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Control of Reflectivity and Bistability in Displays Using Cholesteric Liquid-Crystals

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Control of reflectivity and bistability in displays using cholesteric liquid crystals

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It is demonstrated that the reflective properties and bistability of cholesteric liquid crystals can be controlled by proper surface treatment and dispersed polymers. Dispersing a polymer in the liquid crystal or using a cell with an inhomogeneous surface anchoring creates permanent defects which result in long-term bistability, high contrast at large viewing angles, and gray scale. The wide-angle, reflective feature makes cholesteric materials suitable for displays without backlights and bistability provides flicker-free operation.

It has been some 30 years since cholesteric liquid crystals were considered as a candidate for an electro-optic flat-panel display.[1,2] Their brilliant colors and various optical textures under an applied field make them attractive for this use; however, early work met with immediate problems. One was the strong angular dependence of the reflected light intensity and color. Another problem was the instability of the focal conic texture and the lack of a convenient means to switch between the focal conic and the planar textures. A third problem was obtaining a gray scale, that is, a means to modulate the reflected light intensity.

Recently, we showed that these problems could be overcome by introducing a low concentration of a multifunctional monomer in the cholesteric material and polymerizing it under suitable field conditions.[3–5] The polymer appeared to introduce a domain structure which corrected the view angle problems, introduced bistability and gave gray-scale memory. We explored this concept further by introducing defects in cholesteric textures through surface modifications. We compared the optical response of such samples with those containing polymer networks.

The liquid crystal used in our experiment is a mixture of E48, CE1, ZLI4572 and CB15 (EM Chemicals) and reflects green light. The material was sandwiched between two glass plates with idium tin oxide (ITO) electrodes. Thickness of the cell was controlled by 5 μm glass fibers. We made three cells with different surface anchoring and different dispersed polymers. For cell 1 the glass plates were coated with polyimide (PI) and buffed for homogeneous alignment. For cell 2, besides the PI coating and buffing, small amounts (<5%) of biacrylate monomer and photoinitiator were added into the mixture; the monomer has reactive double bonds at both ends, which were polymerized under UV irradiation to form a cross-linked network. After the polymerization the cell remains selectively reflecting at the same wavelength but the reflection band is broadened and the reflectance is decreased. Our experimental results show that the polymer could be either rigid or flexible and that a thermoplastic can replace biacrylate monomers.[6] For cell 3 there is no special surface treatment except cleaning and there is no dispersed polymer.

The reflection spectra and dynamic response were measured using a lab-made reflection spectrometer depicted in Fig. 1(a). The incident light was unpolarized and collimated with an area of 20 mm^2. The incident angle was 22.5°. The reflected light was detected with a collection cone of 70° centered at the reflection angle of 22.5°. The angular dependence of the reflection was also studied using a spectroscan meter (PR704 made by PhotoResearch) shown in Fig. 1(b). The incident angle was 42° and the detection angle was varied. The collection angle is less than 5°.

At zero field the liquid crystal is in the planar texture where the helical axes are more or less perpendicular to the surface of the cell and the cell is reflecting. When a low field is applied to the cell, the liquid crystal (whose dielectric anisotropy $\epsilon_a > 0$) is transformed into the focal conic texture where the helical axes are oriented randomly and the cell is weakly scattering. After the low field is turned off the liquid crystal remains in the focal conic texture or relaxes back slowly to the planar texture.[7] This relaxation depends on the surface anchoring, the presence of the dispersed polymer, and the pitch of the liquid crystal. When a field above the threshold[8] $E_C = 2\pi^2(\pi K_2/\epsilon_a)^{1/2}(1/P)$ is applied, where K_2 is the twist elastic constant and p is the pitch of the liquid crystal, the liquid crystal is transformed into the homeotropic texture where the liquid crystal molecules are aligned parallel to the field and the cell is transparent. If the field is turned off quickly, the liquid crystal will relax directly back to the planar texture without going through the focal conic texture (the switching mechanism will be discussed in another article.)

Bistability of the display depends on surface anchoring and the dispersed polymer. We studied the response of the cells to ac pulses and the result is shown in Fig. 2. In our experiment ac square pulses of 20 ms duration were used. The incident light was monochromatic and tuned to the reflection peak of the material. When a pulse of 34 V was applied to the cells, the material was driven to the scattering state during the pulse, independent of the state of the material before the pulse. The transformation time from the reflecting state to the scattering state is nearly 1 ms. After the pulse, cells 2 and 3 remain in this state while cell 1 slowly relaxes back to the planar texture. For cell 1 (PI coated and buffed) the strong homogeneous anchoring produced by PI coating favors the planar texture, and the focal conic texture is only metastable. The relaxation time from the focal conic texture to the planar texture is in the order of hours. For cell 2, the focal conic texture is stabilized by the polymer, reported as polymer-stabilized cholesteric textures (PSCT)
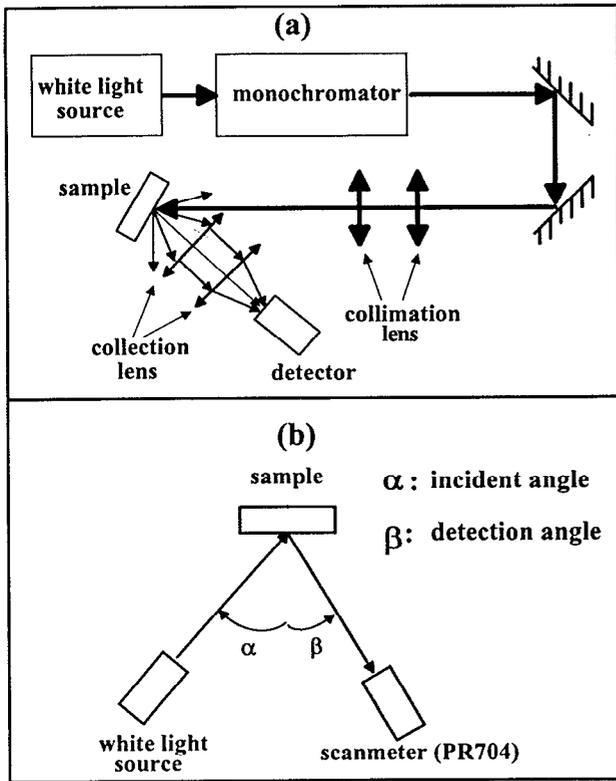
FIG. 3. Reflection spectra of the three cells defined in Fig. 2. R: cells in the reflecting state; S: cells in the scattering state. The experimental condition is shown in Fig. 1(a).

FIG. 1. Schematic diagrams of the experimental setup: (a) lab-made spectrometer where the angles of incidence and reflection are 22.5° with a collection angle 70° for the reflected light; (b) spectroscan meter (PR704) for the viewing angle study, where the incident angle α is set at 42° and the detection angle β is varied. The collection angle is less than 5°.

display.[3-5] For cell 3, the focal conic texture is also stable due to the lack of homogeneous surface anchoring. When a pulse of 50 V is applied to the cells, the material is driven to the homeotropic state during the pulse. After removal of the high electric field, the planar texture is always obtained in-
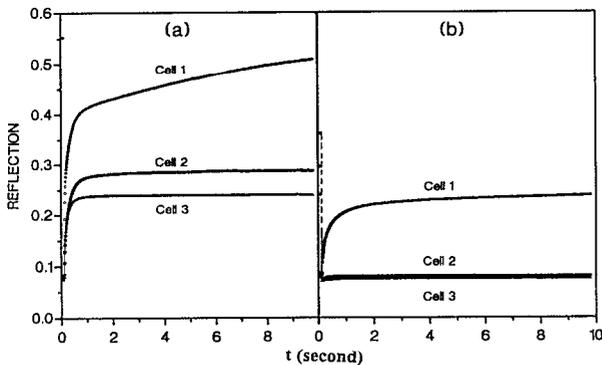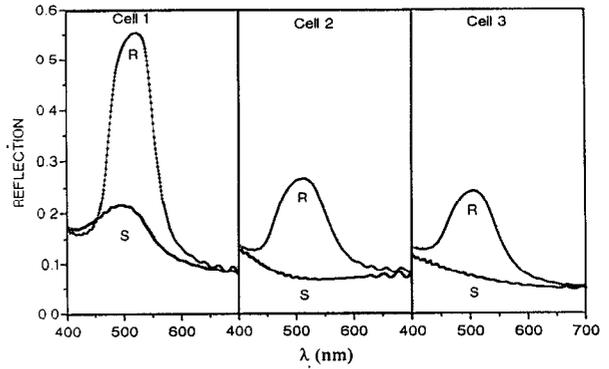

FIG. 2. The reflectance of three different cells following the application of an ac square voltage pulse of 20 ms in duration: cell 1 has buffed polyimide surfaces but no dispersed polymer, cell 2 has buffed polyimide surfaces and a dispersed polymer network, cell 3 has bare ITO surfaces and no dispersed polymer. (a) A 50 V pulse was applied at $t=0$ driving the cells into the reflecting state, (b) a 34 V pulse was applied at $t=0$ driving the cells into the scattering state; the scattering state of cell 1 is not stable. The experimental condition is shown in Fig. 1(a).

dependent of surface anchoring, a phenomenon produced by the switching mechanism. Relaxation times from the homeotropic texture to the planar texture are near 300 ms for cells 2 and 3 and more than 5 s for cell 1. The relaxation consists of two processes. The first process is the transformation from the homeotropic texture to the planar texture and is fast. The second one is related to the annihilation of defects and is slow. For cells 2 and 3, the defects are permanent while for cell 1 the defects are annihilated slowly.

The reflective properties of the cells also depend on the surface anchoring and dispersed polymer. The reflection spectra measured by the spectrometer depicted in Fig. 1(a) are shown in Fig. 3. Cell 1 in the reflecting state (corresponding to the planar texture) has the highest reflection. The peak reflection is slightly higher than 50% (50% from the liquid crystal and the rest from the glass-air interfaces). When the liquid crystal is in the scattering state (corresponding to the focal conic texture), many domains still have the helical axes perpendicular to the surface of the cells because of the strong homogeneous surface anchoring, and the reflection is relatively high. The optical contrast (defined as the ratio between the integrated reflectance of the planar and focal conic textures over the visible region) of cell 1 is, therefore, low. For cells 2 and 3, when the liquid crystal is in the reflecting state, the reflection is about 30%. The decrease of the reflection is caused by the undetected reflection outside the detection angle as well as the loss caused by permanent defects (regions where the helical structure is distorted) in the cells. The optical contrast of cells 2 and 3 are higher than that of cell 1 because of the lower reflectivity of the focal conic state.

We studied the angular dependence of the reflection using the spectroscan meter shown in Fig. 1(b). The reflection spectrum was measured at three different detection angles (Fig. 4) where the negative angle indicates the scanmeter was on the same side of the normal to the cell as the light source. The reflection is normalized to that of the white reflection standard provided by PhotoResearch. Cells 2 and 3 have a much wider viewing angle than cell 1. In cell 1 the helical axes are all perpendicular to the surface of the cell. The incident light is only strongly reflected at an angle that sat-
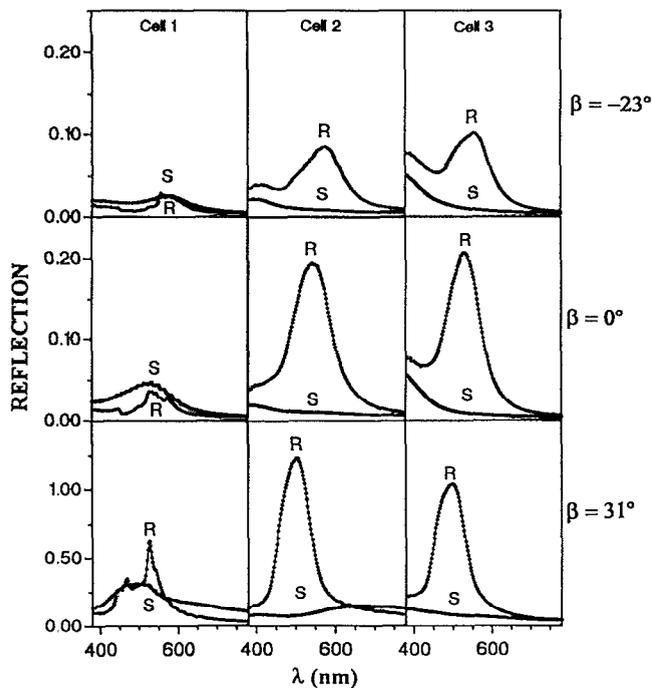
FIG. 4. Reflection spectra of the cells defined in Fig. 2 at three different detection angles. R: cells in the reflecting state; S: cells in the scattering state. The experimental condition is shown in Fig. 1(b).

domains of focal conic texture. These domains are around 10 μm in size. The reflection intensity depends on the relative percentage of material in the planar texture.

We have shown that the bistability and reflective properties of display from cholesteric liquid crystals can be controlled by proper surface treatment and dispersed polymers. Cells without a polyimide coating and cells with a polyimide coating and a dispersed polymer have higher contrast and wider viewing angle than reflective super twist nematic (STN).[9] For these cells the bistability is preserved over years. The bistable cholesteric liquid crystals can be used to make high-definition flat-panel displays without the use of an active matrix.[9] The displays can be operated in the reflection mode under front-lit conditions. They do not need polarizers and exhibit a bright color under room-lit conditions. Although the response time is not fast enough for video rate displays, these materials are well suited for displays for hand-held computers and electronic books that do not require video rate operation. The cholesteric materials can also be used for long-term information storage and optical signal processing. Efforts are underway to improve the dynamic response time and the driving schemes.

isfies the Bragg condition. In cells 2 and 3 the planar texture is not perfect. The helical axes are distributed around the normal to the surface of the cell due to the disturbance of the dispersed polymer or to the imperfect surface anchoring. The reflected light is distributed over a broad range of angles; therefore, cells 2 and 3 have large viewing angles.

Cholesteric liquid crystals have stable gray-scale level.[9] They can be driven into states where the planar and focal conic textures coexist. These states are stable at zero field and have intermediate reflection. Optical microscopy shows that in these states domains of planar texture coexist with

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