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Cholesteric liquid crystal/polymer dispersion for haze-free light shutters

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A new dispersion involving a polymer in low concentration with a cholesteric liquid crystal is reported. Two types of light modulators from these materials are described as a normal mode shutter which is opaque (light scattering) in the field-OFF state and transparent in the field-ON state and a reverse-mode shutter with the opposite field conditions. The transparent state of both cells is haze-free for all viewing angles making the material attractive for window applications and direct view displays.

Liquid crystal polymer dispersions have been studied intensively in recent years for their potential in display and window applications.[1,2] Interest in these materials comes from their potential for bright projection and direct view displays (no polarizer), flexible displays (plastic substrates) coatability on large surfaces, and features which simplify fabrication. Various forms of dispersion have been reported under different acronyms: dispersions from aqueous polymers (NACP);[3] dispersions from phase separation processes (PDLC);[4] dispersions with variations in types of material and concentration (LCPC).[5] One feature these dispersions all have in common is that the polymers are all isotropic and as such have two drawbacks which limit their usefulness. The first drawback is that they exhibit haze at wide angles of view in the transparent state. The second drawback is that they are transparent only in the field-ON condition. In order to solve these problems, it has been suggested that isotropic polymers be substituted by polymer liquid crystals such that the refractive indices can be matched for all angles of incident light.[6] However, it is very difficult to find a polymer liquid crystal which has suitable refractive indices and which also phase separates from the low-molecular weight liquid crystals to form droplets.

We report a new liquid crystal/polymer dispersion[7] which overcomes the limitations described above. In this dispersion, monomers are photopolymerized in a suitably aligned cholesteric liquid crystal. The concentration of the polymer gel is so low that it does not affect the refractive indices. The function of polymer is to stabilize poly-focal conic domains for scattering either in the field-OFF condition or field-ON condition. Whenever the cell is in the focal conic texture, the refractive indices are mismatched between the domains and hence the cell is opaque (scattering).[8,9] The cholestric polymer dispersion can be operated either in normal mode (opaque in a field-OFF condition and clear in a field-ON condition) or reverse-mode cell (clear in a field-OFF condition and opaque in a field-ON condition). In the clear state both cells are haze free for all viewing angles.

The liquid crystal used in our experiment is a mixture of nematic E48 and chiral CB15 (EM Chemicals). The nematic material E48 is a liquid crystal mixture and CB15 a pure chiral compound. The pitch length p of the resulting cholesteric liquid crystal is adjusted by the concentration of CB15. The value of p is selected such that the cholesteric material reflects light in the infrared region. Approximately 2 wt % of lab-synthesized monomers, 4,4′-bisacryloylbiphenyl and 4,4′-biphenylene bis[4(6-acryloyloxy)-benzoate], are added to the liquid crystal along with a small amount of photoinitiator.

The molecular structure of the monomer is similar to that of the liquid crystal but has functional groups at both ends. The mixture is sealed between two glass plates with ITO electrodes. The inner electrode cell spacing is controlled in the usual manner by glass fiber spacers. After the desired alignment of the cholesteric material is achieved the monomers are then polymerized to form an anisotropic network.[10] There is evidence that phase separation occurs in the sample during polymerization.

A normal-mode cell does not require any surface treatment; however, the cell is irradiated by UV light in the homeotropic texture in the presence of the electric field. When the field is removed after the polymerization, the liquid crystals in the vicinity of the polymer tend to remain perpendicular to the surface while the remaining liquid crystal relaxes back to the spiral structure. A focal conic texture is formed as the result of the competition between the intrinsic spiral structure and the constraining effect of the polymer. This focal conic texture is illustrated conceptually in Fig. 1(a). In this state the material is strongly scattering for all polarizations of incident light and the cell is opaque. When the electric field is applied, the liquid crystal transforms into the homeotropic texture as illustrated in Fig. 1(b) and the cell becomes clear. The function of the polymer in the normal-mode cell is to create the poly-domain focal conic texture and control the domain size.

In the reverse-mode cell the glass substrates are treated with polyimide and buffed for homogeneous alignment of the liquid crystal. The cell is prepared by irradiating with UV light with the cell in the planar texture where the liquid crystal molecules and the monomers are parallel to the surface of the cell. After the polymerization the liquid crystal remains in the planar texture. The configuration of the liquid crystal in the planar texture and the structure of the polymer are illustrated conceptually in Fig. 2(a). The pitch length of the cholesteric liquid crystal is in the infrared region and the cell appears clear for visible light. When an electric field is applied to the cell, the liquid crystal transforms into the focal conic texture as shown in Fig. 2(b). The liquid crystal molecules in the vicinity of the

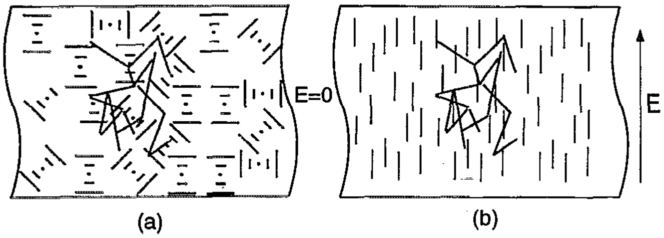

FIG. 1. Conceptual illustration of the configurations of the liquid crystal and the polymer structure of the normal-mode shutter: (a) scattering state (focal conic texture) and (b) clear state (homeotropic texture).

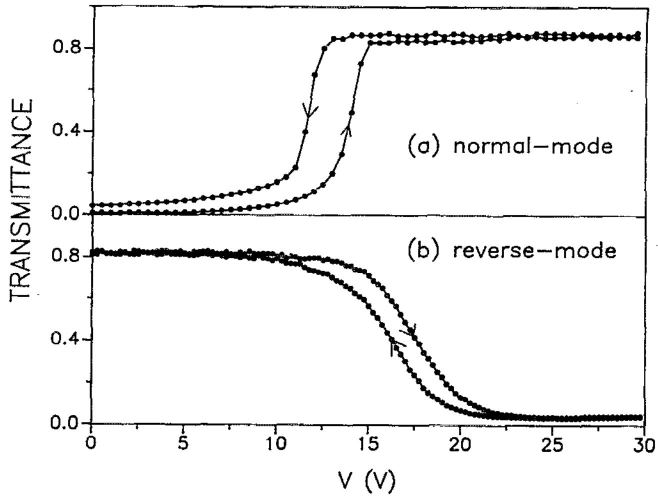

FIG. 3. Transmittance of the shutters vs the applied voltage.

polymer tend to remain in the planar texture where they are anchored by the polymer. In this state the material is scattering for all polarizations of the incident light and the cell is opaque. When the field is turned OFF, the liquid crystal relaxes back to the planar texture and the cell becomes clear. The function of the polymer in the reverse mode is to control the size of focal conic domain, forcing the liquid crystal to relax back to the planar texture when the field is removed.

The electro-optical properties of the cells were studied by measuring their transmittance with a He-Ne laser with a collection angle (full angle) of 2°. The voltage-transmittance curves of the cells are shown in Fig. 3. In this measurement a continuous sine wave 2 kHz was used and the amplitude was varied slowly. The thickness of the cells is 10 μm. For the normal-mode cell the transmittance at a zero potential is low ($\sim$1%). As the voltage is increased, the helical structure is untwisted gradually and therefore, the transmittance increases. When the voltage is increased to 16 V, the liquid crystal is transformed into the homeotropic texture and the transmittance reaches its maximum. In this state the transmittance is about 90%. The loss of light intensity in the ON state is mainly due to the reflections from the glass-air interfaces. When the voltage is decreased, the transmittance decreases. A large hysteresis effect is observed for this cell. The transmittance at zero potential depends on the manner in which the field is turned OFF. If the field is turned OFF abruptly the transmittance is 1%. If the field is turned OFF slowly the transmittance is 5%.

For the reverse-mode cell the transmittance at a zero potential is at maximum (82%). The transmittance does not change until the voltage is increased 13 V where the liquid crystal begins to transform into the focal conic texture. When the voltage is increased above 20 V, the transmittance decreases to its minimum value of 4%. The transition is sharper for this type of cell.

The dynamic response of the cells were studied by using a gated sine wave of widths of 50 or 100 ms. The response of the normal-mode cell is shown in Fig. 4(a), where a pulse of amplitude 40 V is applied. The turn-ON time is 40 ms while the turn-OFF time is 15 ms. The response of the reverse-mode cell is much faster as shown in Fig. 4(b) where a voltage pulse of 30 V was applied. The turn-ON and turn-OFF times are approximately 5 ms.

We have studied the transmittance of the cells for oblique incident light. In this experiment the cell was immersed in a cylinder containing glycerol to reduce refraction at the glass-air interface. The cell was rotated around an axis orthogonal to the direction of the incident light which was polarized perpendicular to the rotation axis of the cell. The angular dependence of transmittance for the normal-mode cell in the clear state is shown in Fig. 5. The result of the reverse-mode cell was identical. In both the

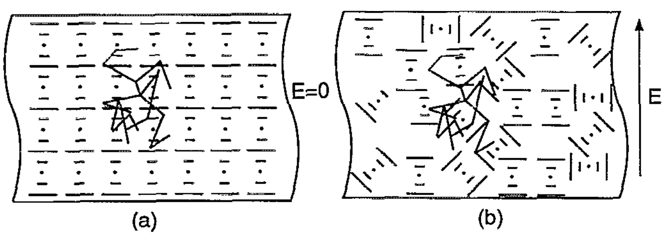

FIG. 2. Conceptual illustration of the configurations of the liquid crystal and the structure of the reverse-mode shutter: (a) clear state (planar texture) and (b) scattering state (focal conic texture).

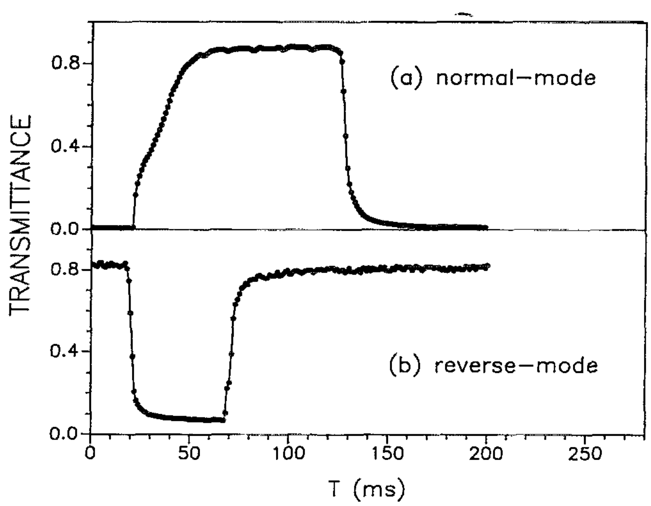

FIG. 4. Dynamic response of the shutters.

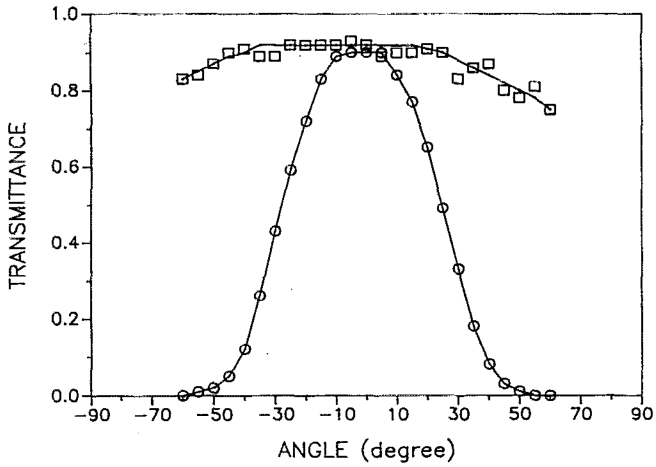

FIG. 5. The angular dependence of the transmittance: □=the normal-mode shuter in the clear state; ○=PDLC.

clear and opaque states transmittance did not change when the sample was rotated. The angular dependence of a standard PDLC film with isotropic polymer is shown in Fig. 5 for comparison.

We have demonstrated that cholesteric liquid crystal/polymer dispersion can be used to make both normal and reverse-mode light shutters. The shutters have the following features: high transmittances in the clear state; haze-free transmittance for all viewing angles; simplicity in cell design not requiring the use of polarizers and amenable to vacuum filling. The reverse-mode shutter has very good electro-optical characteristics, exhibiting a sharp transition, small hysteresis, and fast response. It is feasible to multiplex this display.

Further research to optimize these devices and better understand the physics of operation is in progress.

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