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(54) **SOLID STATE LAMP WITH THERMAL SPREADING ELEMENTS AND LIGHT DIRECTING OPTICS**

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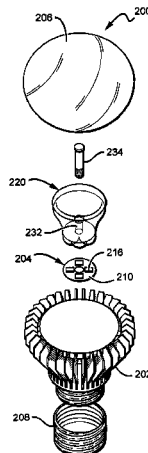
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(57) **ABSTRACT**

Lamps and bulbs are disclosed generally comprising different combinations and arrangements of a light source, one or more wavelength conversion materials, regions or layers which are positioned separately or remotely with respect to the light source, and a separate diffusing layer. This arrangement allows for the fabrication of lamps and bulbs that are efficient, reliable and cost effective and can provide an essentially omni-directional emission pattern, even with a light source comprised of a co-planar arrangement of LEDs. The lamps according to the present invention can also comprise thermal management features that provide for efficient dissipation of heat from the LEDs, which in turn allows the LEDs to operate at lower temperatures. The lamps can also comprise optical elements to help change the emission pattern from the generally directional (e.g. Lambertian) pattern of the LEDs to a more omni-directional pattern.

10 Claims, 8 Drawing Sheets



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 Foreign Office Action for Japanese Appl. No. 2012-556065; dated Nov. 22, 2016.
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 Notice of Allowance for Chinese Application No. 201180022624.8; dated Jan. 3, 2017.
 Notice of Issuance for Chinese Application No. 201180020709.2; dated Jul. 25, 2016.
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 European Office Action for Application No. 11710348.1; dated Aug. 8, 2016.
 Office Action for U.S. Appl. No. 12/985,275; dated Aug. 30, 2016.
 Office Action for U.S. Appl. No. 13/029,063; dated Sep. 8, 2016.

* cited by examiner

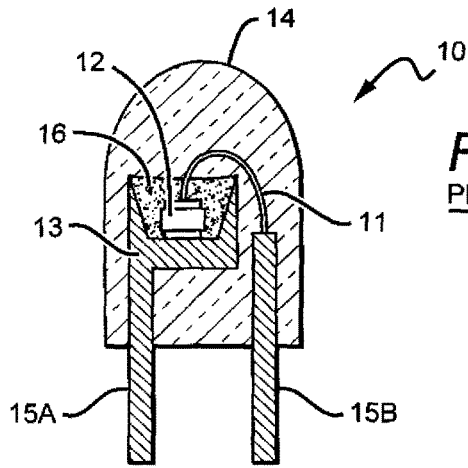


FIG. 1
PRIOR ART

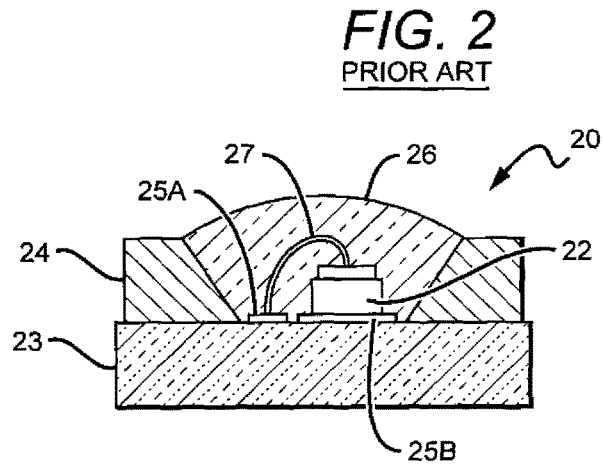


FIG. 2
PRIOR ART

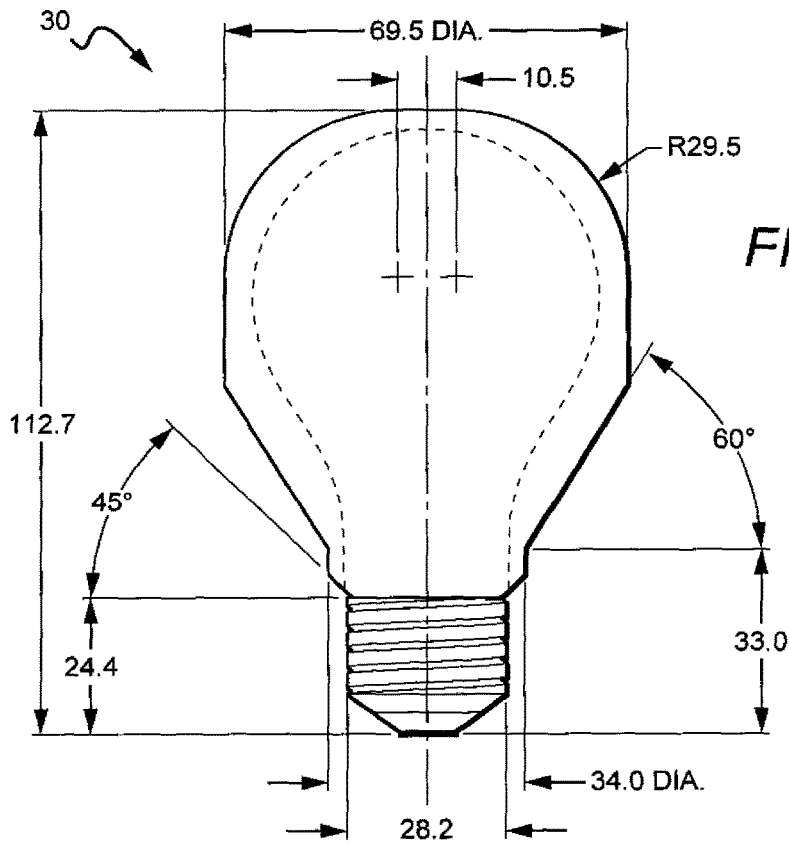
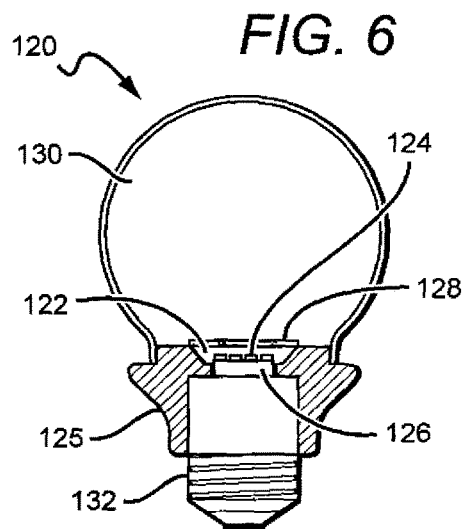
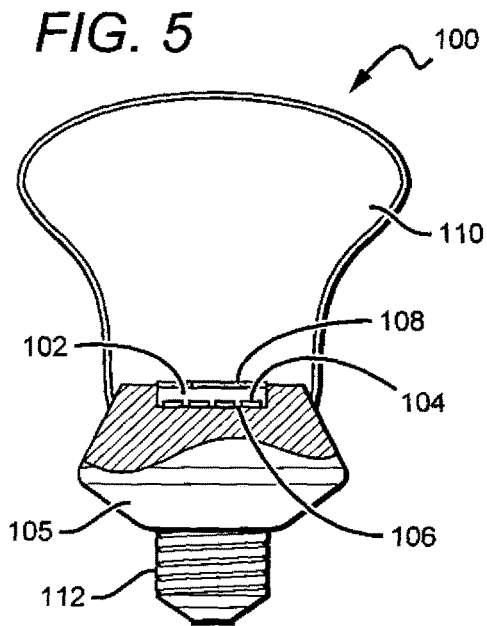
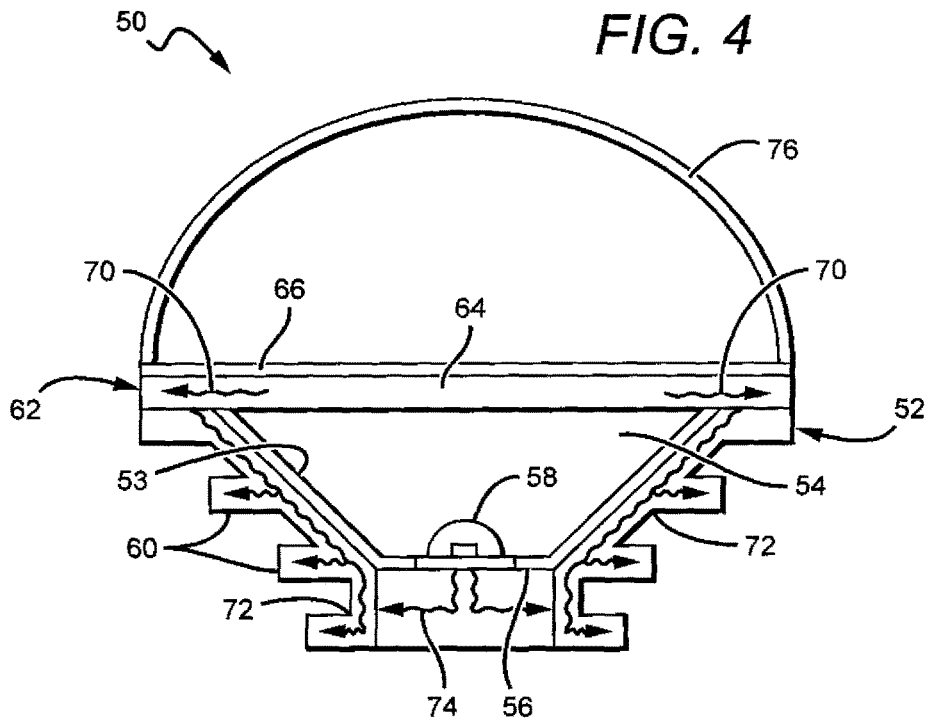


FIG. 3



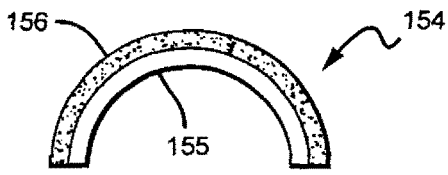


FIG. 7

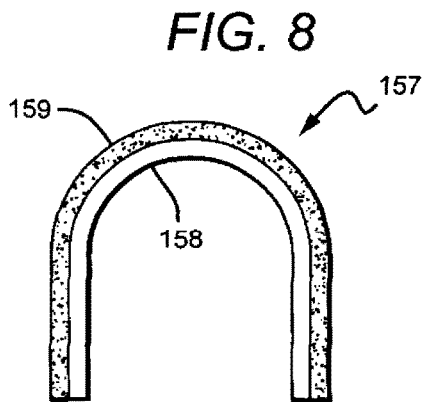


FIG. 8

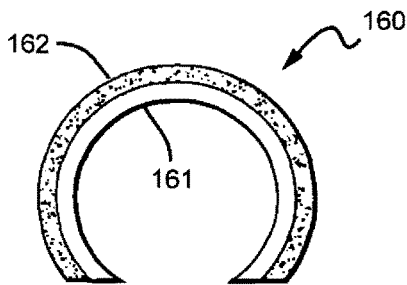


FIG. 9

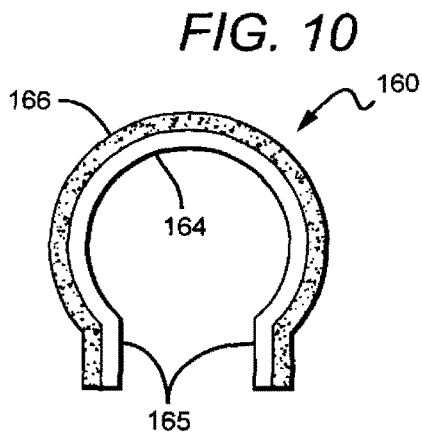


FIG. 10

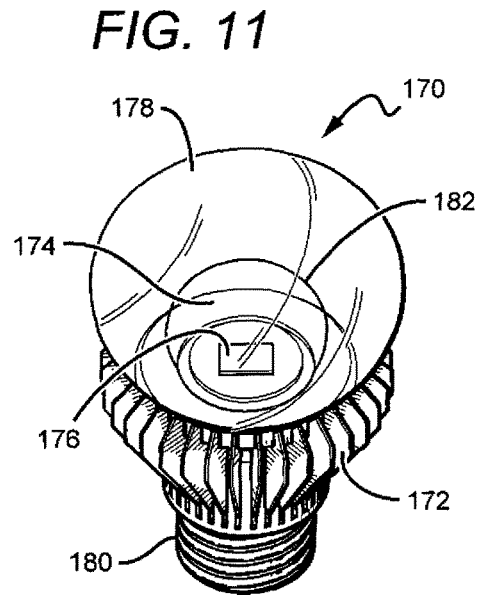


FIG. 11

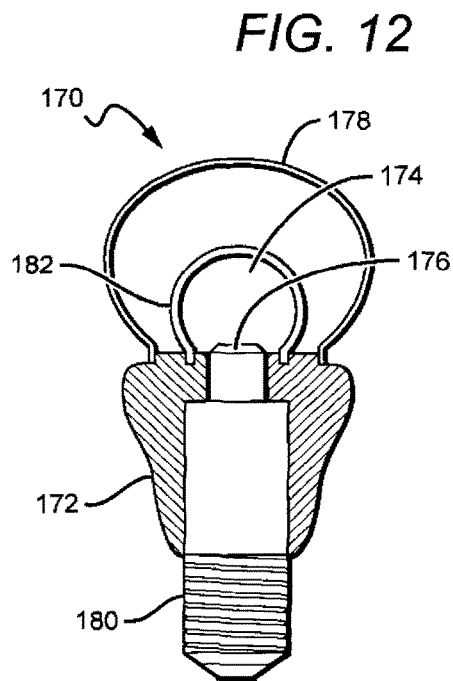


FIG. 12

FIG. 13

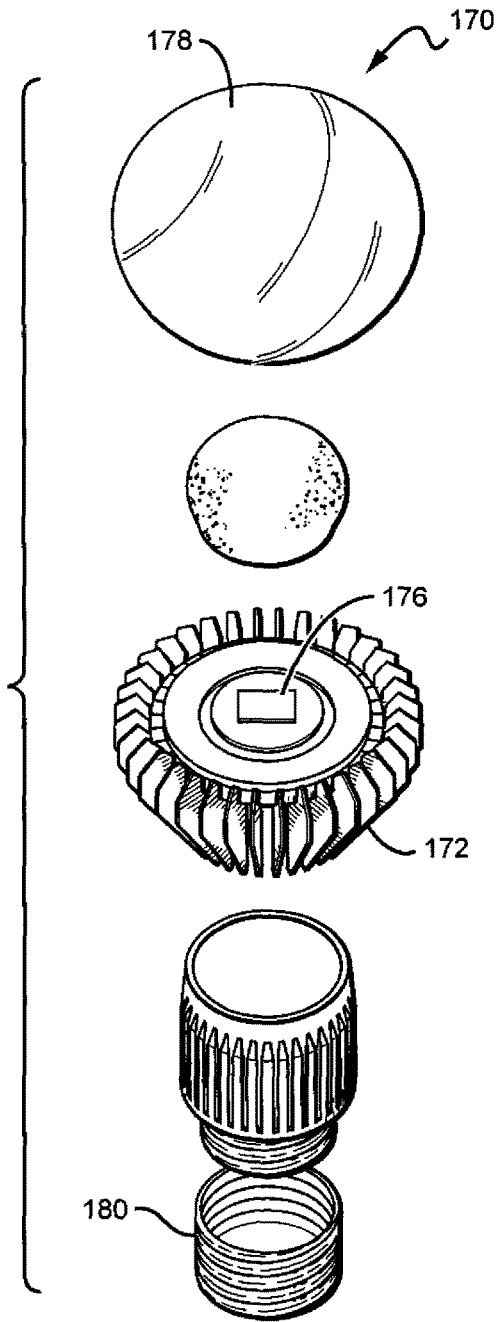


FIG. 14

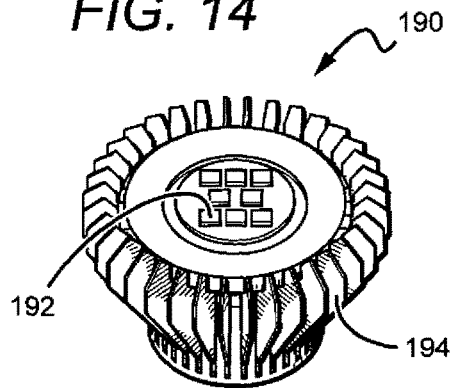


FIG. 15

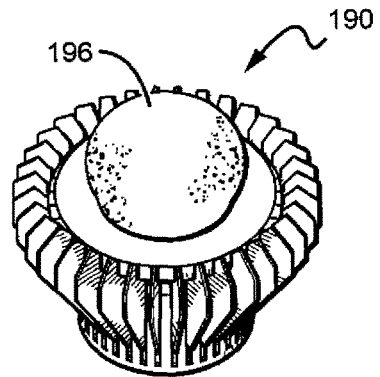


FIG. 16

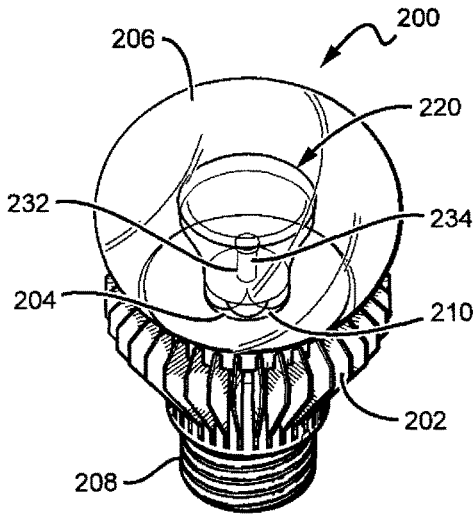


FIG. 18

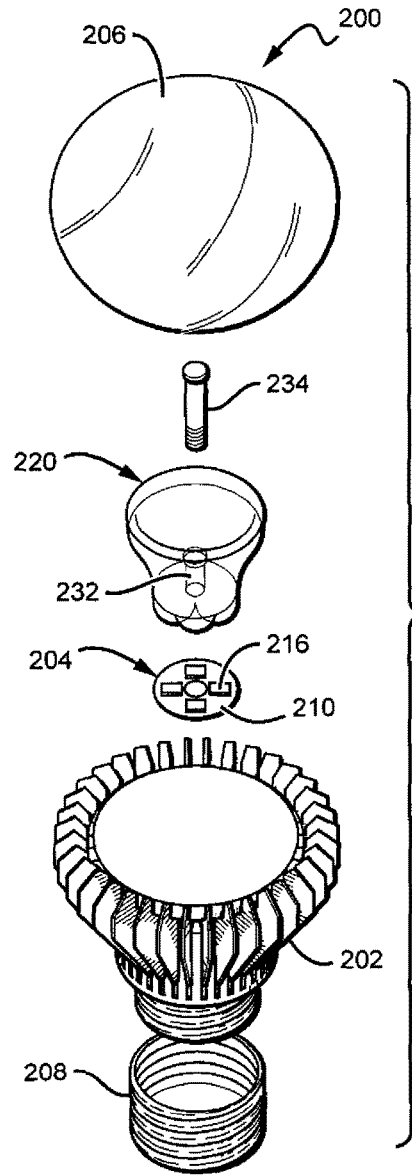
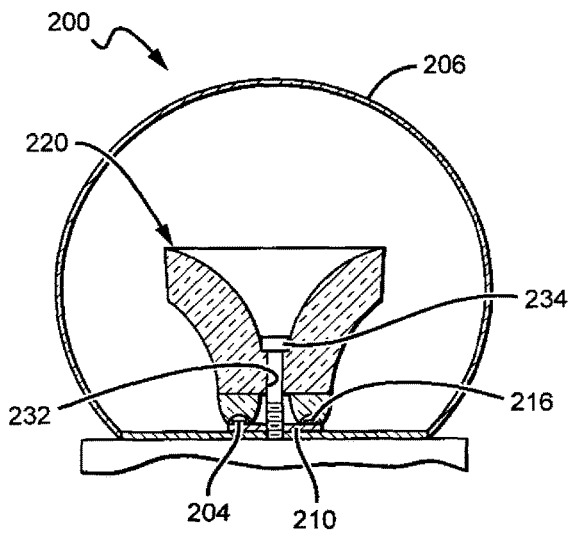


FIG. 17



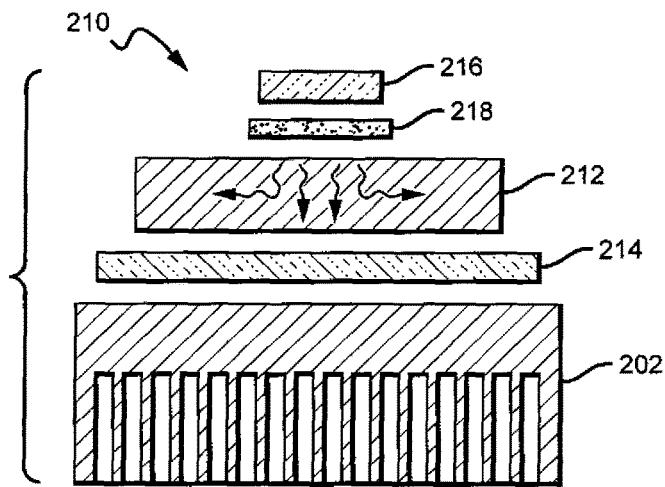


FIG. 19

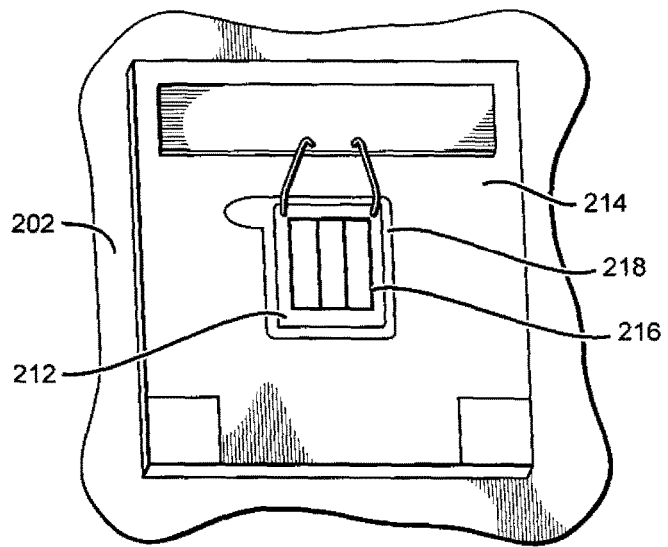


FIG. 20

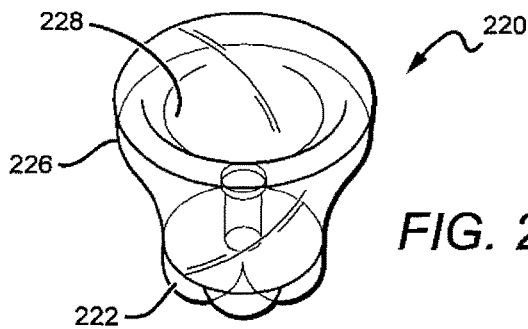


FIG. 21

FIG. 22

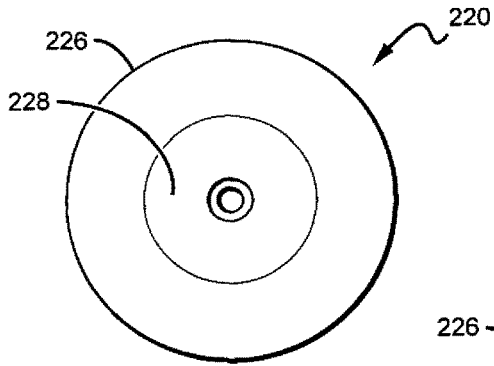


FIG. 23

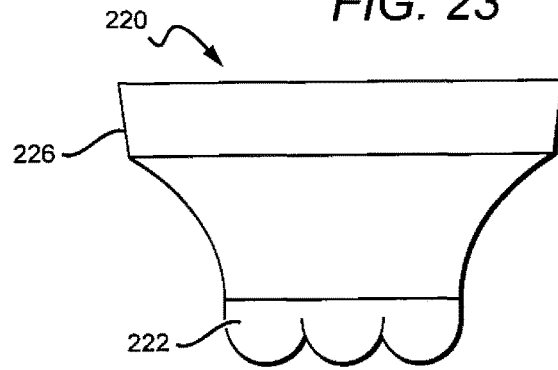


FIG. 24

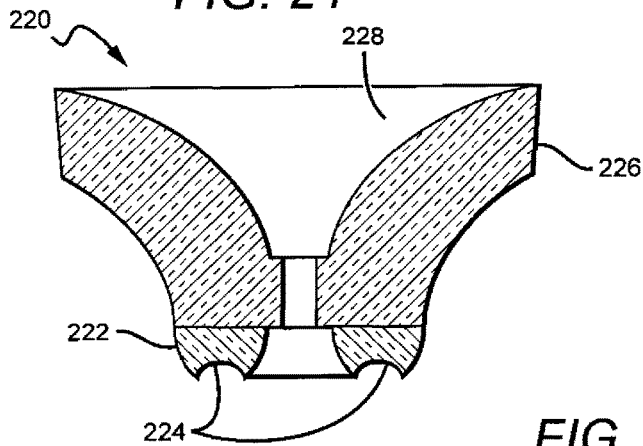


FIG. 25

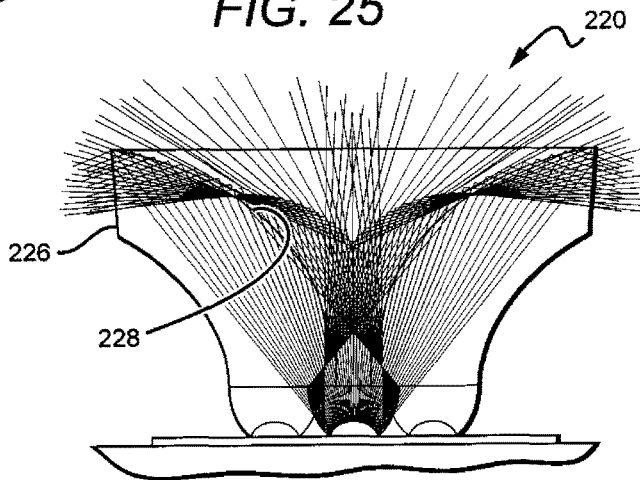


FIG. 26

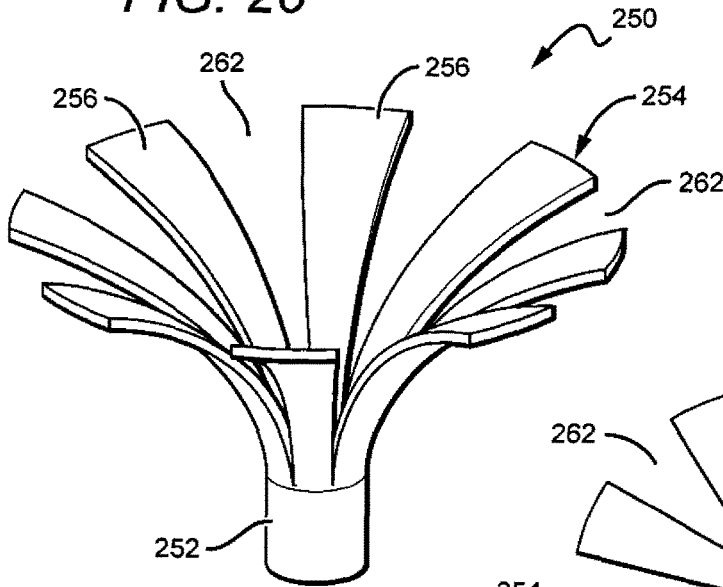


FIG. 27

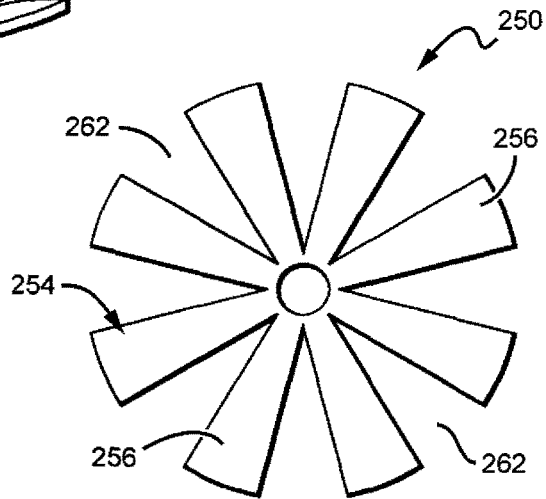
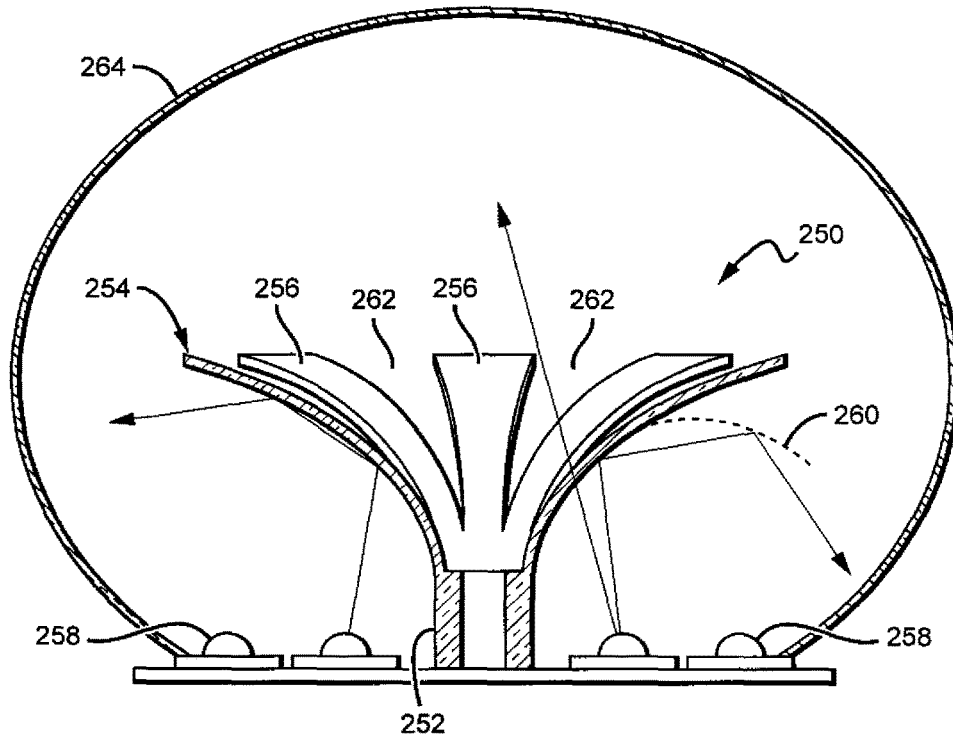


FIG. 28



SOLID STATE LAMP WITH THERMAL SPREADING ELEMENTS AND LIGHT DIRECTING OPTICS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/339,516, filed on Mar. 3, 2010, U.S. Provisional Patent Application Ser. No. 61/339,515, filed on Mar. 3, 2010, U.S. Provisional Patent Application Ser. No. 61/386,437, filed on Sep. 24, 2010, U.S. Provisional Application Ser. No. 61/424,665, filed on Dec. 19, 2010, U.S. Provisional Application Ser. No. 61/424,670, filed on Dec. 19, 2010, U.S. Provisional Patent Application Ser. No. 61/434,355, filed on Jan. 19, 2011, U.S. Provisional Patent Application Ser. No. 61/435,326, filed on Jan. 23, 2011, U.S. Provisional Patent Application Ser. No. 61/435,759, filed on Jan. 24, 2011. This application is also a continuation-in-part from, and claims the benefit of, U.S. patent application Ser. No. 14/848,825, filed on Aug. 2, 2010 now U.S. Pat. No. 8,562,161, U.S. patent application Ser. No. 12/889,719, filed on Sep. 24, 2010, and U.S. patent application Ser. No. 12/975,820, filed on Dec. 22, 2010.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to solid state lamps and bulbs and in particular to efficient and reliable light emitting diode (LED) based lamps and bulbs capable of producing omnidirectional emission patterns.

Description of the Related Art

Incandescent or filament-based lamps or bulbs are commonly used as light sources for both residential and commercial facilities. However, such lamps are highly inefficient light sources, with as much as 95% of the input energy lost, primarily in the form of heat or infrared energy. One common alternative to incandescent lamps, so-called compact fluorescent lamps (CFLs), are more effective at converting electricity into light but require the use of toxic materials which, along with its various compounds, can cause both chronic and acute poisoning and can lead to environmental pollution. One solution for improving the efficiency of lamps or bulbs is to use solid state devices such as light emitting diodes (LED or LEDs), rather than metal filaments, to produce light.

Light emitting diodes generally comprise one or more active layers of semiconductor material sandwiched between oppositely doped 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 various surfaces of the LED.

In order to use an LED chip in a circuit or other like arrangement, it is known to enclose an LED chip in a package to provide environmental and/or mechanical protection, color selection, light focusing and the like. An LED package also includes electrical leads, contacts or traces for electrically connecting the LED package to an external circuit. 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 (i.e. some light may be absorbed by the reflective cup due to the less than 100% reflectivity of practical reflector surfaces). In addition, heat retention may be an issue for a package such as the package **10** shown in FIG. 1, since it may be difficult to extract heat through the leads **15A**, **15B**.

A conventional LED package **20** illustrated in FIG. 2 may be more suited for high power operations which may generate more heat. In the LED package **20**, one or more LED chips **22** are 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 **27** 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.

LED chips, such as those found in the LED package **20** of FIG. 2 can be coated by conversion material comprising one or more phosphors, with the phosphors absorbing at least some of the LED light. The LED chip can emit a different wavelength of light such that it emits a combination of light from the LED and the phosphor. The LED chip(s) can be coated with a phosphor using many different methods, with one suitable method being described in U.S. patent application Ser. Nos. 11/656,759 and 11/899,790, both to Chitnis et al. and both entitled "Wafer Level Phosphor Coating Method and Devices Fabricated Utilizing Method". Alternatively, the LEDs can be coated using other methods such as electrophoretic deposition (EPD), with a suitable EPD method described in U.S. patent application Ser. No. 11/473,089 to Tarsa et al. entitled "Close Loop Electrophoretic Deposition of Semiconductor Devices".

LED chips which have a conversion material in close proximity or as a direct coating have been used in a variety of different packages, but experience some limitations based on the structure of the devices. When the phosphor material is on or in close proximity to the LED epitaxial layers (and in some instances comprises a conformal coat over the LED), the phosphor can be subjected directly to heat generated by the chip which can cause the temperature of the phosphor material to increase. Further, in such cases the phosphor can be subjected to very high concentrations or flux of incident light from the LED. Since the conversion process is in general not 100% efficient, excess heat is produced in the phosphor layer in proportion to the incident light flux. In compact phosphor layers close to the LED chip, this can lead to substantial temperature increases in the phosphor layer as large quantities of heat are generated in small areas. This temperature increase can be exacerbated when phosphor particles are embedded in low thermal conductivity material such as silicone which does not provide an effective dissipation path for the heat generated within the phosphor particles. Such elevated operating tem-

peratures can cause degradation of the phosphor and surrounding materials over time, as well as a reduction in phosphor conversion efficiency and a shift in conversion color.

Lamps have also been developed utilizing solid state light sources, such as LEDs, in combination with a conversion material that is separated from or remote to the LEDs. Such arrangements are disclosed in U.S. Pat. No. 6,350,041 to Tarsa et al., entitled "High Output Radial Dispersing Lamp Using a Solid State Light Source." The lamps described in this patent can comprise a solid state light source that transmits light through a separator to a disperser having a phosphor. The disperser can disperse the light in a desired pattern and/or changes its color by converting at least some of the light to a different wavelength through a phosphor or other conversion material. In some embodiments the separator spaces the light source a sufficient distance from the disperser such that heat from the light source will not transfer to the disperser when the light source is carrying elevated currents necessary for room illumination. Additional remote phosphor techniques are described in U.S. Pat. No. 7,614,759 to Negley et al., entitled "Lighting Device."

One potential disadvantage of lamps incorporating remote phosphors is that they can have undesirable visual or aesthetic characteristics. When the lamps are not generating light the lamp can have a surface color that is different from the typical white or clear appearance of the standard Edison bulb. In some instances the lamp can have a yellow or orange appearance, primarily resulting from the phosphor conversion material, such as yellow/green and red phosphors. This appearance can be considered undesirable for many applications where it can cause aesthetic issues with the surrounding architectural elements when the light is not illuminated. This can have a negative impact on the overall consumer acceptance of these types of lamps.

Further, compared to conformal or adjacent phosphor arrangements where heat generated in the phosphor layer during the conversion process may be conducted or dissipated via the nearby chip or substrate surfaces, remote phosphor arrangements can be subject to inadequate thermally conductive heat dissipation paths. Without an effective heat dissipation pathway, thermally isolated remote phosphors may suffer from elevated operating temperatures that in some instances can be even higher than the temperature in comparable conformal coated layers. This can offset some or all of the benefit achieved by placing the phosphor remotely with respect to the chip. Stated differently, remote phosphor placement relative to the LED chip can reduce or eliminate direct heating of the phosphor layer due to heat generated within the LED chip during operation, but the resulting phosphor temperature decrease may be offset in part or entirely due to heat generated in the phosphor layer itself during the light conversion process and lack of a suitable thermal path to dissipate this generated heat.

Another issue affecting the implementation and acceptance of lamps utilizing solid state light sources relates to the nature of the light emitted by the light source itself. In order to fabricate efficient lamps or bulbs based on LED light sources (and associated conversion layers), it is typically desirable to place the LED chips or packages in a co-planar arrangement. This facilitates manufacture and can reduce manufacturing costs by allowing the use of conventional production equipment and processes. However, co-planar arrangements of LED chips typically produce a forward directed light intensity profile (e.g., a Lambertian profile). Such beam profiles are generally not desired in applications where the solid-state lamp or bulb is intended to replace a

conventional lamp such as a traditional incandescent bulb, which has a much more omni-directional beam pattern. While it is possible to mount the LED light sources or packages in a three-dimensional arrangement, such arrangements are generally difficult and expensive to fabricate.

SUMMARY OF THE INVENTION

The present invention provides lamps and bulbs generally comprising different combinations and arrangement of a light source, one or more wavelength conversion materials, regions or layers which are positioned separately or remotely with respect to the light source, and a separate diffusing layer. This arrangement allows for the fabrication of lamps and bulbs that are efficient, reliable and cost effective and can provide an essentially omni-directional emission pattern, even with a light source comprised of a co-planar arrangement of LEDs. The lamps according to the present invention can also comprise thermal management features that provide for efficient dissipation of heat from the LEDs, which in turn allows the LEDs to operate at lower temperatures. The lamps can also comprise optical elements to help change the emission pattern from the generally directional (e.g. Lambertian) pattern of the LEDs to a more omnidirectional pattern.

One embodiment of a solid state lamp according to the present invention comprises an LED and an optical element over said LED such that light from the LED interacts with the optical element. The optical element changes the emission pattern of the LED to a broader emission pattern. The lamp also comprises a phosphor carrier over the optical element, with the phosphor carrier converting at least some of the LED light to a different wavelength.

Another embodiment of a solid state lamp according to the present invention comprises a heat dissipation element with a dielectric layer on the heat dissipation element. A heat spreading substrate is included on the dielectric layer, and an LED is included on and in thermal contact with the heat spreading substrate. The heat spreading substrate is arranged to spread heat from the LED prior to the LED heat reaching the dielectric layer.

Still another embodiment of a solid state lamp according to the present invention comprises an array of solid state emitters emitting light in a substantially directional emission pattern. A three-dimensional optical element is included over the array of solid state light emitters, the optical element modifying the directional emission pattern of the array of solid state light emitters to a more omni-directional emission pattern. A portion of light from the solid state light emitters provides forward light emission for the lamp emission pattern.

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

FIG. 1 shows a sectional view of one embodiment of a prior art LED lamp;

FIG. 2 shows a sectional view of another embodiment of a prior art LED lamp;

FIG. 3 shows the size specifications for an A19 replacement bulb;

FIG. 4 is a sectional view of one embodiment of a lamp according to the present invention;

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FIG. 5 is a sectional view of one embodiment of a lamp according to the present invention;

FIG. 6 is a sectional view of one embodiment of a lamp according to the present invention;

FIG. 7-10 are sectional views of different embodiments of a phosphor carrier according to the present invention;

FIG. 11 is a perspective view of one embodiment of a lamp according to the present invention;

FIG. 12 is a sectional view of the lamp shown in FIG. 11;

FIG. 13 is an exploded view of the lamp shown in FIG. 11;

FIG. 14 is a perspective view of one embodiment of a lamp according to the present invention;

FIG. 15 is a perspective view of the lamp in FIG. 14 with a phosphor carrier;

FIG. 16 is a perspective view of another embodiment of a lamp according to the present invention;

FIG. 17 is a sectional view of the top portion of the lamp shown in FIG. 16;

FIG. 18 is an exploded view of the lamp shown in FIG. 16;

FIG. 19 is a schematic of one embodiment of a dielectric substrate and heat sink according to the present invention;

FIG. 20 is a perspective view of one embodiment of an LED chip on a metallic substrate according to the present invention;

FIG. 21 is a perspective view of one embodiment of an optical element according to the present invention;

FIG. 22 is top view of the optical element shown in FIG. 21;

FIG. 23 is a side view of the optical element shown in FIG. 21;

FIG. 24 is a sectional view of the optical element shown in FIG. 21;

FIG. 25 is a side view of the an optical element according to the present invention showing light ray traces from the light sources;

FIG. 26 is a perspective view of another embodiment of an optical element according to the present invention;

FIG. 27 is a top view of the optical element shown in FIG. 26; and

FIG. 28 is a side view of another embodiment of a lamp according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to different embodiments of lamp or bulb structures that are efficient, reliable and cost effective, and that in some embodiments can provide an essentially omnidirectional emission pattern from directional emitting light sources, such as forward emitting light sources. The present invention is also directed to lamp structures using solid state emitters with remote conversion materials (or phosphors) and remote diffusing elements or diffusers. In some embodiments, the diffuser not only serves to mask the phosphor from the view by the lamp user, but can also disperse or redistribute the light from the remote phosphor and/or the lamp's light source into a desired emission pattern. In some embodiments the diffuser dome can be arranged to disperse forward directed emission pattern into a more omnidirectional pattern useful for general lighting applications. The diffuser can be used in embodiments having two-dimensional as well as three-dimensional shaped remote conversion materials, with a combination of features capable of transforming forward

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directed emission from an LED light source into a beam profile comparable with standard incandescent bulbs.

The present invention is described herein with reference to conversion materials, wavelength conversion materials, remote phosphors, phosphors, phosphor layers and related terms. The use of these terms should not be construed as limiting. It is understood that the use of the term remote phosphors, phosphor or phosphor layers is meant to encompass and be equally applicable to all wavelength conversion materials.

Some embodiments of lamps can have a dome-shaped (or frusto-spherical shaped) three dimensional conversion material over and spaced apart from the light source, and a dome-shaped diffuser spaced apart from and over the conversion material, such that the lamp exhibits a double-dome structure. The spaces between the various structure can comprise light mixing chambers that can promote not only dispersion of, but also color uniformity of the lamp emission. The space between the light source and conversion material, as well as the space between the conversion material, can serve as light mixing chambers. Other embodiments can comprise additional conversion materials or diffusers that can form additional mixing chambers. The order of the dome conversion materials and dome shaped diffusers can be different such that some embodiments can have a diffuser inside a conversion material, with the spaces between forming light mixing chambers. These are only a few of the many different conversion materials and diffuser arrangement according to the present invention.

Some lamp embodiments according to the present invention can comprise a light source having a co-planar arrangement of one or more LED chips or packages, with the emitters being mounted on a flat or planar surface. In other embodiments, the LED chips can be non co-planar, such as being on a pedestal or other three-dimensional structure. Co-planar light sources can reduce the complexity of the emitter arrangement, making them both easier and cheaper to manufacture. Co-planar light sources, however, tend to emit primarily in the forward direction such as in a Lambertian emission pattern. In different embodiments it can be desirable to emit a light pattern mimicking that of conventional incandescent light bulbs that can provide a nearly uniform emission intensity and color uniformity at different emission angles. Different embodiments of the present invention can comprise features that can transform the emission pattern from the non-uniform to substantially uniform within a range of viewing angles.

Different embodiments of the lamps can have many different shapes and sizes, with some embodiments having dimensions to fit into standard size envelopes, such as the A19 size envelope 30 as shown in FIG. 3. This makes the lamps particularly useful as replacements for conventional incandescent and fluorescent lamps or bulbs, with lamps according to the present invention experiencing the reduced energy consumption and long life provided from their solid state light sources. The lamps according to the present invention can also fit other types of standard size profiles including but not limited to A21 and A23. The lamp having high efficiency and low manufacturing cost.

The present invention comprises an efficient heat dissipation system that serves to laterally spread heat from the LED chips prior to encountering any dielectric layers. This allows the LEDs to operate at lower temperatures. Some embodiments of a thermally efficient heat dissipation system can comprise many different elements arranged in many different ways. Some embodiments comprise a heat-spreading substrate with high thermal conductivity that serves to

laterally spread heat from the LED chips prior to encountering any dielectric layers. The heat dissipation system can also comprise a dielectric layer mounted on a heat dissipation element such as a heat sink or heat pipe. By spreading the LED heat prior to encountering the dielectric layer, the impact of the dielectric layer's thermal resistance is minimized.

An optical element can be included that efficiently guides or reflects light from multiple co-planar LED chips, into a specified beam profile with minimal light loss. The lamps according to the present invention can comprise one or more remotely located phosphors and/or diffusers that can be included over the optical elements with the phosphor carrier converting at least part of the light emitted by the LED chip(s) into light of different wavelength. The phosphor carrier can also be arranged so as to minimize heating and saturation of the phosphor grains in the phosphor carrier. A diffuser can also be included over the phosphor carrier to further disperse light into the desired emission pattern.

In some embodiments the light sources can comprise solid state light sources, such as different types of LEDs, LED chips or LED packages. In some embodiments a single LED chip or package can be used, while in others multiple LED chips or packages can be arranged in different types of arrays. By having the phosphor thermally isolated from LED chips and with good thermal dissipation, the LED chips can be driven by higher current levels without causing detrimental effects to the conversion efficiency of the phosphor and its long term reliability. This can allow for the flexibility to overdrive the LED chips to lower the number of LEDs needed to produce the desired luminous flux. This in turn can reduce the cost on complexity of the lamps. These LED packages can comprise LEDs encapsulated with a material that can withstand the elevated luminous flux or can comprise unencapsulated LEDs.

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 present invention is described below in regards to certain lamps having one or multiple LEDs or LED chips or LED packages in different configurations, but it is understood that the present invention can be used for many other lamps having many different configurations. Examples of different lamps arranged in different ways according to the present invention are described below and in U.S. Provisional Patent application Ser. No. 61/435,759, to Le et al., entitled "Solid State Lamp", filed on Jan. 24, 2011, and incorporated herein by reference.

The embodiments below are described with reference to LED of LEDs, but it is understood that this is meant to encompass LED chips and LED packages. The components can have different shapes and sizes beyond those shown and different numbers of LEDs can be included. It is also understood that the embodiments described below are utilize co-planar light sources, but it is understood that non co-planar light sources can also be used. It is also understood that the lamp's LED light source may be comprised of one or multiple LEDs, and in embodiments with more than one LED, the LEDs may have different emission wavelengths. Similarly, some LEDs may have adjacent or contacting phosphor layers or regions, while others may have either adjacent phosphor layers of different composition or no phosphor layer at all.

The present invention is described herein with reference to conversion materials, phosphor layers and phosphor carriers and diffusers being remote to one another. Remote in

this context refers being spaced apart from and/or to not being on or in direct thermal contact.

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.

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.

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.

The different embodiments of the present invention described herein can be used as a basis for the manufacture and production of efficient, low cost LED-based solid state lamps. One example that can be enabled by the present invention can be the large scale replacement of conventional tungsten based omni-directional light bulbs (also known as "A-lamps") with more efficient, longer lasting LED based lamps or bulbs. The general concept and innovations described herein can also be applied to the replacement of a variety of similar tungsten/halogen based lamps or bulbs with corresponding LED based lamps or bulbs.

The present invention is also directed to particular independent LED lamp related devices such as LED substrates and optical elements. These can be provided to lamp designers and manufactures to incorporate into many different lamp or bulb designs beyond those described herein, with those lamps or bulbs operating pursuant to the innovations described herein. Combinations of the different inventive features could also be provided as "light engines" that can be utilized in different lighting designs. For example, a compact, single chip lamp incorporating an LED, heat spreading substrate, optional optical element, optional dielectric layer, and remote phosphor carrier could be provided as a unit to be incorporated into other lighting designs, all of which would operate pursuant to the innovations described herein.

FIG. 4 shows one embodiment of a lamp 50 according to the present invention that comprises a heat sink structure 52 having an optical cavity 54 with a platform 56 for holding a light source 58. Although this embodiment and some

embodiments below are described with reference to an optical cavity, it is understood that many other embodiments can be provided without optical cavities. These can include, but are not limited to, light sources being on a planar surface of the lamp structure or on a pedestal. The light source **58** can comprise many different emitters with the embodiment shown comprising an LED. Many different commercially available LED chips or LED packages can be used including but not limited to those commercially available from Cree, Inc. located in Durham, N.C. It is understood that lamp embodiments can be provided without a optical cavity, with the LEDs mounted in different ways in these other embodiments. By way of example, the light source can be mounted to a planar surface in the lamp or a pedestal can be provided for holding the LEDs.

The light source **58** can be mounted to the platform using many different known mounting methods and materials with light from the light source **58** emitting out the top opening of the cavity **54**. In some embodiments light source **58** can be mounted directly to the platform **56**, while in other embodiments the light source can be included on a sub-mount or printed circuit board (PCB) that is then mounted to the platform **56**. The platform **56** and the heat sink structure **52** can comprise electrically conductive paths for applying an electrical signal to the light source **58**, with some of the conductive paths being conductive traces or wires. Portions of the platform **56** can also be made of a thermally conductive material and in some embodiments heat generated during operation can spread to the platform and then to the heat sink structure.

The heat sink structure **52** can at least partially comprise a thermally conductive material, and many different thermally conductive materials can be used including different metals such as copper or aluminum, or metal alloys. Copper can have a thermal conductivity of up to 400 W/m-k or more. In some embodiments the heat sink can comprise high purity aluminum that can have a thermal conductivity at room temperature of approximately 210 W/m-k. In other embodiments the heat sink structure can comprise die cast aluminum having a thermal conductivity of approximately 200 W/m-k. The heat sink structure **52** can also comprise other heat dissipation features such as heat fins **60** that increase the surface area of the heat sink to facilitate more efficient dissipation into the ambient. In some embodiments, the heat fins **60** can be made of material with higher thermal conductivity than the remainder of the heat sink. In the embodiment shown the fins **60** are shown in a generally horizontal orientation, but it is understood that in other embodiments the fins can have a vertical or angled orientation. In still other embodiments, the heat sink can comprise active cooling elements, such as fans, to lower the convective thermal resistance within the lamp. In some embodiments, heat dissipation from the phosphor carrier is achieved through a combination of convection thermal dissipation and conduction through the heat sink structure **52**. Different heat dissipation arrangements and structures are described in U.S. Provisional Patent Application Ser. No. 61/339,516, to Tong et al., entitled "LED Lamp Incorporating Remote Phosphor With Heat Dissipation Feature," also assigned to Cree, Inc. application and is incorporated herein by reference.

Reflective layers **53** can also be included on the heat sink structure **52**, such as on the surface of the optical cavity **54**. In those embodiments not having an optical cavity the reflective layers can be included around the light source. In some embodiments the surfaces can be coated with a material having a reflectivity of approximately 75% or more to

the lamp visible wavelengths of light emitted by the light source **58** and/or wavelength conversion material ("the lamp light"), while in other embodiments the material can have a reflectivity of approximately 85% or more to the lamp light. In still other embodiments the material can have a reflectivity to the lamp light of approximately 95% or more.

The heat sink structure **52** can also comprise features for connecting to a source of electricity such as to different electrical receptacles. In some embodiments the heat sink structure can comprise a feature of the type to fit in conventional electrical receptacles. For example, it can include a feature for mounting to a standard Edison socket, which can comprise a screw-threaded portion which can be screwed into an Edison socket. In other embodiments, it can include a standard plug and the electrical receptacle can be a standard outlet, or can comprise a GU24 base unit, or it can be a clip and the electrical receptacle can be a receptacle which receives and retains the clip (e.g., as used in many fluorescent lights). These are only a few of the options for heat sink structures and receptacles, and other arrangements can also be used that safely deliver electricity from the receptacle to the lamp **50**. The lamps according to the present invention can comprise a power supply or power conversion unit that can comprise a driver to allow the bulb to run from an AC line voltage/current and to provide light source dimming capabilities. In some embodiments, the power supply can comprise an offline constant-current LED driver using a non-isolated quasi-resonant flyback topology. The LED driver can fit within the lamp and in some embodiments can comprise a less than 25 cubic centimeter volume, while in other embodiments it can comprise an approximately 20 cubic centimeter volume. In some embodiments the power supply can be non-dimmable but is low cost. It is understood that the power supply used can have different topology or geometry and can be dimmable as well.

A phosphor carrier **62** is included over the top opening of the cavity **54** and a dome shaped diffuser **76** is included over the phosphor carrier **62**. In the embodiment shown phosphor carrier covers the entire opening and the cavity opening is shown as circular and the phosphor carrier **62** is a circular disk. It is understood that the cavity opening and the phosphor carrier can be many different shapes and sizes. It is also understood that the phosphor carrier **62** can cover less than all of the cavity opening. As further described below, the diffuser **76** is arranged to disperse the light from the phosphor carrier and/or LED into the desired lamp emission pattern and can comprise many different shapes and sizes depending on the light it receives from and the desired lamp emission pattern.

Embodiments of phosphor carriers according to the present invention can be characterized as comprising a conversion material and thermally conductive light transmitting material, but it is understood that phosphor carriers can also be provided that are not thermally conductive. The light transmitting material can be transparent to the light emitted from the light source **58** and the conversion material should be of the type that absorbs the wavelength of light from the light source and re-emits a different wavelength of light. In the embodiment shown, the thermally conductive light transmitting material comprises a carrier layer **64** and the conversion material comprises a phosphor layer **66** on the phosphor carrier. As further described below, different embodiments can comprise many different arrangements of the thermally conductive light transmitting material and the conversion material.

When light from the light source **58** is absorbed by the phosphor in the phosphor layer **66** it is re-emitted in isotropic directions with approximately 50% of the light emitting forward and 50% emitting backward into the cavity **54**. In prior LEDs having conformal phosphor layers, a significant portion of the light emitted backwards can be directed back into the LED and its likelihood of escaping is limited by the extraction efficiency of the LED structure. For some LEDs the extraction efficiency can be approximately 70%, so a percentage of the light directed from the conversion material back into the LED can be lost. In the lamps according to the present invention having the remote phosphor configuration with LEDs on the platform **56** at the bottom of the cavity **54** a higher percentage of the backward phosphor light strikes a surface of the cavity instead of the LED. Coating these services with a reflective layer **53** increases the percentage of light that reflects back into the phosphor layer **66** where it can emit from the lamp. These reflective layers **53** allow for the optical cavity to effectively recycle photons, and increase the emission efficiency of the lamp. It is understood that the reflective layer can comprise many different materials and structures including but not limited to reflective metals or multiple layer reflective structures such as distributed Bragg reflectors. Reflective layers can also be included around the LEDs in those embodiments not having an optical cavity.

The carrier layer **64** can be made of many different materials having a thermal conductivity of 0.5 W/m-k or more, such as quartz, silicon carbide (SiC) (thermal conductivity ~120 W/m-k), glass (thermal conductivity of 1.0-1.4 W/m-k) or sapphire (thermal conductivity of ~40 W/m-k). In other embodiments, the carrier layer **64** can have thermal conductivity greater than 1.0 W/m-k, while in other embodiments it can have thermal conductivity of greater than 5.0 W/m-k. In still other embodiments it can have a thermal conductivity of greater than 10 W/m-k. In some embodiments the carrier layer can have thermal conductivity ranging from 1.4 to 10 W/m-k. The phosphor carrier can also have different thicknesses depending on the material being used, with a suitable range of thicknesses being 0.1 mm to 10 mm or more. It is understood that other thicknesses can also be used depending on the characteristics of the material for the carrier layer. The material should be thick enough to provide sufficient lateral heat spreading for the particular operating conditions. Generally, the higher the thermal conductivity of the material, the thinner the material can be while still providing the necessary thermal dissipation. Different factors can impact which carrier layer material is used including but not limited to cost and transparency to the light source light. Some materials may also be more suitable for larger diameters, such as glass or quartz. These can provide reduced manufacturing costs by formation of the phosphor layer on the larger diameter carrier layers and then singulation into the smaller carrier layers.

Many different phosphors can be used in the phosphor layer **66** with the present invention being particularly adapted to lamps emitting white light. As described above, in some embodiments the light source **58** can be LED based and can emit light in the blue wavelength spectrum. The phosphor layer can absorb some of the blue light and re-emit yellow. This allows the lamp to emit a white light combination of blue and yellow light. In some embodiments, the blue LED light can be converted by a yellow conversion material using a commercially available YAG:Ce phosphor, although a full range of broad yellow spectral emission is possible using conversion particles made of phosphors based on the (Gd,Y)₃(Al,Ga)₅O₁₂:Ce system, such as the

Y₃Al₅O₁₂:Ce (YAG). Other yellow phosphors that can be used for creating white light when used with a blue emitting LED based emitter include but not limited to:

Tb_{3-x}RE_xO₁₂:Ce(TAG); RE=Y, Gd, La, Lu; or

5 Sr_{2-x-y}Ba_xCa_ySiO₄:Eu.

The phosphor layer can also be arranged with more than one phosphor either mixed in with the phosphor layer **66** or as a second phosphor layer on the carrier layer **64**. In some embodiments, each of the two phosphors can absorb the LED light and can re-emit different colors of light. In these embodiments, the colors from the two phosphor layers can be combined for higher CRI white of different white hue (warm white). This can include light from yellow phosphors above that can be combined with light from red phosphors.

Different red phosphors can be used including:

Sr_xCa_{1-x}S:Eu, Y; Y=halide;

CaSiAlN₃:Eu; or

Sr_{2-y}Ca_ySiO₄:Eu

20 Other phosphors can be used to create color emission by converting substantially all light to a particular color. For example, the following phosphors can be used to generate green light:

SrGa₂S₄:Eu;

25 Sr_{2-y}Ba_ySiO₄:Eu; or

SrSi₂O₂N₂:Eu.

The following lists some additional suitable phosphors used as conversion particles phosphor layer **66**, although others can be used. Each exhibits excitation in the blue and/or UV emission spectrum, provides a desirable peak emission, has efficient light conversion, and has acceptable Stokes shift:

YELLOW/GREEN

(Sr,Ca,Ba) (Al,Ga)₂S₄:Eu²⁺

35 Ba₂ (Mg,Zn) Si₂O₇:Eu²⁺

Gd_{0.46}Sr_{0.31}Al_{1.23}O_xF_{1.38}:Eu²⁺_{0.06}

(Ba_{1-x-y},Sr_x,Ca_y) SiO₄:Eu

Ba₂SiO₄:Eu²⁺

Lu₃Al₅O₁₂ doped with Ce³⁺

40 (Ca,Sr,Ba) Si₂O₂N₂ doped with Eu²⁺

CaSc₂O₄:Ce³⁺

(Sr,Ba) 2SiO₄:Eu²⁺

RED

Lu₂O₃:Eu³⁺

45 (Sr_{2-x}La_x) (Ce_{1-x}Eu_x)O₄

Sr₂Ce_{1-x}Eu_xO₄

Sr_{2-x}Eu_xCeO₄

SrTiO₃:Pr³⁺,Ga³⁺

CaAlSiN₃:Eu²⁺

50 Sr₂Si₅N₈:Eu²⁺

Different sized phosphor particles can be used including but not limited to particles in the range of 10 nanometers (nm) to 30 micrometers (μm), or larger. Smaller particle sizes typically scatter and mix colors better than larger sized particles to provide a more uniform light. Larger particles are typically more efficient at converting light compared to smaller particles, but emit a less uniform light. In some embodiments, the phosphor can be provided in the phosphor layer **66** in a binder, and the phosphor can also have different concentrations or loading of phosphor materials in the binder. A typical concentration being in a range of 30-70% by weight. In one embodiment, the phosphor concentration is approximately 65% by weight, and is preferably uniformly dispersed throughout the remote phosphor. The phosphor layer **66** can also have different regions with different conversion materials and different concentrations of conversion material.

Different materials can be used for the binder, with materials preferably being robust after curing and substantially transparent in the visible wavelength spectrum. Suitable materials include silicones, epoxies, glass, inorganic glass, dielectrics, BCB, polyimides, polymers and hybrids thereof, with the preferred material being silicone because of its high transparency and reliability in high power LEDs. Suitable phenyl- and methyl-based silicones are commercially available from Dow® Chemical. The binder can be cured using many different curing methods depending on different factors such as the type of binder used. Different curing methods include but are not limited to heat, ultraviolet (UV), infrared (IR) or air curing.

Phosphor layer 66 can be applied using different processes including but not limited to spin coating, sputtering, printing, powder coating, electrophoretic deposition (EPD), electrostatic deposition, among others. As mentioned above, the phosphor layer 66 can be applied along with a binder material, but it is understood that a binder is not required. In still other embodiments, the phosphor layer 66 can be separately fabricated and then mounted to the carrier layer 64.

In one embodiment, a phosphor-binder mixture can be sprayed or dispersed over the carrier layer 64 with the binder then being cured to form the phosphor layer 66. In some of these embodiments the phosphor-binder mixture can be sprayed, poured or dispersed onto or over the a heated carrier layer 64 so that when the phosphor binder mixture contacts the carrier layer 64, heat from the carrier layer spreads into and cures the binder. These processes can also include a solvent in the phosphor-binder mixture that can liquefy and lower the viscosity of the mixture making it more compatible with spraying. Many different solvents can be used including but not limited to toluene, benzene, zylene, or OS-20 commercially available from Dow Corning®, and different concentration of the solvent can be used. When the solvent-phosphor-binder mixture is sprayed or dispersed on the heated carrier layer 64 the heat from the carrier layer 64 evaporates the solvent, with the temperature of the carrier layer impacting how quickly the solvent is evaporated. The heat from the carrier layer 64 can also cure the binder in the mixture leaving a fixed phosphor layer on the carrier layer. The carrier layer 64 can be heated to many different temperatures depending on the materials being used and the desired solvent evaporation and binder curing speed. A suitable range of temperature is 90 to 150° C., but it is understood that other temperatures can also be used. Various deposition methods and systems are described in U.S. Patent Application Publication No. 2010/0155763, to Donofrio et al, entitled "Systems and Methods for Application of Optical Materials to Optical Elements," and also assigned to Cree, Inc. This application was filed concurrently with this application and is incorporated herein by reference.

The phosphor layer 66 can have many different thicknesses depending at least partially on the concentration of phosphor material and the desired amount of light to be converted by the phosphor layer 66. Phosphor layers according to the present invention can be applied with concentration levels (phosphor loading) above 30%. Other embodiments can have concentration levels above 50%, while in still others the concentration level can be above 60%. In some embodiments the phosphor layer can have thicknesses in the range of 10-100 microns, while in other embodiments it can have thicknesses in the range of 40-50 microns.

The methods described above can be used to apply multiple layers of the same of different phosphor materials

and different phosphor materials can be applied in different areas of the carrier layer using known masking processes. The methods described above provide some thickness control for the phosphor layer 66, but for even greater thickness control the phosphor layer can be ground using known methods to reduce the thickness of the phosphor layer 66 or to even out the thickness over the entire layer. This grinding feature provides the added advantage of being able to produce lamps emitting within a single bin on the CIE chromaticity graph. Binning is generally known in the art and is intended to ensure that the LEDs or lamps provided to the end customer emit light within an acceptable color range. The LEDs or lamps can be tested and sorted by color or brightness into different bins, generally referred to in the art as binning. Each bin typically contains LEDs or lamps from one color and brightness group and is typically identified by a bin code. White emitting LEDs or lamps can be sorted by chromaticity (color) and luminous flux (brightness). The thickness control of the phosphor layer provides greater control in producing lamps that emit light within a target bin by controlling the amount of light source light converted by the phosphor layer. Multiple phosphor carriers 62 with the same thickness of phosphor layer 66 can be provided. By using a light source 58 with substantially the same emission characteristics, lamps can be manufactured having nearly the same emission characteristics that in some instances can fall within a single bin. In some embodiments, the lamp emissions fall within a standard deviation from a point on a CIE diagram, and in some embodiments the standard deviation comprises less than a 10-step McAdams ellipse. In some embodiments the emission of the lamps falls within a 4-step McAdams ellipse centered at CIE_{xy}(0.313, 0.323).

The phosphor carrier 62 can be mounted and bonded over the opening in the cavity 54 using different known methods or materials such as thermally conductive bonding materials or a thermal grease. Conventional thermally conductive grease can contain ceramic materials such as beryllium oxide and aluminum nitride or metal particles such colloidal silver. In other embodiments the phosphor carrier can be mounted over the opening using thermal conductive devices such as clamping mechanisms, screws, or thermal adhesive hold phosphor carrier 62 tightly to the heat sink structure to maximize thermal conductivity. In one embodiment a thermal grease layer is used having a thickness of approximately 100 μm and thermal conductivity of $k=0.2$ W/m-k. This arrangement provides an efficient thermally conductive path for dissipating heat from the phosphor layer 66. As mentioned above, different lamp embodiments can be provided without cavity and the phosphor carrier can be mounted in many different ways beyond over an opening to the cavity.

During operation of the lamp 50, phosphor conversion heating is concentrated in the phosphor layer 66, such as in the center of the phosphor layer 66 where the majority of LED light strikes and passes through the phosphor carrier 62. The thermally conductive properties of the carrier layer 64 spreads this heat laterally toward the edges of the phosphor carrier 62 as shown by first heat flow 70. There the heat passes through the thermal grease layer and into the heat sink structure 52 as shown by second heat flow 72 where it can efficiently dissipate into the ambient.

As discussed above, in the lamp 50 the platform 56 and the heat sink structure 52 can be thermally connected or coupled. This coupled arrangement results in the phosphor carrier 62 and that light source 58 at least partially sharing a thermally conductive path for dissipating heat. Heat passing through the platform 56 from the light source 58 as

shown by third heat flow **74** can also spread to the heat sink structure **52**. Heat from the phosphor carrier **62** flowing into the heat sink structure **52** can also flow into the platform **56**. As further described below, in other embodiments, the phosphor carrier **62** and the light source **58** can have separate thermally conductive paths for dissipating heat, with these separate paths being referred to as “decoupled” as described in U.S. Provisional Patent Application Ser. No. 61/339,516, to Tong et al. incorporated by reference above.

It is understood that the phosphor carriers can be arranged in many different ways beyond the embodiment shown in FIG. **4**. The phosphor layer can be on any surface of the carrier layer or can be mixed in with the carrier layer. The phosphor carriers can also comprise scattering layers that can be included on or mixed in with the phosphor layer or carrier layer. It is also understood that the phosphor and scattering layers can cover less than a surface of the carrier layer and in some embodiments the conversion layer and scattering layer can have different concentrations in different areas. It is also understood that the phosphor carrier can have different roughened or shaped surfaces to enhance emission through the phosphor carrier.

As mentioned above, the diffuser is arranged to disperse light from the phosphor carrier and LED into the desired lamp emission pattern, and can have many different shapes and sizes. In some embodiments, the diffuser also can be arranged over the phosphor carrier to mask the phosphor carrier when the lamp is not emitting. The diffuser can have materials to give a substantially white appearance to give the bulb a white appearance when the lamp is not emitting.

Many different diffusers with different shapes and attributes can be used with lamp **50** as well as the lamps described below, such as those described in U.S. Provisional Patent Application No. 61/339,515, titled “LED Lamp With Remote Phosphor and Diffuser Configuration”, file on Mar. 3, 2010, which is incorporated herein by reference. Diffuser can also take different shapes, including but not limited to generally asymmetric “squat” as in U.S. patent application Ser. No. 12/901,405, titled “Non-uniform Diffuser to Scatter Light Into Uniform Emission Pattern,” filed on Oct. 8, 2010, incorporated herein by reference

The lamps according to the present invention can comprise many different features beyond those described above. Referring again to FIG. **4**, in those lamp embodiments having a cavity **54** can be filled with a transparent heat conductive material to further enhance heat dissipation for the lamp. The cavity conductive material could provide a secondary path for dissipating heat from the light source **58**. Heat from the light source would still conduct through the platform **56**, but could also pass through the cavity material to the heat sink structure **52**. This would allow for lower operating temperature for the light source **58**, but presents the danger of elevated operating temperature for the phosphor carrier **62**. This arrangement can be used in many different embodiments, but is particularly applicable to lamps having higher light source operating temperatures compared to that of the phosphor carrier. This arrangement allows for the heat to be more efficiently spread from the light source in applications where additional heating of the phosphor carrier layer can be tolerated.

As discussed above, different lamp embodiments according to the present invention can be arranged with many different types of light sources. In one embodiment eight LEDs can be used that are connected in series with two wires to a circuit board. The wires can then be connected to the power supply unit described above. In other embodiments, more or less than eight LEDs can be used and as mentioned

above, commercially available LEDs from Cree, Inc. can used including eight XLamp® XP-E LEDs or four XLamp® XP-G LEDs. Different single string LED circuits are described in U.S. patent application Ser. No. 12/566,195, to van de Ven et al., entitled “Color Control of Single String Light Emitting Devices Having Single String Color Control, and U.S. patent application Ser. No. 12/704,730 to van de Ven et al., entitled “Solid State Lighting Apparatus with Compensation Bypass Circuits and Methods of Operation Thereof”, both of which are incorporated herein by reference.

FIG. **5** shows still another embodiment of lamp **100** according to the present invention that comprises an optical cavity **102** within a heat sink structure **105**. Like the embodiments above, the lamp **100** can also be provided without a lamp cavity, with the LEDs mounted on a surface of the heat sink or on a three dimensional or pedestal structures having different shapes. A planar LED based light source **104** is mounted to the platform **106**, and a phosphor carrier **108** is mounted to the top opening of the cavity **102**, with the phosphor carrier **108** having any of the features of those described above. In the embodiment shown, the phosphor carrier **108** can be in a flat disk shape and comprises a thermally conductive transparent material and a phosphor layer. It can be mounted to the cavity with a thermally conductive material or device as described above. The cavity **102** can have reflective surfaces to enhance the emission efficiency as described above.

Light from the light source **104** passes through the phosphor carrier **108** where a portion of it is converted to a different wavelength of light by the phosphor in the phosphor carrier **108**. In one embodiment the light source **104** can comprise blue emitting LEDs and the phosphor carrier **108** can comprise a yellow phosphor as described above that absorbs a portion of the blue light and re-emits yellow light. The lamp **100** emits a white light combination of LED light and yellow phosphor light. Like above, the light source **104** can also comprise many different LEDs emitting different colors of light and the phosphor carrier can comprise other phosphors to generate light with the desired color temperature and rendering.

The lamp **100** also comprises a shaped diffuser dome **110** mounted over the cavity **102** that includes diffusing or scattering particles such as those listed above. The scattering particles can be provided in a curable binder that is formed in the general shape of dome. In the embodiment shown, the dome **110** is mounted to the heat sink structure **105** and has an enlarged portion at the end opposite the heat sink structure **105**. Different binder materials can be used as discussed above such as silicones, epoxies, glass, inorganic glass, dielectrics, BCB, polyimides, polymers and hybrids thereof. In some embodiments white scattering particles can be used with the dome having a white color that hides the color of the phosphor in the phosphor carrier **108** in the optical cavity. This gives the overall lamp **100** a white appearance that is generally more visually acceptable or appealing to consumers than the color of the phosphor. In one embodiment the diffuser can include white titanium dioxide particles that can give the diffuser dome **110** its overall white appearance.

The diffuser dome **110** can provide the added advantage of distributing the light emitting from the optical cavity in a more uniform pattern. As discussed above, light from the light source in the optical cavity can be emitted in a generally Lambertian pattern and the shape of the dome **110** along with the scattering properties of the scattering particles causes light to emit from the dome in a more omnidirectional emission pattern. An engineered dome can have

scattering particles in different concentrations in different regions or can be shaped to a specific emission pattern. In some embodiments, including those described below, the dome can be engineered so that the emission pattern from the lamp complies with the Department of Energy (DOE) Energy Star defined omnidirectional distribution criteria. One requirement of this standard met by the lamps herein is that the emission uniformity must be within 20% of mean value from 0 to 135° viewing and; >5% of total flux from the lamp must be emitted in the 135-180° emission zone, with the measurements taken at 0, 45, 90° azimuthal angles. As mentioned above, the different lamp embodiments described herein can also comprise A-type retrofit LED bulbs that meet the DOE Energy Star® standards. The present invention provides lamps that are efficient, reliable and cost effective. In some embodiments, the entire lamp can comprise five components that can be quickly and easily assembled.

Like the embodiments above, the lamp **100** can comprise a mounting mechanism **112** of the type to fit in conventional electrical receptacles. In the embodiment shown, the lamp **100** includes a screw-threaded portion **112** for mounting to a standard Edison socket. Like the embodiments above, the lamp **100** can include standard plug and the electrical receptacle can be a standard outlet, or can comprise a GU24 base unit, or it can be a clip and the electrical receptacle can be a receptacle which receives and retains the clip (e.g., as used in many fluorescent lights).

As mentioned above, the space between some of the features of the lamp **100** can be considered mixing chambers, with the space between the light source **106** and the phosphor carrier **108** comprising a first light mixing chamber. The space between the phosphor carrier **108** and the diffuser **110** can comprise a second light mixing chamber, with the mixing chamber promoting uniform color and intensity emission for the lamp. The same can apply to the embodiments below having different shaped phosphor carriers and diffusers. In other embodiments, additional diffusers and/or phosphor carriers can be included forming additional mixing chambers, and the diffusers and/or phosphor carriers can be arranged in different orders.

Different lamp embodiments according to the present invention can have many different shapes and sizes. FIG. **6** shows another embodiment of a lamp **120** according to the present invention that is similar to the lamp **100** and similarly comprises an optical cavity **122** in a heat sink structure **125** with a light source **124** mounted to the platform **126** in the optical cavity **122**. Like above, the heat sink structure need not have an optical cavity, and the light sources can be provided on other structures beyond a heat sink structure. These can include planar surfaces or pedestals having the light source. A phosphor carrier **128** is mounted over the cavity opening with a thermal connection. The lamp **120** also comprises a diffuser dome **130** mounted to the heat sink structure **125**, over the optical cavity. The diffuser dome can be made of the same materials as diffuser dome **110** described above, but in this embodiment the dome **130** is oval or egg shaped to provide a different lamp emission pattern while still masking the color from the phosphor in the phosphor carrier **128**. It is also noted that the heat sink structure **125** and the platform **126** are thermally de-coupled. That is, there is a space between the platform **126** and the heat sink structure such that they do not share a thermal path for dissipating heat. As mentioned above, this can provide improved heat dissipation from the phosphor carrier compared to lamps not having de-coupled heat paths. The lamp **120** also comprises a screw-threaded portion **132** for mounting to an Edison socket.

In the embodiments above, the phosphor carriers are two dimensional (or flat/planar) with the LEDs in the light source being co-planar. It is understood, however, that in other lamp embodiments the phosphor carriers can take many different shapes including different three-dimensional shapes. The term three-dimensional is meant to mean any shape other than planar as shown in the above embodiments. FIGS. **7** through **10** show different embodiments of three-dimensional phosphor carriers according to the present invention, but it is understood that they can also take many other shapes. As discussed above, when the phosphor absorbs and re-emits light, it is re-emitted in an isotropic fashion, such that the 3-dimensional phosphor carrier serves to convert and also disperse light from the light source. Like the diffusers described above, the different shapes of the 3-dimensional carrier layers can emit light in emission patterns having different characteristics that depends partially on the emission pattern of the light source. The diffuser can then be matched with the emission of the phosphor carrier to provide the desired lamp emission pattern.

FIG. **7** shows a hemispheric shaped phosphor carrier **154** comprising a hemispheric carrier **155** and phosphor layer **156**. The hemispheric carrier **155** can be made of the same materials as the carrier layers described above, and the phosphor layer can be made of the same materials as the phosphor layer described above, and scattering particles can be included in the carrier and phosphor layer as described above.

In this embodiment the phosphor layer **156** is shown on the outside surface of the carrier **155** although it is understood that the phosphor layer can be on the carrier's inside layer, mixed in with the carrier, or any combination of the three. In some embodiments, having the phosphor layer on the outside surface may minimize emission losses. When emitter light is absorbed by the phosphor layer **156** it is emitted omnidirectionally and some of the light can emit backwards and be absorbed by the lamp elements such as the LEDs. The phosphor layer **156** can also have an index of refraction that is different from the hemispheric carrier **355** such that light emitting forward from the phosphor layer can be reflected back from the inside surface of the carrier **355**. This light can also be lost due to absorption by the lamp elements. With the phosphor layer **156** on the outside surface of the carrier **155**, light emitted forward does not need to pass through the carrier **155** and will not be lost to reflection. Light that is emitted back will encounter the top of the carrier where at least some of it will reflect back. This arrangement results in a reduction of light from the phosphor layer **156** that emits back into the carrier where it can be absorbed.

The phosphor layer **156** can be deposited using many of the same methods described above. In some instances the three-dimensional shape of the carrier **155** may require additional steps or other processes to provide the necessary coverage. In the embodiments where a solvent-phosphor-binder mixture is sprayed and the carrier can be heated as described above and multiple spray nozzles may be needed to provide the desired coverage over the carrier, such as approximate uniform coverage. In other embodiments, fewer spray nozzles can be used while spinning the carrier to provide the desired coverage. Like above, the heat from the carrier **155** can evaporate the solvent and helps cure the binder.

In still other embodiments, the phosphor layer can be formed through an emersion process whereby the phosphor layer can be formed on the inside or outside surface of the carrier **155**, but is particularly applicable to forming on the

inside surface. The carrier **155** can be at least partially filled with, or otherwise brought into contact with, a phosphor mixture that adheres to the surface of the carrier. The mixture can then be drained from the carrier leaving behind a layer of the phosphor mixture on the surface, which can then be cured. In one embodiment, the mixture can comprise polyethylen oxide (PEO) and a phosphor. The carrier can be filled and then drained, leaving behind a layer of the PEO-phosphor mixture, which can then be heat cured. The PEO evaporates or is driven off by the heat leaving behind a phosphor layer. In some embodiments, a binder can be applied to further fix the phosphor layer, while in other embodiments the phosphor can remain without a binder.

Like the processes used to coat the planar carrier layer, these processes can be utilized in three-dimensional carriers to apply multiple phosphor layers that can have the same or different phosphor materials. The phosphor layers can also be applied both on the inside and outside of the carrier, and can have different types having different thickness in different regions of the carrier. In still other embodiments different processes can be used such as coating the carrier with a sheet of phosphor material that can be thermally formed to the carrier.

In lamps utilizing the carrier **155**, an emitter can be arranged at the base of the carrier so that light from the emitters emits up and passes through the carrier **155**. In some embodiments the emitters can emit light in a generally Lambertian pattern, and the carrier can help disperse the light in a more uniform pattern.

FIG. **8** shows another embodiment of a three dimensional phosphor carrier **157** according to the present invention comprising a bullet-shaped carrier **158** and a phosphor layer **159** on the outside surface of the carrier. The carrier **158** and phosphor layer **159** can be formed of the same materials using the same methods as described above. The different shaped phosphor carrier can be used with a different emitter to provide the overall desired lamp emission pattern. FIG. **9** shows still another embodiment of a three dimensional phosphor carrier **160** according to the present invention comprising a globe-shaped carrier **161** and a phosphor layer **162** on the outside surface of the carrier. The carrier **161** and phosphor layer **162** can be formed of the same materials using the same methods as described above.

FIG. **10** shows still another embodiment phosphor carrier **163** according to the present invention having a generally globe shaped carrier **164** with a narrow neck portion **165**. Like the embodiments above, the phosphor carrier **163** includes a phosphor layer **166** on the outside surface of the carrier **164** made of the same materials and formed using the same methods as those described above. In some embodiments, phosphor carriers having a shape similar to the carrier **164** can be more efficient in converting emitter light and re-emitting light from a Lambertian pattern from the light source, to a more uniform emission pattern.

FIGS. **11** through **13** show another embodiment of a lamp **170** according to the present invention having a heat sink structure **172**, optical cavity **174**, light source **176**, diffuser dome **178** and a screw-threaded portion **180**. This embodiment also comprises a three-dimensional phosphor carrier **182** that includes a thermally conductive transparent material and one phosphor layer. It is also mounted to the heat sink structure **172** with a thermal connection. In this embodiment, however, the phosphor carrier **182** is hemispheric shaped and the emitters are arranged so that light from the light source passes through the phosphor carrier **182** where at least some of it is converted.

The three dimensional shape of the phosphor carrier **182** provides natural separation between it and the light source **176**. Accordingly, the light source **176** is not mounted in a recess in the heat sink that forms the optical cavity. Instead, the light source **176** is mounted on the top surface of the heat sink structure **172**, with the optical cavity **174** formed by the space between the phosphor carrier **182** and the top of the heat sink structure **172**. This arrangement can allow for a less Lambertian emission from the optical cavity **174** because there are no optical cavity side surfaces to block and redirect sideways emission.

In embodiments of the lamp **170** utilizing blue emitting LEDs for the light source **176** and yellow and red phosphor combination in the phosphor carrier. This can cause the phosphor carrier **182** to appear yellow or orange, and the diffuser dome **178** masks this color while dispersing the lamp light into the desired emission pattern. In lamp **170**, the conductive paths for the platform and heat sink structure are coupled, but it is understood that in other embodiments they can be de-coupled.

FIG. **14** shows one embodiment of a lamp **190** according to the present invention comprising a eight LED light source **192** mounted on a heat sink **194** as described above. The emitters can comprise many different types of LEDs that can be coupled together in many different ways and in the embodiment shown are serially connected. In other embodiments, the LEDs can be interconnected in different series and parallel interconnect combinations. It is noted that in this embodiment the emitters are not mounted in a optical cavity, but are instead mounted on top planar surface of the heat sink **194**. FIG. **15** shows the lamp **190** shown in FIG. **14** with a dome-shaped phosphor carrier **196** mounted over the light source **192** shown in FIG. **14**. The lamp **190** shown in FIG. **15** can be combined with the diffuser **198** as described above to form a lamp with dispersed light emission.

As discussed above, lamps according to the present invention can also comprise thermal dissipation features to allow the LEDs to operate at lower temperatures and optical elements to change the emission pattern of the LEDs chips into a desired emission pattern. In some embodiments that can comprise an substantially omni-directional emission pattern.

FIGS. **16** through **18** show another embodiment of a lamp **200** according to the present invention having a heat sink structure **202**, light source **204**, phosphor carrier **206** and a screw-threaded portion **208**, as described above. The phosphor carrier is three-dimensional and can include a thermally conductive transparent material and a layer of phosphor material as described above. It is also mounted to the heat sink structure **202**, suitably with a thermal connection. The light source **204** comprises a one or a plurality of LED chips mounted on the top surface of the heat sink structure **202**. It is understood that the lamps according to the present invention can also comprise other heat dissipation elements beyond a heat sink, such as heat pipes.

The lamp **200** also comprises a lateral spreading heat dissipation structure **210** below the LEDs to provide for improved thermal management of the heat generated by the LEDs. In conventional lamp arrangements the LEDs can be mounted on dielectric substrates (such as Al_2O_3), and heat from the LEDs can encounter the thermally resistant dielectric materials prior to having the opportunity to spread laterally. The different dissipation structures according to the present invention are arranged to laterally spread heat from the LEDs prior to the heat encountering the thermally resistant dielectric layer.

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FIG. 19 shows one embodiment of a heat dissipation structure 210 according to the present invention, comprising a relatively thick thermally conductive heat spreading substrate 212 and a dielectric layer 214 that are in thermal contact with the heat sink 202. One or more LED chips 216 can be mounted directly to the heat spreading substrate 212 with a thermally conductive material such as a solder 218. This results in a structure where there is no dielectric between the LED chip 216 and the heat spreading substrate 212. By spreading the heat of the LEDs 216 prior to the heat encountering the dielectric layer 214, the thermally resistant impact of the dielectric layer 214 is reduced, and heat more efficiently spreads from the LEDs 216. This arrangement provides enhanced thermal spreading in close proximity to the LED chip(s) and minimizes the total number of thermally impeding (e.g. dielectric) layers between the LED chip and the heat sink 202.

The heat spreading substrate 212 can comprise many different materials that are thermally conductive. In some embodiments the heat spreading substrate can comprise a metal such as copper, while in other embodiments the substrate 212 can comprise copper plated with gold. In still other embodiments the substrate 212 can comprise other thermally conductive materials, such as other metals. The substrate can be many different thicknesses with suitable thicknesses providing the thermal conductivity to efficiently and laterally spread heat from the LED(s) 216. In some embodiments, the thickness of the substrate 212 can be in the range of approximately 0.05 mm to 10 mm, while in other embodiments the thickness can be in the range of 0.5 mm to 2 mm.

As mentioned above, substrate 212 should be in close thermal contact with the LED(s) 216. In some embodiments, the LED(s) can be soldered to the heat spreading substrate 212 using conventional lead-free solders such as SnAgCu or AuSn. The dielectric layers according to the present invention should have suitable thermal conductivity and electrical breakdown resistance properties to allow heat to pass between the heat spreading substrate 212 and the heat sink 202 to allow efficient dissipation of heat into the surrounding ambient while still providing the desired electrical insulation. In some embodiments, the system comprises a single dielectric layer.

In some embodiments, the dielectric layer 214 can be bonded directly to the heat spreading substrate 212, while in other embodiments it can be bonded directly to the heat sink. FIG. 20 shows one embodiment of an LED (or LED chip) 216 bonded directly to the heat spreading substrate 212. Bonding the dielectric layer to the heat sink element allows for the additional advantage of extending the dielectric layer 214 beyond and surrounding the boundaries of the heat spreading substrate 212. This in turn minimizing electric breakdown pathways along the edge of the heat spreading substrate 212 at the boundary. This arrangement can comprise a simple and cost effective structure that provides an LED 216, solder 218, heat spreading substrate 212, dielectric layer 214 and heat sink 202 on one another in a "sandwich" design. The allows for significant lateral spreading of the heat generated by the LED 216 to the heat spreading substrate 212 prior to dielectric layers and thereby significantly decreasing the thermal resistance between the LED 216 and heat sink 202 or the ambient. This enables reduced LED operating temperatures at a given operating current, resulting in improved efficiency (efficacy) and reliability, while simplifying manufacturing assembly and reducing costs. This provides an improvement over current

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technology that typically requires multiple dielectric layers to provide electrical isolation between LED chips and heat sink.

Referring again to FIGS. 16 through 18, the lamp 200 can also comprise an optical element 220 that is arranged to guide light from a single or multiple LED chips into a desired output beam profile. The optical element can be made of material and can have a shape that allows for efficient change the emission profile with minimal light loss. In a preferred embodiment, the optical element can comprise many different clear optical materials such as acrylic, polycarbonate, silicone, glass, cyclo olefin polymers such as Zeonex® commercially available from Zeon Corporation, and commercially available Apel®, and Topas®. The optical element 220 can be arranged to at least partially change the emission pattern from the LED(s), to the desired lamp emission pattern. The optical elements can partially or fully change to the desired emission pattern. In those embodiments where the optical element 220 partially changes the emission pattern, the lamp can utilize a phosphor carrier and/or diffuser for the remainder of the pattern change.

It is understood that the optical element can have many different shapes and sizes depending on the LED light source emission pattern and the desired lamp emission pattern, and in many embodiments comprises a three-dimensional (i.e. non-planar) shape. Referring now to FIGS. 21 through 24, one embodiment of an optical element 220 comprises a curved conical or mushroom shape. The lower portion 222 can have a curved section 224 that is sized to fit over the lens of an LED chip with little or no air gap (best shown in FIG. 24). This helps direct and collimate the LED light so that it passes into the optical element 220. Due to the directional nature of light emission from conventional LEDs (e.g. Lambertian) it can be challenging to achieve omni-directional lamp emission from co-planar LED sources. Coplanar sources, however, can provide improved thermal management and simplified manufacturing compared to non-coplanar arrangements. The optical element 220 can be made of the materials listed above can utilize total internal reflection (TIR) to guide light from coplanar LEDs into a more omni-directional pattern. The desired output light beam pattern can be achieved while preserving the simplicity and performance of co-planar LED arrangements. The optical element can also provide for the uniform distribution of light into a remote phosphor or scattering layer enabling further improvements in efficiency as well as a high degree of color uniformity in the emitted light beam.

FIG. 25 shows the optical element 220 with light ray traces showing how the directional emission of an LED can be changed to more omni-directional. Light from the LED chips is coupled into optical element as described above, with a portion of the LED light being guided down the optical element by TIR in combination with refraction. This guided light can emit from the optical element 220 from side emission surface 226 to provide a portion of the broad beam pattern that can be exceed approximately 70 degrees or more. In other embodiments that emission pattern can exceed approximately 80 degrees or more, and in still other embodiments it can exceed 90 degrees or more. The side surface 226 can be at many different angles depending on the desired emission angle of light from the side surface 226. In the embodiments shown, the side surface 226 is angled slightly downward, but it is understood that the surface can be at other angles or vertical.

A portion of the LED light can also escape from the optical element's upper curved surface 228 (best shown in FIGS. 24 and 25) out its top surface toward the top of the

lamp to provide additional emission beyond that from the emission surface **226**. The amount of light that escapes can depend on different factors such as the curvature of the upper curved surface **228** and the material comprising the optical element **220**. This escaping light contributes to the overall lamp emission pattern, particularly in those embodiments emitting more omni-directional emission patterns. In the embodiment shown the optical element is directing light from four LEDs, but it is understood that other embodiments can utilize either a single LED or multiple LEDs with an optical element to disperse light from the LEDs into the desired beam pattern.

Referring again to FIGS. **16** through **18** and as mentioned above, the lamp **200** can also comprise remote phosphor carrier **206** that can have the feature and materials similar to those described above. In other embodiments, the lamp **200** can also comprise a diffuser, also as described above. By separating the phosphor material from the LEDs by arranging the phosphor in a remote phosphor carrier, improvements in light conversion efficiency and color uniformity can be obtained. For example, this arrangement allows for the use of a more disperse or dilute phosphor concentration, thereby reducing local heating of the phosphor particles, which reduces that impact that heat has on efficiency of the phosphor particles. The phosphor carrier **206** can comprise a thermally conductive material as described above to allow efficient flow of heat generated by the light conversion process from the phosphor material to the surrounding environment or to the heat sink **202**.

By shaping the phosphor carrier **206** into a three-dimensional dome-shape, and illuminating the phosphor carrier with, for example, blue light from the LEDs **216** via the optical element, it is possible to ensure nearly identical path lengths through the phosphor carrier **206** for each light ray emitted from the LED. The probability of light conversion by the phosphor material in phosphor carrier **206** is generally proportional to the path length of light through the phosphor material (assuming substantially uniform phosphor concentrations), uniform color emission can be achieved with the mixture of direct and downconverted LED light, over a broad range of beam angles.

Another advantage of the lamp arrangements according to the present invention having an optical element **220** and remotely located phosphor carrier **206** (or scattering layer) is that the arrangement serves to reduce the amount of light absorbed in the during operation of the lamp **200**, thereby increasing the over efficacy of the lamp **200**. In a typical LED lamp that incorporates one or more phosphors in combination with an LED, the phosphor is located in close proximity to the LED chip. Thus, a significant portion of the light that is emitted by or scattered by the phosphor is directed back towards the LED chip and/or other absorbing surfaces surrounding the chip. This can lead to light absorption and light loss at these surfaces. The lamps embodiments described herein can reduce this light loss in that light emitted or scattered by the remote phosphor carrier **206** (or diffuser) has reduced chance of being directed into the LED chip surface or adjacent absorbing regions due to the optical design of the optical element. In some embodiments, a low-loss scattering or reflective material can be placed on the interior surfaces of the lamp **200** (such as the surface of the dielectric layer or heat sink) to further limit the absorption of light emitted or scattered by the remote phosphor carrier.

The lamp **200** shown in FIG. **16** through **18** comprises a simple and inexpensive arrangement for achieving physical and thermal contact between the heat spreading substrate

212 and the heat sink **202**. The optical element **220** can comprise a central opening or hole **232** through which a fastener or clamping connector (such as a screw or clip) **234** can pass and be mounted to the heat sink **202**. This connector **234** can serve to “clamp” or press the optical element **220**, heat spreading substrate **212**, dielectric layer **214**, and heat sink **202** together. This serves to attach these portions of the lamp **200** together, as well as pressing the heat spreading substrate **212** to the heat sink **202** with a dielectric layer **214** between the two. This can eliminate the need for an adhesive or solder joint layer between these elements that can add expense, manufacturing complexity, and can inhibit heat flow between the LED chip **216** and the ambient.

Another advantage with this arrangement is that it allows for convenient “re-working” of the lamp during manufacturing by allowing for the easy removal of defective lamp components without the danger of damage to surrounding components. This feature can also provide for lifetime cost reduction in that failing components (such as the LED package assembly) could be removed and replaced without replacing the entire lamp assemble (heat sink, bulb enclosure, etc. which typically have very long lifetimes). Further, this component-based assembly could help reduce manufacturing costs since different color point lamps could be achieved simply by replacing the bulb enclosure/phosphor carrier, allowing for uniform manufacture of the remainder of the assembly across color points. As an added benefit, multiple bulb enclosures with different phosphor combinations could be provided to the customer to allow flexible in-service changing of the color/hue of the lamp by the customer.

It is understood that many different optical elements can be arranged in many different ways according to the present invention. They can have many different shapes, made of many different materials, and can have many different properties. FIGS. **26** through **29** show another embodiment of an optical element **250** according to the present invention that can utilize specular and/or scattering reflections to redirect the light from the LED sources into larger beam angles or preferred directions. Optical element **250** is generally flower shaped and is particularly applicable to redirecting light from co-planar solid state light sources such as co-planar LEDs. The optical element comprises a narrow bottom or stem section **252** that can be mounted to the co-planar light source. In the embodiment shown, the bottom section comprises a hollow tube section, but it is understood that it can comprise many different shapes and may not be hollow.

The optical element also comprises an upper reflective section **254** that spreads from bottom section **252** moving up the optical element. The upper section **254** comprises a series of reflective blades or petals **256** that are over the LEDs **258** (best shown in FIG. **28**) so that light from the LEDs **258** strikes the bottom surface of the blades **256** and is reflected. In the embodiment shown, the width of the blades **256** increase moving up the optical element **250** to reflect more LED light at the top, but it is understood that the in other embodiments the blades can have the same or decreasing width moving up the optical element. It is also understood that different ones of the blades can have different widths or can have widths increase or decrease in different ways moving up the optical element.

The reflection of LED light from the blades **256** helps disperse the light from the LEDs **258** to the desired emission pattern. The blades **256** can be angled or curved from the bottom section, and depending on the desired emission pattern, the blades can have different curves or angles. There

can be different curves or angles in different portions of the blades **256** and different ones of the blades can have different angles and curves. Referring now to FIG. **28**, a increased curvature blade **260** is shown, with the increased curvature causing reflection at higher beam angles. The light reflected from the high curvature blade **260** emits in more of a downward direction. This can result in an overall lamp emission with a portion of emission at higher beam angles that is particularly useful in embodiments where omnidirectional emission is desired (e.g. Energy Star® emission).

There can also be a space **262** between the blades **256** that allows light from the LEDs **258** to pass. The light passing the blades **256** can provide forward emitting light from the LEDs, which can also be useful in embodiments where omnidirectional emission is desired. Different embodiments can have different numbers and sizes of blades **256** and spaces **262** depending on the desired emission pattern. In some embodiments, the space **262** between the blades **256** can include a conversion or disperser material that can convert or disperse the LED light as it passes through the space.

Optical element **250** can provide certain advantages in that the dispersing element can be light-weight and fabricated inexpensively from tube or horn-shaped foils or reflective polymer elements. In other embodiments the optical element **250** can simply comprise reflective paper or plastic. Further, by relying on specular and/or scattering reflection, the size of the element may be reduced relative to elements utilizing TIR since TIR surfaces may only reflect the incident light up to a maximum angle determined primarily by the difference in index of refraction between the element and the surrounding ambient.

It is understood that the specular and/or scattering optical elements can have many different shapes and sizes and can be arranged in many different ways. In some embodiments, the spaces between the blades can comprise different shapes such as holes or slots, and the spaces can be in many different locations. It is also understood that the optical element can be mounted in lamps in many different ways beyond mounting to the light source. In some embodiments it can be mounted to a phosphor carrier or diffuser. Other optical element embodiments may include a combinations of TIR, specular reflection and scattering to achieve the desired beam dispersion.

As with the optical element **220** shown in FIGS. **21** to **25** and described above, the optical element **250** can be used in lamp also comprising a phosphor carrier **264** (best shown in FIG. **28**). The phosphor carrier **264** can have the same features as those described above and can be made of the same materials. The phosphor carrier **264** can have a dome-shape over the optical element **250** and LEDs **258** and comprise a conversion material, such as a phosphor, that converts at least a portion of the LED light passing through it. The phosphor carrier **264** can also disperse the light thereby smoothing out emission intensity variations to the blocked or reflected light from the optical element **250**. Other embodiments can also comprise a diffuser (not shown) over the phosphor carrier to further disperse the light into a desired emission pattern. The diffuser can have the same features and can be made of the same materials as the diffusers described above.

The LED arrays according to the present invention can be coupled together in many different serial and parallel combinations. In one embodiment, the red and blue LEDs can be interconnected in different groups that can comprise their own various series and parallel combinations. By having separate strings, the current applied to each can be controlled

to produce the desired lamp color temperature, such as 3000K. FIGS. **28** and **29**, show the performance characteristics for an LED array with 3 red and 5 blue (450 nm) LEDs.

Some LED lamps according to the present invention can have a correlated color temperature (CCT) from about 1200K to 3500K, with a color rendering index of 80 or more. Other lamp embodiments can emit light with a luminous intensity distribution that varies by not more than 10% from 0 to 150 degrees from the top of the lamp. In other embodiments, lamps can emit light with a luminous intensity distribution that varies by not more than 20% from 0 to 135 degrees. In some embodiments, at least 5% of the total flux from the lamps is in the 135-180 degree zone. Other embodiments can emit light having a luminous intensity distribution that varies by not more than 30% from 0 to 120 degrees. In some embodiments, the LED lamp has a color spatial uniformity of such that chromaticity with change in viewing angle varies by no more than 0.004 from a weighted average point. Other lamps can conform to the operational requirements for luminous efficacy, color spatial uniformity, light distribution, color rendering index, dimensions and base type for a 60-watt incandescent replacement bulb.

The lamps according to the present invention can emit light with a high color rendering index (CRI), such as or higher in some embodiments. In some other embodiments, the lamps can emit light with CRI of 90 or higher. The lamps can also produce light having a correlated color temperature (CCT) from 2500K to 3500K. In other embodiments, the light can have a CCT from 2700K to 3300K. In still other embodiments, the light can have a CCT from about 2725K to about 3045K. In some embodiments, the light can have a CCT of about 2700K or about 3000K. In still other embodiments, where the light is dimmable, the CCT may be reduced with dimming. In such a case, the CCT may be reduced to as low as 1500K or even 1200K. In some embodiments, the CCT can be increased with dimming. Depending on the embodiment, other output spectral characteristics can be changed based on dimming.

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.

We claim:

1. A solid state lamp, comprising:

at least one light emitting diode (LED) on a mount surface;

an optical element comprising an inner diameter, an outer diameter, and a curved portion shaped to fit over and at least partially surround said at least one LED, such that light from said at least one LED interacts with said optical element, said optical element shaped to define a hollow central opening, said optical element changing the emission pattern of said LED to a broader emission pattern;

said outer diameter varying with distance away from said mount surface in a perpendicular direction to define a curved conical side emission surface, said inner diameter defining said hollow central opening in said optical element;

a fastener passing through said central opening and fastening said optical element to said mount surface; and
a phosphor carrier over said optical element, said phosphor carrier converting at least some of said LED light to a different wavelength.

- 2. The lamp of claim 1, wherein said optical element comprises a substantially transparent material, light from said at least one LED guided by said optical element into a broader emission pattern.
- 3. The lamp of claim 2, wherein light from said at least one LED is guided in said optical element by total internal reflection. 5
- 4. The lamp of claim 2, wherein light from said at least one LED is guided in said optical element by refraction.
- 5. The lamp of claim 2, wherein a portion of light from said at least one LED is guided by said optical element to emit at an angle of 70 degrees or more to said at least one LED. 10
- 6. The lamp of claim 2, wherein a portion of light from said at least one LED is guided by said optical element to emit at an angle of 80 degrees or more to said at least one LED. 15
- 7. The lamp of claim 2, wherein a portion of light from said at least one LED is guided by said optical element to emit at an angle of 90 degrees or more to said at least one LED. 20
- 8. The lamp of claim 2, wherein a portion of light from said at least one LED passes out of said optical element.
- 9. The lamp of claim 2, wherein said optical element has a three-dimensional shape. 25
- 10. The lamp of claim 1, further comprising a heat spreading substrate to spread heat from said LED prior to encountering heat resistant materials.

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