

P-72: Ionic Effects in Bistable Reflective Cholesteric Liquid Crystals

Xiang-Dong Mi and Deng-Ke Yang

Liquid Crystal Institute and Chemical Physics Program, Kent State University, Kent, OH

Abstract

We have found that ionic effects play an important role in driving cholesteric liquid crystal displays. The ions change the effective electric field inside the liquid crystal and help to create nucleation seeds for transitions. These effects reduce the driving voltages by about 10%, make the response of the liquid crystal faster, and result in a higher contrast ratio.

1. Introduction

The electro-optical properties of the liquid crystals are usually frequency dependent. For example, the threshold voltage of TN and STN changes when the frequency of applied voltage varies [1,2]. While bistable reflective cholesteric liquid crystal displays have many advantages such as low power consumption, sun readability, high brightness, wide viewing angle, and etc, they are suffering from a slow response and requiring a high drive voltage [3,4,5,6]. We have addressed these problems by studying ionic effects of a yellow bistable reflective cholesteric liquid crystal cell. By measuring reflectance, transmission, and resistance, we have found that ionic effects play an important role in driving the cholesteric liquid crystal display

2. Results

2.1 Reflectance measurements

We performed measurements of the reflectance vs pulse voltage with various frequencies to study ionic effects. The cell was initially set either in the planar texture (P) or in the focal conic texture (F). The reflectance was measured 1 second after the pulse was removed. When a low drive voltage pulse was applied, the state of the material remained unchanged. When an intermediate drive voltage pulse was applied, the material was switched from the planar texture to the focal conic texture or remained in the focal conic texture. When a high drive voltage pulse was applied, the material was switched to the homeotropic texture and relaxed to the planar texture after the pulse. Fig. 1 shows the response of the cholesteric liquid crystal display to voltage pulses: when the frequency was 1000 Hz, a 40 ms long pulse could not switch the material from the planar texture completely to the focal conic texture (because the reflectance of the material could not be decreased to that of the focal conic texture), while it could when the frequency was 50 Hz. It also shows that at the frequency of 1000 Hz, the voltages required to achieve the homeotropic texture were about 39 V from the planar texture, and about 42 V from the focal texture. However, at the frequency of 50 Hz, the voltages required to achieve the homeotropic texture were about 36 V from the planar texture, and about 38 V from the focal texture, around 10% lower. We also notice that the black state

achieved with 50 Hz was darker than obtained with 1000 Hz. If we kept the amplitude of the voltage pulse same for both 50 Hz and 1000 Hz, the width of pulse with 50 Hz required was shorter than that with 1000 Hz, indicating that the transition with 50 Hz was faster than that with 1000 Hz. At 50 Hz, when the voltage was close to the transition voltage, a strong turbulence was observed in the cell. This turbulence helped to create more nucleation seeds needed in the planar→homeotropic transition and the focal conic→homeotropic transition. Therefore, the drive voltages were lower and a darker focal conic texture and a brighter planar texture were achieved.

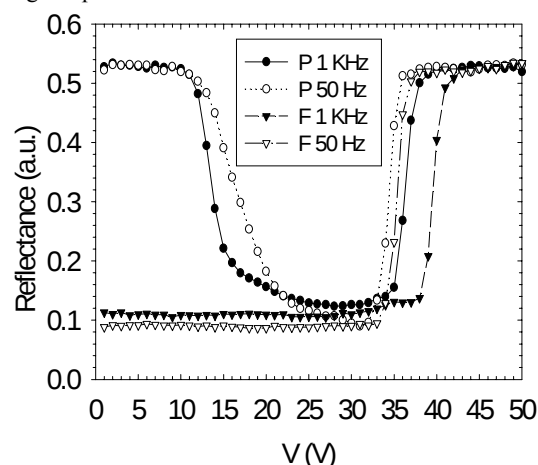


Fig. 1 Reflectance vs amplitude of the pulse. P and F represent that the initial state was in the planar texture and the focal conic texture, respectively. The pulse width was 40 ms.

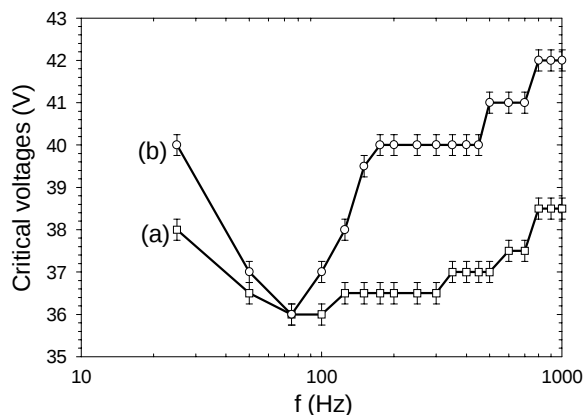


Fig. 2 Critical voltages vs frequency f: Curve (a) for the critical voltage of the planar→homeotropic transition; Curve (b) for the critical voltage of the focal conic→homeotropic transition.

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To directly see how the frequency of voltage pulse affects the driving voltage, we summarize the critical voltage of the planar→homeotropic transition $V_{P\rightarrow H}$ and the critical voltage of the focal conic→homeotropic transition $V_{F\rightarrow H}$ vs frequency in Fig. 2. In this set of measurements, the liquid crystal was refreshed to the planar texture or focal conic texture by voltage pulses of 1000 Hz. Both figures show that the critical voltages had a minimum when the frequency was around 75 Hz. The critical voltages increased when the frequency was too high or too low.

2.2 Transmission measurements

We investigated the transmission of a laser light passing through the cell with voltage applied. Both the applied voltage and the transmission varying with time were simultaneously recorded. The voltage was fixed at 35 V, and the frequency of the voltage varied between 0.1 Hz and 1000 Hz. Fig. 3(a) shows the voltage vs time. When the frequency was high, such as 1000 Hz, the transmission was low, and did not change much with time, as shown in Fig. 3(b). With decreasing the frequency, the transmission became higher, indicating some ionic field effect. At the frequency of around 50 Hz, the transmission reached the maximum (corresponding to the homeotropic texture) as shown in Fig. 3(c). However, when the frequency kept decreasing lower to 5 Hz, the transmission decreased again, indicating during this region of frequency, the ionic field effect had not reached the maximum yet. When the frequency lowered down to 1 Hz, the transmission immediately after the applied voltage reversed polarity started to increase again, and finally reached the maximum as shown in Fig. 3(d) where the frequency was 0.5 Hz.

When the frequency was low, for example, 0.5 Hz, there existed two critical voltages to switch the material from the focal conic texture into the homeotropic texture. Upon the reversal of the polarity of the applied voltage, because the field due to the ions accumulating close to the substrates strengthened the external field, the homeotropic texture can be achieved at the voltage denoted as V_{min} . However, the ions will move from one substrate to another under the applied field, and eventually shield the external field, so the effective voltage decreases and the transmission decreases. Only when the external voltage becomes high enough to overcome the field generated by the ions, the liquid crystal will always stay in the homeotropic texture, and this voltage is called V_{max} . In Fig. 3(d), the transmission reached the maximum upon the reversal of the polarity of the applied voltage, and decreased dramatically afterwards. 35 V was between V_{min} and V_{max} . Only when the voltage was above V_{max} , could the homeotropic texture be maintained. V_{max} and V_{min} at various frequencies are summarized in Fig. 4. In the low frequency range, V_{max} and V_{min} were quite different. In the high frequency range, V_{max} and V_{min} had the same values. The most interesting thing was that at some intermediate frequency range, there existed a minimum V_{max} . Fig. 4 shows that at 50 Hz, V_{max} was about 35 V, while it was 55 V at 0.1 Hz and 40 V at 1000 Hz. The transmission measurements were consistent with the reflectance measurements.

2.3 Resistance measurements

We have also measured the frequency dependence of the resistance of the cholesteric liquid crystal cell with a HP 4284A Precision LCR meter, which functions over 20 Hz to 1 MHz, and 5 mV to 20 V. The cell was first set to either a planar texture or a focal conic texture. Then a test signal of 1 V, which did not change the texture of the liquid crystal, was applied to the cell. The impedance $|Z|$ and the phase θ of the cell vs frequency f were measured.

Because the alignment layer was around 0.2 μm and much thinner than the cell thickness, which was around 5 μm , the capacitance due to the alignment layer could be ignored. We then assumed an equivalent circuit model that consists of an ITO resistor R_{ito} in serial with parallel liquid crystal capacitor C and resistor R . The resistance of ITO could be obtained in the high frequency region around 1 MHz. It was about 680 Ω . We then adjusted the capacitance of the liquid crystal to fit the experiment data, and found that the capacitance was 35 nF for the focal conic texture, and 24 nF for the planar texture. With the parameters of capacitance of liquid crystal cell and the resistance of ITO, we then calculated out the resistance of the liquid crystal as a function of frequency.

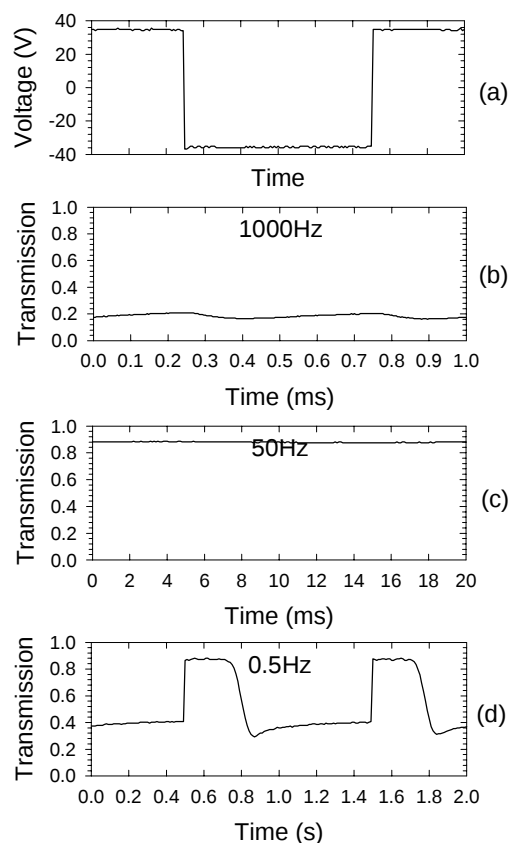


Fig.3 Voltages were kept fixed at 35 V. (a) Pulse voltage vs time; (b) Transmission vs time $f=1000$ Hz; (c) Transmission vs time $f=50$ Hz; (d) Transmission vs time $f=0.5$ Hz.

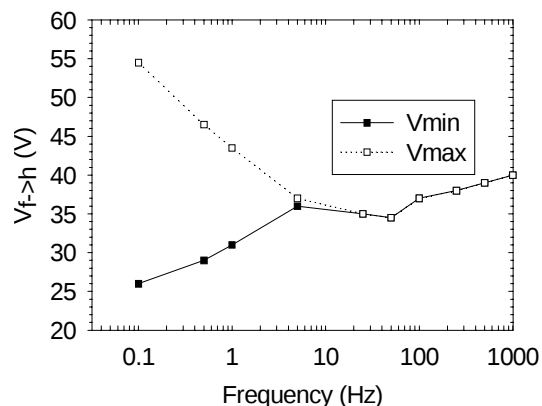


Fig. 4 Frequency dependence of the critical voltages $V_{\max}$ and $V_{\min}$ to switch the material to the homeotropic texture.

The calculated resistance R is shown in Figs. 5(a) and (b) for the planar texture and the focal conic texture, respectively. We notice that the resistance of the planar texture was higher than that of the focal conic texture, indicating that the orientation of liquid crystal in the focal conic texture favored the movement of ions than that in the planar texture. We also saw a minimum resistance at a particular intermediate frequency. The resistance increased at both high and low frequency ends. This was consistent with the reflectance and the transmission measurements, though the positions of minimum had some shift. It can be more accurate if we consider a more detailed model including insulation layers and hydrodynamics.

3. Conclusions

We identify that many liquid crystal mixtures used in reflective bistable cholesteric liquid crystal displays have non-negligible ions. Ionic effects play an important role in driving cholesteric liquid crystal displays. The ions change the effective electric field inside the liquid crystal and help to create nucleation seeds for transitions. These effects reduce the driving voltages by about 10%, make the response of the liquid crystal faster, and result in a higher contrast ratio. These effects have been observed in yellow, green, and other mixtures, in both glass-substrate and plastic-substrate displays, and in both surface stabilized and polymer stabilized black-white reflective bistable cholesteric liquid crystal displays.

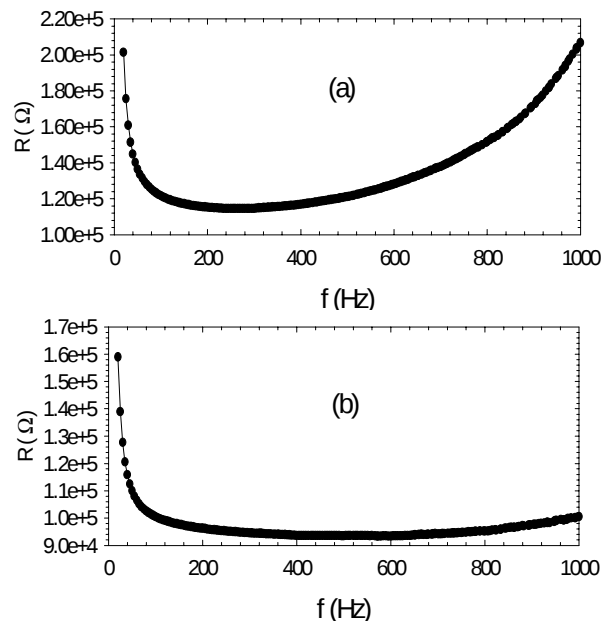


Fig. 5 Calculated resistance R of the liquid crystal vs frequency f . (a) The material was in the planar texture; (b) The material was in the focal conic texture.

4. Acknowledgement

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