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(54) Title: HAZE FREE REVERSE MODE LIQUID CRYSTAL LIGHT CONTROL FILM WITH INHOMOGENEOUS ALIGNMENT LAYER

(57) Abstract: Devices and methods related to an electrically switchable light controlling device are provided. A device comprises two transparent conductive substrates (10), two inhomogeneous alignment layers (20), each coated on a respective transparent substrate (10), a spacer (30) in between the two transparent substrates (10), a liquid crystal layer in between the two transparent substrates (10); and a polymer network (40) inside the liquid crystal layer. The device can be used for smart windows, touch screen, or privacy windows.



DESCRIPTION

HAZE FREE REVERSE MODE LIQUID CRYSTAL LIGHT CONTROL FILM WITH INHOMOGENEOUS ALIGNMENT LAYER

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional application Serial No. 62/603,602, filed June 6, 2017, which is hereby incorporated by reference in its entirety including any tables, figures, or drawings.

FIELD OF INVENTION

The present invention relates to a light controlling device by means of light scattering.

BACKGROUND OF THE INVENTION

Commercially available electrically switchable windows can be divided into liquid crystal and non-liquid crystal classes. Non-liquid crystal classes include electrochromic (EC) windows and suspended particle device (SPD) windows. However, due to long switching times and light leakage, EC and SPD windows are suitable standard windows, but do not function well as privacy windows.

On the other hand, liquid crystal based smart windows such as polymer dispersed liquid crystal (PDLC) devices are able to switch from a voltage-on transparent state to a voltage-off scattering (diffused) state in milliseconds. Light waves are scattered rather than absorbed by the device. PDLC devices are suitable for privacy windows, but cannot block light from entering into the room and therefore are not preferred as standard windows.

BRIEF SUMMARY OF THE INVENTION

Embodiments of the subject invention provide a reverse mode light controlling device having a voltage-off transparent state and a voltage-on opaque state. In an embodiment of the subject invention, polymer can be added to the liquid crystal to form a polymer network immersed with liquid crystal. This can be referred to as a polymer network liquid crystal (PNLC) structure or a polymer stabilized liquid crystal (PSLC) device. A homeotropic

surface alignment layer can be applied to align the liquid crystal molecules in a vertical direction in the voltage-off state.

A negative type liquid crystal that has a negative dielectric anisotropy can be used such that when it is under a vertical electric field, the liquid crystal molecules align perpendicularly to the electric field. A polymer network that has a refractive index close to that of the liquid crystal can be used such that when in the voltage-off state there is minimal light scattering for all viewing angles. The matching refractive indices do not change with the viewing angle, therefore a wide and haze-free viewing angle can be achieved.

In another embodiment, polymer structures can be embedded into the liquid crystal alignment material to form an inhomogeneous alignment layer. This inhomogeneous alignment layer aligns the liquid crystals homeotropically in the voltage-off state and promotes randomness in the liquid crystal alignment in the voltage-on state.

When an applied voltage moves beyond a threshold voltage, the negative type liquid crystal molecules start to deviate from the vertical aligned position. Due to the inhomogeneous alignment surface and the polymer network, many randomly aligned LC domains are formed and enter a scattering state. The scattering increases when the voltage increases and eventually reaches a maximum level. However, the scattering may begin to drop if an excessive voltage is applied. When the applied voltage is turned off, the liquid crystals return to their original vertical alignment and the device is transparent again.

An inhomogeneous alignment layer, polymer network liquid crystals, and homogeneous (planar) aligned liquid crystals with positive dielectric anisotropy can be applied to generate a reverse mode operation without using a homeotropic alignment material.

Embodiments of the subject invention can be used for smart windows, transparent displays, architectural windows, indoor privacy windows. These windows and displays can be used in buildings, conference rooms, hotel rooms and potentially as vehicle windows.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram of a reverse mode polymer network liquid crystal (PNLC) device.

Figure 2 shows an atomic force microscope image of an inhomogeneous surface alignment layer.

Figure 3 shows a line profile of the inhomogeneous layer.

Figure 4 is a diagram showing the liquid crystal alignment near the inhomogeneous alignment layer.

Figure 5 is a diagram showing the device in a voltage-off state.

Figure 6 is a diagram showing the device in a voltage-on state.

Figure 7 is a plot of the transmittance voltage curve of present invention.

Figure 8 is a diagram showing the liquid crystal planar alignment in a voltage-off state when positive dielectric anisotropic liquid crystal is used.

Figure 9 is a diagram illustrating the alignment of positive liquid crystals in a voltage-on state.

Figure 10 is a diagram showing a device that incorporates the use of a dichroic dye in a voltage-off state.

Figure 11 is a diagram showing a device that incorporates the use of a dichroic dye in a voltage-on state.

Figure 12 shows three diagrams illustrating three possible switchable window configurations.

Figure 13 shows two diagrams illustrating a patterned switchable window.

DETAILED DISCLOSURE OF THE INVENTION

The following disclosure and exemplary embodiments are presented to enable one of ordinary skill in the art to make and use an electrically switchable light controlling device, according to the subject invention. Various modifications to the embodiments will be readily apparent to those skilled in the art and the generic principles herein may be applied to other embodiments. Thus, the devices and methods related to the electrically switchable light controlling device are not intended to be limited to the embodiments shown, but are to be accorded the widest scope consistent with the principles and features described herein.

As seen in Figure 1, each substrate **10** is connected to a respective inhomogeneous alignment layer **20**. The distance between the two substrates is determined by the spacers **30** in between the top and bottom substrates **10**. The top and bottom substrates **10** can be transparent conductive electrodes. In an embodiment, the top and bottom substrates **10** comprise indium tin oxide (ITO) on glass, indium tin oxide on Polyethylene Terephthalate (PET) film, or other transparent conductive coating on a glass or plastic substrate. The space between the two substrates **10** is filled with liquid crystals in a polymer network **40**.

The spacers **30** can be made of glass, plastic rods, or beads dispersed into a liquid crystal polymer composite. The spacers **30** can be built-in structures, such as cylinders, bumps, or walls on top of the transparent conductive substrates and can be created by photo-etching, screen printing, or photo-polymerization.

If the substrates are made from flexible plastics, the device can be sandwiched in between glass in an architectural or privacy window. In addition, glass substrates or external glasses (for plastic substrates) may have other functional coatings such as an anti-reflection coating, an ultraviolet (UV) coat, or an infrared (IR) coat.

In one embodiment the alignment layer is made of a homeotropic alignment material with the addition of a reactive mesogen. The function of the homeotropic alignment material is to align the liquid crystals in a vertical orientation during the voltage-off state. Addition of the reactive mesogen creates an inhomogeneous rough surface. The polymerization of the reactive mesogen forms local inhomogeneity on the alignment layer **20**, as seen in Figure 2. The inhomogeneous surface alignment layer **20** seen in Figure 2 has a profile depth of approximately 100 nanometers and domain size in the micrometer range (see also, Figure 3).

A function of the inhomogeneous surface is to give a small polar and random azimuthal angle to the vertically aligned liquid crystal molecules. Another function of the inhomogeneous surface is to enhance the formation of a polymer network on the substrate surface and hence strengthen the adhesion between the substrates. In an embodiment, a homeotropic alignment layer material can be SE-4811 vertical alignment material from Nissan Chemical Industries and a reactive mesogen can be UCL 017 from DIC. Figure 4 illustrates the liquid crystal alignment **50** near the inhomogeneous alignment layer **20**.

In an embodiment, the inhomogeneous alignment surface can be a single layer formed by mixing the alignment material with the reactive mesogen in a homogeneous solution. The solution can then be coated on the top and bottom substrates and the reactive mesogen can then be cured to form an inhomogeneous surface on each of the respective substrates.

In another embodiment, the inhomogeneous alignment surface can be formed in two layers, first a homeotropic alignment layer is coated on each respective top and bottom substrate and then a reactive mesogen layer is coated on each respective homeotropic alignment layer. In yet another embodiment, a reactive mesogen layer can be coated on each respective top and bottom substrate and then a homeotropic alignment layer can be coated on each respective reactive mesogen layer. In each embodiment, the amount of reactive

mesogen used and the curing condition directly affect the inhomogeneity and profile of the inhomogeneous alignment layer.

In another embodiment, an inhomogeneous alignment layer can be formed by either adding monomers or small particles; or directly coating the alignment layer on a rough transparent conductive layer surface without the use of an additional monomer or polymer. In yet another embodiment, an inhomogeneous alignment layer can be formed as a randomly aligned or multiple direction aligned surface layer.

In an embodiment, liquid crystals and monomers can be filled between two transparent conductive substrates. The liquid crystal to monomer ratio by weight can be less than that of the ratio of a conventional polymer dispersed liquid crystal (PDLC) device. In an embodiment, the monomer has less than 10% of the weight of the liquid crystal. The liquid crystal and monomer mixture can be cured under suitable conditions and a polymer network is formed, as seen in Figure 5. In one embodiment, the monomer used is UCL 017 from DIC. The liquid crystal can be an index matched negative nematic liquid crystal. A small amount of photo-initiator can also be added to promote the polymerization of the monomers.

As seen in Figure 5, the liquid crystals **50** are aligned homeotropically and a polymer network is formed in between the top and bottom substrates **10**. Each substrate **10** is coated with a respective inhomogeneous alignment layer **20**. The voltage source **60** is not connected and the device is in a voltage-off transparent state thereby allowing light waves **70** to pass through the device with minimal scattering. A polymer can be chosen that has a refractive index to match the refractive index of the liquid crystal.

When a voltage is applied by a voltage source **60**, an electric field is produced. When liquid crystals **50** have a negative dielectric anisotropy, the liquid crystals **50** rotate horizontally to align perpendicularly to the electric field, as seen in Figure 6. As a result of the rotation of the liquid crystals **50**, the light waves **80** passing through the randomly aligned liquid crystal domains show increased scattering.

Liquid crystals that are not near the inhomogeneous alignment surface or the polymer network rotate towards a horizontal position first. The liquid crystals that are near the inhomogeneous alignment surface resist rotation due to an anchoring force that hinders molecular rotation. Furthermore, the random surface inhomogeneity gives a random azimuthal angle to the liquid crystal molecules. The polymer network also hinders the rotation of the liquid crystal molecules. As a result, small liquid crystal domains with

different liquid crystal orientations are formed. When the voltage is applied, liquid crystal domain scattering and liquid crystal–polymer network scattering occurs. As the voltage increases beyond a certain level, the device reaches a diffused state. Figure 7 shows a typical transmission voltage curve. Light is transmitted through the device at a constant rate until the applied voltage begins to approach 5V, at which point the percentage of light that is transmitted through the device sharply decreases. The plot in Figure 7 also demonstrates that the device can operate at a low voltage level.

In yet another embodiment, no homeotropic alignment material is used to align the liquid crystal molecules. Liquid crystals **90** with a positive dielectric anisotropy are aligned in a homogeneous or planar way in a voltage-off transparent state, as seen in Figure 8. When a voltage is generated by a voltage source **60**, a vertical electric field is produced. The liquid crystals rotate to align with the electric field. Due to surface inhomogeneity and the polymer network, liquid crystal domains are formed and the light waves **100** passing through the device exhibit increased scattering, as seen in Figure 9.

In another embodiment, a dichroic dye is added into a negative dielectric liquid crystal polymer network layer. In one embodiment, the dichroic dye used is a black dye S428 from Mitsui Fine Chemicals. The dichroic dye molecules have an elongated shape and follow the alignment direction of the neighboring liquid crystal molecules. The dichroic dye absorbs light along the long axis of each dye molecule, but allows light waves traveling in orthogonal directions to pass through. In a voltage-off state, normal incident light can pass through the device without significant absorption.

When the device is in a voltage-off state, as seen in Figure 10, the dichroic dye molecules **110** are vertically aligned and do not absorb light passing through the device. However, the dichroic dye **110** does absorb some light waves traveling through the device at oblique angles. Complete absorption of a light wave is not effectuated by a single dye molecule **110**, but by many dye molecules through multiple absorptions. When a voltage is generated from a voltage source **60**, as seen in Figure 11, the randomly aligned liquid crystal domains with the dichroic dye **110** absorb light waves **120** from all incident angles and thus the device is in an opaque dark state.

The reverse mode polymer network inhomogeneous surface liquid crystal light controlling device is well suited for smart glazing, touch screen, or privacy window applications. As seen in Figure 12, a smart glazing or privacy window can be in a transparent

voltage-off state **130**, an opaque scattering state with diffused light passing through **140**, and an opaque absorption state with minimum light coming through **150**. A device employing a dichroic dye can be used for windows in which light transmission control is desirable. It is also well suited for a transparent display that does not require a true dark state.

The transparent conductive layer can be an active matrix thin film transistor to driven pixel by pixel or combined with an active matrix device to become active matrix driven smart display. In one embodiment, the device can be in between two sheets of glass, each coated with a low-emissivity coating. In another embodiment, a simple text or clock pattern **160**, **170** can be formed on the substrate, as shown in Figure 13. At the top right corner a patterned area can show diffused pattern (voltage-on) **160** with a transparent background (voltage off) **170**. This can be used for a view-finder display application.

The invention as presented herein and the specific aspects or embodiments illustrated or material used in examples are meant not to be limiting, but may include variations, modifications or adaptations pertaining to the principle of current invention. As noted all drawings presented are not drawn to scale nor are exact replicate of real devices.

All patents, patent applications, provisional applications, and publications referred to or cited herein are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and the scope of the appended claims. In addition, any elements or limitations of any invention or embodiment thereof disclosed herein can be combined with any and/or all other elements or limitations (individually or in any combination) or any other invention or embodiment thereof disclosed herein, and all such combinations are contemplated with the scope of the invention without limitation thereto.

CLAIMS

What is claimed is:

1. An electrically switchable light controlling device, comprising:
two transparent conductive substrates;
two inhomogeneous alignment layers, respectively coated on the two transparent conductive substrates;
a spacer disposed between the two transparent conductive substrates;
a liquid crystal layer disposed between the two transparent conductive substrates; and
a polymer network disposed inside the liquid crystal layer.
2. The device of claim 1, wherein the two transparent conductive substrates comprise indium tin oxide on glass or indium tin oxide on Polyethylene Terephthalate (PET) film.
3. The device of claim 1, wherein the spacer comprises a piece of glass, a plastic rod, a bead, or a resin-based or polymer-based structure.
4. The device of claim 1, wherein each inhomogeneous alignment layer of the two inhomogeneous alignment layers respectively comprises distinct regions comprising a different respective material and/or distinct regions comprising a different respective topography.
5. The device of claim 1, wherein the two inhomogeneous alignment layers comprise a homeotropic or homogeneous alignment material and a reactive mesogen, a monomer, or sub-micron particles.
6. The device of claim 1, wherein at least one inhomogeneous alignment layer of the two inhomogeneous alignment layers is a randomly aligned layer or a multiple direction aligned layer.

7. The device of claim 1, wherein the two transparent conductive substrates are respectively coated with an anti-reflection coating, an ultraviolet coating, or an infrared coating.

8. The device of claim 1, wherein the liquid crystal layer comprises a negative dielectric liquid crystal.

9. The device of claim 1, wherein the liquid crystal layer comprises a dichroic dye.

10. The device of claim 1, wherein at least one transparent conductive substrate comprises an active matrix thin film transistor (TFT).

11. The device of claim 1, wherein a transparent conductive layer of the two transparent conductive layers is patterned, such that respective portions of the electrically switchable light controlling device can be in a voltage-on state or a voltage-off state.

12. A smart glass device, comprising:
two sheets of glass respectively coated with a low-emissivity coating;
two transparent conductive substrates disposed between the two sheets of glass;
two inhomogeneous alignment layers respectively coated on the two transparent conductive substrates;
a spacer disposed between the two transparent conductive substrates;
a liquid crystal layer disposed between the two transparent conductive substrates; and
a polymer network disposed inside the liquid crystal layer.

13. A method of fabricating an electrically switchable light controlling device, comprising:
providing two transparent conductive substrates;
coating a respective surface of each of the two transparent conductive substrates with an inhomogeneous alignment layer;

disposing a spacer between the respective coated surfaces of the two transparent conductive substrates;

disposing a liquid crystal layer between the respective coated surfaces of the two transparent conductive substrates; and

disposing a polymer network inside the liquid crystal layer.

14. The method of claim 13, wherein disposing a spacer between the respective coated surfaces of the two transparent conductive substrates comprises:

photo-etching, screen printing, or photo-polymerization of the spacer onto at least one transparent conductive substrate of the two transparent conductive substrates.

15. The method of claim 13, wherein coating the respective surface of the two transparent conductive substrates with the inhomogeneous alignment layer comprises:

adding a reactive mesogen, a monomer, or sub-micron particles to a homeotropic or homogeneous alignment material to form a mixture;

coating the mixture on the respective surfaces of the two transparent conductive substrates; and

curing the mixture with heat or light to form the inhomogeneous alignment layer.

16. The method of claim 13, wherein coating the respective surface of each of the two transparent conductive substrates with the inhomogeneous alignment layer comprises:

coating a homeotropic or homogeneous alignment material on the respective surfaces of the two transparent conductive substrates; and

coating a reactive mesogen or a monomer on the homeotropic or homogeneous alignment material.

17. The method of claim 13, wherein coating the respective surface of each of the two transparent conductive substrates with the inhomogeneous alignment layer comprises:

coating a reactive mesogen or a monomer on the respective surfaces of the two transparent conductive substrates; and

coating a homeotropic or homogeneous alignment material on the reactive mesogen or monomer.

18. The method of claim 13, wherein coating the respective surfaces of the two transparent conductive substrates with the inhomogeneous alignment layer comprises: coating a reactive mesogen, a monomer, or sub-micron particles on the respective surfaces of the two transparent conductive substrates.

19. The method of claim 13, wherein coating the respective surface of each of the two transparent conductive substrates with the inhomogeneous alignment layer comprises: coating a homoeotropic or homogeneous alignment material directly on the respective surfaces of two transparent conductive substrates without adding an additional monomer or polymer,

wherein each respective surface of two transparent conductive substrates has a non-uniform topography.

20. The method of claim 13, further comprising polymerizing the reactive mesogen or the monomer with heat or ultraviolet (UV) radiation.

21. The method of claim 13, further comprising: patterning at least one transparent conductive substrate of the two transparent conductive substrates, such that respective portions of the electrically switchable light controlling device can be in either a voltage-on state or a voltage-off state.

FIG. 1

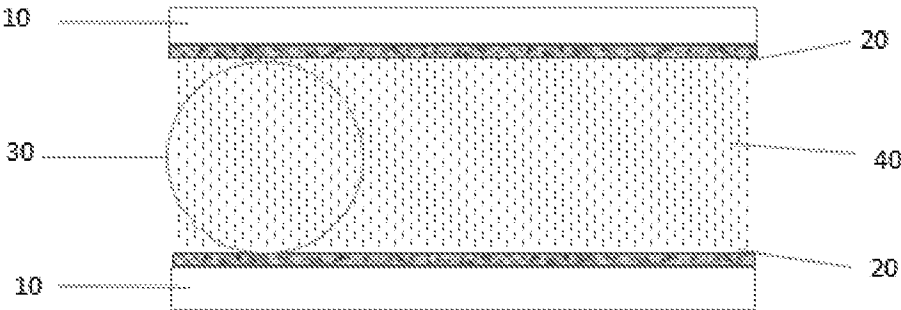


FIG. 2

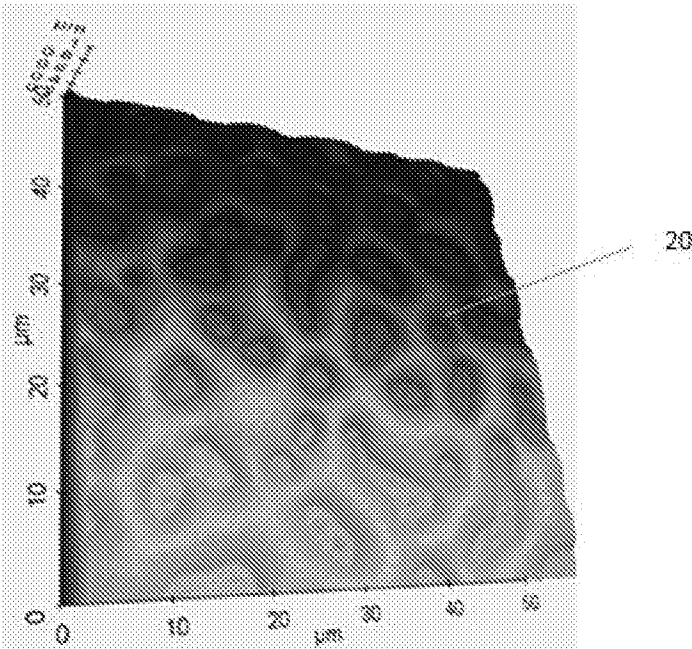


FIG. 3

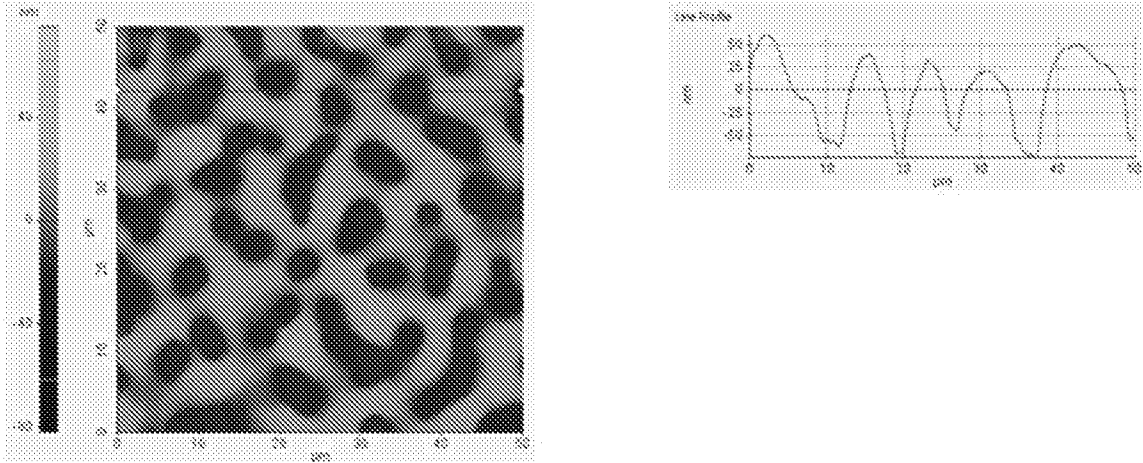


FIG. 4

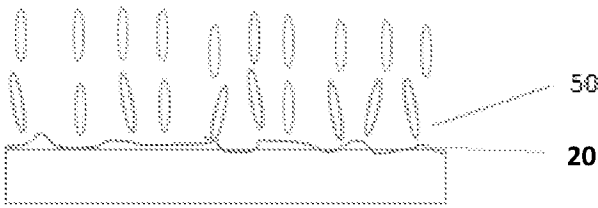


FIG. 5

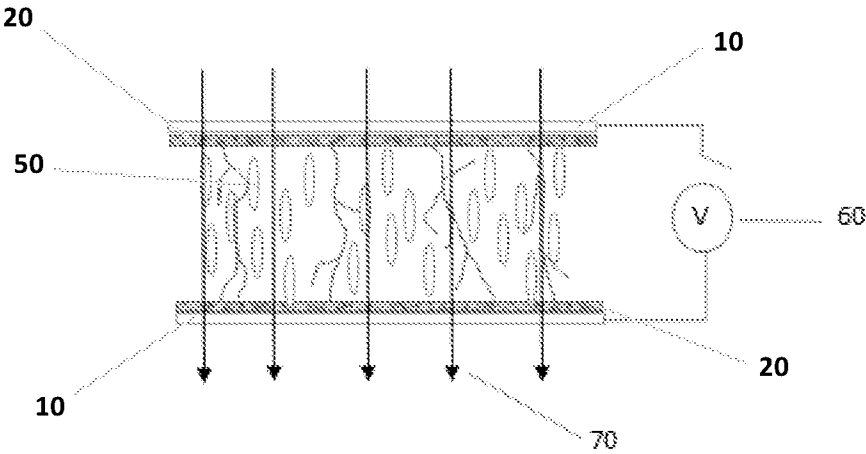


FIG. 6

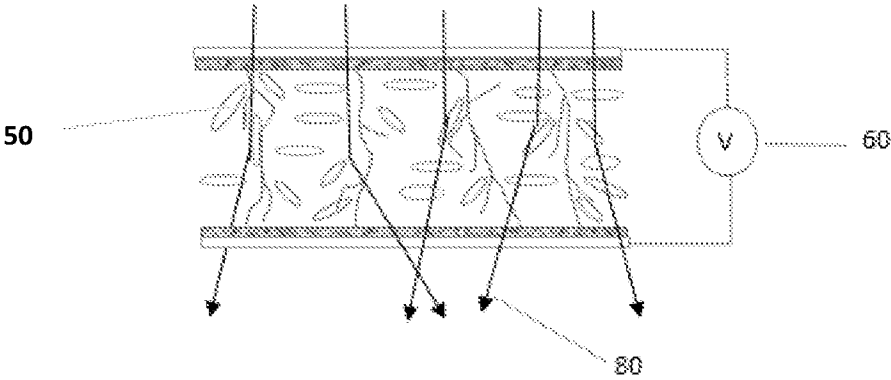


FIG. 7

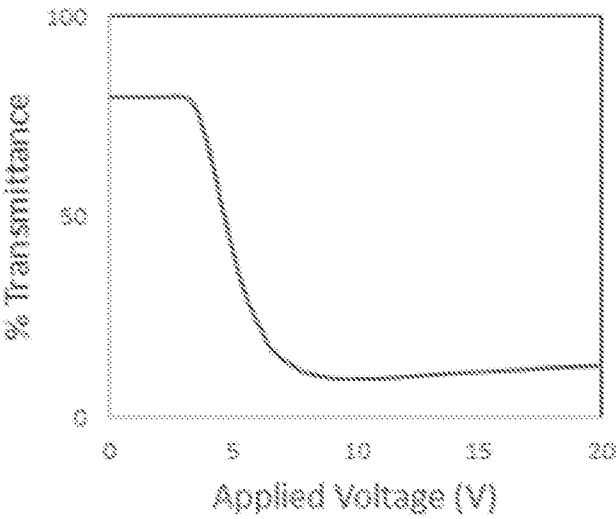


FIG. 8

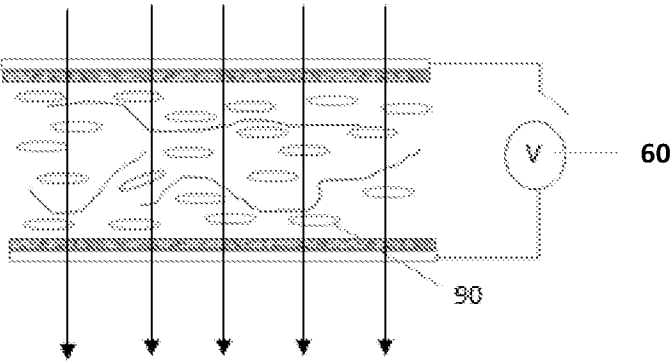


FIG. 9

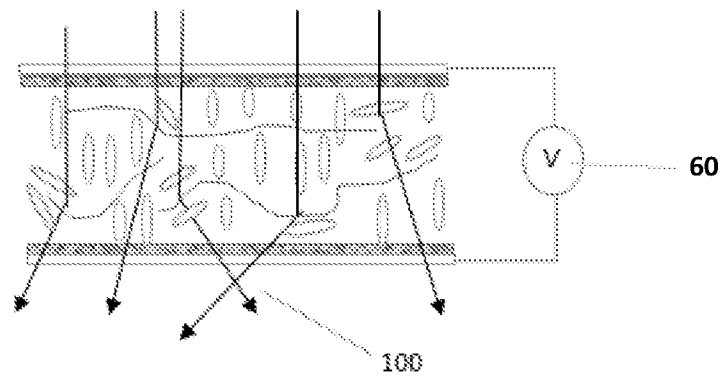


FIG. 10

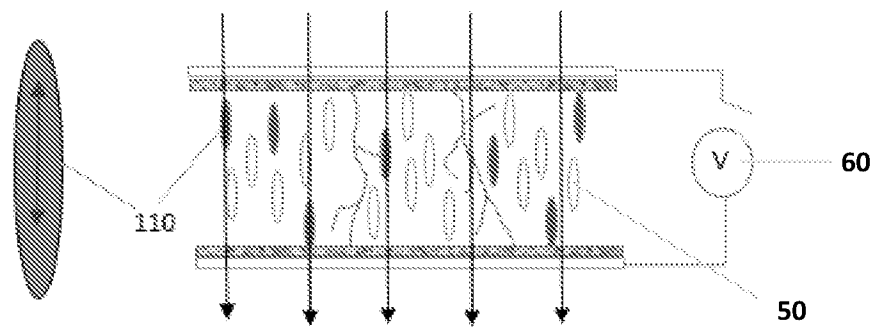


FIG. 11

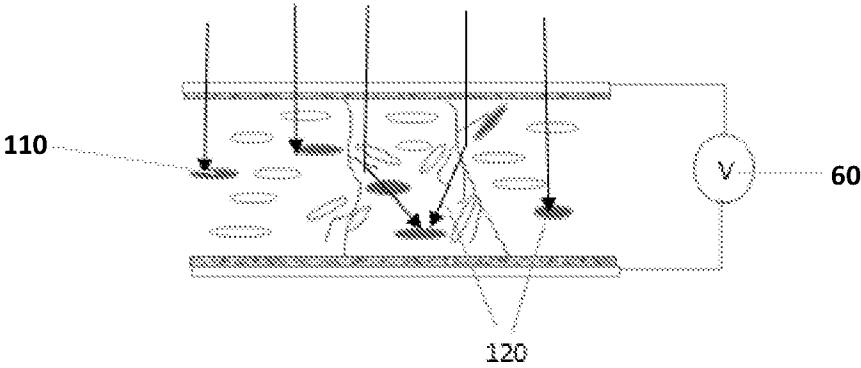


FIG. 12

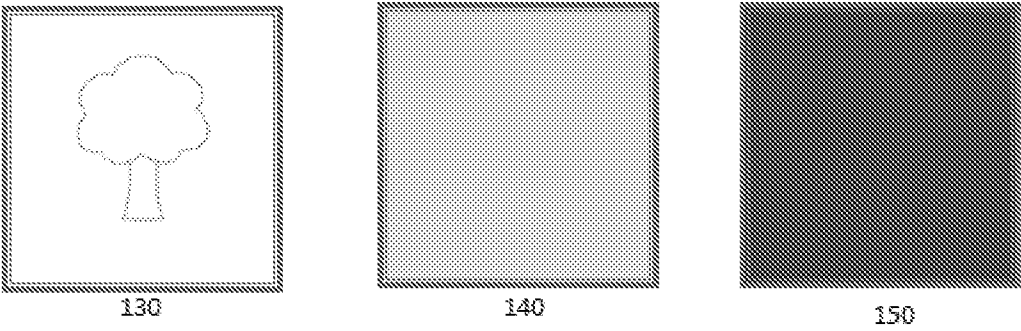
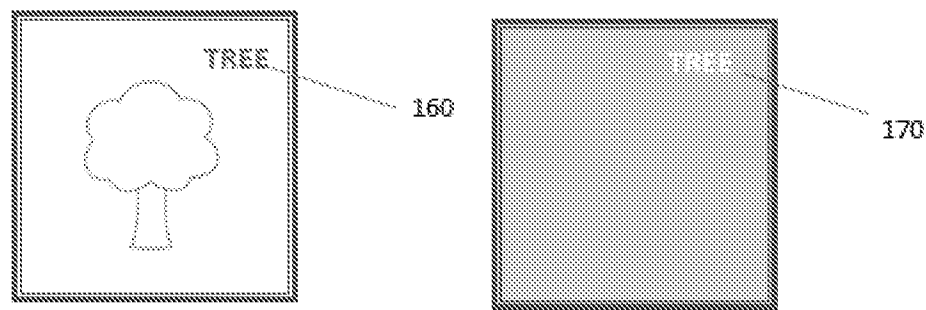


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2018/089588

A. CLASSIFICATION OF SUBJECT MATTER G02F 1/1337(2006.01)i; G02F 1/137(2006.01)i; G02F 1/1334(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 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) CNABS;VEN:orient+, align+, inhomogeneous, inhomogenous, regulat+, uneven+, polymer dispers+ liquid crystal, modulat+, direct+, dim+, inhomogeneity, PDLC, accommodat+, chang+, switch+, irregular+, adjust+,																				
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>Y</td> <td>CN 106125358 A (UNIV SOUTH CHINA NORMAL ET.AL) 16 November 2016 (2016-11-16) description, paragraphs [0020]-[0023], figures 1-6</td> <td>1-21</td> </tr> <tr> <td>Y</td> <td>CN 104035238 A (AU OPTRONICS CORP) 10 September 2014 (2014-09-10) description, paragraphs [0034]-[0048], figures 1-6</td> <td>1-21</td> </tr> <tr> <td>A</td> <td>CN 102408895 A (SHENZHEN CHINA STAR OPTOELECTRONICS TECH) 11 April 2012 (2012-04-11) the whole document</td> <td>1-21</td> </tr> <tr> <td>A</td> <td>JP 2009300844 A (SHARP KK) 24 December 2009 (2009-12-24) 全文</td> <td>1-21</td> </tr> <tr> <td>A</td> <td>US 2011096261 A1 (CASIO COMPUTER CO LTD) 28 April 2011 (2011-04-28) 全文</td> <td>1-21</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	Y	CN 106125358 A (UNIV SOUTH CHINA NORMAL ET.AL) 16 November 2016 (2016-11-16) description, paragraphs [0020]-[0023], figures 1-6	1-21	Y	CN 104035238 A (AU OPTRONICS CORP) 10 September 2014 (2014-09-10) description, paragraphs [0034]-[0048], figures 1-6	1-21	A	CN 102408895 A (SHENZHEN CHINA STAR OPTOELECTRONICS TECH) 11 April 2012 (2012-04-11) the whole document	1-21	A	JP 2009300844 A (SHARP KK) 24 December 2009 (2009-12-24) 全文	1-21	A	US 2011096261 A1 (CASIO COMPUTER CO LTD) 28 April 2011 (2011-04-28) 全文	1-21
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INTERNATIONAL SEARCH REPORT
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