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(54) **LIGHT-EMITTING DEVICE ARRAY WITH INDIVIDUAL CELLS**

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H01L 33/40 (2010.01)

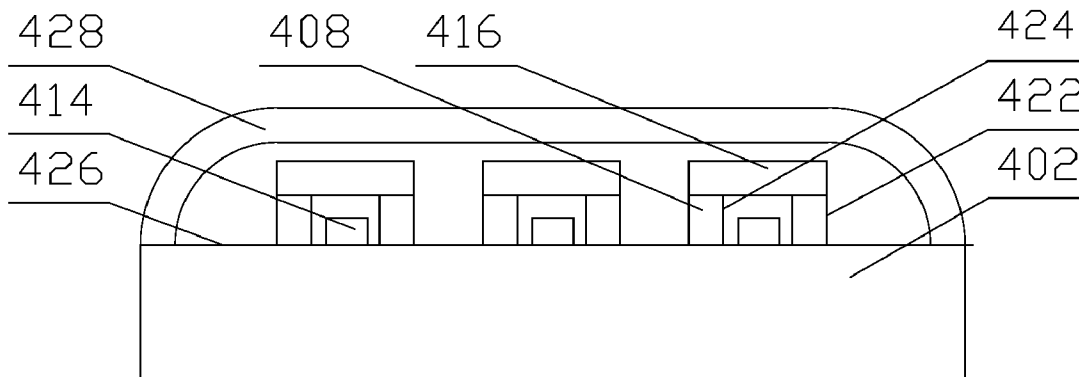
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See application file for complete search history.

(57) **ABSTRACT**
A light-emitting device and a method for manufacturing the light-emitting device is disclosed. Such a light-emitting device comprises a substrate, a plurality of cells disposed on the substrate, and a plurality of semiconductor dice, wherein each of the plurality of cells accommodates at least one of the plurality of dice. Each of the plurality of cells may be filled with an encapsulant, phosphor or a mixture of an encapsulant with phosphor to control light characteristics of the light-emitting device. In an alternative aspect, cells may be filled with an encapsulant, and comprise a transparent cover coated with or filled with phosphors to control light characteristics of the light-emitting device.

18 Claims, 7 Drawing Sheets



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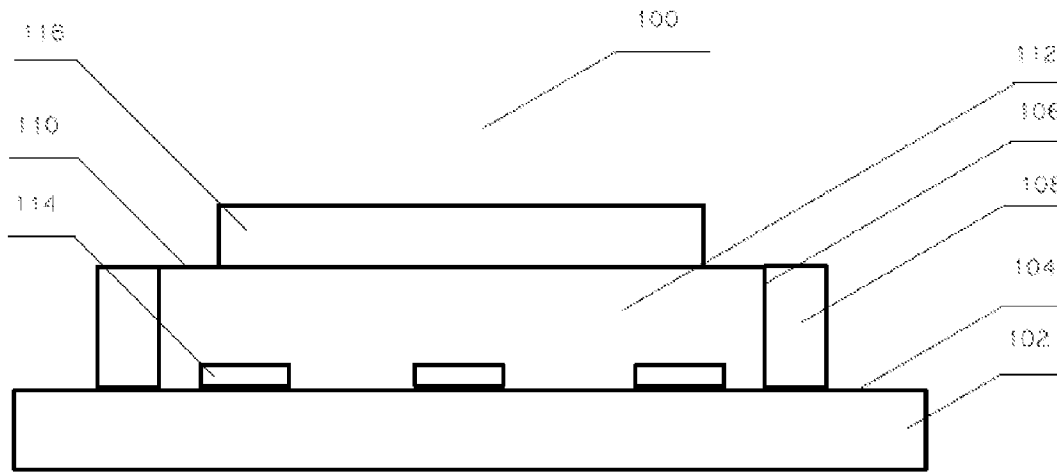


Fig. 1

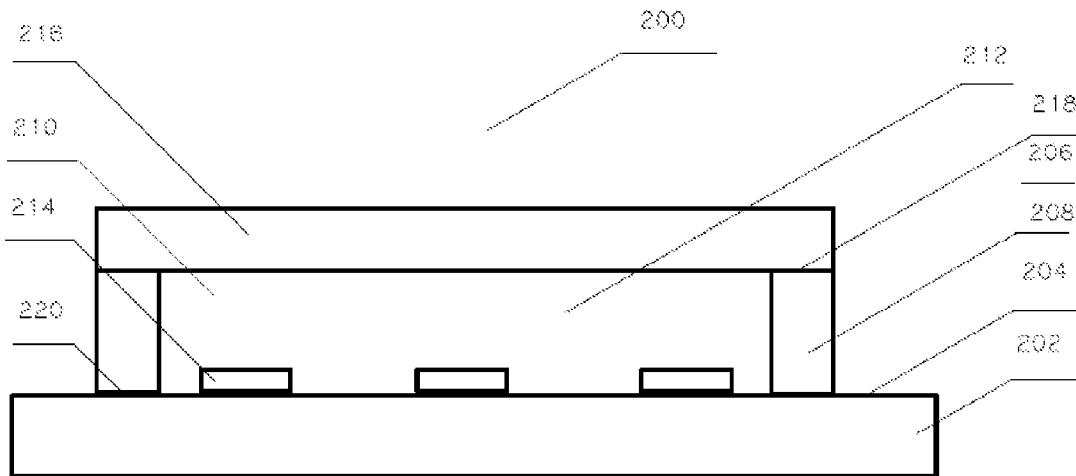


Fig. 2

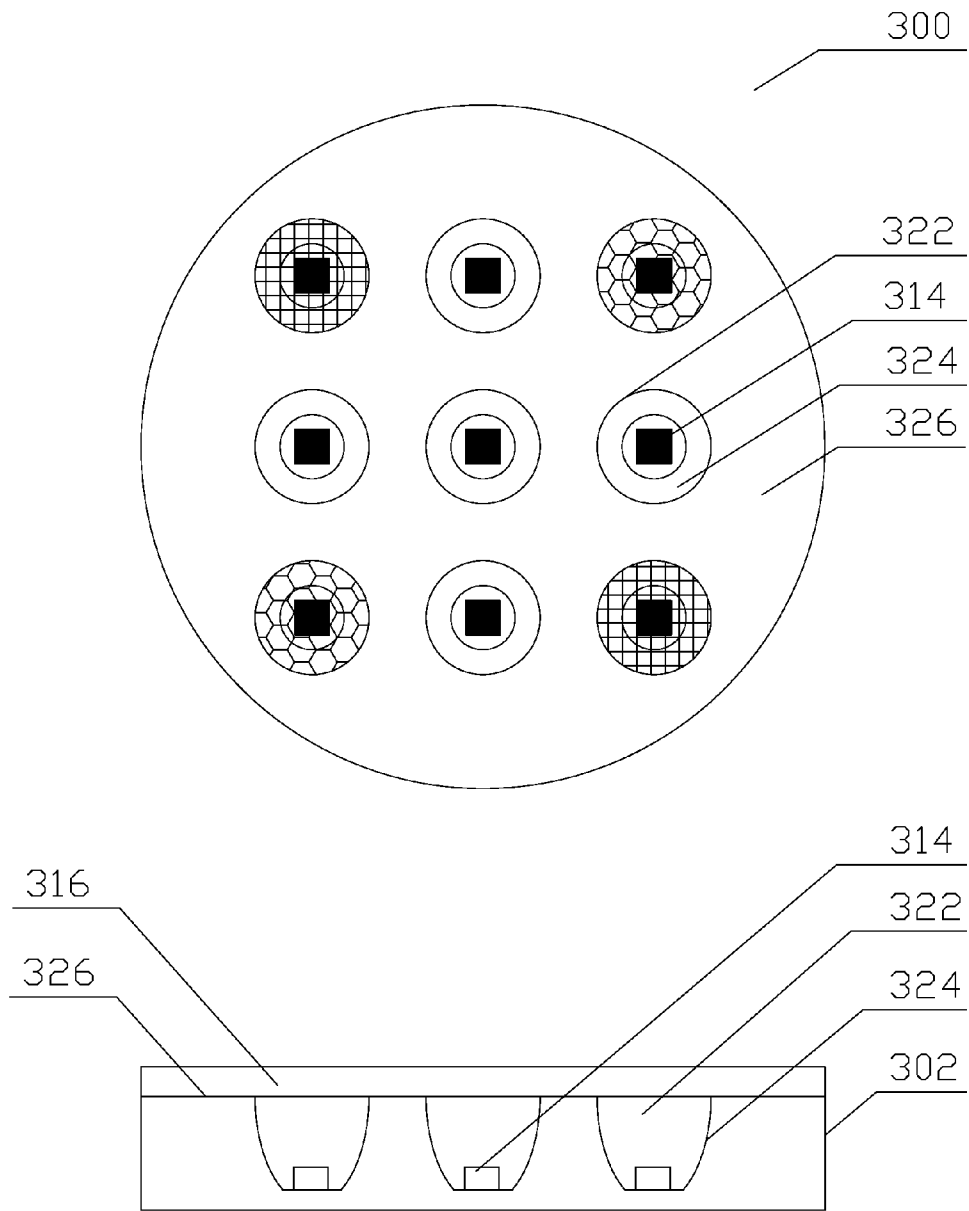


Fig. 3

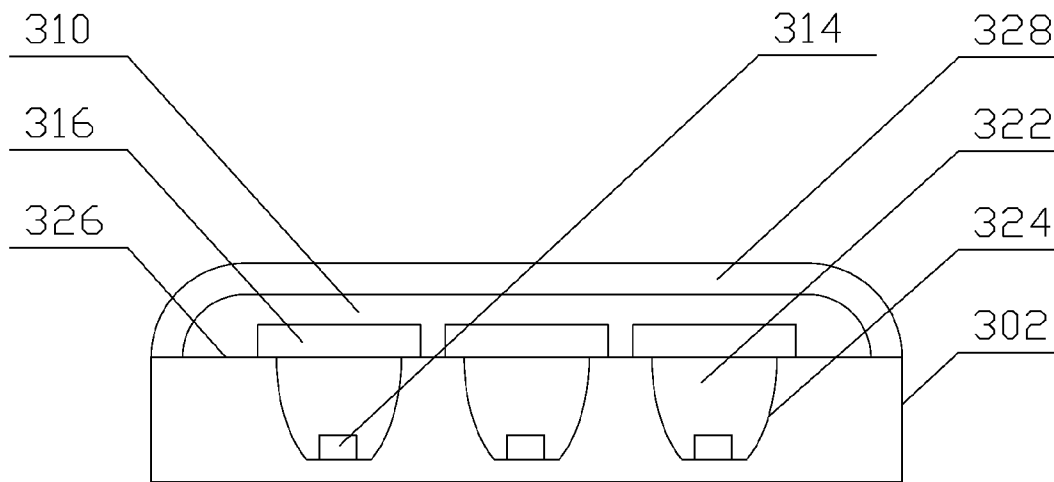


Fig. 3a

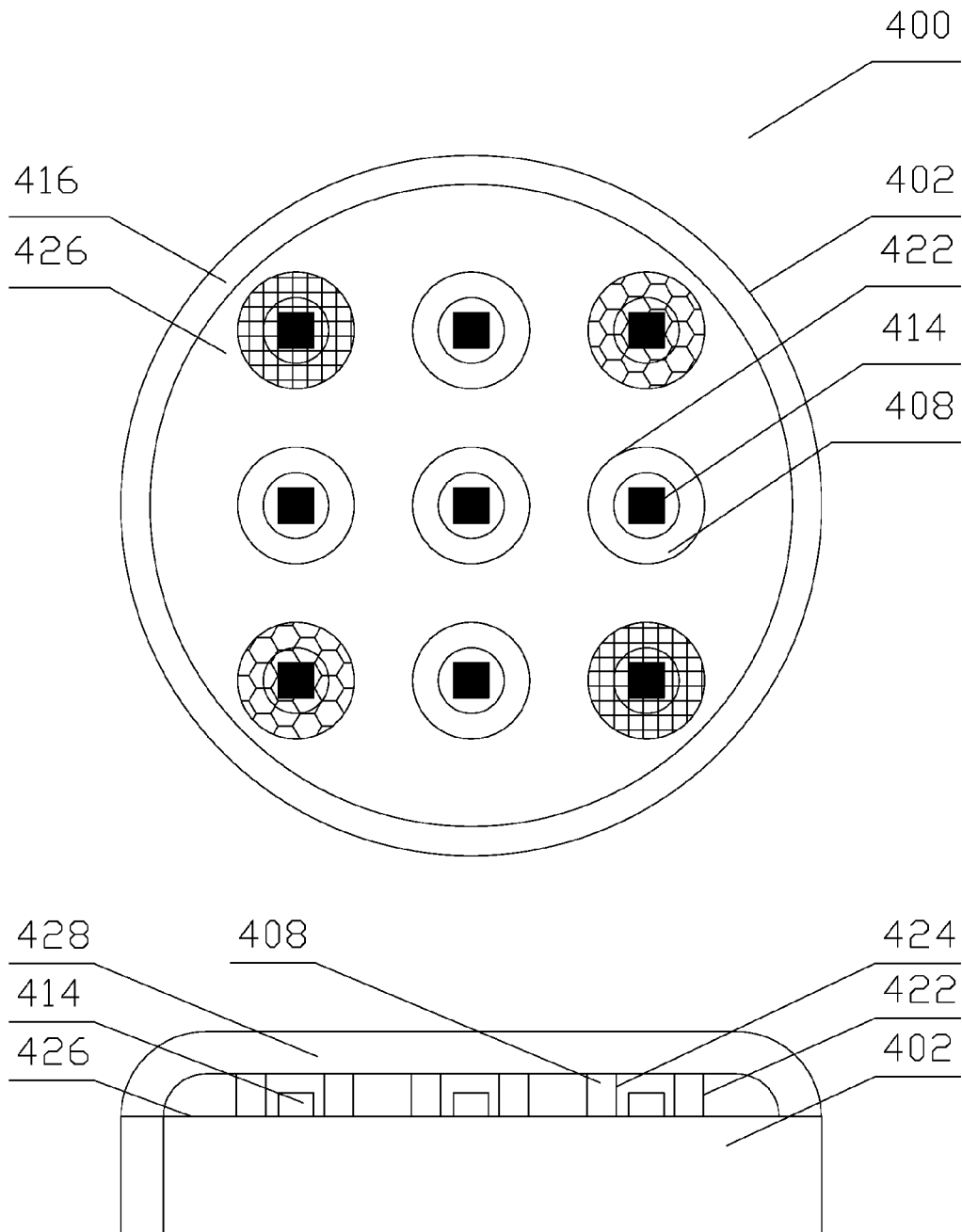


FIG. 4

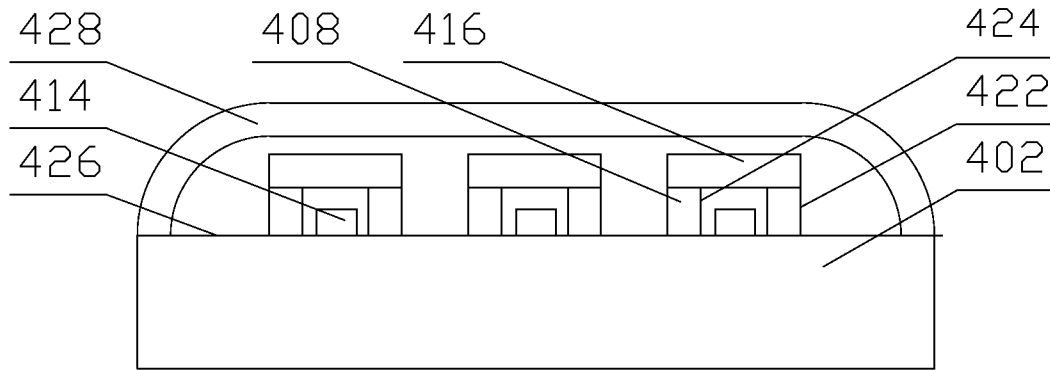


Fig. 4a

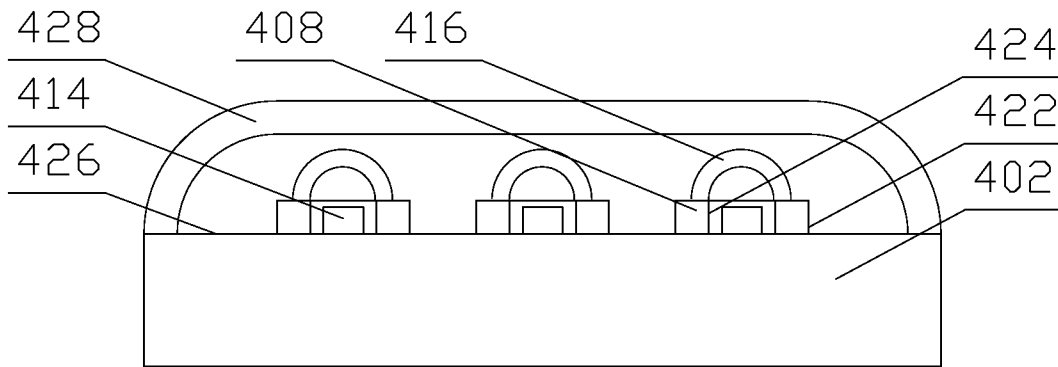


Fig. 4b

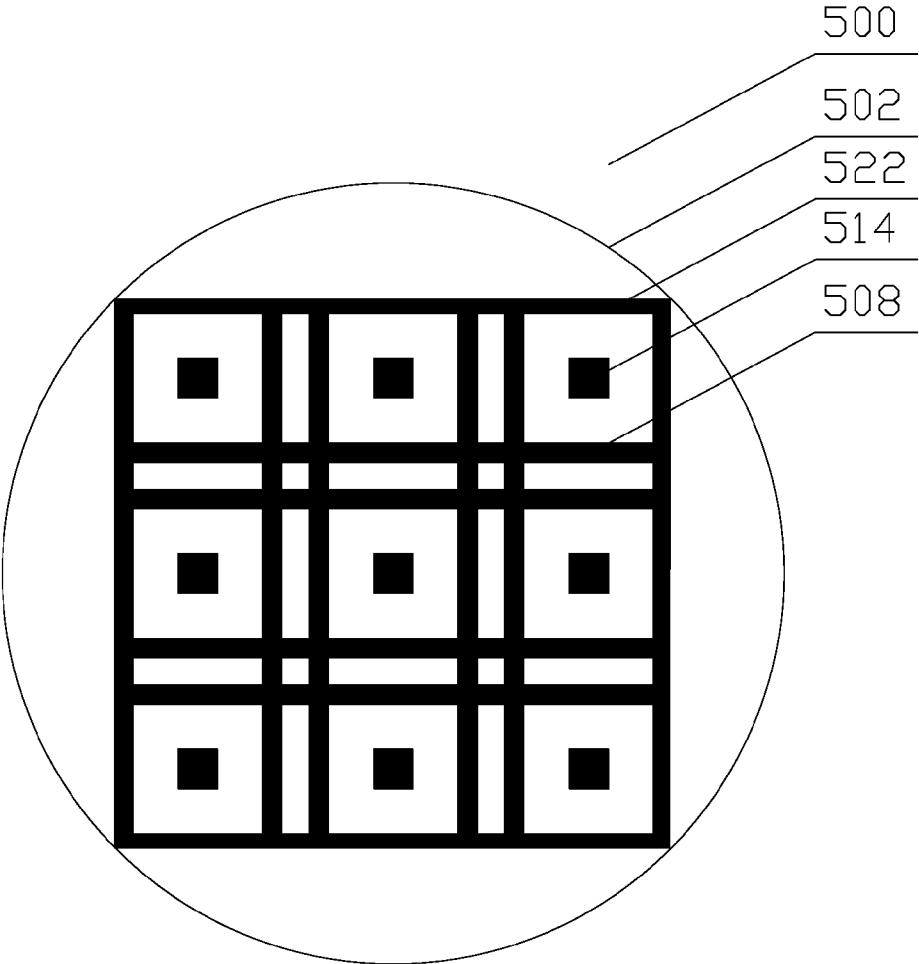


Fig. 5

LIGHT-EMITTING DEVICE ARRAY WITH INDIVIDUAL CELLS

BACKGROUND

1. Field

The present disclosure relates to a light-emitting device, and more particularly, to a method and an apparatus for light-emitting device arrays.

2. Description of Related Technology

A person skilled in the art will appreciate that the concepts disclosed herein are applicable to packages for semiconductor-based light-emitting device, namely a light-emitting diode (LED) device.

LEDs have been used for many years in various light requiring applications, e.g., signaling states for devices, i.e., light on or off, opto-couplers, displays, replacement of bulbs in flashlights, and other applications known in the art. Consequently, LEDs emitting both spectral colors and white light have been developed. There are two primary approaches to producing light with desired properties using LEDs. One is to use individual LED dice that emit the three primary colors—red, green, and blue, and then mix the colors to produce light with the desired properties. The other approach is to use a phosphor material to convert monochromatic light from a blue or ultra-violet color emitting LED die or dice to a light with the desired properties, much in the same way a fluorescent light bulb works. For the purposes of this disclosure a die has its common meaning of a light-emitting semiconductor chip comprising a p-n junction.

Due to LEDs' advantages, i.e., light weight, low energy consumption, good electrical power to light conversion efficiency, and the like, an increased interest has been recently focused on use of LEDs even for high light intensity application, e.g., replacement of conventional, i.e., incandescent and fluorescent light sources, traffic signals, signage, and other high light intensity applications known to a person skilled in the art. It is customary for the technical literature to use the term "high power LED" to imply high light intensity LED; consequently, such terminology is adopted in this disclosure, unless noted otherwise. To increase intensity of the light emitted by the light-emitting device, often more than one light-emitting die is arranged in a package; such a light-emitting device being termed a light-emitting device array. For the purposes of this disclosure, a package is a collection of components comprising the light-emitting device including but not being limited to: a substrate, a die or dice (if an array), phosphors, encapsulant, bonding material(s), light collecting means, and the like. A person skilled in the art will appreciate that some of the components are optional.

A conceptual structure of an exemplary light-emitting device array **100** in accordance with known concepts is depicted in FIG. **1a**. A substantially flat substrate **102** in addition to being a mechanical support for the electrical and optical layers of the light-emitting device is often used as means for heat dissipation from the light-emitting device array. The electrical and optical layers comprise all the components of the package, excluding the substrate **102**. When used as means for heat dissipation, the substrate **102** is made from a material with high thermal conductivity. Such material may comprise metals, e.g., Al, Cu, Si-based materials, ceramics such as AlN, or any other material whose thermal conductivity is appropriate for the light-emitting device array in question. A person skilled in the art will appreciate that material appropriate for a light-emitting device array with power dissipation of, e.g., 35 milliwatts (mW) is different than material appropriate for a light-emitting device array with power

dissipation of, e.g., 350 mW. A material is considered to be substantially flat if the irregularities in flatness would not cause light to be reflected by such irregularities.

The source of light comprises a plurality of dice **114** (three dice shown), disposed on an upper face **104** of the substrate **102**. A person skilled in the art will appreciate that the number of dice is a design decision, and different number of dice can be used to satisfy design goals.

To improve light extraction from the light-emitting device array **100**, several measures are taken. First, surfaces that are transparent to photons emitted at a particular wavelength or that have poor reflectivity of such photons in an undesirable direction of emission may be treated, e.g., by polishing, buffing, or any other process, to acquire a specific reflectivity. Reflectivity is characterized by a ratio of reflected to incident light. Such surfaces are an upper face **104** of the substrate **102** and inner wall **106** of a support member **108**. The support member **108** provides boundary for an encapsulant **110** and reflects light emitted by the dice **114** into desirable direction. Alternatively, the desired reflectivity is achieved by applying a layer of a material with high reflectivity, such as Ag, Pt, and any like materials known to a person skilled in the art, (not shown in FIG. **1**) onto such surfaces.

Furthermore, to prevent reflection of the emitted photons from boundaries between materials characterized by different refraction indexes, and, consequently, loss of light intensity, an encapsulant **110** is applied into a cavity **112**, surrounding the light-emitting region, i.e., the cavity created by the substrate **102**, the support member **108**, and the dice **114**. The material for the encapsulant **110** is selected to moderate the differences between the refraction indexes of the materials from which components creating the reflective boundaries are made. In one aspect of the disclosure the encapsulant **110** is transparent; however, the disclosed concepts apply equally to encapsulant **110** comprising fillers, e.g., phosphors used for light conversion as described above.

Additionally, light-emitting device array package may further comprise a cover **116** disposed above the dice **114**. Such a transparent cover comprises e.g., a window or a lens. In order to prevent delamination of the encapsulant **110** from the surface of the cover **116** and/or the inner wall of the support member **108** and/or the dice **114** and/or the substrate **102**, the cover **116** is allowed to float freely on the encapsulant **110**, without being rigidly anchored onto the support member **108** with an adhesive or another fastening means. Such a configuration prevents significant residual stress, caused by temperature variation as the light-emitting device array **100** heats and cools during the device's lifetime, to develop within the encapsulant **110**. Because any delamination would introduce voids in the encapsulant, the resulting internal reflection optical losses caused by the above-described difference between materials characterized by different refraction indexes would cause loss of light intensity.

Although the configuration depicted in FIG. **1** may be suitable for LED packages comprising a clear cover, it is not particularly suitable for LED package comprising a window or lens coated with or filled with phosphors; such a cover being often used for light conversion. An advantage of such a configuration is that the window or lens coated with or filled with phosphors can be matched appropriately with a LED dice of known wavelength to achieve a more precisely controlled color corrected temperature (CCT). Different windows or lenses may have different phosphor coatings or fillings, and these matched with LED dice of optimal wavelength to achieve target CCT as needed.

However, a problem with this configuration arises from the fact that the temperature of the phosphor coated or filled cover

increases significantly during operation of the light-emitting device array because the conversion inefficiency of the phosphors results in generating significant heat. The increase in the temperature in turn results in decreased efficiency of the light-emitting device array due to decrease in light-conversion efficiency of the phosphors and decrease of efficiency of the die.

The above-described problem may be solved by a configuration according to FIG. 2, which depicts a conceptual cross section of another exemplary light-emitting device array **200** in accordance with known concepts. The description of like elements between FIG. 1 and FIG. 2 is not repeated, the like elements have reference numerals differing by 100, i.e., reference numeral **102** of FIG. 1 becomes reference numeral **202** in FIG. 2.

Referring to FIG. 2, the main conceptual difference from FIG. 1 is that a cover **216** coated with or filled with phosphors is attached to the upper face **218** of the thermally conductive support member **208**. The bottom face **220** of the support member **208** is attached to a thermally conductive substrate **202**. Thus, in this aspect, the support member further serves as supporting means for the cover **216**. The cover **216**, the support member **208**, and the substrate **202** should be attached to one another using any thermally conductive means (not shown in FIG. 2) to maximize heat transfer between these components. By the means of example, such a thermally conductive means may comprise material such as metal filled epoxy, eutectic alloy, and any other thermally conductive means known to a person skilled in the art. Furthermore, it is desirable that the cover **216** is also made from a thermally conductive material. Such a configuration allows heat to flow from the phosphors through the window or the lens **216** and then through the support member **208** to the substrate **202**.

Since additional heat from the cover **216** is now transferred to the substrate **202**, proper heat dissipation from the LED package **200** must be assured to prevent loss of efficiency due to increased temperature of the dice **114**. Such heat dissipation may be achieved by proper design of the above-described components of the LED package **114**. In addition, the LED package **200** may further be attached to a suitable heat sink (not shown).

In any of the above-described configurations, the LED package **200** can operate without the phosphors or the LED dice over-heating beyond temperature that would significantly decrease the efficiency of the LED dice and the phosphors. A person skilled in the art will appreciate that the term significant describes a decrease in efficiency that would cause the light-emitting device array performance fail to meet typical or minimum specification over the product life of the light-emitting device array.

The above-described structures of a light-emitting device array suffer from several shortcomings. The light-emitting device design goal determines geometry of the light-emitting device package, which in turn determines the required quantity of phosphor. Thus, any decrease in the quantity of phosphor would improve economics of production. Additionally, the geometry of the package determines a contact area between the phosphor and the substrate, which is subject to a chemical reaction between the phosphor and substrate, resulting in, e.g., tarnishing, discoloration, and the like, of the substrate. Thus, any decrease of the contact area would decrease such undesirable effect, thus improving reliability. Furthermore, the light efficiency is limited by a light cross-talk, i.e., a condition when a light emitted by one of the plurality of dice is absorbed by one or more other dice of the plurality of dice.

Accordingly, there is a need in the art for a light-emitting device array providing solution to the above identified problems, as well as additional advantages evident to a person skilled in the art.

SUMMARY

In one aspect of the disclosure, a light-emitting device array with individual cells according to appended independent claims is disclosed. Additional aspects are disclosed in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects described herein will become more readily apparent by reference to the following description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 depicts a conceptual structure of an exemplary light-emitting device array in accordance with known concepts;

FIG. 2 depicts a conceptual structure of another exemplary light-emitting device in accordance with known concepts;

FIG. 3 depicts a conceptual structure of an exemplary light-emitting device array in accordance with an aspect of this disclosure;

FIG. 4 depicts a conceptual structure of an exemplary light-emitting device array in accordance with another aspect of this disclosure; and

FIG. 5 depicts a conceptual structure of an exemplary light-emitting device array in accordance with yet another aspect of this disclosure.

DETAILED DESCRIPTION

Various aspects of the present invention will be described herein with reference to drawings that are schematic illustrations of idealized configurations of the present invention. As such, variations from the shapes of the illustrations as a result, for example, manufacturing techniques and/or tolerances, are to be expected. Thus, the various aspects of the present invention presented throughout this disclosure should not be construed as limited to the particular shapes of elements (e.g., regions, layers, sections, substrates, etc.) illustrated and described herein but are to include deviations in shapes that result, for example, from manufacturing. By way of example, an element illustrated or described as a rectangle may have rounded or curved features and/or a gradient concentration at its edges rather than a discrete change from one element to another. Thus, the elements illustrated in the drawings are schematic in nature and their shapes are not intended to illustrate the precise shape of an element and are not intended to limit the scope of the present invention.

It will be understood that when an element such as a region, layer, section, substrate, or the like, is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present. It will be further understood that when an element is referred to as being "formed" on another element, it can be grown, deposited, etched, attached, connected, coupled, or otherwise prepared or fabricated on the other element or an intervening element.

Furthermore, relative terms, such as "lower" or "bottom" and "upper" or "top," may be used herein to describe one element's relationship to another element as illustrated in the

drawings. It will be understood that relative terms are intended to encompass different orientations of an apparatus in addition to the orientation depicted in the drawings. By way of example, if an apparatus in the drawings is turned over, elements disclosed as being on the “lower” side of other elements would then be oriented on the “upper” side of the other elements. The term “lower” can therefore encompass both an orientation of “lower” and “upper,” depending of the particular orientation of the apparatus. Similarly, if an apparatus in the drawing is turned over, elements described as “below” or “beneath” other elements would then be oriented “above” the other elements. The terms “below” or “beneath” can therefore encompass both an orientation of above and below.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and this disclosure.

As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprise,” “comprises,” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The term “and/or” includes any and all combinations of one or more of the associated listed items.

Various disclosed aspects may be illustrated with reference to one or more exemplary configurations. As used herein, the term “exemplary” means “serving as an example, instance, or illustration,” and should not necessarily be construed as preferred or advantageous over other configurations disclosed herein.

Furthermore, various descriptive terms used herein, such as “on” and “transparent,” should be given the broadest meaning possible within the context of the present disclosure. For example, when a layer is said to be “on” another layer, it should be understood that that one layer may be deposited, etched, attached, or otherwise prepared or fabricated directly or indirectly above or below that other layer. In addition, something that is described as being “transparent” should be understood as having a property allowing no significant obstruction or absorption of electromagnetic radiation in the particular wavelength (or wavelengths) of interest, unless a particular transmittance is provided.

FIG. 3 depicts a conceptual structure (top and cross-section view) of an exemplary light-emitting device array 300 in accordance with an aspect of this disclosure. A plurality of cells 322 is formed in the substrate 302, each of the plurality of cells 322 accommodating at least one of plurality of dice 314. By proper design of the shape and dimensions of the plurality of cells 322, characteristics of the light emitted from the plurality of cells 322 can be controlled to eliminate or minimize the cross-talk among the plurality of dice 314.

A person skilled in the art will appreciate that additional design criteria may affect the dimensions and shape of each of the plurality of cells 322. By means of an example, a surface 324 defining a cell 322 may be shaped as a reflector to improve light extraction by focusing light emitted by a die 314 into a desired direction. Additionally, or alternatively, the surface 324 defining the cell 322 may be shaped and dimen-

sioned to minimize volume of the cells’ 322 cavity in order to minimize an amount of encapsulant, phosphor, and/or encapsulant mixed with phosphor needed to fill the cavity.

Although the surfaces 324 defining the plurality of cells 322 are shown with an identical shape and dimensions; this is for purposes of explanation of the concepts only; in different implementations, the surfaces 324 may have a different shape and/or dimensions for each of the plurality of cells 322.

To improve light extraction from the light-emitting device array 300, the surfaces 324 of the plurality of cells 322 may be treated to acquire a specific reflectivity. In one aspect, such a treatment may comprise, e.g., polishing, buffing, or any other process known to a person skilled in the art.

In an alternative aspect, the desired reflectivity may be achieved by applying a layer of reflective material on the surfaces 324 of the plurality of cells 322. To maximize luminous efficiency, material with high reflectivity, e.g., noble metals like Au, Ag, Pt, or other materials like Al, may be used for this purpose. Reflective layers employing such materials possess predominantly specular reflectivity, unless specific technological process designed to increase diffusive reflectivity is followed.

In yet another aspect, further improvement in luminous efficiency as well as in spatial light distribution may be obtained by employing reflective surfaces possessing diffusive reflectivity. Consequently, in an alternative, the reflective layer comprises a material with high diffusive reflectivity.

Although most surfaces poses a mixture of diffuse and specular reflective properties, a person skilled in the art will appreciate that the terms specular and diffuse refer to predominant mode of reflection. Thus, as disclosed above, polished or buffed metallic objects and/or layers of metallic material possess specular reflectivity; matte surfaces, usually achieved by surface roughness, possess diffuse reflectivity.

Furthermore, the upper surface 326 of the substrate 302 between the plurality of cells 322 may be treated in an identical or a similar manner in accordance with design criteria. Thus, by means of an example, the surfaces 324 of the plurality of cells 322 may be treated by polishing and/or buffing, while diffusive reflective layer may be applied on the upper surface 326 of the substrate 302.

The isolation between the plurality of cells 322 allows further control of characteristics of the light emitted by the light-emitting device 300 by enabling control of characteristics of light emitted from each individual cell 322 by an appropriate selection of a die 314, an encapsulant, phosphor and/or an encapsulant mixed with phosphor disposed into the cavity of each individual cell 322. The combination of dice, encapsulant, phosphor and/or an encapsulant mixed with phosphor for each cell in the light-emitting device 300 is a criterion criteria based on design goals. Thus, by means of an example, FIG. 3 depicts two corner cells 322, e.g., the cross-hatched cells, mixed with phosphor or an encapsulant mixed with phosphor of first color; two corner cells 322, e.g., the honeycomb-hatched cells, mixed with phosphor or an encapsulant mixed with phosphor of second color, and four cells filled with an encapsulant.

The light-emitting device array 300 may further comprise a clear transparent cover 316 used for protection of the light-emitting device array 300 from environmental conditions. The term “clear” used herein means a transparent cover without any coat or fill of phosphor(s). Such a clear transparent cover 316 comprises e.g., a window or a lens.

Alternatively, to further control characteristics of the light, the cover 316 may be coated with or filled with phosphors.

The specific configuration and placement of the transparent cover 316 is a criterion based on design goals. By means

of an exemplary configuration, the transparent cover **316** may be disposed directly on, as shown in FIG. **3**, or above the upper surface **326** of the substrate **302**.

FIG. **3a** depicts a cross-section view of an alternative aspect of controlling characteristics of the light emitted by the light-emitting device **300** by controlling characteristics of the light emitted from each individual cell **322**. As depicted in FIG. **3a**, the transparent cover comprises a plurality of transparent covers **316**, each of the plurality of transparent covers **316** being disposed over one the plurality of cells **322** and being coated or filled with phosphor. Thus, the characteristics of light emitted from each individual cell **322** is controlled by an appropriate selection of the die **314** disposed in each cell **322** and phosphor used to coat or fill the transparent cover **316** disposed over each cell **322**. To prevent reflection of emitted photons from boundaries between materials characterized by different refraction indexes encapsulant may be applied into the cells' **322** cavities.

An additional clear transparent cover **328** may be disposed on or above, as shown in FIG. **3a**, the plurality of transparent covers **316** to protect the light-emitting device array **300** from environmental conditions. Alternatively, to further control characteristics of the light the cover **328** may be coated with or filled with phosphors. To prevent reflection of emitted photons from boundaries between materials characterized by different refraction indexes encapsulant may be applied into the cavity delimited by the substrate **302**, the plurality of covers **316**, and the cover **328**.

A person skilled in the art will understand that the aspects disclosed in FIG. **3** and FIG. **3a** regarding controlling characteristics of the light emitted from each individual cell may be combined in accordance with design goals for the light-emitting device array. Consequently, the characteristics of light emitted from each individual cell **322** may be controlled by an appropriate selection of the die **314** disposed in each cell **322**; the filling material disposed into the cavity of each individual cell **322**; and the transparent cover(s) **316** and/or **328**. The selection of die **314** comprises selection of die with appropriate light characteristics; the filling material may comprise no filling material, an encapsulant, phosphor, and/or an encapsulant mixed with phosphor; and the transparent cover(s) **316** and/or **328** comprise any combination of clear and phosphor coated or filled cover, configured as a window or a lens.

FIG. **4** depicts a conceptual structure (top and cross-section view) of an exemplary light-emitting device array package **400** in accordance with another aspect of this disclosure. A plurality of cells **422** is formed on the substrate **402**, each of the plurality of cells **422** accommodating at least one of plurality of dice **414**. The plurality of cells **422** is comprised of a plurality of support members **408**. By proper design of the dimensions and shape of each of the plurality of support members **408**, the characteristics of the light emitted from the plurality of cells **422** can be controlled to eliminate or minimize the cross-talk among the plurality of dice **414**.

A person skilled in the art will appreciate that additional design criteria may affect the dimensions and shape of each of the plurality of support members **408**. Thus, by means of an example, in the cross-section drawings of FIG. **4**-FIG. **4b**, a surface **424** of the support member **408**, defining a cell **422** is cylindrical-shaped. However, other exemplary shapes, e.g., as described in reference to FIG. **3** are within the scope of this aspect. Although the surfaces **424** defining the plurality of cells **422** are shown with an identical shape and dimensions; this is for purposes of explanation of the concepts only; in

different implementations, the surfaces **424** may have a different shape and/or dimensions for each of the plurality of cells **422**.

To improve light extraction from the light-emitting device array **400**, the surfaces **424** of the plurality of cells **422** may be treated to acquire a specific reflectivity. In one aspect, such a treatment may comprise, e.g., polishing, buffing, or any other process known to a person skilled in the art.

In an alternative aspect, the desired reflectivity may be achieved by applying a layer of reflective material on the surfaces **424** of the plurality of cells **422**. To maximize luminous efficiency, material with high reflectivity, e.g., noble metals like Au, Ag, Pt, or other materials like Al, may be used for this purpose. Reflective layers employing such materials possess predominantly specular reflectivity, unless specific technological process designed to increase diffusive reflectivity is followed.

In yet another aspect, further improvement in luminous efficiency as well as in spatial light distribution may be obtained by employing reflective surfaces possessing diffusive reflectivity. Consequently, in an alternative, the reflective layer comprises a material with high diffusive reflectivity applied.

Although most surfaces poses a mixture of diffuse and specular reflective properties, a person skilled in the art will appreciate that the terms specular and diffuse refer to predominant mode of reflection. Thus, as disclosed above, polished or buffed metallic objects and/or layers of metallic material possess specular reflectivity; matte surfaces, usually achieved by surface roughness, possess diffusive reflectivity.

Furthermore, the upper surface **426** of the substrate **402** between the plurality of cells **422** may be treated in an identical or similar manner in accordance with design criteria. Thus, by means of an example, the surfaces **324** of the plurality of cells **322** may be treated by polishing and/or buffing, while diffusive reflective layer may be applied on the upper surface **326** of the substrate **302**.

The light-emitting device array **400** further comprises a transparent cover **428**. As depicted in FIG. **4**, the transparent cover **428** is disposed directly on the upper face of the support members **408**, thus delimiting, together with the substrate **402** and the plurality of support members **408**, the cells' **422** cavity. The physical isolation between the plurality of cells **422** allows further control of characteristics of the light emitted by the light-emitting device **400** by enabling control of characteristics of light emitted from each individual cell **422** by an appropriate selection of a die **414**, an encapsulant, phosphor and/or an encapsulant mixed with phosphor disposed into the cavity of each individual cell **422**. The combination of dice, encapsulant, phosphor and/or an encapsulant mixed with phosphor for each cell in the light-emitting device **400** is a criterion based on design goals. Thus, by means of an example, FIG. **4** depicts two corner cells **422** filled with phosphor or an encapsulant mixed with phosphor of first color, e.g., the cross-hatched cells; two cells filled with phosphor or an encapsulant mixed with phosphor of second color, e.g., the honeycomb-hatched cells, and four cells filled with an encapsulant.

The transparent cover **428** may be clear if the cover's primary purpose is an environmental protection; alternatively, to further control characteristics of the light the cover **416** may be coated with or filled with phosphors.

FIG. **4a** depicts a cross-section view of an alternative aspect of controlling characteristics of the light emitted by the light-emitting device **400** by controlling characteristics of the light emitted from each individual cell **422**. Like in FIG. **4**, the plurality of cells **422** is comprised of a plurality of support

members **408**. In contrast from FIG. **4**, the transparent cover comprises a plurality of transparent covers **416** in a form of a window, each of the plurality of transparent covers **416** being disposed over one the plurality of cells **422** and being coated or filled with phosphor.

Thus, the characteristics of light emitted from each individual cell **422** is controlled by an appropriate selection of the die **414** disposed in each cell **422** and phosphor used to coat or fill the transparent cover **416** disposed over each cell **422**. To prevent reflection of emitted photons from boundaries between materials characterized by different refraction indexes, the cells' **422**, cavity delimited by the substrate **402**, the support member **408**, and the plurality of covers **416** may be filled with encapsulant.

An additional clear transparent cover **428** may be disposed on or above, as shown in FIG. **4a**, the plurality of transparent covers **416** to protect the light-emitting device array **400** from environmental conditions. Alternatively, to further control characteristics of the light the cover **428** may be coated with or filled with phosphors. To prevent reflection of emitted photons from boundaries between materials characterized by different refraction indexes encapsulant may be applied into the cavity delimited by the substrate **402**, the plurality of covers **416**, and the cover **428**.

FIG. **4b** depicts a cross-section view of yet an alternative aspect of controlling characteristics of the light emitted by the light-emitting device **400** by controlling characteristics of the light emitted from each individual cell **422**. The difference from FIG. **4a**, is that each of the plurality of transparent covers **416** comprise a lens to focus light emitted each of the cell's **422** into an appropriate direction.

A person skilled in the art will understand that the aspects disclosed in FIG. **4**-FIG. **4b** regarding controlling characteristics of the light emitted from each individual cell may be combined in accordance with design goals for the light-emitting device array. Consequently, the characteristics of light emitted from each individual cell **422** may be controlled by an appropriate selection of the die **414** disposed in each cell **422**; the filling material disposed into the cavity of each individual cell **422**; and the transparent cover(s) **416** and/or **428**. The selection of die **414** comprises selection of die with appropriate light characteristics; the filling material may comprise no filling material, an encapsulant, phosphor, and/or an encapsulant mixed with phosphor; and the transparent cover(s) **316** and/or **328** comprise any combination of clear and phosphor coated or filled, window or a lens.

A person skilled in the art will appreciate, that the plurality of cells may be constructed by many different technologies. In addition to the exemplary constructions disclosed in FIG. **3** and FIG. **4**, the plurality of cells **522** may be constructed by dispensed material as a grid defining support members **508** on the substrate **502**, using any of the dispensing techniques known to a person skilled in the art, as depicted in FIG. **5**. Because FIG. **5** differs from FIG. **3** and/or FIG. **4** mainly by the technology of construction of the plurality of cells, all the concepts regarding control of characteristics of the light emitted by the light-emitting device by enabling control of characteristics of light emitted from each individual cell apply equally.

The various aspects of this disclosure are provided to enable one of ordinary skill in the art to practice the present invention. Modifications to various aspects of a presented throughout this disclosure will be readily apparent to those skilled in the art, and the concepts disclosed herein may be extended to other applications. Thus, the claims are not intended to be limited to the various aspects of the reflective surfaces for a light-emitting device array presented through-

out this disclosure, but are to be accorded the full scope consistent with the language of the claims. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

What is claimed is:

1. A light-emitting apparatus, comprising:

a substantially flat substrate;

a plurality of cells, shaped and dimensioned to eliminate cross-talk, disposed on the substantially flat substrate;

a plurality of light emitting diodes (LEDs), wherein each of the plurality of cells accommodates at least one of the plurality of LEDs;

a plurality of transparent covers, wherein each cover is in direct contact with a corresponding one of the plurality of cells, wherein the plurality of transparent covers comprises first, second, and third transparent covers, and wherein the second transparent cover is horizontally adjacent to the first transparent cover and the third transparent cover is vertically adjacent to the first transparent cover; and

only a single transparent cover disposed over at least the first, second, and third transparent covers.

2. The apparatus according to claim 1, wherein an encapsulant is disposed into each of the plurality of cells.

3. The apparatus according to claim 1, wherein phosphor is disposed into at least one of the plurality of cells.

4. The apparatus according to claim 1, wherein an encapsulant filled with phosphor is disposed into at least one of the plurality of cells.

5. The apparatus according to claim 4, wherein an encapsulant is disposed into each of the plurality of cells not containing the encapsulant filled with phosphor.

6. The apparatus according to claim 4, wherein at least two of the plurality of cells contain the encapsulant, wherein the encapsulant is filled with phosphor of a different color in each cell of the at least two cells.

7. The apparatus according to claim 1, further comprising an encapsulant disposed into each of the plurality of cells.

8. A method for manufacturing a light-emitting device, comprising:

manufacturing a substantially flat substrate;

disposing a plurality of cells, shaped and dimensioned to eliminate crosstalk, on the substantially flat substrate;

disposing a plurality of light emitting diodes (LEDs) into the plurality of cells, wherein each of the plurality of cells accommodates at least one of the plurality of LEDs;

disposing a plurality of transparent covers over the plurality of cells such that each cover is in direct contact with a corresponding one of the plurality of cells, wherein the plurality of transparent covers comprises first, second, and third transparent covers, and wherein the second transparent cover is horizontally adjacent to the first transparent cover and the third transparent cover is vertically adjacent to the first transparent cover; and

disposing only a single transparent cover over at least the first, second, and third transparent covers.

9. The method according to claim 8, further comprising disposing an encapsulant into each of the plurality of cells.

10. The method according to claim 8, further comprising disposing phosphor into at least one of the plurality of cells.

11. The method according to claim 8, further comprising disposing an encapsulant filled with phosphor into at least one of the plurality of cells. 5

12. The method according to claim 11, wherein an encapsulant is disposed into each of the plurality of cells not containing the encapsulant filled with phosphor. 10

13. The method according to claim 11, wherein at least two of the plurality of cells contains the encapsulant, wherein the encapsulant is filled with phosphor of a different color in each cell of the at least two cells.

14. The method according to claim 8, further comprising disposing an encapsulant into each of the plurality of cells. 15

15. The apparatus according to claim 1, wherein the plurality of cells are defined by a plurality of support members disposed on the substantially flat substrate, and wherein the plurality of transparent covers are each disposed on a top surface of the each of the support members. 20

16. The apparatus according to claim 1, further comprising a transparent cover disposed over the plurality of transparent covers.

17. The method according to claim 8, further comprising: disposing a plurality of support members on the substantially flat substrate to define the plurality of cells; and disposing each of the transparent covers on a top surface of each of the support members. 25

18. The method according to claim 8, further comprising disposing a transparent cover over the plurality of transparent covers. 30

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