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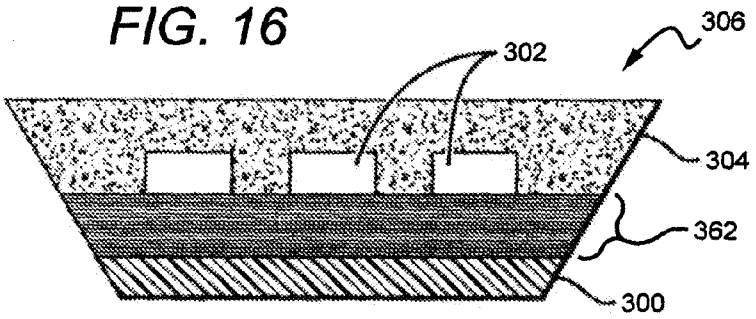
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(54) Title: ENCAPSULATED LED INCLUDING A COMPOSITE HIGH REFLECTIVITY LAYER

FIG. 16



(57) Abstract: A high efficiency light emitting diode with a composite high reflectivity layer integral to said LED or package to improve emission efficiency. One embodiment of a LED package comprises a LED (52,302) mounted on a substrate (300) with an encapsulant (304) over said LED and a composite high reflectivity layer (62, 100, 362) arranged to reflect emitted light. The composite layer comprises a plurality of layers (102, 106, 108, 110, 308) such that at least one of said plurality of layers has an index of refraction lower than the encapsulant (304) and a reflective layer (126, 164, 310) on a side of said plurality of layers opposite the LED. In some embodiments, conductive vias (128, 166, 318) are included through the composite layer to allow an electrical signal to pass through the layer to the LED.

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ENCAPSULATED LED INCLUDING A COMPOSITE HIGH REFLECTIVITY LAYER

This application is a continuation in part of, and claims the benefit of, U.S. Patent Application Serial No. 13/071,349 to Ibbetson et al., filed on March 24, 2011 and having the same title as the present application.

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to light emitting diodes, and to light emitting diodes and packages with high reflectivity contacts, high reflectivity carriers, and methods for forming the same.

Description of the Related Art

[0002] Light emitting diodes (LED or LEDs) are solid state devices that convert electric energy to light, and generally comprise one or more active layers of semiconductor material sandwiched between oppositely doped n-type and p-type layers. When a bias is applied across the doped layers, holes and electrons are injected into the active layer where they recombine to generate light. Light is emitted from the active layer and from all surfaces of the LED.

[0003] For typical LEDs it is desirable to operate at the highest light emission efficiency, and one way that emission efficiency can be measured is by the emission intensity in relation to the input power, or lumens per

watt. One way to maximize emission efficiency is by maximizing extraction of light emitted by the active region of LEDs. For conventional LEDs with a single out-coupling surface, the external quantum efficiency can be limited by total internal reflection (TIR) of light from the LED's emission region. TIR can be caused by the large difference in the refractive index between the LED's semiconductor and surrounding ambient. Some LEDs have relatively low light extraction efficiencies because the high index of refraction of the substrate compared to the index of refraction for the surrounding material, such as epoxy. This difference results in a small escape cone from which light rays from the active area can transmit from the substrate into the epoxy and ultimately escape from the LED package. Light that does not escape can be absorbed in the semiconductor material or at surfaces that reflect the light.

[0004] Different approaches have been developed to reduce TIR and improve overall light extraction, with one of the more popular being surface texturing. Surface texturing increases the light escape probability by providing a varying surface that allows photons multiple opportunities to find an escape cone. Light that does not find an escape cone continues to experience TIR, and reflects off the textured surface at different angles until it finds an escape cone. The benefits of surface texturing have been discussed in several articles. [See Windisch et al., Impact of Texture-Enhanced Transmission on High-Efficiency Surface Textured Light Emitting Diodes, Appl. Phys. Lett., Vol. 79, No. 15, Oct. 2001, Pgs. 2316-2317; Schnitzer et al. 30% External Quantum Efficiency From Surface Textured, Thin Film Light Emitting Diodes, Appl. Phys. Lett., Vol 64, No. 16, Oct.

1993, Pgs. 2174-2176; Windisch et al. Light Extraction Mechanisms in High-Efficiency Surface Textured Light Emitting Diodes, IEEE Journal on Selected Topics in Quantum Electronics, Vol. 8, No. 2, March/April 2002, Pgs. 248-255; Streubel et al. High Brightness AlGaNInP Light Emitting Diodes, IEEE Journal on Selected Topics in Quantum Electronics, Vol. 8, No. March/April 2002].

[0005] U.S. Patent No. 6,657,236, also assigned to Cree Inc., discloses structures formed on the semiconductor layers for enhancing light extraction in LEDs.

[0006] Another way to increase light extraction efficiency is to provide reflective surfaces that reflect light so that it contributes to useful emission from the LED chip or LED package. In a typical LED package 10 illustrated in FIG. 1, a single LED chip 12 is mounted on a reflective cup 13 by means of a solder bond or conductive epoxy. One or more wire bonds 11 connect the ohmic contacts of the LED chip 12 to leads 15A and/or 15B, which may be attached to or integral with the reflective cup 13. The reflective cup may be filled with an encapsulant material 16 which may contain a wavelength conversion material such as a phosphor. Light emitted by the LED at a first wavelength may be absorbed by the phosphor, which may responsively emit light at a second wavelength. The entire assembly is then encapsulated in a clear protective resin 14, which may be molded in the shape of a lens to collimate the light emitted from the LED chip 12. While the reflective cup 13 may direct light in an upward direction, optical losses may occur when the light is reflected. Some light may be absorbed by the reflector cup due to the less than 100% reflectivity of practical reflector surfaces. Some metals can have less

than 95% reflectivity in the wavelength range of interest.

[0007] FIG. 2 shows another LED package in which one or more LED chips 22 can be mounted onto a carrier such as a printed circuit board (PCB) carrier, substrate or submount 23. A metal reflector 24 mounted on the submount 23 surrounds the LED chip(s) 22 and reflects light emitted by the LED chips 22 away from the package 20. The reflector 24 also provides mechanical protection to the LED chips 22. One or more wirebond connections 11 are made between ohmic contacts on the LED chips 22 and electrical traces 25A, 25B on the submount 23. The mounted LED chips 22 are then covered with an encapsulant 26, which may provide environmental and mechanical protection to the chips while also acting as a lens. The metal reflector 24 is typically attached to the carrier by means of a solder or epoxy bond. The metal reflector 24 may also experience optical losses when the light is reflected because it also has less than 100% reflectivity.

[0008] The reflectors shown in FIGs. 1 and 2 are arranged to reflect light that escapes from the LED. LEDs have also been developed having internal reflective surfaces to reflect light internal to the LEDs. FIG. 3 shows a schematic of a LED chip 30 with a LED 32 mounted on a submount 34 by a metal bond layer 36. The LED further comprises a p-contact/reflector 38 between the LED 32 and the metal bond 36, with the reflector 38 typically comprising a metal such as silver (Ag). This arrangement is utilized in commercially available LEDs such as those from Cree® Inc., available under the EZBrightTM family of LEDs. The reflector 38 can reflect light emitted from the LED chip toward the submount back toward the LED's

primary emitting surface. The reflector also reflects TIR light back toward the LED's primary emitting surface. Like the metal reflectors above, reflector 38 reflects less than 100% of light and in some cases less than 95%. The reflectivity of a metal film on a semiconductor layer may be calculated from the materials' optical constants using thin film design software such as TFCalc™ from Software Spectra, Inc. (www.sspectra.com).

[0009] It is generally desirable that LEDs and LED packages have the highest light output efficiency possible. Some light rays emitted from the LED chip either directly or indirectly are emitted, reflected, or scattered towards the substrate or packaging. LED packaging is often made of or coated with reflective materials to improve this efficiency by reflecting, in a desired direction, light which is emitted or reflected towards the package or substrate. In some embodiments the submount or substrate itself is reflective or coated with a reflective substance. Poly-crystalline alumina thick-film substrates are widely used for packaging. However, alumina substrates only have a reflectance of approximately 80%. Metal traces on the substrate are often coated with Ag which has a reflectivity of approximately 90%. However, over 60% of the substrate surface area is not covered by metal traces. In other embodiments, a silver coating over the substrate is used for reflectivity. However, even a silver coated surface only has a reflectivity of approximately 90%, causing losses of 5-10% at each reflection or light bounce. It is desirable to find a more efficient way to reflect off of the substrate, submount or packaging. Efficiency can be improved by utilizing a substrate with a surface which is more reflective than alumina, a coating more

reflective than silver, or both. This would allow the more efficient use of traditionally poor reflective materials, such as Si, as substrates, submounts, and carriers. Though DBRs are highly reflective, they do not function ideally in LED packages because DBRs function only to reflect well at one angle and one wavelength. In LED packages there are multiple wavelength of light being output, either by multiple LEDs or different wavelengths, or by LEDs and wavelength conversion materials. Therefore, it is desirable to incorporate a layer which is able to reflect a range of angles and wavelengths.

[0010] FIG. 4 shows a graph 40 showing the reflectivity of Ag on gallium nitride (GaN) at different viewing angles for light with a wavelength of 460nm. The refractive index of GaN is 2.47, while the complex refractive index for silver is taken from the technical literature. [See Handbook of Optical Constants of Solids, edited by E. Palik.] The graph shows the p-polarization reflectivity 42, s-polarization reflectivity 44, and average reflectivity 46, with the average reflectivity 46 generally illustrating the overall reflectivity of the metal for the purpose of LEDs where light is generated with random polarization. The reflectivity at 0 degrees is lower than the reflectivity at 90 degrees, and this difference can result in up to 5% or more of the light being lost on each reflection. In a LED chip, in some instances TIR light can reflect off the mirror several times before it escapes and, as a result, small changes in the mirror absorption can lead to significant changes in the brightness of the LED. The cumulative effect of the mirror absorption on each reflection can reduce the light intensity such that less than 75% of light from the LED's active region actually escapes as LED light.

SUMMARY OF THE INVENTION

[0011] The present invention discloses a higher reflectivity layer for use in or on LED packages and LED chips to increase emission efficiency. One embodiment of a LED package comprises a LED mounted on a substrate with an encapsulant over said LED and a composite high reflectivity layer arranged to reflect light emitted from said LED. The composite layer comprises a plurality of layers such that at least one of said plurality of layers has an index of refraction lower than the encapsulant and a reflective layer on a side of said plurality of layers opposite the LED. In some embodiments, conductive vias can be included through the composite layer to allow an electrical signal to pass through the composite layer to the LED.

[0012] One embodiment of a LED chip according to the present invention comprises a submount with an LED mounted to the submount. A composite high reflectivity layer is arranged between the submount and the LED to reflect LED light. The composite layer comprises a plurality of layers and a conductive path through the composite layer through which an electrical signal can pass to the LED.

[0013] Another embodiment of an LED chip according to the present invention comprises an LED and a composite high reflectivity layer integral to the LED to reflect light emitted from the active region. The composite layer comprises a first layer, and alternating plurality of second and third layers on the first layer. The second and third layers have a different index of refraction.

[0014] One embodiment of a method for fabricating a LED package comprises providing a substrate, followed by

providing a composite high reflectivity layer, arranged to reflect light emitted from the LED, on the substrate. Next, providing a LED mounted on the composite layer and providing an encapsulant over the LED.

[0015] These and other aspects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings, which illustrate by way of example the features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a sectional view of one embodiment of a prior art LED lamp;

[0017] FIG. 2 is a sectional view of another embodiment of a prior art LED lamp;

[0018] FIG. 3 is a sectional view of another embodiment of a prior art LED chip;

[0019] FIG. 4 is a graph showing the reflectivity of a metal reflector at different viewing angles;

[0020] FIG. 5a is a sectional view of one embodiment of an LED chip at a fabrication step in one method according to the present invention;

[0021] FIG. 5b is a sectional view of the LED chip in FIG. 5a at a subsequent fabrication step;

[0022] FIG. 6 is a sectional view of one embodiment of composite layer according to the present invention;

[0023] FIG. 7 is a graph showing the reflectivity of a composite layer according to the present invention;

[0024] FIG. 8 is a graph showing the reflectivity of a composite layer according to the present invention;

[0025] FIG. 9 is a sectional view of another embodiment of a composite layer according to the present invention;

[0026] FIG. 10a is a sectional view of another embodiment of an LED according to the present invention;

[0027] FIG. 10b is a sectional view of the LED in FIG. 10a at a subsequent fabrication step;

[0028] FIG. 10c is a sectional view of the LED in FIG. 10b at a subsequent fabrication step;

[0029] FIG. 10d is a sectional view of the LED in FIG. 10c at a subsequent fabrication step;

[0030] FIG. 11 is a plan view of one embodiment of a composite layer according to the present invention;

[0031] FIG. 12 is a plan view of another embodiment of a composite layer according to the present invention;

[0032] FIG. 13a is a sectional view of another embodiment of an LED chip according to the present invention;

[0033] FIG 13b is a sectional view of the LED chip shown in FIG. 13a at a subsequent fabrication step;

[0034] FIG 14 is a sectional view of another embodiment of an LED chip according to the present invention;

[0035] FIG. 15 is a sectional view of still another embodiment of an LED chip according to the present invention;

[0036] FIG. 16 is a sectional view of an embodiment of a LED package according to the present invention;

[0037] FIG. 17 is a sectional view of another embodiment of a LED package according to the present invention;

[0038] FIG. 18 is a sectional view of one embodiment of a composite layer according to the present invention;

[0039] FIG. 19 is a chart showing the composition of one embodiment of a traditional silver reflector;

[0040] FIG. 20 is a chart showing the composition of one embodiment of a composite layer according to the present invention;

[0041] FIG. 21 is a chart showing the composition of another embodiment of a composite layer according to the present invention;

[0042] FIG. 22 is a chart showing the composition of another embodiment of a composite layer according to the present invention;

[0043] FIG. 23 is a graph showing the package reflectance of each of the layers from FIGs. 19-22 according to the present invention;

[0044] FIG. 24 is a sectional view of one embodiment of a substrate with composite layers before separation according to the present invention;

[0045] FIG. 25 is a sectional view of one embodiment of a package utilizing traces and wire bonds for electrical connection according to the present invention;

[0046] FIG. 26a is a sectional view of one embodiment of a package utilizing vias for electrical connection according to the present invention;

[0047] FIG. 26b is a sectional view of another embodiment of a package utilizing vias for electrical connection according to the present invention;

[0048] FIG. 27 is a sectional view of one embodiment of a composite layer structure with an air gap according to the present invention; and

[0049] FIG. 28 is a sectional view of another embodiment of a composite layer structure with an air gap according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0050] Embodiments of the present invention are directed to solid-state emitters and methods for fabricating solid-state emitters having one or more composite high reflectivity contacts or layers arranged to increase emission efficiency of the emitters. Embodiments of the present invention are also directed to solid-state emitter packages and methods for fabricating solid-state emitter packages having one or more composite high reflectivity layers arranged to increase emission efficiency of the emitters. The present invention is described herein with reference to light emitting diodes (LED or LEDs) but it is understood that it is equally applicable to other solid-state emitters. The present invention can be used as a reflector in conjunction with one or more contacts, or can be used as a reflector separate from the contacts.

[0051] The improved reflectivity of the composite contact/layer ("composite layer") reduces optical losses

that can occur in reflecting light that is emitted from the active region in a direction away from useful light emission, such as toward the substrate or submount, and also to reduce losses that can occur when TIR light is reflecting within the LED. Embodiments of the present invention provide various unique combinations of layers that can comprise a composite layer. In one embodiment according to the present invention, the composite layer can comprise a first relatively thick layer, with second and third layers having different indices of refraction and different thickness, and a reflective layer. The composite layer can be in many different locations such as on an outer surface of the LED, a submount, or internal to the LED.

[0052] Different embodiments of the invention also provide composite layers having conductive via or path arrangements that provide conductive paths through the composite layer. This allows an electric signal to pass through the composite layer along the vias. This allows the composite layer be used as an internal layer or with a submount, where an electrical signal passes through the composite layer during operation. This via arrangement can take many different shapes and sizes as described in detail below.

[0053] The present invention is described herein with reference to certain embodiments but it is understood that the invention can be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. In particular, the composite layer can comprise many different layers of different material with many different thicknesses beyond those described herein. The composite layer can be in many different locations on different solid-state

emitters, submounts, and packages beyond those described herein. Further, the composite layer can be provided with or without conductive structures to allow electrical signals to pass through.

[0054] It is also understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. Furthermore, relative terms such as "inner", "outer", "upper", "above", "lower", "beneath", and "below", and similar terms, may be used herein to describe a relationship of one layer or another region. It is understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures.

[0055] Although the terms first, second, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the present invention.

[0056] Embodiments of the invention are described herein with reference to cross-sectional view illustrations that are schematic illustrations of embodiments of the invention. As such, the actual thickness of the layers can be different, and variations from the shapes of the illustrations as a result, for example, of manufacturing

techniques and/or tolerances are expected. Embodiments of the invention should not be construed as limited to the particular shapes of the regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. A region illustrated or described as square or rectangular will typically have rounded or curved features due to normal manufacturing tolerances. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region of a device and are not intended to limit the scope of the invention.

[0057] FIGs. 5a and 5b show one embodiment of an LED chip 50 according to the present invention, and although the present invention is described with reference to fabrication of a single LED chip it is understood that the present invention can also be applied to wafer level LED fabrication, fabrication of groups of LEDs, or fabrication of packaged LED chips and LED packaging. The wafer or groups of LEDs can then be separated into individual LED chips using known singulation or dicing methods. This embodiment is also described with reference to an LED chip having vertical geometry arrangement and that is flip chip mounted. As further described below the present invention can be used with other LED arrangements, such as lateral geometry LEDs and non flip-chip orientations.

[0058] The LED chip 50 comprises an LED 52 that can have many different semiconductor layers arranged in different ways. The fabrication and operation of LEDs is generally known in the art and only briefly discussed herein. The layers of the LED 52 can be fabricated using known processes with a suitable process being fabrication using MOCVD. The layers of the LED 52 generally comprise an

active layer/region 54 sandwiched between n-type and p-type oppositely doped epitaxial layers 56, 58, all of which are formed successively on a growth substrate 60. It is understood that additional layers and elements can also be included in the LED 52, including but not limited to buffer, nucleation, contact and current spreading layers as well as light extraction layers and elements. The active region 54 can comprise single quantum well (SQW), multiple quantum well (MQW), double heterostructure or super lattice structures.

[0059] The active region 54 and layers 56, 58 can be fabricated from different material systems, with preferred material systems being Group-III nitride based material systems. Group-III nitrides refer to those semiconductor compounds formed between nitrogen and the elements in the Group III of the periodic table, usually aluminum (Al), gallium (Ga), and indium (In). The term also refers to ternary and quaternary compounds such as aluminum gallium nitride (AlGaN) and aluminum indium gallium nitride (AlInGaN). In one embodiment, the n- and p-type layers 56, 58 are gallium nitride (GaN) and the active region 54 comprises InGaN. In alternative embodiments the n- and p-type layers 56, 58 may be AlGaN, aluminum gallium arsenide (AlGaAs) or aluminum gallium indium arsenide phosphide (AlGaInAsP) and related compounds.

[0060] The growth substrate 60 can be made of many materials such as sapphire, silicon carbide, aluminum nitride (AlN), GaN, with a suitable substrate being a 4H polytype of silicon carbide, although other silicon carbide polytypes can also be used including 3C, 6H and 15R polytypes. Silicon carbide has certain advantages, such as a closer crystal lattice match to Group III-

nitrides than sapphire and results in Group III-nitride films of higher quality. Silicon carbide also has a very high thermal conductivity so that the total output power of Group-III nitride devices on silicon carbide is not limited by the thermal dissipation of the substrate (as may be the case with some devices formed on sapphire). SiC substrates are available from Cree Research, Inc., of Durham, North Carolina and methods for producing them are set forth in the scientific literature as well as in U.S. Patents, Nos. Re. 34,861; 4,946,547; and 5,200,022.

[0061] Different embodiments of the LED 52 can emit different wavelengths of light depending on the composition of the active region 54 and n- and p-type layer 56, 58. In the embodiment shown, the LED 50 emits a blue light in the wavelength range of approximately 450 to 460nm. The LED chip 50 can also be covered with one or more conversion materials, such as phosphors, such that at least some of the light from the LED passes through the one or more phosphors and is converted to one or more different wavelengths of light. In one embodiment, the LED chip emits a white light combination of light from the LED's active region and light from the one or more phosphors.

[0062] In the case of Group-III nitride devices, current typically does not spread effectively through the p-type layer 58 and it is known that a thin current spreading layer 64 can cover some or the entire p-type layer 58. The current spreading layer helps spread current from the p-type contact across the surface of the p-type layer 58 to provide improved current spreading across the p-type layer with a corresponding improvement in current injection from the p-type layer into the active region. The current spreading layer 64 is typically a metal such

as platinum (Pt) or a transparent conductive oxide such as indium tin oxide (ITO), although other materials can also be used. The current spreading layer can have many different thicknesses, with one embodiment of an ITO spreading layer a thickness of approximately 115nm. The current spreading layer 64 as well as the layers that comprise the composite layer described below can be deposited using known methods. It is understood that in embodiments where current spreading is not a concern, the composite layer can be provided without a current spreading layer.

[0063] Referring now to FIG. 5b, a composite high reflectivity layer 62 can be deposited on the p-type layer 58, and in the embodiment shown the current spreading layer is between the reflectivity layer 62 and the p-type layer. The composite layer 62 according to the present invention has higher reflectivity to the wavelength of light generated by the LED 52 compared to standard metal contacts or distributed Bragg reflectors (DBRs). The composite layer generally comprises a thick layer of material followed by a plurality of thinner layers that combine to provide improved reflectivity. The present invention provides a composite layer with the desired reflectivity that also minimizes the number of layers to minimize the manufacturing complexities and cost.

[0064] Referring now to FIG. 6, the different layers that can comprise one embodiment of a composite layer according to the present invention are shown, but it is understood that many different materials, thicknesses and number of layers can also be used. A first layer 66 of the composite layer is provided on the current spreading layer 64, if a current spreading layer is included, and

the first layer can comprise many different materials, with the preferred material comprising a dielectric. Different dielectric materials can be used such as a SiN, SiO_2, Si, Ge, MgOx, MgNx, MgF_2, Ta_2O_5, Al_2O_3, TiO_2, ZnO, SiNx, SiOx, silicone, alloys, porous materials, air gaps, or combinations thereof, with the material in first layer 66 in the embodiment shown comprising SiO_2. This first layer 66 should be relatively thick to provide a reliable viewing angle cut-off point after which the reflectivity of the composite layer is approximately 100%, and in one embodiment used with a blue emitting LED the first layer 66 can have a thickness in the range of 500 to 650 nm, with one embodiment having a thickness of approximately 591 nm.

[0065] Referring now to the graph 72 in FIG. 7, which shows the p-polarization reflectivity 74, s-polarization reflectivity 76, and average reflectivity 78 at different viewing angles for a first layer 66 having a thickness in the range of 500 to 650 nm for blue wavelengths of light. The viewing angle cut-off is at a viewing angle of approximately 36 degrees. That is, the reflectivity of the composite layer 62 is approximately 100% at viewing angles greater than approximately 36 degrees, and below this viewing angle the reflectivity can be as low as 94% at certain viewing angles.

[0066] Referring again to FIG. 6, to improve reflectivity at lower viewing angles and to improve the angle averaged reflectivity (AAR), the composite layer 62 can also comprise second layers 68a, 68b and third layers 70a, 70b with the second and third layers being made of materials with differing indexes of refraction. In different embodiments different materials can be used for the layers and a different number of layers can be included,

with the embodiment shown having two second layers 68a-b comprising SiO_2 and two third layers 70a-b comprising TiO_2. SiO_2 has an index of refraction of 1.46, while TiO_2 has an index of refraction of 2.34. The two SiO_2 layers can have different thicknesses and the two TiO_2 layers can have different thicknesses, which provide a composite layer that is different from standard DBRs where the layers of different materials have the same thickness. One such example of this type of DBR is a ¼ wavelength DBR where each of the second and third SiO_2 and TiO_2 layers can have essentially the same optical thickness approximately equal to a ¼ wavelength of the light. In other embodiments of the composite layer, Ta_2O_5 can be used in place of TiO_2.

[0067] For the composite layer embodiment shown that is used in conjunction with a blue emitting LED, the second layers 68a-b can have thicknesses in the range of 100 to 120nm, and approximately 40 to 60nm respectively, with one embodiment of the second layers being approximately 108nm and 53nm thick. The third TiO_2 layers 70a-b can have thicknesses in the range of 55 to 75nm and 35 to 55nm, respectively, with one embodiment having thicknesses of approximately 65nm and 46nm respectively.

[0068] The composite layer 62 can also comprise a reflective layer 71 on the second layer 68b, deposited using known methods such as sputtering. The reflective layer 71 can have many different thicknesses and can comprise many different reflective materials, with suitable materials being Ag, Ti, Al and Au. The choice of material can depend on many factors with one being the wavelength of light being reflected. In the embodiment shown reflecting blue wavelengths of light, the reflective layer can comprise Ag having a thickness of

approximately 200nm. In other embodiments the reflective layer 71 can comprise composite metal layers such as TiAg, NiAg, CuAg or PtAg, and in some embodiments these composite layers can provide improved adhesion to the layer it is formed on, such as the second layer 68b. Alternatively, because some reflective materials do not have good adhesive properties, a thin layer of material such as indium tin oxide (ITO), Ni, Al_2O_3, Ti or Pt can be included between the second layer 68b and the reflective layer to also improve adhesion. A thin layer of material may also be placed between the reflective layer and any additional layer the reflective layer is in contact with, such as a submount, to improve adhesion.

[0069] The structure of the composite layer 62 provides improved AAR compared to standard ¼ wavelength DBRs. Although there may be a number of reasons why this arrangement provides this improvement, it is believed that one reason is that the different thicknesses of the second layers 68a,68b and the third layers 70a,70b present differently to light at various incident angles. That is, light will reach composite layer 62 at many different angles, and at these different angles the second layers 68a, 68b and third layers 70a, 70b can appear as different thicknesses, such as multiples of a ¼ wavelength thickness depending on the angle. It is believed that the different thicknesses provide the best overall AAR across viewing angles of 0-90 degrees. The use of layers comprised of different materials and thicknesses allows for good reflectivity across many angles and wavelengths.

[0070] FIG 8 is a graph 80 showing the reflectivity of a composite layer similar to that shown in FIG. 6, and shows the p-polarization reflectivity 82, s-polarization

reflectivity 84, and average reflectivity 86 at different viewing angles. In this case, the reflectivity includes the effect of an ITO current spreading layer 64 having a thickness of 115 nm and finite absorption coefficient of 500 /cm, which results in the reflectivity approaching but being slightly below 100% at viewing angles greater than approximately 36 degrees. The AAR across viewing angles of 0-90 degrees for the composite layer shown is approximately 98.79%, which provides an improvement over a standard DBR with a similar number of layers made of the same materials. At certain wavelengths of light the AAR of a standard ¼ wavelength DBR can be approximately 98.73% or less. This difference can have a significant impact on overall LED brightness because light can reflect off the composite layer multiple times before escaping from the LED. This compounding effect of multiple reflections amplifies even small differences in reflectivity.

[0071] FIG. 9 shows another embodiment of the composite layer 100 that is similar to composite layer 62 described above and can be used with a blue emitting LED. The composite layer 100 can have four layers instead of five. In this embodiment the first layer 102 is on a current spreading layer 64, although it is understood that the composite layer 100 can be used without a current spreading layer. The first layer 102 is similar to the first layer 66 described above and can be made of many materials and many different thicknesses. In the embodiment shown the first layer 102 can comprise SiO_2 with thickness in the range of 500 to 650nm, with one embodiment having a thickness of approximately 591nm.

[0072] In this embodiment, the composite layer 100 comprises only one second layer 106 sandwiched between

two third layers 108a-b, like the embodiment above. That is, there are not an equal number of alternating second layers and third layers as in composite layer 62 described above, and as in conventional DBRs. This results in second and third layers combinations that comprise incomplete pairs or that are asymmetric. In embodiments with incomplete second and third layer pairs can comprise different numbers of each layer such as two second layers and three third layers, three second layers and four third layers, etc.

[0073] The second and third layers 106, 108a-b can comprise many different materials and can have many different thicknesses. In the embodiment shown, the second layer 106 can comprise SiO_2 and can have a thickness in the range of approximately 100 to 120nm, with one embodiment having a thickness of 107nm. The third layers 108a-b can comprise TiO_2 and can have thicknesses of in the range of 45 to 65nm and 65 to 85nm respectively, with one embodiment having third layer thicknesses of approximately 56 and 75nm, respectively. The composite layer 100 can also comprise a reflective layer 110 on the third layer 108b that can be deposited using known methods and can comprise the same materials as reflective layer 71 described above.

[0074] By having an asymmetric arrangement, the composite layer can have fewer layers with the corresponding reduction in manufacturing steps and costs. This can also provide the additional advantage of better adhesion to subsequent layers, such as a reflective layer 110. In this embodiment the top layer comprises third layer 108b, which is TiO_2. This material can provide improved adhesion to reflective metals compared to the second layer 106 comprising SiO_2. The composite layer 100, however, can

have a reduced AAR compared to a six-layer arrangement shown in FIG. 6, with the AAR of one embodiment of a five-layer arrangement as shown in FIG. 9 being approximately 98.61%. This, however, represents an improvement over a standard five layer DBR where the AAR can be approximately 96.61%. Similar to the six-layer embodiment above, this difference can have a significant impact on overall LED brightness because of the compounding effect of multiple reflections.

[0075] It is understood that composite layers according to the present invention can have many different layers of different materials and thicknesses. In some embodiments the composite layer can comprise layers made of conductive materials such as conductive oxides. The conductive oxide layers can have different indices of refraction and the differing thicknesses to provide the improved reflectivity. The different embodiments can have different arrangements of complete and incomplete pairs of second and third layers. In some embodiments more layers, in complete or incomplete pairs, can increase the reflection efficiency of the composite layer. However, at some point the increase in layers may result in diminishing returns regarding the reflection efficiency. It is also understood that the composite layer can be arranged in different locations on a LED or package and can comprise different features to provide thermal or electrical conduction through the composite layer.

[0076] Referring now to the FIGs. 10a through 10d, another embodiment of an LED 120 having many of the same features as LED 50 shown in FIGs. 5a and 5b and for those same features the same reference numbers will be used. The LED 50 is fabricated such that it can be arranged in a flip-chip orientation, so for this embodiment the end

LED chip will have the composite layer 62 (or composite layer 100) arranged as an internal layer as further described below. Accordingly, an electric signal should pass through the composite layer 62. Referring now to FIG. 10a and FIG. 11, holes 122 can be formed through the composite layer 62 at random or regular intervals, with the holes sized and positioned so that a conductive material can be deposited in the holes to form conductive vias. In the embodiment shown the holes 122 are at regular intervals.

[0077] In different embodiments having a current spreading layer 64, the holes 122 may or may not pass through the current spreading layer 64. The holes 122 can be formed using many known processes such as conventional etching processes or mechanical processes such as microdrilling. The holes 122 can have many different shapes and sizes, with the holes 122 in the embodiment shown having a circular cross-section with a diameter of approximately 20 microns. Adjacent holes 122 can be approximately 100 microns apart. It is understood that the holes 122 (and resulting vias) can have cross-section with different shapes such as square, rectangular, oval, hexagon, pentagon, etc. In other embodiments the holes are not uniform size and shapes and there can be different spaces between adjacent holes.

[0078] Referring now to FIG. 12, instead of holes an interconnected grid 124 can be formed through the composite layer 62, with a conductive material then being deposited in the grid 124 to form the conductive path through the composite layer. The grid 124 can take many different forms beyond that shown in FIG. 11, with portions of the grid interconnecting at different angles in different embodiment. An electrical signal applied to

the grid 124 can spread throughout along the interconnected portions. It is further understood that in different embodiments a grid can be used in combination with holes.

[0079] Referring now to FIG. 10b, a conductive layer 126 can be deposited on the composite layer 62 covering its reflective layer and filling the holes 122 to form vias 128 through the composite layer 62. In other embodiments, the conductive layer can cover less than all of the composite layer 62. The conductive layer 126 can comprise many different materials such as metals or conductive oxides, both of which can be deposited using known techniques.

[0080] Referring now to FIG. 10c, the LED 120 can be flip-chip mounted to a submount 130 using known mounting techniques. In the embodiment shown, the LED 50 is flip-chip mounted to the submount by a conductive bond material 132. It is understood that in embodiments where the LEDs chips 120 are formed at the wafer level and then singulated, the LEDs chips 120 can be wafer bonded to the submount 130 using known wafer bonding techniques. The submount 130 can be made of many different materials and can have many different thicknesses, with the preferred submount 130 being electrically conductive so that an electrical signal can be applied to the active region of the LED through the submount 130. The signal also passes through the composite layer along conductive vias 128.

[0081] Referring now to FIG. 10d, the growth substrate 60 (as shows in FIG. 10c) can be removed using known grinding and/or etching processes. A first contact 134 can be deposited on the n-type layer 56 and a second contact 136 can be deposited on the submount 130. The

first and second contacts 134, 136 can comprise many different materials such as Au, copper (Cu) nickel (Ni), indium (In), aluminum (Al), silver (Ag), or combinations thereof. In still other embodiments the first and second contacts can comprise conducting oxides and transparent conducting oxides such as ITO, nickel oxide, zinc oxide, cadmium tin oxide, indium oxide, tin oxide, magnesium oxide, $ZnGa_2O_4$, ZnO_2/Sb, Ga_2O_3/Sn, $AgInO_2/Sn$, In_2O_3/Zn, $CuAlO_2$, LaCuOS, $CuGaO_2$ and $SrCu_2O_2$. The choice of material used can depend on the location of the contacts as well as the desired electrical characteristics such as transparency, junction resistivity and sheet resistance. The top surface of the n-type layer 56 can be textured or shaped such as by laser texturing, mechanical shaping, etching (chemical or plasma), scratching or other processes, to enhance light extraction.

[0082] During operation, an electrical signal is applied to the LED 50 across first and second contacts 134, 136. The signal on the first contact 134 spreads into the n-type layer 56 and to the active region 54. The signal on the second contact 136 spreads into the submount 130, through composite layer 62 along the vias 128, through the current spreading layer 64, into the p-type layer 58 and to the active region 54. This causes the active region 54 to emit light and the composite layer 62 is arranged to reflect light emitted from the active region toward the submount 128, or reflected by TIR toward the submount 130, back toward the top of the LED chip 50. The composite layer 62 encourages emission toward the top of the LED chip 50 and because of its improved reflectivity, reduces losses that occur during reflection.

[0083] It is understood that the composite layers can be used in many different ways and in many different

locations on LEDs, LED chips, packages, submounts, carriers, and other solid-state emitters. As shown in FIGs. 13a and 13b, the composite layers can be used in conjunction with a lateral geometry LED chip 150 where both contacts are on one side of the LEDs. The layers of the LED 150 are generally the same as those for LED chip 50 and can comprise an active layer/region 154 sandwiched between n-type and p-type oppositely doped epitaxial layers 156, 158, all of which are formed successively on a growth substrate 160. For lateral geometry LEDs, a portion of the p-type layer 158 and active region 154 is removed, such as by etching, to expose a contact mesa 161 on the n-type layer 156. In this embodiment, a composite layer 162 similar to the composite layer 62 described above can be included on both the surface of the n-type layer 156 and the surface of the p-type layer 158, with the composite layer having a metal layer 164 and conductive vias 166 similar to the metal layer 126 and vias 128 described above.

[0084] Referring now to FIG. 13b, the LED chip 150 can be flip-chip mounted to a submount 168 using known mounting processes preferably by conductive bonds 170 to the metal layers 164 on the composite layers 162. An electrical signal from the submount 168 is applied to the LED through the conductive bonds 170, and composite layers 162, causing the LED chip to emit light. The composite layers 162 reflect light that is directed toward the submount 168 to reflect back toward the emission surface of the LED chip 150. The improved reflectivity of the composite layers 162 reduces reflectivity losses and improves overall emission efficiency of the LED chip 150.

[0085] FIG. 14 shows still another embodiment of LED 180 according to the present invention also having an active

layer/region 184 sandwiched between n-type and p-type oppositely doped epitaxial layers 186, 188, all of which are formed successively on a growth substrate 190. A portion of the p-type layer 188 and active region 184 is removed, such as by etching, to expose a contact mesa on the n-type layer 186. In this embodiment, p- and n-type contacts 192, 194 are deposited on the p-type layer 188 and the contact mesa of the n-type 186, and a composite layer 196 can be included on the bottom surface of the substrate 190.

[0086] In this embodiment, an electrical signal is not applied to the LED through the composite layer 196. Instead, the electrical signal is applied through the p- and n-type contacts 192, 194 where it spreads laterally to the active region 184. As a result, an electrical signal does not need to pass through the composite layer 196 and the composite layer 196 does not need electrically conductive vias. Instead, an uninterrupted composite layer can be included across the substrate bottom surface to reflect light emitted from the active region toward the substrate and TIR light that reflects toward the substrate. It is understood that in different embodiments the composite layer can also cover all or part of the side surfaces of the LED 180, and a composite layer can be used in with the n- and p-type contacts 192, 194 to improve their reflectivity.

[0087] It is also understood that a composite layer can also be used on the bottom surface of submounts in flip-chip embodiments where the submounts are transparent. In these embodiments the desired reflectivity can be achieved without having internal composite layers 162 as shown in FIG. 13b.

[0088] FIG. 15 shows still another embodiment of an LED chip 210 having an active layer/region 214; n-type and p-type oppositely doped epitaxial layers 216, 218, all of which are formed successively on a growth substrate 220. LED 210 has vertical geometry with a p-type contact 224 on the p-type layer 218. A thin semitransparent current spreading layer (not shown) can cover some or the entire p-type layer 218, which is typically a metal such as Pt or a transparent conductive oxide such as ITO, although other materials can also be used. A composite layer 226 is included on the substrate 220 and, because the LED 210 has vertical geometry, an electrical signal can be applied to the LED through the composite layer 226. The composite layer comprises conductive vias 228 similar to those described above that allow an electrical signal to pass through the composite layer 226. The composite layer 226 can also comprise a metal layer 230 with an n-type contact 232 on the metal layer. This embodiment is particularly applicable to LEDs having electrically conductive substrates and an electrical signal applied to the p-type 224 and n-type contact 232 spreads to the LED active region 214 causing it to emit light. It is also understood that a composite layer can be included with the p-type contact to improve its reflectivity.

[0089] In different embodiments of the present invention the vias can serve additional purposes beyond conducting electrical signals. In some embodiments the vias can be thermally conductive to assist in thermal dissipation of heat generated by the LED. Heat can pass away from the LED through the vias where it can dissipate.

[0090] In some embodiments the composite layer can also be used at the package level, and in some embodiments the composite layer may be placed on a substrate, submount,

or carrier which the LED is mounted on. In yet other embodiments, the composite layer may be disposed anywhere within a package to increase light output efficiency. As described above, the composite layer may comprise a multilayer stack that includes a number of dielectric layers of different materials and thicknesses. In some embodiments, these dielectric layers may function to create an electrically insulating substrate. It may be preferable to have the dielectric materials be as optically smooth as possible to increase efficiency of the reflectivity of these layers. Inclusion of a composite layer in a LED package encourages emission toward the top of the LED package and because of its improved reflectivity, reduces losses that occur during reflection.

[0091] When used in a package, one of these dielectric layers should have an index of refraction lower than the encapsulant or other adjacent material to the composite layer on the side of the composite layer closer to the output surface. This would provide a step down in refractive index between the composite layer and the encapsulant increasing output efficiency. This same layer should be thick, to aid in reflection. This thickness could be 0.25 μm or thicker, 0.5 μm or thicker, or 1.0 μm or thicker. A thickness of 0.5 μm or larger is preferable. This layer can be located anywhere within the dielectric layer stack. In addition to various materials which have an index of refraction lower than the encapsulant, this layer may also be comprised of an air gap or a porous material. If this layer is the topmost layer it must be coated with an additional layer to seal the pores because the dielectric layers as a whole must be pin-hole free for electrical insulation.

Heated or ion-assisted depositions can be used in embodiments where dense films are desired. As described above, the dielectric material stack may include any number of layers and complete or incomplete layer pairs.

[0092] In some embodiments, a layer of reflective material can be included under the dielectric material stack. This material may be any suitable reflective material such as those described above, preferably a highly reflective metal. This layer of reflective material can also comprise any number of layers. The metal layer may be patterned such that it terminates before the dicing or cutting point of a substrate, to maintain reliability. In some embodiments, an adhesion layer may be included on either or both sides of the metal layer. This adhesion layer may be made of any suitable material such as those described previously. An adhesion layer may help adhere the metal or reflective layer to the dielectric layer stack or may also be used to adhere the metal or reflective layer to a substrate, submount, carrier, or other surface. For ease of reference, substrates, submounts, and carriers will be referred to interchangeably. These submount or packaging surfaces may be made of any suitable material. Examples of such materials include ceramics, Alumina, Silicon and AlN. In some embodiments, where the composite layer is placed directly on the substrate, it is preferred that the substrate have an optically smooth surface such that the composite layer is formed to be optically smooth as well. In other embodiments it may be preferred that the substrate have good thermal conductivity for heat dissipation and a heat dissipation path exist away from the LEDs to the substrate.

[0093] FIG. 16 shows one embodiment of a LED package 306 according to the present invention, and although the embodiment is described with reference to fabrication of a single package it is understood that the present invention can also be applied to fabrication of groups of LED packages. This embodiment is also described herein with reference to LED chips 302, but it is understood that other embodiments can use other types of light emitters. LEDs chips 302 may include a submount and may have any configuration or fabrication including those described previously in this application. The LED chip can be contacted using conventional techniques. As further described below, the present invention can be used with other LED package arrangements. In addition, the LEDs may be mounted within the package by any suitable means such as traditional mounting, flip-chip mounting, wafer bonding, or any other mounting means. In some embodiments, these LEDs may also utilize the composite layer within their contacts in addition to at the package level. Also, it is understood that in different embodiments the composite layer can also cover other areas of the package, all or part of the side surfaces of the LED 302, and a composite layer can be used with contacts or traces to improve their reflectivity.

[0094] Different embodiments of the package 306 can emit different wavelengths of light depending on the composition of the LEDs 302 and encapsulant 304. In some embodiments, the LEDs 302 emit a blue light in the wavelength range of approximately 450 to 460nm. In other embodiments the LEDs 302 may each emit different wavelengths of light. The LED chips 302 can also be covered with one or more conversion materials. As shown

in FIG. 16 the encapsulant 304 can comprise a conversion materials, such as phosphors, such that at least some of the light from the LED is absorbed by the one or more phosphors and is converted to one or more different wavelengths of light. In one embodiment, the LED package emits a white light combination of light from the LED's active region and light from the one or more phosphors.

[0095] Referring to FIG. 16, a composite high reflectivity layer 362 can be deposited on the submount or substrate 300. The composite layer 362 according to the present invention has higher reflectivity of the wavelength of light generated by the LEDs 302 compared to standard metal layers or distributed Bragg reflectors (DBRs). The improved reflectivity of the composite layer 362, over DBR's and traditional reflective layers, reduces reflectivity losses and improves overall emission efficiency of the LED package 306. As described above, the composite layer generally comprises a thick layer of material coupled with a plurality of thinner layers that combine to provide improved reflectivity. Light emitted out of the LEDs 302, light emitted from phosphors in the encapsulant 304, and light which reflects off of the exit surface of the encapsulant 304 may be emitted towards the substrate 300. At least a portion of this light is reflected off the composite layer 362 and redirected so that it can exit the package.

[0096] Referring now to FIGs. 17-22, the different layers that can comprise one embodiment of a composite layer according to the present invention are shown, but it is understood that many different materials, thicknesses and number of layers can also be used. Fig. 17 shows a side view of a LED package 306 with composite layers 362 applied. As discussed previously, the placement of

composite layers 362 allows for more efficient reflection and therefore emission of light. FIG. 18 shows one possible configuration of a reflective composite layer 362. In this configuration, a set of dielectric layers 308 are included over a set of metal layers. The portion of the dielectric layers 308 adjacent to the metal layer 310 may be an adhesion layer 312. In other embodiments, the portion of the metal layer 310 adjacent to the dielectric layer 308 may be an adhesion layer 312. The portion of metal layer 310 adjacent to the substrate 300 may also be an adhesion layer 312. In some embodiments, the adhesion layer 312 adjacent to the substrate does not necessarily impact the optical properties of the composite layer 362. Though the adhesion layers 312 in FIG. 18 are shown as either a part of the dielectric material layer 308 or the metal layer 310, the adhesion layers 312 may be any suitable material.

[0097] The specific layers 308, 310, of the composite layer 362, may include a variety of materials at varying thicknesses designed to maximize the AAR across the visible spectrum. Though any combination of materials and thicknesses may be used, as discussed above, FIGs. 20-22 show three specific examples of material and thickness combinations of composite layer 362. In all three figures the second to last layer of Al_2O_3 can function as an adhesion layer 312. Also further adhesion layers may be included after the Ag layer. Though specific material layers and thicknesses are shown in these figures, it is understood that any suitable materials and thicknesses may be used, such as those mentioned elsewhere in this application. FIG. 20 shows a dielectric thin film stack 308 comprised of layers of Ta_2O_5 and SiO_2 terminated by an Al_2O_3 adhesion layer 312,

followed by an Ag metal layer 310. FIG. 21 shows a dielectric thin film stack 308 comprised of layers of Ta_2O_5, and airgap, and SiO_2 terminated by an Al_2O_3 adhesion layer 312, followed by an Ag metal layer 310. FIG. 22 shows a dielectric thin film stack 308 comprised of layers of Ta_2O_5 and silicone terminated by an Al_2O_3 adhesion layer 312, followed by an Ag metal layer 310. The performance of each of these composite layers 362 shown in FIGs. 20-22 and a baseline Ag layer with a thickness of 200nm, as shown in FIG. 19, in terms of AAR percentage, is shown in FIG. 23. As the graph in FIG. 23 shows, the different multilayer composite stacks 362 outperform the baseline Ag layer. In other embodiments there may not be an equal number of alternating layers as in the composite layers 362 shown in FIGs. 20-22, and as in conventional DBRs. This results in layer combinations that comprise incomplete pairs or that are asymmetric. In embodiments with incomplete layer pairs, the composite layer can comprise different numbers of each layer such as two of one type of layer and three of another type of layer, three of a first type of layer and four of a second type of layer, or different variations of different numbers of types of layers, etc. Furthermore, FIGs. 20-22 show particular thicknesses of the layers however these can be varied as desired. Preferably, the thickness of the individual layers are optimized, using optimization software, such that the plurality of the layers combined provides the highest reflectivity across the desired range of angles and wavelengths.

[0098] These composite reflective layers 362 may be fabricated and placed on the substrates or submounts 300 using any suitable methods such as those described previously in this application. In some embodiments, it

is preferable, during fabrication, that the composite layers 362 are not diced or cut as this may cause the layers to deform and thereby impact the optical qualities of the composite layers 362. One method to avoid this is to dispose the composite layers 362 such that they terminate at a point where dicing or cutting of the underlying substrate, submount, or carrier 300 would occur, as shown in FIG. 24. This allows the mass-manufacturing of substrates on large dimeter wafers, for example Si wafers, prior to LED or LED submount attachment. Preferably, the distance left between composite layers 362 is the minimal distance required for dicing, cutting, or separating of the substrate 300, however, any distance may be left. In one embodiment, distance 'A' of FIG. 24 is the distance which would be left between terminated composite layer 362 sections. This distance 'A' may be on the order of μm. For example, in some embodiments distance 'A' may be 1-20 μm. In other embodiments, distance 'A' may be 5-50 μm. In yet other embodiments, distance 'A' may be 10-100 μm. Distance 'B', in contrast, is the distance or length of continuous composite layer 362 sections. This distance 'B' may be in the range of several mm rather than μm.

[0099] In some embodiments, during fabrication it is also preferred that the layers are disposed such that stress is reduced after the placement of each layer or such that stress compensation between the layers is utilized. This process reduces the overall stress of the composite layer 362 and therefore helps prevent stress related deformations of the composite layer 362. This is desirable because it is preferable to have the composite layer or dielectric layers as optically smooth as possible.

[00100] Light emitters mounted over a composite layer 362 may be electrically connected by any suitable method known in the art. Such methods include traces, wire bonds, grids, and vias. FIGs. 25, 26a. and 26b show exemplary connection methods. FIG. 25 shows one portion of the LED utilizing a trace 314 for electrical connectivity and another portion utilizing a wire bond 316. In other embodiments these traces and wire bonds may also extend beyond the substrate 300. As a result, an electrical signal does not need to pass through the composite layer 362 and the composite layer 362 does not need electrically conductive vias. Instead, an uninterrupted composite layer can be included across the substrate surface to reflect light emitted from the LED or wavelength conversion material toward the substrate and TIR light that reflects toward the substrate.

[00101] FIGs. 26a and 26b show embodiments utilizing vias through the composite layer 362 to provide electrical connectivity to the light emitter 302. In some embodiments, such as in FIG. 26b these vias may terminate at the substrate 300, possibly connecting to traces on the substrate 300. In other embodiments, such as in FIG. 26a, the vias may extend through the substrate as well. Holes can be formed through the composite layer 362 at random or regular intervals, with the holes sized and positioned so that a conductive material can be deposited in the holes to form conductive vias. Further, these vias may be created using any suitable method and may be through holes or grids of various shapes and sizes as described in this application. These vias may also be used for heat dissipation. It is understood that any other suitable electrical or thermal connectivity methods can be used in conjunction with the composite layer 362.

[00102] As described previously, it is preferable in packaging application to include a thick layer which has an RI lower than the encapsulant being used. In some embodiments this may be accomplished by the incorporation of a porous material, such as MgF_2 deposited by e-beam evaporation or any other suitable porous material or depositing method. In other embodiments, however, an air gap may be used rather than a layer of some material. As shown in FIG. 27, an air gap 322 may be situated with the use of posts or protrusions 320 from other layers to create an air gap 322 while still supporting the composite layer structure. These posts or protrusions 320 may be formed by any suitable means. For example in some embodiments, a layer may be patterned or have portions removed in order to create the protrusions 320. Whereas in other embodiments the same layer may just be formed such that it has protrusions. In yet another embodiment the posts or protrusions 320 may be their own layer independent of the adjacent layers.

[00103] As shown in FIG. 28, the posts or protrusions may instead be formed in the substrate 300. Subsequently, the metal layer 310 portion of the composite layer 362 may be placed over the patterned substrate 300, taking the same or similar form as the substrate. Next, the dielectric 308 portion of the composite layer 362 is placed over the metal layer 310 forming air gaps 322 in the voids between protrusions 320. In some embodiments the dielectric portion 308 may further include a carrier or support structure to maintain its rigid shape when placed over the protrusions 320. This support layer or structure may be comprised of any suitable dielectric material. One example including glass. In some embodiments, the dielectric portion of the composite

layer may be preformed and then attached to the metal layer 310, leaving air gaps 322 between protrusions 320.

[00104] Although the present invention has been described in detail with reference to certain preferred configurations thereof, other versions are possible. Therefore, the spirit and scope of the invention should not be limited to the versions described above.

I CLAIM:

1. A light emitting diode (LED) package, comprising:

an LED mounted on a substrate;

an encapsulant over said LED; and

a composite high reflectivity layer arranged to reflect light emitted from said LED, said composite layer comprising:

a plurality of layers such that at least one of said plurality of layers has an index of refraction lower than said encapsulant; and

a reflective layer on a side of said plurality of layers opposite said LED.

2. The LED package of claim 1, wherein said plurality of layers comprise first and second layers.

3. The LED package of claim 2, wherein said first layers have an index of refraction different from said second layers.

4. The LED package of claim 2, wherein said first and second layers alternate, and each of said second layers having different thicknesses compared to the other of said second layers.

5. The LED package of claim 1, wherein said plurality of layers comprise a dielectric material.

6. The LED package of claim 1, further comprising an adhesion layer between said plurality of layers and said reflective layer.

7. The LED package of claim 1, wherein said reflective layer is on said substrate.

8. The LED package of claim 7, further comprising an adhesion layer between said reflective layer and said substrate.

9. The LED package of claim 1, wherein said composite layer further comprises conductive vias.

10. The LED package of claim 1, further comprising conductive traces to provide an electrical connection to said LED.

11. The LED package of claim 10, wherein said conductive traces at least partially pass over said composite layer.

12. The LED package of claim 1, further comprising wire bonds to provide an electrical connection to said LED.

13. The LED package of claim 12, wherein said wire bonds at least partially pass over said composite layer.

14. The LED package of claim 1, wherein said composite layer formed such that stress is reduced between each of said plurality of layers and reflective layer.

15. The LED package of claim 1, wherein the reflectivity of said composite layer within a desired range of angles is approximately 100%.

16. The LED package of claim 1, wherein the reflectivity of said composite layer within a desired range of angles

is greater than the reflectivity of a similarly situated Ag layer.

17. The LED package of claim 2, wherein said one or more first layers comprises two layers having different thicknesses.

18. The LED package of claim 2, wherein said one or more first layers comprises one layer between said plurality of second layers.

19. The LED package of claim 1, wherein said composite layer comprises an angle averaged reflectivity greater than a quarter wavelength distributed Bragg reflector having the same number of layers.

20. The LED package of claim 2, wherein said one or more first layers and said plurality of second layers comprise incomplete first and second layer pairs.

21. The LED package of claim 1, wherein said composite layer is internal to said LED package.

22. The LED package of claim 1, wherein said at least one of said plurality of layers with an index of refraction lower than said encapsulant has a thickness of at least 0.25 μm.

23. The LED package of claim 1, wherein said composite layer is optically smooth.

24. The LED package of claim 1, further comprising a thermal path between said LED and said substrate.

25. A method for fabricating a light emitting diode (LED) package, comprising:

providing a substrate;

providing composite high reflectivity layer, arranged to reflect light emitted from said LED, on said substrate;

providing a LED mounted on said composite layer; and

providing an encapsulant over said LED.

26. The method of claim 25 wherein providing said composite layer further comprises:

providing a reflective layer on said substrate; and

providing a plurality of layers over said reflective layer such that at least one of said plurality of layers has an index of refraction lower than said encapsulant.

27. The method of claim 26, wherein said plurality of layers comprise first and second layers.

28. The method of claim 27, wherein said first layers have an index of refraction different from said second layers.

29. The method of claim 27, wherein said first and second layers alternate, and each of said second layers having different thicknesses compared to the other of said second layers.

30. The method of claim 26, wherein said plurality of layers comprise a dielectric material.

31. The method of claim 26, further comprising providing an adhesion layer between said plurality of layers and said reflective layer.

32. The method of claim 26, further comprising providing an adhesion layer between said reflective layer and said substrate.

33. The method of claim 25, further comprising providing an at least one conductive via within said composite layer.

34. The method of claim 25, further comprising providing an at least one conductive trace to provide an electrical connection to said LED.

35. The method of claim 34, wherein said conductive trace at least partially passes over said composite layer.

36. The method of claim 25, further comprising providing an at least one wire bond to provide an electrical connection to said LED.

37. The method of claim 36, wherein said wire bonds at least partially pass over said composite layer.

38. The method of claim 26, wherein providing said composite layer further comprises reducing layer stress between each of said plurality of layers and reflective layer.

39. The method of claim 25, wherein the reflectivity of said composite layer within a desired range of angles is approximately 100%.

40. The method of claim 25, wherein the reflectivity of said composite layer within a desired range of angles is greater than the reflectivity of a similarly situated Ag layer.

41. The method of claim 27, wherein said one or more first layers comprises two layers having different thicknesses.

42. The method of claim 27, wherein said one or more first layers comprises one layer between said plurality of second layers.

43. The method of claim 25, wherein said composite layer comprises an angle averaged reflectivity greater than a quarter wavelength distributed Bragg reflector having the same number of layers.

44. The method of claim 27, wherein said one or more first layers and said plurality of second layers comprise incomplete first and second layer pairs.

45. The method of claim 25, wherein said composite layer is internal to said LED package.

46. The method of claim 25, wherein said at least one of said plurality of layers with an index of refraction lower than said encapsulant has a thickness of at least 0.25 μm.

47. The method of claim 25, wherein said composite layer is provided such that it is optically smooth.

48. The method of claim 25, further comprising providing a thermal path between said LED and said substrate.

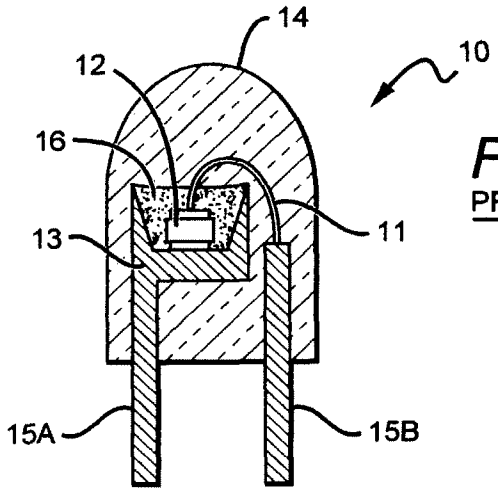


FIG. 1
PRIOR ART

FIG. 2
PRIOR ART

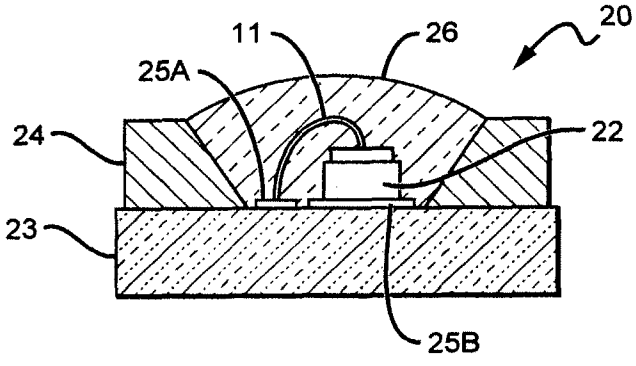


FIG. 3
PRIOR ART

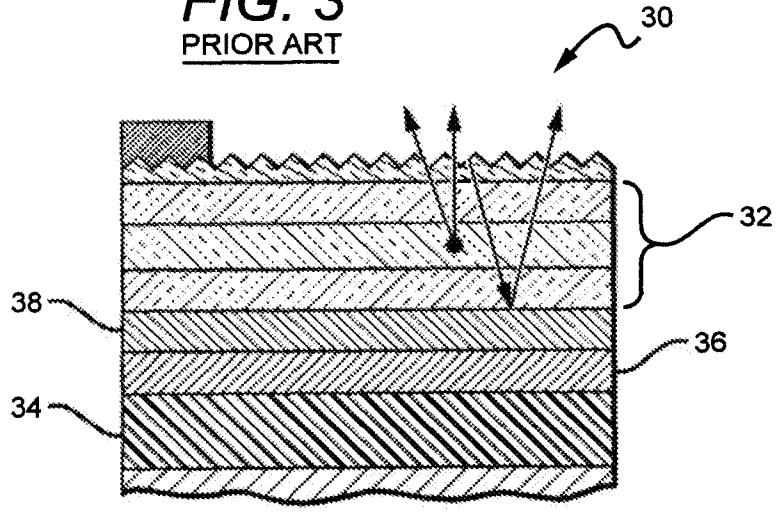


FIG. 4

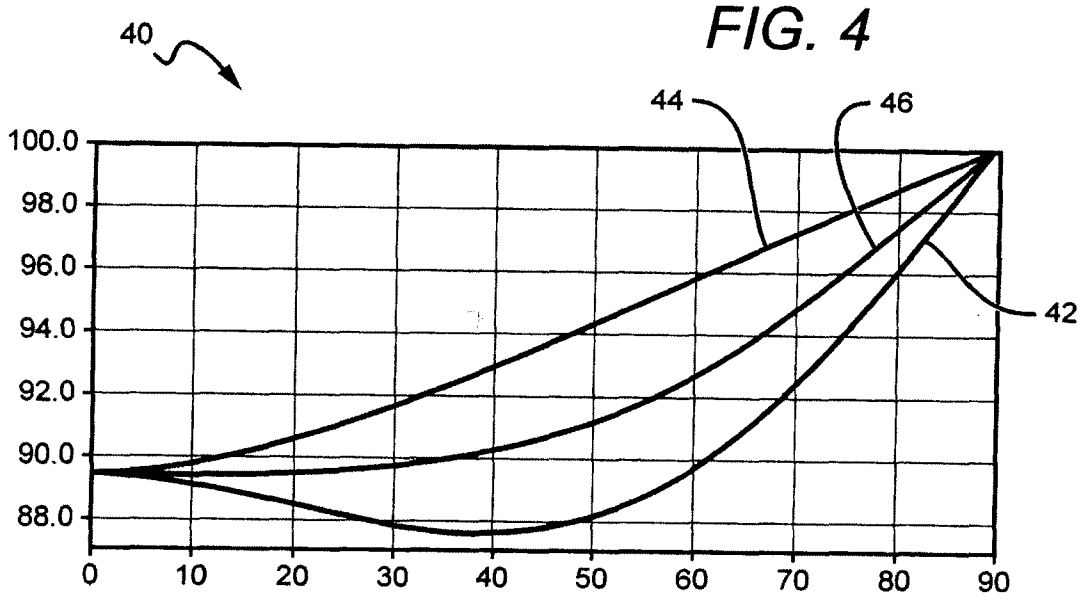


FIG. 5a

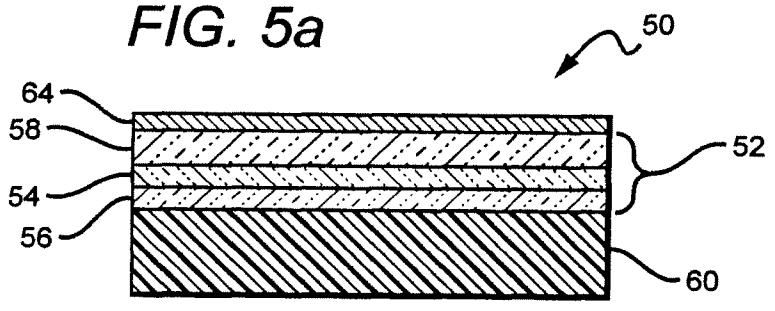


FIG. 5b

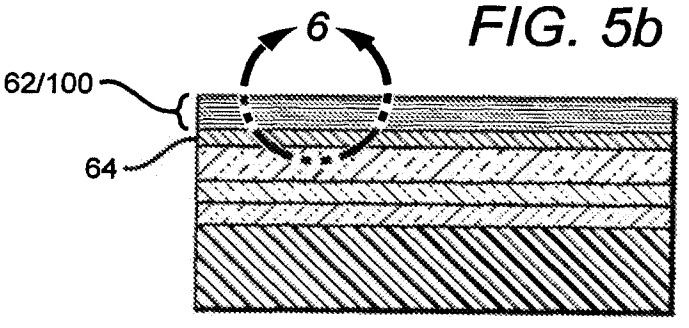


FIG. 6

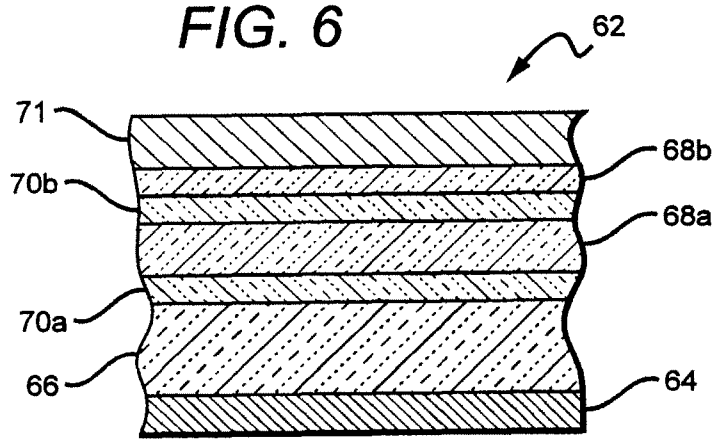


FIG. 9

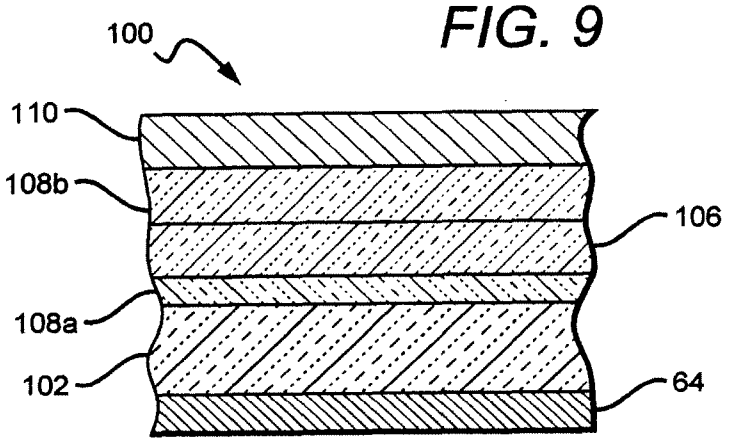


FIG. 7

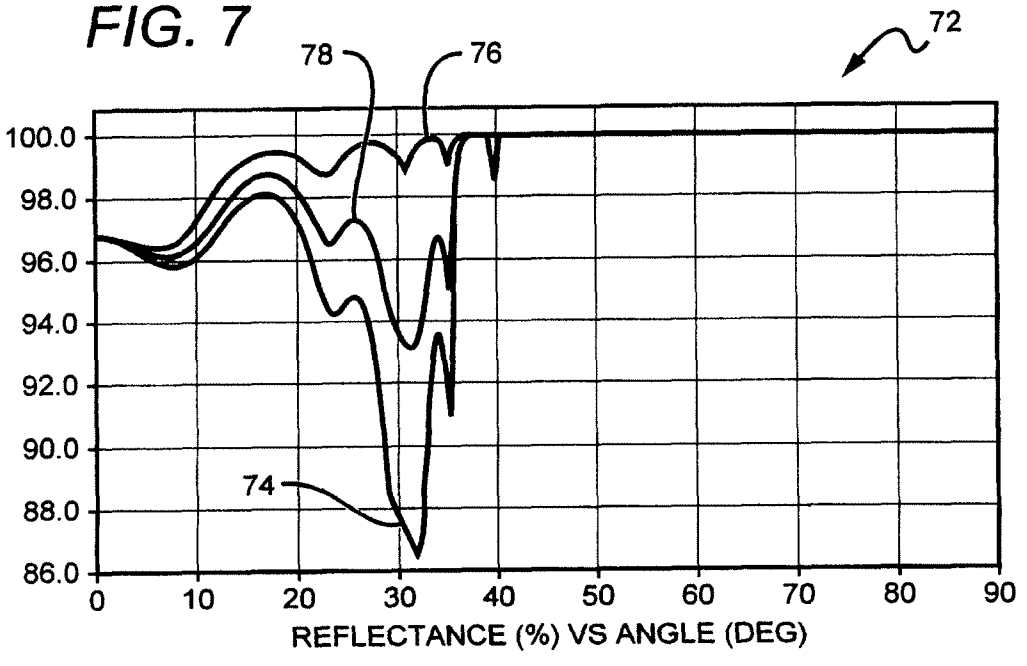


FIG. 8

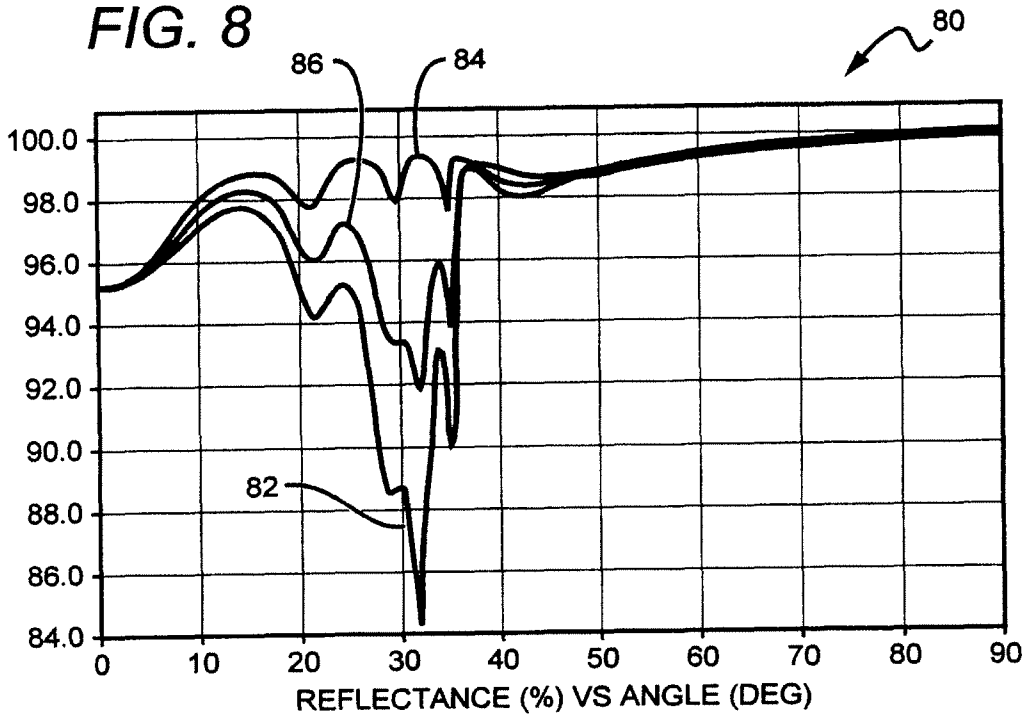


FIG. 10a

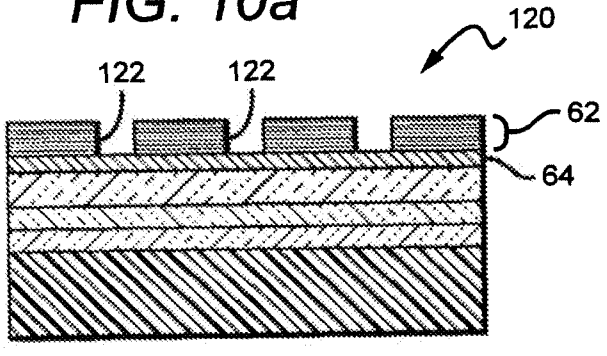
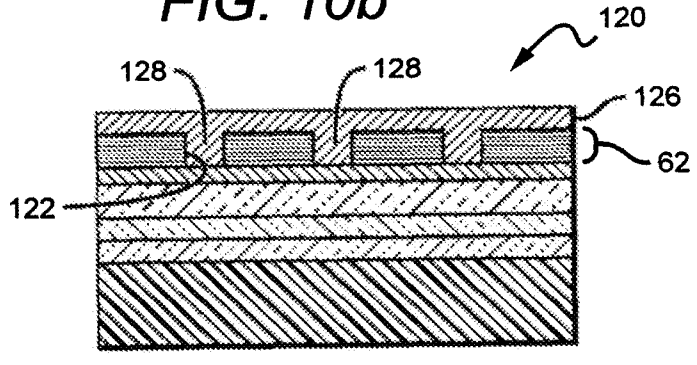


FIG. 10b



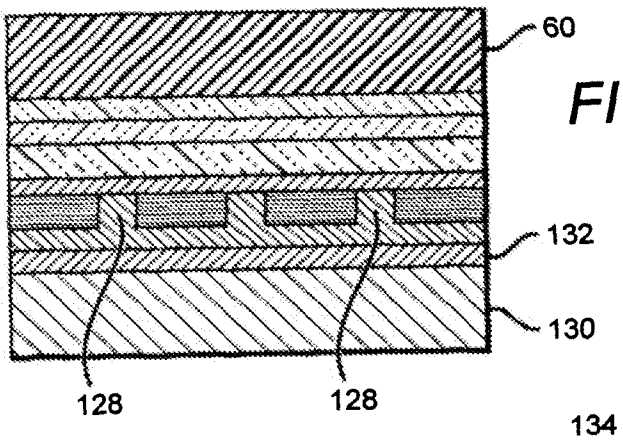


FIG. 10c

FIG. 10d

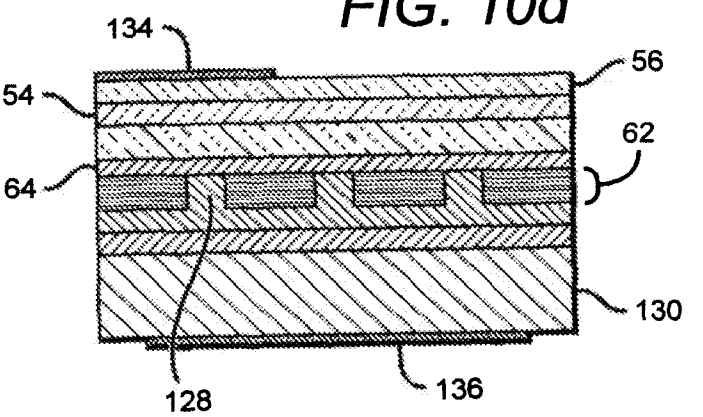


FIG. 11

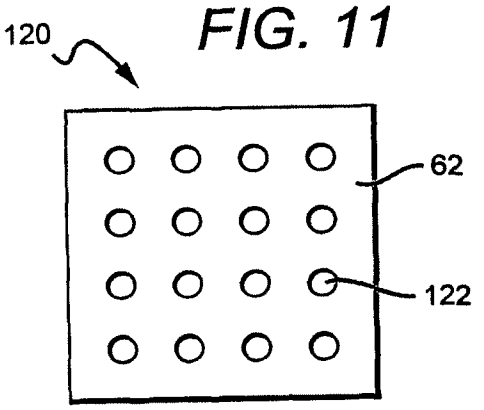


FIG. 12

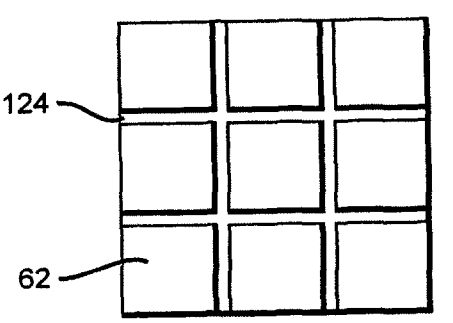


FIG. 13a

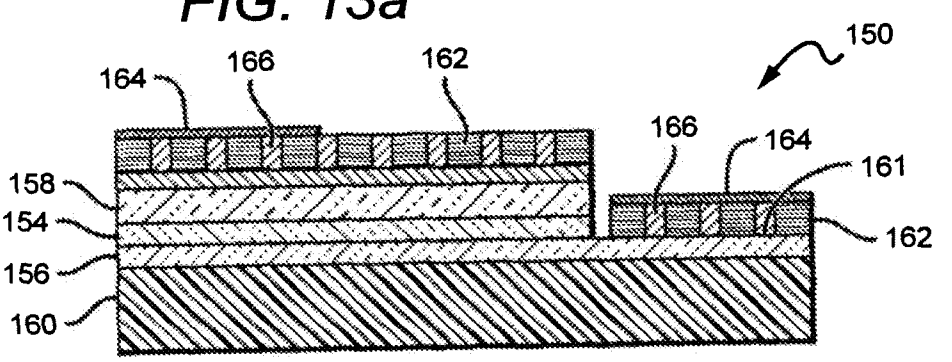
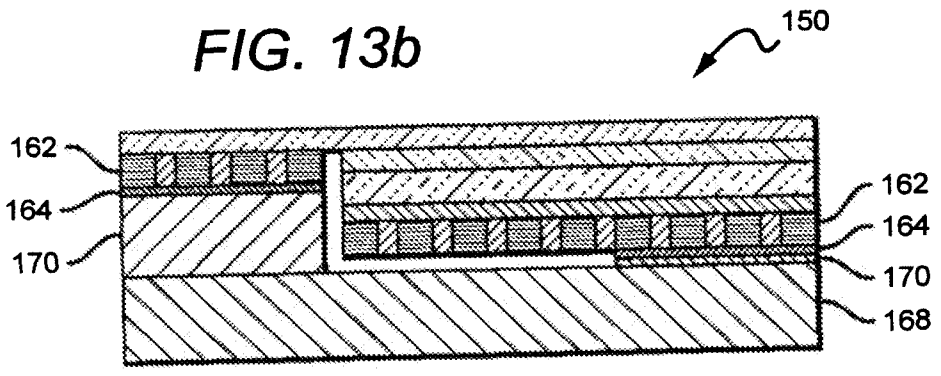


FIG. 13b



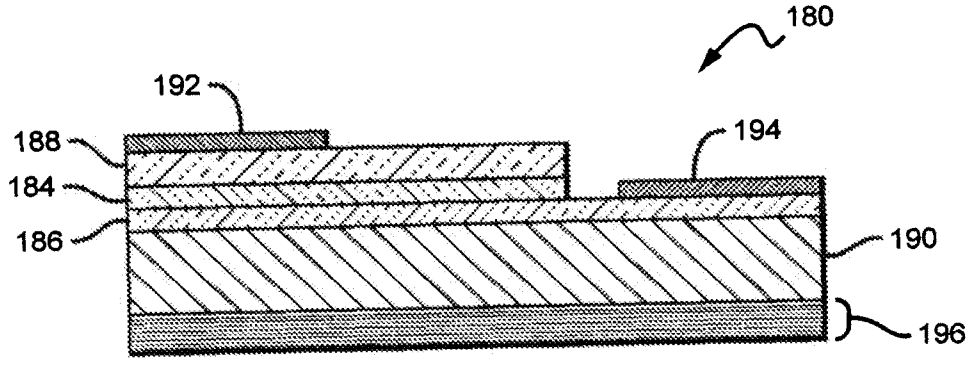


FIG. 14

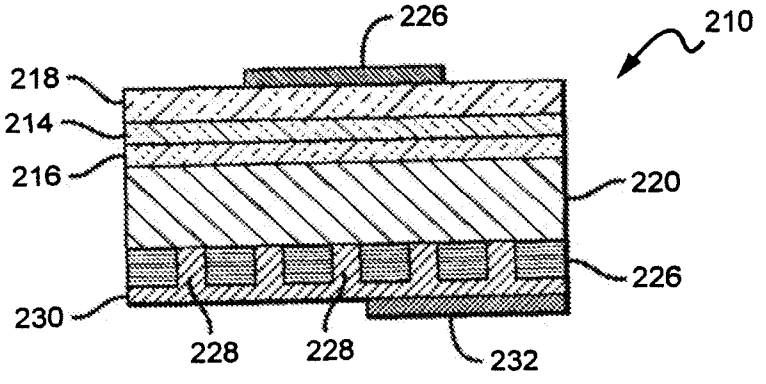


FIG. 15

FIG. 16

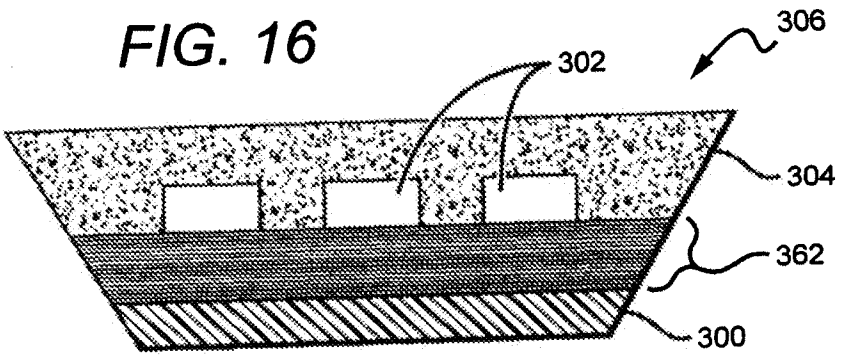


FIG. 17

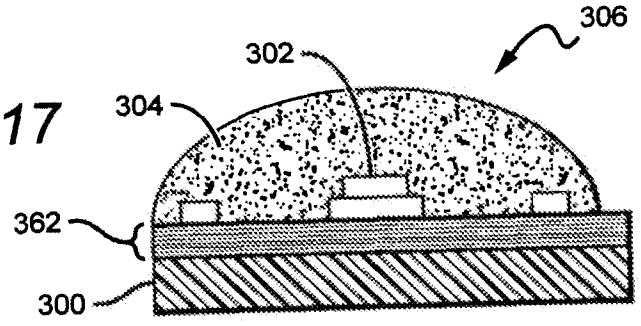


FIG. 18

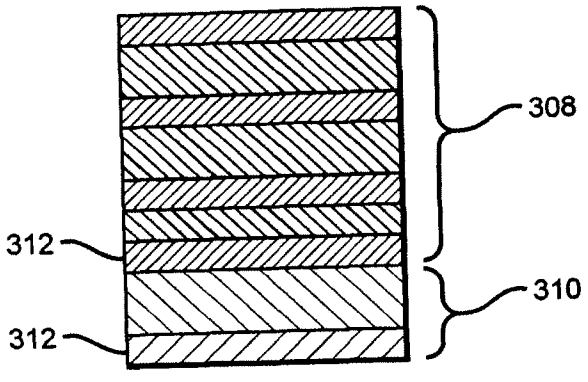


FIG. 19

Layer	t (nm)
Ag	200

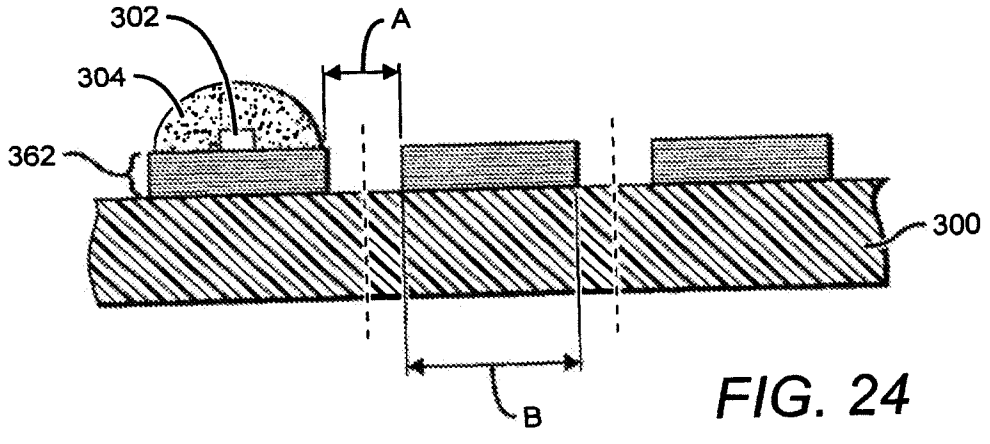


FIG. 24

FIG. 20

Layer	t (nm)
TA2O5	80
SIO2	380.0
TA2O5	59.0
SIO2	300.0
TA2O5	20.0
SIO2	80.0
AL203	20
Ag	200

308
310
312

FIG. 21

Layer	t (nm)
TA2O5	80
AIRGAP	380.0
TA2O5	59.0
SIO2	300.0
TA2O5	20.0
SIO2	80.0
AL203	20
Ag	200

308
310
312

FIG. 22

Layer	t (nm)
TA2O5	127.8
SILICONE	322.0
TA2O5	61.5
SILICONE	326.6
TA2O5	61.6
SILICONE	35.6
AL203	20
Ag	200

308
310
312

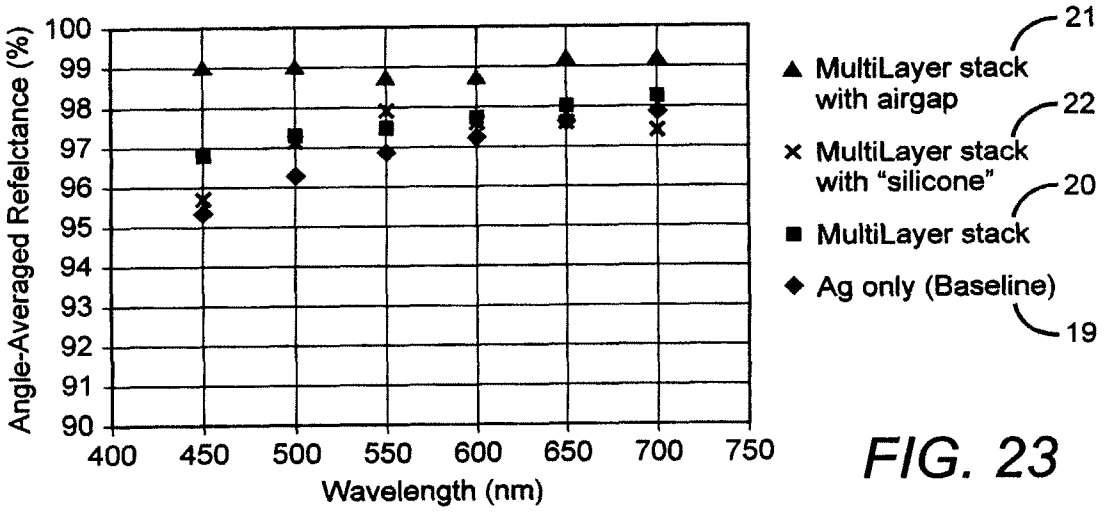


FIG. 23

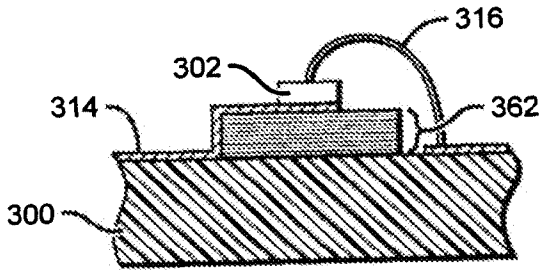


FIG. 25

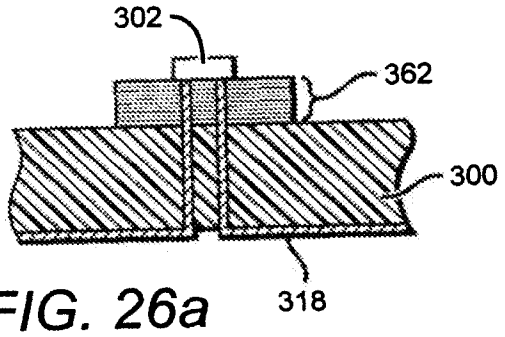


FIG. 26a

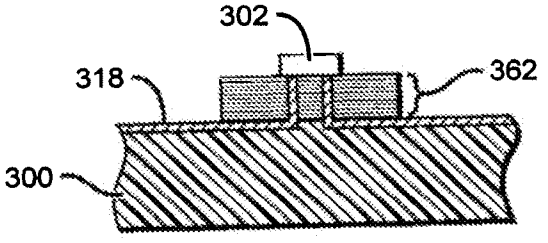


FIG. 26b

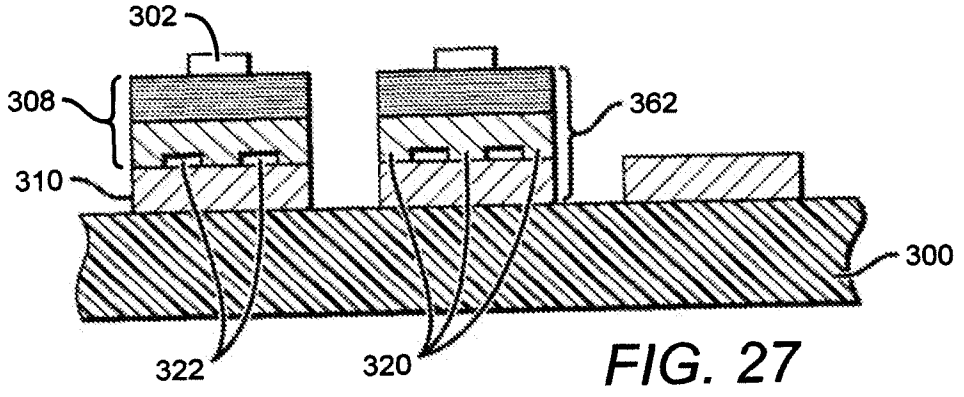


FIG. 27

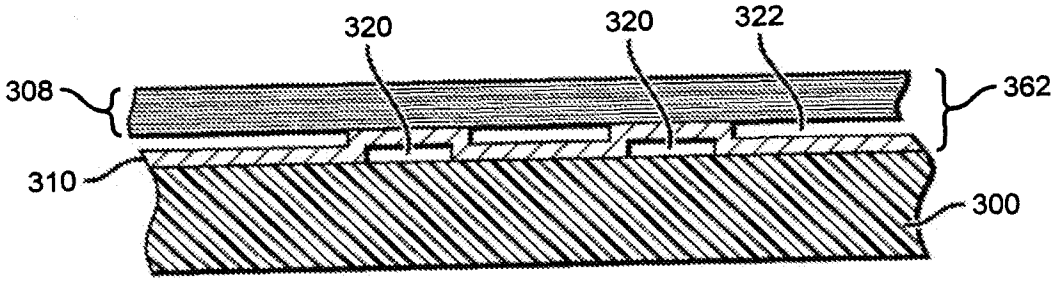


FIG. 28

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/028684

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L33/46 G02B19/00
ADD. H01L33/48 H01L33/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 369 650 A2 (LG INNOTEK CO LTD [KR]) 28 September 2011 (2011-09-28)	1-3, 5-16,18, 21-28, 30-40, 42,45-48
Y	abstract; figures 1-3,5-8 paragraphs [0057], [0058], [0061] paragraphs [0066], [0067], [0074] -----	4,17,19, 20,29, 41,43,44
Y	US 2010/140635 A1 (IBBETSON JAMES [US] ET AL LI TING [US] ET AL) 10 June 2010 (2010-06-10)	4,17,19, 20,29, 41,43,44
A	abstract; figures 6-15 paragraph [0056] paragraphs [0051] - [0057] -----	6,8,31, 32
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
21 May 2013	28/05/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Heising, Stephan

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/028684

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/028684

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HUANG H W ET AL: "High-Performance GaN-Based Vertical-Injection Light-Emitting Diodes With TiO-SiO Omnidirectional Reflector and n-GaN Roughness", IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 19, no. 8, 15 April 2007 (2007-04-15) , pages 565-567, XP011175438, ISSN: 1041-1135	1-48
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Information on patent family members

International application No
PCT/US2013/028684

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International application No
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