**Title:** LIQUID CRYSTAL DISPLAY FOR POLYMER SUSTAINED ALIGNMENT

**Abstract:** A liquid crystal display panel including a first substrate, a second substrate, a seal disposed around and between peripheral edge portions of the first and second substrates that forms an LCD cell therebetween, a liquid crystal material including a polymerizable material disposed in the LCD cell, and wherein at least one major surface of at least the first or the second substrate is roughened.
LIQUID CRYSTAL DISPLAY FOR POLYMER SUSTAINED ALIGNMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of U.S. Provisional Application Serial No. 62/662,477 filed on April 25, 2018 the contents of which are relied upon and incorporated herein by reference in their entirety as if fully set forth below.

BACKGROUND

FIELD

[0002] The present disclosure relates to a liquid crystal display device, and more particularly, a liquid crystal display device for facilitating vertical alignment of nematic liquid crystal molecules.

TECHNICAL BACKGROUND

[0003] While organic light emitting diode display devices are gaining in popularity, costs are high, and liquid crystal display (LCD) devices still represent most of display devices sold, particularly large panel size devices, such as television sets and other large-format devices such as commercial signs.

[0004] An LCD panel is fabricated with a stack of micro-fabricated patterns in thin films produced by photolithographic methods on the inner surface of the TFT and CF substrate glasses. These patterned films provide much of the mechanical, electrical, and optical functions to the LCD panel. Additional LCD panel optical functionality, such as liquid crystal alignment and liquid crystal alignment films, may be provided from UV activated components in the liquid crystal material after the liquid crystal cell assembly is exposed to ultraviolet (UV) light through panel substrate glass and the patterned films. The patterned films can include metals, insulators, and semiconductors with various levels of UV transmission. Consequently, shadowing effects can be produced within the liquid crystal material during the UV exposure, potentially resulting in under exposed regions. These underexposed regions can cause reliability issues, non-optimum tact time, lower LCD optical transmission, and lower overall optical performance. As the resolution of LCD panels increases, the ratio of patterned film area to non-patterned film area increases, and such a shadowing effect is also expected to increase, thus further impacting the performance of the LCD panel.
SUMMARY

[0005] A liquid crystal display panel is disclosed, comprising a first substrate comprising a first pair of major surfaces, a second substrate comprising a second pair of major surfaces, and a seal disposed around and between peripheral edge portions of the first and second substrates, the first substrate, the second substrate, and the seal forming an LCD cell therebetween. A liquid crystal material including a polymerizable material can be disposed in the LCD cell. At least one major surface of the first pair of major surfaces or the second pair of major surfaces is roughened, with an average surface roughness Ra.

[0006] In some embodiments, both major surfaces of the first pair of major surfaces or the second pair of major surfaces are roughened with an average surface roughness Ra.

[0007] In various embodiments, Ra can be equal to or less than about 350 nm.

[0008] In other embodiments, a method of forming a liquid crystal display panel are described, comprising forming an LCD cell, the LCD cell comprising a first substrate comprising a first pair of major surfaces, a second substrate comprising a second pair of major surfaces, and a seal disposed around and between peripheral edge portions of the first and second substrates. The method may further comprise filling the LCD cell with a liquid crystal material comprising a polymerizable component and exposing the liquid crystal material to UV light through at least one of the first or second substrates. At least one major surface of the first pair of major surfaces or the second pair of major surfaces comprises an average surface roughness Ra equal to or less than a wavelength of the UV light. For example, in various embodiments, Ra can be equal to or less than about 350 nm.

[0009] In some embodiments, both major surfaces of the first pair of major surfaces or the second pair of major surfaces are roughened with an average surface roughness Ra.

[0010] In some embodiments, the first substrate can be a color filter substrate. In some embodiments, the second substrate can be a backplane substrate.

[0011] Additional features and advantages of the embodiments disclosed herein will be set forth in the detailed description that follows, and in part will be clear to those skilled in the art from that description or recognized by practicing the embodiments as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0012] It is to be understood that both the foregoing general description and the following detailed description present embodiments intended to provide an overview or framework for understanding the nature and character of the embodiments disclosed herein. The
accompanying drawings are included to provide further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description explain the principles and operations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a cross-sectional view of an exemplary display device;
[0014] FIG. 2 is a cross-sectional view of a portion of an embodiment of a display panel cell comprising light blocking black matrix material deposited on a substrate of the cell, wherein the substrate is illuminated with UV light and portions of the light are blocked by the black matrix material;
[0015] FIG. 3 is a cross-sectional view of a portion of another embodiment of a display panel cell comprising light blocking black matrix material, wherein an outside surface of a cell substrate of the display device is roughened to scatter incident UV light into shadow regions of the liquid crystal material;
[0016] FIG. 4 is a cross-sectional view of a portion of still another embodiment of a display panel cell comprising light blocking black matrix material, wherein an inside surface of a cell substrate of the display device is roughened to scatter incident UV light into shadow regions of the liquid crystal material; and
[0017] FIG. 5 is a cross-sectional view of a portion of yet another embodiment of a display panel cell comprising light blocking black matrix material, wherein both the inside and the outside surfaces of a cell substrate of the display device are roughened to scatter incident UV light into shadow regions of the liquid crystal material.

DETAILED DESCRIPTION

[0018] Reference will now be made in detail to embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings. Whenever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0019] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, another embodiment includes from the one particular value to the other particular value. Similarly, when values are expressed as approximations by use of the antecedent "about," it will be understood that
the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0020] Directional terms as used herein - for example up, down, right, left, front, back, top, bottom - are made only with reference to the figures as drawn and are not intended to imply absolute orientation.

[0021] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order, nor that with any apparatus, specific orientations be required. Accordingly, where a method claim does not actually recite an order to be followed by its steps, or that any apparatus claim does not actually recite an order or orientation to individual components, or it is not otherwise specifically stated in the claims or description that the steps are to be limited to a specific order, or that a specific order or orientation to components of an apparatus is not recited, it is in no way intended that an order or orientation be inferred in any respect. This holds for any possible non-express basis for interpretation, including: matters of logic with respect to arrangement of steps, operational flow, order of components, or orientation of components; plain meaning derived from grammatical organization or punctuation, and; the number or type of embodiments described in the specification.

[0022] As used herein, the singular forms "a," "an" and "the" include plural references unless the context clearly dictates otherwise. Thus, for example, reference to “a” component includes aspects having two or more such components, unless the context clearly indicates otherwise.

[0023] The word “exemplary,” “example,” or various forms thereof are used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as “exemplary” or as an “example” is not necessarily to be construed as preferred or advantageous over other aspects or designs. Furthermore, examples are provided solely for purposes of clarity and understanding and are not meant to limit or restrict the disclosed subject matter or relevant portions of this disclosure in any manner. It is to be appreciated that a myriad of additional or alternate examples of varying scope could have been presented, but have been omitted for purposes of brevity.

[0024] Modern liquid crystal displays typically utilize nematic liquid crystal materials, wherein the liquid crystal molecules are generally elongated and tend to align parallel to each other in their lowest energy state along an average orientation unit axis. The dielectric
constant and the refractive index of the liquid crystal molecules differ along the unit vector and perpendicular to the unit vector. Thus, the molecules exhibit both dielectric and optical anisotropy, and the orientation of the molecules can be reoriented in an electric field.

[0025] Shown in FIG. 1 is an exemplary LCD display device 10 comprising an LCD display panel 12 formed from a first substrate 14 and a second substrate 16, typically glass, joined by a sealing material 18 positioned between and around a peripheral edge portion of the first and second substrates. First and second substrates 14, 16 and sealing material 18 form a gap or cell 20 therebetween containing liquid crystal material. Spacers (not shown) may also be used at various locations within the gap to maintain consistent spacing of the gap. First substrate 14 may include color filter material. Accordingly, first substrate 14 may be referred to as the color filter substrate. On the other hand, second substrate 16 can include thin film transistors (TFTs) configured to control the polarization state of the liquid crystal material, and may be referred to as the backplane. First and second substrates 14, 16 may each include conducting electrodes on their inner surfaces, wherein an electric field between the electrodes is controlled by the TFTs. LCD display panel 12 may further include one or more polarizing filters 22 positioned on the outside surfaces thereof, for example a polarizing film on at least one of an outside surface of first substrate 14 or an outside surface of second substrate 16.

[0026] LCD display device 10 may further comprise a back-light unit (BLU) 24 arranged to illuminate LCD display panel 12 from behind, i.e., from the backplane side of LCD display panel 12. In some embodiments, BLU 24 may be spaced apart from LCD display panel 12, although in further embodiments, BLU 24 may be in contact with or coupled to LCD display panel 12, such as with a transparent adhesive. BLU 24 provides illumination for LCD display panel 12, which illumination selectively passes through pixels of LCD display panel 12 in accordance with the state of respective TFTs, to form images seen from the front side of the LCD display panel by a viewer. BLU 24 can comprise a light guide plate (LGP) 26 and a reflector 28 positioned along an opposite surface of LGP 26 from LCD display panel 12. Reflector 28 reflects light that may escape from LGP 26 from a backside thereof back in a direction toward LGP 26. In some embodiments, LGP 26 may be a glass light guide plate, although in further embodiments, LGP 26 may be formed from a polymer material such as poly(methyl methacrylate), i.e., PMMA. BLU 24 may further comprise a light source, typically along an edge surface of LGP 26. For example, in various embodiments, BLU 24 may include a linear array of light emitting diodes 30 arranged along at least one edge of LGP 26.
At or near the inner surfaces of first and second substrates 14, 16 the molecules of liquid crystal material can exhibit alignment. This alignment can be increased by the addition of various organic or inorganic films on the inner surfaces of the substrates to obtain a predetermined orientation. Orientation orthogonal to the inner surfaces is called homeotropic alignment, whereas orientation parallel to the surfaces is called homogeneous alignment. Both properties are used in modern display devices, along with polarizing films 22 positioned on the outside of first and/or second substrates 14, 16.

To set a predetermined alignment (pre-tilt angle) in the absence of an electric field, typical display panels include an alignment layer applied to one or both substrate surfaces to provide homeotropic alignment of the liquid crystal material. For example, the alignment layer may be a polyimide alignment layer. The alignment layer of each substrate is rubbed or buffed with a fine-haired cloth, for example positioned on a rotating drum. The rubbing step determines alignment of the liquid crystal molecules at the inner surface of the substrate, and their anchoring strength. The quality of the alignment layer, for example the ability of the alignment layer to determine the pre-tilt angle, depends on such parameters as the pressure of the drum against the alignment layer, the rotational speed of the drum, and the quality of the rubbing cloth. Accordingly, conventional methods of providing alignment via alignment layers can require considerable process control. To wit, optimization of the rubbing process is often performed empirically to obtain optimum results. Thus, the rubbing process can be a significant factor affecting yield.

Another process is a vertical aligned (VA) nematic mode. In vertical alignment (VA) mode devices, the liquid crystal molecules are aligned perpendicular to the substrate surfaces in the absence of an electric field. While VA mode devices eliminate the need for rubbing, an alignment layer is still present. In VA mode devices, the liquid crystal molecules comprise a negative dielectric anisotropy and lateral polar substituents that produce a dipole moment perpendicular to the long axis of the molecule. Thus, the long axis of the molecule rotates in the presence of an electric field to an orientation parallel with the substrate surfaces. To provide a more symmetric viewing angle, each pixel can be divided into domains. Rotation of the liquid crystal molecules starts with a well-defined initial tilt. Hence, the method is termed multi-domain vertical alignment. To obtain the domains, protrusions are added to the substrate alignment layers, causing the pixels to have areas of different preferential tilt direction when an electric field is applied between the two substrates.
More recently, polymer sustained alignment (PSA) techniques have been introduced, wherein a small amount of one or more polymerizable materials are added to the liquid crystal material. After introduction of liquid crystal material into cell 20, the polymerizable material is polymerized, typically by exposure to UV light, with or without an applied electric field. PSA can be achieved without protrusions, greatly simplifying the manufacturing process.

As noted above, substrates that form the display panel cell typically include one or more layers of other materials. For example, in the case of the color filter substrate, color filter material is disposed on the substrate, as well as an interpixel black opaque matrix material, and electrodes. On the other hand, the backplane includes thin film transistor materials, including electrode materials. The various materials can interfere with UV exposure of the polymerizable material during a PSA process.

FIG. 2 depicts a portion of an exemplary LCD panel cell 20 comprising a liquid crystal material 102 including a polymerizable component. Also shown is a simplified view of a color filter substrate, e.g., first substrate 104, including black matrix material 106. UV light 108 is directed at outside surface 110 of first substrate. While the UV light incident on the substrate at a gap between black matrix locations is transmitted through the substrate and into the liquid crystal material in lighted region 112, UV light incident on first substrate 104 directly opposite the black matrix material is blocked, creating a shadow region 114 within the liquid crystal material. As a result, polymerizable material within the shadow region may be incompletely polymerized.

In accordance with the present disclosure, at least one surface of a substrate comprising the LCD panel can be provided with a light scattering surface. For example, FIG. 3 is a cross-sectional view of a portion of an LCD cell 200 comprising a liquid crystal material 202 including a polymerizable component. Also shown is a simplified view of a color filter substrate, e.g., first substrate 204, including black matrix material 206. While not shown, LCD cell 200 further comprises a second substrate opposite first substrate 204, wherein first substrate 204, the second substrate and a seal disposed around and between peripheral edge portions of the first and second substrates form LCD cell 200.

UV light 208 is directed at the substrate outside surface 210. While UV light 208 incident on first substrate 204 opposite a gap between black matrix material locations is transmitted through first substrate 204 and into liquid crystal material 202 in lighted regions 212, UV light 208 incident on first substrate 204 directly opposite the black matrix material is blocked, creating shadow regions 214 within liquid crystal material 202. However, in the
embodiment of FIG. 3, outside surface 210 of first substrate 204 has been provided with scattering features to produce a light scattering surface that scatters UV light 208 directed at first substrate 204 and incident on outside surface 210. For example, the light scattering features can comprise a roughened outside surface 210 of first substrate 204. The scattered light 216 extends into the shadow regions 214, thereby providing increased polymerization of the polymerizable component of the liquid crystal material. A size of the scattering features on outside surface 210 can be less than the wavelength of UV light 208. Scattering features at this scale will scatter the UV light, but have little impact on visible light produced by BLU 24. For example, an average roughness Ra of outside surface 210 can be equal to or less than about 350 nm, where Ra is the arithmetic average value of a filtered roughness profile determined from deviations about a center line representing the nominal surface of the substrate. A roughened outside surface 210 can be obtained, for example, by treating outside surface 210 with a suitable etchant. For example, NaF and/or H3PO4 can be used. Roughened surfaces can also be obtained by abrading outside surface 210 and inside surface 216 (e.g., grinding and/or polishing), for example prior to assembly of LCD cell 200.

[0035] FIG. 4 is a cross-sectional view of a portion of another exemplary LCD cell 300 comprising a liquid crystal material 302 including a polymerizable component. Also shown is a simplified view of a color filter substrate, e.g., first substrate 304, including black matrix material 306. While not shown, LCD cell 300 further comprises a second substrate opposite first substrate 304, wherein first substrate 304, the second substrate and a seal disposed around and between peripheral edge portions of the first and second substrates form LCD cell 300. UV light 308 is directed at the outside surface 310 of first substrate 304. While the UV light incident on the substrate at a gap between black matrix material locations is transmitted through the substrate and into liquid crystal material 302 in lighted regions 312, UV light 308 incident on outside surface 310 of first substrate 304 directly opposite the black matrix material is blocked, creating shadow regions 314 within the liquid crystal material. However, in the embodiment of FIG. 4, inside surface 316 of first substrate 304 has been provided with scattering features to produce a light scattering surface that scatters UV light 308 directed at first substrate 304 and incident on outside surface 310. For example, the light scattering features can comprise a roughened inside surface 316 of first substrate 304. The resultant scattered light 318 produced by inside surface 316 extends into shadow regions 314, thereby providing increased polymerization of the polymerizable component of the liquid crystal material. A size of the scattering features on inside surface 316 can be less than the
wavelength of the UV light 308. Scattering features at this scale will scatter the UV light, but have little impact on visible light produced by BLU 24. For example, an average roughness Ra of inside surface 316 can be equal to or less than about 350 nm, where Ra is the arithmetic average value of a filtered roughness profile determined from deviations about a center line representing the nominal surface of the substrate. A roughened inside surface 316 can be obtained, for example, by treating inside surface 316 with a suitable etchant. For example, NaF and/or H₃PO₄ can be used. Roughened surfaces can also be obtained by abrading outside surface 310 and inside surface 316 (e.g., grinding and/or polishing), for example prior to assembly of LCD cell 300.

[0036] FIG. 5 is a cross-sectional view of a portion of still another exemplary LCD cell 400 comprising a liquid crystal material 402 including a polymerizable component. Also shown is a simplified view of a color filter substrate, e.g., first substrate 404, including black matrix material 406. While not shown, LCD cell 400 further comprises a second substrate opposite first substrate 404, wherein first substrate 404, the second substrate and a seal disposed around and between peripheral edge portions of the first and second substrates form LCD cell 400. UV light 408 is directed at outside surface 410 of first substrate 404. While the UV light incident on the substrate at a gap between black matrix material locations is transmitted through first substrate 404 and into the liquid crystal material in lighted regions 412, UV light incident on first substrate 404 directly opposite the black matrix material is blocked, creating shadow regions 414 within liquid crystal material 402. However, in the embodiment of FIG. 5, both outside surface 410 and inside surface 416 of first substrate 404 are provided with scattering features to produce light scattering surfaces that scatter UV light 408 directed at first substrate 404 and incident on outside surface 410. For example, the light scattering features can comprise a roughened outside surface 410 and a roughened inside surface 416 of first substrate 404. The resultant scattered light 418 extends into the shadow regions 414, thereby providing increased polymerization of the polymerizable component of liquid crystal material 402. A size of the scattering features on outside surface 410 and inside surface 416 is less than the wavelength of the UV light 408 to which liquid crystal cell 400 is exposed. Scattering features at this scale will scatter the UV light, but have little impact on visible light produced by BLU 24. For example, an average roughness Ra of both outside surface 410 and inside surface 416 can be equal to or less than about 350 nm. A roughened outside surface 410 and a roughened inside surface 416 can be obtained, for example, by treating outside surface 410 and inside surface 416 with a suitable etchant. For example, NaF and/or H₃PO₄ can be used. Roughened surfaces can also be obtained by abrading outside surface 410 and
inside surface 416 (e.g., grinding and/or polishing), for example prior to assembly of LCD cell 400.

[0037] It will be apparent to those skilled in the art that various modifications and variations can be made to embodiments of the present disclosure without departing from the spirit and scope of the disclosure. For example, while the foregoing embodiments described UV light directed through a color filter substrate of an LCD panel, in further embodiments, the UV light could be directed through the roughened surface(s) of an LCD panel backplane substrate. Thus, it is intended that the present disclosure cover such modifications and variations provided they come within the scope of the appended claims and their equivalents.
What is claimed is:

1. A liquid crystal display panel, comprising:
   a first substrate comprising a first pair of major surfaces;
   a second substrate comprising a second pair of major surfaces;
   a seal disposed around and between peripheral edge portions of the first and second substrates, the first substrate, the second substrate, and the seal forming an LCD cell therebetween; and
   wherein at least one major surface of the first pair of major surfaces or the second pair of major surfaces is roughened, with an average surface roughness Ra.

2. The liquid crystal display panel according to claim 1, wherein both major surfaces of the first pair of major surfaces or the second pair of major surfaces are roughened, with an average surface roughness Ra.

3. The liquid crystal display panel according to claim 1 or claim 2, wherein Ra is equal to or less than about 350 nm.

4. The liquid crystal display panel according to any one of claims 1 to 3, further comprising a liquid crystal material including a polymerizable component disposed in the LCD cell.

5. The liquid crystal display panel according to any one of claims 1 to 4, wherein the first and second substrates comprise glass.

6. A method of forming a liquid crystal display panel, comprising:
   forming an LCD cell, the LCD cell comprising
   a first substrate comprising a first pair of major surfaces;
   a second substrate comprising a second pair of major surfaces;
   a seal disposed around and between peripheral edge portions of the first and second substrates;
   filling the LCD cell with a liquid crystal material comprising a polymerizable component;
exposing the liquid crystal material to a UV light through at least one of the first or second substrates; and

wherein at least one major surface of the first pair of major surfaces or the second pair of major surfaces comprises an average surface roughness Ra equal to or less than a wavelength of the UV light.

7. The method according to claim 6, wherein both major surfaces of the first pair of major surfaces or the second pair of major surfaces are roughened, with an average surface roughness Ra.

8. The method according to claim 6 or claim 7, wherein Ra is equal to or less than about 350 nm.

9. The method according to any one of claims 6 to 8, wherein the first substrate is a color filter substrate.

10. The method according to any one of claims 6 to 9, wherein the second substrate is a backplane substrate.
A. CLASSIFICATION OF SUBJECT MATTER
G02F 1/1339(2006.01)i, G02F 1/1333(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 1/1339; G02B 5/02; G02F 1/1335; G02F 1/1337; G02F 1/1333

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, substrate, major surface, roughness, UV light, polymerizable component, alignment

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>Y</td>
<td>JP 2010-049207 A (SHARP CORP.) 04 March 2010&lt;br&gt;See paragraphs [0048], [0061]-[0066]: claim 7; and figures 1-4.</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
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"&" document member of the same patent family

Date of the actual completion of the international search
05 August 2019 (05.08.2019)

Date of mailing of the international search report
05 August 2019 (05.08.2019)

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