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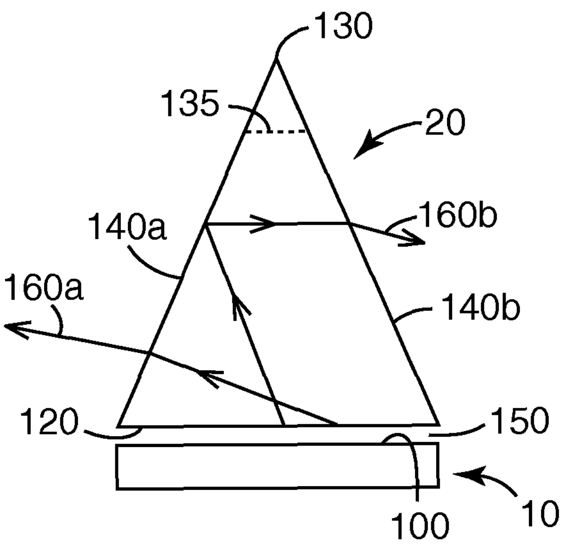
(54) **Title:** LED PACKAGE WITH COMPOUND CONVERGING OPTICAL ELEMENT



(57) **Abstract:** The present application discloses a light source comprising an LED die having an emitting surface and an optical element including a base, an apex, and a converging side joining the base and the apex, wherein the base is optically coupled to the emitting surface. Furthermore, the optical element comprises a first section including the base and that is composed of a first material and a second section including the apex and that is composed of a second material.

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LED Package With Compound Converging Optical Element

Field of Invention

The present invention relates to light sources. More particularly, the present invention relates to light sources in which light emitted from a light emitting diode (LED) is extracted using an optical element.

Background

LEDs have the inherent potential to provide the brightness, output, and operational lifetime that would compete with conventional light sources. Unfortunately, LEDs produce light in semiconductor materials, which have a high refractive index, thus making it difficult to efficiently extract light from the LED without substantially reducing brightness, or increasing the apparent emitting area of the LED. Because of a large refractive index mismatch between the semiconductor and air, an angle of an escape cone for the semiconductor-air interface is relatively small. Much of the light generated in the semiconductor is totally internally reflected and cannot escape the semiconductor thus reducing brightness.

Previous approaches of extracting light from LED dies have used epoxy or silicone encapsulants, in various shapes, e.g. a conformal domed structure over the LED die or formed within a reflector cup shaped around the LED die. Encapsulants have a higher index of refraction than air, which reduces the total internal reflection at the semiconductor-encapsulant interface thus enhancing extraction efficiency. Even with encapsulants, however, there still exists a significant refractive index mismatch between a semiconductor die (typical index of refraction, n of 2.5 or higher) and an epoxy encapsulant (typical n of 1.5).

Recently, it has been proposed to make an optical element separately and then bring it into contact or close proximity with a surface of an LED die to couple or “extract” light from the LED die. Such an element can be referred to as an extractor. Examples of such optical elements are described in U.S. Patent Application Publication No. US 2002/0030194A1, “LIGHT EMITTING DIODES WITH IMPROVED LIGHT EXTRACTION EFFICIENCY” (Camras et al.).

Summary

The present application discloses a light source comprising an LED die having an emitting surface and an optical element including a base, an apex, the base, and a converging side joining the base and the apex, wherein the base is optically coupled to the emitting surface. Furthermore, the optical element comprises a first section including the base and that is composed of a first material and a second section including the apex and that is composed of a second material. The above summary of the present invention is not intended to describe each disclosed embodiment or every implementation of the present invention. The Figures and the detailed description below more particularly exemplify illustrative embodiments.

Brief Description of the Drawings

The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, where like reference numerals designate like elements. The appended drawings are intended to be illustrative examples and are not intended to be limiting. Sizes of various elements in the drawings are approximate and may not be to scale.

FIG.1 is a schematic side view illustrating an optical element and LED die configuration in one embodiment.

FIGS. 2a-c are perspective views of an optical element according to additional embodiments.

FIG. 3 is a perspective view of an optical element according to another embodiment.

FIGS. 4a – 4i are top views of optical elements according to several alternative embodiments.

FIG. 5a-c are schematic front views illustrating optical elements in alternative embodiments.

FIGS. 6a-e are schematic side views of optical elements and LED dies according to several alternative embodiments.

FIGS. 7a-d are bottom views of optical elements and LED dies according to several embodiments.

FIG. 8 is a perspective view of an optical element and an LED die array according to another embodiment.

FIG. 9 is partial view of an optical element and an LED die according to another embodiment.

FIG. 10a-b are perspective views of optical elements according to other embodiments.

Detailed Description

Recently, it has been proposed to make optical elements to more efficiently "extract" light from an LED die. Extracting optical elements are made separately and then brought into contact or close proximity with a surface of the LED die. Such optical elements can be referred to as extractors. Most of the applications utilizing optical elements such as these have shaped the optical elements to extract the light out of the LED die and to emit it in a generally forward direction. Some shapes of optical elements can also collimate light. These are known as "optical concentrators." See e.g. U.S. Patent Application Publication No. US 2002/0030194A1, "LIGHT EMITTING DIODES WITH IMPROVED LIGHT EXTRACTION EFFICIENCY" (Camras et al.); U.S. Patent Application No. 10/977577, "HIGH BRIGHTNESS LED PACKAGE" (Attorney Docket No. 60217US002); and U.S. Patent Application No. 10/977249, titled "LED PACKAGE WITH NON-BONDED OPTICAL ELEMENT" (Attorney Docket No. 60216US002).

Side emitting optical elements have also been proposed. See U.S. 7,009,213 titled "LIGHT EMITTING DEVICES WITH IMPROVED LIGHT EXTRACTION EFFICIENCY" (Camras et al.; hereinafter "Camras et al. '213"). The side-emitters described in Camras et al. '213 rely on mirrors to redirect the light to the sides.

The present application discloses optical elements that are shaped to redirect light to the sides without the need for mirrors or other reflective layers. Applicants found that particular shapes of optical elements can be useful in redirecting the light to the sides due to their shape, thus eliminating the need for additional reflective layers or mirrors. Such optical elements generally have at least one converging side, as described below. The converging side serves as a reflective surface for light incident at high angles because the light is totally internally reflected at the interface of the optical element (preferably high refractive index) and the surrounding medium (e.g. air, lower refractive index).

Eliminating mirrors improves the manufacturing process and reduces costs. Furthermore, optical elements having converging shapes use less material thus providing additional cost savings, since materials used for optical elements can be very expensive.

It is desirable in some situations to form the optical element from high refractive index materials to reduce reflections at the LED emitting surface over the base of the optical element, so that light is more efficiently coupled out of, or extracted from, the LED die. It can also be desirable to fabricate the optical element using a material having high thermal conductivity and high thermal stability. In this way, the optical element can perform not only an optical function but a thermal management function as well.

Unfortunately, transparent materials that have sufficiently high refractive indices at the LED emission wavelength, e.g., greater than about 1.8, 2.0, or even 2.5, and/or that have thermal conductivities greater than about 0.2 W/cm/K, tend to be expensive and/or difficult to fabricate. Some of the relatively few materials that have both high refractive index and high thermal conductivity include diamond, silicon carbide (SiC), and sapphire (Al_2O_3). These inorganic materials are expensive, physically very hard, and difficult to shape and polish to an optical grade finish.

The present application discloses light sources having optical elements for efficiently extracting light out of LED dies and for modifying the angular distribution of the emitted light. Each optical element is optically coupled to the emitting surface an LED die (or LED die array) to efficiently extract light and to modify the emission pattern of the emitted light. LED sources that include optical elements can be useful in a variety of applications, including, for example, backlights in liquid crystal displays or backlit signs.

Light sources comprising converging optical elements described herein can be suited for use in backlights, both edge-lit and direct-lit constructions. Wedge-shaped optical elements are particularly suited for edge-lit backlights, where the light source is disposed along an outer portion of the backlight. Pyramid or cone-shaped converging optical elements can be particularly suited for use in direct-lit backlights. Such light sources can be used as single light source elements, or can be arranged in an array, depending on the particular backlight design.

For a direct-lit backlight, the light sources are generally disposed between a diffuse or specular reflector and an upper film stack that can include prism films, diffusers, and reflective polarizers. These can be used to direct the light emitted from the light source towards the viewer with the most useful range of viewing angles and with uniform brightness. Exemplary prism films include brightness enhancement films such as BEF™ available from 3M Company, St. Paul, MN. Exemplary reflective polarizers include DBEF™ also available from 3M Company, St. Paul, MN. For an edge-lit backlight, the light source can be positioned to inject light into a hollow or solid light guide. The light guide generally has a reflector below it and an upper film stack as described above.

FIG. 1 is a schematic side view illustrating a light source according to one embodiment. The light source comprises an optical element **20** and an LED die **10**. The optical element **20** has a triangular cross-section with a base **120** and two converging sides **140** joined opposite the base **120** to form an apex **130**. The apex can be a point, as shown at **130** in FIG. 1, or can be blunted, as for example in a truncated triangle (shown by dotted line **135**). A blunted apex can be flat, rounded, or a combination thereof. The apex is smaller than the base and preferably resides over the base. In some embodiments, the apex is no more than 20% of the size of the base. Preferably, the apex is no more than 10% of the size of the base. In FIG. 1, the apex **130** is centered over the base **120**. However, embodiments where the apex is not centered or is skewed away from the center of the base are also contemplated.

The optical element **20** is optically coupled to the LED die **10** to extract light emitted by the LED die **10**. The primary emitting surface **100** of the LED die **10** is substantially parallel and in close proximity to the base **120** of the optical element **20**. The LED die **10** and optical element **20** can be optically coupled in a number of ways including bonded and non-bonded configurations, which are described in more detail below.

The converging sides **140a-b** of the optical element **20** act to modify the emission pattern of light emitted by the LED die **10**, as shown by the arrows **160a-b** in FIG. 1. A typical bare LED die emits light in a first emission pattern. Typically, the first emission pattern is generally forward emitting or has a substantial forward emitting component. A converging optical element, such as optical element **20** depicted in FIG. 1, modifies the first emission pattern into a second, different emission pattern. For example, a wedge-shaped optical element directs light emitted by the LED die to produce a side emitting pattern having two lobes. FIG. 1 shows exemplary light rays **160a-b** emitted by the LED die entering the optical element **20** at the base. A light ray emitted in a direction forming a relatively low incidence angle with the converging side **140a** will be refracted as it exits the high index material of the optical element **20** into the surrounding medium (e.g. air). Exemplary light ray **160a** shows one such light ray, incident at a small angle with respect to normal. A different light ray, emitted at a high incidence angle, an angle greater than or equal to the critical angle, will be totally internally reflected at the first converging side it encounters (**140a**). However, in a converging optical element such as the one illustrated in FIG. 1, the reflected ray will subsequently encounter the second converging side (**140b**) at a low incidence angle, where it will be refracted and allowed to exit the optical element. An exemplary light ray **160b** illustrates one such light path.

An optical element having at least one converging side can modify a first light emission pattern into a second, different light emission pattern. For example, a generally forward emitting light pattern can be modified into a second, generally side-emitting light pattern with such a converging optical element. In other words, a high index optical element can be shaped to direct light emitted by the LED die to produce a side emitting pattern. If the optical element is rotationally symmetric (e.g. shaped as a cone) the resulting light emission pattern will have a torroidal distribution – the intensity of the emitted light will be concentrated in a circular pattern around the optical element. If, for example, an optical element is shaped as a wedge (e.g. see FIG. 3) the side emitting pattern will have two lobes – the light intensity will be concentrated in two zones. In case of a symmetric wedge, the two lobes will be located on opposing sides of the optical element (two opposing zones). For optical elements having a plurality of converging sides, the side emitting pattern will have a corresponding plurality of lobes. For example, for an optical element shaped as a four-sided pyramid, the resulting side emitting pattern will have four lobes. The side emitting pattern can be symmetric or asymmetric. An asymmetric pattern will be produced when the apex of the optical element is placed asymmetrically with respect to the base or emission surface. Those skilled in the art will appreciate the various permutations of such arrangements and shapes to produce a variety of different emission patterns, as desired.

In some embodiments, the side emitting pattern has an intensity distribution with a maximum at a polar angle of at least 30°, as measured in an intensity line plot. In other embodiments the side emitting pattern has an intensity distribution centered at a polar angle of at least 30°. Other intensity distributions are also possible with presently disclosed optical elements, including, for example those having maxima and/or centered at 45° and 60° polar angle.

Converging optical elements can have a variety of forms. Each optical element has a base, an apex, and at least one converging side. The base can have any shape (e.g. square, circular, symmetrical or non-symmetrical, regular or irregular). The apex can be a point, a line, or a surface (in case of a blunted apex). Regardless of the particular converging shape, the apex is smaller in surface area than the base, so that the side(s) converge from the base towards the apex. A converging optical element can be shaped as a pyramid, a cone, a wedge, or a combination thereof. Each of these shapes can also be truncated near the apex, forming a blunted apex. A converging optical element can have a polyhedral shape, with a polygonal base and at least two converging sides. For example, a pyramid or wedge-shaped optical element can have a rectangular or square base and four sides wherein at least two of the sides are converging sides. The other sides can be parallel sides, or alternatively can be diverging or converging. The shape of the base need not be symmetrical and can be shaped, for example, as a trapezoid, parallelogram, quadrilateral, or other polygon. In other embodiments, a converging optical element can have a circular, elliptical, or an irregularly-shaped but continuous base. In these embodiments, the optical element can be said to have a single converging side. For example, an optical element having a circular base can be shaped as a cone. Generally, a converging optical element comprises a base, an apex residing (at least partially) over the base, and one or more converging sides joining the apex and the base to complete the solid.

FIG. 2a shows one embodiment of a converging optical element **200** shaped as a four-sided pyramid having a base **220**, an apex **230**, and four sides **240**. In this particular embodiment, the base **220** can be rectangular or square and the apex **230** is centered over the base (a projection of the apex in a line **210** perpendicular to the plane of the base is centered over the base **220**). FIG. 2a also shows an LED die **10** having an emitting surface **100** which is proximate and parallel to the base **220** of the optical element **200**. The LED die **10** and optical element **200** are optically coupled at the emitting surface – base interface. Optical coupling can be achieved in several ways, described in more detail below. For example, the LED die and optical element can be bonded together. In FIG. 2a the base and the emitting surface of the LED die are shown as substantially matched in size. In other embodiments, the base can be larger or smaller than the LED die emitting surface.

FIG. 2b shows another embodiment of a converging optical element **202**. Here, optical element **202** has a hexagonal base **222**, a blunted apex **232**, and six sides **242**. The sides extend between the base and the apex and each side converges towards the apex **232**. The apex **232** is blunted and forms a surface also shaped as a hexagon, but smaller than the hexagonal base.

FIG. 2c shows another embodiment of an optical element **204** having two converging sides **244**, a base **224**, and an apex **234**. In FIG. 2c, the optical element is shaped as a wedge and the apex **234** forms a line. The other two sides are shown as parallel sides. Viewed from the top, the optical element **204** is depicted in FIG. 4d.

Alternative embodiments of wedge-shaped optical elements also include shapes having a combination of converging and diverging sides, such as the optical element **22** shown in FIG. 3. In the embodiment shown in FIG. 3, the wedge-shaped optical element **22** resembles an axe-head. The two diverging sides **142** act to collimate the light emitted by the LED die. The two converging sides **144** converge at the top forming an apex **132** shaped as a line residing over the base when viewed from the side (see FIG. 1), but having portions extending beyond the base when viewed as shown in FIG. 3 (or FIG. 4e). The converging sides **144** allow the light emitted by the LED die **10** to be redirected to the sides, as shown in FIG. 1. Other embodiments include wedge shapes where all sides converge, for example as shown in FIG. 4f.

The optical element can also be shaped as a cone having a circular or elliptical base, an apex residing (at least partially) over the base, and a single converging side joining the base and the apex. As in the pyramid and wedge shapes described above, the apex can be a point, a line (straight or curved) or it can be blunted forming a surface.

FIGS. 4a – 4i show top views of several alternative embodiments of an optical element. FIGS. 4a – 4f show embodiments in which the apex is centered over the base. FIGS. 4g – 4i show embodiments of asymmetrical optical elements in which the apex is skewed or tilted and is not centered over the base.

FIG. 4a shows a pyramid-shaped optical element having a square base, four sides, and a blunted apex **230a** centered over the base. FIG. 4h shows a pyramid-shaped optical element having a square base, four sides, and a blunted apex **230h** that is off-center. FIG.

4b shows an embodiment of an optical element having a square base and a blunted apex **230b** shaped as a circle. In this case, the converging sides are curved such that the square base is joined with the circular apex. FIG. 4c shows a pyramid-shaped optical element having a square base, four triangular sides converging at a point to form an apex **230c**, which is centered over the base. FIG. 4i shows a pyramid-shaped optical element having a square base, four triangular sides converging at a point to form an apex **230i**, which is skewed (not centered) over the base.

FIGS. 4d-4g show wedge-shaped optical elements. In FIG. 4d, the apex **230d** forms a line residing and centered over the base. In FIG. 4e, the apex **230e** forms a line that is centered over the base and partially resides over the base. The apex **230e** also has portions extending beyond the base. The top view depicted in FIG. 4e can be a top view of the optical element shown perspective in FIG. 3 and described above. FIG. 4f and FIG. 4g show two alternative embodiments of a wedge-shaped optical element having an apex forming a line and four converging sides. In FIG. 4f, the apex **230f** is centered over the base, while in FIG. 4g, the apex **230g** is skewed.

FIGS. 5a – 5c show side views of an optical element according to alternative embodiments. FIG. 5a shows one embodiment of an optical element having a base **50** and sides **40** and **41** starting at the base **50** and converging towards an apex **30** residing over the base **50**. Optionally, the sides can converge toward a blunted apex **31**. FIG. 5b shows another embodiment of an optical element having a base **52**, a converging side **44** and a side **42** perpendicular to the base. The two sides **42** and **44** form an apex **32** residing over the edge of the base. Optionally, the apex can be a blunted apex **33**. FIG. 5c shows a side view of an alternative optical element having a generally triangular cross section. Here, the base **125** and the sides **145** and **147** generally form a triangle, but the sides **145** and **147** are non-planar surfaces. In FIG. 5c the optical element has a left side **145** that is curved and a right side that is faceted (i.e. it is a combination of three smaller flat portions **147a-c**). The sides can be curved, segmented, faceted, convex, concave, or a combination thereof. Such forms of the sides still function to modify the angular emission of the light extracted similarly to the planar or flat sides described above, but offer an added degree of customization of the final light emission pattern.

FIGS. 6a – 6e depict alternative embodiments of optical elements **620a-e** having non-planar sides **640a-e** extending between each base **622a-e** and apex **630a-e**, respectively. In FIG. 6a, the optical element **620a** has sides **640a** comprising two faceted portions **641a** and **642a**. The portion **642a** near the base **622a** is perpendicular to the base **622a** while the portion **641a** converges toward the apex **630a**. Similarly, in FIGS. 6b-c, the optical elements **620b-c** have sides **640b-c** formed by joining two portions **641b-c** and **642b-c**, respectively. In FIG. 6b, the converging portion **641b** is concave. In FIG. 6c, the converging portion **641c** is convex. FIG. 6d shows an optical element **620d** having two sides **640d** formed by joining portions **641d** and **642d**. Here, the portion **642d** near the base **622d** converges toward the blunted apex **630d** and the top-most portion **641d** is perpendicular to the surface of the blunted apex **630d**. FIG. 6e shows an alternative embodiment of an optical element **620e** having curved sides **640e**. Here, the sides **640e** are s-shaped, but generally converge towards the blunted apex **630e**. When the sides are formed of two or more portions, as in FIGS. 6a-e, preferably the portions are arranged so that the side is still generally converging, even though it may have portions which are non-converging.

Preferably, the size of the base is matched to the size of the LED die at the emitting surface. FIGS. 7a – 7d show exemplary embodiments of such arrangements. In FIG. 7a an optical element having a circular base **50a** is optically coupled to an LED die having a square emitting surface **70a**. Here, the base and emitting surface are matched by having the diameter "d" of the circular base **50a** equal to the diagonal dimension (also "d") of the square emitting surface **70a**. In FIG. 7b, an optical element having a hexagonal base **50b** is optically coupled to an LED die having a square emitting surface **70b**. Here, the height "h" of the hexagonal base **50b** matches the height "h" of the square emitting surface **70b**. In FIG. 7c, an optical element having a rectangular base **50c** is optically coupled to an LED die having a square emitting surface **70c**. Here, the width "w" of both the base and the emitting surface are matched. In FIG. 7d, an optical element having a square base **50d** is optically coupled to an LED die having a hexagonal emitting surface **70d**. Here, the height "h" of both the base and the emitting surface are matched. Of course, a simple arrangement, in which both the base and emitting surface are identically shaped and have the same surface area, also meets this criteria. Here, the surface area of the base is matched to the surface area of the emitting surface of the LED die.

Similarly, when an optical element is coupled to an array of LED dies, the size of the array at the emitting surface side preferably can be matched to the size of the base of the optical element. Again, the shape of the array need not match the shape of the base, as long as they are matched in at least one dimension (e.g. diameter, width, height, or surface area).

Alternatively, the size of the LED die at the emitting surface or the combined size of the LED die array can be smaller or larger than the size of the base. FIGS. 6a and 6c show embodiments in which the emitting surface (**612a** and **612c**, respectively) of the LED die (**610a** and **610c**, respectively) is matched to the size of the base (**622a** and **622c**, respectively). FIG. 6b shows an LED die **610b** having an emitting surface **612b** that is larger than the base **622b**. FIG. 6d shows an array **612d** of LED dies, the array having a combined size at the emitting surface **612d** that is larger than the size of the base **622d**. FIG. 6e shows an LED die **610e** having an emitting surface **612e** that is smaller than the base **622e**.

For example, if the LED die emitting surface is a square having sides of 1 mm, the optical element base can be made having a matching square having a 1mm side. Alternatively, a square emitting surface could be optically coupled to a rectangular base, the rectangle having one of its sides matched in size to the size of the emitting surface side. The non-matched side of the rectangle can be larger or smaller than the side of the square. Optionally, an optical element can be made having a circular base having a diameter equal to the diagonal dimension of the emitting surface. For example, for a 1mm by 1mm square emitting surface a circular base having a diameter of 1.41 mm would be considered matched in size for the purpose of this application. The size of the base can also be made slightly smaller than the size of the emitting surface. This can have advantages if one of the goals is to minimize the apparent size of the light source, as described in commonly owned U.S. Patent Application titled "High Brightness LED Package", (Attorney Docket No. 60217US002).

FIG. 8 shows another embodiment of a light source comprising a converging optical element **24** optically coupled to a plurality of LED dies **14a-c** arranged in an array **12**. This arrangement can be particularly useful when red, green, and blue LEDs are combined in the array to produce white light when mixed. In FIG. 8, the optical element **24** has converging sides **146** to redirect light to the sides. The optical element **24** has a base **124** shaped as a square, which is optically coupled to the array of LED dies **12**. The array of LED dies **12** also forms a square shape (having sides **16**).

Optical elements disclosed herein can be manufactured by conventional means or by using precision abrasive techniques disclosed in commonly assigned U.S. Patent Application No. 10/977239, titled "PROCESS FOR MANUFACTURING OPTICAL AND SEMICONDUCTOR ELEMENTS", (Attorney Docket No. 60203US002), U.S. Patent Application 10/977240, titled "PROCESS FOR MANUFACTURING A LIGHT EMITTING ARRAY", (Attorney Docket No. 60204US002), and U.S. Patent Application No. 11/288071, titled "ARRAYS OF OPTICAL ELEMENTS AND METHOD OF MANUFACTURING SAME", (Attorney Docket No. 60914US002).

The optical element is transparent and preferably has a relatively high refractive index. Suitable materials for the optical element include without limitation inorganic materials such as high index glasses (e.g. Schott glass type LASF35, available from Schott North America, Inc., Elmsford, NY under a trade name LASF35) and ceramics (e.g. sapphire, zinc oxide, zirconia, diamond, and silicon carbide). Sapphire, zinc oxide, diamond, and silicon carbide are particularly useful since these materials also have a relatively high thermal conductivity (0.2 – 5.0 W/cm K). High index polymers or nanoparticle filled polymers are also contemplated. Suitable polymers can be both both thermoplastic and thermosetting polymers. Thermoplastic polymers can include polycarbonate and cyclic olefin copolymer. Thermosetting polymers can be for example acrylics, epoxy, silicones and others known in the art. Suitable ceramic nanoparticles include zirconia, titania, zinc oxide, and zinc sulfide.

The index of refraction of the optical element (n_o) is preferably similar to the index of LED die emitting surface (n_e). Preferably, the difference between the two is no greater than 0.2 ($|n_o - n_e| \leq 0.2$). Optionally, the difference can be greater than 0.2, depending on the materials used. For example, the emitting surface can have an index of refraction of 1.75. A suitable optical element can have an index of refraction equal to or greater than 1.75 ($n_o \geq 1.75$), including for example $n_o \geq 1.9$, $n_o \geq 2.1$, and $n_o \geq 2.3$. Optionally, n_o can be lower than n_e (e.g. $n_o \geq 1.7$). Preferably, the index of refraction of the optical element is matched to the index of refraction of the primary emitting surface. In some embodiments, the indexes of refraction of both the optical element and the emitting surface can be the same in value ($n_o = n_e$). For example, a sapphire emitting surface having n_e=1.76 can be matched with a sapphire optical element, or a glass optical element of SF4 (available from Schott North America, Inc., Elmsford, NY under a trade name SF4) n_o = 1.76. In other embodiments, the index of refraction of the optical element can be higher or lower than the index of refraction of the emitting surface. When made of high index materials, optical elements increase light extraction from the LED die due to their high refractive index and modify the emission distribution of light due to their shape, thus providing a tailored light emission pattern.

Throughout this disclosure, the LED die **10** is depicted generically for simplicity, but can include conventional design features as known in the art. For example, the LED die can include distinct p- and n-doped semiconductor layers, buffer layers, substrate layers, and superstrate layers. A simple rectangular LED die arrangement is shown, but other known configurations are also contemplated, e.g., angled side surfaces forming a truncated inverted pyramid LED die shape. Electrical contacts to the LED die are also not shown for simplicity, but can be provided on any of the surfaces of the die as is known. In exemplary embodiments the LED die has two contacts both disposed at the bottom surface in a “flip chip” design. The present disclosure is not intended to limit the shape of the optical element or the shape of the LED die, but merely provides illustrative examples.

An optical element is considered optically coupled to an LED die, when the minimum gap between the optical element and emitting surface of the LED die is no greater than the evanescent wave. Optical coupling can be achieved by placing the LED die and the optical element physically close together. FIG. 1 shows a gap **150** between the emitting surface **100** of the LED die **10** and the base **120** of optical element **20**. Typically, the gap **150** is an air gap and is typically very small to promote frustrated total internal reflection. For example, in FIG. 1, the base **120** of the optical element **20** is optically close to the emitting surface **100** of the LED die **10**, if the gap **150** is on the order of the wavelength of light in air. Preferably, the thickness of the gap **150** is less than a wavelength of light in air. In LEDs where multiple wavelengths of light are used, the gap **150** is preferably at most the value of the longest wavelength. . Suitable gap sizes include 25 nm, 50 nm, and 100 nm. Preferably, the gap is minimized, such as when the LED die and the input aperture or base of the optical element are polished to optical flatness and wafer bonded together.

In addition, it is preferred that the gap **150** be substantially uniform over the area of contact between the emitting surface **100** and the base **120**, and that the emitting surface **100** and the base **120** have a roughness of less than 20 nm, preferably less than 5 nm. In such configurations, a light ray emitted from LED die **10** outside the escape cone or at an angle that would normally be totally internally reflected at the LED die-air interface will instead be transmitted into the optical element **20**. To promote optical coupling, the surface of the base **120** can be shaped to match the emitting surface **100**. For example, if the emitting surface **100** of LED die **10** is flat, as shown in FIG. 1, the base **120** of optical element **20** can also be flat. Alternatively, if the emitting surface of the LED die is curved (e.g. slightly concave) the base of the optical element can be shaped to mate with the emitting surface (e.g. slightly convex).The size of the base **120** may either be smaller, equal, or larger than LED die emitting surface **100**. The base **120** can be the same or different in cross sectional shape than LED die **10**. For example, the LED die can have a square emitting surface while the optical element has a circular base. Other variations will be apparent to those skilled in the art.

Suitable gap sizes include 100 nm, 50 nm, and 25 nm. Preferably, the gap is minimized, such as when the LED die and the input aperture or base of the optical element are polished to optical flatness and wafer bonded together. The optical element and LED die can be bonded together by applying high temperature and pressure to provide an optically coupled arrangement. Any known wafer bonding technique can be used. Exemplary wafer bonding techniques are described in U.S. Patent Application No. 10/977239, titled “Process for Manufacturing Optical and Semiconductor Elements” (Attorney Docket No. 60203US002).

In case of a finite gap, optical coupling can be achieved or enhanced by adding a thin optically conducting layer between the emitting surface of the LED die and the base of the optical element. FIG. 9 shows a partial schematic side view of an optical element and LED die, such as that shown in FIG. 1, but with a thin optically conducting layer **60** disposed within the gap **150**. Like the gap **150**, the optically conducting layer **60** can be 100nm, 50nm, 25nm in thickness or less. Preferably, the refractive index of the optically coupling layer is closely matched to the refractive index of the emission surface or the optical element. An optically conducting layer can be used in both bonded and non-bonded (mechanically decoupled) configurations. In bonded embodiments, the optically conducting layer can be any suitable bonding agent that transmits light, including, for example, a transparent adhesive layer, inorganic thin films, fusable glass frit or other similar bonding agents. Additional examples of bonded configurations are described, for example, in U.S. Patent Publication No. U.S. 2002/0030194 titled "Light Emitting Diodes with Improved Light Extraction Efficiency" (Camras et al.) published on March 14, 2002.

In non-bonded embodiments, an LED die can be optically coupled to the optical element without use of any adhesives or other bonding agents between the LED die and the optical element. Non-bonded embodiments allow both the LED die and the optical element to be mechanically decoupled and allowed to move independently of each other. For example, the optical element can move laterally with respect to the LED die. In another example both the optical element and the LED die are free to expand as each component becomes heated during operation. In such mechanically decoupled systems the majority of stress forces, either sheer or normal, generated by expansion are not transmitted from one component to another component. In other words, movement of one component does not mechanically affect other components. This configuration can be particularly desirable where the light emitting material is fragile, where there is a coefficient of expansion mismatch between the LED die and the optical element, and where the LED is being repeatedly turned on and off.

Mechanically decoupled configurations can be made by placing the optical element optically close to the LED die (with only a very small air gap between the two). The air gap should be small enough to promote frustrated total internal reflection, as described above.

Alternatively, as shown in FIG. 9, a thin optically conducting layer **60** (e.g. an index matching fluid) can be added in the gap **150** between the optical element **20** and the LED die **10**, provided that the optically conducting layer allows the optical element and LED die to move independently. Examples of materials suitable for the optically conducting layer **60** include index matching oils, and other liquids or gels with similar optical properties. Optionally, optically conducting layer **60** can also be thermally conducting.

The optical element and LED die can be encapsulated together using any of the known encapsulant materials, to make a final LED package or light source. Encapsulating the optical element and LED die provides a way to hold them together in the non-bonded embodiments.

Additional non-bonded configurations are described in commonly owned U.S. Patent Application No. 10/977249, titled "LED Package with Non-bonded Optical Element" Attorney Docket No. 60216US002.

The optical element can be made from a single structure, for example cut from a single block of material, or can be made by joining two or more sections together in a compound construction.

A first section desirably makes optical contact with the LED die, and is made of a first optical material having a high refractive index (preferably about equal to the LED die refractive index at the emitting surface), and optionally high thermal conductivity, and/or high thermal stability. In this regard, high thermal stability refers to materials having a decomposition temperature of about 600 °C or more. The thickness of the first section is preferably optically thick (e.g. effectively at least 5 microns, or 10 times the wavelength of light).

Silicon carbide is also electrically conductive, and as such may also provide an electrical contact or circuit function. Scattering within optical elements may be acceptable if the scattering is limited to a position near the input end or base of the optical element. However, it would be expensive and time consuming to make an optical element with sufficient length to efficiently couple light from an LED die. An additional challenge in making one-piece optical elements is that the material yield may be relatively low, and the form-factor may force the LED die to be individually assembled with the optical element. For these reasons, it can be advantageous to divide the optical element into two (or more) sections, the sections being made of different optical materials, to reduce manufacturing cost.

A second section is joined to the first section and is made of a second optical material, which may have lower material costs and be more easily fabricated than the first optical material. The second optical material may have a lower refractive index, lower thermal conductivity, or both relative to the first optical material. For example, the second optical material can comprise glasses, polymers, ceramics, ceramic nanoparticle-filled polymers, and other optically clear materials. Suitable glasses include those comprising oxides of lead, zirconium, titanium, and barium. The glasses can be made from compounds including titanates, zirconates, and stannates. Suitable ceramic nanoparticles include zirconia, titania, zinc oxide, and zinc sulfide.

Optionally, a third section composed of a third optical material can be joined to the second section to further aid in coupling the LED light to the outside environment. In one embodiment the refractive indices of the three sections are arranged such that $n_1 > n_2 > n_3$ to minimize overall Fresnel surface reflections associated with the optical element.

FIG. 10a shows a front view of an exemplary compound optical element **80a** according to one embodiment. The optical element **80a** includes a base **182a**, an apex **183a**, and converging sides **184a**, arranged as described elsewhere herein. In this embodiment, the optical element **80a** comprises a first section **82a** and a second section **84a**. The first section includes the base **182a** and is composed of a first material. The second section **84a** includes the apex **183a** and is composed of a second material. At the interface of the first and second sections, the blunted apex of the first section **82a** is joined with the base of the second section **84a** (shown as element **181a**).

FIG. 10b shows a front view of an alternative embodiment of a compound optical element **80b**. The optical element **80b** includes a base **182b**, an apex **183b**, and converging sides **184b**. As in the above embodiment, the optical element **80b** comprises a first section **82b** including the base **182b** and a second section **84b** including the apex **183b**. The first section **82b** is composed of a first material while the second section **84b** is composed of a second material. At the interface of the first and second sections, the sides **185b** of the first section **82b** are joined to the base of the second section **84b**, as shown.

The first and second materials used to make the first and second sections, respectively, can be two different materials having two different indexes of refraction. They can be two different optical materials having the same index of refraction. Alternatively, the first and second materials can differ in optical characteristics, for example having different degrees of transparency, while having the same or different indexes of refraction. Other permutations are also contemplated and will be apparent to those skilled in the art.

The compound optical element can have any shape having at least one converging side as described herein, and is not limited to the exemplary shape depicted in FIG. 10. Additional details relating to converging optical elements are described in co-filed and commonly assigned U.S. Patent Applications "LED Package With Converging Optical Element" (U.S. Application No. 11/381,324), "LED Package With Wedge-Shaped Optical Element" (U.S. Application No. 11/381,293), "LED Package With Encapsulated

Converging Optical Element" (U.S. Application No. 11/381,332), and "LED Package With Non-bonded Converging Optical Element" (U.S. Application No. 11/381,334).

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and the detailed description. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A light source, comprising:
an LED die having an emitting surface;
an optical element including a base, an apex, and a converging side joining the base and the apex, wherein the base is optically coupled to the emitting surface;
wherein the optical element comprises a first section including the base and that is composed of a first material; and
wherein the optical element comprises a second section including the apex and that is composed of a second material.

2. The light source of claim 1, wherein the first material has a refractive index greater than that of the second material.

3. The light source of claim 1, wherein the optical element directs light emitted by the LED die to produce a side emitting pattern.

4. The light source of claim 1, wherein the side emitting pattern includes a plurality of side lobes.

5. The light source of claim 1, wherein the side emitting pattern is torroidal.

6. The light source of claim 1, wherein the side emitting pattern is asymmetric.

7. The light source of claim 1, wherein the apex resides over the emitting surface.

8. The light source of claim 1, wherein the apex is centered over the base.

9. The light source of claim 1, wherein the apex is blunted.

10. The light source of claim 1, further comprising an optically conducting layer disposed between the optical element and the emitting surface.

11. The light source of claim 1, wherein the optical element is bonded to the LED die at the emitting surface.

12. The light source of claim 11, wherein the optical element is wafer bonded to the LED die at the emitting surface.

13. The light source of claim 1, wherein the base and the emitting surface are substantially matched in size.

14. The light source of claim 1, wherein the base is smaller than the emitting surface.

15. The light source of claim 1, wherein the first section has an index of refraction of at least 1.75.

16. The light source of claim 15, wherein at least one of the first and second sections consists of inorganic material.

17. The light source of claim 1, wherein the LED die is one of a plurality of LED dies arranged in an array.

18. The light source of claim 1, wherein the optical element is shaped as a polyhedron.

19. The light source of claim 18, wherein the base is rectangular and wherein the optical element includes four sides, each side extending between the base and the apex.

20. The light source of claim 1, wherein the base is circular.

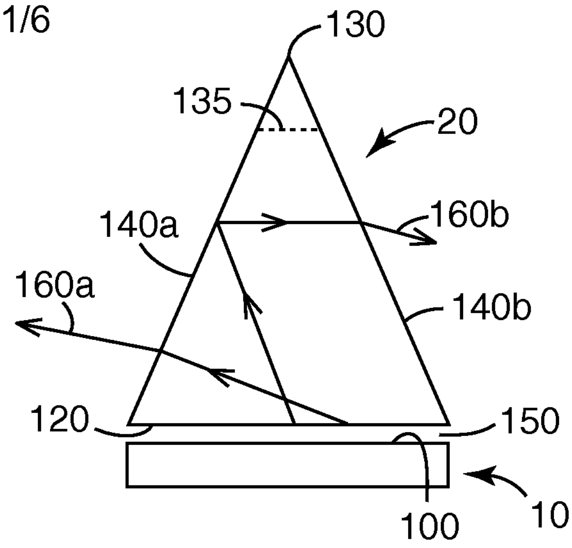

Fig. 1

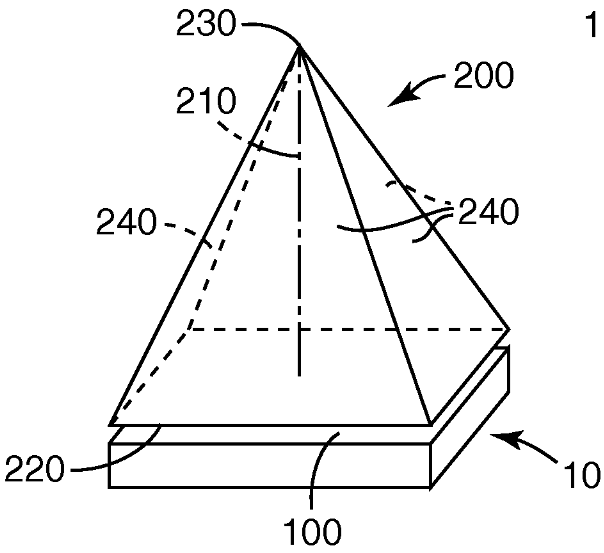

Fig. 2a

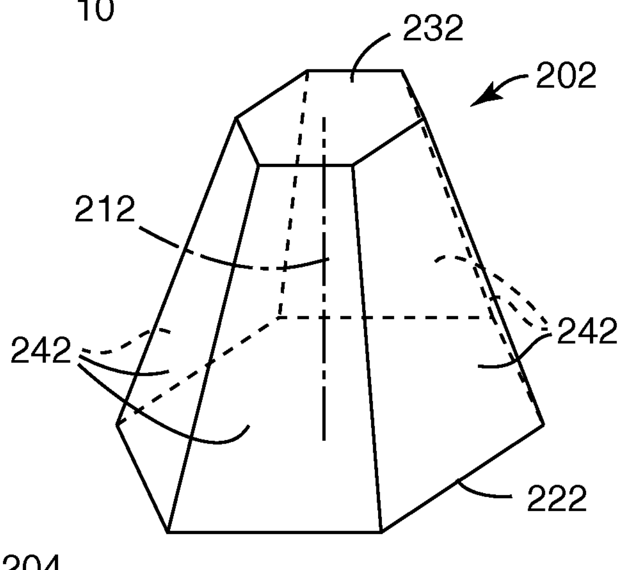

Fig. 2b

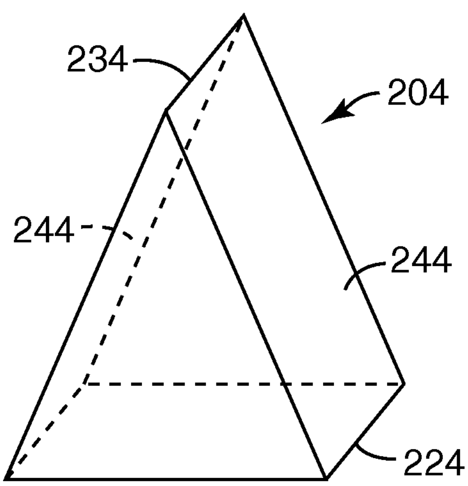

Fig. 2c

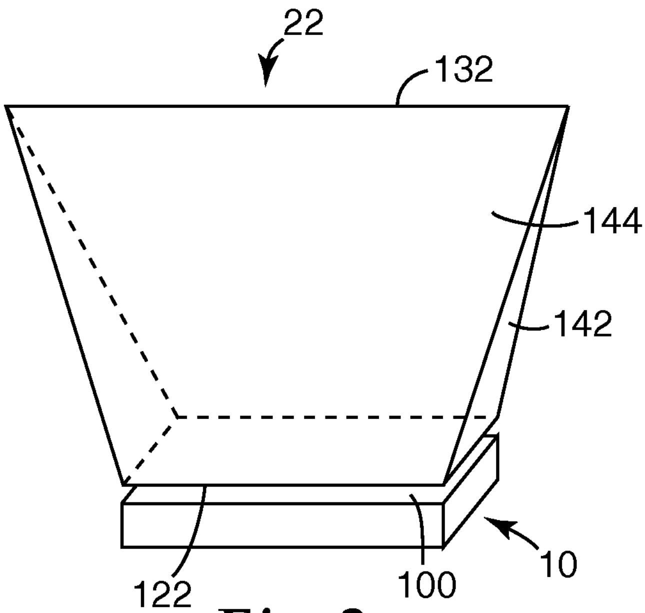

Fig. 3

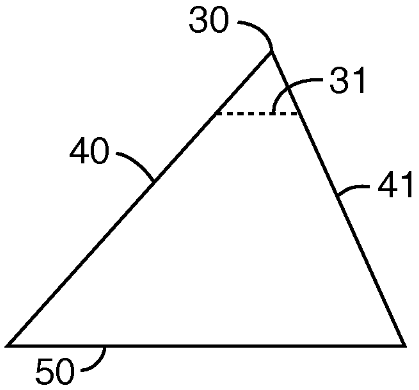

Fig. 5a

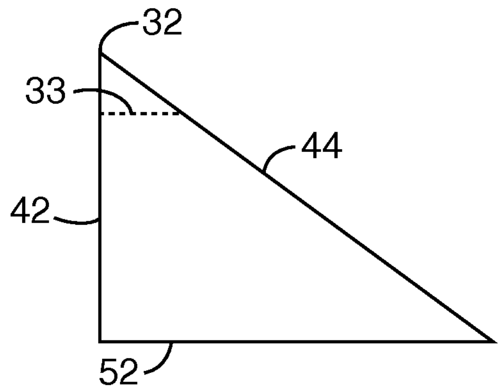

Fig. 5b

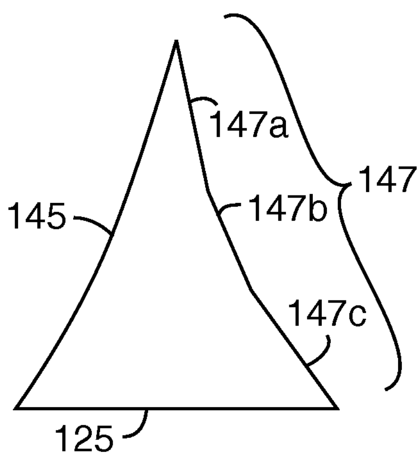

Fig. 5c

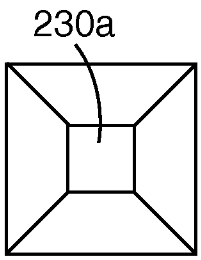

Fig. 4a

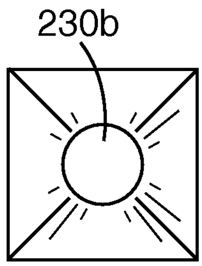

Fig. 4b

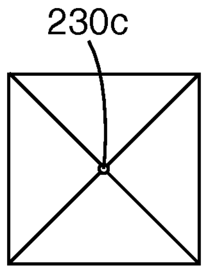

Fig. 4c

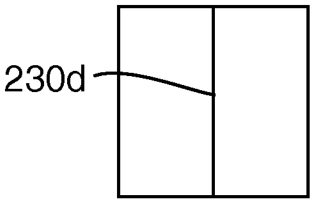

Fig. 4d

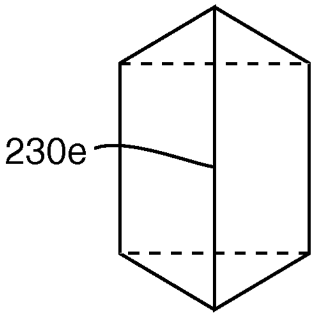

Fig. 4e

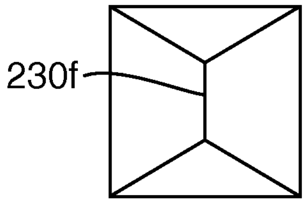

Fig. 4f

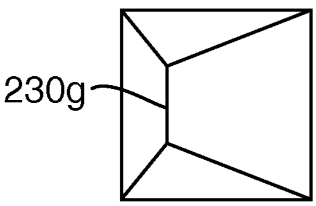

Fig. 4g

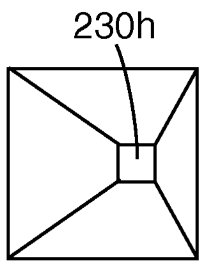

Fig. 4h

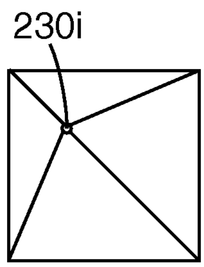

Fig. 4i

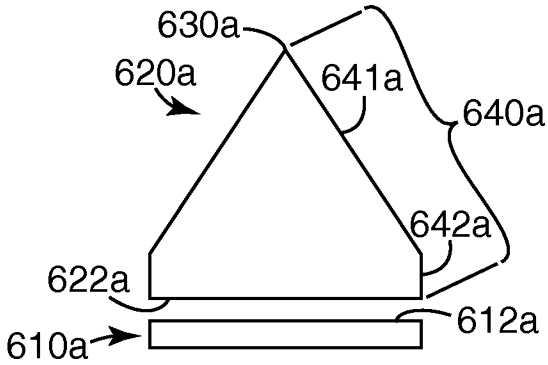

Fig. 6a

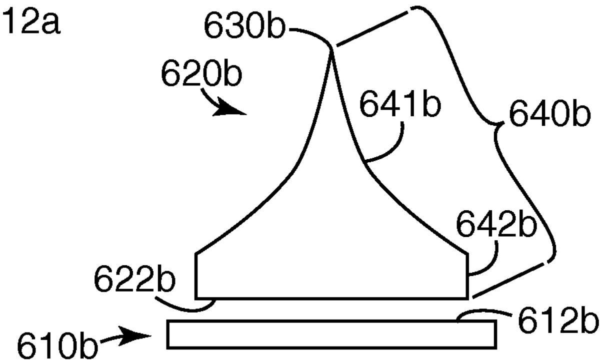

Fig. 6b

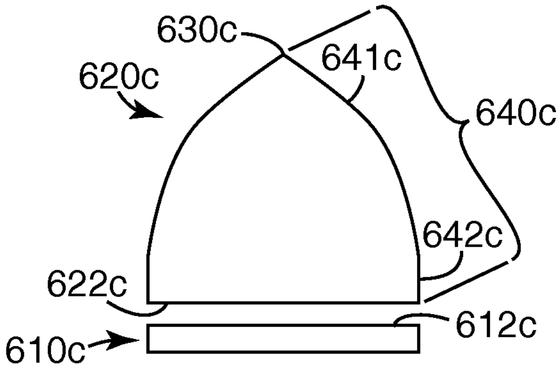

Fig. 6c

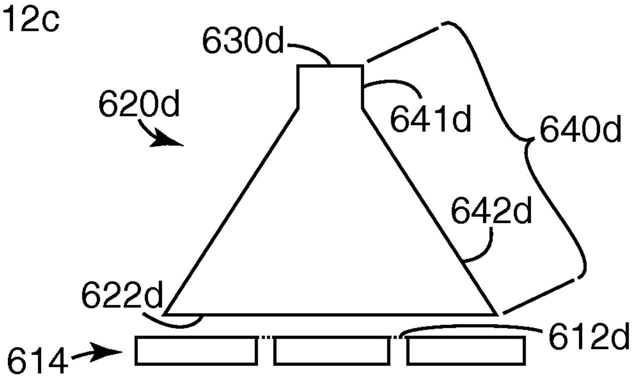

Fig. 6d

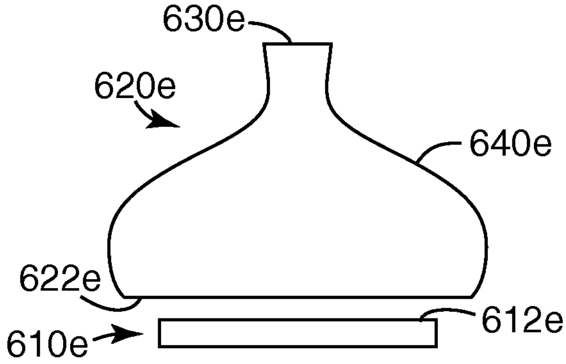

Fig. 6e

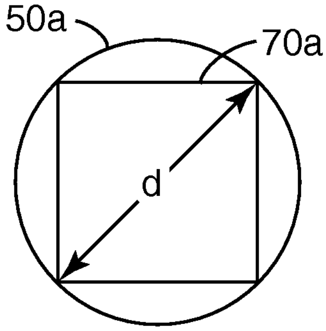

Fig. 7a

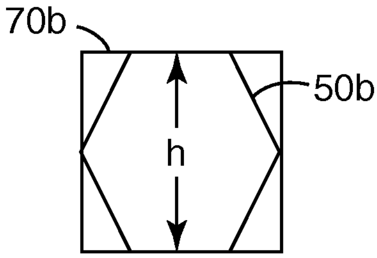

Fig. 7b

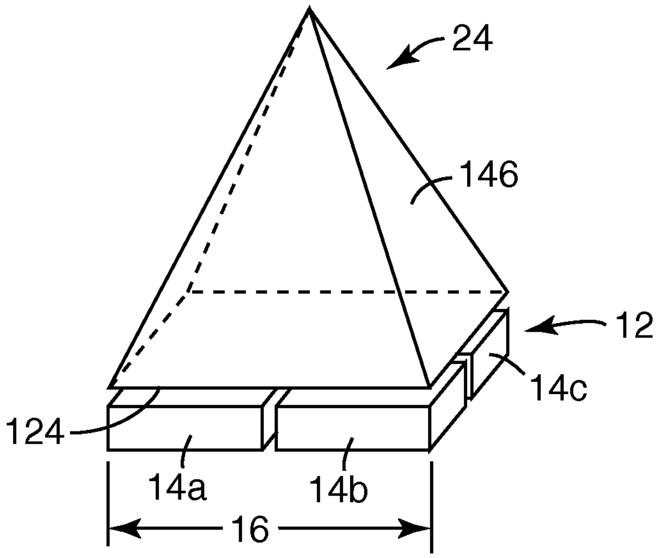

Fig. 8

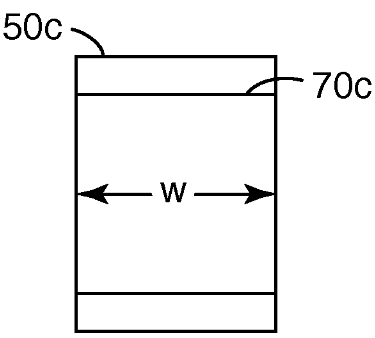

Fig. 7c

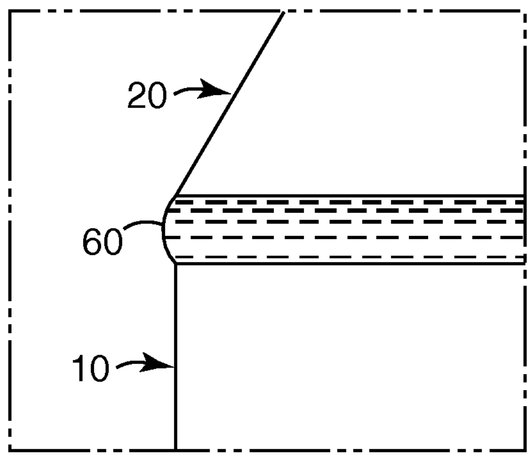

Fig. 9

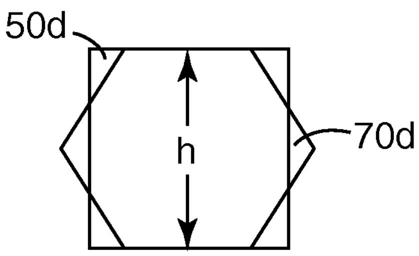

Fig. 7d

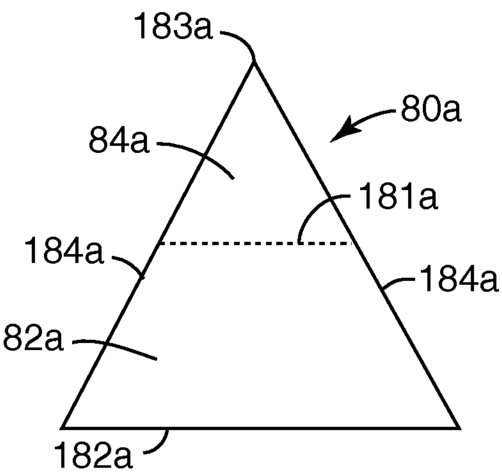

Fig. 10a

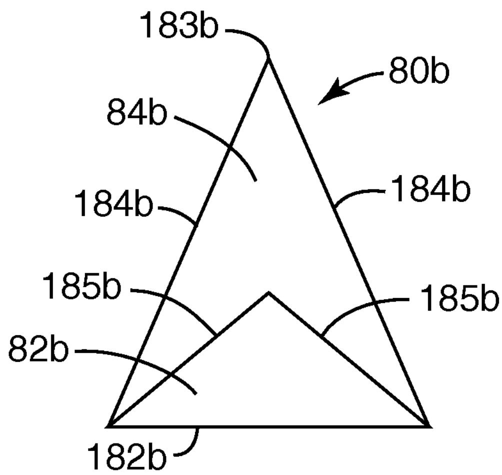

Fig. 10b

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/067873

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L33/00
ADD. G02B17/08

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 G02B

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 528 603 A2 (OSRAM OPTO SEMICONDUCTORS GMBH [DE]) 4 May 2005 (2005-05-04) figures 2,3,5,6 -----	1,3,4, 6-11, 13-16
X	EP 1 119 058 A1 (CITIZEN ELECTRONICS [JP]) 25 July 2001 (2001-07-25) paragraphs [0030], [0031]; figure 3 -----	1,7-11, 13,20
X	US 2005/093430 A1 (IBBETSON JAMES [US] ET AL) 5 May 2005 (2005-05-05) paragraphs [0057] - [0062]; figures 9-12 -----	1
A	WO 2006/026939 A (OSRAM OPTO SEMICONDUCTORS GMBH [DE]; WANNINGER MARIO [DE]) 16 March 2006 (2006-03-16) the whole document ----- -/--	1

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 September 2007	27/09/2007

Name and mailing address of the ISA/	Authorized officer
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International application No
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