

17.2: Polymer Effect on the Electro-Optic Properties of Blue-Phase Liquid Crystals

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Abstract

Polymer effect on the electro-optic properties of blue phase liquid crystal (BPLC) composites is investigated. A higher polymer concentration gives a more stable structure and faster response time, but its operating voltage is also higher. Monomer ratio also affects the stability of the polymer-stabilized BPLC. However, hysteresis is not affected by polymer concentration but mainly determined by the host liquid crystal and chiral dopants.

1. Introduction

Blue phase liquid crystal (BPLC) has been studied for decades [1-3]. However, the narrow temperature range limits its useful applications. Recently, with polymer stabilization method, the temperature range of BPLC was widened to more than 60K [4]. The polymer-stabilized blue phase liquid crystal (PS-BPLC) has potential to become next-generation display technology since it exhibits several revolutionary features, such as alignment-layer free, submillisecond response time, and wide viewing angle [5]. However, the polymer concentration effect on the blue-phase liquid crystals has not been studied systematically.

In this paper, we investigate the polymer effect on the electro-optic properties of a BPLC composite. A PS-BPLC requires two kinds of monomers: mono-functional and di-functional monomers. We control the overall monomers concentration, as well as the ratio between the two monomers. Polymer effects on the stability, operating voltage, hysteresis, and response time of the PS-BPLC device are presented.

2. Experiment

We prepared a BPLC mixture consisting of 65 wt% Merck BL038 and 35 wt% chiral dopants (25% CB15 and 10% ZLI-4572). A monofunctional monomer C12A and a difunctional monomer RM257, as well as a small amount of photoinitiator (~0.5 wt%) were added to the BPLC mixture. To investigate the polymer effects, nine precursors with different monomer concentrations were prepared, as listed in Table 1.

Table 1: Monomer concentrations of precursors

Overall monomer concentration (wt%)	Monomer ratio (RM257 : C12A)		
	1:1	2:1	3:1
9%	Sample 1	Sample 2	Sample 3
12%	Sample 4	Sample 5	Sample 6
15%	Sample 7	Sample 8	Sample 9

Among these nine precursors, sample 7 did not show blue phase because the high concentration of C12A would suppress the formation of blue phase. Sample 9 had poor solubility due to the high concentration of RM257. Blue phase appears in the other seven samples. These precursors were heated up to an isotropic

phase and then filled into in-plane-switching (IPS) cells with 10- μm electrode width, 10- μm electrode gap, and 7.5- μm cell gap. UV light with an intensity of 2 mW/cm² was then irradiated for 30 min. near the BP to chiral nematic transition temperature. After UV irradiation, PS-BPLC composites were formed. Although green bluish color was observed under crossed polarizers, the PS-BPLC composites are transparent and optically isotropic for the probing light at $\lambda=633$ nm.

3. Results

3.1. Residual birefringence

The seven samples were driven from 0V to 200V for ~30 min and then examined under a polarized optical microscope. Figure 1 shows the morphologies of the seven samples. Due to the strong electric field, blue phase structure was distorted in some samples. As a result, light leakage (caused by residual birefringence) was observed at the electrode gap, which degraded the device contrast ratio.

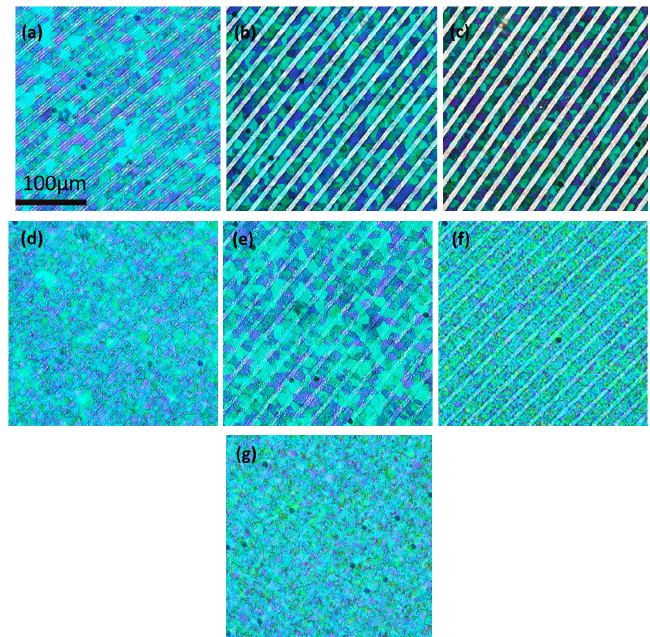


Figure 1. Microscope photos of IPS cells after driving from 0V to 200 V for 30 min. Sample 1 (a), sample 2 (b), sample 3 (c), sample 4 (d), sample 5 (e), sample 6 (f), and sample 8 (g).

Comparing Figs. 1(a), (b) and (c), we find that Fig. 1(a) has less residual birefringence, indicating a more stable structure. Similarly, sample 5 is more stable than samples 6 and 7 when we examine Figs. 1(d), (e) and (f). Therefore, the 1:1 ratio of RM257 and C12A gives a more stable structure. On the other hand, comparing Figs. 1(b), (e), and (g), we find that a higher overall polymer concentration also gives a more stable structure.

3.2. VT curves

We measured the voltage-dependent transmittance (VT) curves of our IPS cells by placing it between two crossed polarizers. To maximize transmittance, the electrode direction was oriented at 45° to the polarizer's transmission axis. A He-Ne laser ($\lambda=633\text{nm}$) was used as the light source. The cells were driven by a square wave voltage with 1 kHz frequency. To get rid of the diffraction effect, we measured the VT curves under crossed polarizers and parallel polarizers, respectively, and then calculated the normalized transmittance as follows:

$$T_{nor}(V) = \frac{T_{\perp}(V)}{T_{\parallel}(V) + T_{\perp}(V)}, \quad (1)$$

where T_{\perp} is the transmittance under crossed polarizers and T_{\parallel} is that under parallel polarizers. Afterwards, T_{nor} was again normalized to one for comparison between different samples. Figure 2 shows the normalized VT curves of six samples, because sample 8 has an on-state voltage higher than 200V and is not included.

In Fig. 2, samples 1-3 have a lower on-state voltage (V_{on}) than samples 4-6 due to the lower concentration of polymers. The contributions of lower polymer concentration are twofold: there are more liquid crystals, and the voltage shielding is less. As a result, the required driving voltage is lower. Samples 4-6 have a similar on-state voltage. Therefore, V_{on} is insensitive to the monomer ratio, as long as the total polymer concentration is fixed. Although it looks like sample 1 has a higher voltage than samples 2 and 3, this is because samples 2 and 3 are not quite stable; they are easier to be distorted.

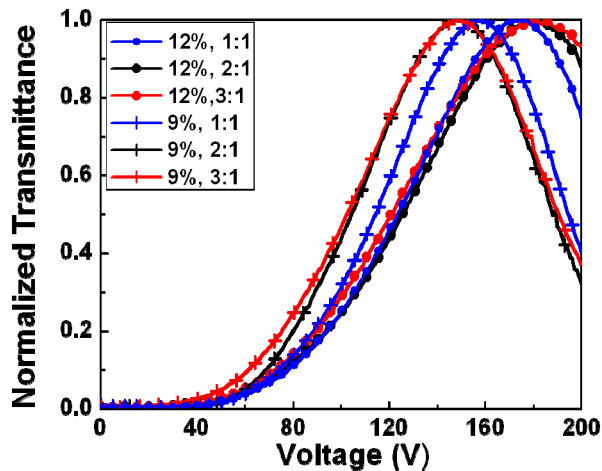


Figure 2. Normalized VT curves of samples 1-6. $\lambda=633\text{ nm}$.

3.3. Hysteresis

Hysteresis affects gray scale control accuracy and needs to be suppressed [6]. To measure hysteresis, we drive the IPS devices by ascending the applied voltage to the on-state (peak transmittance) and then gradually descending the voltage. Hysteresis is defined as $\Delta V/V_{on}$, where ΔV is the voltage difference during the forward and backward scans at half of the peak transmittance; V_{on} is the on-state voltage.

Table 2 lists the measured hysteresis of the IPS devices. We found that hysteresis is similar for all the samples investigated.

Therefore, hysteresis is insensitive to the overall monomer concentrations and monomer ratios. It is possible that hysteresis is mainly determined by the host BPLC mixture. Moreover, the hysteresis is relatively small (only 3-4%) for our BPLC mixtures.

Table 2: Measured hysteresis of the prepared samples

Overall monomer concentration (wt%)	Monomer ratio (RM257 : C12A)		
	1:1	2:1	3:1
9%	4.0%	3.0%	3.5%
12%	3.5%	3.0%	3.0%
15%	No BP	$V_{on}>200\text{V}$	Poor solubility

Hysteresis is also voltage dependent. Figure 3 shows the hysteresis loop for sample 4, represented by the black line. For comparison, we took another measurement by driving the sample to half of the peak transmittance and then returning to the dark state gradually, indicated by the red line. In this way, the hysteresis is very small and can be considered as hysteresis free. This information is very important since most displayed images are at around 50% gray levels. [7]

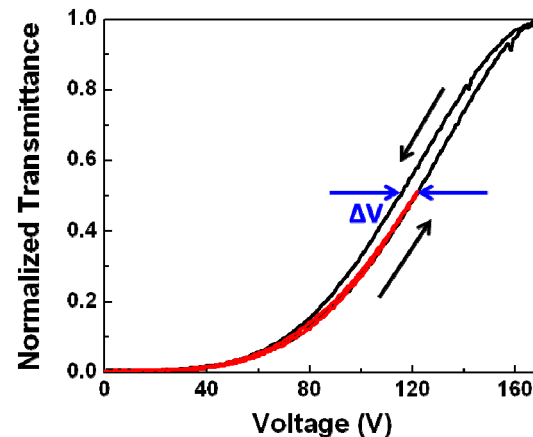


Figure 3. Voltage-dependent hysteresis loop for sample 4. Black line represents driving to the peak transmittance and red line stands for driving to 50% transmittance.

3.4. Response time

Submillisecond gray-to-gray response time is one of the most attractive features of PS-BPLC since it helps to reduce motion blur and enables color sequential displays using RGB LEDs. The latter is particularly favorable because it triples optical efficiency and resolution density. We measured the decay time for all the samples, and results are listed in Table 3. Rise time is not included here because it is dependent on the driving voltage. The decay process was performed from the on-state voltage to $V=0$. We calculated the decay time based on the transmittance change from 90% to 10% of the maximum transmittance. All the measurements were conducted at the room temperature.

Response time is highly related to the stability of the samples. For example, samples with 1:1 monomer ratio have a faster response

time than the samples with 2:1 and 3:1 monomer ratios. A higher monomer concentration also gives a faster response time. Therefore, a more stable sample tends to have a faster response time.

Table 3: Decay time (ms) for the prepared samples

Overall monomer concentration (wt%)	Monomer ratio (RM257 : C12A)		
	1:1	2:1	3:1
9%	0.44	0.68	0.84
12%	0.34	0.54	0.52
15%	No BP	0.30 (at 200V)	Poor solubility

4. Impact

Polymer-stabilized blue phase liquid crystal is emerging as next-generation display technology. Optimization of materials plays a crucial role for advancing the technology. Our experimental results indicate that, as the polymer concentration increases the network becomes more stable which in turn leads to a higher operating voltage and a faster response time. Moreover, once the overall polymer concentration is fixed, samples with 1:1 monomer ratio forms a more stable structure than samples with 2:1 and 3:1 monomer ratios. Hysteresis is insensitive to the polymer concentration and perhaps it is mainly determined by the host BPLC mixture. Our study will help guide future PS-BPLC material optimization.

5. Acknowledgements

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6. References

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