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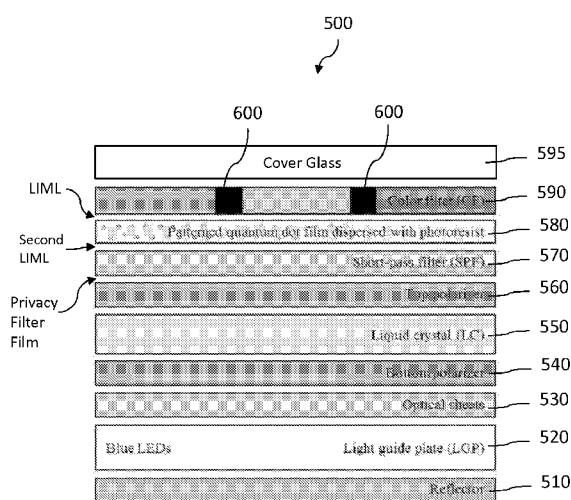


FIG. 5

(57) Abstract: A quantum dots on color filter (QDCF) LCD apparatus having certain combinations of enhancement features that enhance contrast ratio by eliminating or minimizing high angle incident light within the LCD stack is disclosed.

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
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ENHANCED QUANTUM DOT ON COLOR FILTER LCD

CROSS REFERENCES

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/798607 filed on January 30, 2019 and U.S. Provisional Application Serial No. 62/773449 filed on November 30, 2018, the contents of each of which are relied upon and incorporated herein by reference in their entireties.

BACKGROUND

[0002] Liquid crystal display (LCD) industry is seeking solutions that improve the efficiency of LCDs and improve their color gamut (the color content of the display), in order to be competitive with organic light emitting display (OLED) products. Traditional LCDs lag behind OLEDs particularly in the color gamut performance. The use of quantum dots (QD) in LCDs has improved the color gamut performance of LCDs; indeed, such improvements are already visible in LCD designs where QD film elements are used in the backlighting units (BLUs), the light source that provides light that gets passed through an active matrix of liquid crystal (LC) filled pixels of the LCD pixelated panel. In these BLU designs, blue LED light is coupled to a light guiding plate (LGP) and extracted from the LGP in the direction towards the LCD pixelated panel. The guided blue light then encounters QD which absorb a portion of the blue light and emits light in green and red spectrum. The resulting light in red, green, and blue spectrum provides a white light source for the LCD pixelated panel.

[0003] In other designs, QD material is placed directly into the corresponding individual pixels within the LCD pixelated panel. This design promises not only larger color gamut, but potentially replaces the color filters (CF) that define the color of the individual pixels in traditional (QD-free) LCD designs. Such design is referred to as “quantum dots on color filter” (QDCF) design. In the QDCF design, QD pixels are placed after the light encounters two polarizers that are part of an LCD that, in conjunction with LC, manipulate the polarization of the light.

[0004] Even a perfect pair of polarizers will allow light leakage for light that is incident upon them at ‘non-normal to the plane of the sheet polarizer’ direction (normal direction being perpendicular to the surface of the emitting element). FIGs. 1A and 1B illustrate light transmission through a pair of crossed polarizers with a phase retarder in between them to mimic LC medium as a function of viewing angle. FIGs. 1A and 1B show light transmission through a pair of crossed polarizers as a function of viewing angle (normal viewing angle being in the center of the figures) in case when the pixel is “on” and “off,”

respectively. x-axis and y-axis labels H and V denote “horizontal” and “vertical” angles (in degrees) deviating from the normal viewing angle (center of the figures) in the horizontal and vertical directions, respectively. FIG. 1A shows the light emitted from a traditional LCD in its ON state transmitted through a pair of crossed polarizers. The high angle rays lead to a sharp decrease in contrast ratio (CR) at high incidence (or viewing) angles. Thus, the dark regions around the periphery of FIG. 1A closer to 90 degree viewing angle show lower transmission at higher viewing angles. FIG. 1B shows the light emitted from the LCD in its OFF state (*i.e.*, light leakage) transmitted through a pair of crossed polarizers.

[0005] Comparing the light emission between ON and OFF states shown in FIGS. 1A and 1B, in traditional LCD, high angle rays lead to a dramatic decrease in contrast ratio (CR) at high incidence (or viewing) angles. CR measures the ratio between the light emitted by LCD in its ON state and the light emitted by LCD in its OFF state. Ideally the OFF state should be as dark as possible for all angles of incidence, hence it is referred to as the dark state. CR is very sensitive to the light in the dark state (in the denominator). Even a small amount of light in the dark state lowers the CR significantly.

[0006] In simulations of QDCF, the inventors observed that the drastic decrease in the CR is a consequence of the high viewing angle light leakage through the polarizers. While in the traditional LCD the leaked light remains directed towards high viewing angles, in QDCF this light is scattered significantly including the blue source light. This means that the leaked light is directed also towards the angles close to the normal viewing angle, increasing the value of the dark state light in the denominator of the CR definition for normal (and other) direction, effectively averaging CR over various viewing angles. Such averaging substantially reduces CR which is not desirable.

[0007] FIG. 2A is a plot of the CR for an example of a traditional LCD and FIG. 2B is a plot of the CR for a conventional QDCF. x-axis and y-axis labels H and V denote “horizontal” and “vertical” angles in degrees from the normal viewing (the center of the figures) in the horizontal and vertical directions. FIG. 2A shows CR for a traditional LCD. The CR in a traditional LCD was calculated to be ~3200:1 at normal viewing angle (*i.e.*, the horizontal and vertical angles are at 0 degrees), represented by the peak in the center of the plot, but drops off significantly as the horizontal and vertical viewing angles increase. Thus, the CR in a traditional LCD deteriorates substantially if the viewer is not looking at the LCD at a normal viewing angle. This provides very non-uniform viewing experience for the viewer. FIG. 2B shows CR for a QDCF LCD. The CR for a QDCF LCD is more uniform but its value is very low ~128:1. The low CR results in diminished picture quality for the

viewer. Even though the CR at normal viewing angle can have a value of several 1000s (Vertical Alignment LC mode displays can have CR ~ 5000), CR drops to <10 for high viewing angles.

[0008] QD based displays generally offer greater color accuracy and wider color gamut. Current technology uses blue LED's for backlighting and QD film with a mixture of red and green QD's inside the backlight unit (BLU) to convert blue light to white. Another concept of QDCF allows for even better color gamut as conversion will take place in the color filters (CF's) and not in the BLU. In such designs, a short-pass filter is between the QD layer/Color filter layer and the BLU. In another approach disclosed in United States patent application publication No. US2017/0153366 the contents of which are incorporated herein by reference, band cut filters are used to filter out blue light after conversion. There are also schemes which utilize UV light coming from the backlight and blue QD's, also described in US2017/0153366.

[0009] Another problem observed in these designs, in addition to the low CR, is that light at high output angles will be trapped inside the cover glass due to total internal reflection (TIR). In conventional LCD design, the light output is often concentrated in some limited output angle, so that TIR is not a limiting factor. However, in QDCF design, QD layers re-emit light at various angles, so that there will be a significant amount of light experiencing TIR. The light reflected back by TIR may be absorbed by color filter (CF) of a different color or the same color (typical absorbing CFs have 80%~90% transmission), resulting in significant loss in the amount of light ultimately emitted by the LCD.

[0010] Therefore, there is a need for improved QDCF architecture with improved CR.

SUMMARY

[0011] According to an embodiment of the present disclosure, a QDCF LCD apparatus is disclosed. The QDCF LCD apparatus comprising: a cover glass; a back reflector layer; a liquid crystal panel layer between the cover glass and the back reflector layer; a backlight unit between the liquid crystal panel layer and the back reflector, the backlight unit configured to generate image-forming light to the liquid crystal panel layer; a quantum dot layer between the cover glass and the liquid crystal panel layer; a color filter layer between the cover glass and the quantum dot layer, the color filter and the quantum dot layer in combination configured to form a color by converting a wavelength of the image-forming light from the backlight unit and penetrated through the liquid crystal panel; a bottom polarizer layer located between the liquid crystal panel layer and the backlight unit; a top

polarizer layer located between the liquid crystal panel layer and the quantum dot layer; and further comprising one or more of the following enhancement features:

- (a) a low-index material layer (LIML) provided between the color filter layer and the quantum dot layer;
- (b) the backlight unit configured to generate collimated image-forming light to the liquid crystal panel layer;
- (c) one or both of the bottom polarizer and the top polarizer are made of an *E*-type polarizer material;
- (d) the bottom polarizer and the top polarizer are each made of a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and
- (e) a privacy filter film provided between the top polarizer and the quantum dot layer.

[0012] According to some embodiments, the QDCF LCD apparatus comprises a backlight unit that is configured to generate image-forming light to the liquid crystal panel layer and the LIML provided between the color filter layer and the quantum dot layer; and further comprising one or more of the following enhancement features:

- (a) one or both of the bottom polarizer and the top polarizer are made of an *E*-type polarizer material;
- (b) the backlight unit configured to generate collimated image-forming light to the liquid crystal panel layer;
- (c) the bottom polarizer and the top polarizer are each made of a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and
- (d) a privacy filter film provided between the top polarizer and the quantum dot layer.

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

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] These figures are provided for the purposes of illustration, it being understood that the embodiments disclosed and discussed herein are not limited to the arrangements and instrumentalities shown.

[0015] FIGS. 1A and 1B show angular dependence of light transmission through a pair of crossed polarizers in case when the pixel is "on" and "off," respectively.

[0016] FIG. 2A is a plot of Contrast Ratio for a traditional LCD.

[0017] FIG. 2B is a plot of Contrast Ratio for a conventional QDCF LCD.

[0018] FIG. 3 is a plot of Contrast Ratio improvement trend for QDCF as a function of the source light collimation.

[0019] FIG. 4A is a plot of Contrast Ratio for a conventional QDCF LCD with non-collimated light.

[0020] FIG. 4B is a plot of Contrast Ratio for a QDCF LCD with collimated light.

[0021] FIG. 5 is a schematic illustration of an exemplary QDCF LCD structure according to the present disclosure.

[0022] FIG. 6 is a schematic cross-sectional view of a pixel region in the QDCF LCD structure according to the present disclosure.

[0023] FIG. 7A is a schematic cross-sectional view of a portion of a pixel region in a prior art QDCF structure.

[0024] FIG. 7B is a schematic cross-sectional view of a portion of a pixel region in a QDCF structure with an LIML according to an embodiment of the present disclosure.

[0025] FIG. 8 is a plot of Relative Luminous Efficacy vs. Refractive Index of LIML.

[0026] FIG. 9 is a schematic illustration of an example of black matrix structure according to an embodiment of the present disclosure.

[0027] While this description can include specifics, these should not be construed as limitations on the scope, but rather as descriptions of features that can be specific to particular embodiments.

DETAILED DESCRIPTION

[0028] Various embodiments for luminescent coatings and devices are described with reference to the figures, where like elements have been given like numerical designations to facilitate an understanding.

[0029] It also is understood that, unless otherwise specified, terms such as "top," "bottom," "outward," "inward," and the like are words of convenience and are not to be

construed as limiting terms. In addition, whenever a group is described as comprising at least one of a group of elements and combinations thereof, the group can comprise, consist essentially of, or consist of any number of those elements recited, either individually or in combination with each other.

[0030] Similarly, whenever a group is described as consisting of at least one of a group of elements or combinations thereof, the group can consist of any number of those elements recited, either individually or in combination with each other. Unless otherwise specified, a range of values, when recited, includes both the upper and lower limits of the range. As used herein, the indefinite articles "a," and "an," and the corresponding definite article "the" mean "at least one" or "one or more," unless otherwise specified

[0031] Those skilled in the art will recognize that many changes can be made to the embodiments described while still obtaining the beneficial results of the disclosure. It also will be apparent that some of the desired benefits of the present disclosure can be obtained by selecting some of the described features without using other features. Accordingly, those of ordinary skill in the art will recognize that many modifications and adaptations are possible and can even be desirable in certain circumstances and are part of the disclosure. Thus, the following description is provided as illustrative of the principles of the present disclosure and not in limitation thereof.

[0032] Those skilled in the art will appreciate that many modifications to the exemplary embodiments described herein are possible without departing from the spirit and scope of the disclosure. Thus, the description is not intended and should not be construed to be limited to the examples given but should be granted the full breadth of protection afforded by the appended claims and equivalents thereto. In addition, it is possible to use some of the features of the present disclosure without the corresponding use of other features. Accordingly, the foregoing description of exemplary or illustrative embodiments is provided for the purpose of illustrating the principles of the present disclosure and not in limitation thereof and can include modification thereto and permutations thereof.

[0033] Inventors have identified light leakage through the polarizers in the "dark state" as the reason for CR decrease in QDCF displays. The present disclosure addresses the problem by reducing or eliminating the light leakage. This is achieved by incorporating one or more of certain technologies into QDCF which is not previously known. The technologies are: (1) eliminating the high incidence angles for the light within the LCD structure by collimating the light from the backlight unit (BLU) light source; (2) using *E*-type polarizers with lower high incidence angle light leakage than *O*-type polarizers; (3) using compensation

films that reduce high incidence angles that cause light polarizers' leakage; (4) using privacy viewing films that reduce high incidence angles that cause light polarizers' leakage; and (5) adding a low refractive index material layer (LIML) on top of the QD layer in the QDCF structure. According to the present disclosure, these technologies are individually incorporated into a QDCF structure or sometimes in combination of two or more of them.

[0034] The benefits of the techniques disclosed herein are that they allow use of QD within the LC cell (*i.e.* pixelated) with the color gamut advantages of QD, color angular uniformity (minimal color shift) of QD, without compromising CR or brightness. The resulting QDCF will be more efficient than traditional QDCF LCD.

[0035] The use of substantially collimated light from the LCD's BLU light source allows the use of thick polarizers since the negative parallax problems found in traditional LCDs is minimized. The use of *E*-type polarizers, compensation films, or privacy viewing films enables use of certain technologies, while keeping the benefits of light recycling in the back light unit (BLU).

[0036] Collimating the source light: Eliminating the high incidence angles for the light within the LCD structure by collimating the light from the LCD light source improves CR. FIG. 3 shows CR improvement trend for QDCF LCD as a function of the source light collimation. For these measurements, the BLU was replaced with a rectangular Lambertian source. Collimation is given as a half-apex angle (in degrees) of the cone characterizing the angular extent of the source light. Thus, half-apex angle of 0 degrees represent completely collimated light where the source light is incident on the LCD plane at a normal angle. Collimation was simulated by confining the light source within cones having different half-apex angles. The plot of FIG. 3 shows that the beneficial effect of collimation on CR is exponential. In our example, limiting the collimation to half-apex angle of less than or equal to ± 30 degrees, preferably less than or equal to ± 20 degrees, and more preferably less than or equal to ± 15 degrees, CR can range from 1277:1 to 3885:1.

[0037] In FIGS. 4A and 4B, the performance of QDCF with collimated light was compared to the performance of traditional QDCF with non-collimated light. FIG. 4A is the same plot shown in FIG. 2B, which is a plot of CR for QDCF with non-collimated light (with angular distribution as produced by the modeled BLU unit) as a function of viewing angles H for "horizontal" angles and V for "vertical" angles. The CR is uniform with a value of $\sim 128:1$. FIG. 4B is a plot of CR for QDCF with a ± 15 degrees cone source collimation. The CR is also uniform but the CR value is significantly enhanced to $\sim 3885:1$. The collimation of

± 15 degrees is given as a half-apex angle (in degrees) of the cone characterizing the extent of the angular dispersion of the source light. An example of a collimated light source for BLU that can be applied here is a double-sided turning film disclosed in United States Patent No. 7,530,721, the contents of which are incorporated herein by reference. Another example is found in T. Ishikawa and Xiang-Dong Mi, P-82: "New Design for a Highly Collimating Turning Film," SID 06 DIGEST (2006), the contents of which are incorporated herein by reference

[0038] FIG. 5 shows a schematic vertical cross-sectional illustration of an example of a QDCF LCD panel structure **500** according to the present disclosure. The QDCF LCD panel structure **500** comprises, starting furthest from the cover glass **595**, a back reflector layer **510**, a light guide plate (LGP) **520**, one or more optical sheets **530**, a bottom polarizer **540**, liquid crystal (LC) layer **550**, a top polarizer **560**, short-pass filter (SPF) **570**, patterned quantum dot (QD) layer **580**, color filter (CF) **590**, and the cover glass **595**. The QD layer **580** and the CF layer **590** are patterned or pixelated structure defined into sub-pixel regions of **Red**, **Green**, and **Blue** as shown in FIG. 6. The sub-pixel regions in the CF layer **590** are separated by black matrix **600** structures. The component layers of the QDCF LCD panel structure **500** are not limited to just those shown in FIG. 5. Different embodiments of the QDCF LCD panel can include one or more of other functional layers of QDCF LCD panels and LCD panels that are known in the art. Examples of such additional functional layers are brightness enhancing films and diffusers. The locations of the some of the enhancement features of the present disclosure are noted along the left hand side of the QDCF structure **500** shown in FIG. 5.

[0039] Since making efficient collimated light sources can be challenging and costly (e.g., because the use of recycling of light is limited and the structures are complex to manufacture), additional methods of reducing the high incidence angles for use in QDCF are also disclosed. Referring to the exemplary QDCF structure **500** shown in FIG. 5, according to an embodiment, one or both of the top and bottom polarizers **560**, **540** can be *E*-type polarizers rather than *O*-type polarizers used in conventional QDCF devices. *O*-type polarizers suppress the extraordinary optical wave (in uniaxial materials that corresponds to one-dimension in the 3-D space of directions). The *E*-type polarizers, however, suppress the ordinary optical wave that occupy two-dimensions in the 3-D space of directions and would be more effective. A variety of *E*-type polarizers are available. One example is the single-layered *E*-type polarizer manufactured according to the method described in U.S. patent No. 5,739,296, the contents of which are incorporated herein by reference.

[0040] In some embodiments, compensation films designed to eliminate high incidence angle light can also be incorporated into the QDCF structure **500** in combination with one or more of the novel enhancements for QDCF disclosed herein. For example, compensation films can be incorporated into the QDCF structure in combination with the collimated light, in order to reduce dark state light leakage in the QDCF structure. Examples of such compensation films are disclosed in U.S. patent No. 6,995,816, the contents of which are incorporated herein by reference. U.S. patent No. 6,995,816 discloses examples of polarizer packages that utilize different combinations of A-plate, C-plate, and biaxial-plate for a compensation film. A pair of such polarizer packages can be used for the top polarizer **560** and the bottom polarizer **540** in the QDCF structure **500**. Another example of a compensation film is disclosed in T. Ishikawa and Xiang-Dong Mi, "Compensation of Various LCD Modes by Positive O-Plates," SID 06 DIGEST (2006), the contents of which are incorporated herein by reference. Because the compensation films replace the top and bottom polarizers **560** and **540**, the compensation films and the *E*-type polarizers would not be incorporated into a QDCF structure at the same time.

[0041] In some embodiments, a privacy filter film can also be incorporated into the QDCF structure **500** in combination with one or more of the above-mentioned techniques in order to reduce dark state light leakage in the QDCF structure. Privacy filter films are transmissive optical films that employ microlouvers that function similar to Venetian blinds that point straight out toward the viewer. Thus, the privacy filter films filter out high emission angled light and allow low emission angle light to be transmitted. As indicated in FIG. 5, a privacy filter film can be placed between the top polarizer **560** and the short-pass filter **570** before the QD layer **580**.

[0042] Referring to FIGS. 5 and 6, according to another embodiment, an improved QDCF structure **500** comprises a low-index material layer (LIML) layer **585** between the CF layer **590** and the QD layer **580** to minimize or eliminate the light efficiency loss due to the TIR effect. The QDCF structure **500** when viewed from top comprises an array of pixel regions and FIG. 6 is a schematic vertical cross-sectional illustration of some of the relevant layers in a pixel region in the QDCF structure **500**. FIG. 6 shows the short-pass filter **570** layer and above up to the cover glass **595**. The pixel region comprises a red sub-pixel **R**, a green sub-pixel **G**, and a blue sub-pixel **B**, defined by the respective color filters, red filter **591**, green filter **592**, and blue filter **593**, over the QD layer **580**. The black matrix **600** barriers are between the color filters **591**, **592**, and **593** extending down through the QD layer **580** defining the sub-pixel regions **R**, **G**, and **B**. The collimated blue light from the backlight

unit (BLU) is represented by the vertical arrows in the lower portion of FIG. 6. The blue light is remitted by the quantum dots in the **R**, **G**, and **B** sub-pixel regions of the QD layer **580** and transmitted through the respective color filters, **591**, **592**, and **593** and the cover glass **595**. As illustrated in FIG. 6, the LIML layer **585** between the QD layer **580** and the CF layer **590** are pixelated along with the sub-pixel color filters **591**, **592**, and **593**. The black matrix **600** between the sub-pixel color filters **591**, **592**, and **593** extend down into the LIML layer **585** defining the LIML **585** into sub regions corresponding to the sub-pixel color filters **591**, **592**, and **593**. The LIML **585** improves the light emission efficiency of the LCD. This effect is explained further with reference to FIGs. 7A and 7B.

[0043] As shown in the schematic illustration of FIG. 7A, in the conventional QDCF structure without an LIML layer, a lot of light from the QD layer **580** having high emission angle is lost due to total internal reflection (TIR) and recycling inside the CF layer **590** and the cover glass **595**. This effect is illustrated by the arrow **L_B** representing a high emission angle light from the QD layer **580**. The high emission angle light **L_B** will arrive at the cover glass-to-air interface **597** with a high incident angle and, thus, experience TIR at the cover glass-to-air interface **597**. The cover glass **595** is generally made of high index glass having a refractive index of about 1.5. Much of those light rays will not exit the LCD panel because those rays are likely to be absorbed by the color filters in the CF layer **590**. The absorption can be by a color filter of a different color or the same color, since a typical CF has 80% - 90% transmittance.

[0044] Referring to FIG. 7B, the QD layer **580** generates light omni directionally and, thus, emits light in all possible angles. Of the light emitted by the QD layer, the light rays with normal emission angle (*i.e.*, orthogonal to the QD layer **580**) or generally low-angle emission, exemplified by the arrow **L_A**, will transmit through the cover glass **595** and exit the LCD panel.

[0045] When the LIML **585** is between the QD layer **580** and the CF **590**, the TIR at the boundary between the QD layer **580** and the LIML **585** recycles the high-angle emission rays **L_B** within the QD layer **580** and convert them into low-angle rays **L_B'** that can exit the high index cover glass **595**. The recycling of the high-angle rays **L_B** within the QD layer **580** is the result of scattering within the QD layer. Thus, this increases the overall efficiency of the QDCF structure **500**.

[0046] In some embodiments, the QDCF LCD panel **500** can further comprise an additional LIML between the QD layer **580** and the short-pass filter layer (SPF) **570**. Such additional LIML can assist the SPF **570** in reflecting high angle incident light. This

additional LIML does not need to be pixelated and can be directly laminated on to the SPF 570.

[0047] Preferably, the interface between the LIML 585 and the QD layer 580 should not introduce too much scattering. Preferably, in order to control the scattering of the light at the interface between the LIML 585 and the QD layer 580, the planarity of the LIML and QD layer interfaces should be controlled so that the light energy scattered into rays having angles large enough to encounter TIR at the cover glass-to-air interface 597 is minimized.

Volumetric scattering from LIML 585 and surface scattering from the interface 587 between the LIML 585 and the QD layer 580 is beneficially controlled such that the light energy scattered into rays having angles large enough to encounter TIR at the cover glass-to-air interface 597 is minimized. The scattering of the films may be characterized by haze (in transmission) taking into account both volumetric and surface scattering. The planarity of the interface 587 between the LIML 585 and the QD layer 580 is controlled to limit the haze value, as measured according to ASTM D1003 standard, to be less than or equal to 50%, preferably less than or equal to 30%, and most preferably less than or equal to 5%.

[0048] The degree of improvement in the QDCF's luminous efficiency from the LIML will depend on the refractive index of the LIML 585. Any material with a refractive index lower than the refractive indices of the CF and the QD layer 580 can be used as the LIML 585. The larger the difference in the refractive indices between the QD layer 580 and the LIML 585, the better the performance of the LIML would be. This relationship of the refractive indices means that the QD layer 580 can be made with a refractive index higher than 1.5 (the refractive index of the cover glass 595), which will allow greater window of possible refractive indices for the LIML material. The cover glass 595 generally has a refractive index of 1.5.

[0049] Calculations show that the luminous efficiency of the QDCF will gradually increase as the refractive index of the LIML 585 decreases from 1.5 to 1.0. This data is plotted in FIG. 8. As the refractive index of the LIML goes from 1.5 to 1.0 on the x-axis, the relative luminous efficacy changes from 0.65 to about 1.025. According to an embodiment, LIML having a refractive index value within a range from 1.5 to 1.0, inclusive of the end points, is desired. According to some embodiments, the refractive index of the LIML is within a range from 1.4 to 1.0, preferably within a range from 1.3 to 1.0, and more preferably within a range from 1.2 to 1.0.

[0050] Some examples of nano-porous material with low index and low scattering properties that can be used for the LIML are disclosed in Werdehausen *et al.*, "Design rules

for customizable materials based on nanocomposites,” Optical Materials Express 8 (11), 3456 (2018). Additional examples of the possible materials for the LIML **585** are provided in the table below:

Material	Refractive index	Examples
Polymer	1.3-1.4	Acrylate, Propionate, Acetate, and Siloxane.
Porous material	1.07-1.16	Porous material having a refractive index as low as 1.07 described in Masato Yamaguchi, Hiroyuki Nakayama, Kazuhiro Yamada, and Hiroaki Imai, “Ultralow refractive index coatings consisting of mesoporous silica nanoparticles,” Optics Letters, 34(13), 2009). An example is silica with air pores.
		Nanoparticle-polymer composites above the decomposition temperature form hydrophobic films with refractive indices as low as 1.048 described for example in Venumadhav Korampally, Minseong Yun, Thiruvengadathan Rajagopalan, Purnendu K Dasgupta, Keshab Gangopadhyay and Shubhra Gangopadhyay (Journal Nanotechnology, Volume 20, Number 42, 2009). An example is polymethylsilsesquioxane nanoparticles.
		Ultra low refractive index (as low as 1.04), crack-free thick coatings (as thick as 3.6 microns) based on organosilicate nanoparticulate (NPO) networks developed, for example, by Venumadhav Korampally, Maruf Hossain, Minseong Yun, Keshab Gangopadhyay, Luis Polo-Parada and Shubhra Gangopadhyay (Twelfth International Conference on Miniaturized Systems for Chemistry and Life Sciences, October 12 - 16, 2008, San Diego, California, USA). An example is organosilicate nanoparticulate network.
		Mesoporous silica films with a refractive index of 1.14 for use in 2D photonic crystal waveguide systems described, for example, in Frank Marlow, Denan Konjhodzic, Helmut Bretinger and Hongliang Li (Advances in Solid State Physics, 2006, Volume 45/2006, 149-161).

[0051] Black matrix, located at the spaces between sub-pixels **R**, **G**, and **B**, block light that is extraneous to the display that would otherwise emerge on the viewing side of the

QDCF panel and thus reduce the overall CR. Generally, the blockage of the undesired light by the black matrix is achieved by the black matrix material reflecting the incoming light. The conventional black matrix comprises a reflective metal layer such as chromium. While most of the light reflected by the black matrix never finds its way into the final image, some of it does get turned around through scattering and through reflection at one or more of the several optical interfaces internal to the LCD panel structure and ends up contributing to the final image, thereby reducing the contrast level, *i.e.* diminished CR. Therefore, in exemplary QDCF panel structures, the black matrix is coated with a layer of light absorbing material such as a polymer or an oxide to generally reduce the unwanted reflection by the black matrix. In other examples, the black matrix is made with a photoresist resin in which a black pigment has been dispersed to reduce reflectivity.

[0052] Referring to FIG. 9, according to an embodiment of the present disclosure however, the black matrix structures **600** are configured with slanted sides and are partially reflective which also independently improves the light emission efficiency of the QDCF structure. Here, “partially reflective” feature only refers to the black matrix comprising reflective surfaces that are exposed to the QD layer **580**, with the remaining surfaces of the black matrix being the conventional light absorbing or non-reflective surfaces as mentioned above. FIG. 9 is a schematic illustration of an example of such black matrix structure **600**. The black matrix **600** are barriers between the color filters in the color filter layer **590** and extends down through the QD layer **580** defining the sub-pixel regions **R**, **G**, and **B** (see FIG. 6). The black matrix **600** comprises sides **602** that are slanted at an angle α so that in the sectional plan view shown in FIG. 9, the black matrix **600** has a substantially trapezoid shape that is narrower at the top near the cover glass **595** than at the bottom. Additionally, the sides **602** facing toward the CF layer **590** and the QD layer **580** are reflective while the remaining sides like the top side **603** that faces the cover glass **595** being non-reflective. The slant angle α of the sides **602** is 45 degrees with a deviation less than or equal to ± 20 degrees, preferably less than or equal to ± 10 degrees, and more preferably less than or equal to ± 5 degrees. In the QDCF devices utilizing blue source light, the slanted sides **602** result in the Red and Green light generated in the QD layer being “guided” or “trapped” in the QD layer **580** to be re-directed towards the viewer. The Blue source light could be either reflected by the black matrix **600** towards the viewer and absorbed by color filter (RG), or absorbed by the black matrix.

[0053] According to some embodiments, a QDCF LCD apparatus **500** is disclosed which comprises: a cover glass **595**; a back reflector layer **510**; a liquid crystal panel layer

550 between the cover glass and the back reflector layer; a backlight unit **520** (comprising a blue LED light source and light guide plate) between the liquid crystal panel layer **550** and the back reflector **510**, the backlight unit configured to generate image-forming light for the liquid crystal panel layer; a patterned quantum dot layer **580** between the cover glass and the liquid crystal panel layer; a color filter layer **590** between the cover glass and the quantum dot layer, the color filter **590** and the quantum dot layer **580** in combination configured to form a color by converting a wavelength of the image-forming light from the backlight unit and penetrated through the liquid crystal panel **550**; a bottom polarizer layer **540** located between the liquid crystal panel layer **550** and the backlight unit **520**; and a top polarizer layer **560** located between the liquid crystal panel layer and the quantum dot layer. In this embodiment of the QDCF LCD apparatus, one or more of the following enhancement features are also incorporated: (a) an LIML **585** provided between the color filter layer **590** and the quantum dot layer **580**; (b) the backlight unit configured to generate collimated image-forming light for the liquid crystal panel layer; (c) one or both of the bottom polarizer **540** and the top polarizer **560** are made of an *E*-type polarizer material; (d) the bottom polarizer **540** and the top polarizer **560** are each made of a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and (e) a privacy filter film provided between the top polarizer **560** and the quantum dot layer **580**.

[0054] In other embodiments, the QDCF LCD apparatus **500** comprises the LIML **585** between the color filter layer **590** and the quantum dot layer **580**, and one or more of the following enhancement features are also incorporated therein: (a) one or both of the bottom polarizer **540** and the top polarizer **560** are made of an *E*-type polarizer material; (b) the backlight unit configured to generate collimated image-forming light for the liquid crystal panel layer; (c) the bottom polarizer **540** and the top polarizer **560** are each made of a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and (d) a privacy filter film provided between the top polarizer **560** and the quantum dot layer **580**.

[0055] While preferred embodiments of the present disclosure have been described, it is to be understood that the embodiments described are illustrative only and that the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalence, many variations and modifications naturally occurring to those of skill in the art from a perusal hereof.

What is claimed is:

1. A quantum dot color filter (QDCF) liquid crystal display (LCD) apparatus comprising:
 - a cover glass;
 - a back reflector layer;
 - a liquid crystal panel layer between the cover glass and the back reflector layer;
 - a backlight unit between the liquid crystal panel layer and the back reflector, the backlight unit configured to generate image-forming light to the liquid crystal panel layer;
 - a quantum dot layer between the cover glass and the liquid crystal panel layer;
 - a color filter layer between the cover glass and the quantum dot layer, the color filter and the quantum dot layer in combination configured to form a color by converting a wavelength of the collimated image forming light;
 - a bottom polarizer layer located between the liquid crystal panel layer and the backlight unit;
 - a top polarizer layer located between the liquid crystal panel layer and the quantum dot layer; and
 - further comprising one or more of the following:
 - (a) a low-index material layer (LIML) between the color filter layer and the quantum dot layer;
 - (b) the backlight unit configured to generate collimated image-forming light to the liquid crystal panel layer;
 - (c) one or both of the bottom polarizer and the top polarizer comprise an *E*-type polarizer material;
 - (d) the bottom polarizer and the top polarizer each comprise a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and
 - (e) a privacy filter film between the top polarizer and the quantum dot layer.
2. The QDCF LCD apparatus of claim 1, comprising (a) and ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 50 %.
3. The QDCF LCD apparatus of claim 2, wherein the ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 30 %.

4. The QDCF LCD apparatus of claim 2, wherein the ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 5 %.
5. The QDCF LCD apparatus of claim 1, comprising (a) and the LIML's refractive index value is within a range from 1.5 to 1.0.
6. The QDCF LCD apparatus of claim 5, wherein the LIML's refractive index value is within a range from 1.4 to 1.0.
7. The QDCF LCD apparatus of claim 5, wherein the LIML's refractive index value is within a range from 1.3 to 1.0.
8. The QDCF LCD apparatus of claim 5, wherein the LIML's refractive index value is within a range from 1.2 to 1.0.
9. The QDCF LCD apparatus of claim 1, comprising (a); further comprising: a short-pass filter between the quantum dot layer and the top polarizer; and an additional LIML between the quantum dot layer and the short-pass filter layer.
10. A QDCF LCD apparatus of claim 1, comprising (e); further comprising a short-pass filter between the quantum dot layer and the top polarizer; and the privacy filter film is between the top polarizer and the short-pass filter.
11. The QDCF LCD apparatus of claim 1, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than or equal to ± 30 degrees.
12. The QDCF LCD apparatus of claim 1, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than equal to ± 20 degrees.
13. The QDCF LCD apparatus of claim 1, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than or equal to ± 15 degrees.

14. The QDCF LCD apparatus of claim 1, wherein the color filter layer and the quantum dot layer together comprising a plurality of pixel regions, each pixel region comprising a red sub-pixel region, a green sub-pixel region, and a blue sub-pixel region; and

the apparatus further comprising a black matrix barrier structure extending through the color filter layer and the quantum dot layer separating two adjacent sub-pixel regions, wherein the black matrix comprises side surfaces contacting the color filter layer and a quantum dot layer;

wherein the side surfaces of the black matrix are slanted at a 45 degree angle with a deviation less than or equal to ± 20 degrees.

15. The QDCF LCD apparatus of claim 14, wherein the side surfaces are slanted at a 45 degree angle with a deviation less than or equal to ± 10 degrees.

16. The QDCF LCD apparatus of claim 14, wherein the side surfaces are slanted at a 45 degree angle with a deviation less than or equal to ± 5 degrees.

17. The QDCF LCD apparatus of claim 14, wherein the side surfaces and the bottom surface of the black matrix are reflective.

18. A quantum dot color filter (QDCF) liquid crystal display (LCD) apparatus comprising:

a cover glass;

a back reflector layer;

a liquid crystal panel layer between the cover glass and the back reflector layer;

a backlight unit between the liquid crystal panel layer and the back reflector, the backlight unit configured to generate image-forming light to the liquid crystal layer;

a quantum dot layer between the cover glass and the liquid crystal panel layer;

a color filter layer between the cover glass and the quantum dot layer, the color filter and the quantum dot layer in combination configured to form a color by converting a wavelength of the collimated image forming light from the backlight unit and penetrated through the liquid crystal panel;

a bottom polarizer layer located between the liquid crystal panel layer and the backlight unit;

a top polarizer layer located between the liquid crystal panel layer and the quantum

dot layer;

a low-index material layer (LIML) provided between the color filter layer and the quantum dot layer; and

further comprising one or more of the following:

(a) one or both of the bottom polarizer and the top polarizer are made of an *E*-type polarizer material;

(b) the backlight unit configured to generate collimated image-forming light to the liquid crystal panel layer;

(c) the bottom polarizer and the top polarizer are each made of a compensation film comprising one or more of A-plate, C-plate, and biaxial-plate; and

(d) a privacy filter film provided between the top polarizer and the quantum dot layer.

19. The QDCF LCD apparatus of claim 18, wherein ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 50 %.

20. The QDCF LCD apparatus of claim 19, wherein the ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 30 %.

21. The QDCF LCD apparatus of claim 19, wherein the ASTM D1003 haze value for the interface between the LIML and the quantum dot layer is less than or equal to 5 %.

22. The QDCF LCD apparatus of claim 18, wherein the LIML's refractive index value is within a range from 1.5 to 1.0.

23. The QDCF LCD apparatus of claim 22, wherein the LIML's refractive index value is within a range from 1.4 to 1.0.

24. The QDCF LCD apparatus of claim 22, wherein the LIML's refractive index value is within a range from 1.3 to 1.0.

25. The QDCF LCD apparatus of claim 22, wherein the LIML's refractive index value is within a range from 1.2 to 1.0.

26. The QDCF LCD apparatus of claim 18, further comprising a short-pass filter between the quantum dot layer and the top polarizer; and

further comprising an additional LIML between the quantum dot layer and the short-pass filter layer.

27. A QDCF LCD apparatus of claim 18, comprising (d); further comprising a short-pass filter between the quantum dot layer and the top polarizer; and the privacy filter film is between the top polarizer and the short-pass filter.

28. The QDCF LCD apparatus of claim 18, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than or equal to ± 30 degrees.

29. The QDCF LCD apparatus of claim 18, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than or equal to ± 20 degrees.

30. The QDCF LCD apparatus of claim 18, wherein the collimated image-forming light produced by the backlight unit has a half-apex angle of less than or equal to ± 15 degrees.

31. The QDCF LCD apparatus of claim 18, wherein the color filter layer and the quantum dot layer together comprising a plurality of pixel regions, each pixel region comprising a red sub-pixel region, a green sub-pixel region, and a blue sub-pixel region; and

the apparatus further comprising a black matrix barrier structure extending through the color filter layer and the quantum dot layer separating two adjacent sub-pixel regions, wherein the black matrix comprises side surfaces contacting the color filter layer and the quantum dot layer;

wherein the side surfaces of the black matrix are slanted at a 45 degree angle with a deviation less than or equal to ± 20 degrees.

32. The QDCF LCD apparatus of claim 31, wherein the side surfaces are slanted at a 45 degree angle with a deviation less than or equal to ± 10 degrees.

33. The QDCF LCD apparatus of claim 31, wherein the side surfaces are slanted at a 45 degree angle with a deviation less than or equal to ± 5 degrees.

34. The QDCF LCD apparatus of claim 31, wherein the side surfaces and the bottom surface of the black matrix are reflective.

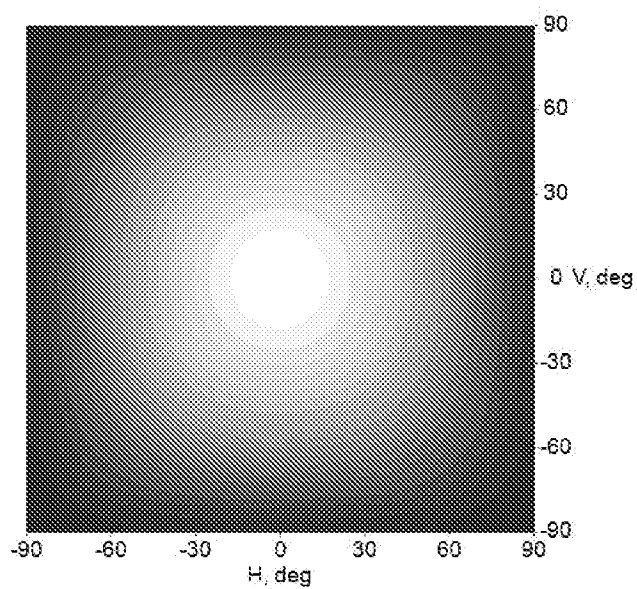


FIG. 1A
(Related Art)

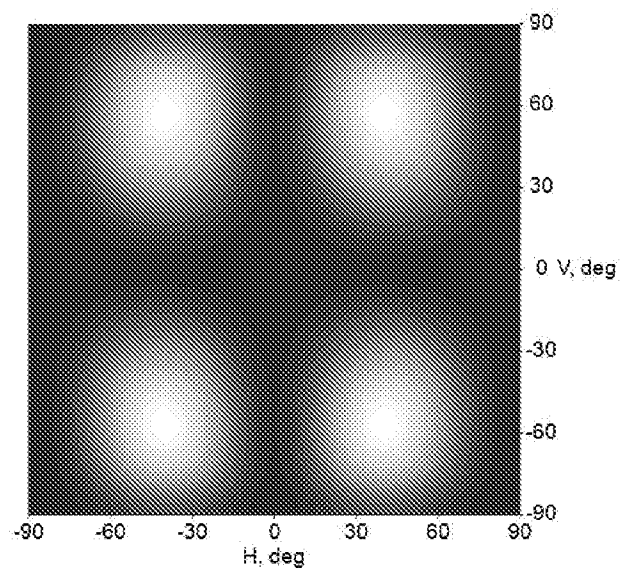


FIG. 1B
(Related Art)

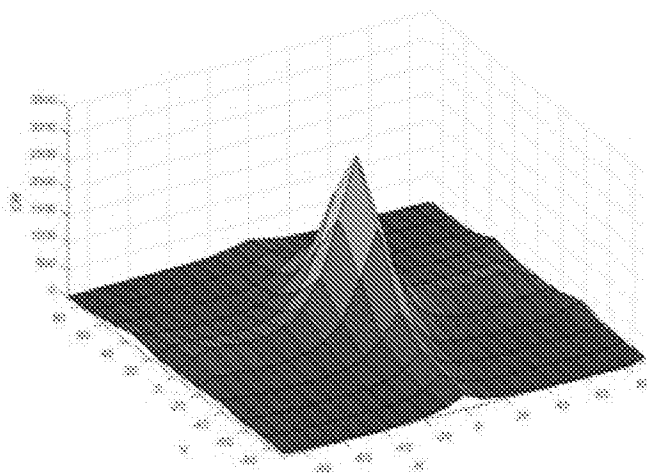


FIG. 2A
(Related Art)

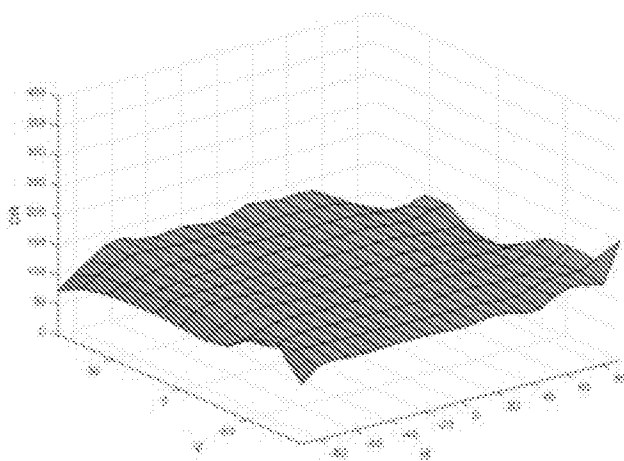


FIG. 2B
(Related Art)

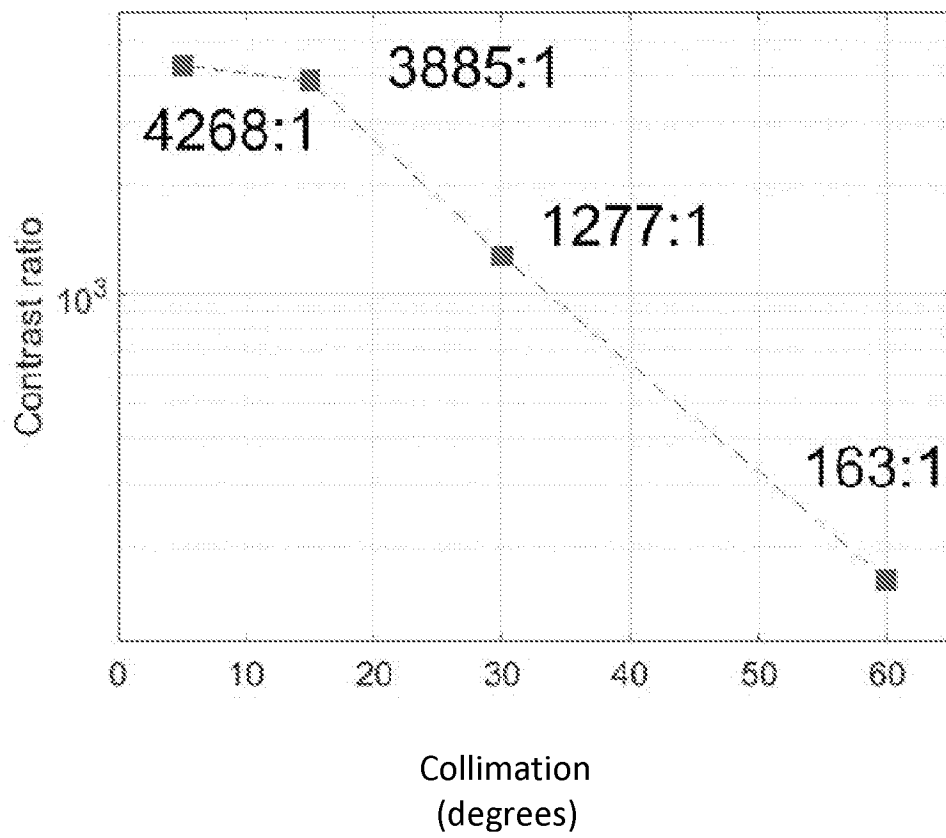


FIG. 3

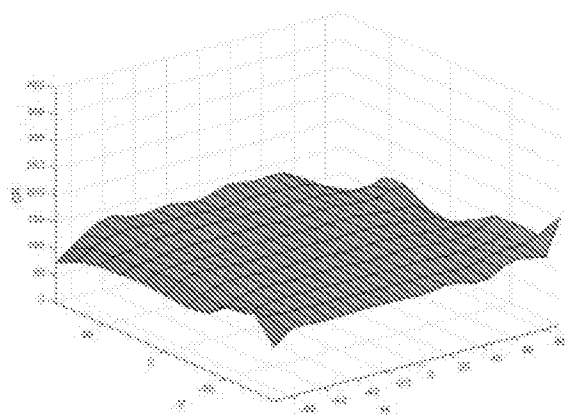


FIG. 4A

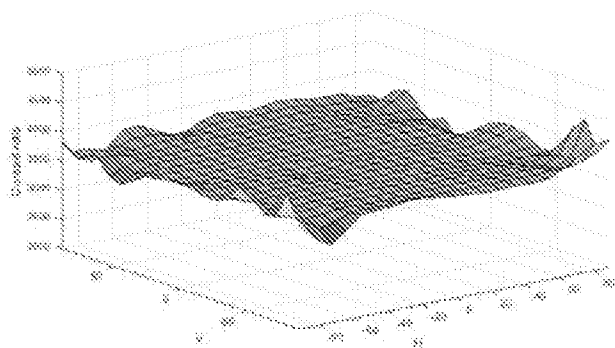


FIG. 4B

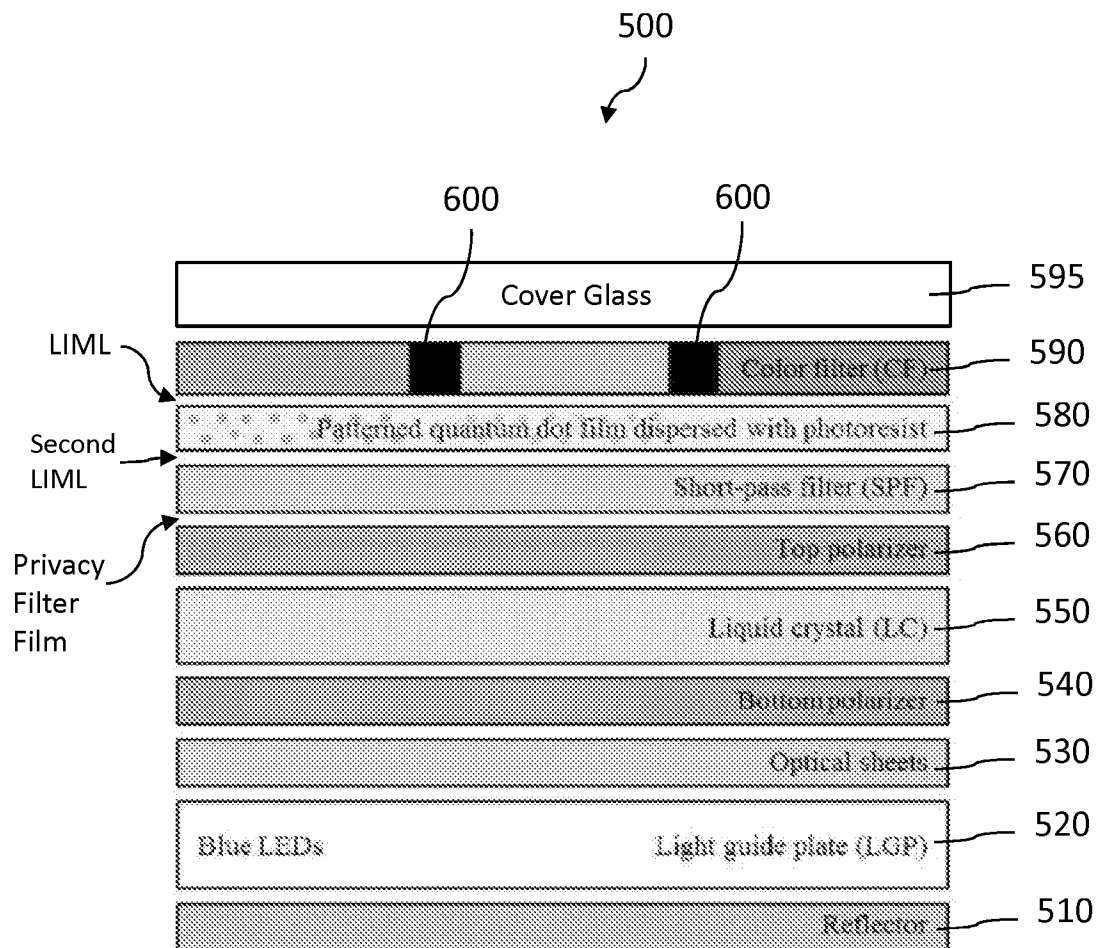


FIG. 5

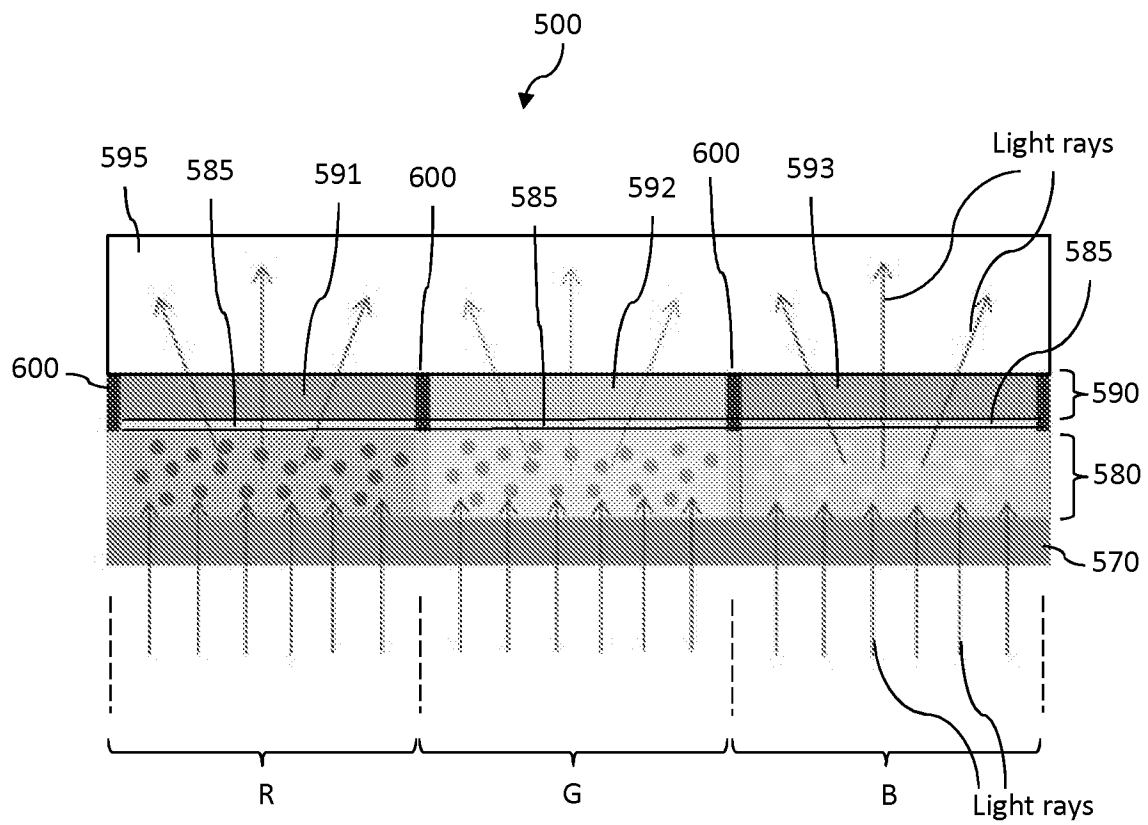


FIG. 6

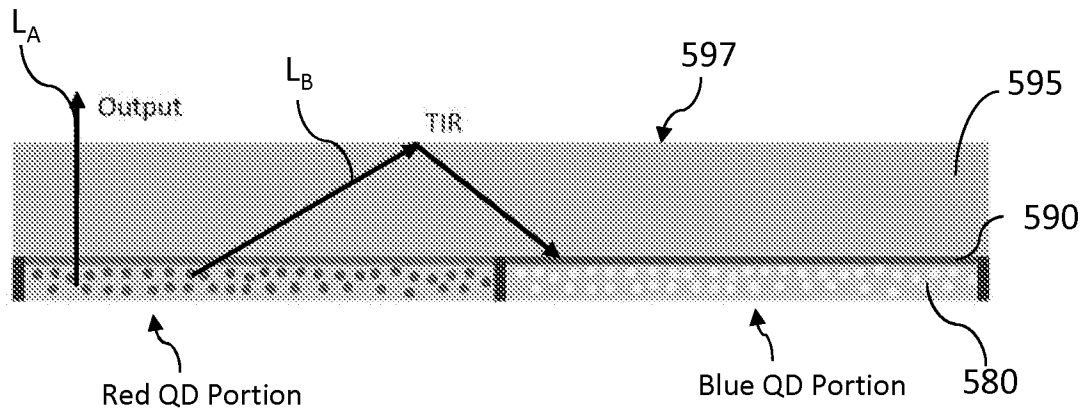


FIG. 7A
(Prior Art)

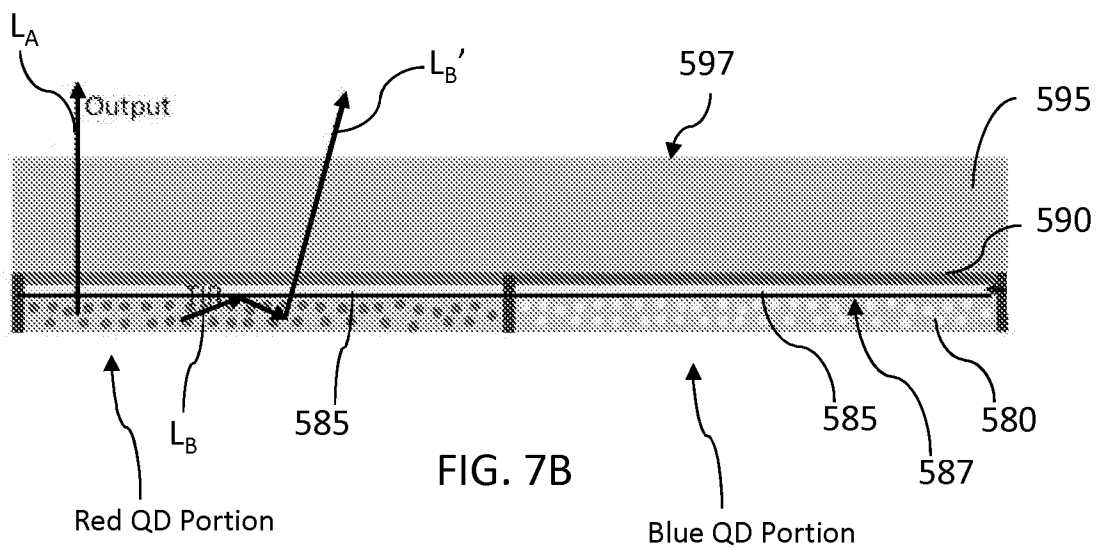


FIG. 7B

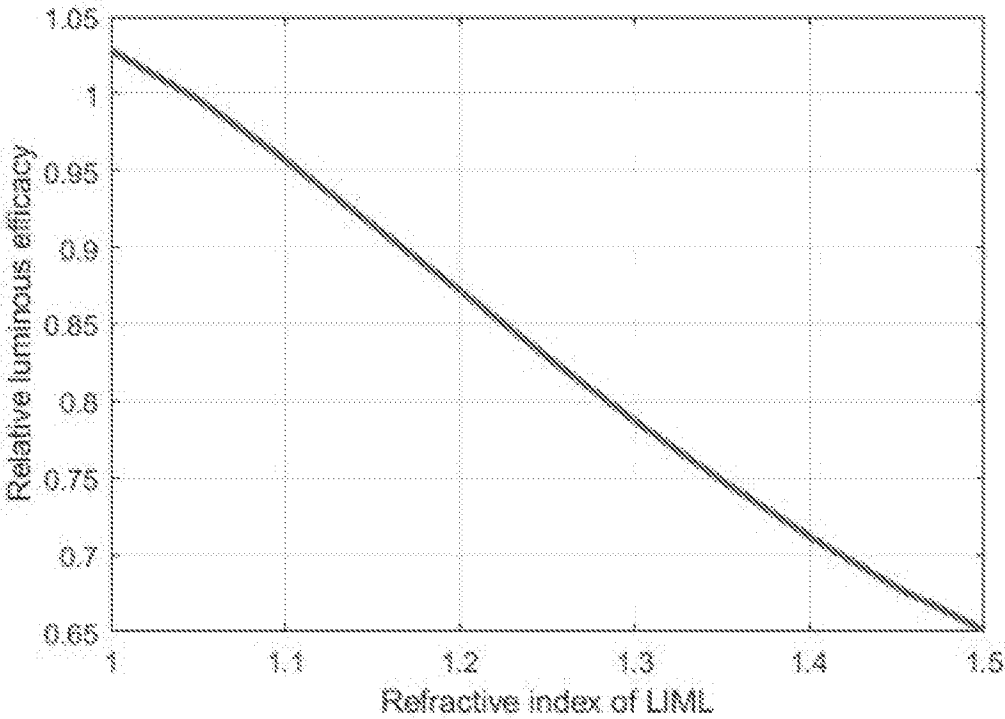


FIG. 8

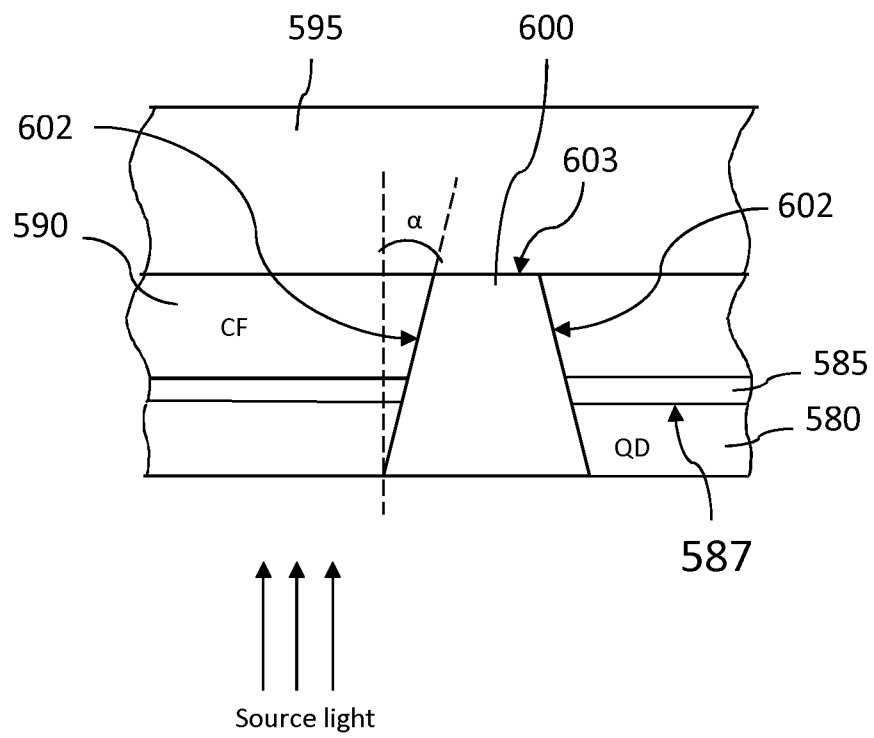


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/062526**A. CLASSIFICATION OF SUBJECT MATTER****G02F 1/1335(2006.01)i, G02F 1/017(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)

G02F 1/1335; F21K 99/00; G02F 1/017; G02F 1/13; G02F 1/1333; G02F 1/1334; G02F 1/13357; G02F 1/1343; G02F 1/1368

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: liquid crystal display (LCD), quantum dot, color filter, low-index material, polarizer, layer, backlight

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013-0010229 A1 (JONG-SUK SHIN et al.) 10 January 2013 paragraphs [0029], [0038], [0054]-[0065], [0090], [0106]; and figure 4.	1
A		2-34
Y	US 2015-0176775 A1 (APPLE INC.) 25 June 2015 paragraphs [0031]-[0032], [0041]-[0042], [0052]-[0058], [0085]; and figures 5-6, 21.	1
A	US 2017-0261778 A1 (SHENZHEN CHINA STAR OPTOELECTRONICS TECHNOLOGY CO., LTD.) 14 September 2017 paragraphs [0044], [0050]-[0053]; and figures 5-6.	1-34
A	KR 10-2016-0128801 A (SAMSUNG ELECTRONICS CO., LTD.) 08 November 2016 paragraphs [0095]-[0102]; and figure 7.	1-34
A	JP 6069418 B2 (AU OPTRONICS CORPORATION) 01 February 2017 paragraphs [0042]-[0052]; and figures 4A-4C.	1-34



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

16 March 2020 (16.03.2020)

Date of mailing of the international search report

16 March 2020 (16.03.2020)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2019/062526

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