Disclosed are various reverse-mode direct-view liquid crystal displays (LCD) employing a liquid crystal having a characteristic wavelength in the non-visible spectrum, including transmissive mode displays, and methods of fabrication. In accordance with the principles disclosed, a transmittance mode direct-view LCD includes a first linear polarizer, a second linear polarizer, an internal light source and a cholesteric liquid crystal (CLC) located between the first and second linear polarizers and having a characteristic wavelength to reflect in a non-visible region of light. Portions of the CLC can selectively exhibit a planar state or a focal-conic state, the portions of the CLC in the planar state appearing black, and the portions of the CLC in the focal-conic state appearing white to an observer of the LCD.
FIGURE 2
REVERSE TRANSMITTANCE MODE DIRECT-VIEW LIQUID CRYSTAL DISPLAY EMPLOYING A LIQUID CRYSTAL HAVING A CHARACTERISTIC WAVELENGTH IN THE NON-VISIBLE SPECTRUM

CROSS-REFERENCE TO APPLICATION


TECHNICAL FIELD OF THE INVENTION

[0002] The present invention is directed, in general, to liquid crystal displays and, more specifically, to transmissive black-and-white and color cholesteric liquid crystal displays.

BACKGROUND OF THE INVENTION

[0003] The development of improved low-power-consumption flat-panel liquid crystal displays (LCDs) is an area of very active research, driven by the proliferation and demand for portable electronic appliances, including computers and wireless telecommunications devices. Moreover, as the quality of LCDs improve, and the cost of manufacturing declines, LCDs may eventually replace conventional display technologies, such as cathode-ray-tubes.

[0004] Cholesteric liquid crystal ("CLC") technology is a particularly attractive candidate for many display applications. CLC displays can be used to provide bi-stable and multi-stable displays that, owing to their stability, do not require a continuous driving circuit to maintain a display image, thereby significantly reducing power consumption. Moreover, some CLC displays can be easily viewed in ambient light without the need for back-lighting; such displays are referred to as "reflective" mode displays, while those requiring a back-light are referred to as "transmissive" mode displays. The elimination of the need for back-lighting is particularly significant in that lighting requirements typically represent approximately 90 percent of the total power consumption of conventional LC displays. The visibility of a LC display is governed in part by the contrast between quality of bright and dark states of LC cells in the display. For example, traditional normal mode CLC displays, using CLCs having a characteristic wavelength for the reflection of light in the visible spectrum, may have poor contrast because of an unfavorably low brightness to darkness ratio.

[0005] Accordingly, to meet the growing demand for LCDs, there is a need in the art for high contrast LCDs operable in the transmissive mode.

SUMMARY OF THE INVENTION

[0006] To address the above-described deficiencies of the prior art, the present invention provides a reverse mode direct-view liquid crystal display employing a liquid crystal having a characteristic wavelength to reflect light in a non-visible region, including transmissive mode displays, and methods of fabricating such displays. In accordance with the principles disclosed, the basic structure of the direct-view liquid crystal display (LCD) includes a first linear polarizer, a second linear polarizer having a polarity different from the first linear polarizer, a light source behind the second linear polarizer and a cholesteric liquid crystal (CLC) located in a gap between the first and second linear polarizers. At least one of the first and second linear polarizers does not form a portion of a circular polarizer. The CLC has a characteristic wavelength in a non-visible region and is capable of exhibiting planar or focal-conic states. Thus, portions of the LCD can be controlled to selectively exhibit a planar state or a focal-conic state, thereby achieving high contrast.

[0007] The foregoing has outlined, preferred and alternative features of the present invention so that those skilled in the art may better understand the detailed description of the invention that follows. Additional features of the invention will be described hereinafter that form the subject of the claims of the invention. Those skilled in the art should appreciate that they can readily use the disclosed conception and specific embodiment as a basis for designing or modifying other structures for carrying out the same purposes of the present invention. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0009] FIGS. 1A and 1B illustrates a cross-sectional view of an exemplary reverse mode transmissive LCD structure, in accordance with the principles of the present invention, and its operation when its liquid crystal is in planar and focal-conic states, respectively; and

[0010] FIG. 2 illustrates exemplary embodiments of a method of fabricating a direct-view LCD, in accordance with the principles of the present invention.

DETAILED DESCRIPTION

[0011] As further described below with reference to the exemplary embodiments, illustrated in FIGS. 1A and 1B, and method of fabrication, illustrated in FIG. 2, the present invention discloses the heretofore unrecognized capability to construct a direct-view LCD by combining a CLC having a characteristic intrinsic reflective wavelength, \( \lambda_0 \), reflecting light maximally in a non-visible region of light, with two or more linear polarizers having different polarity, and a light source situated behind the second linear polarizer. At least one of the first or second polarizers does not form a portion of a circular polarizer. For purposes of the present invention, visible light is defined as the range of the light spectrum that the human visual system is relatively most sensitive to, i.e., a relative sensitivity of about greater than 5%, compared to the most sensitive wavelength, between about 450 nm to about 700 nm, with the non-visible spectrum laying above and below this range.

[0012] In particular embodiments, the CLC comprises a mixture of a nematic liquid crystal, and a chiral dopant. The
mixture may comprise about 60 percent to about 90 percent by weight of the nematic liquid crystal, with a balance of the mixture comprising the chiral dopant. In certain embodiments, the mixture contains sufficient amounts of the appropriate dopant or combination of dopants to produce a helical CLC structure having a characteristic pitch that establishes a maximum reflective wavelength within either an infrared or an ultraviolet region of the light spectrum. In an exemplary embodiment, the infrared range may be greater than 700 nm and the ultraviolet range may be less than 450 nm.

[0013] In other embodiments, however, the infrared range may be greater than 780 nm and the ultraviolet range may be 400 nm or less. Portions of the CLC may be selectively controlled to exhibit a planar state or a focal-conic state. Portions of the CLC in the planar state within the direct-view LCD appear black to an observer, and portions of the CLC in the focal-conic state within the direct-view LCD appear white to an observer of the LCD.

[0014] Referring to FIGS. 1A and 1B, illustrated is a cross-sectional view of a reverse transmittance mode LCD 100, and its operation when CLC 140 is in planar and focal-conic states, respectively. LCD 100 comprises a first linear polarizer 110, a second linear polarizer 120 having a polarity different from the first polarizer, the first and second linear polarizers thereby forming a gap 130, a CLC 140 of the above described embodiments located in the gap, and an internal light source 190. For example, the light source 190 can be a conventional LCD backlight, such as an electroluminescent panel. The gap 130 may range from about 1 micron to about 6 microns, and in certain preferred embodiments is about 2 to 3 microns.

[0015] The LCD 100 may also include first electrode 150 adjacent an inner surface of the first linear polarizer 110 and second electrode 160 adjacent an inner surface of the second linear polarizer 120. Electrodes 150, 160 are preferably made from conventional substantially transparent materials, such as indium tin oxide (ITO), and optionally laminated onto a glass substrate. The electrodes 150, 160 may further be optionally coated with an alignment coating material, for example, comprising a polyimide. Preferably, overlying polyimide layers on the two electrodes 150, 160 are buffered antiparallel to each other. The first and second electrodes, 150, 160 are further coupled to a conventional driving circuit (not shown) operative to cause the CLC 140 to selectively transform to a planar or focal-conic state. When in the planar state, the CLC 140 will reflect polarized light passing through the second linear polarizer 120 from internal light source 190 maximally at λp, plus an associated bandwidth. CLC 140, however, allows nonreflected light 180 at substantially all wavelengths of light outside of the reflected bandwidth to pass through the CLC 140 without effecting the polarity of the nonreflected light 180. When in the focal-conic state, however, the CLC 140 is operative to optically retard and scatter at all wavelengths, thereby changing the polarity of the nonreflected light 180. In certain embodiments, colored filters (not shown), located between the light source and the first linear polarizer, may be included in the LCD to provide a single or multi-colored display.

[0016] The first linear polarizer 110 is a conventionally made linear polarizer and does not include any retarder layer, or other material producing a retarder effect, between it and the CLC 140 that would cause the first linear polarizer 110 to comprise part of a circular polarizer. The first linear polarizer 110 may preferably be positioned on the outer surface of the first electrode 150; those skilled in the art, however, will recognize that the first linear polarizer 110 alternatively could be positioned on the inner surface of the first electrode 150, or the first linear polarizer 110 could have a first electrode integrally formed therewith.

[0017] The second linear polarizer 120, also a conventionally made linear polarizer, has a polarity different from and preferably opposite to the polarity of the first linear polarizer 110. Analogous to that discussed above, the second linear polarizer 120 is not associated with any materials that would cause it to comprise part of a circular polarizer. The second linear polarizer 120 may be positioned on the outer surface of the second electrode 160; those skilled in the art, however, will recognize that the second linear polarizer 120 alternatively could be positioned on the inner surface of the second electrode 160, or the second linear polarizer 120 could have a second electrode integrally formed therewith, and thereby minimize parallax effects.

[0018] With continuing reference to FIG. 1A, shown is the operation of a preferred embodiment of LCD 100 when CLC 140 is in the planar state. Nonreflected light 180, including visible light, is polarized as it passes through the second linear polarizer 120. According to the principles of the present invention, the polarity of the light 180 is substantially unaffected as it passes through the CLC 140. Moreover, because λp is in the nonvisible region of the spectrum, substantially all light 180 in the visible region of the spectrum reaching the CLC 140 will not be reflected by the CLC 140. The light 180 passing through the CLC 140, however, will not pass through the first linear polarizer 110 because the first and second polarizers 110, 120 have a different polarity. Consequently, the first linear polarizer 110 will block the exit of light 180. In a preferred embodiment, the first and second linear polarizers 110, 120 have the opposite polarity, and therefore the amount of light 180 exiting the LCD 100 is minimized. In another preferred embodiment, where λp is in the ultraviolet spectrum, polishing a surface 125 of second linear polarizer 120 at a boundary between CLC 140 and second linear polarizer 120 is thought to minimize changes to the polarity of light 180, thereby maximizing the blockage of light 180 reaching the first linear polarizer 110. Thus, an observer of LCD 100 when CLC 140 is in the planar state will observe the LCD to be black.

[0019] Turning now to FIG. 1B, shown is the operation of a preferred embodiment of LCD 100 when CLC 140 is in the focal-conic state. Due to the light retarding and scattering properties of CLC 140 when in the focal-conic state, the polarity of nonreflected light 180 passing through second linear polarizer 120 is altered during its passage through the CLC 140. As noted above, because λp is in the nonvisible region of the spectrum, substantially all light 180 in the visible region of the spectrum reaching the CLC 140 will not be reflected by the CLC 140. Consequently, at least a portion of the light 180 will have a polarity the substantially the same as the first linear polarizer 110, and therefore exit LCD 100. And because λp is in the nonvisible region of the spectrum, substantially all light in the visible region of the spectrum will pass through the CLC and appear to an observer of the LCD 100 as a white display. Thus, an
observer of the transmissive LCD 100 when CLC 140 is in the focal-conic state will observe the LCD to be white. In one preferred embodiment, \(\lambda_o\) is in the infrared spectrum. In summary, the LCD 100 is capable of a substantially black and white display, corresponding to the CLC 140 in the planar and focal-conic state, respectively.

[0020] Turning now to FIG. 2, illustrated is an exemplary embodiment of a method of fabricating a reverse mode direct-view LCD 200, in accordance with the principles of the present invention. The LCD 200 is fabricated by placing a first linear polarizer 210, placing a second linear polarizer 220 having a polarity different from the first polarizer 210, wherein, as discussed above, at least one of the first and second polarizers 210, 220 does not form a portion of a circular polarizer. Placing the polarizers 210, 220 thereby forms a gap 230. A light source 290 is placed behind the second linear polarizer 220. The gap 240 is filled with a CLC having a \(\lambda_o\) in a non-visible region of light and capable of exhibiting a planar state or a focal-conic state. Conventional filling techniques, such as capillary or vacuum filling, well known to those of ordinary skill in the art, may be used. Filling the gap 240 includes filling with a mixture of a nematic liquid crystal and a chiral dopant. In certain embodiments, the mixture comprises about 60 percent to about 90 percent by weight of the nematic liquid crystal and a balance of the mixture comprises the chiral dopant. One of ordinary skill in the art will understand that the chiral dopant may in some embodiments contain a combination of chiral dopants to produce the desired \(\lambda_o\) in an ultraviolet or infrared region of light. In certain embodiments, forming the gap 230 results in gaps ranging from about 1 micron to about 6 microns and in certain preferred embodiments, about 2 micron to about 3 microns. When \(\lambda_o\) is in the infrared region of the light spectrum, the gap is preferably about 2 microns. Fabricating the LCD 200 further includes positioning conventional first and second electrodes 250, 260; as discussed above, the electrodes could alternately be formed and positioned integrally with the first and second linear polarizer 210, 220, respectively. In certain preferred embodiments, alignment coating materials rubbed antiparallel to each other may be coated 245 onto the electrodes.

EXAMPLES

[0021] Two different types of direct-view transmissive reverse-mode LCDs were prepared according to the present invention, each having a \(\lambda_o\) in either an infrared or ultraviolet region of the light spectrum. For all preparations, unless otherwise indicated, two pieces of four inch square glass substrates, were laminated with electrode material comprising ITO having a resistance of 60 \(\Omega\) per square inch. The ITO layers were then coated with an alignment coating material of polyamide (PI-150; Nissan Chemical Industries, Ltd., Houston, Tex.). The polyamide coatings were buffed anti-parallel to each other. The electrodes were then laminated to a linear polarizer and a reflector, described below, to form test cells.

[0022] The desired electronic waveforms were applied on the cell as described in U.S. Pat. No. 5,625,477, entitled, “Zero Field Multistable Cholesteric Liquid Crystal Display;” U.S. Pat. No. 5,889,566, entitled, “Multistable Cholesteric Liquid Crystal Devices Driven By Width-Dependent Voltage Pulses;” and U.S. Pat. No. 5,933,203, entitled, “Apparatus for and Method Of Driving A Cholesteric Liquid Crystal Flat Panel Display,” all to Bao-Gang Wu, et. al., which are commonly assigned with the present invention, and incorporated herein by reference as if reproduced herein in its entirety. Using the apparatus described in the above cited references, every pixel of the cell can be switched between planar state and focal conic states. All nematic liquid crystals and chiral dopants were obtained from EM industries (Hawthorne, N.Y.).

[0023] A transmissive reverse-mode type LCD (designated LCD-I) having a \(\lambda_o\) in the infrared range was prepared in the following way. A first linear polarizing plate, was laminated onto the first substrate. A second linear polarizing plate, was laminated onto the second substrate. Spacers were used to form a gap of about 3 microns between the polarizers. A liquid crystal mixture containing by weight about 90.1% ZLI-5400-100™ (nematic liquid crystal), and chiral dopant, comprising about 3.8% ZLI-4571™, and 6.1% ZLI-811™, was filled into the cell. In addition, a backlighting was placed behind a linear polarizing plate that was laminated onto the backside of the cell. A second transmissive reverse-mode type LCD (designated LCD-2) having a \(\lambda_o\) in the ultraviolet range was prepared by filling a similarly fabricated cell with a liquid crystal mixture containing about 63.1% by weight ZLI-5400-100™, and chiral dopant comprising by weight: about 22.4% CB-15™, 6.5% ZLI-4572™, and 8.0% ZLI-3786™.

[0024] The resulting transmissive reverse-mode type LCDs have a \(\lambda_o\) centered at about 780 nm and about 400 nm, for LCD-I and LCD-2, respectively. For both LCDs, planar state and focal conic states are stable at least one month in the absence of an electrical field. And for both LCDs, when the back-light is turned on, the planar state appears as black and the focal conic state appears as white.

[0025] From the foregoing detailed description, it is apparent that the present application discloses novel reverse-mode direct-view liquid crystal displays employing liquid crystal having a characteristic wavelength to reflect light in the non-visible spectrum, including transmissive and transflective displays.

[0026] Although the present invention and its advantages have been described in detail, those skilled in the art should understand that they can make various changes, substitutions and alterations herein without departing from the spirit and scope of the invention.

What is claimed is:

1. A direct-view liquid crystal display (LCD), comprising:
   - a first linear polarizer;
   - a second linear polarizer having a polarity different from said first linear polarizer, wherein at least one of said first and second linear polarizers does not form a portion of a circular polarizer;
   - a cholesteric liquid crystal (CLC) located in a gap between said first and second linear polarizers, said CLC having a characteristic wavelength in a non-visible region and capable of exhibiting a planar state or a focal-conic state; and
   - a light source situated behind said second linear polarizer.
2. The direct-view LCD recited in claim 1 wherein said CLC comprises a mixture of a nematic liquid crystal and a chiral dopant.
3. The direct-view LCD recited in claim 2 wherein said mixture comprises about 60 percent to about 90 percent by weight of said nematic liquid crystal and a balance of said mixture comprising said chiral dopant.

4. The direct-view LCD recited in claim 1 wherein said gap ranges from about 1 microns to about 6 microns.

5. The direct-view LCD recited in claim 1 wherein said gap ranges from about 2 microns to about 3 microns.

6. The direct-view LCD recited in claim 1 wherein said LCD further includes an alignment coating material.

7. The direct-view LCD recited in claim 6 wherein said alignment coating material comprises a polyimide.

8. The direct-view LCD recited in claim 1 wherein said characteristic wavelength of said CLC is in an infrared region.

9. The direct-view LCD recited in claim 8 wherein said characteristic wavelength of said CLC is greater than about 780 nm.

10. The direct-view LCD recited in claim 8 wherein said characteristic wavelength of said CLC is greater than about 700 nm.

11. The direct-view LCD recited in claim 1 wherein said characteristic wavelength of said CLC is in an ultraviolet region.

12. The direct-view LCD recited in claim 11 wherein said characteristic wavelength of said CLC is less than about 380 nm.

13. The direct-view LCD recited in claim 11 wherein said characteristic wavelength of said CLC is less than about 450 nm.

14. The direct-view LCD recited in claim 11 wherein a surface of said reflector at a boundary between said CLC and said second linear polarizer is polished.

15. The direct-view LCD recited in claim 1 further comprising a first electrode beside an inner surface of said first linear polarizer and a second electrode beside an inner surface of said second linear polarizer.

16. The direct-view LCD recited in claim 1 wherein said second linear polarizer has an opposite polarity as said first linear polarizer.

17. The direct-view LCD recited in claim 1 further including one or more colored filters located between said light source and said first linear polarizer.

18. A method of fabricating a direct-view LCD comprising the steps of:

- placing a first linear polarizer;
- placing a second linear polarizer thereby forming a gap between said first linear polarizer and said second polarizer, said second linear polarizer having a polarity different from said first linear polarizer, wherein at least one of said first and second linear polarizers does not form a portion of a circular polarizer;
- filling said gap with a cholesteric liquid crystal (CLC), said CLC having a characteristic wavelength in a non-visible region and capable of exhibiting a planar state or a focal-conic state; and
- placing a light source behind said second linear polarizer.

19. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said filling with said CLC comprising a mixture of a nematic liquid crystal and a chiral dopant.

20. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said filling with said mixture comprising about 60 percent to about 90 percent by weight of said nematic liquid crystal and a balance of said mixture comprising said chiral dopant.

21. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said forming said gap ranging from about 1 microns to about 6 microns.

22. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said forming said gap ranging from about 2 microns to about 3 microns.

23. The method as recited in claim 18 wherein fabricating said direct-view LCD further includes coating said polarizer and said reflector with an alignment coating material.

24. The method as recited in claim 23 wherein fabricating said direct-view LCD further includes coating said alignment coating material comprising a polyimide.

25. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said filling said CLC having said characteristic wavelength in an infrared region.

26. The method as recited in claim 25 wherein said characteristic wavelength of said CLC is greater than about 780 nm.

27. The method as recited in claim 25 wherein said characteristic wavelength of said CLC is greater than about 700 nm.

28. The method as recited in claim 18 wherein fabricating said direct-view LCD includes said filling said CLC having said characteristic wavelength an ultraviolet region.

29. The method as recited in claim 28 wherein said characteristic wavelength of said CLC is less than about 380 nm.

30. The method as recited in claim 28 wherein said characteristic wavelength of said CLC is less than about 450 nm.

31. The method as recited in claim 28 wherein fabricating said direct-view LCD includes polishing a surface of said second linear polarizer, said surface at a boundary between said CLC and said second linear polarizer.

32. The method as recited in claim 18 wherein fabricating said direct-view LCD includes placing a first electrode beside an inner surface of said first linear polarizer and placing a second electrode beside an inner surface of said second linear polarizer.

33. The method as recited in claim 18 wherein said polarity of said second linear polarizer is opposite a polarity of said first linear polarizer.

34. The method as recited in claim 18 wherein fabricating said direct-view LCD further includes locating a colored filter between said light source and said first linear polarizer.