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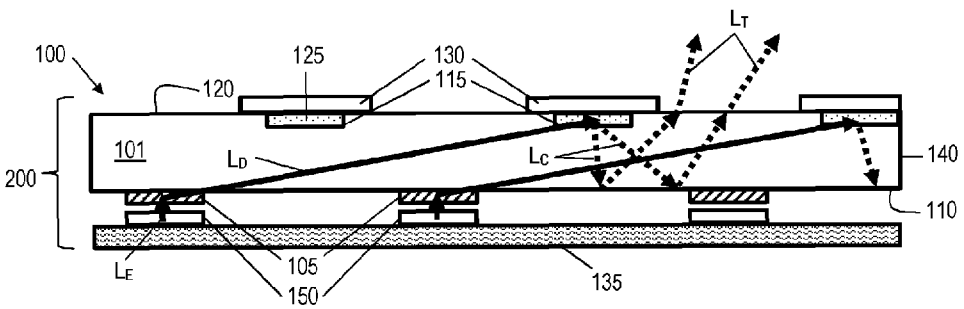


FIG. 1A

(57) Abstract: Disclosed herein are light guide plates comprising diffraction and color conversion features. Optical assemblies comprising at least one light source optically coupled to such a light guide plate are also disclosed. Display, lighting, and electronic devices comprising such assemblies and devices are further disclosed herein.

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COLOR-CONVERTING LIGHT GUIDE PLATES AND DEVICES COMPRISING THE SAME

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/384,417 filed on September 7, 2016, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The disclosure relates generally to light guide plates and display or lighting devices comprising such light guide plates, and more particularly to light guide plates comprising color conversion and light diffraction features.

BACKGROUND

[0003] Liquid crystal displays (LCDs) are commonly used in various electronics, such as cell phones, laptops, electronic tablets, televisions, and computer monitors. Conventional LCDs typically comprise a light emitting diode (LED) and color converting elements, such as a phosphors or quantum dots (QDs). LEDs may also be used in combination with color converting elements in lighting applications, such as luminaires. Light guide assemblies may include one or more "white" LEDs optically coupled to a light guide plate (LGP) comprising one or more light extraction features for scattering light in a desired direction.

[0004] A white LED can be produced, for example, by coating an LED emitting blue light with a silicone/phosphor slurry that may convert some of the light to green and/or red light as it passes through. The combination of blue, green, and red light is perceived by the human eye as white light. However, silicone may darken over time after prolonged exposure to the LED optical flux and heat. Moreover, phosphors tend to have a poor color gamut as compared to other color converting elements (e.g., QDs) due to their relatively broader emission spectrum.

[0005] It would thus be useful to provide lighting and display components, such as light guide assemblies, that can utilize QDs in place of, or in addition to, traditional phosphor materials. However, color converting elements such as phosphors and QDs are not 100% quantum efficient in converting light and some of the light energy may be absorbed by the color

converting element as heat. The color conversion process itself may also generate heat, e.g., due to Stokes shift when shorter wavelengths are converted to longer wavelengths. In some instances, up to 20-40% of the absorbed light can be converted to heat. Because excess heat may degrade the color converting element, it can be important to establish adequate cooling or heat sink pathways to dissipate the generated heat and maintain the color converting element within a desired operating temperature.

[0006] While phosphor materials may be able to operate at moderate temperatures (e.g., up to about 300°C), QDs are highly temperature sensitive and may experience degradation at temperatures of greater than about 100°C. Due to the temperature sensitivity of QDs, traditional display and lighting assemblies are generally configured to avoid close proximity and/or direct contact between the QDs and the LEDs. As such, design of LGP assemblies comprising QDs as the color converting element has, to date, been difficult if not impossible.

[0007] Accordingly, it would be advantageous to provide a LGP comprising color conversion features with a suitable heat dissipation pathway. It would also be advantageous to provide a color-converting LGP with an improved color gamut. Furthermore, it would be advantageous to provide a LGP comprising features capable of both converting blue light to white light and scattering the light in a desired direction.

SUMMARY

[0008] The disclosure relates, in various embodiments, to light guide plates comprising a transparent substrate having a light incident surface and an opposing light emitting surface, wherein the light incident surface comprises at least one light diffraction feature and at least one of the light incident surface and the light emitting surface comprises at least one color conversion feature.

[0009] According to various embodiments, the at least one color conversion feature may comprise a cavity containing a color conversion medium. For instance, the cavity may comprise a recess in the light emitting and/or light incident surface, or the cavity may be disposed between a sealing layer and the light emitting surface and/or between a sealing layer and the light incident surface. The sealing layer may, in some embodiments, be transparent, reflective, or partially reflective, and/or continuous or discontinuous. In certain embodiments, the transparent substrate may be patterned with a plurality of light extraction features which may,

for instance, comprise a gradient pattern such as a periodic pattern. The light extraction features may be chosen from surface or sub-surface features. According to non-limiting embodiments, the at least one light diffraction feature can comprise an array of periodic or chirped diffraction gratings. The diffraction gratings may comprise, for example, a polymeric or metallic layer patterned on the light incident surface of the transparent substrate, or one or more laser-damaged, ion-exchanged, or crystallized regions on the light incident surface of the transparent substrate.

[0010] Optical assemblies comprising a LGP optically coupled to at least one light source are also disclosed herein. In certain embodiments, the light source may be optically coupled to the light incident surface of the LGP. Exemplary light sources may include, e.g., light emitting diodes (LEDs) emitting ultraviolet, near-ultraviolet, or blue light. According to various embodiments, the light diffraction feature and light source may be positioned in overlying registration with one another and/or the light diffraction feature may be configured to direct propagation of light from the at least one light source to a predetermined color conversion feature. Display, lighting, and electronic devices comprising such optical assemblies are further disclosed herein.

[0011] The disclosure additionally relates to methods for making an optical assembly, the methods comprising forming at least one light diffraction feature on a light incident surface of a transparent substrate, forming at least one color conversion feature on at least one of the light incident surface or an opposing light emitting surface of the transparent substrate, and optically coupling at least one light source to the at least one light diffraction feature.

[0012] Additional features and advantages of the disclosure will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the methods as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0013] It is to be understood that both the foregoing general description and the following detailed description present various embodiments of the disclosure, and are intended to provide an overview or framework for understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding of the disclosure, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure and, together with the description, serve to explain the principles and operations of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The following detailed description can be further understood when read in conjunction with the following drawings in which, where possible, like numerals are used to refer to like elements, and:

[0015] **FIGS. 1A-D** illustrate optical assemblies comprising LGPs according to various embodiments of the disclosure; and

[0016] **FIGS. 2A-B** illustrate optical assemblies comprising LGPs including light extraction features according to additional embodiments of the disclosure.

DETAILED DESCRIPTION

[0017] Various embodiments of the disclosure will now be discussed with reference to **FIGS. 1-2**, which illustrate exemplary embodiments of optical assemblies and light guide plates (LGPs). Display, lighting, and electronic devices comprising such LGPs and assemblies are also disclosed herein. The following general description is intended to provide an overview of the claimed devices, and various aspects will be more specifically discussed throughout the disclosure with reference to the non-limiting depicted embodiments, these embodiments being interchangeable with one another within the context of the disclosure.

[0018] Disclosed herein are LGPs comprising a transparent substrate having a light incident surface and an opposing light emitting surface, wherein the light incident surface comprises at least one light diffraction feature and at least one of the light incident surface or the light emitting surface comprises at least one color conversion feature. Optical assemblies comprising at least one light source optically coupled to the LGP are also disclosed herein, as well as display, lighting, and electronic devices comprising such assemblies.

[0019] **FIG. 1A** illustrates an optical assembly **200** comprising a light guide plate (LGP) **100** according to embodiments of the disclosure. The LGP **100** can comprise a transparent substrate **101** having a light incident surface **110** and an opposing light emitting surface **120**. The light incident and light emitting surface may also be interchangeably referred to herein as opposing "first" and "second" major surfaces, respectively. The light incident surface **110** can include at least one light diffraction feature **105**, and the light emitting surface **120** and/or the light incident surface **110** can include at least one color conversion feature. As illustrated in **FIG. 1A**, the color conversion feature can comprise at least one cavity **115** in the

light emitting surface **120** containing a color conversion medium **125**. The cavities **115** may be sealed by at least one sealing layer **130**, which may be discontinuous (as shown in **FIG. 1A**) or continuous (as shown in **FIG. 1B**). Optionally, a reflector **135**, such as a metal film or substrate coated with a reflective paint, may be provided proximate the light incident surface **110** to reflect any backscattered light rays in the forward (light emitting) direction. Additional reflectors (not illustrated) may also be provided along edge surfaces **140** of the LGP.

[0020] An optical assembly **200** as disclosed herein can comprise at least one light source **150** optically coupled to the light incident surface **110** of the LGP **100**. As used herein, the term "optically coupled" is intended to denote that a light source is positioned relative to the LGP so as to introduce or inject light into the LGP. A light source may be optically coupled to the LGP even though it is not in direct physical contact with the LGP. The light source may, for instance, be positioned proximate to, but not physically touching, the LGP.

[0021] While **FIG. 1A** depicts evenly spaced apart light diffraction features **105** and cavities **115**, each having the same size and shape, it is to be understood that any configuration can be used and is intended to fall within the scope of the disclosure. For instance, the light diffraction features **105** and/or cavities **115** may be spaced apart by varying distances and/or the size and/or shape of the light diffraction features **105** and/or cavities **115** may vary, as appropriate to produce the desired light output.

[0022] Moreover, while **FIG. 1A** depicts the cavities **115** as recesses or wells within the transparent substrate, it is to be understood that the cavities **115** may also be formed between the light emitting surface **120** and the sealing layer **130**, e.g., as shown in **FIG. 1B**. For instance, sealing layer **130** may comprise a substrate having one or more recesses, and cavities **115** may be formed upon joining the sealing layer **130** with the light emitting surface **120**. Alternatively, color conversion medium **125** can be deposited or patterned on the light emitting surface **120** and a sealing layer can be coated over the color conversion medium **125** to encapsulate it and to form cavities **115** on the light emitting surface **120**. For example, the sealing layer can be deposited atop the color conversion medium by sputtering, vapor deposition, and other similar processes.

[0023] Further, while **FIGS. 1A-B** depict the cavities **115** as present only on the light emitting surface **120**, it is to be understood that the cavities **115** may also be present on the light incident surface **110**, as depicted in **FIG. 1C**, or on both the light incident surface **110** and the light emitting surface **120**, as shown in **FIG. 1D**. Positioning one or more color conversion

features on the light incident surface **110** may provide the additional advantage of scattering light forward without the use of light extraction features. The color conversion features may thus serve the dual purpose of converting blue light to longer wavelengths and to scatter the converted light forward such that it is transmitted from the light emitting surface. In embodiments comprising cavities **115** on the light incident surface **110**, the cavities may be spaced between one or more of the light diffraction features **105**, as appropriate to produce the desired light output. Additionally, it is to be understood that any cavities **115** present on the light incident surface **110** may be sealed using any method disclosed above with reference to the light emitting surface **120**.

[0024] According to various embodiments, the LGP **100** may be patterned with one or more light extraction features **160**, **160'**. For example, as shown in **FIG. 2A**, the LGP **100** can comprise a plurality of surface light extraction features **160** patterned on the light emitting surface **120** in a suitable density to produce substantially uniform light output intensity across the light-emitting surface **120** of the LGP **100**. In other embodiments, the LGP may be patterned with sub-surface light extraction features **160'**, as illustrated in **FIG. 2B**.

[0025] The light extraction features may produce surface scattering and/or volumetric scattering of light, depending on the depth of the features in the LGP surface. The sizes of the light extraction features may also affect the light scattering properties of the LGP. Without wishing to be bound by theory, it is believed that small features may scatter light backwards as well as forwards, whereas larger features tend to scatter light predominantly forward. Thus, for example, according to various embodiments, the light extraction features may have a correlation length less than about 100 nm, such as 70 nm, or less than about 50 nm. Furthermore, larger extraction features may, in some embodiments, provide a forward light scatter but at a small angular spread. Accordingly, in various embodiments, the light extraction features may range in correlation length from about 20 nm to about 500 nm, such as from about 50 nm to about 100 nm, from about 150 nm to about 200 nm, or from about 250 to about 350 nm, including all ranges and subranges therebetween. The optical characteristics of the light extraction features can be controlled, e.g., by the processing parameters used when producing the extraction features.

[0026] The LGP may be treated to create light extraction features according to any method known in the art, e.g., the methods disclosed in co-pending and co-owned International

Patent Application Nos. PCT/US2013/063622 and PCT/US2014/070771, each incorporated herein by reference in their entirety. Exemplary light extraction features can comprise scattering particles, such as polymethylmethacrylate (PMMA), SiO_2, or TiO_2 particles, which may be printed, painted or otherwise coated on the light emitting surface **120** of the LGP **100**. Alternatively, light scattering features may be provided by etching or laser damaging the light emitting surface **120** of the LGP **100**. Sub-surface light extraction features may also be created by laser damaging, e.g., by focusing a laser just below the light emitting surface **120**. Furthermore, light scattering particles can be incorporated into the matrix of the LGP in certain embodiments. The surface and sub-surface light extraction features **160**, **160'** may, for example, be patterned on or under the light emitting surface **120** as illustrated in **FIGS. 2A-B**, although it is also possible to pattern such features anywhere on or within the LGP matrix.

[0027] As used herein, the term "patterning" is intended to denote that the light extraction features are present in any given pattern or design, which may, for example, be random or arranged, repetitive or non-repetitive, uniform or non-uniform. The light extraction features on or near a surface of the LGP may, for example, vary along its length such that the extraction efficiency per unit length, $\varepsilon(x) = \frac{\eta}{L - x\eta}$, where $\eta \equiv \frac{Power(x=0) - Power(x=L)}{Power(x=0)}$, L is the length of the light guide, and x is the position along the LGP. The extraction efficiency per unit length may be used to engineer the light extraction feature density across the LGP, and the functional form of the extraction per unit length can be modified to accommodate multiple passes of light through the LGP. The density of the light extraction features at any given location along the LGP may thus be controlled so as to produce a substantially spatially, spectrally, and/or angularly uniform light emission, in which the emission brightness may be substantially constant across the light-emitting surface. In some embodiments, to produce a more uniform light distribution across the LGP, the light extraction feature density may vary inversely with the distance from the injection point, e.g., higher density at locations further away from the light source.

[0028] According to non-limiting embodiments, as shown in **FIGS. 2A-B**, the light extraction features **160**, **160'** may be patterned to form a gradient. For instance, the density of light extraction features **160**, **160'** proximate the light source **150** may be lower than a density at a point further removed from the light source **150**, e.g., at a midpoint between two light sources,

as appropriate to create the desired light output distribution across the LGP. In **FIGS. 2A-B**, the gradient **G** is indicated by arrows pointing from a region of lower density to a region of higher density. In the case of an array of light sources, the gradient pattern may comprise a periodic pattern, with regions of lower extraction feature density corresponding to the light sources, and regions of higher extraction feature density falling between the light sources. However, it is to be understood that different gradient patterns are also possible, depending on the desired light output, and are intended to fall within the scope of the disclosure. Further, while **FIG. 2A** illustrates a LGP comprising only surface light extraction features **160** and **FIG. 2B** illustrates an LGP comprising only sub-surface light extraction features **160'**, it is to be understood that any combination of these features may be used and is intended to fall within the scope of the disclosure.

[0029] Referring back to **FIGS. 1A-D**, emitted light $\mathbf{L_E}$ from the at least one light source **150**, may be directed through a light diffraction feature **105**, which can redirect the light in a desired direction. The diffracted light $\mathbf{L_D}$ may then travel through the LGP **100** until striking a region comprising the color conversion medium **125**, at which point it may be converted to a different wavelength to produce converted light $\mathbf{L_C}$. Converted light $\mathbf{L_C}$ may then propagate through the LGP **100** until it is transmitted through the light emitting surface **120** as transmitted light $\mathbf{T_L}$. For instance, the light may strike a light extraction feature (not illustrated), which may scatter the light forward at a desired angle, as discussed in more detail below.

[0030] Light diffraction features **105** can comprise, in certain embodiments, periodic or chirped diffraction gratings, which can be configured to redirect emitted light $\mathbf{L_E}$ along a desired path. Light "diffraction" as used herein is intended to denote the redirection or guidance of light rays in a desired direction, which may be accomplished by spreading out the light waves, e.g., by interference. In contrast, light "scattering" disperses light rays in several different directions through interaction with an interface, e.g., between materials with different indices of refraction. The diffraction features **105** can include structures that leverage interference effects to change the direction of light incident upon the features. Light diffraction can be used to redirect all or substantially all of light incident upon the diffraction feature in a predetermined direction or along a predetermined pathway. In various embodiments, the light diffraction features may be optically coupled to the light sources, for instance, the light diffraction features may be positioned at least partially or fully in overlying registration with the light source.

[0031] Light diffraction features **105** may, for example, include diffraction gratings comprising a plurality of slits provided on or in the light incident surface **110**. Gratings can be created, e.g., by patterning a polymeric or metallic material on the light incident surface **110**. The light diffraction features **105** can be formed on the light incident surface **110** of the transparent substrate **101** by any suitable deposition technique known in the art. Polymeric or metallic materials can be deposited onto the surface, e.g., by printing methods such as microreplication, 3D printing, or holographic printing. The polymeric or metallic materials can be deposited in a pattern, such as an array of slits, or, in other embodiments, portions of the polymeric or metallic can be removed after deposition to create the pattern. Removal techniques can include lithography, masking, etching, UV curing, and other like processes. Suitable polymeric materials may include, for example, UV curable acrylates, thermally curable epoxy resins, and other like materials. Exemplary metallic materials may include, but are not limited to, Al, Au, Ag, Pt, Pd, Cu, other similar metals, and alloys thereof.

[0032] Gratings can also be created by modifying the transparent substrate itself, e.g., by laser damaging the light incident surface **110** to create one or more slits. Laser processing can be used, for example, to form diffraction features, such as an array of periodic diffraction gratings, in the light incident surface. In the case of glass substrates, gratings may also be provided by ion exchanging one or more regions of the light incident surface **110**. For instance, a glass substrate may be treated by localized ion exchange processes to form regions capable of diffracting light incident thereon. Exemplary ion exchange processes include thermal and electrical poling techniques, as well as molten salt bath immersion, optionally with the use of a masking agent. Diffraction features may also be provided in the light incident surface of the substrate by localized devitrification of a glass substrate, followed by recrystallization, to form regions on the light incident surface capable of diffracting light incident thereon.

[0033] According to various embodiments, the diffraction gratings may comprise slits having a slit width and/or grating period within an order of magnitude of the wavelength of light to be diffracted. For instance, the slit width and/or grating period may be less than about 1000 nm, less than about 700 nm, less than about 500 nm, less than about 400 nm, or less than about 300 nm, e.g., ranging from about 100 nm to about 1000 nm, including all ranges and subranges therebetween. In additional embodiments, the overall width of the diffraction grating may be chosen to accommodate the area over which the light is projected onto a given region of the

light incident surface and may range, for example, from about 1 mm to about 10 mm, such as from about 2 mm to about 9 mm, from about 3 mm to about 8 mm, from about 4 mm to about 7 mm, or from 5 mm to about 6 mm, including all ranges and subranges therebetween.

[0034] As used herein, the term "slit width" is intended to refer to the width of an individual slit in a diffraction grating. The term "grating period" is intended to refer to the distance between individual slits in the diffraction grating. The grating period may determine the angle at which a given wavelength of light is diffracted, e.g., using the formula $m\lambda = d*\sin\Theta$, where Θ is the angle of diffraction, λ is the light wavelength, d is the grating period, and m is an integer representing the interference order. The term "overall width" is intended to refer to the overall dimension of a collection of slits making up an individual diffraction grating. The overall width of the grating period may correspond, for instance, to the width of a light source, e.g., LED, optically coupled to the grating.

[0035] In some embodiments, emitted light can be redirected by a light diffraction feature to a desired color conversion feature. For instance, as shown in **FIG. 1A**, emitted light $\mathbf{L_E}$ can be redirected by light diffraction feature **105** to a desired cavity **115** containing color conversion medium **125**. The pathway can be selected, for instance, such that emitted light $\mathbf{L_E}$ travels a predetermined distance before passing through the color conversion medium **125**. Referring to **FIG. 1C**, it is also possible, in non-limiting embodiments, to redirect emitted light $\mathbf{L_E}$ such that it strikes the light emitting surface **120** at a predetermined angle in a region that does not correspond to a color conversion feature. The predetermined angle may be chosen to be less than the critical angle such that the diffracted light $\mathbf{L_D}$ is reflected off of light emitting surface **120** due to total internal reflection (TIR) and strikes a cavity **115** containing color conversion medium **125** on the light incident surface **110**. In further embodiments, as illustrated in **FIG. 1B**, the light diffraction feature **105** may redirect light such that it propagates along the LGP for a specified distance due to TIR until striking a predetermined cavity **115**.

[0036] Total internal reflection (TIR) is the phenomenon by which light propagating in a first material (e.g., glass, plastic, etc.) comprising a first refractive index can be totally reflected at the interface with a second material (e.g., air, etc.) comprising a second refractive index lower than the first refractive index. TIR can be explained using Snell's law:

$$n_1 \sin(\theta_i) = n_2 \sin(\theta_r)$$

which describes the refraction of light at an interface between two materials of differing indices of refraction. In accordance with Snell's law, n_1 is the refractive index of a first material, n_2 is the refractive index of a second material, Θ_i is the angle of the light incident at the interface relative to a normal to the interface (incident angle), and Θ_r is the angle of refraction of the refracted light relative to the normal. When the angle of refraction (Θ_r) is 90°, e.g., $\sin(\Theta_r) = 1$, Snell's law can be expressed as:

$$\theta_c = \theta_i = \sin^{-1}(\frac{n_2}{n_1})$$

The incident angle Θ_i under these conditions may also be referred to as the critical angle Θ_c. Light having an incident angle greater than the critical angle ($\Theta_i > \Theta_c$) will be totally internally reflected within the first material, whereas light with an incident angle equal to or less than the critical angle ($\Theta_i \leq \Theta_c$) will be transmitted by the first material.

[0037] In the case of an exemplary interface between air (n_1=1) and glass (n_2=1.5), the critical angle (Θ_c) can be calculated as 41°. Thus, if light propagating in the glass strikes the air-glass interface at an incident angle greater than 41°, all the incident light will be reflected from the interface at an angle equal to the incident angle. If the reflected light encounters a second interface comprising an identical refractive index relationship as the first interface, the light incident on the second interface will again be reflected at a reflection angle equal to the incident angle. Accordingly, if, for example, the glass is a glass plate comprising two opposing parallel surfaces defining two opposing air-glass interfaces, light injected into the glass plate can propagate through the glass plate, reflecting alternately between the first and second parallel interfaces unless or until there is a change to the interfacial conditions.

[0038] Using light diffraction and/or TIR, an optical assembly may be engineered such that the light emitted by the at least one light source travels a predetermined distance before coming into contact with the color conversion medium. The predetermined pathway and/or distance traveled may thus be varied as desired such that the color conversion medium is exposed to a reduced light flux density. Without wishing to be bound by theory, it is believed that the optical flux density of a light ray may decrease as the light ray travels greater distances and spreads out spatially. In some embodiments, the optical flux within the LGP may be reduced by as much as one or even two orders of magnitude. In other words, diffracted light impinging on the color conversion medium may have an intensity as low as 1% of that of the light

originally emitted from the light source. Because the light flux density to which the color conversion medium may be exposed can be reduced, the overall assembly may be operated at a higher light intensity as compared to prior art configurations. Moreover, the lifetime of the optical assembly may be extended as compared to prior art devices due to one or more of the above advantages.

[0039] In certain embodiments, a traditional phosphor-coated "white" LED can be replaced by a blue LED coupled to a LGP patterned with QDs. Since QDs have a narrower emission spectrum than phosphors, the resulting assembly may have an improved color gamut. Of course, in other embodiments, the LGP may be patterned with color converting elements other than QDs, such as phosphors, fluorophores, and the like. In further non-limiting embodiments, the patterned color conversion medium can fully or partially replace light extraction features traditionally provided on the LGP surface, e.g., by coating, painting, laser damaging, and other like processes. Of course, the color-converting LGP disclosed herein may also be used in conjunction with additional light extraction features, e.g., as illustrated in **FIGS. 2A-B**.

[0040] With reference to **FIGS. 1-2**, the color conversion medium **125** can comprise at least one color converting element. The color converting element may, in some embodiments, be suspended in an organic or inorganic matrix, such as a silicone or other suitable material. In certain embodiments, the color converting element may be suspended in a thermally conductive matrix. According to various embodiments, the color conversion medium may be deposited as a layer having a thickness, for example, ranging from about 5 μm to about 400 μm, such as from about 10 μm to about 300 μm, from about 20 μm to about 200 μm, or from about 50 μm to about 100 μm, including all ranges and subranges therebetween.

[0041] The color conversion features can be formed using any method known in the art. For instance, a color conversion medium can be deposited on a surface or in a recess using any suitable deposition method, such as printing, e.g., inkjet printing, screen printing, microprinting, and the like, coating, such as spin coating, slot coating, dip coating, and the like, drop-casting, pipetting, or any combination thereof. In certain embodiments, droplets of color conversion medium suspended in one or more solvents can be deposited in any desired pattern. The solvent may optionally be removed by drying at ambient or elevated temperatures.

[0042] The at least one color converting element can be chosen, for example, from phosphors, quantum dots (QDs), and lumiphores such as fluorophores or light emitting polymers, and the like. Exemplary phosphors can include, but are not limited to, red and green emitting phosphors, such as yttrium- and zinc sulfide-based phosphors, e.g., yttrium aluminum garnet (YAG), Eu^{2+} doped red nitride, and combinations thereof.

[0043] QDs can have varying shapes and/or sizes depending on the desired wavelength of emitted light. For example, the frequency of emitted light may increase as the size of the quantum dot decreases, e.g., the color of the emitted light can shift from red to blue as the size of the quantum dot decreases. When irradiated with blue, UV, or near-UV light, a quantum dot may convert the light into longer red, yellow, green, or blue wavelengths. According to various embodiments, the color converting element can be chosen from QDs that emit in red and green wavelengths when irradiated with blue, UV, or near-UV light.

[0044] It is possible, in various embodiments, for the at least one cavity **115** to comprise the same or different types of color converting element, e.g., elements emitting the same or different wavelengths of light. For example, in some embodiments, a cavity can comprise color converting elements emitting both green and red wavelengths, to produce a red-green-blue (RGB) spectrum in the cavity. However, according to other embodiments, it is possible for an individual cavity to comprise only color converting elements emitting the same wavelength, such as a cavity comprising only green quantum dots or a cavity comprising only red phosphors. In further embodiments, a single cavity may be subdivided, with alternating sub-cavities filled with green color converting elements and complementary sub-cavities filled with red color converting elements.

[0045] It is within the ability of one skilled in the art to choose the configuration of the cavity or cavities and the types and amounts of color conversion medium to place in each cavity to achieve a desired display or lighting effect. Moreover, although red and green emitting elements are discussed above, it is to be understood that any type of color converting element can be used, which can emit any wavelength of light including, but not limited to, red, orange, yellow, green, blue, or any other color in the visible spectrum (e.g., ~420-750nm). For instance, in solid-state lighting applications, quantum dots having various sizes may be combined to emulate the output of a black body, which may provide excellent color rendering.

[0046] With continued reference to **FIGS. 1-2**, the substrate **101** and/or sealing layer **130** can, for example, comprise a transparent or substantially transparent material, such as a glass or plastic. As used herein, the term "transparent" is intended to denote that a lens, substrate, or material has an optical transmission of greater than about 80% in the visible region of the spectrum (~420-750nm). For instance, an exemplary transparent substrate or lens may have greater than about 85% optical transmittance in the visible light range, such as greater than about 90%, or greater than about 95%, including all ranges and subranges therebetween.

[0047] In some embodiments, the LGP **100**, transparent substrate **101**, and/or sealing layer **130** can comprise a color shift Δy less than 0.015, such as ranging from about 0.005 to about 0.015 (e.g., about 0.005, 0.006, 0.007, 0.008, 0.009, 0.010, 0.011, 0.012, 0.013, 0.014, or 0.015). In other embodiments, the transparent substrate can comprise a color shift less than 0.008. According to certain embodiments, the LGP **100**, transparent substrate **101**, and/or sealing layer **130** can have a light attenuation α_1 (e.g., due to absorption and/or scattering losses) of less than about 4 dB/m, such as less than about 3 dB/m, less than about 2 dB/m, less than about 1 dB/m, less than about 0.5 dB/m, less than about 0.2 dB/m, or even less, e.g., ranging from about 0.1 dB/m to about 4 dB/m, for wavelengths ranging from about 420-750 nm.

[0048] Color shift may be characterized by measuring variation in the x and y chromaticity coordinates along the length L using the CIE 1931 standard for color measurements. For glass light-guide plates the color shift Δy can be reported as $\Delta y = y(L_2) - y(L_1)$ where L_2 and L_1 are Z positions along the panel or substrate direction away from the source launch and where $L_2 - L_1 = 0.5$ meters. Exemplary light-guide plates may have $\Delta y < 0.01$, $\Delta y < 0.005$, $\Delta y < 0.003$, or $\Delta y < 0.001$.

[0049] Suitable transparent materials may include, for instance, any glass known in the art for use in display and other electronic devices. Exemplary glasses can include, but are not limited to, aluminosilicate, alkali-aluminosilicate, borosilicate, alkali-borosilicate, aluminoborosilicate, alkali-aluminoborosilicate, and other suitable glasses. These substrates may, in various embodiments, be chemically strengthened and/or thermally tempered. Non-limiting examples of suitable commercially available substrates include EAGLE XG®, Lotus™, Iris™, Willow®, and Gorilla® glasses from Corning Incorporated, to name a few. In other embodiments, polymeric materials, such as plastics, e.g., polymethylmethacrylate (PMMA),

methylmethacrylate styrene (MS), or polydimethylsiloxane (PDMS), may be used as suitable transparent materials.

[0050] Glasses that have been chemically strengthened by ion exchange may be suitable as transparent substrates **101** according to some non-limiting embodiments. During the ion exchange process, ions within a glass sheet at or near the surface of the glass sheet may be exchanged for larger metal ions, for example, from a salt bath. The incorporation of the larger ions into the glass can strengthen the sheet by creating a compressive stress in a near surface region. A corresponding tensile stress can be induced within a central region of the glass sheet to balance the compressive stress.

[0051] Ion exchange may be carried out, for example, by immersing the glass in a molten salt bath for a predetermined period of time. Exemplary salt baths include, but are not limited to, KNO_3, $LiNO_3$, $NaNO_3$, $RbNO_3$, and combinations thereof. The temperature of the molten salt bath and treatment time period can vary. It is within the ability of one skilled in the art to determine the time and temperature according to the desired application. By way of a non-limiting example, the temperature of the molten salt bath may range from about 400°C to about 800°C, such as from about 400°C to about 500°C, and the predetermined time period may range from about 4 to about 24 hours, such as from about 4 hours to about 10 hours, although other temperature and time combinations are envisioned. By way of a non-limiting example, the glass can be submerged in a KNO_3 bath, for example, at about 450°C for about 6 hours to obtain a K-enriched layer which imparts a surface compressive stress.

[0052] In certain embodiments, the transparent substrate **101** may comprise a glass having the following composition:

55-75 wt% SiO_2;

5-25 wt% Al_2O_3;

1-15 wt% MgO;

0-1% wt% SnO_2;

0-5 wt% Na_2O;

0-5 wt% SrO; and

0-10 wt% B_2O_3.

According to further embodiments, the glass may comprise less than 200 ppm Fe_2O_3. In further embodiments, the glass may comprise less than 2 ppm Cr_2O_3. In still further embodiments, the

glass may comprise less than 2 ppm NiO. According to yet further embodiments, the glass may comprise less than 1 ppm each of NiO and Cr_2O_3 and/or less than about 100 ppm of Fe_2O_3, such as less than about 50 ppm, less than about 20 ppm, or less than about 10 ppm of Fe_2O_3. Additional non-limiting exemplary glass compositions are listed in Table I below, with amounts expressed as percent by weight.

Table I: Exemplary Glass Compositions

	Composition A	Composition B	Composition C
SiO_2	58.68	66.41	74.97
Al_2O_3	21.42	12.08	8.61
MgO	14.5	1.38	4.36
SnO_2	0.18	0.19	0.24
Na_2O	12.89	7.84	11.86
B_2O_3	5.38	8.27	
SrO		3.34	
Fe_2O_3		<0.001	<0.015
Cr_2O_3		<0.0002	
NiO		<0.0002	

[0053] The transparent substrate **101** can have any desired size and/or shape as appropriate to produce a desired light distribution. The opposing major surfaces, e.g., light emitting and light incident surfaces **110**, **120** of the substrate **101** may, in certain embodiments, be planar or substantially planar and/or parallel or substantially parallel. The transparent substrate **101** may comprise four edges, e.g. a square or rectangular sheet, or may comprise more than four edges, such as a multi-sided polygon, or less than four edges, such as a triangle. By way of a non-limiting example, the light guide may comprise a rectangular, square, or rhomboid sheet having four edges, although other shapes and configurations are intended to fall within the scope of the disclosure including those having one or more curvilinear portions or edges. In certain embodiments, the transparent substrate **101** may have a thickness of less than or equal to about 3 mm, for example, ranging from about 0.1 mm to about 2.5 mm, from about 0.3 mm to about 2 mm, from about 0.5 mm to about 1.5 mm, or from about 0.7 mm to about 1 mm, including all ranges and subranges therebetween.

[0054] In non-limiting embodiments, the sealing layer **130** can comprise a reflective layer, such as a metal, metal oxide, metal alloy, or mixtures thereof. Alternatively, the sealing

layer **130** can comprise a transparent material (e.g., glass, plastic, etc.) or a non-transparent material (e.g., ceramic, glass-ceramic, etc.) completely or partially coated with a reflective material (such as a metal or an oxide, alloy, or salt thereof, etc.). Exemplary reflective metals include, but are not limited to, Al, Au, Ag, Pt, Pd, Cu, other similar metals, and alloys thereof. A reflective or partially reflective sealing layer **130** may be advantageous in terms of providing an opportunity for any blue (unconverted) light passing through the color conversion medium **125** to reflect off the sealing layer **130** and have another opportunity to be converted to the desired wavelength as it passes back through the color conversion medium **125**. A sealing layer **130** comprising a thermally conductive material may also provide an additional pathway for dissipating heat generated by the color conversion medium **125**. The sealing layer **130** can be continuous as illustrated in **FIG. 1B**, or discontinuous as illustrated in **FIG. 1A**.

[0055] Some non-limiting examples of additional materials that can be used as a sealing layer **130** include oxides of tin, zinc, titanium, or copper, indium tin oxide (ITO), low melting glass (LMG), or low liquidus temperature (LLT) compositions. LMG compositions can have a glass transition temperature of less than or equal to about 400°C, e.g., less than about 350°C, 300°C, 250°C or 200°C, such as ranging from about 150°C to about 400°C. Suitable LLT materials may have a liquidus temperature less than or equal to about 1000°C, e.g., less than about 800°C, 600°C, or 400°C, e.g., ranging from about 400°C to about 1000°C. Exemplary LLT or LMG materials may include, for example, tin fluorophosphate glass, tungsten-doped tin fluorophosphate glass, chalcogenide glass, tellurite glass, borate glass, and phosphate glass.

[0056] Exemplary tin fluorophosphate glass compositions can be expressed in terms of the respective compositions of SnO, SnF_2 and P_2O_5 in a corresponding ternary phase diagram. Suitable tin fluorophosphates glasses include 20-100 mol% SnO, 0-50 mol% SnF_2 and 0-30 mol% P_2O_5. These tin fluorophosphates glass compositions can optionally include 0-10 mol% WO_3, 0-10 mol% CeO_2 and/or 0-5 mol% Nb_2O_5. For example, a composition of a doped tin fluorophosphate starting material suitable for forming a glass sealing layer comprises 35 to 50 mol% SnO, 30 to 40 mol% SnF_2, 15 to 25 mol% P_2O_5, and 1.5 to 3 mol% of a dopant oxide such as WO_3, CeO_2 and/or Nb_2O_5. A tin fluorophosphate glass composition according to one particular embodiment can be a niobium-doped tin oxide/tin fluorophosphate/phosphorus pentoxide glass comprising about 38.7 mol% SnO, 39.6 mol% SnF_2, 19.9 mol% P_2O_5 and 1.8

mol% Nb_2O_5. A tin phosphate glass composition according to another embodiment comprises about 27 mol% Sn, 13 mol% P and 60 mol% O. Suitable tin fluoroborate glass compositions include 20-100 mol% SnO, 0-50 mol% SnF_2 and 0-30 mol% B_2O_3. These tin fluoroborate glass compositions can optionally include 0-10 mol% WO_3, 0-10 mol% CeO_2 and/or 0-5 mol% Nb_2O_5.

[0057] In some embodiments, the sealing layer can include B_2O_3-ZnO-Bi_2O_3 ternary glasses. Suitable glasses can include, in some embodiments, about 10-80 mol% B_2O_3, about 5-60 mol% Bi_2O_3, and about 0-70 mol% ZnO. In non-limiting embodiments, the glass composition can include about 40-75 mol% B_2O_3, about 20-45 mol% Bi_2O_3, and about 0-40 mol% ZnO. Such glasses may have a relatively low Tg, such as less than about 600°C, less than about 500°C, or less than about 400°C, e.g., ranging from about 300°C to about 500°C.

[0058] As will be appreciated, the various glass compositions disclosed herein may refer to the composition of the deposited layer or to the composition of a source sputtering target. Additional aspects of suitable low Tg glass compositions and methods used to form glass sealing layers from these materials are disclosed in commonly-assigned U.S. Patent No. 5,089,446 and U.S. Patent Application Serial Nos. 11/207,691, 11/544,262, 11/820,855, 12/072,784, 12/362,063, 12/763,541, 12/879,578, and 13/841,391, the entire contents of which are incorporated by reference herein.

[0059] Sealing methods can include, for example, placing a sealing layer over an array of cavities in the light incident and/or light emitting surface and bonding the sealing layer to the light incident or light emitting surface. Bonding methods can include, for example, laser sealing, frit sealing, glass-to-glass welding, or any other suitable technique. Exemplary sealing techniques are disclosed in commonly-assigned U.S. Patent Application No. 14/271,797, which is incorporated herein by reference in its entirety.

[0060] In additional embodiments, the transparent substrate and/or sealing layer may comprise one or more cavities in which the color conversion medium may be deposited. Cavities can be provided in the substrate, e.g., by pressing, molding, cutting, or any other suitable method, and color conversion medium may be deposited in the cavities. The color conversion medium may be deposited on a surface of the transparent substrate or in a recess thereof and a sealing layer or film may be subsequently deposited to at least partially encapsulate the color conversion medium. Deposition methods for the sealing layer can include, for example, sputtering or vapor deposition processes.

[0061] In various embodiments, the transparent substrate and sealing layer may form a hermetic capsule in which the color conversion medium is contained. With reference to **FIGS. 1-2**, cavities **115** may be hermetically sealed, e.g., by laser sealing or otherwise bonding a sealing layer **130** to the transparent substrate **101** or by sputtering or vapor depositing a sealing layer atop the transparent substrate. For example, the cavities can be hermetically sealed such that they are impervious or substantially impervious to water, moisture, air, and/or other contaminants. By way of non-limiting example, a hermetic seal can be configured to limit the transpiration (diffusion) of oxygen to less than about 10^{-2} $cm^3/m^2/day$ (e.g., less than about 10^{-3} $cm^3/m^2/day$), and limit transpiration of water to about 10^{-2} $g/m^2/day$ (e.g., less than about 10^{-3}, 10^{-4}, 10^{-5}, or 10^{-6} $g/m^2/day$). In various embodiments, a hermetic seal can substantially prevent water, moisture, and/or air from contacting the color conversion medium protected by the hermetic seal.

[0062] The LGPs and optical assemblies depicted in **FIGS. 1-2** can be used in a variety of applications including, but not limited to, display and lighting applications. For instance, an illuminating device, such as a luminaire or solid state lighting device, can comprise an optical assembly disclosed herein. In certain embodiments, the optical assemblies can be used alone or in an array to mimic the broadband output of the sun. Such assemblies can comprise, for example, color converting elements of various types and/or sizes emitting at various wavelengths, such as visible wavelengths ranging from 420-750nm. According to various embodiments, an optical assembly disclosed herein can also be incorporated into a backlight unit (BLU) in a display device, such as an LCD.

[0063] It will be appreciated that the various disclosed embodiments may involve particular features, elements or steps that are described in connection with that particular embodiment. It will also be appreciated that a particular feature, element or step, although described in relation to one particular embodiment, may be interchanged or combined with alternate embodiments in various non-illustrated combinations or permutations.

[0064] It is also to be understood that, as used herein the terms "the," "a," or "an," mean "at least one," and should not be limited to "only one" unless explicitly indicated to the contrary. Thus, for example, reference to "a cavity" includes examples having one such "cavity" or two or more such "cavities" unless the context clearly indicates otherwise. Similarly, a

"plurality" or an "array" is intended to denote two or more, such that an "array of cavities" or a "plurality of cavities" denotes two or more such cavities.

[0065] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, examples include from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0066] All numerical values expressed herein are to be interpreted as including "about," whether or not so stated, unless expressly indicated otherwise. It is further understood, however, that each numerical value recited is precisely contemplated as well, regardless of whether it is expressed as "about" that value. Thus, "a dimension less than 10 mm" and "a dimension less than about 10 mm" both include embodiments of "a dimension less than about 10 mm" as well as "a dimension less than 10 mm."

[0067] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[0068] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase "comprising," it is to be understood that alternative embodiments, including those that may be described using the transitional phrases "consisting" or "consisting essentially of," are implied. Thus, for example, implied alternative embodiments to a method comprising A+B+C include embodiments where a method consists of A+B+C, and embodiments where a method consists essentially of A+B+C.

[0069] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the disclosure. Since modifications combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the disclosure may occur to persons skilled in the art, the disclosure should be construed to include everything within the scope of the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A light guide plate comprising:

a transparent substrate having a light incident surface and an opposing light emitting surface, wherein

the light incident surface comprises at least one light diffraction feature; and

at least one of the light incident surface and the light emitting surface comprises at least one color conversion feature.

2. The light guide plate of claim 1, wherein the at least one color conversion feature comprises a cavity containing a color conversion medium.

3. The light guide plate of claim 2, wherein the color conversion medium comprises at least one color converting element chosen from phosphors, quantum dots, and lumiphores.

4. The light guide plate of claim 2, wherein the cavity is hermetically sealed.

5. The light guide plate of claim 2, wherein the cavity comprises a recess in at least one of the light emitting surface and the light incident surface.

6. The light guide plate of claim 2, further comprising a sealing layer bonded to at least one of the light emitting surface and the light incident surface of the transparent substrate, and wherein the cavity comprises a region between the light emitting surface and the sealing layer or between the light incident surface and the sealing layer.

7. The light guide plate of claim 6, wherein the sealing layer is transparent.

8. The light guide plate of claim 6, wherein the sealing layer is reflective or partially reflective.

9. The light guide plate of claim 6, wherein the sealing layer is discontinuous.

10. The light guide plate of claim 1, wherein the transparent substrate is patterned with a plurality of light extraction features.

11. The light guide plate of claim 10, wherein the plurality of light extraction features comprises surface or sub-surface light extraction features.

12. The light guide plate of claim 10, wherein the plurality of light extraction features comprises a gradient pattern.

13. The light guide plate of claim 12, wherein the gradient pattern is periodic.

14. The light guide plate of claim 1, wherein the transparent substrate is chosen from glass and plastic substrates.

15. The light guide plate of claim 1, wherein the transparent substrate comprises a glass having the following composition:

55-75 wt% SiO_2;

5-25 wt% Al_2O_3;

1-15 wt% MgO;

0-1% wt% SnO_2;

5-15 wt% Na_2O;

0-5 wt% SrO; and

0-10 wt% B_2O_3.

16. The light guide plate of claim 15, wherein the glass comprises at least one of:

less than 200 ppm Fe_2O_3;

less than 2 ppm Cr_2O_3; or

less than 2 ppm NiO.

17. The light guide plate of claim 1, wherein the at least one light diffraction feature comprises an array of periodic or chirped diffraction gratings.

18. The light guide plate of claim 17, wherein the diffraction gratings comprise a polymeric or metallic layer patterned on the light incident surface of the transparent substrate.

19. The light guide plate of claim 17, wherein the diffraction gratings comprise one or more laser-damaged, ion-exchanged, or crystallized regions of the transparent substrate.

20. An optical assembly comprising the light guide plate of claim 1 optically coupled to at least one light source.

21. The optical assembly of claim 20, wherein the at least one light source is optically coupled to the light incident surface of the transparent substrate.

22. The optical assembly of claim 20, wherein the at least one light source is a diode emitting ultraviolet, near-ultraviolet, or blue light.

23. The optical assembly of claim 20, wherein the transparent substrate comprises a plurality of light extraction features arranged in a pattern to produce a substantially spatially uniform transmission of light from the at least one light source.

24. The optical assembly of claim 20, wherein the at least one light diffraction feature is positioned in overlying registration with the at least one light source.

25. The optical assembly of claim 20, wherein the at least one light diffraction feature is configured to direct propagation of light from the at least one light source to a predetermined color conversion feature.

26. A display, lighting, or electronic device comprising the optical assembly of claim 20.

27. A method of making an optical assembly, the method comprising:

forming at least one light diffraction feature on a light incident surface of a transparent substrate;

forming at least one color conversion feature on at least one of the light incident surface and an opposing light emitting surface of the transparent substrate; and

optically coupling at least one light source to the at least one light diffraction feature.

28. The method of claim 27, further comprising patterning the transparent substrate with a plurality of light extraction features.

29. The method of claim 28, wherein patterning the plurality of light extraction features comprises printing or laser damaging.

30. The method of claim 27, wherein forming the at least one light diffraction feature comprises patterning a polymeric or metallic layer on the light incident surface by lithography, microreplication, 3D printing, or holographic printing processes.

31. The method of claim 27, wherein forming the at least one light diffraction feature comprises modifying the light incident surface by ion exchange, laser exposure, or localized devitrification and recrystallization processes.

32. The method of claim 27, wherein forming the at least one color conversion feature comprises placing a color conversion medium in at least one cavity of at least one of the light emitting surface or the light incident surface.

33. The method of claim 32, further comprising hermetically sealing the at least one cavity.

34. The method of claim 27, wherein forming the at least one color conversion feature comprises:

patterning a color conversion medium on at least one of the light emitting surface and the light incident surface; and

depositing a sealing layer to encapsulate the color conversion medium.

35. The method of claim 34, wherein the sealing layer is deposited by vapor deposition or sputtering.

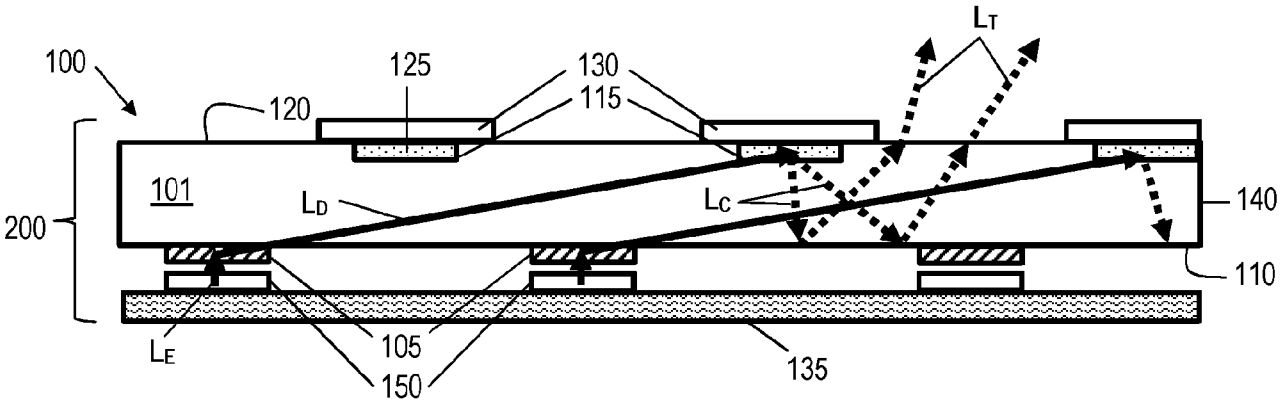

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FIG. 1A

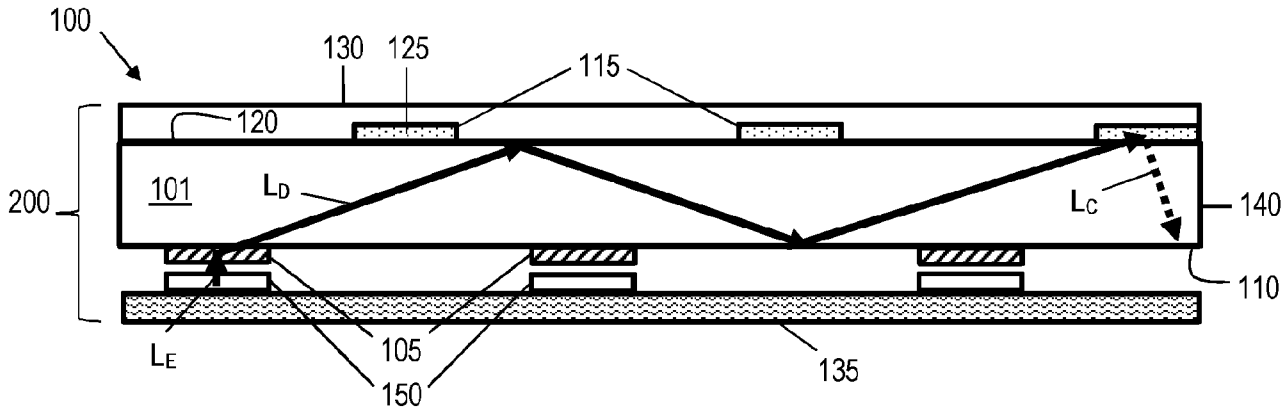

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FIG. 1B

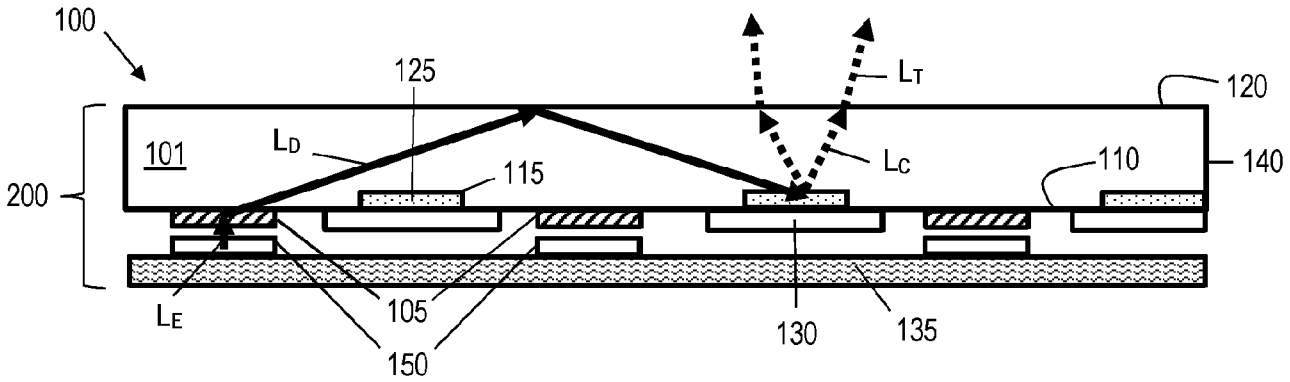

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FIG. 1C

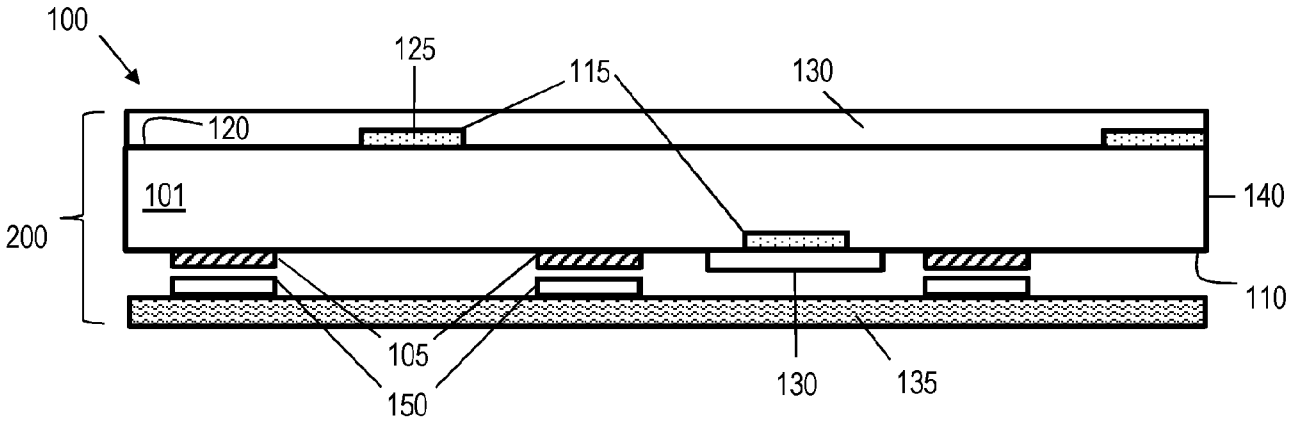

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FIG. 1D

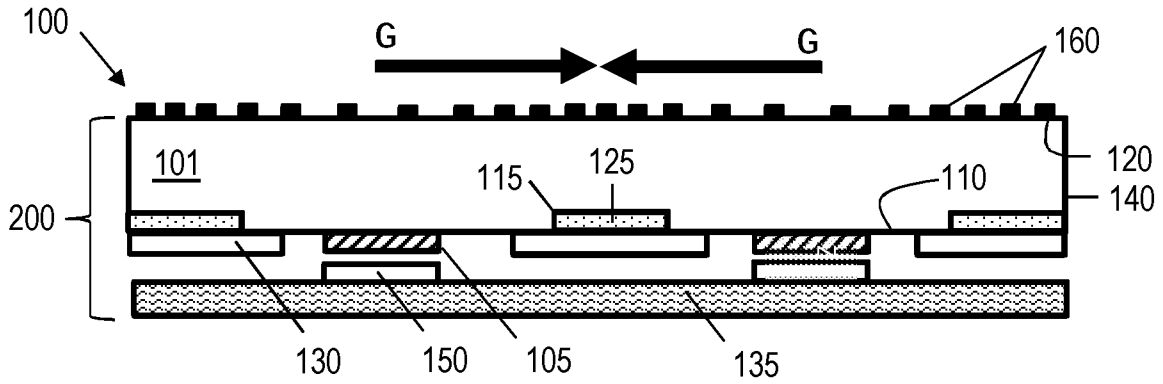

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FIG. 2A

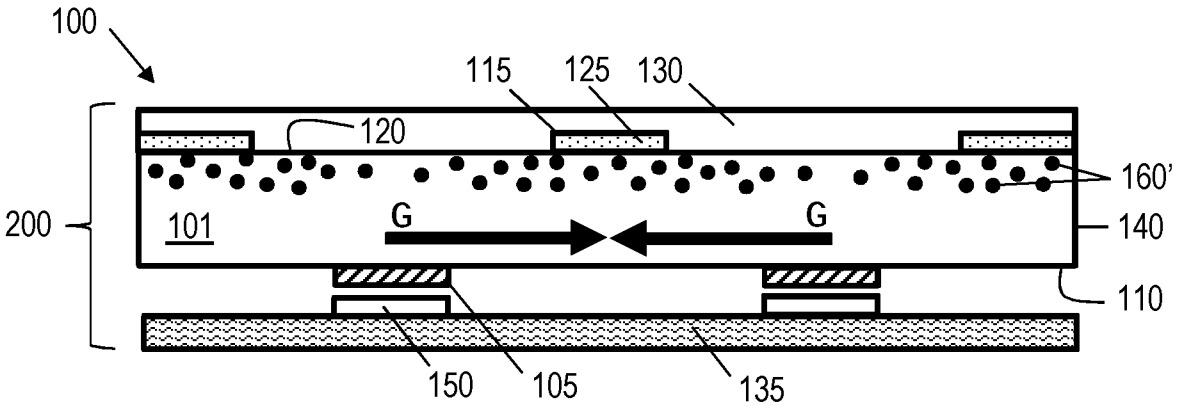

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FIG. 2B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/050189

A. CLASSIFICATION OF SUBJECT MATTER

F21V 8/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F21V 8/00; G06K 7/10; G02F 1/13357; G02F 1/1335; G02B 6/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: light guide plate, diffraction grating, color conversion feature, quantum dot, phosphor, sealing

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014-0022818 A1 (MASANAO NATSUMEDA et al.) 23 January 2014 See paragraphs 22-65, claims 1-9 and figures 1-7.	1,10-13,17-31
Y		2-9,14-16,32-35
Y	US 9146419 B1 (MUNISAMY ANANDAN et al.) 29 September 2015 See column 11, line 39 - column 19, line 30, claims 1-13 and figures 7a-14.	2-9,14-16,32-35
A	KR 10-2003-0004021 A (SAMSUNG ELECTRO-MECHANICS CO., LTD.) 14 January 2003 See pages 4-6, claim 1 and figures 4a-9.	1-35
A	KR 10-2012-0007050 A (KONINKLIJKE PHILIPS N.V.) 19 January 2012 See paragraphs 17-19, claims 1-14 and figures 3a-4.	1-35
A	US 2016-0195663 A1 (QD VISION, INC.) 07 July 2016 See paragraphs 168-170, claim 1 and figures 2-4.	1-35

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Information on patent family members

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