Bistable Polymer Stabilized Cholesteric Texture Light Shutter

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We developed a bistable polymer stabilized cholesteric texture (PSCT) light shutter which can be switched between a transparent state and an opaque state by voltage pulses. The PSCT light shutter is switched to a transparent state by a low frequency voltage pulse and remains transparent after the pulse. It is switched to an opaque state by a high frequency voltage pulse and remains opaque after the pulse. It can be used for architectural and greenhouse windows and is very energy-efficient.

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Liquid crystals (LCs) have been used to make switchable privacy windows. The state-of-the art technologies for switchable windows are polymer dispersed liquid crystals (PDLCs) and polymer stabilized cholesteric texture (PSCT) windows. In PDLCs, liquid crystals exist in micron size droplets which are dispersed in isotropic polymers.[1–8] In PSCTs, a cholesteric texture is stabilized by polymer networks.[9–13] In these switchable windows, the liquid crystal materials are sandwiched between two parallel substrates (glass plates or plastic films) with transparent electrodes. Electric voltage can be applied to the electrodes to switch the liquid crystal material. At one voltage condition, the materials are *opaque* (optical scattering), because the liquid crystal is randomly oriented throughout the system and thus the refractive indices between the liquid crystal and polymer (in PDLC) or between liquid crystal domains (in PSCT) are mismatched. At another voltage condition, the materials are *transparent*, because the liquid crystal is uniformly aligned and the material becomes an optically uniform medium. These liquid crystal switchable windows have the advantages of fascinating visual effect, no mechanically moving parts and instant switching. They have been used for architectural and greenhouse windows for privacy and energy flow control. Voltages can be applied to vary the transmittance and thus adjust the light passing through the windows. The heating effect on greenhouse and photo-synthesis effect on plants can be controlled. There is, however, one problem with the switchable LC windows that a voltage must be applied to sustain one of the optical states, namely, they are monostable. Although liquid crystals are dielectric media, in reality their conductivities are not zero due to impurities and capacitance effect. The switchable windows consume a lot of energy when a voltage must be applied for prolonged periods.

We have previously reported a thermally switchable bistable PSCT light shutter.[14] In this paper we report on a bistable switchable liquid crystal light shutter which can be switched between a transparent state and an opaque state by voltage pulses. No voltage has to be applied to sustain the optical states, and therefore this window is very energy-efficient. The switchable light shutter is based on PSCT. The transparent state is the homeotropic (H) state (texture) where the LC is uniformly aligned in the cell normal direction as shown in Fig. 1(b). The scattering state is the focal conic (FC) state (texture) where the LC exists in randomly oriented poly-domains as shown in Fig. 1(a). With proper polymer networks, both the homeotropic and focal conic states are stabilized at zero voltage.

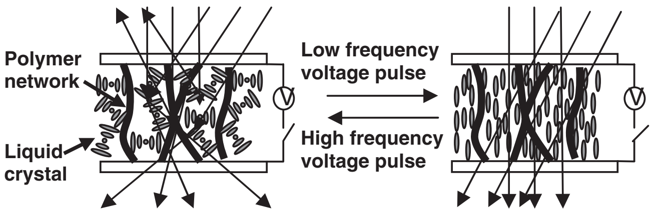

Fig. 1. Schematic diagram of the bistable PSCT light shutter.

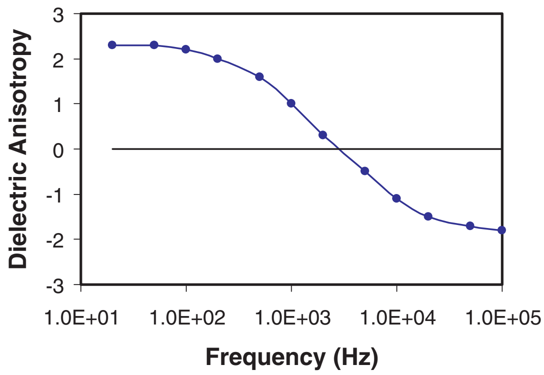

Fig. 2. Dielectric anisotropy of the ChLCl as a function of the frequency of applied voltage.

The cholesteric (Ch) LC used in our experiment exhibits dual dielectric anisotropies as shown in Fig. 2.[15] For low frequency AC electric fields, the dielectric anisotropy is positive and the liquid crystal tends to be parallel to the applied field. For high frequency AC electric fields, the dielectric anisotropy is negative and the liquid crystal tends to be perpendicular to the applied field. The pitch of the ChLC is about 1.6 µm. The liquid crystal is mixed with a multi-functional acrylate monomer RM257 (from Merck) which has a molecular structure, consisting of a rigid core and flexible tails, similar to liquid crystal molecules. A small amount of photo-initiator is also added to the mixture. The mixture is in Ch phase at room temperature and is sandwiched between two glass substrates with transparent ITO electrode. Cell thickness is controlled by 10 µm glass fiber spacers. The cell is irradiated by UV light to polymerize the monomers. During polymerization, a sufficiently high low frequency voltage is applied across the cell

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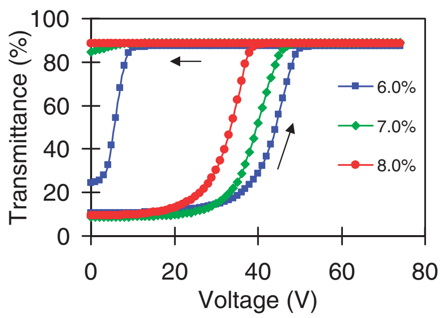

Fig. 3. The transmittance vs applied voltage (100 Hz) curve of the PSCT light shutters with various polymer concentrations.

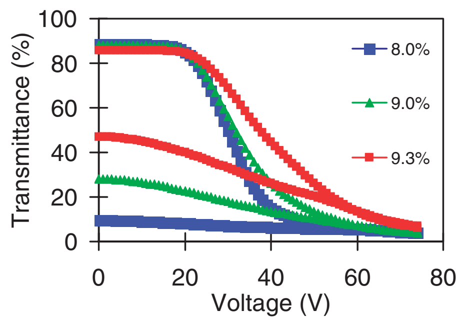

Fig. 4. The transmittance vs applied voltage (20 kHz) curve of the PSCT light shutters with various polymer concentrations.

and the mixture is in the homeotropic texture where the liquid crystal and monomer molecules are aligned along the cell normal direction.[16,17] The formed polymer network (even after the removal of the voltage) is in the cell normal direction as shown in Fig. 1, which was confirmed by scanning electron microscopy (SEM).[16]

After polymerization, the state of the material depends on the pitch of the LC, polymer concentration and applied electric field. The intermolecular interaction between LC molecules favors the FC state where the helical structure is preserved. The shorter the pitch, the stronger the LC tends to be in the FC state. The interaction between the LC molecules and the polymer network favors the H state where the helical structure is unwound. The higher the polymer concentration, the stronger the polymer network tends to keep the LC in the H state.[17–20] When a low frequency electric field is applied across the cell, the LC tends to be aligned parallel to the field and thus the H state is favored. When a high frequency electric field is applied across the cell, the LC tends to be aligned perpendicular to the field and thus the FC state is favored.

Figure 3 shows the response of the PSCT cells to low frequency applied voltages. In the electro-optical measurement, a white light from an arc lamp was used. The collection angle of the detection was 4.7°. The PSCT cells are initially in the FC state with low transmittance. When the voltage is increased, the cells are switched to the H state and the transmittance increases. When the voltage is removed, the state of the cells depends on the polymer concentration. When the polymer concentration is 6.0%, the material relaxes back to the FC state and the transmittance decreases, because the polymer network is not strong enough to hold the material in the H state. As the polymer concentration increases, its aligning effect increases. When the polymer concentration is 7.0%, the material relaxes partially back to the FC state and the transmittance decreases slightly. When the polymer concentration is 8.0%, its aligning effect is strong and can hold the material in the H state and the transmittance remains high. The aligning effect of the polymer network is proportional to the surface area of the polymer network in per unit volume. When the lateral size of the network is fixed, as the polymer concentration is increased, the network density increases; the surface area per unit volume increases and therefore the aligning effect increases. The stronger aligning effect of the higher concentration polymer network is also shown by the lower voltage needed to switch the material to the H state.[17,20]

Figure 4 shows the response of the PSCT cells to high frequency applied voltages. The cells are initially in the H state with high transmittance. When the voltage is increased, the cells are switched to the FC state and the transmittance decreases. When the voltage is removed, the state of the cells also depends on the polymer concentration. When the polymer concentration is 8.0%, the material remains in the FC state and the transmittance remains low, because the polymer network is not too strong to pull the material back to the H state. As the polymer concentration increases, its aligning effect increases. When the polymer concentration is 9.0%, its aligning effect is too strong and pulls the material partially back to the H state and the transmittance increases. When the polymer concentration is 9.3%, its aligning effect is even stronger and pulls the material further into the H state and the transmittance increases even more. The stronger aligning effect of the higher concentration polymer network effect is also shown by the higher voltage needed to switch the material to the FC state.

The PSCT cell with 8.0% polymer is bistable at zero voltage. It can be either in the FC state with low transmittance or the H state with high transmittance. Voltage pulses with different frequencies can be used to switch it back and forth. Figure 5(a) shows the response of the bistable PSCT cell initially in the H state to a 500 ms wide high frequency voltage pulse. The amplitude of the pulse is 50 V and the frequency is 20 kHz. Before the pulse the material is in the H state with high transmittance. When the high frequency voltage pulse is applied, the material is switched to the FC state and the transmittance decreases. After the pulse, the material remains in the FC state except for a small reorientation of the LC as indicated by the slight increase of the transmittance. Figure 5(b) shows the response of the bistable PSCT cell initially in the FC state to a 500 ms wide low frequency voltage pulse. The amplitude of the pulse is 50 V and the frequency is 100 Hz. Before the pulse the material is in the FC state with low transmittance. When the low frequency voltage pulse is applied, the material is switched to H state and the transmittance increases. After the pulse, the material remains in the H state with high transmittance. If the voltage pulses are too short, they will not be able to switch the PSCT cell into the maximum and minimum transmittance states. Also gray scale is possible by varying the pulse width because of the multi-domain structure of the PSCT cell.

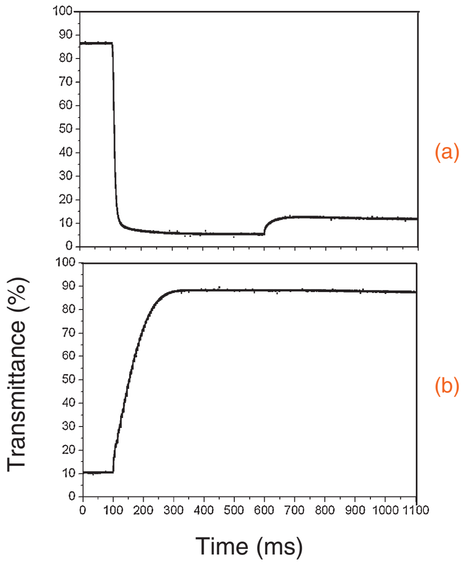

Fig. 5. The response of the bistable PSCT light shutter to a 500 ms voltage pulse with the amplitude of 50 V. The frequency of the voltage: (a) 20 kHz; (b) 100 Hz.

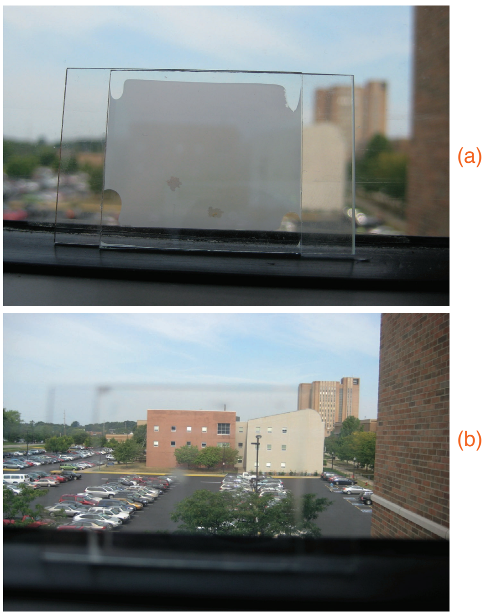

Fig. 6. Photographs of the bistable PSCT light shutter at zero voltage: (a) in focal conic state; (b) in homeotropic state.

Figure 6(a) shows a photograph of the bistable PSCT light shutter at zero field after being switched to the FC texture by a high frequency voltage pulse. The light shutter is scattering and blocks the scene behind. Figure 6(b) shows a photograph of the shutter at zero field after being switched to the H texture by a low frequency voltage pulse. The shutter is transparent and the scene behind is visible.

We studied the aligning effect of the polymer network in a polymer stabilized cholesteric texture light shutter. We observed that the aligning effect increases with increasing polymer concentration. By using a proper polymer network and a dual frequency ChLC, we developed a bistable PSCT light shutter at zero field. The bistable light shutter can be switched to the scattering focal conic state by applying a high frequency voltage pulse and can be switched to the transparent homeotropic state by applying a low frequency voltage pulse. The bistable PSCT material can be used to make architectural and greenhouse windows to control light energy flow; the windows are energy-efficient, because no voltage is needed to sustain its state. When ambient temperature is low, the window is switched to the transparent state and sunlight can pass through the window to warm the building. When the ambient temperature is high, the window is switched to the scattering state and sunlight is scattered (some of the sunlight is scattered backward and does not enter the building) and the heating effect of sunlight is thereby reduced.[21,22)]

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