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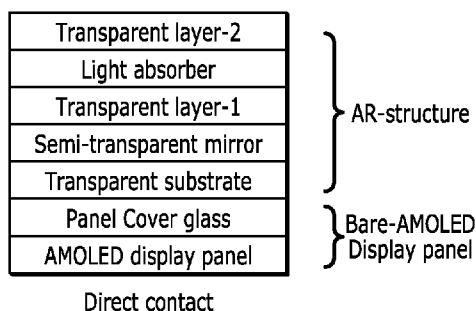
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FIG. 2



(57) Abstract: The present disclosure relates to asymmetric broadband light absorption-transmission structures which absorb ambient light while allowing for an active matrix organic light emitting (AMOLED) device light transmission from a display device. The anti-reflective AMOLED structures reduce the ambient light reflection and enhance the AMOLED light output. The structures described herein are ultrathin and comprise a light absorber layer between two transparent layers, and further comprise a reflective layer. The structures of the present disclosure may be formed by a roll-to-roll sputtering process allowing for high throughput mass production, low-cost, and flexible and ultrathin AMOLED display elements.

# ASYMMETRIC LIGHT ABSORPTION-TRANSMISSION ARCHITECTURE FOR ENHANCED AMOLED DISPLAY READABILITY UNDER HIGH-AMBIENT LIGHT

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## CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application claims priority to U.S. Provisional Application No. 63/262,125, filed October 5, 2021, which is incorporated by reference in its entirety.

## BACKGROUND

Unless otherwise indicated in the present disclosure, the materials described in the present disclosure are not prior art to the claims in the present application and are  
10   not admitted to be prior art by inclusion in this section.

Organic light emitting diodes (OLEDs) are useful to create optical displays in devices such as television screens, computer monitors, and portable systems such as smartphones, handheld game consoles and personal data assistants (PDAs). These display devices may comprise a layered construct with reflective cathode, an emissive  
15   layer, and a transparent anode, wherein application of an electrical current to the cathode and the anode generates light outward from the display device. Since the light is generated in both directions from the emissive layer, a reflective cathode is often used to redirect the emitted light outwards from the display device towards the viewer. One type of OLED display is an active matrix organic light emitting display device  
20   (AMOLED). An AMOLED display may consist of an active matrix of OLED pixels, generating light (luminescence) upon electrical activation, that have been deposited or integrated onto a thin-film transistor (TFT) array which functions as a series of switches to control the current flowing to each individual pixel. Typically, this continuous current flow is controlled by at least two TFTs at each pixel (to trigger the  
25   luminescence), with one TFT to start and stop the charging of a storage capacitor and the second to provide a voltage source at the level needed to create a constant current to the pixel, thereby eliminating the need for the very high currents required for passive-matrix OLED operation.

AMOLED displays may be problematic because of their highly reflective electrodes, which impairs the emitted display. Additionally, AMOLED displays consist of OLED pixels, where highly reflective electrodes cause high reflection of ambient light. Conventional solutions to this problem include utilizing linear polarizer film and/or one-quarter wavelength retardation film. However, these solutions may have delamination difficulties between the adhesive and the various layers, increased thickness, and limited output, e.g., about 43%.

Thus, there is a need for improved display characteristics in ambient light while maintaining increased OLED display device clarity and output.

## SUMMARY

The embodiments of the present disclosure generally relate to an asymmetric light absorption-transmission architecture (or structure) that absorbs ambient light to reduce reflection while also enhancing the OLED light output. The present disclosure is distinct from conventional polarizer concepts, in that it is ultrathin (nanometer scale), comprises a light absorber layer between two transparent layers, and a semi-transparent reflective mirror layer underneath the layers and adjacent to the OLED display device surface. The thickness of the present anti-reflection (AR) structure is less than 200 nm, which may be formed by a roll-to-roll sputtering process having high throughput, allowing mass production. In this way, there is potential for low-cost, flexible, and ultrathin structures that enhance the readability of an OLED display device under high ambient light conditions.

In some embodiments, the asymmetric light absorption-transmission structure may be an asymmetric broadband light absorption-transmission structure, which absorbs more ambient light, reducing the ambient light reflection, while allowing enhanced transmission from the OLED light display.

Some embodiments include an asymmetric light absorption structure comprising: a reflective layer; a first transparent layer, disposed upon and in optical communication with the reflective layer; a light absorber layer, disposed upon and in optical communication with the first transparent layer; and a second transparent layer, disposed upon and in optical communication with the light absorber layer; wherein the

reflective layer, the first transparent layer, the light absorber layer, and the second transparent layer are disposed upon an active matrix organic light emitting display (AMOLED) display device; wherein incident light traveling through the asymmetric light absorption structure is asymmetrically absorbed and asymmetrically reflected; and  
5 wherein asymmetric light absorption decreases ambient light reflection, while asymmetric light transmission enhances the light emission of the AMOLED device.

Some embodiments include a method for preparing an asymmetric light absorption structure comprising: disposing a reflective layer upon an AMOLED substrate; disposing a first transparent layer comprising a transparent material in  
10 optical communication with the reflective layer; disposing a light absorbing layer upon the first transparent layer; and disposing a second transparent layer upon the light absorbing layer; wherein the layers are disposed upon and in optical communication with one another.

#### 15 BRIEF DESCRIPTION OF THE DRAWINGS

**FIG. 1** is a schematic of an embodiment of the anti-reflection (AR) structure incorporating an AMOLED display as described herein.

**FIG. 2** is a schematic of an embodiment of the AR-structure in direct contact with a bare-AMOLED display panel.

20 **FIG. 3** is a schematic of an embodiment of the AR-structure coupled with an AMOLED display panel with OCA film or epoxy.

**FIG. 4** is a schematic of an embodiment of the AR-structure directly formed on the bare display panel glass.

**FIG. 5** is a schematic of an embodiment of the AR-structure.

25 **FIG. 6** is a graph showing the light transmittance (T%) and reflectance (R%) for incident light from both directions for of an embodiment of the AR-structure.

**FIG. 7** is a graph showing the asymmetric light absorption for the AR-structure for light from the two opposite directions (ambient light direction and OLED light direction).

**FIG. 8** is a schematic of negative coupling of AR-structure with bare-AMOLED  
30 display panel.

**FIG. 9** is a schematic of positive coupling AR-structure with bare-AMOLED display panel.

**FIG. 10** is a schematic of three types of configurations for measurement of the reflectance and OLED light output (color and brightness) of an embodiment of the AR-structure.

**FIG. 11** is a graph showing the wavelength dependence of the R% for (a) bare AMOLED display, (b) commercial AMOLED display with polarizer retardation AR-structure. (c) the bare AMOLED display of an embodiment of the AR-structure.

**FIG. 12** is a graph showing the total reflectance for the three types of configurations: (a) bare AMOLED display, (b) commercial AMOLED display with polarizer retardation AR-structure. (c) the bare AMOLED display of an embodiment of the AR-structure.

**FIG. 13a** is a graph showing CIE(x) of the white OLED light output from the AMOLED display panel with three types of configurations: (1) bare panel without AR-structure, (2) commercial AMOLED display with its polarizer-retardation AR-structure (3) bare AMOLED display of an embodiment of the AR-structure.

**FIG. 13b** is a graph showing CIE(y) of the white OLED light output from the AMOLED display panel with three types of configurations: (1) bare panel without AR-structure, (2) commercial AMOLED display with its polarizer-retardation AR-structure (3) bare AMOLED display of an embodiment of the AR-structure.

**FIG. 14** is a graph showing the viewing angular dependence of the AMOLED display panel with and without AR-structures.

### DETAILED DESCRIPTION

The embodiments herein relate to AMOLED displays having enhanced anti-reflective properties.

The asymmetric broadband light absorption-transmission structure presented herein may comprise: a transparent substrate; a semi-transparent semi-reflective mirror layer (reflective layer) disposed above the substrate; a first transparent layer, disposed above the reflective layer; a light absorber layer, disposed above the first transparent layer; and a second transparent layer, disposed above the light absorber

layer; wherein incident light passes through the second transparent layer into the light absorber layer and at least a portion of the light that passes through the light absorber layer and the first transparent layer and is partially reflected back by the reflective mirror layer and partially transmitted to OLED pixels when it is attached/coupled to an emissive OLED display device or bare AMOLED display panel.

In some embodiments, an AR-structure may absorb incident ambient light and prevent its reflection from an OLED display device. The incident light may be reemitted from the OLED pixels for minimum ambient light reflection, while the display device emits light from OLED pixels having less light absorption by the AR-structure through the AR-structure described herein. It is believed that interference cancellation enhances ambient light absorption, while the asymmetric light reflectance of the AR-structure enhances the OLED light emission towards the viewer.

The AR-structures described herein have the function of higher broadband light absorption of ambient light than OLED emitting light, and the OLED emission has higher transmission than ambient light, such that anti-reflection and enhancing the OLED light output may be realized in the AR-structure described herein.

In some embodiments, the semi-transparent semi-reflective mirror layer (also referred to as the reflective layer) may comprise a buffer layer and a highly reflective layer. In some embodiments, the reflective layer may comprise a metal or metal alloy. In some embodiments, the buffer layer may comprise copper (Cu) and/or chromium (Cr), and the highly reflective layer may comprise silver (Ag). In some embodiments, the first transparent layer may comprise a transparent insulating layer. In some embodiments, the first transparent layer may comprise an oxide, nitride, or halide. In some embodiments, the light absorber layer comprises metals, partially oxidized metal, or semiconductors. In some embodiments, the second transparent layer may comprise a transparent insulating layer. In some embodiments, the nominal thickness of the reflective layer disposed in or upon the coated surface can be about 0.0001 nm to about 2 nm or about 0.001 nm to about 0.75 nm. In some embodiments, the reflective layer may be a discontinuous layer defining apertures or voids between islands of metal material. In some embodiments, the reflective layer can be a continuous, uniform, and/or ultrathin layer.

The term "transparent" as used herein includes a property in which the corresponding layer has a minimal amount of light absorption and it transmits or passes light, and it can have a transmittance of light of at least about 80% and up to about 100%.

5       The term "broadband" as used herein includes plural wavelength light, e.g., light having a wavelength spectrum of about 400 nm to about 750 nm.

The term "ultrathin" as used herein refers to a thickness on the order of nanometers thick.

10       The term of "asymmetric light absorption" means the light absorption for light from the ambient light direction(s) is different from the light absorbed by the OLED display device in the direction of the viewer.

The term of "asymmetric light transmission" means the light transmittance for ambient light through the designed AR-structure is lower than the display OLED pixels emitting light through the AR-structure towards the viewer.

15       Use of the term "may" or "may be" should be construed as shorthand for "is" or "is not" or, alternatively, "does" or "does not" or "will" or "will not," etc. For example, the statement "the light absorbing material may comprise a metal" should be interpreted as, for example, "In some embodiments, the light absorbing material comprises a metal," or "In some embodiments, the light absorbing material does not  
20       comprise a metal."

25       The present disclosure generally relates to anti-reflection (or AR-) elements, which include materials having one or more optical properties that may provide varying optical absorption, transmittance, and reflectance. Particularly, but not exclusively, the present disclosure relates to a broadband asymmetric light absorber transmission and reflectance structures utilizing ultrathin light absorber layers with a structure exhibiting enhanced broadband anti-reflection.

30       The present disclosure generally relates to an asymmetric broadband light absorption-transmission structure. This structure absorbs more ambient light than is emitted by the OLED light from the display, reducing the ambient light reflection and thus enhancing the OLED light output. The present disclosure is distinct from conventional polarizer concepts as it is ultrathin (in nanometer scale), consists of a

light absorber layer positioned between two transparent layers, and comprises a reflective mirror layer underneath. In some embodiments, the reflective (or mirror) layer may be referred to as a semi-transparent-semi-reflective layer. In some embodiments the reflective layer may be referred to as a semi-transparent layer. In some embodiments the reflective layer may be referred to as a semi-reflective layer. The thickness of the AR-structure described herein may be less than 200 nm, which can be formed by a roll-to-roll sputtering process having the potential for high throughput mass production. Therefore, the present disclosure relates to broadband light absorption-transmission structures that are believed to be low-cost, flexible, ultrathin, and which enhance the readability and/or clarity under high ambient light conditions.

Asymmetric broadband light absorption/transmission structures are described herein. In some embodiments, the broadband asymmetric light absorption and transmission structure may comprise: a transparent and reflective mirror layer disposed upon the substrate; a first transparent layer, disposed upon the reflective layer; a light absorber layer disposed upon the first transparent layer; and/or a second transparent layer disposed upon the light absorber layer. In some embodiments, incident light passes through the second transparent layer into the light absorber layer and at least a portion of the light passes through the light absorber layer and the first transparent layer and is partially reflected back by the reflective layer. In some examples, incident light from opposite directions travels through the structure having asymmetric light absorption and reflection, and partially transmits to the OLED pixels. In some embodiments, the asymmetric filter structure may comprise a transparent substrate. In some embodiments, the asymmetric light transmission enhances the OLED light emission through the structure.

In some embodiments, an AMOLED display device or element comprising a bare AMOLED display and an anti-reflection structure of the present disclosure is designed in such a way that it absorbs much of the incident ambient light and prevents the reflection of the ambient light. In some embodiments, the display emitting light from the AMOLED pixels has less light absorption by the AR-structure described herein, and has higher light transmission through the AR-structure. It is believed that

interference cancellation enhances ambient light absorption, while the asymmetric light reflectance of the AR-structure enhances the OLED light emission towards the viewer.

Some embodiments include a broadband light absorber structure comprising:  
5 a substrate, such as an AMOLED display device; a semi-transparent reflective layer disposed above the substrate; a first transparent layer, disposed above the semi-transparent reflective layer; a light absorber layer, disposed above the first transparent layer; and a second transparent layer, disposed above the light absorber layer; wherein incident light passes through the second transparent layer into the light  
10 absorber layer and at least a portion of the light may pass through the light absorber layer and the first transparent layer and be partially reflected back by the semi-transparent reflective layer; wherein the incident light interacts with reflected light of the opposite phase thereby causing interference cancellation to decrease the reflected light so as to enhance light absorption in the light absorber layer.

15 In some embodiments, the reflective layer may comprise a highly reflective material. In some embodiments, the reflective layer may comprise a first metallic layer and a second metallic layer. In some embodiments, the first metallic layer may comprise copper. In some embodiments, the first metallic layer may comprise chromium. In some embodiments, second metallic layer may comprise a noble metal.  
20 In some embodiments, the noble metal may comprise silver. In some embodiments, the reflective layer may comprise a discontinuous layer defining apertures or voids between islands of metallic material. In some embodiments, the reflective layer may comprise a continuous, uniform layer. In some embodiments, the reflective layer may comprise a buffer layer and a highly ultrathin reflective metal layer. In some  
25 embodiments, the buffer layer may help to form a thin film layer of the highly reflective material, e.g., a thickness such as less than 10 nm. In some embodiments, the buffer layer may comprise Cu, Cr, or Ag. In some examples, the reflective layer may allow at least 20-50% transmittance (e.g., 30% light transmission), allowing OLED pixels emitting light output. In some embodiments, 36% light transmission of the AR-structure  
30 can have more than 44% OLED light output through an AR-structure described herein. The reflective layer may have a reflectance characteristic of between 20% to 50%

(e.g., reflectance more than 30%), to produce asymmetric light absorption and reflection through the AR-structures described herein.

In some embodiments, the first transparent layer may comprise a transparent insulating layer. In some embodiments, the first transparent layer may comprise an oxide, nitride, or halide. In some embodiments, the light absorber layer comprises metals, partially oxidized metals, semiconductors, or combinations thereof. In some embodiments, the second transparent layer can comprise a transparent insulating layer.

In some embodiments, the first transparent layer can have less than about 10% light absorption, less than about 5% light absorption, less than about 1% light absorption, less than about 0.5% light absorption, or no light absorption.

In some embodiments, the second transparent layer can have less than about 10% light absorption, less than about 5% light absorption, less than about 1% light absorption, less than about 0.5% light absorption, or no light absorption.

In some embodiments, the first and second transparent layers may comprise different materials. In some embodiments, the first and second transparent layers may comprise the same materials. In some embodiments, the first and second transparent layers may have different thicknesses. In some embodiments, the first and/or second transparent layers may comprise a material having a refractive index between 1 and 3.

**FIG.1** is an embodiment of a asymmetric broadband light absorption-transmission structure comprising: a transparent substrate; a semi-transparent-semi-reflective layer (or reflective layer) disposed above the substrate; a first transparent layer, disposed above the reflective layer; a light absorber layer, disposed above the first transparent layer; and a second transparent layer; wherein incident light from opposite directions through the structure have asymmetric light absorption and reflection. When an emissive OLED display device or bare AMOLED display device is attached to the structure, the asymmetric light absorption decreases the ambient light reflection, and asymmetric light transmission enhances the OLED light emission through the device's architecture.

In some embodiments, the reflective layer consists of one or two metal layers, with at least 20%-50% transmittance, and 20-50% reflectance. In some embodiments, the first and the second transparent layers may be the same materials or different materials, and have less than about 10% light absorption, less than about 5% light absorption, less than about 1% light absorption, less than about 0.5% light absorption, no light absorption. In some embodiments, the light absorber layer comprises an ultrathin metal or metal alloys. In some embodiments, the thickness of the structure layers is arranged in such a way that interference cancellation occurs wherein the incident light from the reflective layer has no reflection, or very small reflection. In some embodiments, the asymmetric broadband light absorption-transmission structure shown in **FIG. 1** can be coupled to the AMOLED display panel with adhesive layer or simple air gap. In some embodiments, the asymmetric broadband light absorption-transmission structure in **FIG. 1** can be directly formed on the cover glass of AMOLED display panel.

In some embodiments, the asymmetric light absorption structure may be coupled to the transparent substrate. In some embodiments, the coupling may comprise an adhesive layer. In some embodiments, the coupling may comprise a simple air gap. The coupling of the AR-structure is illustrated in **FIGs. 2, 3, and 4**. **FIG. 2** illustrates the direct contact of AR-structure with a bare-AMOLED display panel. **FIG. 3** illustrates the AR-structure coupled with AMOLED display panel with OCA film or epoxy. **FIG. 4** illustrates the AR-structure directly formed on the bare display panel glass.

One embodiment is shown in **FIG. 5**. **FIG. 6** shows the light transmittance and reflectance from both directions from the depiction in **FIG. 5**. It can be seen from **FIG. 6** that the light transmittance (T%) is almost flat in the visible range, indicating the AR-structure of the present disclosure performs well through the visible wavelength, having broadband light transmittance.

The AR-structure light transmittance T% and reflectance R% for incident light from both directions is shown in the figures. The transmittance is the same for both directions when the AR-structure stands alone without coupling to the AMOLED display, it has high reflectance when the incident light from the substrate side (OLED

light), and it has very low reflectance of the incident light from the film structure side (ambient light). The high reflectance of the OLED light by the AR-structure reflected back by the reflective electrode of the OLED enhances the light transmittance of OLED from the AR-structure.

**FIG. 7** shows the asymmetric light absorption through the AR-structure for incident light from the two opposite directions. For light from the two opposite directions (ambient light direction and OLED light direction) it has 43% absolute value of absorbance A% difference average from 400 nm to 800 nm wavelength (See Table 1).

**Table 1:**

| Incident light from:     | T%    | R%    | A%    |
|--------------------------|-------|-------|-------|
| Substrate (OLED) side    | 29.2% | 45.5% | 25.2% |
| Film (AR-structure) side | 30.0% | 1.6%  | 68.4% |
| $\Delta$                 |       | 43.9% | 43.2% |

The AR-structure coupled to an orange-color OLED display device when both coupled directions (positive coupling and negative coupling) are described in **FIG. 8** and **FIG. 9**. As shown in **FIG. 8**, an embodiment of the AR-structure is negatively coupled to an OLED display device. As shown in **FIG. 9**, an embodiment of the AR-structure is positively coupled to an OLED display device. In **FIGs. 8** and **9**, the coupling is simply direct physical contact of the AR-structure and the OLED display device without any coupling materials as described in **FIG. 2**.

The OLED display device light output (transmittance) though the two types of couplings are 32.8% for negative coupling (**FIG. 8**) and 49.8% for positive coupling (**FIG. 9**). The 32.8% OLED light output is similar to the AR-structure T% when it stands alone (Table 1), but the light output of 49.8% when it is positively coupled to the OLED display device is much higher than the negative-coupling. This is the asymmetric light transmittance of OLED and ambient light through the AR-structure of the current disclosure. When the AR-structure of the present disclosure is applied to a

commercial AMOLED display, for comparison, three types of configurations for measurement (**FIG. 10**) of the reflectance and OLED light output (color and brightness). The types of configurations for the measurement are as follows:

- (1) AMOLED display w/o AR-structure (**FIG. 10a**)
- 5 (2) AMOLED display with commercial polarizer-retardation film AR-structure (**FIG. 10b**)
- (3) AMOLED display with designed AR-structure of the current disclosure (**FIG. 10c**)

The light reflectance (R%) is measured by Filmetrics thin film analyzer with  
 10 model number F10-RT-UV, the reflectance measured by this Filmetrics system is the specular reflectance only as shown in **FIG. 11**, it does not include the diffused light that caused by the patterned AMOLED pixels. **FIG. 11** shows the wavelength dependence of the R% for (a) bare AMOLED display; (b) commercial AMOLED display with polarizer retardation AR-structure; (c) the bare AMOLED display with  
 15 current disclosure AR-structure. For total light reflectance including the diffused lights was measured by Ultrascan Pro as shown in **FIG. 12**. **FIG. 12** shows the total reflectance for the three types of configurations: (a) bare AMOLED display; (b) commercial AMOLED display with polarizer retardation AR-structure; (c) the bare AMOLED display with current disclosure's AR-structure.

20 The specular and total reflectance mean values from 400 to 750 nm wavelength for the three types of configurations are shown in Table 2.

**Table 2:**

| 400-750nm<br>mean | AMOLED<br>display panel<br>without AR | AMOLED display panel<br>w/ commercial polarizer-<br>retardation AR | AMOLED display<br>panel w/ AR of<br>current disclosure |
|-------------------|---------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------|
| Spectral<br>R%    | 16.6%                                 | 4.4%                                                               | 3.9%                                                   |
| Total R%          | 55.0%                                 | 5.3%                                                               | 8.9%                                                   |

The AR structure of the present disclosure shows better performance for specular reflectance total reflection, which may be further improved with other materials and thickness tuning.

When the AMOLED display panels show a white color screen, the viewing-  
5 angular-dependence of the OLED light output are measured by GS-1164 Spectroradiometer, Gamma-Scientific. The color coordinate CIE(x,y) and brightness have been measured. The CIE(x) and CIE(y) of the white OLED light output from the AMOLED display panel with three types of configurations: (1) bare panel without AR-structure; (2) commercial AMOLED display with its polarizer-retardation AR-structure;  
10 (3) bare AMOLED display panel with current disclosure's AR-structure are shown in **FIG. 13(a)** and **13(b)**. It can be seen from **FIG. 13(a)** and **13(b)**, that the commercial AR-structure of polarizer with retardation film changes the original bare AMOLED display color, while with current disclosure's AR-structure color coordinates CIE(x,y) is similar as the original bare AMOLED display color.

15 The viewing angular dependence of brightness of the display with and without the AR-structures of the current disclosure is shown in **FIG. 14**. The average relative brightness through 0 to 60 degree viewing angles for AMOLED display with polarizer-retardation AR-structure (commercial source) is 42% relative the bare panel, and the current disclosure's AR-structure relative light output is 50.8%.

20 Examples of suitable AMOLED display devices include, but are not limited to "Super AMOLED" branded SAMSUNG displays used in conjunction with Samsung Galaxy S III; Super AMOLED Advanced brand optical displays used in conjunction with Motorola Droid RAZR and HTC One S display devices; "Super AMOLED Plus" brand SAMSUNG displays, e.g., Samsung Galaxy S II and Samsung Droid Charge  
25 smartphone; "HD Super AMOLED Plus" brand SAMSUNG displays, e.g., Samsung Galaxy Note, Galaxy Nexus and Galaxy S III; "Full HD AMOLED" brand SAMSUNG displays, e.g., Samsung Galaxy S 4, Galaxy S5, and Samsung Galaxy Note 3 display devices; "Quad HD Super AMOLED" brand AU Optronics displays and SAMSUNG displays, e.g., Samsung Galaxy Note 4 and Galaxy Note 5 Broadband LTE-A and  
30 Samsung Galaxy S6 and S7.

In some embodiments, the transparent materials may be SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub>, AlN, WO<sub>3</sub>, and or MoO<sub>3</sub>. Suitable transparent materials can also be seen in Table 3 below:

**Table 3:**

| Compound                       | Refractive index at 550 nm |
|--------------------------------|----------------------------|
| Acrylic                        | 1.49                       |
| SiO <sub>2</sub>               | 1.46                       |
| Quartz                         | 1.55                       |
| Al <sub>2</sub> O <sub>3</sub> | 1.77                       |
| ITO                            | 1.95                       |
| TiO <sub>2</sub>               | 2.66                       |

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In some embodiments, the first transparent layer may have a thickness of about 1-100 nm, about 1-2 nm, about 2-3 nm, about 3-4 nm, about 4-5 nm, about 5-10 nm, about 10-20 nm, about 20-40 nm, about 40-60 nm, about 60-80 nm, about 80-100 nm, about 15-70 nm, about 45-95 nm, or about 30 nm, about 50 nm, about 55 nm, about 70 nm, about 100 nm, or any thickness in a range bounded by any of these values.

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In some embodiments, the second transparent layer may have a thickness of about 1-100 nm, about 1-2 nm, about 2-3 nm, about 3-4 nm, about 4-5 nm, about 5-10 nm, about 10-20 nm, about 20-40 nm, about 40-60 nm, about 60-80 nm, about 80-100 nm, about 15-70 nm, about 45-95 nm, or about 30 nm, about 50 nm, about 55 nm, about 70 nm, about 100 nm, or any thickness in a range bounded by any of these values.

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In some embodiments, the AR-structure element can comprise the same or different materials for the two transparent layers. The refractive index and layer thickness may be arranged in a way that ambient reflection light may be largely canceled by interference and the majority of light will be absorbed in the ultra-thin light absorber layer. In some embodiments, when the transparent layers have the same or similar refractive index, the layer more proximal to the exterior impinging light and more distal from the reflective surface, may be thicker to provide a layer that has a greater refractive index value, e.g., a greater value of thickness of transparent layer

20

times the thickness of the respective layer. For example, where the first and second transparent layers comprise silica dioxide, the first transparent layer (more proximal to the reflective layer and distal to the impinging incident light), may be between 15 and 70 nm thick (e.g., 30 nm thick), and the second transparent layer, that more distal to the reflective layer (and proximal to the impinging incident light) may be between 45 and 95 nm thick, e.g., 55 nm thick. In some embodiments, the first and second dielectric layers may comprise different dielectric materials, e.g., one having a higher refractive index. In some embodiments, the first and second transparent layers may have the same thickness, but may comprise materials having different refractive indices.

In some embodiments, the AR-structure element may comprise a light absorbing layer. The absorbing layer may comprise light absorbing material. In some embodiments, the light absorbing material may comprise a metal, such as tungsten (W), nickel (Ni), chromium (Cr), aluminum (Al), manganese (Mn), molybdenum (Mo), or a combination thereof. In some embodiments, the light absorbing material may be a partially oxidized metal. In some embodiments, the partially oxidized metal may be  $WO_x$ , wherein  $x$  is 3 or less (for example,  $WO_2$ ). It is believed these materials share the characteristic of absorbing light by electron oscillations, for example, the free electrons in metals or locally-free electrons in some semiconductors such as  $WO_3$ . In some embodiments, the light absorber material may comprise semiconductors, including organic semiconductors, inorganic semiconductors, or a combination thereof. In some embodiments, the absorbing layer may comprise Mo. In some embodiments, the light absorbing layer may have a thickness of about 1-30 nm, about 1-2 nm, about 2-3 nm, about 3-4 nm, about 4-5 nm, about 5-6 nm, about 6-7 nm, about 7-8 nm, about 8-9 nm, about 9-10 nm, about 10-12 nm, about 12-15 nm, about 15-20 nm, about 20-25 nm, about 25-30 nm, 5-10 nm, 6-8 nm, or about 7 nm, or any thickness in a range bounded by any of these values.

The AR-structures of the present disclosure are arranged in such a way that incident (or ambient) light impinging the top surface of the second transparent layer interferes with the reflected light from the reflective layer, causing destructive interference at the top surface of the second transparent layer. In this way, light

reflection from the top surface of the second transparent layer is reduced, which leads to light confinement in the light absorber layer and results in enhancement of the ambient light absorption in the ultra-thin light absorber layer. This is the light cancellation by interference.

5           In some embodiments, a method for preparing a light absorber structure is described. In some embodiments, the method may comprise providing a substrate. In some embodiments, the method may comprise providing a semi-reflective-transmissive layer. In some embodiments, the method may comprise providing a first transparent layer wherein the first transparent layer may comprise a transparent  
10   material and in optical communication with the first transparent layer. In some embodiments, the method may comprise providing a light absorbing layer. In some embodiments, the method may comprise providing a second transparent layer. In some embodiments, the aforementioned layers may be disposed atop one another in the aforementioned order or stack.

15

## EMBODIMENTS

**Embodiment 1.** An asymmetric light absorption structure comprising:  
a semi-transparent-semi-reflective layer;

5 a first transparent layer, disposed above the semi-transparent-semi-reflective layer;

a light absorber layer, disposed above the first transparent layer; and

a second transparent layer, disposed above the light absorber layer,

wherein incident light from opposite directions travels through the structure

10 having asymmetric light absorption and reflection,

wherein asymmetric light absorption decreases ambient light reflection, while asymmetric light transmission enhances the OLED light emission through the architecture.

**Embodiment 2.** The asymmetric light absorption structure of embodiment

15 1, further comprising a transparent substrate, wherein the semi-transparent-semi-reflective layer is disposed above the transparent substrate.

**Embodiment 3.** The asymmetric light absorption structure of embodiment 1, wherein the semi-transparent-semi-reflective layer comprises a discontinuous layer defining apertures or voids between islands of metallic material

20 **Embodiment 4.** The asymmetric light absorption structure of embodiment 1, wherein the semi-transparent-semi-reflective layer comprises a continuous, uniform layer.

**Embodiment 5.** The asymmetric light absorption structure of embodiment

1, wherein the semi-transparent-semi-reflective layer comprises a first metallic layer

25 and a second metallic layer.

**Embodiment 6.** The asymmetric light absorption structure of embodiment 5, wherein the first metallic layer comprises copper.

**Embodiment 7.** The asymmetric light absorption structure of embodiment

5, wherein the first metallic layer comprises chromium.

30 **Embodiment 8.** The asymmetric light absorption structure of embodiment

5, wherein the second metallic layer comprises a noble metal.

**Embodiment 9.** The asymmetric light absorption structure of embodiment 8, wherein the noble metal comprises silver (Ag).

**Embodiment 10.** The asymmetric light absorption structure of embodiment 1, wherein an emissive OLED device or bare AMOLED display panel is attached to the structure.

**Embodiment 11.** The asymmetric light absorption structure of embodiment 1, wherein the semi-transparent-semi-reflective layer has a transmittance characteristic between 20%-50% transmittance, and a reflectance characteristic of 20-50%.

**Embodiment 12.** The asymmetric light absorption structure of embodiment 1, wherein the first transparent layer and the second transparent layer has no light absorption.

**Embodiment 13.** The asymmetric light absorption structure of embodiment 12, wherein the first transparent layer and the second transparent layer comprise the same material.

**Embodiment 14.** The asymmetric light absorption structure of embodiment 12, wherein the first transparent layer and the second transparent layer comprise different materials.

**Embodiment 15.** The asymmetric light absorption structure of embodiment 1, wherein the light absorber layer comprises an ultrathin metal or metal alloys.

**Embodiment 16.** The asymmetric light absorption structure of embodiment 1, wherein the first transparent layer and the second transparent layer comprise silica dioxide, wherein the first transparent layer has a thickness between 15 nm and 70 nm, wherein the second transparent layer has a thickness between 45 nm and 95 nm.

**Embodiment 17.** The asymmetric light absorption structure of embodiment 1, wherein the first transparent layer and the second transparent layer comprise a refractive index between 1 and 3.

**Embodiment 18.** The asymmetric light absorption structure of embodiment 1, wherein the ambient light reflection is substantially eliminated.

**Embodiment 19.** The asymmetric light absorption structure of embodiment 2, further comprising an AMOLED display panel, wherein the AMOLED display panel is coupled to the transparent substrate with an adhesive layer or simple air gap.

**Embodiment 20.** The asymmetric light absorption structure of embodiment 5 19, AMOLED display panel further comprising a cover glass, wherein the transparent substrate is directly formed on the cover glass of the AMOLED display panel.

**Embodiment 21.** A method for preparing an asymmetric light absorption structure comprising:

- providing a substrate;
- 10 providing a semi-transparent-semi-reflective layer;
- providing a first transparent layer comprising a transparent material in optical communication with the first transparent layer;
- providing a light absorbing layer; and
- 15 providing a second transparent layer, wherein the layers are disposed atop one another.

## **Preparation of asymmetric light absorption-transmission elements for enhanced AMOLED display readability under high-ambient light**

Glass substrates were loaded onto a sputtering system. The base vacuum was less than  $2 \times 10^{-6}$  torr. First, DC sputtering Cu for 1 nm thickness as the buffer layer, followed by DC sputtering Ag 9 nm as the semi-transparent-reflective layer, followed is the reactive sputtering of SiO<sub>2</sub> for the first transparent layer (30 nm) from a Si sputtering target under a processing gas of argon (Ar) and oxygen (O<sub>2</sub>), the gases controlled separately by mass flow controllers, the Ar flow rate was 10 Standard Cubic Centimeters per Minute (SCCM), the O<sub>2</sub> rate was 2 SCCM, the deposition rate was about 2 Å/sec. Next an absorbing layer of 7 nm thick Mo layer was deposited from either a Molybdenum (Mo) target at a deposition rate of about 0.5 Å/s. Next, a second transparent layer of silicon oxide (SiO<sub>2</sub>, 55 nm) was deposited similar as the second transparent layer to finish the AR-structure fabrication.

## **Measurement of the light transmittance (T%), reflectance (R%) and absorbance (A%), specular and total reflection, and the viewing-angle dependent light output and color**

Filmetrics system, model number F10-RT-UV was used for the measurement of specular light transmission reflection and absorption. The light source is the combination of Halogen lamp and D2 lamp. Incident angle was 2 degree, spectral reflectance R% and transmittance T% was measured by photo diode, for samples without scattering or haze, the light absorbance A% was obtained from  $A\% = 1 - T\% + R\%$ . the testing incident light direction was from the top surface of the second transparent layer.

The total reflection was measured with Ultrascan Pro instrument. The viewing-angle dependent light output and color CIE(x,y) coordinates were measure by of GS-1164 Spectroradiometer, Gamma-Scientific.

For the processes and/or methods disclosed, the functions performed in the processes and methods may be implemented in differing order, as may be indicated by context. Furthermore, the outlined steps and operations are only provided as

examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations.

This disclosure may sometimes illustrate different components contained within, or connected with, different other components. Such depicted architectures  
5 are merely examples, and many other architectures can be implemented which achieve the same or similar functionality.

The terms used in this disclosure, and in the appended embodiments, are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including, but not limited to," the term "having" should be interpreted as "having at  
10 least," the term "includes" should be interpreted as "includes, but is not limited to," etc.). In addition, if a specific number of elements is introduced, this may be interpreted to include at least the recited number, as may be indicated by context (e.g., the bare recitation of "two recitations," without other modifiers, includes at least two recitations, or two or more recitations). As used in this disclosure, any disjunctive word  
15 and/or phrase presenting two or more alternative terms should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

The terms and words used are not limited to the bibliographical meanings but  
20 are merely used to enable a clear and consistent understanding of the disclosure. It is to be understood that the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a component surface" includes reference to one or more of such surfaces.

By the term "substantially" it is meant that the recited characteristic, parameter,  
25 or value need not be achieved exactly, but that deviations or variations, including for example, tolerances, measurement error, measurement accuracy limitations and other factors known to those skilled in the art, may occur in amounts that do not preclude the effect the characteristic was intended to provide.

Aspects of the present disclosure may be embodied in other forms without  
30 departing from its spirit or essential characteristics. The described aspects are to be considered in all respects illustrative and not restrictive. The embodied subject matter

is indicated by the appended embodiments rather than by the foregoing description. All changes, which come within the meaning and range of equivalency of the embodiments described herein, are to be embraced within their scope.

## CLAIMS

What is claimed is:

1. An asymmetric light absorption structure comprising:
  - a reflective layer;
  - a first transparent layer, disposed upon and in optical communication with the reflective layer;
  - a light absorber layer, disposed upon and in optical communication with the first transparent layer; and
  - a second transparent layer, disposed upon and in optical communication with the light absorber layer;wherein the reflective layer, the first transparent layer, the light absorber layer, and the second transparent layer are disposed upon an active matrix organic light emitting display (AMOLED) display device;
  - wherein incident light traveling through the asymmetric light absorption structure is asymmetrically absorbed and asymmetrically reflected; and
  - wherein asymmetric light absorption decreases ambient light reflection, while asymmetric light transmission enhances the light emission of the AMOLED device.
2. The asymmetric light absorption structure of claim 1, further comprising a transparent substrate upon the AMOLED display device, wherein the reflective layer is disposed upon the transparent substrate in optical communication with the AMOLED display device.
3. The asymmetric light absorption structure of claim 1, wherein the reflective layer comprises a discontinuous layer defining apertures or voids between islands of metallic material.
4. The asymmetric light absorption structure of claim 1, wherein the reflective layer comprises a continuous, uniform layer.
5. The asymmetric light absorption structure of claim 1, wherein the reflective layer comprises a first metallic layer and a second metallic layer.

6. The asymmetric light absorption structure of claim 5, wherein the first metallic layer comprises copper.
7. The asymmetric light absorption structure of claim 5, wherein the first metallic layer comprises chromium.
8. The asymmetric light absorption structure of claim 5, wherein the second metallic layer comprises a noble metal.
9. The asymmetric light absorption structure of claim 8, wherein the noble metal comprises silver.
10. The asymmetric light absorption structure of claim 1, wherein the reflective layer has a transmittance of about 20%-50%, and a reflectance of about 20-50%.
11. The asymmetric light absorption structure of claim 1, wherein the light absorption layer comprises molybdenum.
12. The asymmetric light absorption structure of claim 12, wherein the light absorption layer has a thickness of about 7 nm.
13. The asymmetric light absorption structure of claim 1, wherein the first transparent layer and the second transparent layer have no light absorption.
14. The asymmetric light absorption structure of claim 13, wherein the first transparent layer and the second transparent layer comprise the same material.
15. The asymmetric light absorption structure of claim 13, wherein the first transparent layer and the second transparent layer comprise different materials.
16. The asymmetric light absorption structure of claim 1, wherein the light absorber layer comprises a metal or metal alloys.
17. The asymmetric light absorption structure of claim 1, wherein the first transparent layer and the second transparent layer comprise silica dioxide, wherein the first transparent layer has a thickness between about 15 nm and about 70 nm, wherein the second transparent layer has a thickness between about 45 nm and about 95 nm.
18. The asymmetric light absorption structure of claim 1, wherein the first transparent layer and the second transparent layer have a refractive index between 1 and 3.

19. The asymmetric light absorption structure of claim 2, wherein the AMOLED display device is coupled to the transparent substrate with an adhesive layer or simple air gap.

20. The asymmetric light absorption structure of claim 1, wherein the AMOLED display device further comprises a cover glass, wherein the asymmetric light absorption structure is directly formed on the cover glass of the AMOLED display device.

21. A method for preparing an asymmetric light absorption structure comprising:  
disposing a reflective layer upon an AMOLED substrate;  
disposing a first transparent layer comprising a transparent material in optical communication with the reflective layer;  
disposing a light absorbing layer upon the first transparent layer; and  
disposing a second transparent layer upon the light absorbing layer;  
wherein the layers are disposed upon and in optical communication with one another.

FIG. 1

|                         |
|-------------------------|
| Transparent layer-2     |
| Light absorber          |
| Transparent layer-1     |
| Semi-transparent mirror |
| Transparent substrate   |

FIG. 2

|                         |   |                              |
|-------------------------|---|------------------------------|
| Transparent layer-2     | } | AR-structure                 |
| Light absorber          |   |                              |
| Transparent layer-1     |   |                              |
| Semi-transparent mirror |   |                              |
| Transparent substrate   |   |                              |
| Panel Cover glass       | } | Bare-AMOLED<br>Display panel |
| AMOLED display panel    |   |                              |
| Direct contact          |   |                              |

FIG. 3

|                         |   |                              |
|-------------------------|---|------------------------------|
| Transparent layer-2     | } | AR-structure                 |
| Light absorber          |   |                              |
| Transparent layer-1     |   |                              |
| Semi-transparent mirror |   |                              |
| Transparent substrate   |   |                              |
| Coupling Layer          | } | Bare-AMOLED<br>Display panel |
| Panel Cover glass       |   |                              |
| AMOLED display panel    |   |                              |

FIG. 4

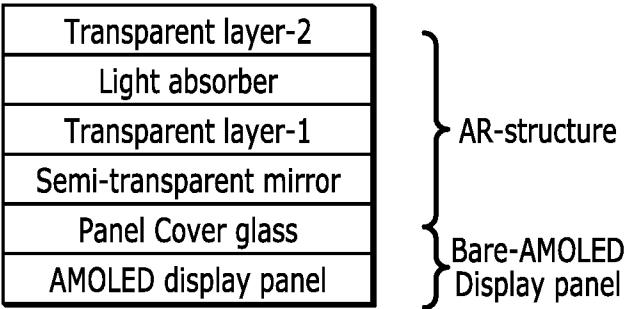


FIG. 5

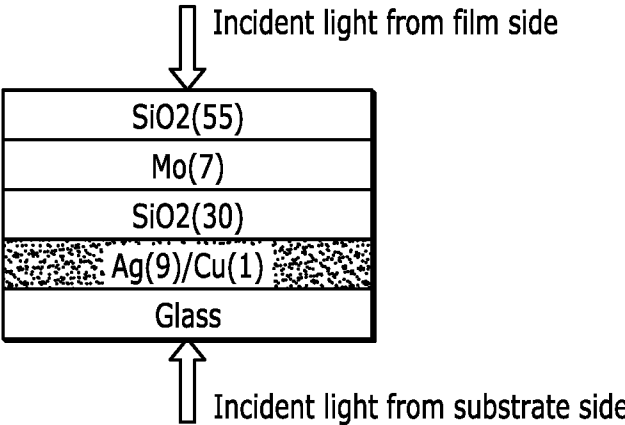


FIG. 6

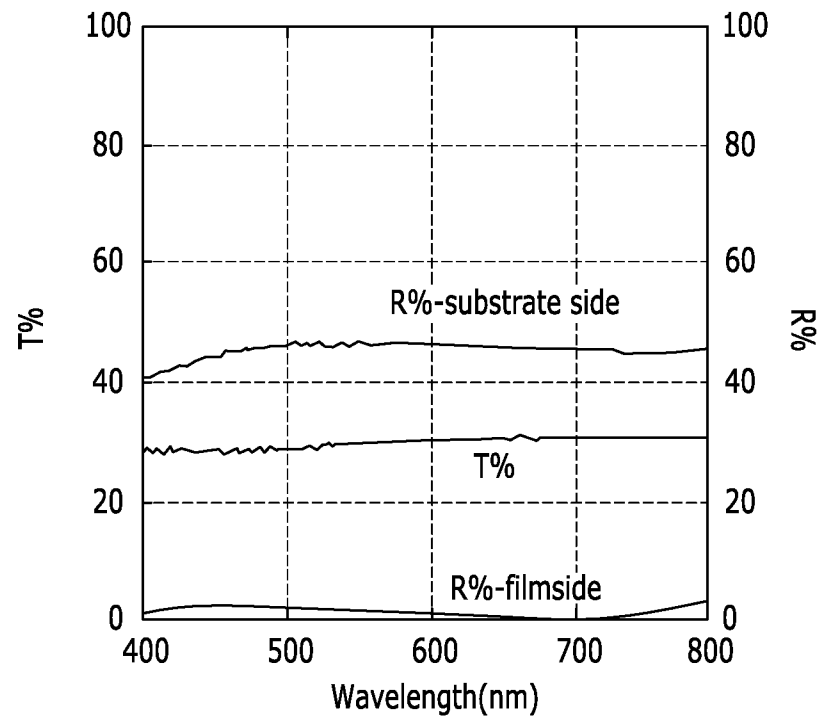
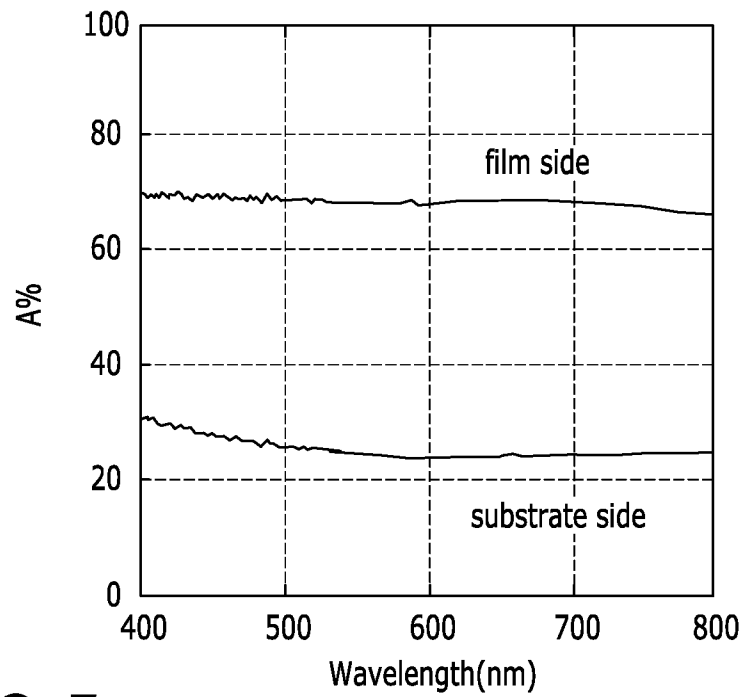


FIG. 7

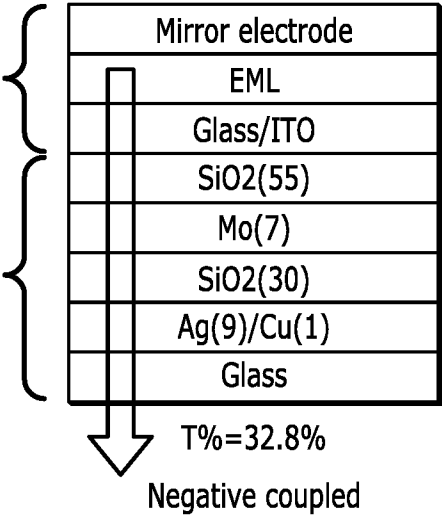


FIG. 8

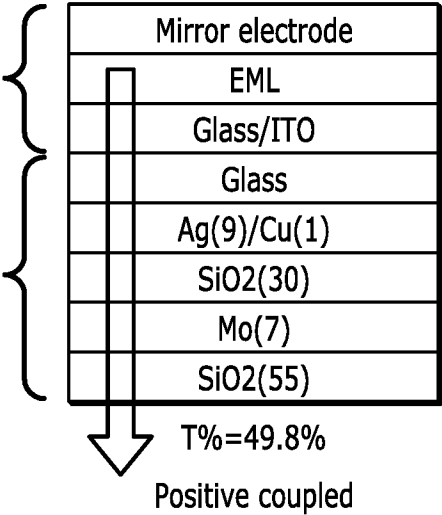
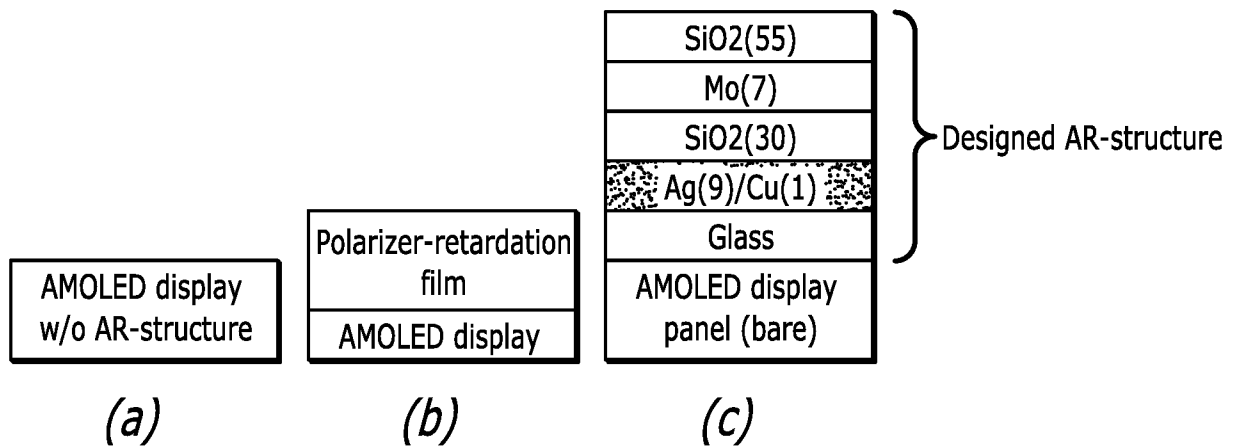
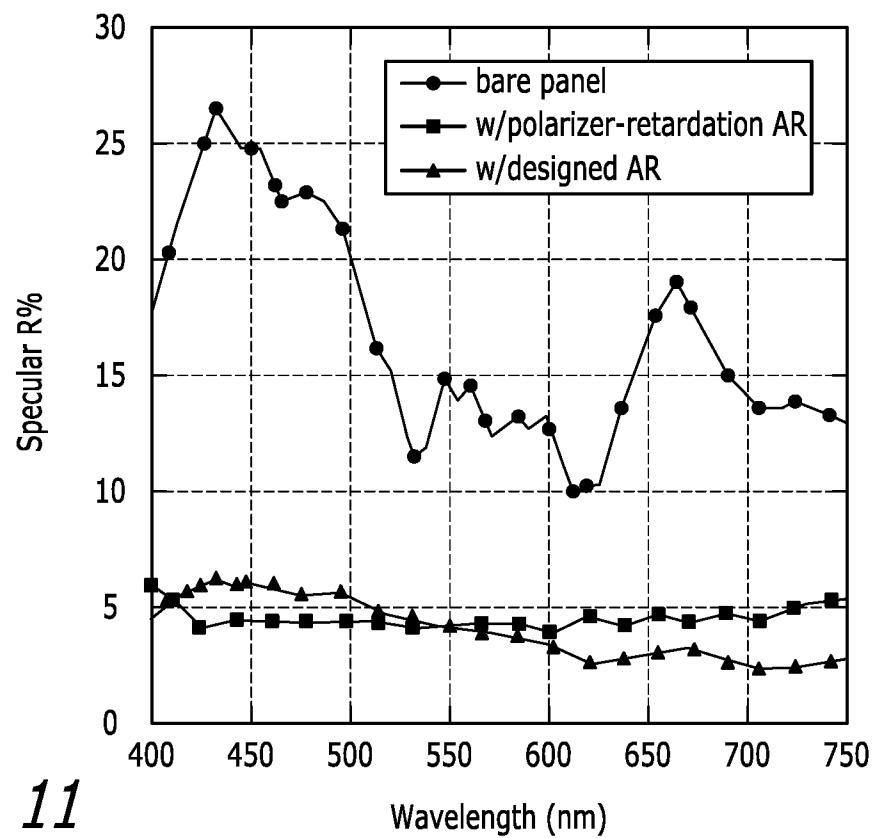


FIG. 9

*FIG. 10**FIG. 11*

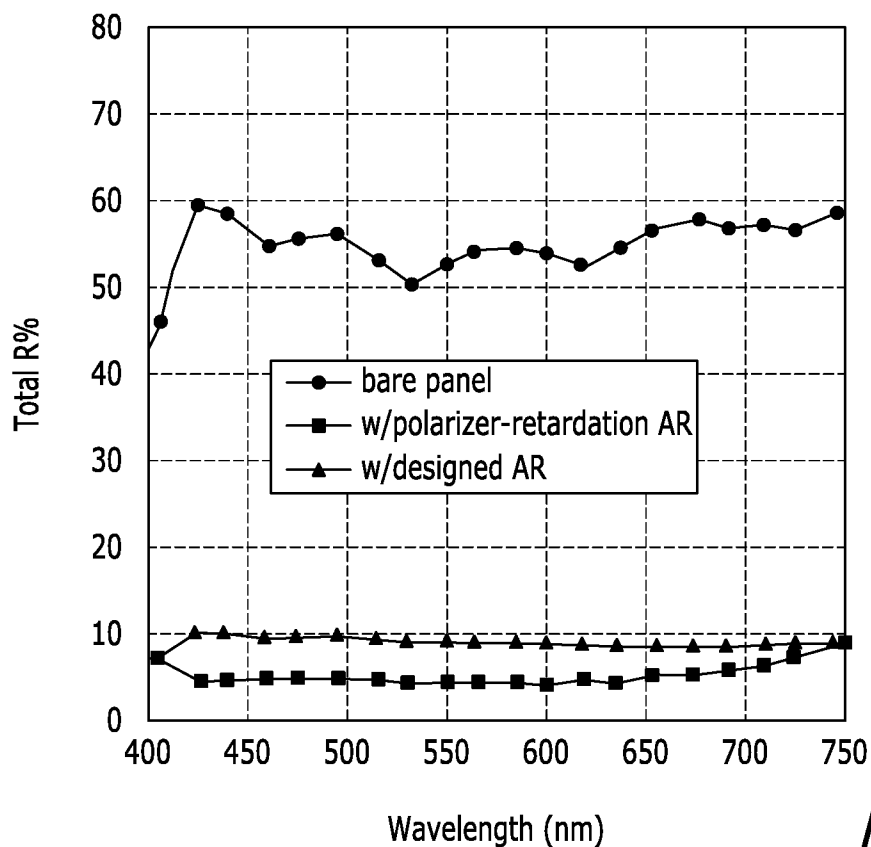


FIG. 12

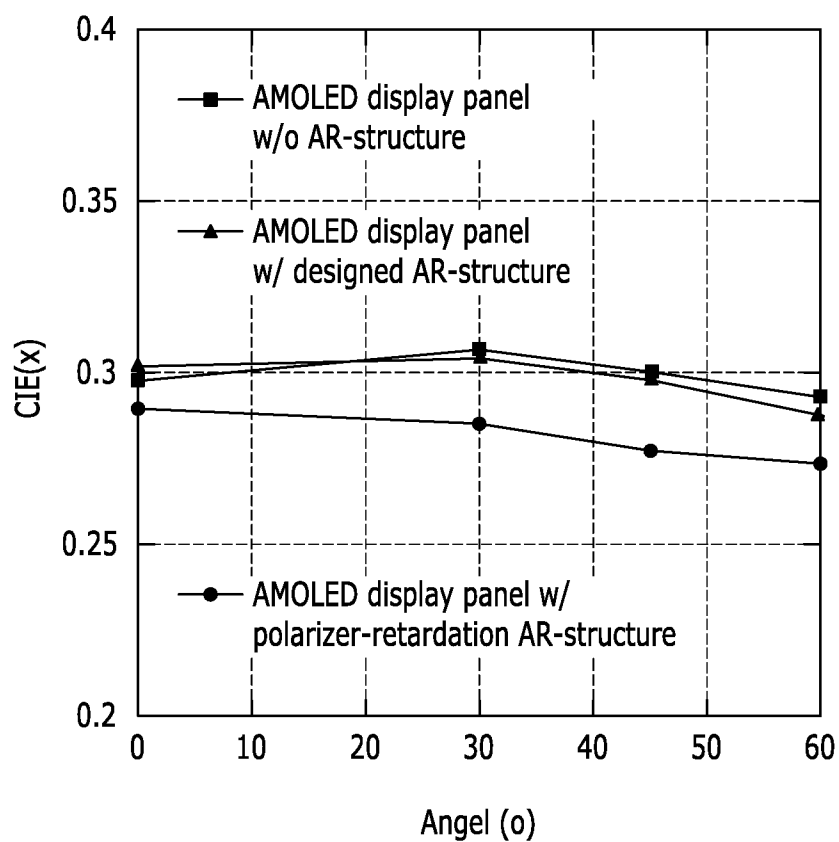


FIG. 13A

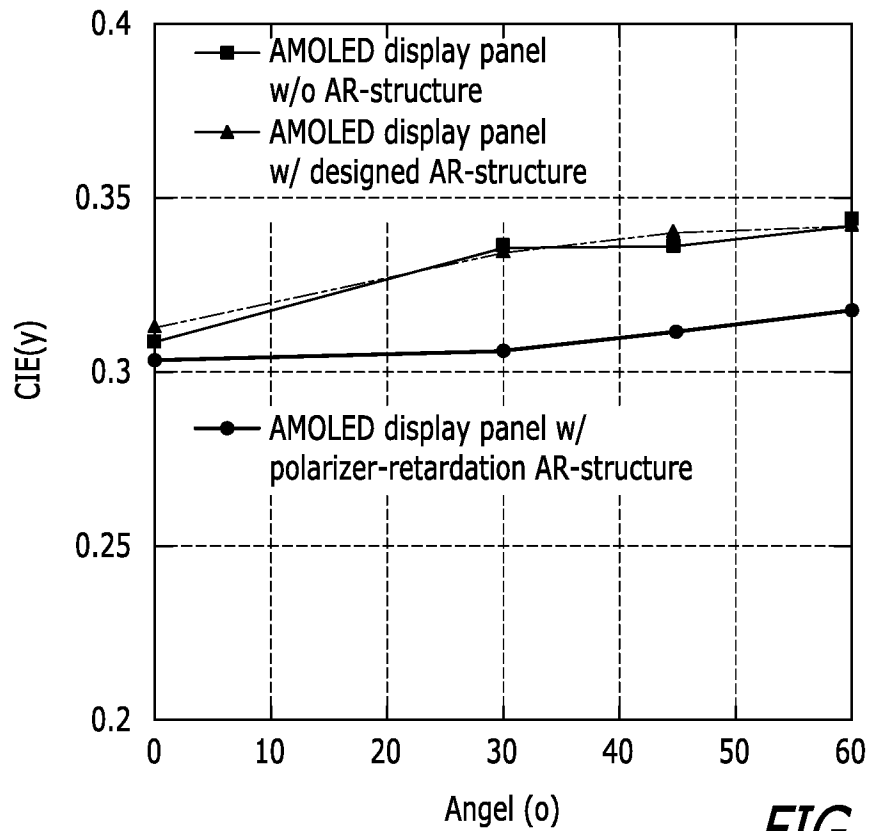


FIG. 13B

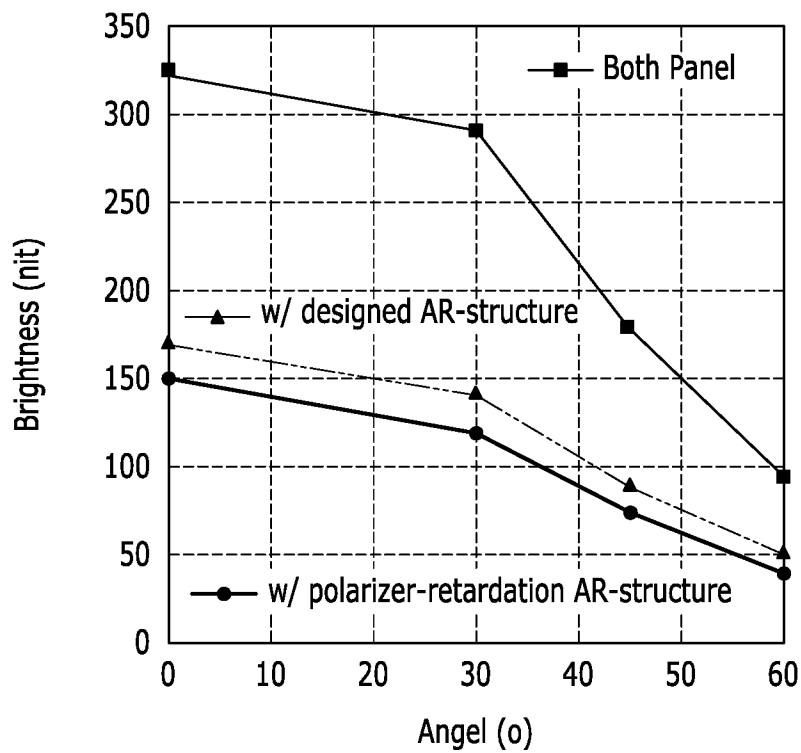


FIG. 14

# INTERNATIONAL SEARCH REPORT

International application No  
**PCT/US2022/077577**

## A. CLASSIFICATION OF SUBJECT MATTER

**INV.** H01L27/32 H01L51/52  
**ADD.**

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**H01L**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**EPO-Internal**

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                    | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------|-----------------------|
| <b>X</b>  | <b>US 2014/367648 A1 (CHO SANG-HWAN [KR] ET AL) 18 December 2014 (2014-12-18)</b>                                     | <b>1, 2, 4-21</b>     |
| <b>Y</b>  | <b>paragraph [0053] - paragraph [0075];<br/>figures 2-6, 22</b>                                                       | <b>3</b>              |
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| <b>Y</b>  | <b>paragraph [0068] - paragraph [0076];<br/>figure 4</b>                                                              | <b>3</b>              |
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| <b>Y</b>  | <b>figure 9; examples 1-6</b>                                                                                         | <b>3</b>              |
|           | -----<br>-/--                                                                                                         |                       |



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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

**23 December 2022**

Date of mailing of the international search report

**09/01/2023**

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
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Fax: (+31-70) 340-3016

Authorized officer

**Bernabé Prieto, A**

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2022/077577

## C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2022/077577

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