P-152: High Performance Reflective and Transflective Displays Using Guest-Host Liquid Crystal Gels

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Abstract

Two high performance reflective guest-host liquid crystal displays (GH LCDs) using a dual-frequency liquid crystal (DFLC) gel and a negative liquid crystal (NLC) gel are developed. These polarizer-free GH-LCDs exhibit ~50% reflectance, ~200:1 contrast ratio, and <5 ms response time. Such reflective LCDs can also be used in double cell gap transflective displays.

1. Introduction

Guest-host liquid crystal displays (GH LCDs) exhibit a high brightness and wide viewing angle because they do not require any polarizer [1,2]. Several device configurations such as Cole-Kashnow cell [3], White-Taylor cell [4] and double orthogonal cells [5-7] have been proposed for achieving polarization independence. A typical reflectance of the GH LCD is ~50%, but the contrast ratio is only ~5:1. The low contrast ratio is limited by the dichroic ratio (typically ~10:1) of the employed dyes. To enhance contrast ratio, one could increase the LC cell gap or dye concentration, however, the tradeoff is the decreased reflectance. Increasing LC cell gap or dye concentration could improve the contrast ratio; however, its reflectance is sacrificed. Recently, we developed a new GH LCD using a dye-doped dual-frequency liquid crystal (DFLC) gel on the ITO-only substrates [8]. Although its contrast ratio reaches ~150:1 and response time ~6 ms, its driving voltage is still too high for TFT-LCD applications.

In this paper, we demonstrate two new polarizer-free, fast-response, and high-contrast guest host LC gels for reflective and transflective displays. The normally white gels exhibit ~52% reflectance, ~200:1 contrast ratio, ~5 ms response time, and ~20 V_{rms} driving voltage. Two black and white segmented reflective displays using such LC gels are demonstrated.

2. Mechanism and Sample Preparation

The structure and light modulation mechanisms of the dye-doped NLC gel are schematically depicted in Figure 1(a) and Figure 1(b). At V=0, the cell does not scatter light and the absorption is rather weak. Therefore, the display has the highest reflectance. When we apply a high voltage at f= 1 kHz in the dye-doped NLC gel, the liquid crystals and dye molecules are reoriented in the x-y plane, as Figure 1(b) depicts. The polymer network scatters light strongly. Since the alignment layer has no rubbing treatment, the absorption has no preferred direction; therefore, the light scattering and dye absorption efficiency reaches their maxima. As a result, the display appears black.

For comparison purpose, two types of LC gels were fabricated: 1) DFLC and 2) negative $\Delta\varepsilon$ LC (NLC). Our DFLC mixture has following physical properties: birefringence Δn=0.267 (at λ=633 nm, T=21°C), crossover frequency f_c=10 kHz, and dielectric anisotropy $\Delta\varepsilon$= 7.72 at f= 1 kHz and $\Delta\varepsilon$= -3.51 at f= 50 kHz. The NLC we employed is ZLI-4788 (Merck, Δn=0.1647 at λ=589 nm; $\Delta\varepsilon$= -5.7 at f= 1 kHz). We prepared two LC cells: one is dye-doped DFLC cell, and the other is dye-doped negative LC cell. We mixed the DFLC (or ZLI-4788) and a diacrylate monomer (bisphenol-A-dimethacrylate) with a dichroic dye S428 (Mitsui, Japan) at 90:5:5 wt % ratios. The dye-doped DFLC mixture (or the dye-doped NLC mixture) was then injected into an empty cell whose inner surfaces were coated with a thin indium-tin-oxide (ITO) electrode and polyimide (PI) layer *without* rubbing treatment. The PI layer provides vertical alignment for the LC molecules. The cell gap was 5 μm. The filled cell was irradiated by a UV light (λ~365 nm, I~15 mW/cm^2). Both cells were cured at 13°C for 2 hr. After photo-polymerization, the formed chain-like polymer networks are along the z direction because the LC directors are aligned perpendicular to the glass substrates during the UV curing process, as Figure 1(a) shows.

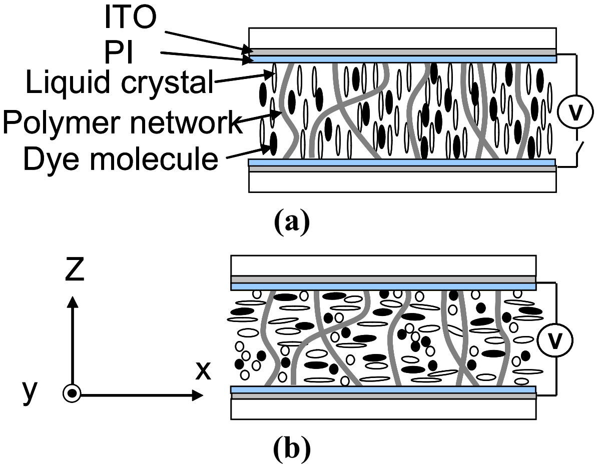

Figure 1: Operating principle of the dye-doped DFLC gel and dye-doped negative LC gel. (a) Voltage-off state, and (b) voltage-on state. The PI has no rubbing treatment.

3. Results and Discussions

Because the guest-host system we employed appears dark red rather than black, we used a linearly polarized green diode laser

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(λ=532 nm) instead of a white light source for characterizing the device performances. A dielectric mirror was placed behind the cell so that the laser beam passed through the cell twice. A large area photodiode detector was placed at ~25 cm (the normal distance for viewing a mobile display) behind the sample which corresponds to ~2^o collection angle. A computer controlled LabVIEW data acquisition system was used for driving the sample and recording the light reflectance.

Figure 2 plots the voltage-dependant reflectance of the dye-doped DFLC gel at *f*=50 kHz (gray line) and dye-doped NLC gel *f*=1 kHz (solid black line). These curves are independent of laser polarization. The reflectance is normalized to that of a pure DFLC cell or pure negative LC cell with the same cell gaps. The maximum reflectance is ~52% in the low voltage regime and decreases gradually as V>V_{th} because the employed LC has a negative $\Delta\varepsilon$ and LC directors are in homeotropic structure at V=0. At V=30 V_{rms}, the measured contrast ratio of the dye-doped DFLC cell is as high as 190:1 at *f*=50 kHz. As to dye-doped NLC gel, it reaches the same contrast at 20 V_{rms} at *f*=1 kHz.

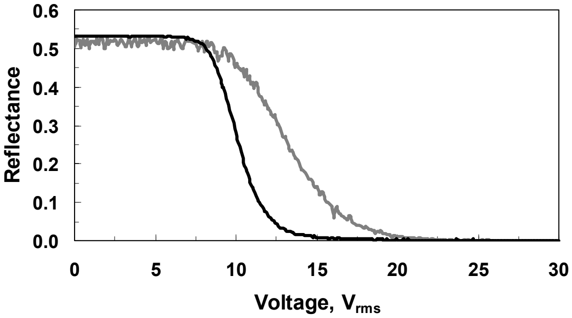

Figure 2: The voltage-dependent reflectance of the dye-doped DFLC gel at *f*=50 kHz (gray line), and the dye-doped NLC gel at *f*=1 kHz (black line). λ=532 nm.

Response time is another important issue for guest-host displays. A typical response time of a guest-host display is around 50 ms. The response time of our dye-doped DFLC gel and dye-doped NLC gel is fast, as shown in Figure 3 and Figure 4. If we fix the voltage at 30 V_{rms} while switching the frequency between 1 kHz and 50 kHz in the dye-doped DFLC gel, the rise time is ~0.93 ms and decay time is ~0.47 ms. For the dye-doped NLC gel, the rise time is 1.03 ms and decay time is 4.54 ms when the applied voltage is from 0 to 20 V_{rms} at f=1 kHz.

To prove principle, we also fabricated a segmented reflective display using the dye-doped NLC gel. To avoid specular reflection, we laminated a diffusive reflector on the backside of the bottom glass substrate in order to widen the viewing angle. The ambient white light was used to illuminate the samples. Figure 5 shows the displays using a 4-µm dye-doped NLC gel. The bright segments represent the state of V=0. The dark areas represent the ITO electrodes with V=20 V_{rms} at *f*=1 kHz in dye-doped NLC gel.

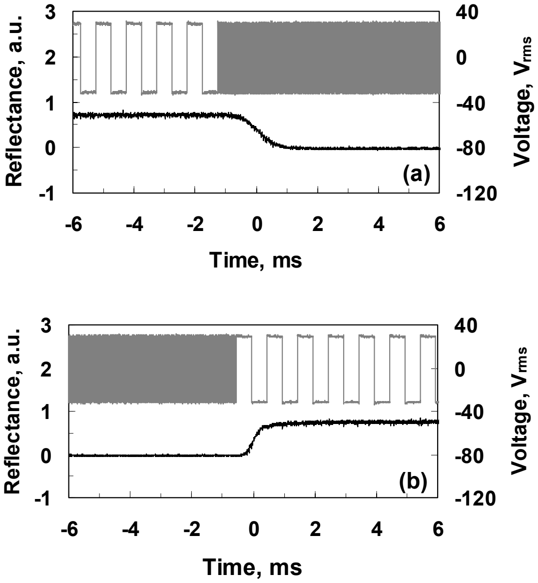

Figure 3: Response time of the dye-doped DFLC gel.

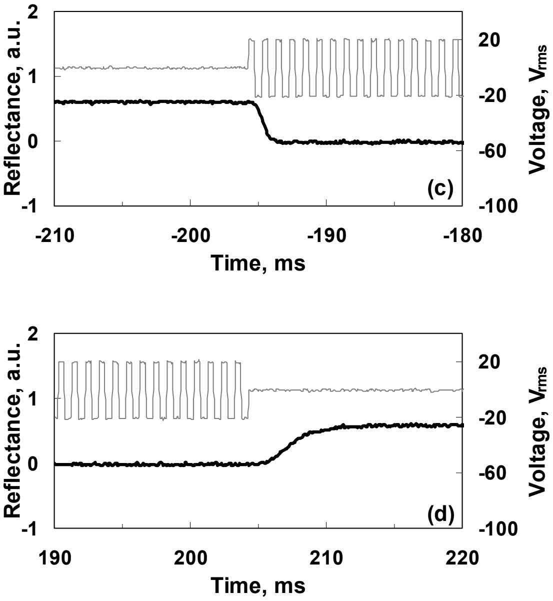

Figure 4: Response time of the dye-doped negative LC gel.

This dye-doped LC gel can also be used for polarizer-free transflective display as well. To match the electro-optic properties, the double cell gap approach should be implemented. The concept is shown in Figure 6. Since no polarizer is needed, the display should exhibit high optical efficiency and wide viewing angle. To lower the driving voltage, a high birefringence and high $\Delta\varepsilon$ negative LC and slightly lower polymer concentration could be considered.

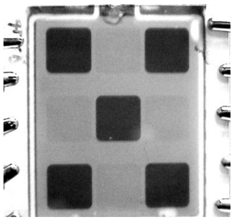

Figure 5: Displayed images using a reflective dye-doped NLC gel.

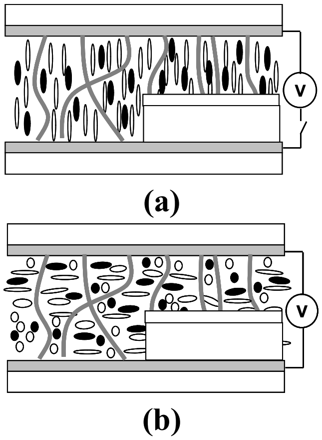

Figure 6: The concept of a polarizer-free transflective GH LCD using dye-doped LC gels.

4. Conclusion

We have demonstrated two high-contrast and polarization-independent reflective guest-host LCDs using dye-doped DFLC gel and dye-doped negative Δε LC gel. The fabrication process is simple compared to the doubled layer GH LCDs. The response time is fast in dye-doped DFLC gel, but the driving voltage is high. Besides, DFLC has dielectric heating effect and usually the Δε is small. The dye-doped negative LC gel is a more practical way for applications. The driving voltage is low in dye-doped negative LC gel; however, the tradeoff is the slightly slower response time. Since no polarizer is needed, the viewing angle is wide and the brightness is high in both cells. The new designs of polarizer-free guest-host LCDs are useful in electronic paper application and also have potential to be used in polarizer-free transflective LCD using double cell gaps.

5. Acknowledgements

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