE
GaP
InGaAlP(GaAs)
ZnO

FIG. 10

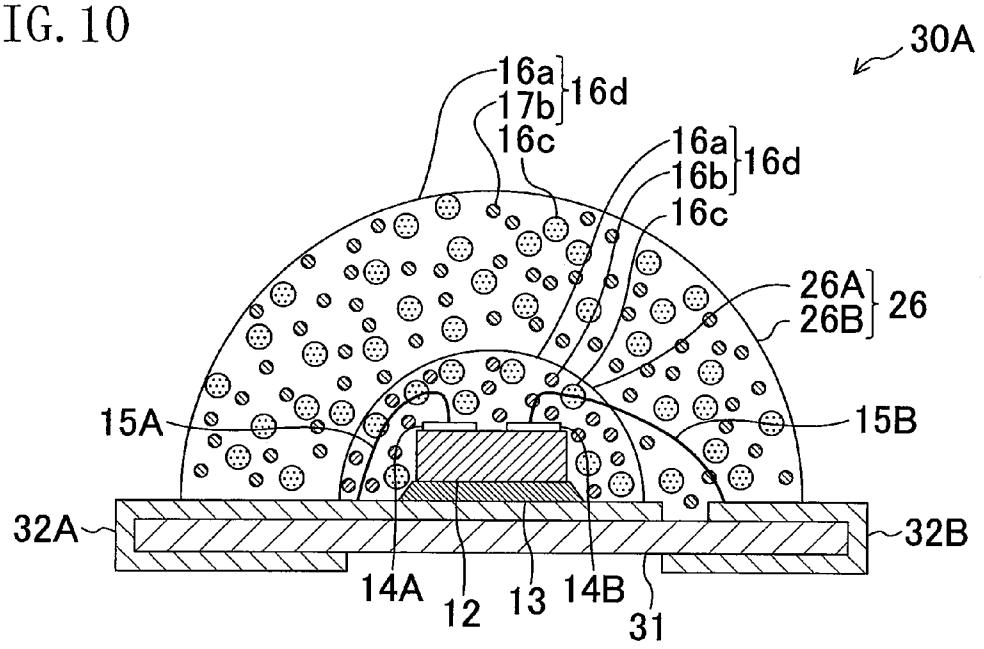

30A
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 11

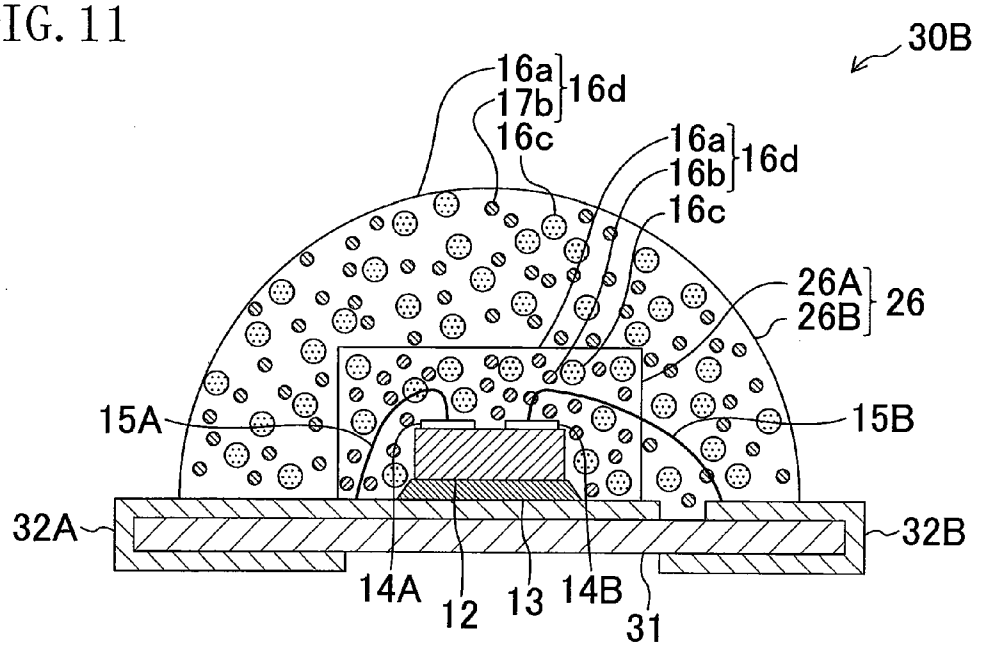

30B
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 12

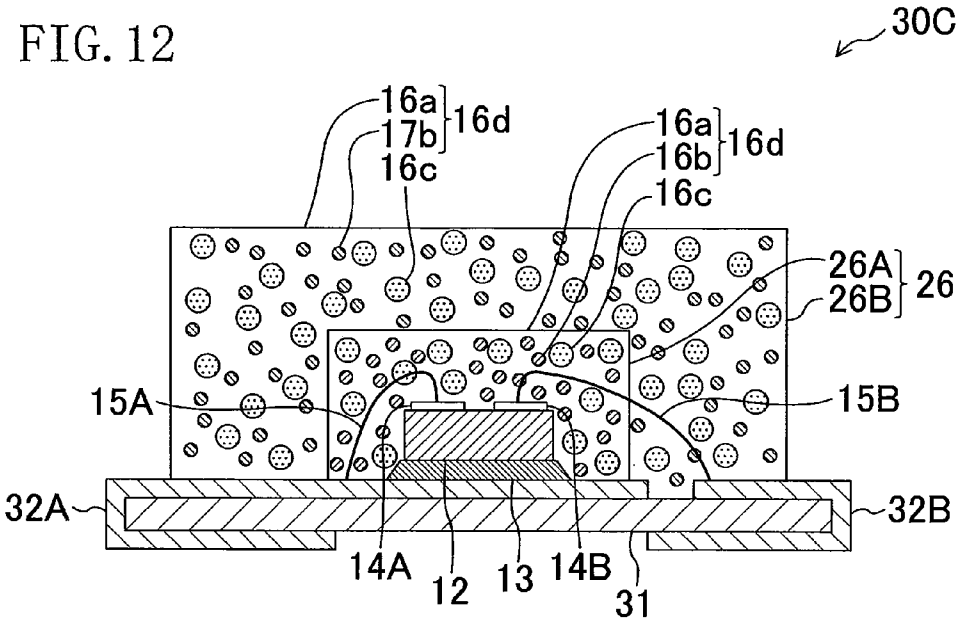

30C
16a
17b
16c
16d
16a
16b
16c
16d
26A
26B
26
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 13

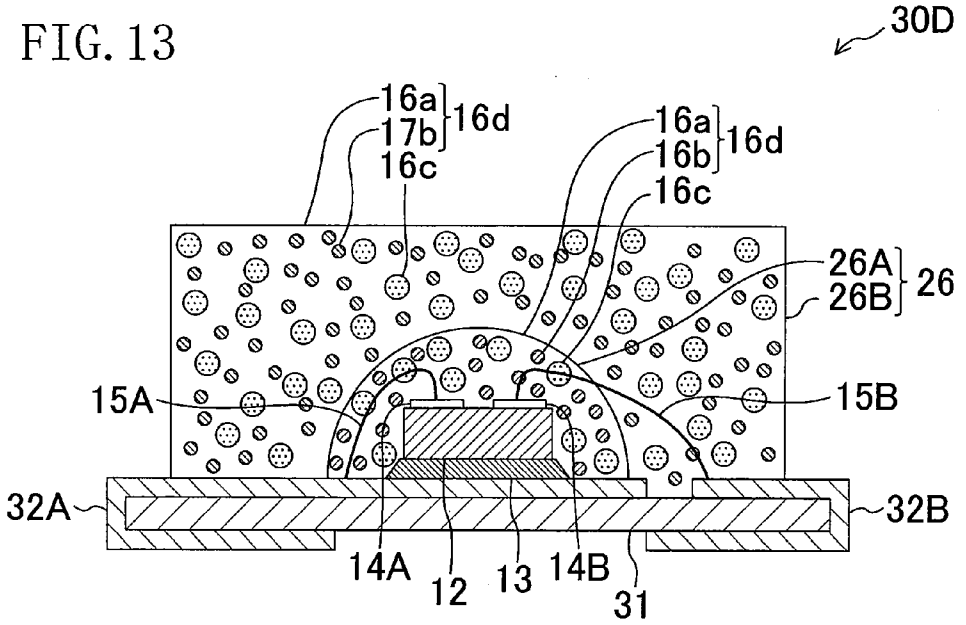

30D
16a
17b
16c
16d
16a
16b
16c
16d
26A
26B
26
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 14

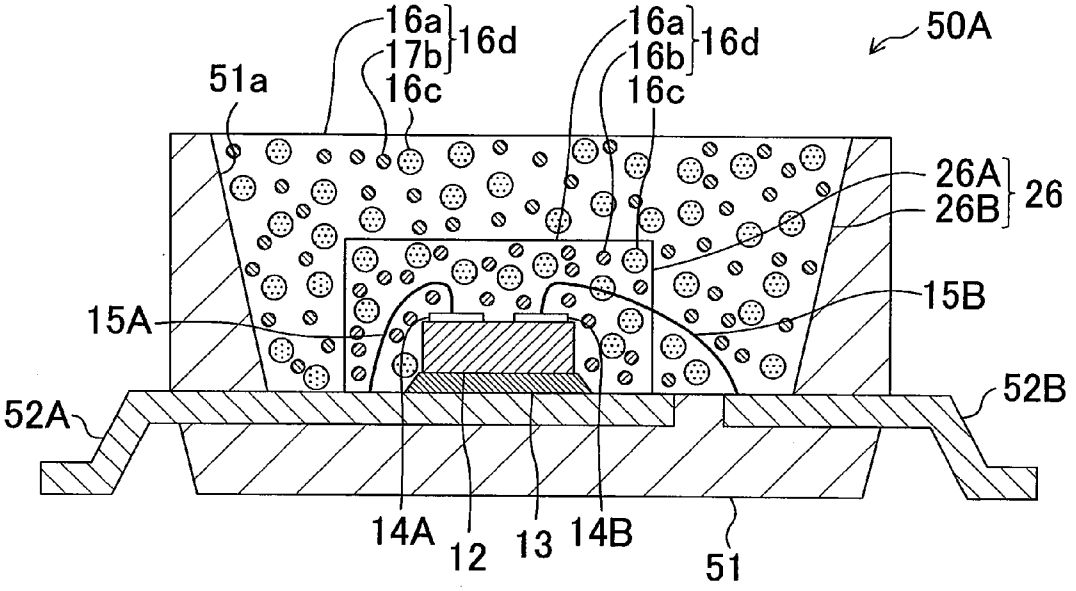
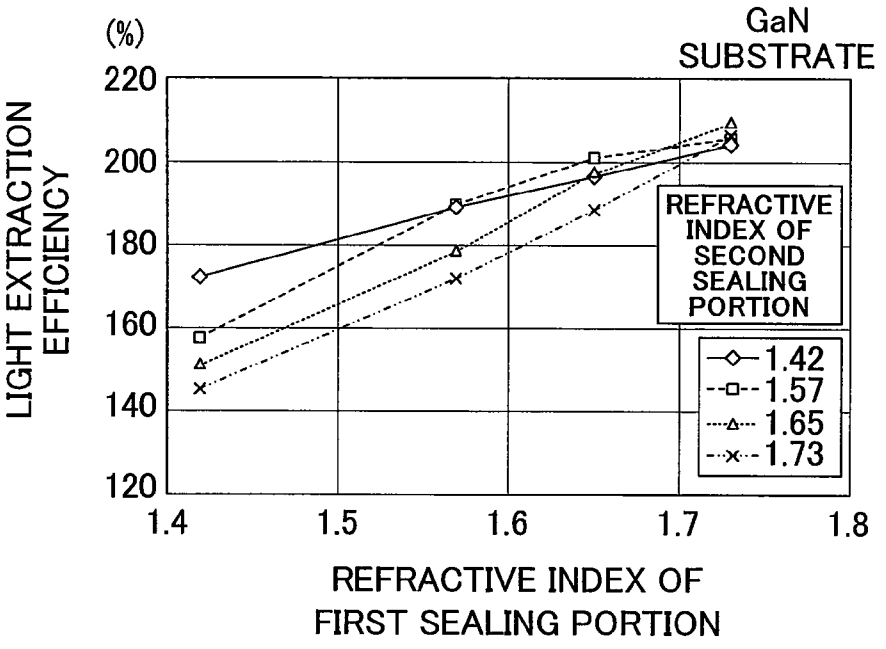

16a
17b
16d
16c
16a
16b
16d
16c
50A
51a
26A
26B
26
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 15

(a)


GaN
SUBSTRATE
(%)
220
200
180
160
140
120
LIGHT EXTRACTION EFFICIENCY
REFRACTIVE INDEX OF SECOND SEALING PORTION
1.42
1.57
1.65
1.73
1.4
1.5
1.6
1.7
1.8
REFRACTIVE INDEX OF FIRST SEALING PORTION

(b)

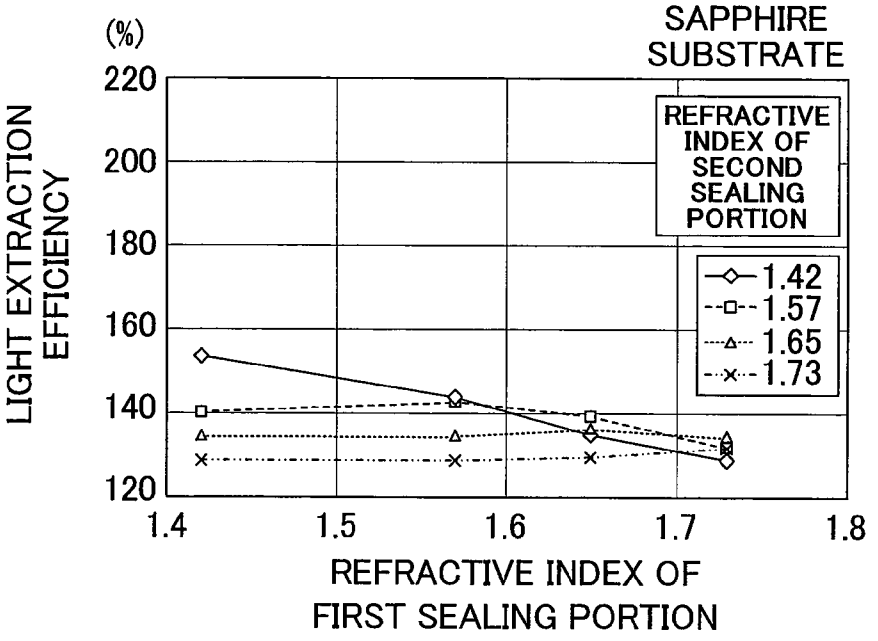

SAPPHIRE
SUBSTRATE
(%)
220
200
180
160
140
120
LIGHT EXTRACTION EFFICIENCY
REFRACTIVE INDEX OF SECOND SEALING PORTION
1.42
1.57
1.65
1.73
1.4
1.5
1.6
1.7
1.8
REFRACTIVE INDEX OF FIRST SEALING PORTION

FIG. 16

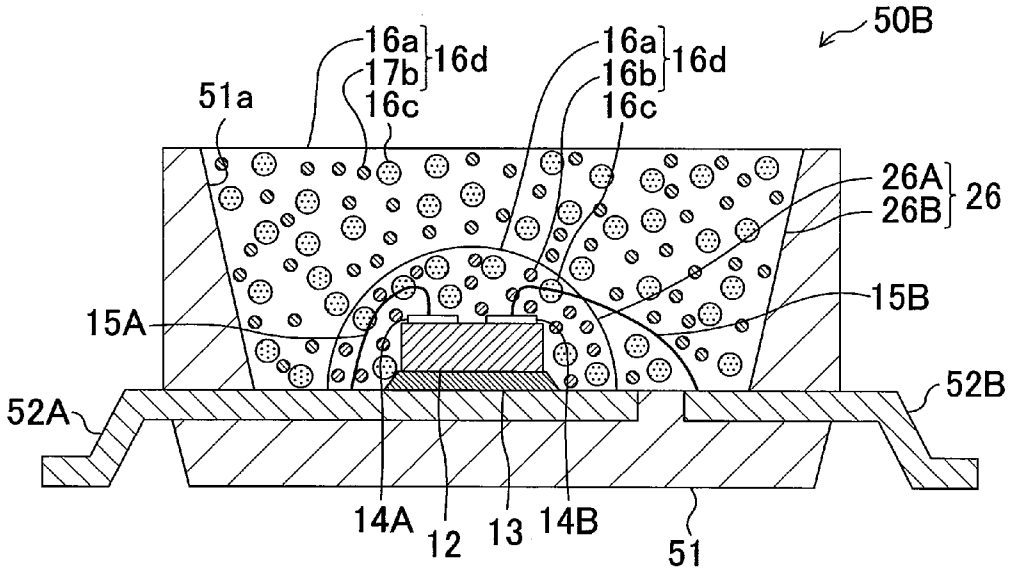

50B
16a
17b
16c
16d
16a
16b
16c
16d
51a
26A
26B
26
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 17

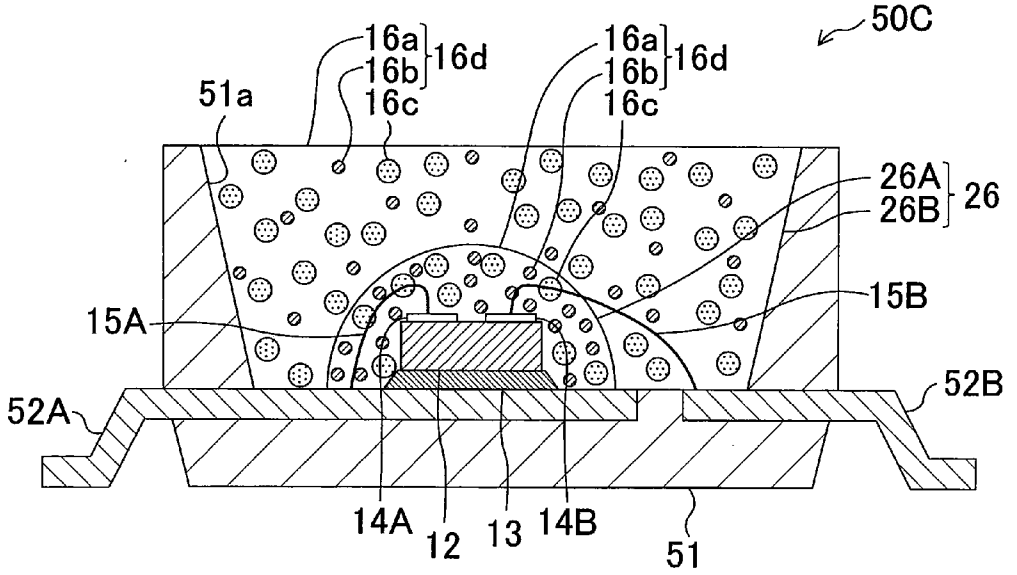

50C
16a
16b
16c
16d
16a
16b
16c
16d
51a
26A
26B
26
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 18

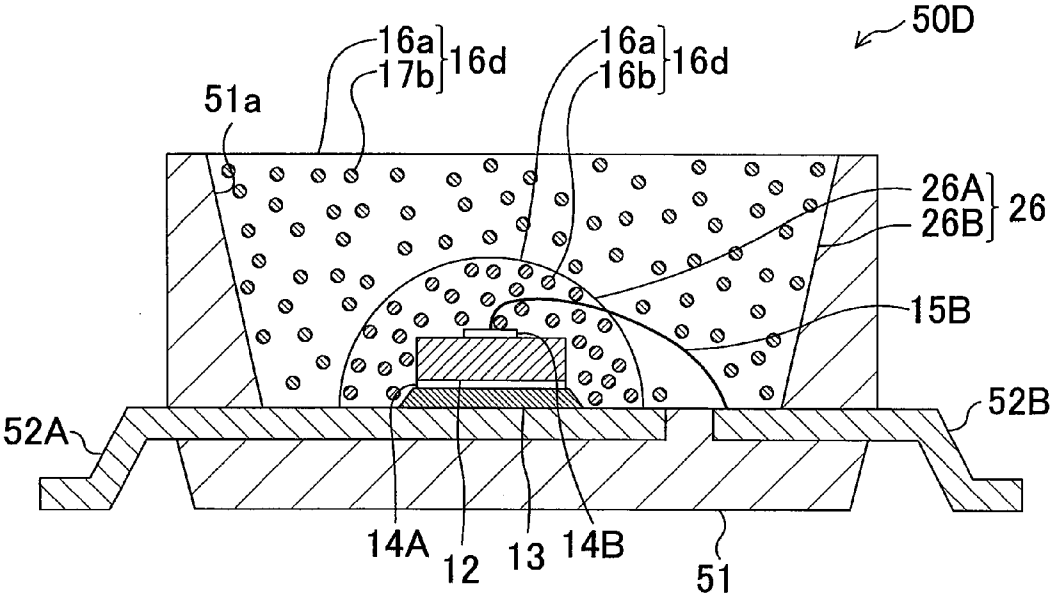

50D
16a
17b
16d
16a
16b
16d
51a
26A
26B
26
15B
52B
52A
14A
12
13
14B
51

FIG. 19

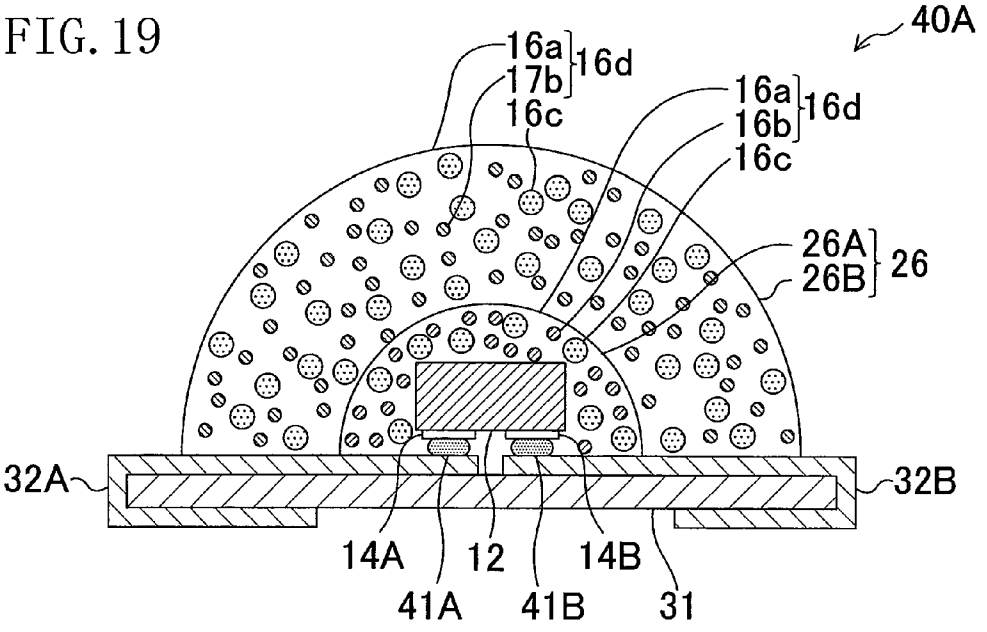

40A
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
32A
32B
14A
12
14B
41A
41B
31

FIG. 20

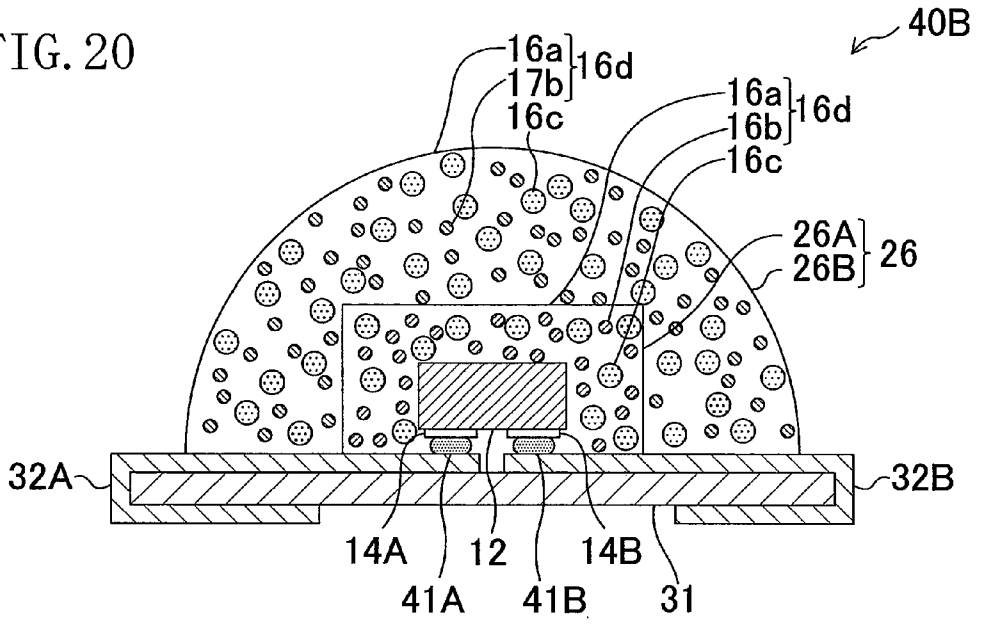

40B
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
32A
32B
14A
12
14B
41A
41B
31

FIG. 21

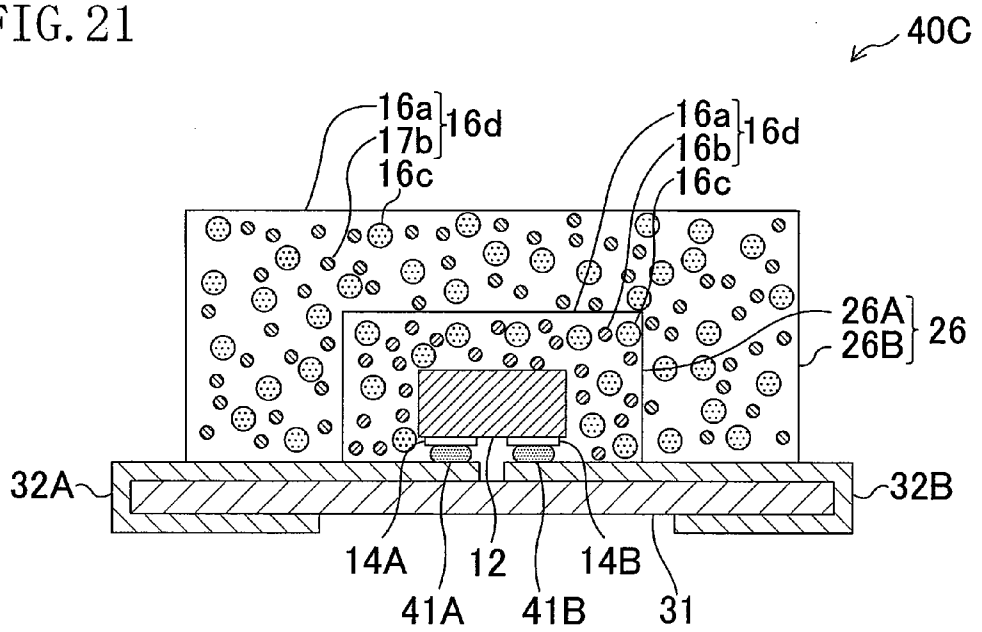

40C
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
32A
32B
14A
12
14B
41A
41B
31

FIG. 22

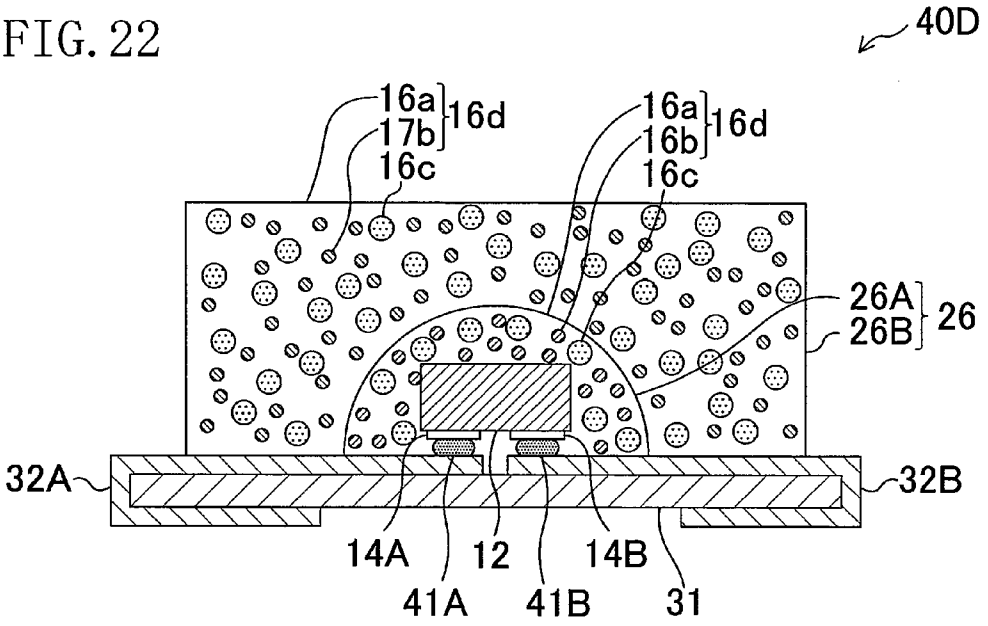

40D
16a
17b
16d
16c
16a
16b
16d
16c
26A
26B
26
32A
32B
14A
12
14B
41A
41B
31

FIG. 23

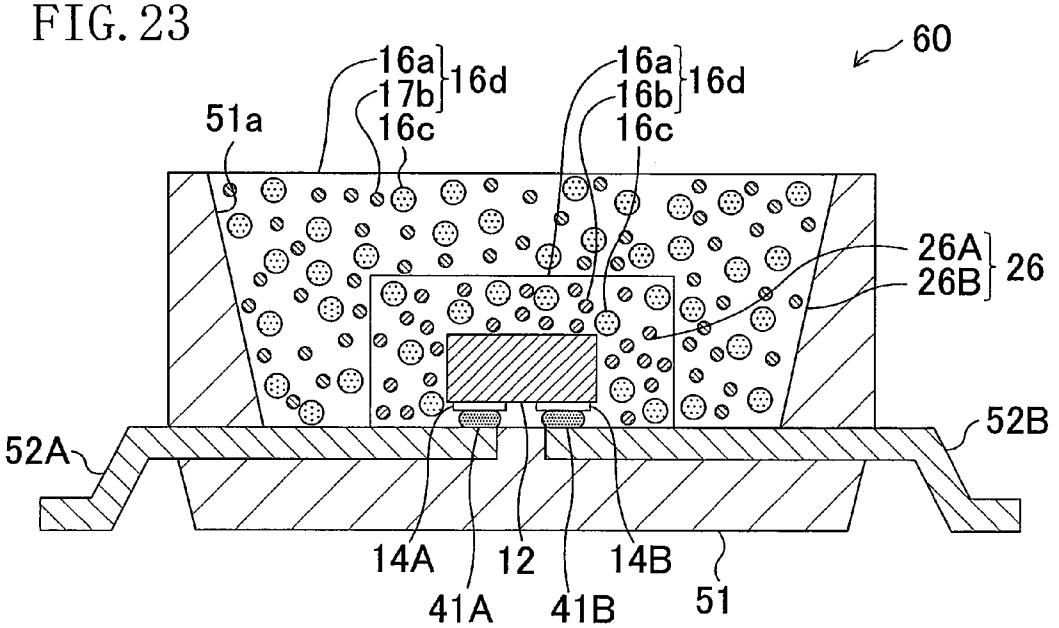

60
16a
17b
16d
51a
16c
16a
16b
16d
16c
26A
26B
26
52A
52B
14A
12
14B
41A
41B
51

FIG. 24

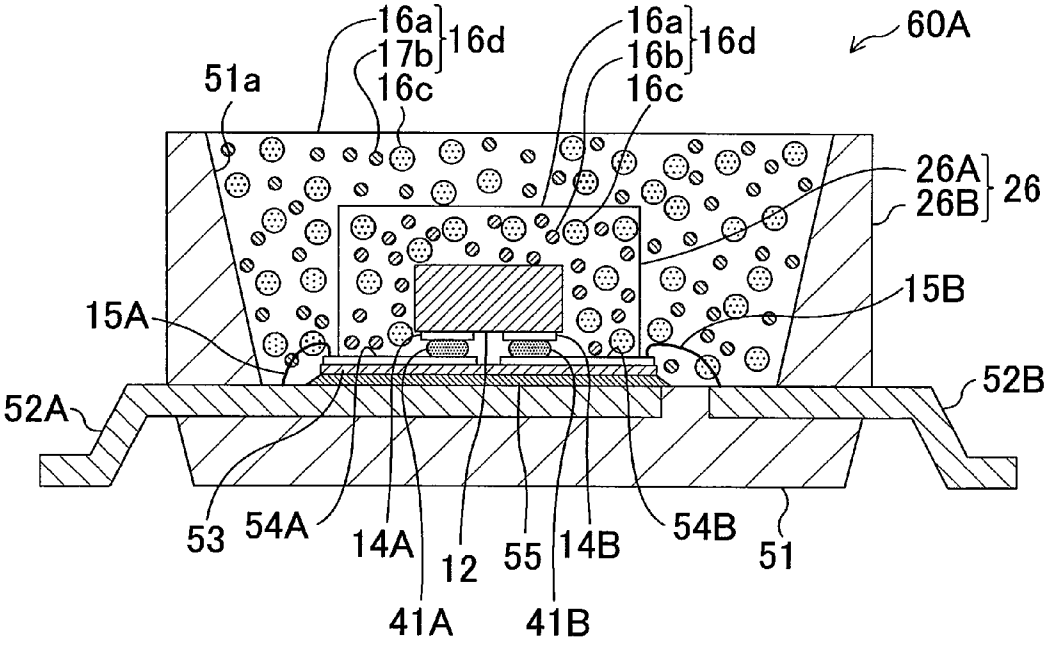

16a
17b
16d
16c
16a
16b
16d
16c
60A
51a
26A
26B
26
15A
15B
52A
52B
53
54A
14A
12
55
14B
54B
51
41A
41B

FIG. 25

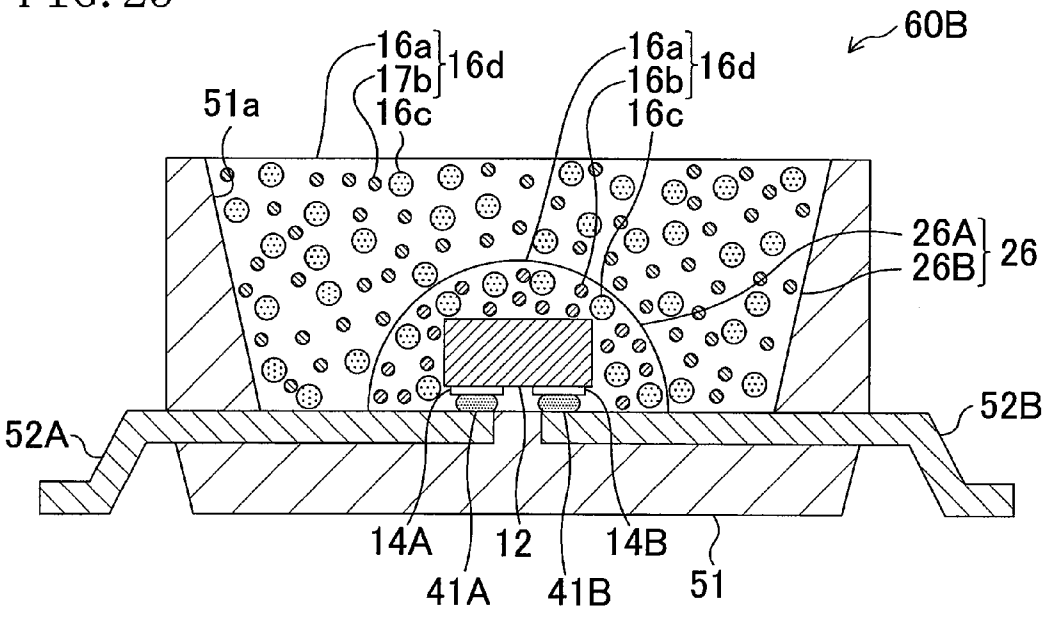

16a
17b
16d
16c
16a
16b
16d
16c
60B
51a
26A
26B
26
52A
52B
14A
12
14B
51
41A
41B

FIG. 26

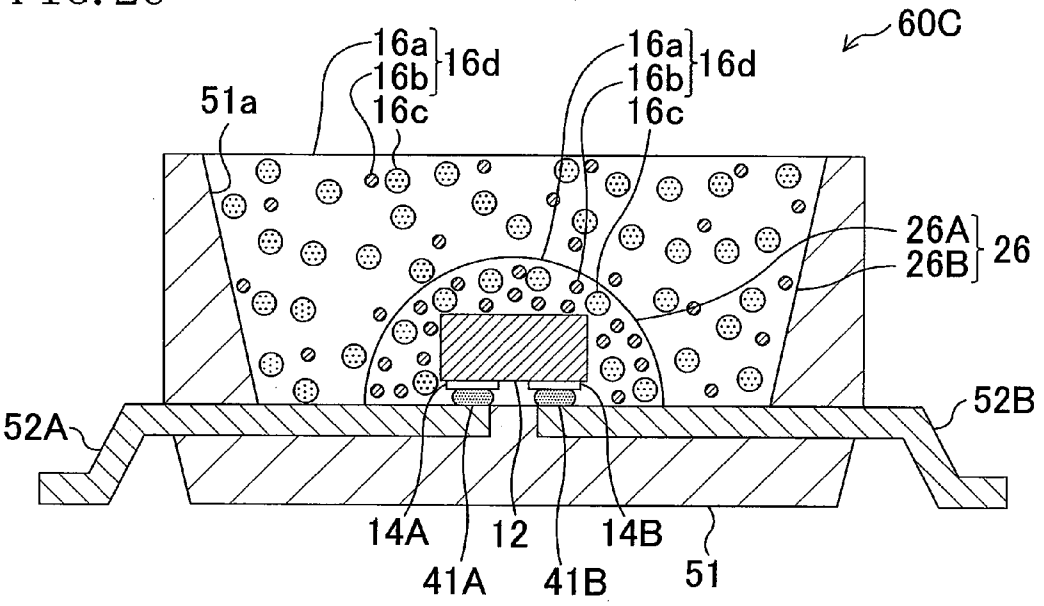

60C
16a
16b
16c
16d
51a
26A
26B
26
52A
52B
14A
12
14B
41A
41B
51

FIG. 27

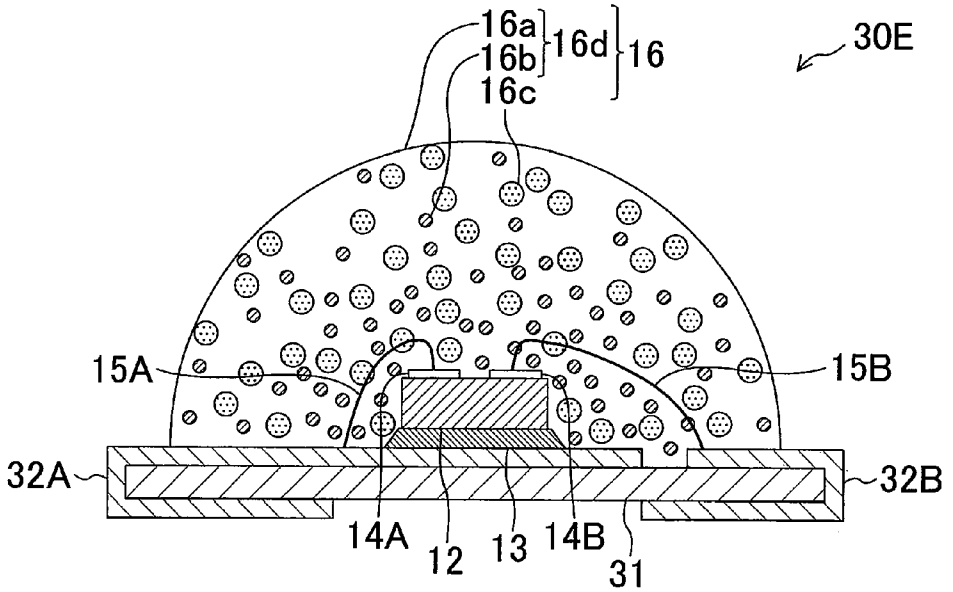

16a
16b
16c
16d
16
30E
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 28

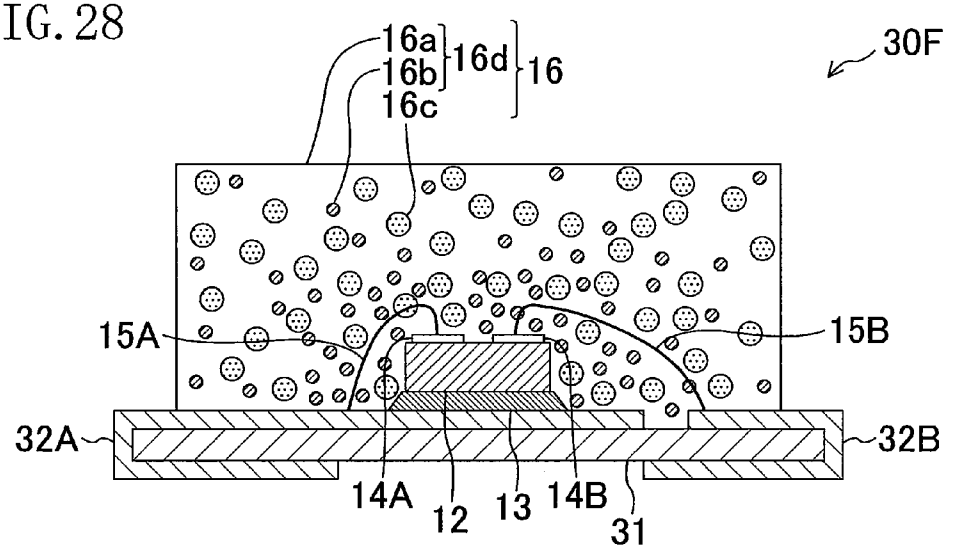

16a
16b
16c
16d
16
30F
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 29

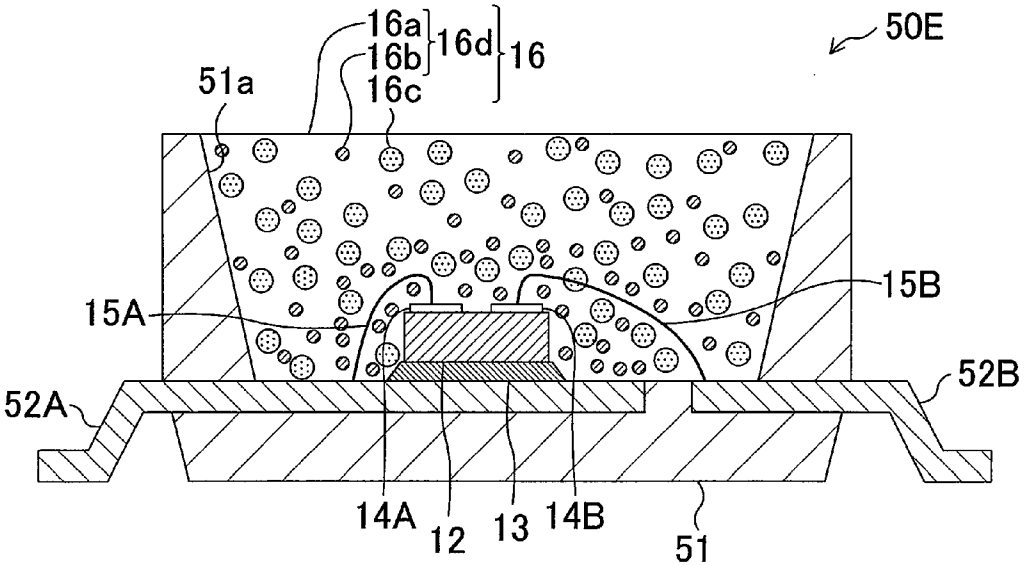

16a
16b
16c
16d
16
50E
51a
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 30

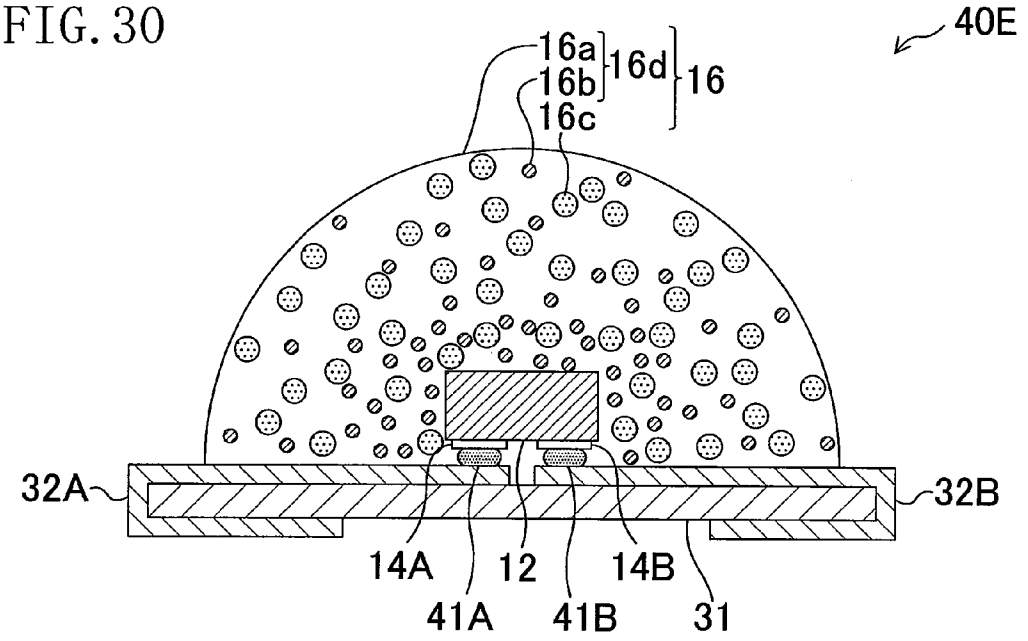

40E
16a
16b
16c
16d
16
32A
32B
14A
12
14B
41A
41B
31

FIG. 31

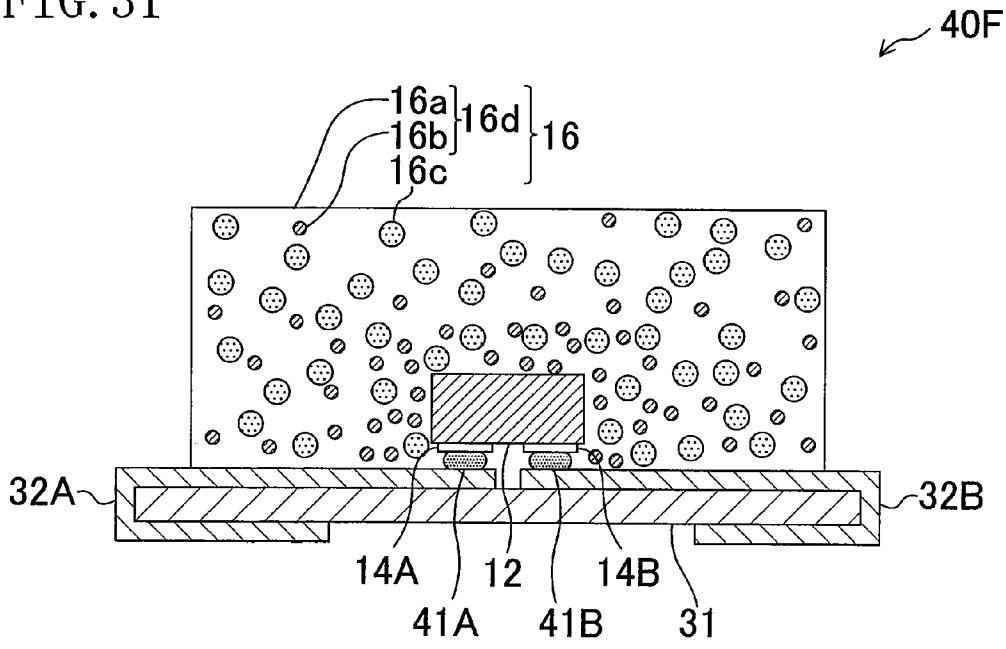

40F
16a
16b
16c
16d
16
32A
32B
14A
12
14B
41A
41B
31

FIG. 32

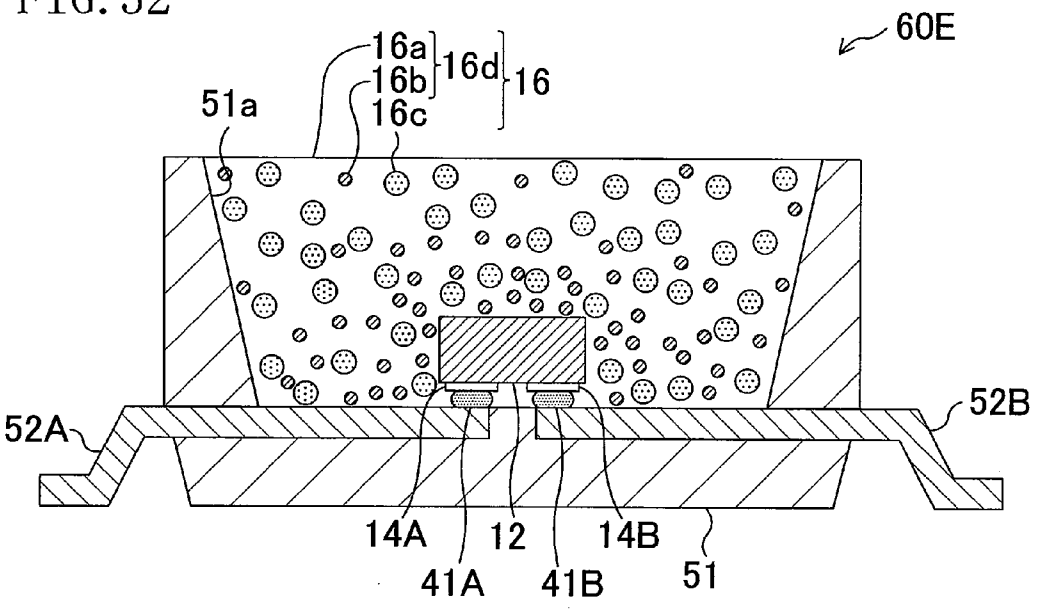

60E
16a
16b
16d
16
16c
51a
52A
52B
14A
12
14B
41A
41B
51

FIG. 33

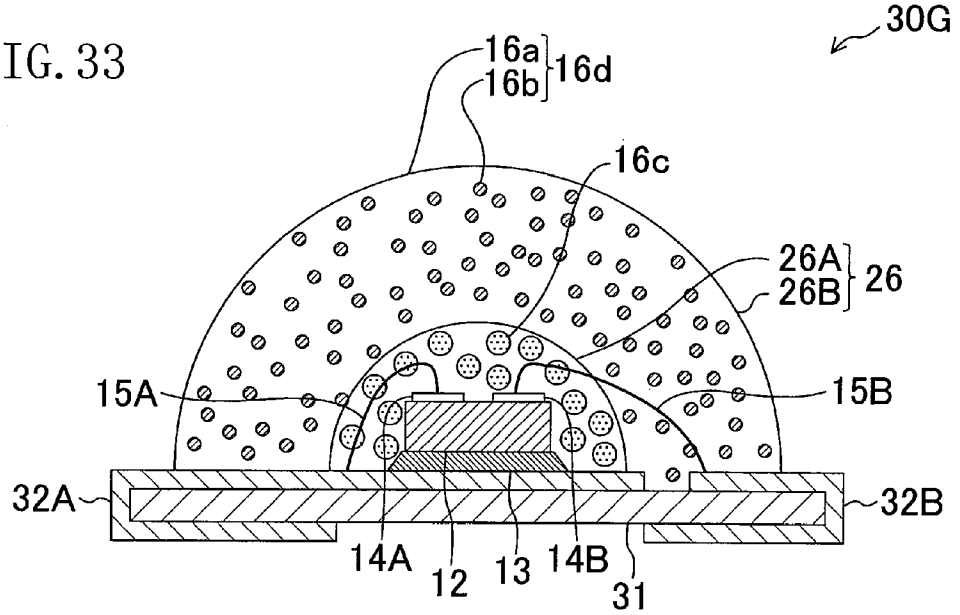

30G
16a
16b
16d
16c
26A
26B
26
15A
15B
32A
32B
14A
12
13
14B
31

FIG. 34

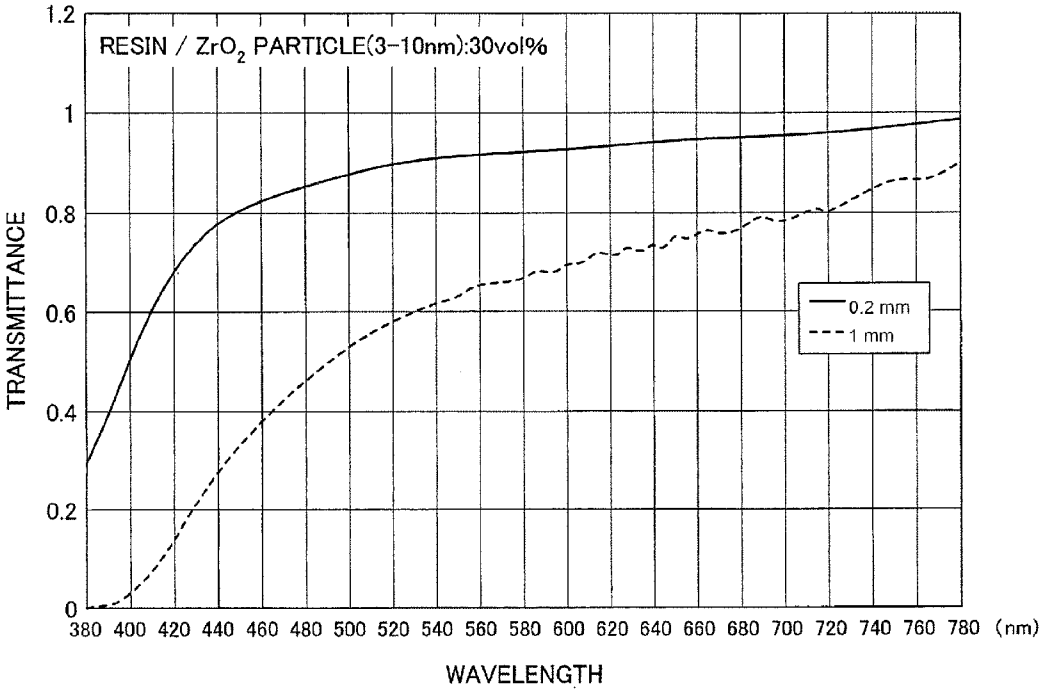

RESIN / ZrO_2 PARTICLE(3-10nm):30vol%
TRANSMITTANCE
1.2
1
0.8
0.6
0.4
0.2
0
0.2 mm
1 mm
380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760 780 (nm)
WAVELENGTH

FIG. 35

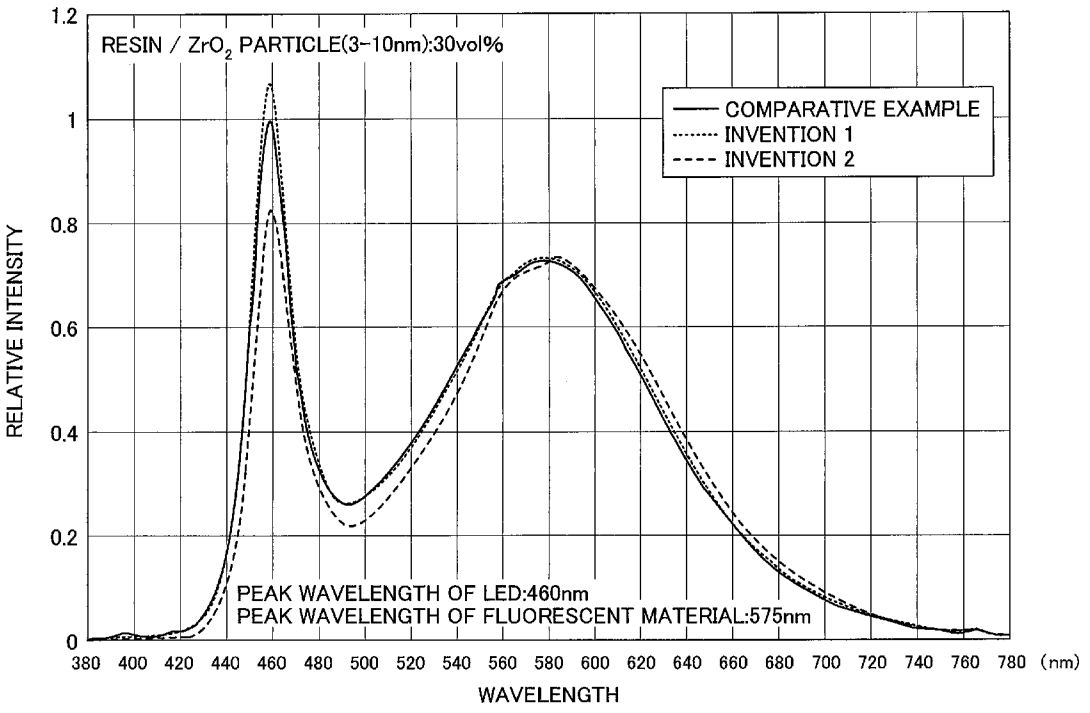

RESIN / ZrO_2 PARTICLE(3-10nm):30vol%
COMPARATIVE EXAMPLE
INVENTION 1
INVENTION 2
PEAK WAVELENGTH OF LED:460nm
PEAK WAVELENGTH OF FLUORESCENT MATERIAL:575nm
RELATIVE INTENSITY
1.2
1
0.8
0.6
0.4
0.2
0
380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760 780 (nm)
WAVELENGTH

FIG. 36

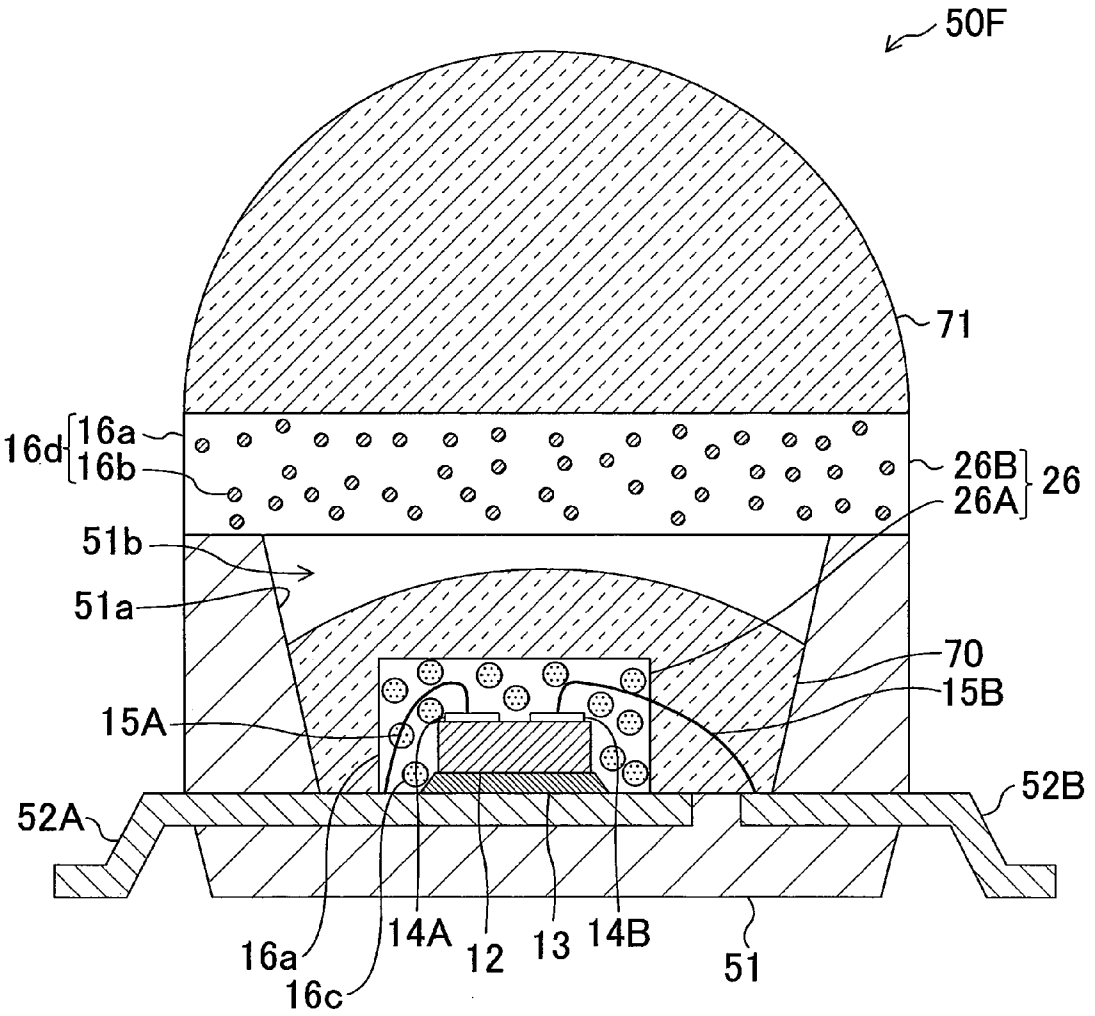

50F
71
16d
16a
16b
26B
26A
26
51b
51a
70
15B
15A
52B
52A
16a
16c
14A
12
13
14B
51

FIG. 37

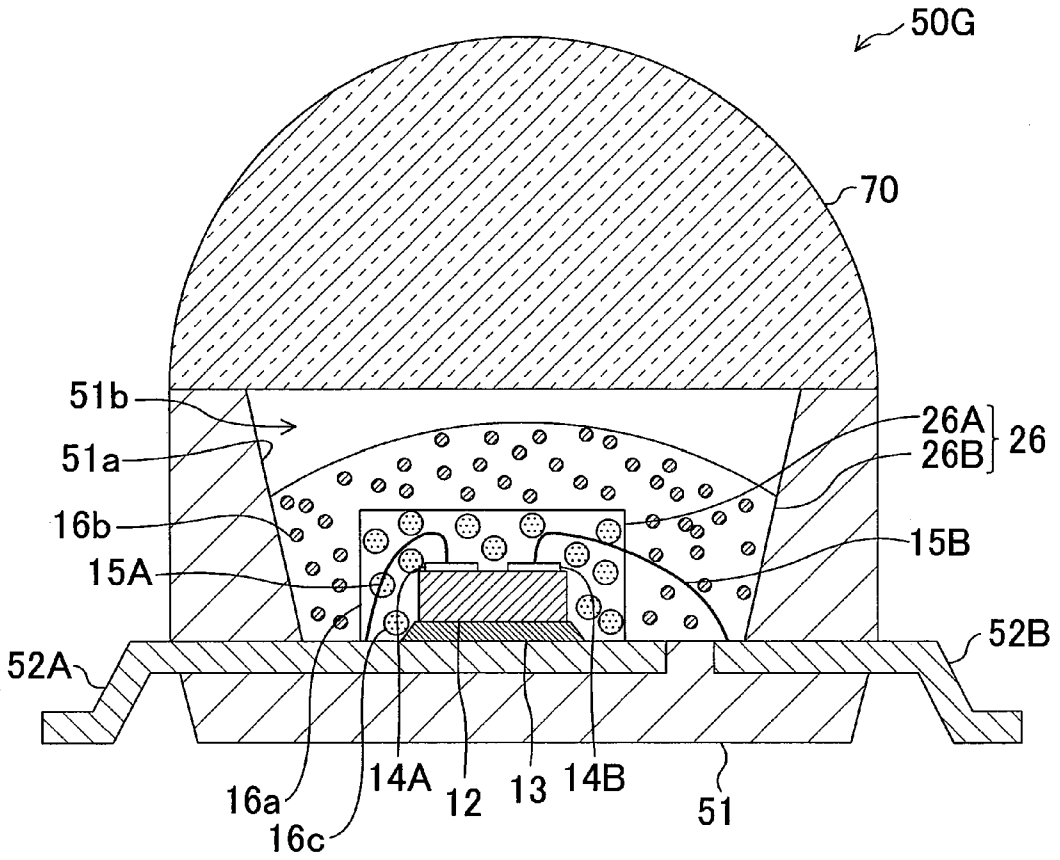

50G
70
51b
51a
16b
15A
26A
26B
26
15B
52A
52B
16a
16c
14A
12
13
14B
51

FIG. 38

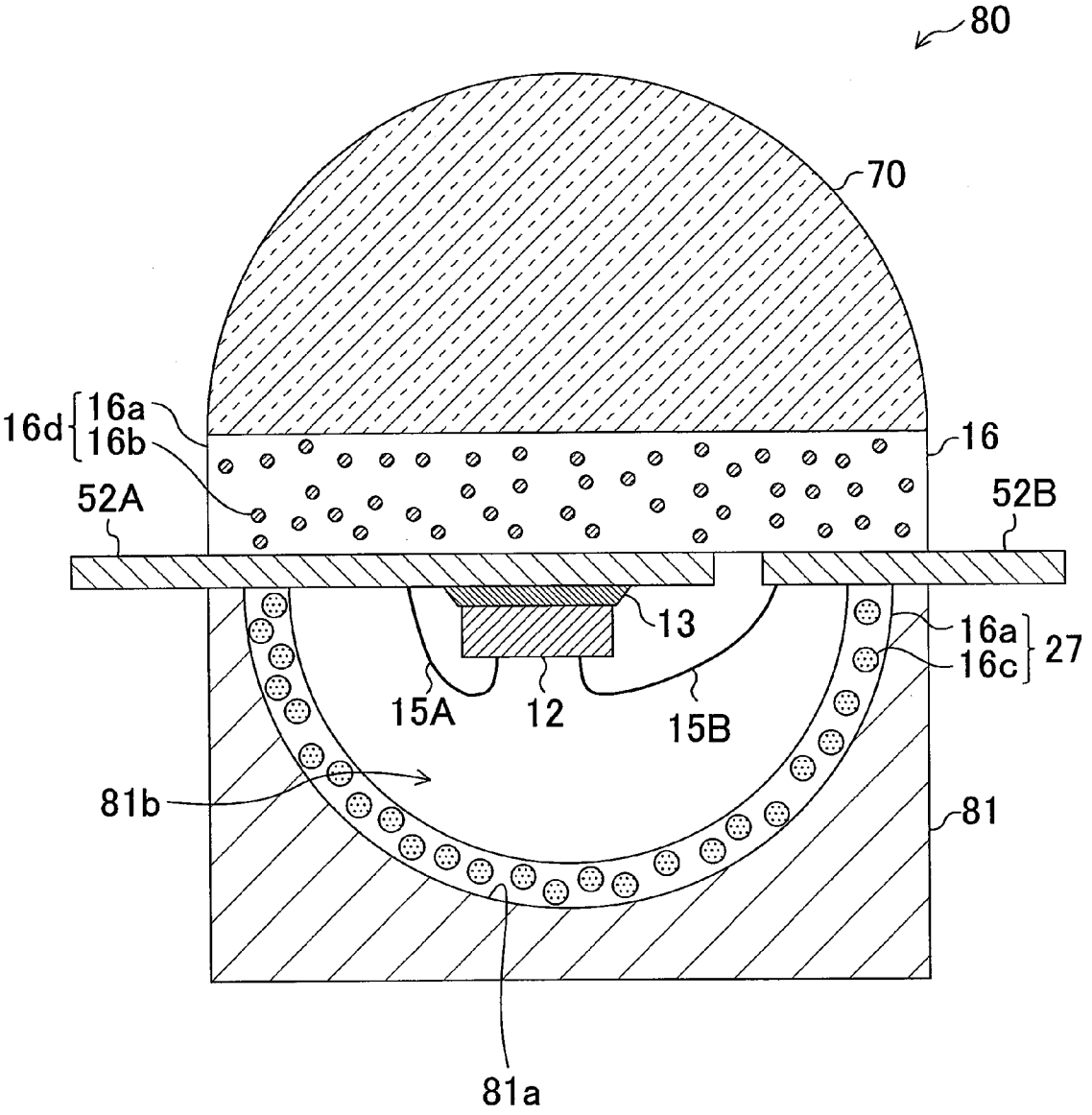


FIG. 39

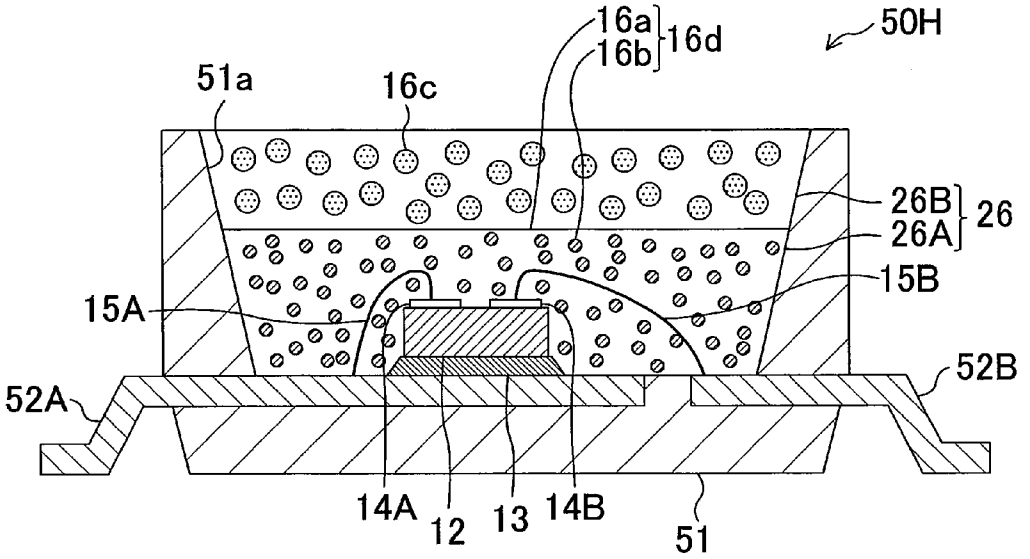

16a
16b
16d
50H
51a
16c
26B
26A
26
15B
15A
52B
52A
14A
12
13
14B
51

FIG. 40

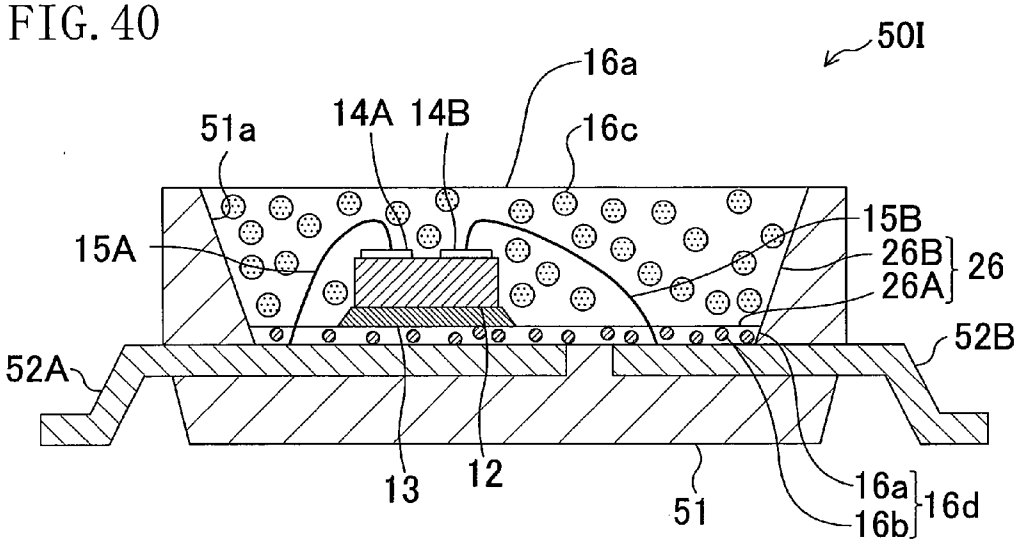

50I
16a
51a
14A
14B
16c
15B
15A
26B
26A
26
52B
52A
13
12
51
16a
16b
16d

FIG. 41

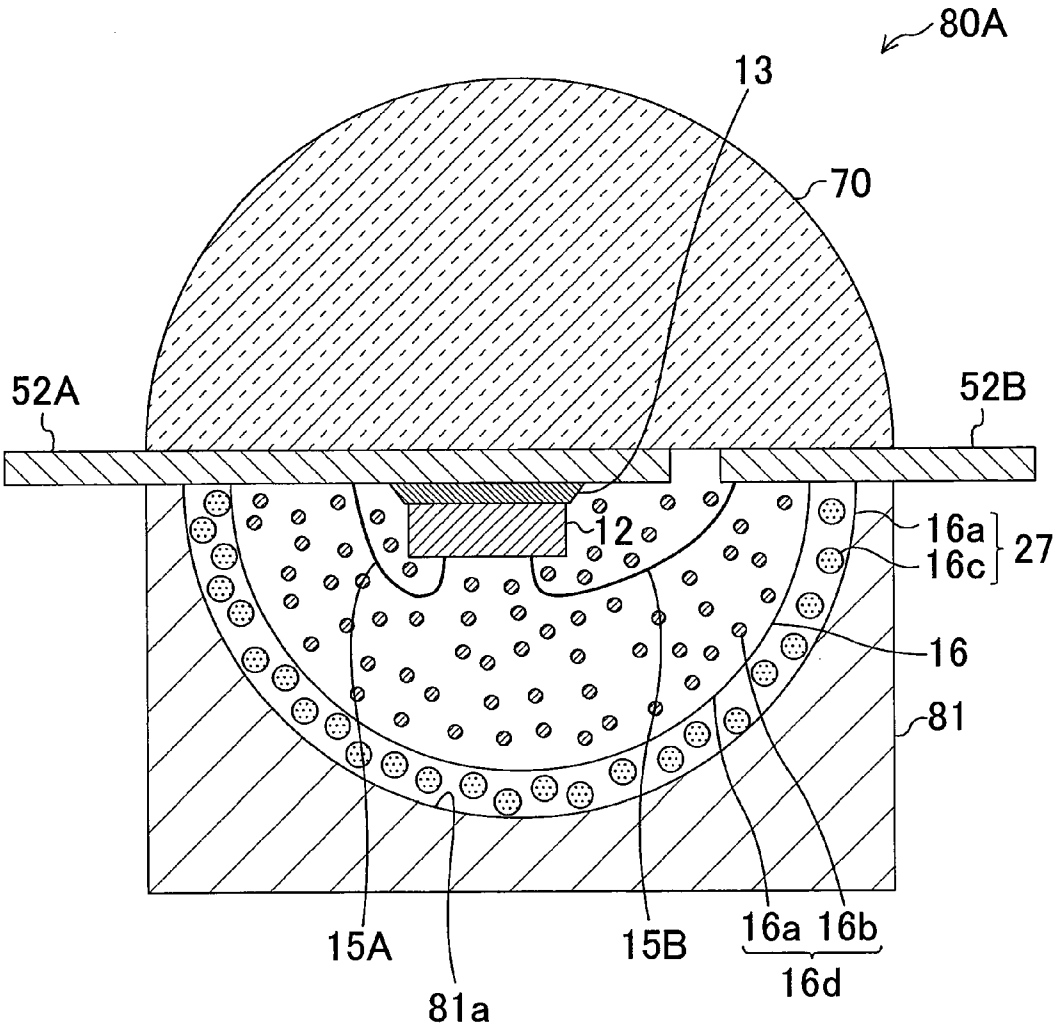


FIG. 42

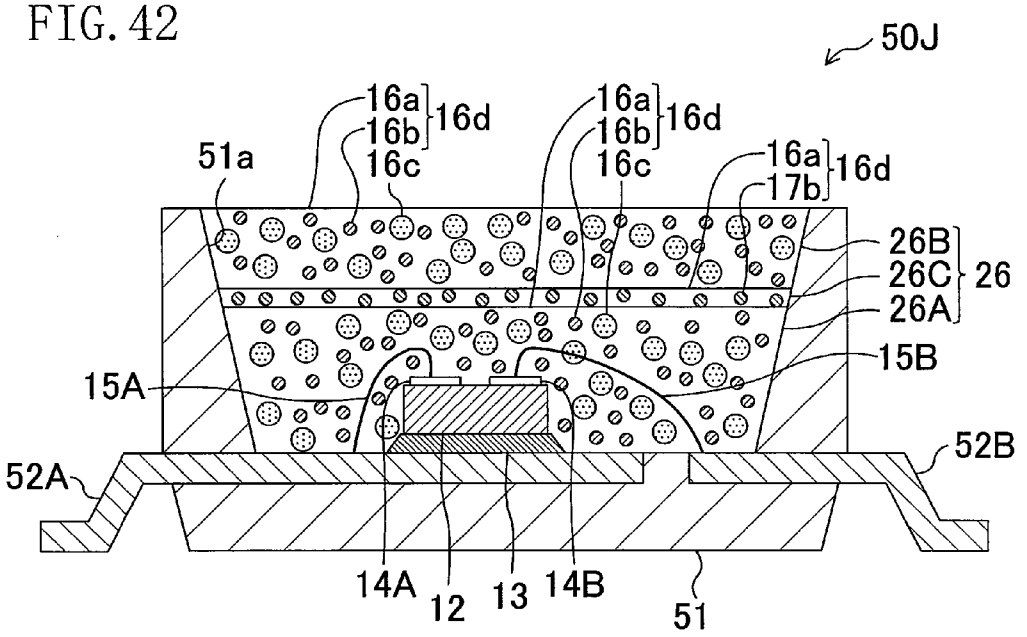

50J
16a
16b
16c
16d
51a
16a
16b
16c
16d
16a
17b
16d
26B
26C
26A
26
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 43

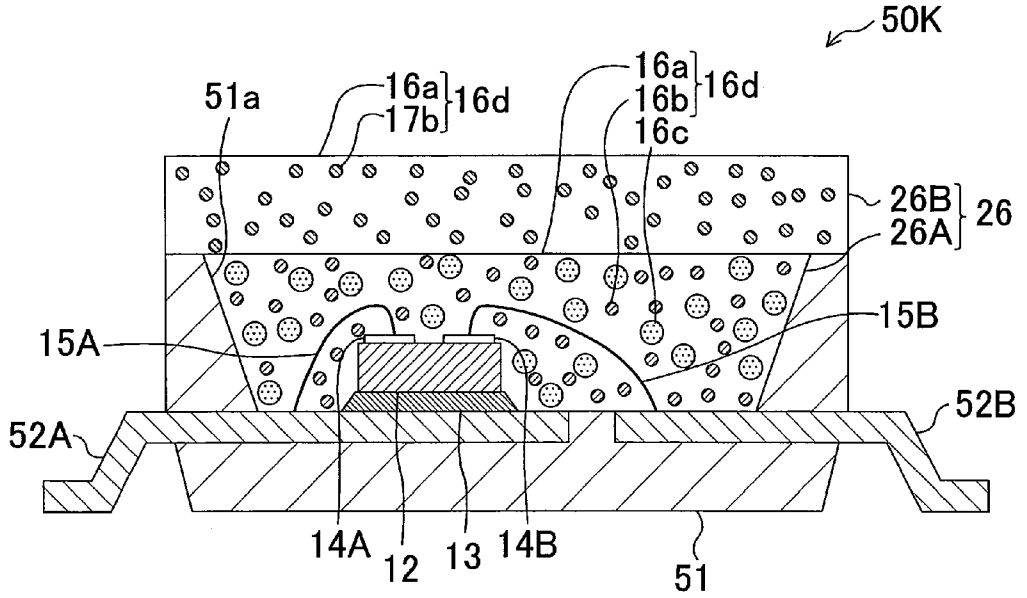

50K
51a
16a
17b
16d
16a
16b
16c
16d
26B
26A
26
15A
15B
52A
52B
14A
12
13
14B
51

FIG. 44

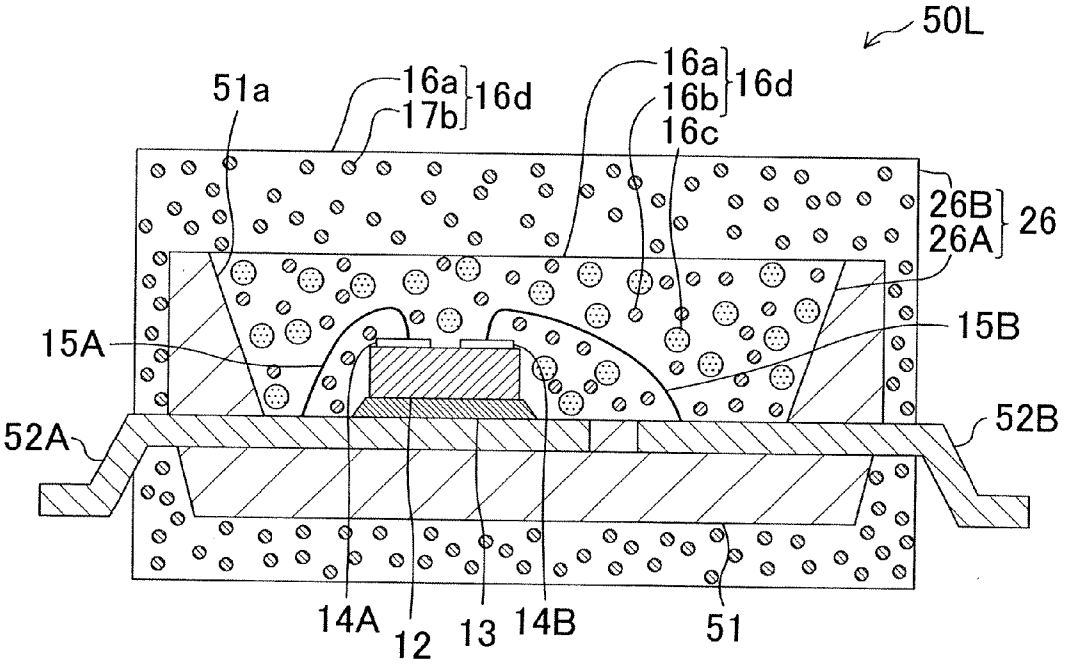
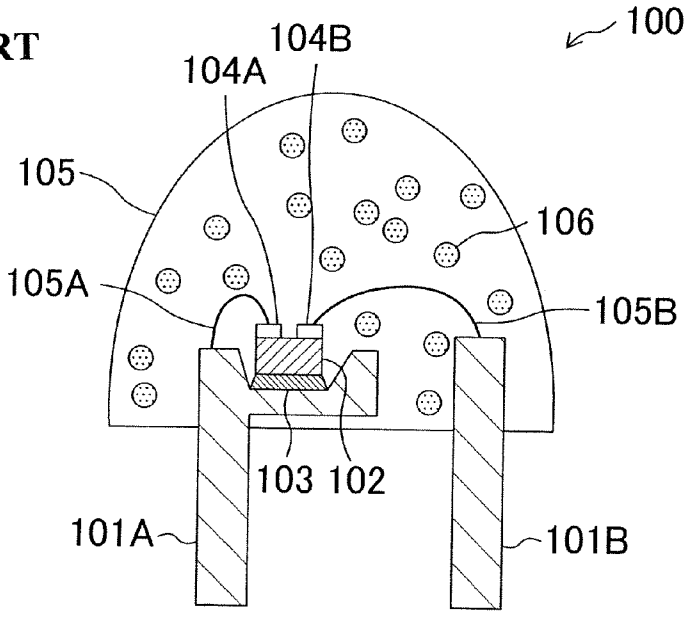


FIG. 45

PRIOR ART



SEMICONDUCTOR LIGHT-EMITTING DEVICE

RELATED APPLICATIONS

[0001] This application is a Continuation of U.S. patent application Ser. No. 11/995,924 filed on Jan. 16, 2008, which_is the U.S. National Phase under 35 U.S.C. §371 of International Application No. PCT/JP2006/314844, filed on Jul. 27, 2006, which in turn claims the benefit of Japanese Application No. 2005-228748, filed on Aug. 5, 2005, Japanese Application No. 2006-164958, filed on Jun. 14, 2006, and the disclosures of which Applications are incorporated by reference herein.

TECHNICAL FIELD

[0002] The present invention relates to a semiconductor light-emitting device in which a semiconductor chip, such as an LED (Light Emitting Diode) chip or the like, is packaged.

BACKGROUND ART

[0003] In recent years, a white LED device has come into practice and attracted attention because they would be expected to replace fluorescent lamps.

[0004] The development of an LED chip which employs a gallium nitride (GaN)-based compound semiconductor and emits light in blue to ultraviolet regions has spurred the commercialization of the white LED device.

[0005] There are mainly two methods for obtaining white light by using the LED chip which emits light in blue to ultraviolet regions (see, for example, Non-Patent Document 1). In a first method, white light is obtained from blue light which is radiated by a blue LED chip and yellow light which is obtained by exciting a fluorescent material (cerium-doped yttrium aluminum garnet (YAG:Ce), etc.) using the blue light. In a second method, white light is obtained by exciting a plurality of fluorescent materials using light which is radiated by an LED chip which emits light in a violet region to an ultraviolet region to obtain red, green, and blue (three primary colors) light. Fluorescent materials includes Y_2O_2S:Eu (abbreviated as P22-RE3) for red, ZnS:Cu, Al (abbreviated as P22-GN4) or (Ba, Mg)$Al_{10}O_{17}$:Eu, Mn (abbreviated as LP-G3) for green, and (Sr, Ca, Ba, Mg)$_{10}(PO_4)_6C_{12}$:Eu (abbreviated as LP-B1) or (Ba, Mg)$Al_{10}O_{17}$:Eu (abbreviated as LP-B4) for blue.

[0006] The white LED device is achieved by packaging the LED chip which emits light in blue to ultraviolet regions and the fluorescent material using a sealing resin material. The package is formed of a sealing resin material which is shaped into a bullet (see, for example, Non-Patent Document 2).

[0007] Hereinafter, the conventional white LED device having the bullet-shaped package will be described with reference to FIG. **45**.

[0008] As shown in FIG. **45**, in the conventional white LED device **100**, an LED chip **102** which emits light in blue to ultraviolet regions is fixed via a chip fixing paste material **103**, such as a Ag paste material, an insulating paste material or the like, to a bottom surface of a cup-shaped die pad portion provided at one end of a first lead frame **101**A.

[0009] A first electrode **104**A and a second electrode **104**B are formed on an upper surface of the LED chip **102**. The first electrode **104**A is electrically connected via a first wire **105**A to the first lead frame **101**A, and the second electrode **104**B is electrically connected via a second wire **105**B to a second lead frame **101**B which is paired with the first lead frame **101**A.

[0010] The LED chip **102** is sealed by a resin material **105** which is molded in the shape of a bullet. The resin material **105** is generally a resin material transparent to visual light, such as an epoxy resin, a silicone resin or the like. Also, a fluorescent material **106**, such as those described above, is kneaded into the resin material **105** (see, for example, Patent Document 1).

[0011] Non-Patent Document 1; Kazuyuki Tadatomo et al., "Mitsubishi Cable Industries Review", Vol. 99, July 2002, pp. 35-41

[0012] Non-Patent Document 2: Masaru Sugimoto et al., "Matsushita Electric Works Technical Report", Vol. 53, No. 1, pp. 4-9

[0013] Patent Document 1: Japanese Unexamined Patent Application Publication No. 2004-71908

[0014] Patent Document 2: Japanese Unexamined Patent Application Publication No. 2005-93724

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

[0015] However, the conventional white LED device **100** has the following problems when an epoxy resin or a silicone resin is employed as the sealing resin material **105**.

[0016] When the epoxy resin is used, the color of the material is changed into yellow. Specifically, the color of the epoxy resin is changed into yellow by light in blue to ultraviolet regions radiated by the LED chip **102**, so that the luminance of light emitted from the white LED device **100** is reduced or the color tone is changed. Therefore, light resistance and heat resistance are required for the sealing resin material **105**.

[0017] Also, when the chip fixing paste material **103** is a resin, the color of the chip fixing paste material **103** is changed by light radiated from the LED chip **102**, leading to a reduction in light emission luminance or a deterioration in intensity.

[0018] Further, not only the resin material **105** and the fluorescent material **106** of the semiconductor light-emitting device, but also the chip fixing paste material **103** which is a resin, are degraded by externally incident light in an ultraviolet region.

[0019] Also, since silicone resins have a lower optical refractive index than that of epoxy resins, light radiated by the LED chip **102** is more likely to be totally reflected by the silicone resin, so that light extraction efficiency from the LED chip **102** is reduced (see, for example, Patent Document 2).

[0020] Note that, even when an epoxy resin is used, since the refractive index of the epoxy resin is much smaller than the refractive index of an LED chip (particularly, GaN-based semiconductors), the light extraction efficiency is not sufficient.

[0021] Also, the light extraction efficiency is not sufficient in LED chips having light emission wavelengths longer than blue as well as in LED chips having light emission wavelengths in blue to ultraviolet regions.

[0022] In view of the above-described conventional problems, an object of the present invention is to improve the light resistance, heat resistance and light extraction efficiency of a

sealing material for sealing a semiconductor chip in which a light emitting device is formed.

Solution to the Problems

[0023] To achieve the above-described object, the present invention provides a semiconductor light-emitting device in which particles made of an inorganic material and having an effective particle size of ¼ or less of a light emission wavelength are included in a matrix material of a sealing portion.

[0024] Specifically, a first semiconductor light-emitting device according to the present invention comprises a semiconductor chip for emitting light having a wavelength in blue to ultraviolet regions, and a sealing portion formed in at least a partial region on a passage path on which the light is passed. The sealing portion includes a sealing material which is a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of the wavelength of the light in the matrix material, and a fluorescent material.

[0025] According to the first semiconductor light-emitting device, the particles distributed in the matrix material of the sealing portion are made of an inorganic material. Therefore, the light resistance and heat resistance of the sealing portion are improved as compared to when the particle made of the inorganic material is not included. In addition, since the effective particle size of the particles distributed in the matrix material is ¼ or less of the wavelength of light emitted from the semiconductor chip, the transparency of the sealing portion is not impaired. In other words, the light extraction efficiency is not impaired. Note that, when the particle size is sufficiently smaller than the light wavelength, the composite material in which the inorganic particles are distributed can be considered as a uniform medium having no variation in refractive index. Also, if the particle size is ¼ or less of the light wavelength, scattering of light in the composite material is only Rayleigh scattering, so that the translucency is unlikely to be degraded.

[0026] In the first semiconductor light-emitting device, the sealing portion is preferably formed, covering surroundings of the semiconductor chip.

[0027] Thereby, the mechanical strength of the sealing portion is increased, and the heat resistance is improved, so that the sealing portion is unlikely to be peeled off and a crack is unlikely to occur.

[0028] In the first semiconductor light-emitting device, the sealing portion is preferably formed, contacting the semiconductor chip.

[0029] Even when the sealing portion and the semiconductor chip contact each other, a difference in thermal expansion coefficient between the sealing portion and the semiconductor chip is reduced as compared to when the particles are not included in the matrix material of the sealing portion, so that the sealing portion is unlikely to be peeled off and a crack is unlikely to occur.

[0030] In the first semiconductor light-emitting device, the sealing portion preferably comprises a first sealing portion made of the sealing material, and a second sealing portion formed outside the first sealing portion and including the fluorescent material.

[0031] By thus providing the first sealing portion made of the sealing material (composite material) near the semiconductor chip, i.e., in a portion having a relatively high optical density, a high level of light extraction efficiency from the semiconductor chip can be achieved and high levels of light resistance and heat resistance can be obtained. Further, by providing the second sealing portion having a higher level of transparency than that of the composite material and including the fluorescent material far from the semiconductor chip, i.e., in a portion having a relatively low optical density, the transmittance of light in the second sealing portion can be improved. As a result, the light extraction efficiency from the semiconductor light-emitting device can be improved.

[0032] When the first sealing portion is made of the composite material, the semiconductor light-emitting device preferably further comprises a reflection member for reflecting the light which is provided below and lateral to the semiconductor chip in the first sealing portion.

[0033] Thereby, the particle included in the composite material of the first sealing portion near the semiconductor chip attenuates spectra in blue to ultraviolet regions as described below, so that spectra having short wavelengths in a red region or the like are relatively increased. This phenomenon is herein referred to as a filter effect. Thereby, an average color rendering index (Ra) can be increased and color temperature can be decreased.

[0034] Further, in this case, the sealing material is preferably an underlying layer, wherein the semiconductor chip is fixed to the underlying layer via a paste material having transparency and is held by the reflection member.

[0035] Even when the composite material is used as the underlying layer, since the paste material for fixing the semiconductor chip is transparent, the filter effect of the particle included in the underlying layer can increase the average color rendering index (Ra) and decrease the color temperature.

[0036] Also, in the first semiconductor light-emitting device, the sealing portion preferably comprises a first sealing portion including the sealing material, and a second sealing portion formed outside the first sealing portion.

[0037] Thereby, the particle for absorbing light in an ultraviolet region which is included in the composite material of the first sealing portion can suppress degradation of the sealing material including a resin or the like due to ultraviolet light.

[0038] Also, in the first semiconductor light-emitting device the sealing portion preferably comprises a first sealing portion including the fluorescent material, and a second sealing portion formed outside the first sealing portion and including the sealing material.

[0039] Thereby, the particle included in the composite material of the second sealing portion formed outside the first sealing portion attenuates spectra in blue to ultraviolet regions, so that spectra having short wavelengths in a red region or the like are relatively increased, i.e., the filter effect can be obtained. Thereby, the average color rendering index (Ra) can be improved and the color temperature can be decreased.

[0040] A second semiconductor light-emitting device according to the present invention comprises a semiconductor chip for emitting light, and a sealing portion formed in at least a partial region on a passage path on which the light is passed. The sealing portion includes a sealing material which is a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of a wavelength of the light in the matrix material, and comprises a first sealing portion for covering the

semiconductor chip and a second sealing portion formed outside the first sealing portion. A first refractive index with respect to the wavelength of the light in the first sealing portion is larger than a second refractive index with respect to the wavelength of the light in the second sealing portion.

[0041] According to the second semiconductor light-emitting device, the sealing portion includes the particles made of an inorganic material which are distributed in the matrix material and have an effective particle size of ¼ of the light wavelength in the matrix material, as in the first semiconductor light-emitting device. Therefore, the light resistance and heat resistance of the sealing portion are improved and the transparency of the sealing portion is not impaired. In addition, since the first refractive index with respect to the light wavelength in the first sealing portion is larger than the second refractive index with respect to the light wavelength in the second sealing portion, the refractive index of the whole sealing portion is high in an inner region near the semiconductor chip and low in a region outside the inner region. Therefore, due to the low refractive index of the outer region, the total reflection of radiated light from the semiconductor chip is reduced, so that the light extraction efficiency is improved.

[0042] In the second semiconductor light-emitting device, the particle included in the first sealing portion and the particle included in the second sealing portion preferably have different compositions.

[0043] For example, when particles having a refractive index larger than that of particles included in the second sealing portion are included in the first sealing portion, the refractive index of the first sealing portion can be reliably caused to be larger than that of the second sealing portion.

[0044] Also, in the second semiconductor light-emitting device, the proportion of the particles in the composite material of the first sealing portion is preferably higher than the proportion of the particles in the composite material of the second sealing portion.

[0045] Thereby, the refractive index of the first sealing portion can be reliably caused to be larger than that of the second sealing portion.

[0046] A third semiconductor light-emitting device according to the present invention comprises a semiconductor chip for emitting light, and a sealing portion formed in at least a partial region on a passage path on which the light is passed. The sealing portion includes a sealing material which is a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of a wavelength of the light in the matrix material, and has a refractive index with respect to the wavelength of the light, the refractive index being set to become smaller from an inner region near the semiconductor chip to an outer region.

[0047] According to the third semiconductor light-emitting device, the sealing portion includes the particles made of an inorganic material which are distributed in the matrix material and have an effective particle size of ¼ of the light wavelength in the matrix material, as in the first semiconductor light-emitting device. Therefore, the light resistance and heat resistance of the sealing portion are improved and the transparency of the sealing portion is not impaired. In addition, since the refractive index with respect to the light wavelength is set to become smaller from an inner region near the semiconductor chip to an outer region, the refractive index of the whole sealing portion is high in an inner region near the semiconductor chip and low in a region outside the inner region. Therefore, due to the low refractive index of the outer region, the total reflection of radiated light from the semiconductor chip is reduced, so that the light extraction efficiency is improved.

[0048] In the third semiconductor light-emitting device, a proportion of the particles in the composite material of the sealing portion is preferably higher in the inner region near the semiconductor chip than in the outer region.

[0049] Thereby, the refractive index of the inner region can be reliably caused to be larger than that of the outer region in the sealing portion.

[0050] Also, in the third semiconductor light-emitting device, of the particles included in the sealing portion, the particle included in the inner region of the sealing portion and the particle included in the outer region preferably have different compositions.

[0051] For example, when particles having a composition having a refractive index larger than that of the particle included in the outer region of the sealing portion are included in the inner region of the sealing portion, the refractive index of the inner region can be reliably caused to be larger than that of the outer region in the sealing portion.

[0052] A fourth semiconductor light-emitting device comprises a semiconductor chip for emitting light, and a sealing portion formed in at least a partial region on a passage path on which the light is passed. The sealing portion includes a sealing material which is a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of a wavelength of the light in the matrix material, and comprises a first sealing portion for covering the semiconductor chip and a second sealing portion formed outside the first sealing portion. The particle included in the second sealing portion is made of a material which absorbs light in an ultraviolet region.

[0053] According to the fourth semiconductor light-emitting device, the second sealing portion includes particles made of a material which absorbs light in an ultraviolet region, so that emission of undesired ultraviolet light can be suppressed when light emitted by the semiconductor chip includes wavelength components in an ultraviolet region. Also, external incident ultraviolet light is absorbed by the particle added to the second sealing portion, so that degradation of the sealing material or the like can be prevented.

[0054] In the fourth semiconductor light-emitting device, the second sealing portion is preferably formed, covering an upper, lower and lateral portions of the semiconductor chip.

[0055] A fifth semiconductor light-emitting device comprises a semiconductor chip for emitting light having a wavelength in blue to ultraviolet regions, a sealing portion formed in at least a partial region on a passage path on which the light is passed, a holding material for holding the semiconductor chip, and a paste material having transparency for fixing the semiconductor chip and the holding material. The paste material includes a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of the wavelength of the light in the matrix material. The particle is made of a material for absorbing light in an ultraviolet region.

[0056] According to the fifth semiconductor light-emitting device, the paste material having transparency for fixing the semiconductor chip and the holding material includes a composite material including particles made of an inorganic material. The particle is made of a material for absorbing light in an ultraviolet region. Therefore, a degradation in the paste material due to ultraviolet light and a reduction in light emission luminance can be suppressed. Also, since the paste material is transparent, light emitted from the semiconductor chip can be output via the paste material to the outside, resulting in an improvement in light extraction efficiency. Also, the paste material including the composite material improves heat radiation performance in which heat generated from the semiconductor chip is radiated to the holding material.

[0057] In the second or third semiconductor light-emitting device, the sealing portion preferably includes a fluorescent material.

[0058] Thereby, when radiated light from the semiconductor chip is light in a blue region or an ultraviolet region, the fluorescent material can be excited to obtain white light.

[0059] In the first to third semiconductor light-emitting devices, the particle is preferably made of an inorganic compound.

[0060] Thereby, the range of options for the material for improving light resistance, heat resistance, or mechanical strength can be broadened.

[0061] In the first to third semiconductor light-emitting devices, the matrix material preferably includes a resin material.

[0062] Thereby, the molding performance of the sealing portion is improved.

[0063] In this case, the resin material is preferably an inorganic polymer material. Thereby, the light resistance and the heat resistance can be easily improved.

[0064] Also, in this case, the resin material is preferably an organic polymer material. Thereby, the molding performance is easily improved.

[0065] In the first to third semiconductor light-emitting devices, the matrix material is preferably transparent to visual light.

[0066] Thereby, the transparency of the sealing portion is further improved, so that the light extraction efficiency is further improved.

[0067] In the first to third semiconductor light-emitting devices, the composite material is preferably transparent to visual light.

[0068] Thereby, since the transparency of the sealing portion is further improved, the light extraction efficiency is further improved.

[0069] In the first to third semiconductor light-emitting devices, preferably, a refractive index with respect to the light wavelength of the particle is larger than a refractive index with respect to the light wavelength of the matrix material, and is smaller than or equal to a refractive index of the semiconductor chip.

[0070] Thereby, the refractive index of the sealing portion is higher than when the particle is not added, so that the light extraction efficiency is further improved.

[0071] In the first to third semiconductor light-emitting devices, a proportion of the particles in the composite material is preferably 5% by volume or more and 60% by volume or less.

[0072] Thereby, the light resistance and heat resistance of the composite material can be improved while its transparency is sufficiently secured. Note that the proportion of the particles in the composite material is more preferably 10% by volume or more and 50% by volume or less, even more preferably 20% by volume or more and 40% by volume or less.

[0073] In the first or third semiconductor light-emitting device, the sealing portion preferably has a hemispherical outer shape.

[0074] Thereby, an effect of suppression of total reflection of radiated light from the semiconductor chip can be enhanced.

[0075] Also, in the first or third semiconductor light-emitting device, the sealing portion preferably has a quadrangular outer shape.

[0076] Thereby, the sealing material including the composite material can be applied by a printing method or the like, so that formation is facilitated. Also, since the upper surface is flat, it is easy to handle the device.

[0077] In the first semiconductor light-emitting device which has a first sealing portion and a second sealing portion or in the third semiconductor light-emitting device, the first sealing portion and the second sealing portion preferably have a hemispherical outer shape.

[0078] In the first semiconductor light-emitting device which has a first sealing portion and a second sealing portion or in the third semiconductor light-emitting device, preferably, the first sealing portion has a cross-section having a quadrangular outer shape, and the second sealing portion has a hemispherical outer shape.

[0079] In the first semiconductor light-emitting device which has a first sealing portion and a second sealing portion or in the third semiconductor light-emitting device, the first sealing portion and the second sealing portion preferably have a quadrangular outer shape.

[0080] In the first semiconductor light-emitting device which has a first sealing portion and a second sealing portion or in the third semiconductor light-emitting device, preferably, the first sealing portion has a hemispherical outer shape, and the second sealing portion has a quadrangular outer shape.

[0081] The first to third semiconductor light-emitting devices preferably further comprises a reflection member for reflecting the light provided in a region lateral to the semiconductor chip of the sealing portion.

[0082] Thereby, the light extraction efficiency is further improved.

[0083] In this case, the sealing portion preferably has a reverse taper shape such that a cross-sectional shape of the sealing portion becomes wider from a lower portion thereof to an upper portion thereof.

Effect of the Invention

[0084] According to the semiconductor light-emitting device of the present invention, a semiconductor light-emitting device, such as a long-life and high-luminance white LED or the like, can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0085] FIG. **1** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a first embodiment of the present invention.

[0086] FIG. **2** An enlarged cross-sectional view of a sealing portion in the semiconductor light-emitting device of the first embodiment of the present invention.

[0087] FIG. **3** A graph for describing an effective particle size of nano-particles added to the sealing portion in the semiconductor light-emitting device of first embodiment of the present invention.

[0088] FIG. **4** A graph showing a relationship between a refractive index of the sealing portion (composite material) and an added amount (volume ratio) of nano-particles in the semiconductor light-emitting device of the first embodiment of the present invention.

[0089] FIG. **5** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a second embodiment of the present invention.

[0090] FIG. **6** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a third embodiment of the present invention.

[0091] FIG. **7** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fourth embodiment of the present invention.

[0092] FIG. **8** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fifth embodiment of the present invention.

[0093] FIG. **9** (*a*) is a graph obtained by simulation, showing a relationship between the refractive index of the sealing portion and a change rate of total luminous flux of radiated light for each substrate material included in an LED chip in the semiconductor light-emitting device of the fifth embodiment of the present invention. (*b*) is a graph obtained by simulation, showing a relationship between the refractive index of the sealing portion and the total luminous flux for each substrate material included in an LED chip in the semiconductor light-emitting device of the fifth embodiment of the present invention.

[0094] FIG. **10** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a sixth embodiment of the present invention.

[0095] FIG. **11** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a first variation of the sixth embodiment of the present invention.

[0096] FIG. **12** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a second variation of the sixth embodiment of the present invention.

[0097] FIG. **13** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a third variation of the sixth embodiment of the present invention.

[0098] FIG. **14** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fourth variation of the sixth embodiment of the present invention.

[0099] FIGS. **15** (*a*) and (*b*) are graphs showing obtained by simulation, showing a relationship between refractive indices of a first sealing portion and a second sealing portion and light extraction efficiency in the semiconductor light-emitting device of the fourth variation of the sixth embodiment of the present invention.

[0100] FIG. **16** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fifth variation of the sixth embodiment of the present invention.

[0101] FIG. **17** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a sixth variation of the sixth embodiment of the present invention.

[0102] FIG. **18** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a seventh variation of the sixth embodiment of the present invention.

[0103] FIG. **19** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a seventh embodiment of the present invention.

[0104] FIG. **20** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a first variation of the seventh embodiment of the present invention.

[0105] FIG. **21** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a second variation of the seventh embodiment of the present invention.

[0106] FIG. **22** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a third variation of the seventh embodiment of the present invention.

[0107] FIG. **23** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fourth variation of the seventh embodiment of the present invention.

[0108] FIG. **24** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fifth variation of the seventh embodiment of the present invention.

[0109] FIG. **25** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a sixth variation of the seventh embodiment of the present invention.

[0110] FIG. **26** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a seventh variation of the seventh embodiment of the present invention.

[0111] FIG. **27** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to an eighth embodiment of the present invention.

[0112] FIG. **28** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a first variation of the eighth embodiment of the present invention.

[0113] FIG. **29** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a second variation of the eighth embodiment of the present invention.

[0114] FIG. **30** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a ninth embodiment of the present invention.

[0115] FIG. **31** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a first variation of the ninth embodiment of the present invention.

[0116] FIG. **32** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a second variation of the ninth embodiment of the present invention.

[0117] FIG. **33** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a tenth embodiment of the present invention.

[0118] FIG. **34** A graph showing a relationship between the wavelength and transmittance of light of a sealing material where the proportion of nano-particles in a matrix material is 30% by volume, in the semiconductor light-emitting device of the tenth embodiment of the present invention.

[0119] FIG. **35** A graph showing spectra of emitted light in the semiconductor light-emitting device of the tenth embodiment of the present invention.

[0120] FIG. **36** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fourth variation of the tenth embodiment of the present invention.

[0121] FIG. **37** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fifth variation of the tenth embodiment of the present invention.

[0122] FIG. **38** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a sixth variation of the tenth embodiment of the present invention.

[0123] FIG. **39** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to an eleventh embodiment of the present invention.

[0124] FIG. **40** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fourth variation of the eleventh embodiment of the present invention.

[0125] FIG. **41** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a fifth variation of the eleventh embodiment of the present invention.

[0126] FIG. **42** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a twelfth embodiment of the present invention.

[0127] FIG. **43** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a thirteenth embodiment of the present invention.

[0128] FIG. **44** A schematic cross-sectional view of a structure of a semiconductor light-emitting device according to a variation of the thirteenth embodiment of the present invention.

[0129] FIG. **45** A schematic cross-sectional view showing a conventional semiconductor light-emitting device.

DESCRIPTION OF THE REFERENCE CHARACTERS

[0130] **10** semiconductor light-emitting device
[0131] **11**A first lead frame
[0132] **11**B second lead frame
[0133] **12** LED chip
[0134] **13** chip fixing paste material
[0135] **14**A first electrode
[0136] **14**B second electrode
[0137] **15**A first wire
[0138] **15**B second wire
[0139] **16** sealing portion
[0140] **16***a* matrix material
[0141] **16***b* nano-particle (first nano-particle)
[0142] **16***b***1** primary nano-particle
[0143] **16***b***2** complex nano-particle
[0144] **16***c* fluorescent material
[0145] **16***d* sealing material
[0146] **17***b* second nano-particle
[0147] **20** semiconductor light-emitting device
[0148] **25** resin material
[0149] **26** sealing portion
[0150] **27** fluorescent material layer
[0151] **26**A first sealing portion
[0152] **26**B second sealing portion
[0153] **30** semiconductor light-emitting device
[0154] **30**A semiconductor light-emitting device
[0155] **30**B semiconductor light-emitting device
[0156] **30**C semiconductor light-emitting device
[0157] **30**D semiconductor light-emitting device
[0158] **30**E semiconductor light-emitting device
[0159] **30**F semiconductor light-emitting device
[0160] **30**G semiconductor light-emitting device
[0161] **31** substrate
[0162] **32**A first wiring
[0163] **32**B second wiring
[0164] **40** semiconductor light-emitting device
[0165] **40**A semiconductor light-emitting device
[0166] **40**B semiconductor light-emitting device
[0167] **40**C semiconductor light-emitting device
[0168] **40**D semiconductor light-emitting device
[0169] **40**E semiconductor light-emitting device
[0170] **40**F semiconductor light-emitting device
[0171] **41**A first bump
[0172] **41**B second bump
[0173] **50** semiconductor light-emitting device
[0174] **50**A semiconductor light-emitting device
[0175] **50**B semiconductor light-emitting device
[0176] **50**C semiconductor light-emitting device
[0177] **50**D semiconductor light-emitting device
[0178] **50**E semiconductor light-emitting device
[0179] **50**F semiconductor light-emitting device
[0180] **50**G semiconductor light-emitting device
[0181] **50**H semiconductor light-emitting device
[0182] **50**I semiconductor light-emitting device
[0183] **50**J semiconductor light-emitting device
[0184] **50**K semiconductor light-emitting device
[0185] **50**L semiconductor light-emitting device
[0186] **51** case material
[0187] **51***a* hollow portion
[0188] **51***b* interstice portion
[0189] **52**A first lead
[0190] **52**B second lead
[0191] **53** sub-mount material
[0192] **54**A first sub-mount electrode
[0193] **54**B first sub-mount electrode
[0194] **55** paste material
[0195] **60**A semiconductor light-emitting device
[0196] **60**B semiconductor light-emitting device
[0197] **60**C semiconductor light-emitting device
[0198] **60**D semiconductor light-emitting device
[0199] **60**E semiconductor light-emitting device
[0200] **70** (first) lens
[0201] **71** second lens
[0202] **80** semiconductor light-emitting device
[0203] **80**A semiconductor light-emitting device
[0204] **81** reflector

[0205] **81***a* reflection portion

[0206] **81***b* interstice portion

BEST MODE FOR CARRYING OUT THE INVENTION

First Embodiment

[0207] A semiconductor light-emitting device according to a first embodiment of the present invention will be described with reference to the accompanying drawings.

[0208] FIG. **1** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the first embodiment of the present invention. As shown in FIG. **1**, in the white LED device **10** of the first embodiment, an LED chip **12** is fixed and held via a chip fixing paste material **13**, such as a Ag paste material, an insulating paste material or the like, to a bottom surface of a cup-shaped die pad portion provided at an upper end portion of a first lead frame **11**A.

[0209] As the LED chip **12**, an LED chip is employed which is formed of, for example, a GaN-based compound semiconductor, and emits light having a wavelength in blue to ultraviolet regions.

[0210] A first electrode **14**A and a second electrode **14**B are formed on an upper surface of the LED chip **12**. The first electrode **14**A is electrically connected via a first wire **15**A to the first lead frame **11**A, and the second electrode **14**B is electrically connected via a second wire **15**B to a second lead frame **11**B which is paired with the first lead frame **11**A.

[0211] The LED chip **12** is sealed by a sealing portion **16** which is molded in the shape of a bullet so that the die pad portion of the first lead frame **11**A and an upper end portion of the second lead frame **11**B are covered.

[0212] The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0213] Light having a wavelength in blue to ultraviolet regions radiated from the LED chip **12** (hereinafter referred to as radiated light) excites the fluorescent material **16***c* located on an emission pathway in the sealing portion **16**. Excited light and the radiated light are mixed, or excited light waves having a plurality of colors are mixed, so that white light is obtained from the white LED device **10**.

[0214] FIG. **2** is a partially enlarged view of the sealing portion **16**. As shown in FIG. **2**, the nano-particles **16***b* made of an inorganic material include primary nano-particles **16***b***1** and complex nano-particles **16***b***2** which are aggregates of the primary nano-particles **16***b***1**. Therefore, the uniform distribution of the nano-particles **16***b* in the matrix material **16***a* means that the primary nano-particles **16***b***1** and the complex nano-particles **16***b***2** are substantially uniformly distributed, independently of their locations.

[0215] Examples of the matrix material **16***a* include a resin material which is an organic polymer material and is transparent to visual light (e.g., an epoxy resin, an acrylic resin, a cycloolefin resin, etc.), and a resin material which is an inorganic polymer material (e.g., a silicone resin, etc.).

[0216] Here, the effective particle size of the nano-particle **16***b* is set to be smaller than or equal to ¼ of the wavelength of radiated light from the LED chip **12**, i.e., the wavelength in the matrix material **16***a*.

[0217] For example, it is assumed that the wavelength of radiated light from the LED chip **12** is 400 nm in the air, and the matrix material **16***a* is an epoxy resin. In this case, since the epoxy resin has a refractive index of about 1.5, the wavelength of radiated light in the matrix material **16***a* is 267 nm. Therefore, when the effective particle size of the nano-particle **16***b* is caused to be smaller than or equal to 67 nm, the size can be set to be smaller than or equal to ¼ of the wavelength in the matrix material **16***a*.

[0218] Note that the effective particle size of the nano-particle **16***b* is not limited to ¼ or less of the wavelength in the matrix material **16***a*. If the effective particle size of the nano-particle **16***b* is set to be 1 nm or more and 100 nm or less, the effect of the present invention can be obtained. In order to obtain a more sufficient level of transparency to radiated light having a wavelength in blue to ultraviolet regions, the effective particle size of the nano-particle **16***b* may be preferably 1 nm or more and 50 nm or less.

[0219] In this case, if the particle size of the nano-particle is less than 1 nm, then when the nano-particle is made of a material which exhibits a quantum effect, fluorescent light may be generated, thereby affecting characteristics. Note that the particle size and the effective particle size of the nano-particle **16***b* added to the matrix material **16***a* can be determined by an electron microscope or the like.

[0220] The particle size of the primary nano-particle **16***b***1** is preferably 1 nm or more and 100 nm or less, and more preferably, the substantial effective particle size is 1 nm or more and 50 nm or less. Note that the value of the effective particle size of the primary nano-particle **16***b***1** can be obtained by particle size measurement employing a particle size distribution analyzer in solution, or in addition, particle size measurement employing a gas adsorption method in powder, or particle size measurement in which observation is performed using an electron microscope.

[0221] More preferably, if the primary nano-particles **16***b***1** have an average particle size of 1 nm or more and 10 nm or less, and almost all primary nano-particles **16***b***1** are uniformly distributed without aggregation, Rayleigh scattering is more reduced, preferably resulting in a sufficient level of transparency. In this state, the uniform distribution can be confirmed by observing the composite material using a transmission electron microscope.

[0222] The effective particle size will be now described with reference to FIG. **3**. In FIG. **3**, the horizontal axis represents the particle sizes of the nano-particles **16***b*, the left vertical axis represents the frequencies of the nano-particles **16***b* with respect to the particle sizes on the horizontal axis, and the right vertical axis represents the cumulative frequencies of the particle sizes. The effective particle size refers to a particle size range B in which cumulative frequencies are present within a range A which covers 50% of the particle size frequency distribution (particle frequencies) of all nano-particles **16***b* around a center particle size (median size: d50) which is a particle size whose cumulative frequency is 50% in the particle size frequency distribution. The same is true of the effective particle size of the primary nano-particle **16***b***1**. The precise value of the effective particle size may require measurement of, for example, 200 or more nano-particles **16***b* or primary nano-particles **16***b***1**.

[0223] The nano-particle **16***b* may be, for example, made of at least one type of inorganic material selected from the group consisting of inorganic oxides, metal nitrides, metal carbides, carbon compounds, and sulfides.

[0224] Examples of inorganic oxides include titanium oxide (refractive index: 2.2 to 2.5), tantalum oxide (refractive index: 2.0 to 2.3), niobium oxide (refractive index: 2.1 to 2.3), tungsten oxide (refractive index: 2.2), zirconium oxide (refractive index: 2.1), zinc oxide (refractive index: 1.9 to 2.0), indium oxide (refractive index: 2.0), tin oxide (refractive index: 2.0), hafnium oxide (refractive index: 2.0), yttrium oxide (refractive index: 1.9), silicon oxide (refractive index: 1.4 to 1.5), aluminum oxide (refractive index: 1.7 to 1.8), and the like. A composite inorganic oxide of these can also be used. Examples of metal nitrides include silicon nitride (refractive index: 1.9 to 2.0) and the like. Examples of metal carbides include silicon carbide (refractive index: 2.6) and the like. Examples of carbon compounds include inorganic materials having translucency, such as diamond (refractive index: 3.0), diamond-like carbon (refractive index: 3.0), and the like, though they are made only of carbon. Examples of sulfides include copper sulfide, tin sulfide, and the like. Note that a refractive index added to the name of each inorganic material indicates a refractive index with respect to radiated light from the LED chip **12**, i.e., radiated light having a wavelength in blue to ultraviolet regions.

[0225] Further, the nano-particle **16***b* may be an inorganic particle which includes, as a major ingredient, at least one oxide selected from the group consisting of titanium oxide, tantalum oxide, zirconium oxide, and zinc oxide described above as an inorganic compound for causing the sealing material **16***d* to have a high refractive index. These inorganic particles are easily available as many types of commercial products.

[0226] Note that an inorganic compound which is likely to exhibit a photocatalytic action due to ultraviolet light, such as titanium oxide, needs to have the rutile crystal structure, but not the anatase crystal structure having a strong photocatalytic action, or needs to be amorphous, or the surface of a nano-particle made of such an inorganic compound needs to be modified by an inorganic compound having an inactive photocatalytic action, such as silicon oxide (SiO_2), aluminum oxide (alumina: Al_2O_3) or the like.

[0227] The proportion of the nano-particles **16***b* in the sealing material **16***d* (composite material) is preferably 5% by volume or more and 60% by volume or less. If the proportion of the nano-particles **16***b* is excessively high, the transparency of the sealing material **16***d* decreases. Conversely, if the proportion of the nano-particles **16***b* is excessively low, the effect of addition of the nano-particles **16***b* is small.

[0228] FIG. **4** shows the results of calculation of changes in the refractive indices n_c of composite materials with respect to the proportion of nano-particles **16***b* in sealing materials **16***d* (the composite materials), where, for example, the matrix materials **16***a* are made of materials having refractive indices of 1.4, 1.5 and 1.6, respectively, and the nano-particle **16***b* is made of titanium oxide (TiO_2) (refractive index: 2.4). The calculation is performed using Expression (1) below (Maxwell-Garnett Theory). Note that the refractive index of a composite material refers to an effective refractive index when the composite material is considered as a medium having a single refractive index.

$$n_c^2=n_2^2\times\{n_1^2+2n_2^2+2P_1(n_1^2-n_2^2)\}/\{n_1^2+2n_2^2-P_1(n_1^2-n_2^2)\} \quad (1)$$

[0229] In Expression (1), n_c represents the refractive index of the composite material, n_1 represents the refractive index of the nano-particle **16***b*, n_2 represents the refractive index of the matrix material **16***a*, and P_1 represents the proportion (by volume) of the nano-particles **16***b* in the composite material.

[0230] As can be seen from FIG. **4**, the refractive index of the composite material may be caused to be 1.8 or more by setting the proportion of the nano-particles **16***b* in the composite material to be 46% by volume, 37% by volume, or 28% by volume when the refractive index of the matrix material **16***a* is 1.4, 1.5, or 1.6, respectively. Here, since general optical resins have refractive indices ranging from 1.4 to 1.7, it is considerably difficult to attain a refractive index exceeding 1.7 (e.g., 1.8 or more) when only optical resins are used. Therefore, the proportion of the nano-particles **16***b* in the composite material is preferably 5% by volume or more and 60% by volume or less, though the valid range varies depending on the material properties of the matrix material **16***a* and the nano-particle **16***b*. More preferably, the proportion is 10% by volume or more and 50% by volume or less. Further, when a general-purpose optical resin having a refractive index of 1.4 to 1.55 is used as the matrix material **16***a*, the proportion is more preferably about 20% by volume or more and 40% by volume or less.

[0231] The fluorescent material **16***c* may be a fluorescent material with which yellow light is obtained, such as YAG:Ce or the like, when the LED chip **12** outputs radiated light of blue. When radiated light in a violet region to an ultraviolet region is output, a plurality of types of fluorescent materials are used as the fluorescent material **16***c*. Specifically, Y_2O_2S:Eu can be used for red; ZnS:Cu, Al or (Ba, Mg)$Al_{10}O_{17}$:Eu, Mn can be used for green; and (Sr, Ca, Ba, Mg)$_{10}(PO_4)_6C_{12}$:Eu or (Ba, Mg)$Al_{10}O_{17}$:Eu can be used for blue.

[0232] According to the semiconductor light-emitting device of the first embodiment, the nano-particles **16***b* made of an inorganic material are uniformly distributed in the sealing material **16***d* included in the sealing portion **16**, so that the light resistance and heat resistance of the sealing portion **16** are improved as compared to when the nano-particle **16***b* is not added. Also, since the effective particle size of the distributed nano-particles **16***b* is set to be ¼ or less of the wavelength of light radiated from the LED chip **12** (semiconductor chip), the transparency of the sealing portion **16** is not impaired, and therefore, the light extraction efficiency is not impaired.

[0233] Further, since the difference in thermal expansion coefficient between the sealing portion **16** and the LED chip **12** is smaller than when the nano-particle **16***b* is not added, the sealing portion **16** is unlikely to be peeled off the LED chip **12** and a crack is unlikely to occur in the sealing portion **16** (sealing material **16***d*).

[0234] Also, since the refractive index of the sealing portion **16** with respect to radiated light is higher than when the nano-particle **16***b* is not added, the light extraction efficiency is further improved.

[0235] Note that, if zinc oxide (ZnO), titanium oxide (TiO_2), or cerium oxide (CeO_2), which can absorb light in an ultraviolet region, is used as the nano-particle **16***b* added to the sealing portion **16**, then when the matrix material **16***a* of the sealing material **16***d* is an organic polymer material, such as an epoxy resin or the like, discoloring due to light in an ultraviolet region can be suppressed.

[0236] Further, when transparency is imparted to the chip fixing paste material **13**, radiated light from the LED chip **12** is not absorbed by the chip fixing paste material **13**, so that the light extraction efficiency is improved. Note that the chip fixing paste material **13** having transparency can be obtained

by causing a transparent paste material having, for example, an epoxy resin or a silicone resin as a major ingredient, a low-melting glass material, or a compound having a siloxane bond to react with each other using a catalyst (first step), subjecting the reaction product obtained in the first step to hydrolysis and dehydration-condensation (second step), and adding the nano-particle **16***b* for absorbing ultraviolet light to a low-temperature hardened glass material obtained by drying the product of the second step to obtain a composite material.

[0237] Also, by adding the nano-particle **16***b* to the chip fixing paste material **13**, the heat radiation performance of the chip fixing paste material **13** is improved, and since ultraviolet light is absorbed by the nano-particle **16***b*, the light resistance (UV resistance) of the chip fixing paste material **13** is also improved.

Second Embodiment

[0238] Hereinafter, a semiconductor light-emitting device according to a second embodiment of the present invention will be described with reference to the drawings.

[0239] FIG. **5** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the second embodiment of the present invention. Note that the same parts as those shown in FIG. **1** are indicated by the same symbols and will not be described.

[0240] As shown in FIG. **5**, in the semiconductor light-emitting device **20** of the second embodiment, the sealing portion **26** comprises a first sealing portion **26**A which directly covers an LED chip **12** held on a die pad portion of a first lead frame **11**A, and a second sealing portion **26**B in the shape of a bullet which covers upper end portions of the first lead frame **11**A (including the first sealing portion **26**A) and a second lead frame **11**B.

[0241] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including the nano-particles **16***b* of the first embodiment. The second sealing portion **26**B comprises a resin material **25** into which a fluorescent material **16***c* is kneaded. The resin material **25** may be the same material that is used for the matrix material **16***a* of the first embodiment.

[0242] According to the semiconductor light-emitting device **20** of the second embodiment, the first sealing portion **26**A made of the sealing material **16***d* which is a composite material is provided in a portion which is near the LED chip **12** and has a relatively high optical density, thereby making it possible to achieve a high level of light extraction efficiency from the LED chip **12** and high levels of light resistance and heat resistance as in the first embodiment.

[0243] Also, the second sealing portion **26**B made of the resin material **25** having a higher level of transparency than that of the sealing material **16***d* is provided at a portion which is at a distance from the LED chip **12** and has a relatively low optical density, covering the first sealing portion **26**A, so that the light transmittance of the second sealing portion **26**B can be improved. As a result, the light extraction efficiency from the semiconductor light-emitting device **20** can be improved.

[0244] Note that, if the radiated light of the LED chip **12** has a wavelength longer than that in a blue region, then when zinc oxide, titanium oxide, or cerium oxide, which can absorb ultraviolet light, is used as the nano-particle **16***b* added to the first sealing portion **26**A, the degradation of the matrix material **16***a* included in the first sealing portion **26**A due to ultraviolet light can be suppressed. As a result, as the matrix material **16***a*, a material which has an excellent level of transparency but is likely to be changed into yellow due to ultraviolet light, such as an epoxy resin or the like, can be used.

Third Embodiment

[0245] Hereinafter, a semiconductor light-emitting device according to a third embodiment of the present invention will be described with reference to the drawings.

[0246] FIG. **6** shows a schematic cross-sectional view of a white LED device which is the semiconductor light-emitting device of the third embodiment of the present invention. Also here, the same parts as those shown in FIG. **1** are indicated by the same symbols and will not be described.

[0247] As shown in FIG. **6**, in the semiconductor light-emitting device **30** of the third embodiment, an LED chip **12** is provided on a printed wiring board which has a substrate **31**, and a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31**.

[0248] Specifically, the LED chip **12** is fixed via a chip fixing paste material **13** onto the first wiring **32**A. Of a first electrode **14**A and a second electrode **14**B formed on an upper surface of the LED chip **12**, the first electrode **14**A is electrically connected via a first wire **15**A to the first wiring **32**A, and the second electrode **14**B is electrically connected a the second wire **15**B to the second wiring **32**B.

[0249] The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. The materials constituting the sealing portion **16** may be similar to those constituting the sealing portion **16** of the first embodiment.

[0250] Surroundings of the LED chip **12** which is electrically connected to the first wiring **32**A and the second wiring **32**B are sealed by the sealing portion **16** on the printed wiring board.

[0251] Note that the first wiring **32**A and the second wiring **32**B are formed by, for example, forming a wiring made of a copper (Cu) thin film on the substrate **31** by a plating method, and growing nickel (Ni) and gold (Au) successively on the formed wiring by a plating method.

[0252] Thus, the semiconductor light-emitting device **30** of the third embodiment is achieved by mounting the LED chip **12** on the printed wiring board, and thereafter, transfer molding a material obtained by mixing the composite material of the matrix material **16***a* and the nano-particle **16***b* with the fluorescent material **16***c*.

[0253] Thereby, also in the semiconductor light-emitting device **30** of the third embodiment, the light resistance and heat resistance of the sealing portion **16** are improved, and the light extraction efficiency is also improved, as in the semiconductor light-emitting device **10** of the first embodiment.

Fourth Embodiment

[0254] Hereinafter, a semiconductor light-emitting device according to a fourth embodiment of the present invention will be described with reference to the drawings.

[0255] FIG. **7** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the fourth embodiment of the present invention. Also here, the same parts as those shown in FIG. **1** are indicated by the same symbols and will not be described.

[0256] As shown in FIG. **7**, in the semiconductor light-emitting device **40** of the fourth embodiment, an LED chip **12** is mounted on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31**, using a so-called flip-chip (face-down) mounting method, where an upper surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0257] Specifically, of a first electrode **14**A and a second electrode **14**B which are formed in the LED chip **12** and are each opposed to the substrate **31**, the first electrode **14**A is electrically connected via a first bump **41**A to the first wiring **32**A, and the second electrode **14**B is electrically connected via a second bump **41**B to the second wiring **32**B.

[0258] Surroundings of the LED chip **12** which is electrically connected to the first wiring **32**A and the second wiring **32**B are sealed on the printed wiring board by a sealing portion **16**.

[0259] The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. The materials constituting the sealing portion **16** may be similar to those constituting the sealing portion **16** of the first embodiment.

[0260] Note that, for example, gold (Au) can be used as a constituent material for the first bump **41**A and the second bump **41**B.

[0261] Thus, the semiconductor light-emitting device **40** of the fourth embodiment is achieved by flip-chip mounting the LED chip **12** on the printed wiring board, and thereafter, transfermolding a material obtained by mixing the composite material of the matrix material **16***a* and the nano-particle **16***b* with the fluorescent material **16***c*.

[0262] Therefore, also in the semiconductor light-emitting device **40** of the fourth embodiment, the light resistance and heat resistance of the sealing portion **16** are improved, and the light extraction efficiency is also improved, as in the semiconductor light-emitting devices **10** and **30** of the first and third embodiments.

[0263] Also, in the semiconductor light-emitting device **40** of the fourth embodiment, the LED chip **12** is electrically connected to the printed wiring board via a bump, but not a wire. Therefore, the thickness can be reduced as compared to the semiconductor light-emitting device **30** of the third embodiment.

Fifth Embodiment

[0264] Hereinafter, a semiconductor light-emitting device according to a fifth embodiment of the present invention will be described with reference to the drawings.

[0265] FIG. **8** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the fifth embodiment of the present invention. Also here, the same parts as those shown in FIG. **1** are indicated by the same symbols and will not be described.

[0266] As shown in FIG. **8**, in the semiconductor light-emitting device **50** of the fifth embodiment, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a*. The case material **51** is a heat-resistant resin material, such as, for example, a liquid crystal polymer or the like. At least a first lead **52**A and a second lead **52**B are inserted and formed in the case material **51**. Note that, in view of reflection with respect to visual light, a white heat-resistant resin material is preferably used.

[0267] The first lead **52**A and the second lead **52**B are exposed from the bottom surface of the hollow portion **51***a* of the case material **51**, and the LED chip **12** is fixed via a chip fixing paste material **13** to an exposed region of the first lead **52**A.

[0268] Of a first electrode **14**A and a second electrode **14**B formed on an upper surface of the LED chip **12**, the first electrode **14**A is electrically connected via a first wire **15**A to the first lead **52**A, and the second electrode **14**B is electrically connected via a second wire **15**B to the second lead **52**B.

[0269] In the fifth embodiment, the LED chip **12** fixed onto the bottom surface of the hollow portion **51***a* of the case material **51**, is sealed by filling the hollow portion **51***a* of the case material **51** with the sealing portion **16**.

[0270] The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. The materials constituting the sealing portion **16** may be similar to those constituting the sealing portion **16** of the first embodiment.

[0271] Note that, here, portions outside the case material **51** of the first lead **52**A and the second lead **52**B are each in the shape of a so-called Gull Wing (GW) type terminal. Note that the outer shape of each of the leads **52**A and **52**B is not limited to the GW type, and may be molded in a J shape.

[0272] Thus, also in the semiconductor light-emitting device **50** of the fifth embodiment, the light resistance and heat resistance of the sealing portion **16** are improved, and the light extraction efficiency is also improved, as in the semiconductor light-emitting devices **10**, **30** and **40** of the first, third and fourth embodiments.

[0273] Note that, instead of the sealing portions **16** of the third, fourth and fifth embodiments, the LED chip **12** may be directly covered with a sealing material **16***d* including nano-particles **16***b* made of an inorganic material, and the sealing material **16***d* may be covered with a matrix material **16***a* including a fluorescent material **16***c*, as with the first sealing portion **26**A and the second sealing portion **26**B of the second embodiment.

[0274] Also, in the first to fifth embodiments, a predetermined space may be provided partly between the composite material and the semiconductor chip.

[0275] FIG. **9**(*a*) shows a relationship between the refractive index of the sealing portion **16** and the change rate of the total luminous flux of radiated light, which was obtained by simulation of each material for the substrate included in the LED chip **12** of the semiconductor light-emitting device **50** of the fifth embodiment. FIG. **9**(*b*) shows a relationship between the refractive index of the sealing portion **16** and total luminous flux, which was obtained by similar simulation. Here, the substrate materials which were used in the simulation are shown in [Table 1]. Also, the refractive index of each substrate material in [Table 1] is a representative value in the visual light region for the material.

TABLE 1

Substrate materials	Refractive index
GaN	2.5
ZnSe	2.5

TABLE 1-continued

Substrate materials	Refractive index
SiC	2.6
Sapphire	1.7
GaP	3.3
InGaAlP	3.45
GaAs	3.66
ZnO	2.15

[0276] As can be seen from FIGS. **9**(*a*) and **9**(*b*), the refractive index of the sealing portion **16** is preferably 1.2 or more and 2.5 or less. Also, when zinc oxide (ZnO), gallium nitride (GaN), silicon carbide (SiC) or the like, which has a refractive index of more than 2.0, is used as the substrate material, the refractive index of the sealing portion **16** is preferably 1.4 or more and 2.2 or less, more preferably 1.6 or more and 2.0 or less.

Sixth Embodiment

[0277] Hereinafter, a semiconductor light-emitting device according to a sixth embodiment of the present invention will be described with reference to the drawings.

[0278] FIG. **10** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the sixth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **1** and **6** are indicated by the same symbols and will not be described.

[0279] As shown in FIG. **10**, in the semiconductor light-emitting device **30**A of the sixth embodiment, an LED chip **12** is provided on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31**, by so-called junction-up (face-up) mounting, where a rear surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0280] A sealing portion **26** comprises a first sealing portion **26**A which is in the shape of a hemisphere and directly covers the semiconductor light-emitting device chip **12**, and a second sealing portion **26**B which is in the shape of a hemisphere and directly covers the first sealing portion **26**A.

[0281] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and first nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0282] The second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and second nano-particles **17***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. Here, materials for the first sealing portion **26**A and the second sealing portion **26**B may be similar to those for the sealing portion **16** of the first embodiment. Note that, in the sixth embodiment, the material for the first nano-particle **16***b* is selected which has a larger refractive index than that of the second nano-particle **17***b*.

[0283] When the LED chip **12** as well as the crystal growth substrate (epitaxial substrate) are made of a gallium nitride (GaN)-based semiconductor, the difference in refractive index between the sealing portion and the air is large even if the refractive index of the sealing portion is set to be about 1.8, which allows the highest extraction efficiency, by adding nano-particles to GaN, whose refractive index is about 2.5 as shown in [Table 1].

[0284] Therefore, in the sixth embodiment, the value of the refractive index of the first sealing portion **26**A near the LED chip **12** is set to be larger than the value of the refractive index of the second sealing portion **26**B far from the LED chip **12**. Specifically, as the second nano-particle **17***b* added to the second sealing portion **26**B, an inorganic material is used which has a refractive index smaller than the refractive index of the first nano-particle **16***b* added to the first sealing portion **26**A.

[0285] With this structure, the refractive index of the second sealing portion **26**B which contacts the air is smaller than the refractive index of the first sealing portion **26**A which contacts the LED chip **12**, so that the difference in refractive index between the second sealing portion **26**B and the air is reduced. Therefore, the total reflection of radiated light on an interface between the second sealing portion **26**B and the air can be reduced, thereby making it possible to improve the light resistance and heat resistance of the sealing portion **26**, and further improve the light extraction efficiency.

[0286] Also, in the sixth embodiment, the outer shapes of the first sealing portion **26**A and the second sealing portion **26**B are both shaped into a hemisphere by, for example, a potting method, so that the total reflection of radiated light is further reduced.

[0287] Although the fluorescent material **16***c* is here added to both the first sealing portion **26**A and the second sealing portion **26**B, the fluorescent material **16***c* may be added to only one of them.

[0288] (First Variation of Sixth Embodiment)

[0289] FIG. **11** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a first variation of the sixth embodiment of the present invention.

[0290] As shown in FIG. **11**, in the semiconductor light-emitting device **30**B of the first variation, a first sealing portion **26**A which covers an LED chip **12** has a cross-section having a quadrangular outer shape.

[0291] Thereby, in the case of this first sealing portion **26**A, a sealing material **16***d* can be formed by a printing method, resulting in an improvement in productivity.

[0292] (Second Variation of Sixth Embodiment)

[0293] FIG. **12** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a second variation of the sixth embodiment of the present invention.

[0294] As shown in FIG. **12**, in the semiconductor light-emitting device **30**C of the second variation, a first sealing portion **26**A which directly covers an LED chip **12** and a second sealing portion **26**B which covers the first sealing portion both have a cross-section having a quadrangular outer shape.

[0295] Thereby, in the case of this first sealing portion **26**A, a sealing material **16***d* can be formed by a printing method, and the second sealing portion **26**B can be formed by a transfermolding method, resulting in an improvement in productivity. In addition, the sealing portion **26** has a flat upper surface, thereby making it easy to handle the device.

[0296] (Third Variation of Sixth Embodiment)

[0297] FIG. **13** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor

light-emitting device according to a third variation of the sixth embodiment of the present invention.

[0298] As shown in FIG. **13**, in the semiconductor light-emitting device **30**D of the third variation, a first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, and a second sealing portion **26**B which covers the first sealing portion **26**A has a cross-section having a quadrangular outer shape.

[0299] Thereby, the total reflection is reduced by the first sealing portion **26**A having a hemispherical outer shape, and handling of the device is facilitated by the second sealing portion **26**B having a flat upper surface.

[0300] (Fourth Variation of Sixth Embodiment)

[0301] FIG. **14** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fourth variation of the sixth embodiment of the present invention.

[0302] As shown in FIG. **14**, in the semiconductor light-emitting device **50**A of the fourth variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0303] Here, a first sealing portion **26**A which directly covers the LED chip **12** and a second sealing portion **26**B which covers the first sealing portion **26**A both have a quadrangular cross-section.

[0304] In this variation, when a white heat-resistant resin material is used as the case material **51**, an inner wall of the case material **51** is further subjected to metallizing (deposition or the like of a metal, such as aluminum (Al) or the like), so that the inner wall surface of the case material **51** functions as a reflection surface. In addition, the inner wall surface of the case material **51** has a reverse taper shape which gradually becomes wider from a lower portion thereof to an upper portion thereof. Therefore, the light extraction efficiency of the sealing portion **26** is improved not only by the structure in which the refractive index difference between the first nano-particle **16***b* and the second nano-particle **17***b* is provided, but also by the case material **51** and its shape.

[0305] Note that, when the first sealing portion **26**A is formed by a printing method and cannot be directly printed onto the bottom surface of the hollow portion **51***a* of the case material **51**, the LED chip **12** may be previously mounted on a sub-mount material, the first sealing portion **26**A may be formed by the printing method, and thereafter, the sub-mount material may be mounted on the bottom surface of the case material **51**, for example.

[0306] FIGS. **15**(*a*) and **15**(*b*) show the results of simulation of a relationship between the refractive index of each of the first sealing portion **26**A and the second sealing portion **26**B and the light extraction efficiency in the semiconductor light-emitting device **50**A of the fourth variation of the sixth embodiment. Here, FIG. **15**(*a*) shows a case where GaN is used as a substrate material for the LED chip **12**, and FIG. **15**(*b*) shows a case where sapphire is used as the substrate material. Here, it is assumed that the first sealing portion **26**A has a thickness of 500 μm, and the second sealing portion **26**B has a thickness of 200 μm.

[0307] As can be seen from FIGS. **15**(*a*) and **15**(*b*), when the substrate of the LED chip **12** is made of GaN, the larger the refractive index of the first sealing portion **26**A, the higher the light extraction efficiency. When the substrate of the LED chip **12** is made of sapphire, the influence of a change in the refractive index of the first sealing portion **26**A is small.

[0308] Also, no matter whether the substrate is made of GaN or sapphire, the smaller the refractive index of the second sealing portion **26**B, the higher the light extraction efficiency, but the smaller the change rate of the light extraction efficiency with respect to the refractive index of the first sealing portion **26**A.

[0309] (Fifth Variation of Sixth Embodiment)

[0310] FIG. **16** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fifth variation of the sixth embodiment of the present invention.

[0311] As shown in FIG. **16**, in the semiconductor light-emitting device **50**B of the fifth variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a*.

[0312] Here, a first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, and a second sealing portion **26**B which covers the first sealing portion **26**A has a cross-section having a quadrangular outer shape.

[0313] Thereby, the reflection is reduced by the first sealing portion **26**A having a hemispherical outer shape, and the light extraction efficiency is improved by the case material **51**.

[0314] (Sixth Variation of Sixth Embodiment)

[0315] FIG. **17** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a sixth variation of the sixth embodiment of the present invention.

[0316] As shown in FIG. **17**, in the semiconductor light-emitting device **50**C of the sixth variation, nano-particles **16***b* added to a sealing material **16***d* for a second sealing portion **26**B and nano-particles **16***b* added to a sealing material **16***d* for a first sealing portion **26**A are caused to have the same composition, and in addition, the proportion of the nano-particles **16***b* in the sealing material **16***d* of the first sealing portion **26**A is caused to be higher than the proportion of the nano-particles **16***b* in the sealing material **16***d* of the second sealing portion **26**B. In other words, the added concentration of the nano-particles **16***b* in the second sealing portion **26**B is caused to be smaller than the added concentration of the nano-particles **16***b* in the first sealing portion **26**A. Here, the difference in added concentration may be provided by a concentration gradient or stepwise changes.

[0317] Also in this case, the refractive index of the second sealing portion **26**B is smaller than the refractive index of the first sealing portion **26**A.

[0318] Note that, in this variation, the nano-particles **16***b* added to the first sealing portion **26**A and the nano-particles **16***b* added to the second sealing portion **26**B are made of inorganic materials having the same composition and have different added concentrations. Instead of this, the nano-particles **16***b* added to the first sealing portion **26**A and the nano-particles **16***b* added to the second sealing portion **26**B may have different compositions and different added concentrations as long as the refractive index of the second sealing portion **26**B is smaller than the refractive index of the first sealing portion **26**A.

[0319] Although it has been assumed in FIG. **17** that the first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, the first sealing portion **26**A may have a cross-section having a quadrangular outer shape as in FIG. **14** described in the fourth variation of the sixth embodiment.

[0320] Also in the sixth embodiment and the first to third variations of the sixth embodiment, as in this variation, the nano-particle **17***b* added to the sealing material **16***d* of the second sealing portion **26**B may be replaced with the nano-particle **16***b* and may be caused to have the same composition as that of the nano-particle **16***b* added to the sealing material **16***d* of the first sealing portion **26**A, and the proportion of the nano-particles **16***b* in the sealing material **16***d* of the first sealing portion **26**A may be caused to be higher than the proportion of the nano-particles **16***b* in the sealing material **16***d* of the second sealing portion **26**B.

[0321] (Seventh Variation of Sixth Embodiment)

[0322] In the sixth embodiment and its variations, the fluorescent material **16***c* is added to both the first sealing portion **26**A and the second sealing portion **26**B. Alternatively, the fluorescent material **16***c* may be added to only one of the first sealing portion **26**A and the second sealing portion **26**B.

[0323] In a semiconductor light-emitting device SOD according to a seventh variation shown in FIG. **18**, a gallium phosphide (GaP)-based semiconductor, which can emit green light, is used for an LED chip **12**. In this case, the fluorescent material **16***c* does not need to be added to the sealing portion **26**.

[0324] When a GaP-based semiconductor is used for the LED chip **12**, a first electrode **14**A and a second electrode **14**B are formed on a lower surface and an upper surface of the LED chip **12**, respectively, and are opposed to each other. The first electrode **14**A is electrically connected via a chip fixing paste material **13** having conductivity, such as a Ag paste material or the like, to a first lead **52**A, and the second electrode **14**B is electrically connected via a wire **15**B to a second lead **52**B.

[0325] Although the sealing portion **26** has a double-layer structure including the first sealing portion **26**A and the second sealing portion **26**B in the sixth embodiment and its variations, the present invention is not limited to the double-layer structure and may have a multilayer structure having three or more layers. Note that, in the case of the multilayer structure having three or more layers, the refractive indices of the sealing portions need to be successively reduced with distance from the LED chip **12**.

Seventh Embodiment

[0326] Hereinafter, a semiconductor light-emitting device according to a seventh embodiment of the present invention will be described with reference to the drawings.

[0327] FIG. **19** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the seventh embodiment of the present invention. Also here, the same parts as those shown in FIGS. **1** and **7** are indicated by the same symbols and will not be described.

[0328] As shown in FIG. **19**, in the semiconductor light-emitting device **40**A of the seventh embodiment, an LED chip **12** is provided on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31** by flip-chip mounting, where an upper surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0329] A sealing portion **26** comprises a first sealing portion **26**A which is in the shape of a hemisphere and directly covers the semiconductor light-emitting device chip **12**, and a second sealing portion **26**B which is in the shape of a hemisphere and directly covers the first sealing portion **26**A.

[0330] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and first nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0331] The second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and second nano-particles **17***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. Here, the materials constituting the first sealing portion **26**A and the second sealing portion **26**B may be similar to the materials constituting the sealing portion **16** of the first embodiment. Note that a material for the first nano-particle **16***b* needs to be selected which has a larger refractive index than that of the second nano-particle **17***b*.

[0332] Thereby, also in the seventh embodiment, as in the sixth embodiment, the value of the refractive index of the first sealing portion **26**A near the LED chip **12** is caused to be larger than the value of the refractive index of the second sealing portion **26**B far from the LED chip **12**.

[0333] Specifically, with this structure, the refractive index of the second sealing portion **26**B which contacts the air is smaller than the refractive index of the first sealing portion **26**A which contacts the LED chip **12**, so that the difference in refractive index between the second sealing portion **26**B and the air is reduced. Therefore, the total reflection of radiated light on an interface between the second sealing portion **26**B and the air can be reduced, thereby making it possible to improve the light resistance and heat resistance of the sealing portion **26**, and further improve the light extraction efficiency.

[0334] Also, in this embodiment, the outer shapes of the first sealing portion **26**A and the second sealing portion **26**B are both shaped into a hemisphere by, for example, a potting method, so that the total reflection of radiated light is further reduced.

[0335] Although the fluorescent material **16***c* is added to both the first sealing portion **26**A and the second sealing portion **26**B in the seventh embodiment, the fluorescent material **16***c* may be added to only one of them.

[0336] (First Variation of Seventh Embodiment)

[0337] FIG. **20** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a first variation of the seventh embodiment of the present invention.

[0338] As shown in FIG. **20**, in the semiconductor light-emitting device **40**B of the first variation, a first sealing portion **26**A which directly covers an LED chip **12** has a cross-section having a quadrangular outer shape.

[0339] Thereby, in the case of this first sealing portion **26**A, the sealing material **16***d* can be formed by a printing method, resulting in an improvement in productivity.

[0340] (Second Variation of Seventh Embodiment)

[0341] FIG. **21** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a second variation of the seventh embodiment of the present invention.

[0342] As shown in FIG. **21**, in the semiconductor light-emitting device **40**C of the second variation, a first sealing portion **26**A which directly covers an LED chip **12** and a

second sealing portion **26**B which covers the first sealing portion both have a cross-section having a quadrangular outer shape.

[0343] Thereby, in the case of this first sealing portion **26**A, the sealing material **16***d* can be formed by a printing method, and the second sealing portion **26**B can be formed by a transfermolding method, resulting in an improvement in productivity. In addition, the sealing portion **26** has a flat upper surface, thereby making it easy to handle the device.

[0344] (Third Variation of Seventh Embodiment)

[0345] FIG. **22** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a third variation of the seventh embodiment of the present invention.

[0346] As shown in FIG. **22**, in the semiconductor light-emitting device **40**D of the third variation, a first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, and a second sealing portion **26**B which covers the first sealing portion **26**A has a cross-section having a quadrangular outer shape.

[0347] Thereby, the total reflection is reduced by the first sealing portion **26**A having a hemispherical outer shape, and handling of the device is facilitated by the second sealing portion **26**B having a flat upper surface.

[0348] (Fourth Variation of Seventh Embodiment)

[0349] FIG. **23** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fourth variation of the seventh embodiment of the present invention.

[0350] As shown in FIG. **23**, in the semiconductor light-emitting device **60** of the fourth variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by flip-chip mounting.

[0351] Here, a first sealing portion **26**A which directly covers the LED chip **12** and a second sealing portion **26**B which covers the first sealing portion **26**A both have a quadrangular cross-section.

[0352] In this variation, when a white heat-resistant resin material is used as the case material **51**, an inner wall surface of the case material **51** functions as a reflection surface. In addition, the inner wall surface of the case material **51** has a reverse taper shape which gradually becomes wider from a lower portion thereof to an upper portion thereof. Therefore, the light extraction efficiency of the sealing portion **26** is improved not only by the structure in which a difference in refractive index between a first nano-particle **16***b* and a second nano-particle **17***b* is provided, but also by the case material **51** and its shape.

[0353] (Fifth Variation of Seventh Embodiment)

[0354] FIG. **24** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fifth variation of the seventh embodiment of the present invention.

[0355] As shown in FIG. **24**, in the semiconductor light-emitting device **60**A of the fifth variation, an LED chip **12** is provided via a sub-mount material **53** on a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by flip-chip mounting.

[0356] The LED chip **12** is flip-chip mounted on the sub-mount material **53** made of, for example, a ceramic, on an upper surface of which a first sub-mount electrode **54**A and a second sub-mount electrode **54**B are formed.

[0357] Specifically, a first sealing portion **26**A is formed by a printing method, covering the LED chip **12**. The sub-mount material **53** having the LED chip **12** sealed by the first sealing portion **26**A, is mounted on a bottom surface of a case material **51**. Of the first sub-mount electrode **54**A and the second sub-mount electrode **54**B formed on the upper surface of the sub-mount material **53**, the first sub-mount electrode **54**A is electrically connected via a first wire **15**A to a first lead **52**A, and the second sub-mount electrode **54**B is electrically connected via a second wire **15**B to a second lead **52**B.

[0358] Note that a zener diode may be used as the sub-mount material **53**.

[0359] Also, although the first sealing portion **26**A of FIG. **24** has a cross-section having a quadrangular outer shape, the outer shape of the first sealing portion **26**A may have a hemispherical outer shape.

[0360] (Sixth Variation of Seventh Embodiment)

[0361] FIG. **25** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a sixth variation of the seventh embodiment of the present invention.

[0362] As shown in FIG. **25**, in the semiconductor light-emitting device **60**B of the sixth variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a*.

[0363] Here, a first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, and a second sealing portion **26**B which covers the first sealing portion **26**A has a cross-section having a quadrangular outer shape.

[0364] Thereby, the total reflection is reduced by the first sealing portion **26**A having a hemispherical outer shape, and the light extraction efficiency is improved by the case material **51**.

[0365] (Seventh Variation of Seventh Embodiment)

[0366] FIG. **26** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a seventh variation of the seventh embodiment of the present invention.

[0367] As shown in FIG. **26**, in the semiconductor light-emitting device **60**C of the seventh variation, nano-particles **16***b* added to a sealing material **16***d* of a second sealing portion **26**B and nano-particles **16***b* added to a sealing material **16***d* of a first sealing portion **26**A are caused to have the same composition, and in addition, the proportion of the nano-particles **16***b* in the sealing material **16***d* of the first sealing portion **26**A is caused to be higher than the proportion of the nano-particles **16***b* in the sealing material **16***d* of the second sealing portion **26**B. In other words, the added concentration of the nano-particles **16***b* in the second sealing portion **26**B is caused to be smaller than the added concentration of the nano-particles **16***b* in the first sealing portion **26**A. Here, the difference in added concentration may be provided by a concentration gradient or stepwise changes.

[0368] Also in this case, the refractive index of the second sealing portion **26**B is smaller than the refractive index of the first sealing portion **26**A.

[0369] Note that, in this variation, the nano-particles **16***b* added to the first sealing portion **26**A and the nano-particles **16***b* added to the second sealing portion **26**B are made of inorganic materials having the same composition and have different added concentrations. Instead of this, the nano-particles **16***b* added to the first sealing portion **26**A and the nano-particles **16***b* added to the second sealing portion **26**B

may have different compositions and different added concentrations as long as the refractive index of the second sealing portion **26**B is smaller than the refractive index of the first sealing portion **26**A.

[0370] Although it has been assumed in FIG. **26** that the first sealing portion **26**A which directly covers the LED chip **12** has a hemispherical outer shape, the first sealing portion **26**A may have a cross-section having a quadrangular outer shape as in FIG. **23** described in the fourth variation of the seventh embodiment.

[0371] Also in the seventh embodiment and the first to third and fifth variations of the seventh embodiment, as in this variation, the nano-particle **17***b* added to the sealing material **16***d* of the second sealing portion **26**B may be replaced with the nano-particle **16***b* and may be caused to have the same composition as that of the nano-particle **16***b* added to the sealing material **16***d* of the first sealing portion **26**A, and the proportion of the nano-particles **16***b* in the sealing material **16***d* of the first sealing portion **26**A may be caused to be higher than the proportion of the nano-particles **16***b* in the sealing material **16***d* of the second sealing portion **26**B.

[0372] Although the fluorescent material **16***c* is added to both the first sealing portion **26**A and the second sealing portion **26**B in the seventh embodiment and its variations, the fluorescent material **16***c* may be added to only one of them.

[0373] Although the sealing portion **26** has a double-layer structure including the first sealing portion **26**A and the second sealing portion **26**B in the seventh embodiment and its variations, the present invention is not limited to the double-layer structure and may have a multilayer structure having three or more layers. Note that, in the case of the multilayer structure having three or more layers, the refractive indices of the sealing portions need to be successively reduced with distance from the LED chip **12** increases.

Eighth Embodiment

[0374] Hereinafter, a semiconductor light-emitting device according to an eighth embodiment of the present invention will be described with reference to the drawings.

[0375] FIG. **27** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the eighth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **1** and **6** are indicated by the same symbols and will not be described.

[0376] As shown in FIG. **27**, in the semiconductor light-emitting device **30**E of the eighth embodiment, an LED chip **12** is provided on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31**, using so-called junction-up (face-up) mounting, where a rear surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0377] A sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. The sealing portion **16** may comprise the same materials which are included in the sealing portion **16** of the first embodiment. Note that, in the eighth embodiment, the proportion of the nano-particles **16***b* in the composite material is caused to be higher in an inner region thereof near the LED chip **12** than in an outer region thereof.

[0378] When the LED chip **12** as well as the crystal growth substrate (epitaxial substrate) are made of a gallium nitride (GaN)-based semiconductor, the difference in refractive index between the sealing portion and the air is large even if the refractive index of the sealing portion is set to be about 1.8, which allows the highest extraction efficiency, by adding nano-particles to GaN, whose refractive index is about 2.5 as shown in [Table 1].

[0379] Therefore, in the eighth embodiment, the value of the refractive index of the inner region near the LED chip **12** of the sealing portion **16** is set to be larger than the value of the refractive index of the outer region. Specifically, the concentration of the nano-particles **16***b* added to the sealing portion **16** is caused to be high in the inner region and is decreased outward, so that the refractive index of the outer region of the sealing portion **16** is caused to be smaller than that of the inner region. In this case, the concentration of the nano-particles **16***b* may be decreased from the inner region to the outer region gradually or stepwise.

[0380] Therefore, with this structure, the refractive index of the outer region which contacts the air is smaller than the refractive index of the inner region which contacts the LED chip **12**, so that the difference in refractive index between the outer region of the sealing portion **16** and the air is reduced. Therefore, the total reflection of radiated light on an interface between the sealing portion **16** and the air can be reduced, thereby making it possible to improve the light resistance and heat resistance of the sealing portion **16**, and further improve the light extraction efficiency.

[0381] Also, in this embodiment, the outer shape of the sealing portion **16** is shaped into a hemisphere by, for example, a potting method, so that the total reflection of radiated light is further reduced. Here, in order to cause the added concentration of the nano-particles **16***b* to be high in the inner region and low in the outer region, a liquid composite material before curing is potted in a plurality of divided amounts, for example. Specifically, potting may be performed so that the added proportion of the nano-particles **16***b* in a composite material for the outer region is smaller than the added proportion of the nano-particles **16***b* in a composite material for the inner region. In this case, as the nano-particles **16***b* in the second time and later, other nano-particles made of an inorganic material having a refractive index smaller than the refractive index of the nano-particle **16***b* in the first time, may be selected. Thereafter, curing is performed to obtain the sealing portion **16** made of the composite material, thereby making it possible to form the structure of this embodiment.

[0382] Although the fluorescent material **16***c* is added to the sealing portion **16** in the eighth embodiment, the fluorescent material **16***c* does not need to be added to the sealing portion **16** in the case of a green LED device or the like in which a GaP-based semiconductor is used for the LED chip **12**.

[0383] (First Variation of Eighth Embodiment)

[0384] FIG. **28** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a first variation of the eighth embodiment of the present invention.

[0385] As shown in FIG. **28**, in the semiconductor light-emitting device **30**F of the first variation, a sealing portion **16** in which the added concentration of nano-particles **16***b* is gradually decreased outward has a cross-section having a quadrangular outer shape.

[0386] A sealing material **16***d* of the sealing portion **16** of this variation can be formed by performing, a plurality of times, a transfermolding method which causes the added concentration of the nano-particles **16***b* to be smaller in an outer portion of the sealing portion **16** than in an inner portion thereof.

[0387] (Second Variation of Eighth Embodiment)

[0388] FIG. **29** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a second variation of the eighth embodiment of the present invention.

[0389] As shown in FIG. **29**, in the semiconductor light-emitting device **50**E of the second variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0390] Here, a sealing portion **26**A of the LED chip **12** has a quadrangular cross-section.

[0391] In this variation, when a white heat-resistant resin material is used as the case material **51**, an inner wall of the case material **51** is further subjected to metallizing (deposition or the like of a metal, such as aluminum (Al) or the like), so that the inner wall surface of the case material **51** functions as a reflection surface. In addition, the inner wall surface of the case material **51** has a reverse taper shape which gradually becomes wider from a lower portion thereof to an upper portion thereof. Therefore, the light extraction efficiency of the sealing portion **26** is improved not only by providing a gradually decreasing refractive index difference in the sealing portion **16** by decreasing the added concentration of nano-particles **16** outward, but also by the case material **51** and its shape.

[0392] Note that the sealing portion **16** of this variation can be formed by performing a potting method a plurality of times.

Ninth Embodiment

[0393] Hereinafter, a semiconductor light-emitting device according to a ninth embodiment of the present invention will be described with reference to the drawings.

[0394] FIG. **30** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the ninth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **1** and **7** are indicated by the same symbols and will not be described.

[0395] As shown in FIG. **30**, in the semiconductor light-emitting device **40**E of the ninth embodiment, an LED chip **12** is provided on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31** by flip-chip mounting, where an upper surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0396] A sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*. The sealing portion **16** may comprise the same materials which are included in the sealing portion **16** of the first embodiment. Note that, in the ninth embodiment, the proportion of the nano-particles **16***b* in the composite material is caused to be higher in an inner region thereof near the LED chip **12** than in an outer region thereof.

[0397] Thereby, in the ninth embodiment, the value of the refractive index of the inner region near the LED chip **12** of the sealing portion **16** is set to be larger than the value of the outer region, as in the sixth and eighth embodiments.

[0398] Specifically, with this structure, the refractive index of the outer region which contacts the air is smaller than the refractive index of the inner region which contacts the LED chip **12**, so that the difference in refractive index between the outer region of the sealing portion **16** and the air is reduced. Therefore, the total reflection of radiated light on an interface between the sealing portion **16** and the air can be reduced, thereby making it possible to improve the light resistance and heat resistance of the sealing portion **16**, and further improve the light extraction efficiency. Here, the added concentration of the nano-particles **16***b* may be decreased from the inner region to the outer region gradually or stepwise.

[0399] Also, in this embodiment, the outer shape of the sealing portion **16** is shaped into a hemisphere by, for example, a potting method, so that the total reflection of radiated light is further reduced. Here, in order to cause the added concentration of the nano-particles **16***b* to be high in the inner region and low in the outer region, a liquid composite material before curing is potted in a plurality of divided amounts, for example. Specifically, potting may be performed so that the added proportion of the nano-particles **16***b* in a composite material for the outer region is smaller than the added proportion of the nano-particles **16***b* in a composite material for the inner region. In this case, as the nano-particles **16***b* in the second time and later, other nano-particles made of an inorganic material having a refractive index smaller than the refractive index of the nano-particle **16***b* in the first time, may be selected. Thereafter, curing is performed to obtain the sealing portion **16** made of the composite material, thereby making it possible to form the structure of this embodiment.

[0400] Also, in the ninth embodiment, the outer shape of the sealing portion **16** is shaped into a hemisphere by, for example, a potting method, so that the total reflection of radiated light is further reduced.

[0401] Although the fluorescent material **16***c* is here added to the sealing portion **16**, the fluorescent material **16***c* does not need to be added to the sealing portion **16** in the case of a green LED device or the like in which a GaP-based semiconductor is used for the LED chip **12**.

[0402] (First Variation of Ninth Embodiment)

[0403] FIG. **31** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a first variation of the ninth embodiment of the present invention.

[0404] As shown in FIG. **31**, in the semiconductor light-emitting device **40**F of the first variation, a sealing portion **16** in which the added concentration of nano-particles **16***b* is gradually decreased outward has a cross-section having a quadrangular outer shape.

[0405] A sealing material **16***d* of the sealing portion **16** of this variation can be formed by performing, a plurality of times, a transfermolding method which causes the added concentration of the nano-particles **16***b* to be smaller in an outer portion of the sealing portion **16** than in an inner portion thereof.

[0406] (Second Variation of Ninth Embodiment)

[0407] FIG. **32** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a second variation of the ninth embodiment of the present invention.

[0408] As shown in FIG. **32**, in the semiconductor light-emitting device **60**E of the second variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by flip mounting.

[0409] Here, a sealing portion **16** for the LED chip **12** has a quadrangular cross-section.

[0410] In this variation, when a white heat-resistant resin material is used as the case material **51**, an inner wall of the case material **51** is further subjected to metallizing (deposition or the like of a metal, such as aluminum (Al) or the like), so that the inner wall surface of the case material **51** functions as a reflection surface. In addition, the inner wall surface of the case material **51** has a reverse taper shape which gradually becomes wider from a lower portion thereof to an upper portion thereof. Therefore, the light extraction efficiency of the sealing portion **16** is improved not only by providing a gradually decreasing refractive index difference in the sealing portion **16** by decreasing the added concentration of the nano-particles **16***b* outward, but also by the case material **51** and its shape.

[0411] Note that the sealing portion **16** of this variation can be formed by performing a potting method a plurality of times.

[0412] Also, in this variation, as described in the fifth variation of the seventh embodiment, an LED chip **12** may be provided via a sub-mount material **53** on a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by flip-chip mounting.

Tenth Embodiment

[0413] FIG. **33** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a tenth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **6** and **10** are indicated by the same symbols and will not be described.

[0414] As shown in FIG. **33**, in the semiconductor light-emitting device **30**G of the tenth embodiment, an LED chip **12** is provided on a printed wiring board having a substrate **31** and at least a first wiring **32**A and a second wiring **32**B selectively formed on a front surface and a rear surface of the substrate **31**, using so-called junction-up (face-up) mounting, where a rear surface of the LED chip **12** is opposed to a major surface of the substrate **31**.

[0415] A sealing portion **26** comprises a first sealing portion **26**A which is in the shape of a hemisphere and directly covers the semiconductor light-emitting device chip **12**, and a second sealing portion **26**B which is in the shape of a hemisphere and directly covers the first sealing portion **26**A.

[0416] The first sealing portion **26**A comprises a resin material into which a fluorescent material **16***c* is kneaded. The second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*.

[0417] FIG. **34** shows a relationship between the wavelength and transmittance of light when zirconium oxide (ZrO_2) having a diameter of 3 nm to 10 nm is used as the nano-particle **16***b* added to the second sealing portion **26**B, and the proportion of the nano-particles **16***b* to the matrix material **16***a* is 30% by volume. It will be understood from FIG. **34** that the transmittance of light significantly decreases in a short-wavelength region. As used herein, this phenomenon is referred to as a "filter effect".

[0418] According to the semiconductor light-emitting device **30**G of the tenth embodiment, an effect similar to that of the first embodiment is obtained, and in addition, spectral components in a red region are relatively increased by the above-described filter effect as shown in FIG. **35**. Specifically, radiated light from the LED chip **12** and combined light excited by the fluorescent material **16***c* are scattered by the nano-particles **16***b*, so that spectral components in blue to ultraviolet regions are attenuated, resulting in a relative increase in the spectral components in the red region. Note that a semiconductor light-emitting device which was used for measurement has the structure of FIG. **23** in which the LED chip **12** is mounted on the case material **51**. Also, the radiated light of the LED chip **12** is blue light having a peak wavelength of 460 nm, and the excited light of the fluorescent material **16***c* is yellow light having a peak wavelength of 575 nm. Note that the fluorescent material **16***c* is a mixture of a fluorescent material for an orange color having a peak wavelength of 590 nm and a fluorescent material for a green color having a peak wavelength of 535 nm.

[0419] Thereby, as shown in [Table 2], an average color rendering index Ra increases, and color temperature decreases. Here, a high average color rendering index Ra indicates an excellent level of color reproducibility of an object illuminated under a light source, and low color temperature indicates a warm color of a light source.

TABLE 2

	Comparative Example	Invention 1	Invention 2
Thickness	none	0.2 mm	1 mm
Color temperature	4400 K	4400 K	3900 K
Ra	74	76	74

[0420] Here, the comparative example indicates a case where no second sealing portion **26**B is provided, the invention **1** indicates a case where the second sealing portion **26**B including the nano-particles **16***b* has a thickness of 0.2 mm, and the invention **2** indicates a case where the second sealing portion **26**B has a thickness of 1 mm.

[0421] As can be seen from Table 2, the invention **1** has an average color rendering index higher than that of the comparative example, and the invention **2** has a color temperature smaller by 400 K than that of the comparative example. Note that color temperature has a duv (difference from a black body locus on the chromaticity coordinates) of ±0.002.

[0422] Note that a fluorescent material which provides green light or yellow light may be added to both the first sealing portion **26**A and the second sealing portion **26**B (a first variation of the tenth embodiment). Even in this case, the nano-particle **16***b* added to the second sealing portion **26**B attenuates spectral components in blue to ultraviolet regions of combined light, so that spectral components in a red region relatively increase.

[0423] Also, a first fluorescent material which provides green light or yellow light may be added to the first sealing portion **26**A, and the nano-particle **16***b* and a second fluorescent material which provides red light may be added to the second sealing portion **26**B (second variation). In this case, green light or yellow light from the first fluorescent material is absorbed by the second fluorescent material for a red color, which is in turn excited, so that spectral components in a red

region are further increased. Thereby, the average color rendering index is further increased and the color temperature is further decreased.

[0424] Also, a first fluorescent material which provides red light may be added to the first sealing portion **26**A, and the nano-particle **16***b* and a second fluorescent material which provides green light or yellow light may be added to the second sealing portion **26**B (third variation). In this case, since the first fluorescent material for a red color does not absorb green light or yellow light which is emitted by the second fluorescent material, the conversion efficiency of radiated light from the LED chip **12** is improved.

[0425] Also, in the tenth embodiment and its variations, the refractive index of the first sealing portion **26**A is preferably caused to be lower than the refractive index of the LED chip, and the refractive index of the second sealing portion **26**B is preferably caused to be smaller than the refractive index of the first sealing portion **26**A, as in the sixth embodiment. In this case, the light extraction efficiency is improved.

[0426] Note that, when the wavelength of radiated light of the LED chip **12** ranges from a blue-violet region of 410 nm or less to an ultraviolet region of 380 nm or less, but not in a blue region, a fluorescent material for a blue color is added to at least the first sealing portion **26**A in addition to a fluorescent material for a green color and a fluorescent material for a red or yellow color, so that white combined light can be obtained.

[0427] Also, the outer shape of the semiconductor light-emitting device **30**G and the mounting method of the LED chip **12** are not limited to those of FIG. **33**, and may be similar to those of the second embodiment, the first to fifth variations of the sixth embodiment, or the first to sixth variations of the seventh embodiment.

[0428] (Fourth Variation of Tenth Embodiment)

[0429] FIG. **36** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fourth variation of the tenth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **14** are indicated by the same symbols and will not be described.

[0430] As shown in FIG. **36**, in the semiconductor light-emitting device **50**F of the fourth variation, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0431] A first sealing portion **26**A comprises a resin material into which a fluorescent material **16***c* is kneaded. A second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*.

[0432] The fourth variation is characterized in that the first sealing portion **26**A contacts the LED chip **12** and covers surroundings thereof, while the second sealing portion **26**B is provided on an upper end surface of the case **51** and in parallel with the bottom surface of the case **51**, so that an interstice portion **51***b* is formed between the first sealing portion **26**A and the second sealing portion **26**B.

[0433] Further, a first lens **70** which covers the first sealing portion **26**A is formed in the interstice portion **51***b*, and a second lens portion **71** which covers the second sealing portion **26**B is formed over the second sealing portion **26**B. Here, the first lens **70** and the second lens **71** can be made of, for example, a silicone resin, an epoxy resin, an olefin resin, an acrylic resin, an urea resin, an imide resin, a polycarbonate resin, glass or the like. Note that the second lens **71** does not necessarily need to be provided.

[0434] Thus, according to this variation, even when the interstice portion **51***b* is provided between the first sealing portion **26**A and the second sealing portion **26**B, the filter effect can lead to an increase in average color rendering index and a decrease in color temperature, which are effects of the tenth embodiment.

[0435] The lenses **70** and **71** of this variation can be formed by a potting method. Also, the second sealing portion **26**B can be previously formed in the shape of a plate, and can be fixed onto the upper end surface of the case **51**.

[0436] (Fifth Variation of Tenth Embodiment)

[0437] FIG. **37** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fifth variation of the tenth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **14** are indicated by the same symbols and will not be described.

[0438] As shown in FIG. **37**, in the semiconductor light-emitting device **50**G of the fifth variation of the tenth embodiment, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0439] The first sealing portion **26**A comprises a resin material into which a fluorescent material **16***c* is kneaded. The second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*.

[0440] The fifth variation is characterized in that the first sealing portion **26**A contacts the LED chip **12** and covers surroundings thereof, while the second sealing portion **26**B is provided, filling the hollow portion **51***a* of the case **51** while leaving an upper portion of the hollow portion **51***a* so that an interstice portion **51***b* is formed in the upper portion of the hollow portion **51***a*.

[0441] Further, a lens **70** is formed on an upper end surface of the case **51**, covering the interstice portion **51***b*.

[0442] Note that, when the first sealing portion **26**A functions as a lens, the lens **70** does not necessarily need to be provided.

[0443] Thus, according to this variation, even when the interstice portion **51***b* is provided between the second sealing portion **26**B and the lens **70**, the filter effect can lead to an increase in average color rendering index and a decrease in color temperature, which are effects of the tenth embodiment.

[0444] Note that the lens **70** of this variation may be previously molded using a molding die or the like and may be then fixed onto the upper end surface of the case **51**.

[0445] (Sixth Variation of Tenth Embodiment)

[0446] FIG. **38** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a sixth variation of the tenth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **37** are indicated by the same symbols and will not be described.

[0447] As shown in FIG. **38**, the semiconductor light-emitting device **80** of the sixth variation of the tenth embodiment comprises a reflector **81** which is made of, for example, a heat-resistant resin material, such as a liquid crystal polymer or the like. At least a first lead **52**A and a second lead **52**B are fixed to an upper end portion of the reflector **81**. The reflector

81 has a reflection portion **81***a* having an inwardly concave shape, i.e., a hemispherical surface shape or a parabolic shape. The reflector **81** also serves as a case. Note that, in view of reflection with respect to visual light, the reflector **81** is preferably made of a white heat-resistant resin material, or the reflection portion **81***a* is metallized with a metal, such as aluminum or the like.

[0448] The LED chip **12** is fixed onto a lower surface of the first lead **52**A by a face-up method. Specifically, mounting is performed so that an upper surface of the LED chip **12** is opposed to a bottom portion of the reflection portion **81***a*.

[0449] A fluorescent material layer **27** made of a resin material into which a fluorescent material **16***c* is kneaded is formed on a reflection surface of the reflection portion **81***a*. An interstice portion **81***b* is formed between the fluorescent material layer **27** and the LED chip **12**. A sealing portion **16** is formed on an upper end surface of the reflector **81**, covering the interstice portion **81***b* as well as the leads **52**A and **52**B. The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0450] A lens **70** is formed on the sealing portion **16**. Note that the lens **70** does not necessarily need to be provided.

[0451] Thus, even when the LED chip **12** is provided in the vicinity of a focus of the reflection portion **81***a* of the reflector **81**, an effect of the present invention can be obtained.

[0452] Note that the interstice portion **81***b* of the reflector **81** may be filled with a sealing resin material, or further, a composite material having the same composition as that of the sealing portion **16** or a composite material having a different refractive index.

Eleventh Embodiment

[0453] FIG. **39** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to an eleventh embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **14** are indicated by the same symbols and will not be described.

[0454] As shown in FIG. **39**, in the semiconductor light-emitting device **50**H of the eleventh embodiment, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0455] A white heat-resistant resin material is used as the case material **51**, or further, an inner wall and a bottom surface of the hollow portion **51***a* of the case material **51** are subjected to metallizing (deposition or the like of a metal, such as aluminum (Al) or the like), so that the inner wall surface of the case material **51** functions as a reflection surface.

[0456] A sealing portion **26** comprises a first sealing portion **26**A which directly covers the LED chip **12** and fills a lower portion of the hollow portion **51***a* of the case material **51**, and a second sealing portion **26**B which is formed in the shape of a layer on the first sealing portion **26**A.

[0457] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*. The second sealing portion **26**B comprises a resin material into which a fluorescent material **16***c* is kneaded.

[0458] With this structure, a portion of radiated light from the LED chip **12** which is reflected by the fluorescent material **16***c* added to the second sealing portion **26**B, and a portion of light emitted by the fluorescent material **16***c*, are reflected by an interface between the inner wall or bottom surface of the hollow portion **51***a* of the case material **51** and the first sealing portion **26**A, and is then transmitted through the first sealing portion **26**A again.

[0459] According to the semiconductor light-emitting device **50**H of the eleventh embodiment, an effect similar to that of the first embodiment is obtained, and in addition, spectral components in a red region are relatively increased by the above-described filter effect that combined light in blue to ultraviolet regions is attenuated. Thereby, the average color rendering index is increased and the color temperature is decreased.

[0460] Note that, when radiated light of the LED chip **12** is blue light, a fluorescent material which provides green light or yellow light may be added to both the first sealing portion **26**A and the second sealing portion **26**B (a first variation of the eleventh embodiment). Even in this case, the nano-particle **16***b* added to the first sealing portion **26**A attenuates spectral components in blue to ultraviolet regions of combined light, so that spectral components in a red region relatively increase.

[0461] Also, a first fluorescent material which provides green light or yellow light may be added to the first sealing portion **26**A, and a second fluorescent material which provides red light may be added to the second sealing portion **26**B (second variation). In this case, green light or yellow light from the first fluorescent material is absorbed by the second fluorescent material for a red color, which is in turn excited, so that the average color rendering index is further increased and the color temperature is further decreased.

[0462] Also, a first fluorescent material which provides red light may be added to the first sealing portion **26**A, and a second fluorescent material which provides green light or yellow light may be added to the second sealing portion **26**B (third variation). In this case, since the first fluorescent material for a red color does not absorb green light or yellow light which is emitted by the second fluorescent material, the conversion efficiency of radiated light from the LED chip **12** is improved.

[0463] Also, in the eleventh embodiment and its variations, the refractive index of the first sealing portion **26**A is preferably caused to be smaller than the refractive index of the LED chip **12**, and the refractive index of the second sealing portion **26**B is preferably caused to be smaller than the refractive index of the first sealing portion **26**A, as in the sixth embodiment. In this case, the light extraction efficiency is improved.

[0464] Also, the outer shape of the semiconductor light-emitting device **50**H and the mounting method of the LED chip **12** are not limited to those of FIG. **39**, and may be similar to those of the second embodiment, the sixth embodiment, the first to fifth variations of the sixth embodiment, the seventh embodiment, or the first to sixth variations of the seventh embodiment.

[0465] (Fourth Variation of Eleventh Embodiment)

[0466] FIG. **40** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fourth variation of the eleventh embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **14** are indicated by the same symbols and will not be described.

[0467] As shown in FIG. **40**, in the semiconductor light-emitting device **50**I of the fourth variation, a sealing portion **26** comprises a first sealing portion **26**A as an underlying layer formed below an LED chip **12** and a second sealing portion **26**B which is formed on the first sealing portion **26**A, covering the LED chip **12**, and fills a hollow portion **51***a* of a case material **51**.

[0468] Specifically, the first sealing portion **26**A is formed on a bottom surface of the case material **51**, and the LED chip **12** is fixed onto the first sealing portion **26**A via a chip fixing paste material **13** which is transparent to visible light, by a face-up method. A white heat-resistant resin material is used as the case material **51**, or further, a bottom surface or an inner wall surface of the hollow portion **51***a* of the case material **51** is subjected to metallizing (deposition or the like of a metal, such as aluminum (Al) or the like), so that the inner wall surface of the case material **51** functions as a reflection surface.

[0469] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*. The second sealing portion **26**B comprises a resin material into which a fluorescent material **16***c* is kneaded.

[0470] With this structure, a portion of radiated light from the LED chip **12** which is reflected by the fluorescent material **16***c* added to the second sealing portion **26**B, and a portion of excited light from the fluorescent material **16***c*, are reflected by an interface between the hollow portion **51***a* of the case material **51** and the first sealing portion **26**A, and is then transmitted through the first sealing portion **26**A again. As a result, spectral components in a red region are relatively increased by the above-described filter effect, so that the average color rendering index is increased and the color temperature is decreased.

[0471] In addition, since the nano-particle **16***b* is added to the first sealing portion **26**A which is the underlying layer for the LED chip **12**, the heat radiation performance of the LED chip **12** is improved.

[0472] Also, since the chip fixing paste material **13** is a transparent paste material, and the bottom surface of the hollow portion **51***a* of the case material **51** is metallized with a metal, the light extraction efficiency is improved.

[0473] Note that nano-particles may be added to the second sealing portion **26**B so that the second sealing portion **26**B is caused to be a composite material. In this case, the nano-particle is preferably selected which causes the refractive index of the second sealing portion **26**B to be smaller than the refractive index of the first sealing portion **26**A.

[0474] (Fifth Variation of Eleventh Embodiment)

[0475] FIG. **41** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a fifth variation of the eleventh embodiment of the present invention. Also here, the same parts as those shown in FIG. **38** are indicated by the same symbols and will not be described.

[0476] As shown in FIG. **41**, the semiconductor light-emitting device **80**A of the fifth variation of the eleventh embodiment comprises a reflector **81** which is made of, for example, a heat-resistant resin material, such as a liquid crystal polymer or the like. At least a first lead **52**A and a second lead **52**B are fixed to an upper end portion of the reflector **81**. The reflector **81** has a reflection portion **81***a* having an inwardly concave shape, i.e., a hemispherical surface shape or a parabolic shape. The reflector **81** also serves as a case. Note that the reflector **81** is preferably made of a white heat-resistant resin material, or the reflection portion **81***a* is metallized with a metal, such as aluminum or the like.

[0477] The LED chip **12** is fixed onto a lower surface of the first lead **52**A by a face-up method. Specifically, mounting is performed so that an upper surface of the LED chip **12** is opposed to a bottom portion of the reflection portion **81***a*.

[0478] A fluorescent material layer **27** made of a resin material into which a fluorescent material **16***c* is kneaded is formed on a reflection surface of the reflection portion **81***a*. An interstice between the fluorescent material layer **27** and the LED chip **12** is filled with a sealing portion **16**. The sealing portion **16** comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*.

[0479] A lens **70** is formed on an upper end surface of the reflector **81**, covering the leads **52**A and **52**B. Note that the lens **70** does not necessarily need to be provided.

[0480] With this structure, a portion of radiated light from the LED chip **12** which is reflected by the fluorescent material **16***c* added to the fluorescent material layer **27**, and a portion of light emitted by the fluorescent material **16***c*, are reflected by the reflection portion **81***a* of the reflector **81**, and is then passed through the sealing portion **16** again. As a result, spectral components in a red region are relatively increased by the above-described filter effect, so that the average color rendering index is increased and the color temperature is decreased.

[0481] Note that the sealing portion **16** may have a double-layer structure of at least a first sealing portion and a second sealing portion as in the sixth embodiment, and the refractive index of the second sealing portion positioned outside the first sealing portion may be caused to be lower than the refractive index of the first sealing portion.

Twelfth Embodiment

[0482] Hereinafter, a semiconductor light-emitting device according to a twelfth embodiment of the present invention will be described with reference to the drawings.

[0483] FIG. **42** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the twelfth embodiment of the present invention. Also here, the same parts as those shown in FIGS. **8** and **14** are indicated by the same symbols and will not be described.

[0484] As shown in FIG. **42**, in the semiconductor light-emitting device **50**J of the twelfth embodiment, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0485] A sealing portion **26** comprises a first sealing portion **26**A which directly covers the LED chip **12** and fills a lower portion of the hollow portion **51***a* of the case material **51**, and a second sealing portion **26**B which is formed in the shape of a layer on the first sealing portion **26**A via a third sealing portion **26**C.

[0486] The first sealing portion **26**A and the second sealing portion **26**B comprise a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0487] The third sealing portion **26**C comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and second nano-particles **17***b* made of an inorganic material capable of absorbing ultraviolet light, such as zinc oxide, titanium oxide, cerium oxide or the like, which are uniformly distributed in the matrix material **16***a*.

[0488] According to the semiconductor light-emitting device **50**J of the twelfth embodiment, an effect similar to that of the first embodiment is obtained, and in addition, since the third sealing portion **26**C is provided as an ultraviolet light absorbing layer between the first sealing portion **26**A and the second sealing portion **26**B, light components in an ultraviolet region included in radiated light from the LED chip **12** are absorbed by the third sealing portion **26**C. As a result, as the matrix material **16***a* included in the second sealing portion **26**B, an epoxy resin can be used which has an excellent level of water resistance and heat resistance and is easily changed into yellow by ultraviolet light.

[0489] Note that, in the sealing portion **26**, preferably, the refractive index of the second sealing portion **26**B is lower than the refractive index of the third sealing portion **26**C, and the refractive index of the third sealing portion **26**C is lower than the refractive index of the first sealing portion **26**A.

[0490] Also, the first sealing portion **26**A and the second sealing portion **26**B do not necessarily need to include the second nano-particle **17***b*. The fluorescent material **16***c* may be included in either the first sealing portion **26**A or the third sealing portion **26**C. Note that, when radiated light of the LED chip **12** mainly includes ultraviolet light, the first sealing portion **26**A needs to include the fluorescent material **16***c*.

[0491] Also, the outer shape of the semiconductor light-emitting device **50**J and the mounting method of the LED chip **12** are not limited to those of FIG. **43**, and may be similar to those of the second embodiment, the sixth embodiment, the first to fifth variations of the sixth embodiment, the seventh embodiment or the first to sixth variations of the seventh embodiment.

Thirteenth Embodiment

[0492] Hereinafter, a semiconductor light-emitting device according to a thirteenth embodiment of the present invention will be described with reference to the drawings.

[0493] FIG. **43** is a schematic cross-sectional view of a structure of a white LED device which is the semiconductor light-emitting device of the thirteenth embodiment of the present invention. Here, the same parts as those shown in FIG. **8** are indicated by the same symbols and will not be described.

[0494] As shown in FIG. **43**, in the semiconductor light-emitting device **50**K of the thirteenth embodiment, an LED chip **12** is fixed onto a bottom surface of a hollow portion **51***a* in a case material **51** having the hollow portion **51***a* by a face-up method, as in the fifth embodiment.

[0495] A sealing portion **26** comprises a first sealing portion **26**A which directly covers the LED chip **12** and fills the hollow portion **51***a* of the case material **51**, and a second sealing portion **26**B which is formed on an upper surface of the first sealing portion **26**A, covering the first sealing portion **26**A.

[0496] The first sealing portion **26**A comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and nano-particles **16***b* made of an inorganic material which are uniformly distributed in the matrix material **16***a*, and a fluorescent material **16***c*.

[0497] The second sealing portion **26**B comprises a sealing material **16***d* which is a composite material including a matrix material **16***a* and second nano-particles **16***d* made of an inorganic material capable of absorbing ultraviolet light, such as zinc oxide, titanium oxide, cerium oxide or the like, which are uniformly distributed in the matrix material **16***a*. Thus, by using the sealing material **16***d* which is a composite material, the composite material is likely to scatter light having a wavelength of ultraviolet light, in addition to the adsorption effect of the nano-particle **16***b*, so that an effect of suppressing transmission of ultraviolet light is considerably improved.

[0498] According to the semiconductor light-emitting device **50**K of the thirteenth embodiment, an effect similar to that of the first embodiment is obtained, and in addition, since the second sealing portion **26**B is provided as an ultraviolet light absorbing layer on the first sealing portion **26**A, light components in an ultraviolet region included in radiated light from the LED chip **12** are absorbed by the third sealing portion **26**B. As a result, undesired ultraviolet light can be prevented from being output from the semiconductor light-emitting device **50**K.

[0499] In addition, the second sealing portion **26**B which absorbs ultraviolet light is provided outside the first sealing portion **26**A, so that the sealing material **16***d* and the fluorescent material **16***c* are prevented from being degraded due to external incident ultraviolet light.

[0500] Note that the wavelength region of radiated light of the LED chip **12** is not limited to blue to ultraviolet regions. Therefore, the semiconductor light-emitting device **50**K is not limited to a white LED device.

[0501] Also, the first sealing portion **26**A does not necessarily need to include the first nano-particle **16***b*.

[0502] Also, the outer shape of the semiconductor light-emitting device **50**K and the mounting method of the LED chip **12** are not limited to those of FIG. **43**, and may be similar to those of the first to fourth embodiments.

[0503] (Variation of Thirteenth Embodiment)

[0504] FIG. **44** is a schematic cross-sectional view of a structure of a white LED device which is a semiconductor light-emitting device according to a variation of the thirteenth embodiment of the present invention.

[0505] As shown in FIG. **44**, in the semiconductor light-emitting device SOL of this variation, a second sealing portion **26**B including second nano-particles **17** capable of absorbing ultraviolet light is formed, covering all surroundings of a case material **51** including not only an upper surface, but also a side surface and a bottom surface of the case material **51**.

[0506] With this structure, an effect similar to that of the thirteenth embodiment is obtained, and in addition, the heat radiation performance of the case material **51** can be improved.

[0507] The second sealing portion **26**B which covers the surroundings of the case material **51** is formed, for example, as follows. After the first sealing portion **26**A is formed, the first sealing portion **26**A is dipped in a liquid sealing material **16***d* in which the second nano-particles **17** are distributed (dipping method).

[0508] Note that, in the sixth embodiment, the first to sixth variations of the sixth embodiment, the seventh embodiment, the first to seventh variations of the seventh embodiment, the tenth embodiment, the eleventh embodiment, the first to fourth variations of the eleventh embodiment, the twelfth embodiment, the thirteenth embodiment, and the variation of

the thirteenth embodiment, the matrix material **16***a* of the first sealing portion **26**A is assumed to be the same as the matrix material **16***a* of the second sealing portion **26**B. In this case, the adhesion between the sealing portions is preferably improved, so that the sealing portions are not likely to be peeled off each other, for example. The adhesion between the sealing portions is relatively largely attributed to the adhesion between the matrix materials of these sealing portions. When the sealing portions are made of a composite material, since the proportion of the matrix material is low, the adhesion between the sealing portions can be increased by using the same matrix material for the sealing portions.

[0509] Also, although it has been assumed in all embodiments and their variations described above that most of the semiconductor light-emitting devices are a white LED device, the present invention is not limited to the white LED device, and may be applicable to a semiconductor light-emitting device in which an LED chip is sealed by a sealing material to which nano-particles are added.

[0510] Note that, if a composite material is used as a sealing portion, the sealing portion is preferably adapted to suppress the attenuation of the transmission amount of emitted light no matter whether the sealing portion has a single-layer structure or a double-layer structure. Note that the structure of the sealing portion may be determined, depending on the application. For example, when the color rendering property is controlled as in the tenth embodiment or when an LED chip includes ultraviolet light and the ultraviolet light is desired to be removed, light having a corresponding wavelength is attenuated by the composite material.

[0511] The degree of Rayleigh scattering occurring due to the composite material varies depending on the size of the nano-particle, the mixture concentration of the nano-particle, and the thickness of the sealing portion, and also the wavelength of transmitted light. In particular, the shorter the wavelength of light, the larger the degree of scattering. Therefore, the transmission amount may be affected by the light emission wavelength of an LED chip used, or the structure of the sealing portion made of the composite material.

[0512] When the composite material used for the sealing portion has a scattering degree of less than 0.3 with respect to the light emission wavelength of the semiconductor light emitting device, the attenuation amount during transmission of emitted light is reduced. Therefore, the light extraction efficiency is improved. In this case, the Rayleigh scattering component of the transmittance of the sealing portion is less than about 25%.

[0513] More preferably, when the scattering degree is 0.2 or less, the attenuation amount during transmission of light is further reduced, so that the light extraction efficiency is improved. Note that, in this case, the Rayleigh scattering component of the transmittance is about 20% or less. In particular, when the scattering degree is 0.1 or less, the Rayleigh scattering component of the transmittance is about 10% or less. Further, when the scattering degree is 0.05 or less, the Rayleigh scattering component of the transmittance is about 5% or less, i.e., the sealing portion is almost transparent and the attenuation amount during transmission of light is negligible.

[0514] As used herein, the scattering degree has a value which is represented by a product αt of a Rayleigh scattering extinction coefficient α and a thickness t of a composite material portion. The scattering degree is determined by measuring a transmittance T (%) of the composite material portion having a predetermined thickness t, and from that value, calculating the scattering degree $\alpha t=-\ln(T/100)$, where ln represents natural logarithm. The Rayleigh scattering extinction coefficient α can be obtained by dividing the scattering degree by the thickness. The Rayleigh scattering extinction coefficient α is a material parameter which is determined by the particle size of a nano-particle, the refractive index, or the material composition (mixture amount). By determining the value of the Rayleigh scattering extinction coefficient α, the optical design of a device, such as the thickness of the sealing portion or the like, can be easily achieved.

[0515] Here, other examples of fluorescent materials available for the present invention, which are described in the first embodiment, will be listed for each color.

i. Blue Fluorescent Materials

(1) Halophosphate fluorescent material: $(Sr, Ba)_{10}(PO_4)_6Cl_2:Eu^{2+}$, $Sr_{10}(PO_4)_6Cl_2:Eu^{2+}$

(2) Silicate fluorescent material=>$Ba_3MgSi_2O_8:Eu^{2+}$

ii. Blue-Green Fluorescent Materials

(1) Aluminate fluorescent material: $Sr_4Al_{14}O_{25}:Eu^{2+}$

(2) Silicate fluorescent material: $Sr_2Si_3O_8.2SrCl_2:Eu^{2+}$

iii. Green Fluorescent Materials

(1) Aluminate fluorescent material: $(Ba, Sr, Ca)Al_2O_4:Eu^{2+}$

(2) Silicate fluorescent material: $(Ba, Sr)_2SiO_4:Eu^{2+}$

(3) α-SIALON fluorescent material: $Sr_{1.5}Al_3Si_9N_{16}:Eu^{2+}$, Ca-$\alpha$-SiAlON:$Yb^{2+}$

(4) β-SIALON fluorescent material: β-$Si_3N_4:Eu^{2+}$

(5) Oxynitride fluorescent materials

[0516] Oxonitrido-silicate: $(Ba, Sr, Ca)Si_2O_2N_2:Eu^{2+}$

[0517] Oxonitrido-aluminosilicate: $(Ba, Sr, Ca)_2Si_4AlON_7:Ce^{3+}$,

[0518] $(Ba, Sr, Ca)Al_{2-x}Si_xO_{4-x}N_x:Eu^{2+}(0<x<2)$

(6) Nitride fluorescent materials

[0519] Nitorido-silicate fluorescent material: $(Ba, Sr, Ca)_2Si_5N_8:Ce^{3+}$

(7) Sulfide fluorescent material

[0520] Thiogallate: $SrGa_2S_4:Eu^{2+}$

(8) Garnet fluorescent material: $Ca_3Sc_2Si_3O_{12}:Ce^{3+}$, $BaY_2SiAl_4O_{12}:Ce^{3+}$,

[0521] $Y_3(Al, Ga)_5O_{12}:Ce^{3+}$

(9) Oxide fluorescent material: $CaSc_2O_4:Ce^{3+}$

iv. Yellow Fluorescent Materials

(1) Silicate fluorescent material: $(Sr, Ba)_2SiO_4:Eu^{2+}$, $Sr_3SiO_5:Eu^{2+}$

(2) Garnet fluorescent material: $(Y, Gd)_3Al_5O_{12}:Ce^{3+}$, $Y_3Al_5O_{12}:Ce^{3+}$, Pr^{3+}

(3) Sulfide fluorescent material

[0522] Thiogallate: $CaGa_2S_4:Eu^{2+}$

(4) α-SIALON fluorescent material: Ca-α-SiAlON:Eu^{2+},

[0523] $(0.75(Ca_{0.9}Eu_{0.1})O.2.25AlN.3.25Si_3N_4:Eu^{2+}$,

[0524] $Ca_{1.5}Al_3Si_9N_{16}:Eu^{2+}$, etc.)

v. Orange Fluorescent Materials

(1) Silicate fluorescent material: $(Sr, Ca)_2SiO_4:Eu^{2+}$

(2) Garnet Fluorescent Material: $Gd_3Al_5O_{12}:Ce^{3+}$

[0525] (3) α-SIALON fluorescent material: Ca-α-SiAlON:Eu^{2+}

vi. Red fluorescent materials

(1) Sulfide fluorescent material: $(Sr, Ca)S:Eu^{2+}$, $La_2O_2S:Eu^{3+}$, Sm^{3+}

(2) Silicate fluorescent material: $Ba_3MgSi_2O_8:Eu^{2+}$, Mn^{2+}

(3) Nitride or oxynitride fluorescent material: $(Ca, Sr)SiN_2:Eu^{2+}$,

[0526] $(Ca, Sr)AlSiN_3:Eu^{2+}$,

[0527] $Sr_2Si_{5-x}Al_xO_xN_{8-x}:Eu^{2+}(0\leqq x\leqq 1)$

[0528] Note that a wavelength converting material, such as a metal complex, an organic dye, a pigment or the like, can be used instead of fluorescent materials.

[0529] Nano-particles added to a translucent material (a fluorescent material layer, a sealing material) can be expected to provide an improvement in thixotropy, the light scattering effect, the adjustment of the refractive index of the sealing material, an improvement in thermal conductivity, and the like. Examples of the nano-particles include metal compounds, such as $BaSO_4$, ZnS or V_2O_5, or a mixture thereof in addition to those described in the first embodiment. The center particle size of the nano-particle is several tens of nanometers to several hundreds of nanometers.

[0530] Also, the substrate **31** or a pedestal on which the LED chip **12** is mounted can be made of a ceramic, such as AlN, Al_2O_3, BN, AlN, MgO, ZnO, SiC or C, or a mixture of at least two of them, or a metal, such as Al, Cu, Fe or Au, or an alloy including at least two of them. Further, a glass epoxy can be used.

[0531] The reflection layer provided in the case material **51** or the reflector **81** can be made of a metal, such as Ag, Au, Ni, Rh or Pd, or an alloy including at least two of them, in addition to Al.

[0532] The matrix material **16***a* of the sealing material **16***d* can be a resin, such as an epoxy resin, a silicone resin, an acrylic resin, a urea resin, an imide resin, a polycarbonate resin, a polyphenylsulfide resin, a liquid crystal polymer resin or an acrylonitrile-butadiene-styrene (ABS) resin, or a mixture of at least two of them. Silica or heat-resistant hard glass can be used as cap glass. Low-melting glass can be used as sealing glass.

[0533] Sealing gas which seals the LED chip can be nitrogen, argon, or dried air.

INDUSTRIAL APPLICABILITY

[0534] The present invention provides a semiconductor light-emitting device comprising a long-life and high-luminance LED and the like, and is useful for, for example, a semiconductor light-emitting device in which a semiconductor chip in which a light emitting device is formed is packaged by resin-sealing.

1-38. (canceled)

39. A semiconductor light-emitting device comprising:

a semiconductor chip for emitting light; and

a sealing portion formed in at least a partial region on a passage path on which the light is passed,

wherein the sealing portion includes:

a sealing material which is a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of the wavelength of the light in the matrix material; and

a fluorescent material,

the fluorescent material and the particles are mixed in the same region of the composite material, and

a proportion of the particles in the composite material of the sealing portion is higher in the inner region near the semiconductor chip than in the outer region.

40. The semiconductor light-emitting device of claim **39**, wherein

the sealing portion is formed so as to cover surroundings of the semiconductor chip.

41. The semiconductor light-emitting device of claim **39**, wherein

the sealing portion is formed so as to contact the semiconductor chip.

42. The semiconductor light-emitting device of claim **39**, further comprising:

a reflection member for reflecting the light provided below and lateral to the semiconductor chip in the sealing portion.

43. The semiconductor light-emitting device of claim **39**, wherein

the sealing portion comprises a first sealing portion including the sealing material, and a second sealing portion formed outside the first sealing portion, and

the particle is made of a material which absorbs light in an ultraviolet region.

44. The semiconductor light-emitting device of claim **39**, wherein

of the particles included in the sealing portion, the particle included in the inner region of the sealing portion and the particle included in the outer region have different compositions.

45. The semiconductor light-emitting device of claim **39**, further comprising:

a paste material having transparency for fixing the semiconductor chip and the holding material,

wherein the paste material includes a composite material including a matrix material and particles made of an inorganic material which are distributed in the matrix material, the particle having an effective particle size which is ¼ or less of the wavelength of the light in the matrix material.

46. The semiconductor light-emitting device of claim **45**, wherein the particle included in the paste material is made of a material for absorbs light in an ultraviolet region.

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