Polymer System Effect on Polymer-Stabilized Blue Phase Liquid Crystals

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Abstract

The effect of polymer system on polymer-stabilized blue phase liquid crystals (PSBPLCs) is investigated. The experimental results indicate that the electro-optic properties of PSBPLC are affected by the interface energy between the liquid crystal molecules and polymer system. As the anchoring energy of polymer system decreases, the driving voltage will decrease, but hysteresis and residual birefringence will increase. In addition, if the anchoring energy is less than a threshold value, the BPLC cannot be stabilized well by polymer network.

1. Introduction

Blue phase liquid crystals (BPLCs) [1-3] promise great potential applications in liquid crystal displays since it exhibits several interesting features, such as fast response time, alignment-layer free, and wide viewing angle [4]. The narrow temperature range is a challenge holding back its practical application. Recently, with polymer stabilization method, the temperature range of BPLC has been broadened to more than 60 K [5]. However, there are still several issues to be overcome before wide applications of the PSBPLCs, which include hysteresis effect, residual birefringence and high driving voltage. The normal materials used to stabilize the blue phase consist of a cross-linking agent (RM257) and a monomer (TMPTA, 12A, or EHA). In order to improve the electro-optic performances of the PSBPLC, several studies have been carried out, such as the effects of chiral pitch [6, 7], polymerization process [8], and polymer concentration [9]. However, the polymer network system which may have significant effect on the properties of the PSBPLCs has rarely been studied. In this research, the effects of polymer system on the stability, operating voltage, hysteresis and residual birefringence of PSBPLCs with different stiffness are investigated.

2. Materials and Experimental Design

To investigate the effects of different polymer system on the PSBPLC, several kinds of the monomers were doped in the conventional PSBPLCs mixtures consisted of a positive nematic liquid crystal (BP-06, Δn = 0.158, Δε = 34.2, HCCH), a chiral dopant (R5011, HCCH), a cross-linking agent (RM257), an ultraviolet (UV)-curable monomer (TMPTA, HCCH), and a photoinitiator (IRG184, HCCH). The stiffness of polymer system depends on the structure of monomers used to form the polymer network. As the number of functional group increases and the chain length of monomer decreases, the stiffness of polymer system increases. To make the polymer systems of different stiffness, five monomer dopants with different chemical structure, TMPTA, NVP, ACMO, 12A, and MP, were chosen to use in the experiment, whose structures are illustrated in Table I. Among them, MP is used as a diluent because it cannot be polymerized with other monomers.

To compare the different polymer system in same conditions, five precursors were prepared whose overall monomers concentration were controlled at 9.9 wt% and chiral pitches were controlled at the same value, 329 nm, by adjusting the chiral dopant concentration, as listed in Table II. After mixing, the precursors were filled into the in-plane switching (IPS) cells, whose cell gap is 7.5 μm, the indium tin oxide (ITO) electrode width is 7.5 μm, and the electrode gap is 12.5 μm, at an isotropic phase in a temperature controller (HCS302, Instec Co.).

Table I. Chemical structure of the monomers

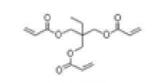
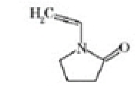
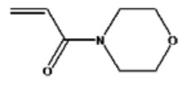
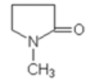
Type	Name	Chemical Structure	
Tri-function monomer	TMPTA		Three-dimension
Mono-function monomer	NVP		Five-membered ring
	ACMO		Six-membered ring
	12A		Linearity
Non-function monomer	MP		Five-membered ring

Table II. Summary of PSBPLC precursors with different component ratios

Precursors	BPLC	RM257	TMPTA	Dopant Monomers	IRG184
A	89.5%	4.4%	5.5%		0.6%
B	89.5%	3.3%	3.3%	3.3% (NVP)	0.6%
C	89.5%	3.3%	3.3%	3.3% (ACMO)	0.6%
D	89.5%	3.3%	3.3%	3.3% (12A)	0.6%
E	89.5%	3.3%	3.3%	3.3% (MP)	0.6%

3. Results and Discussions

3.1. Thermal stability

To study the polymer system effect on the thermal stability, the samples were irradiated at blue phase under an ultraviolet light with an intensity of 3 mW·cm^{-2}. After 15 minutes exposure, the

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temperature range of the samples was observed under a reflective polarizing optical microscopy. Figure 1 shows the platelet textures of the samples after polymerization.

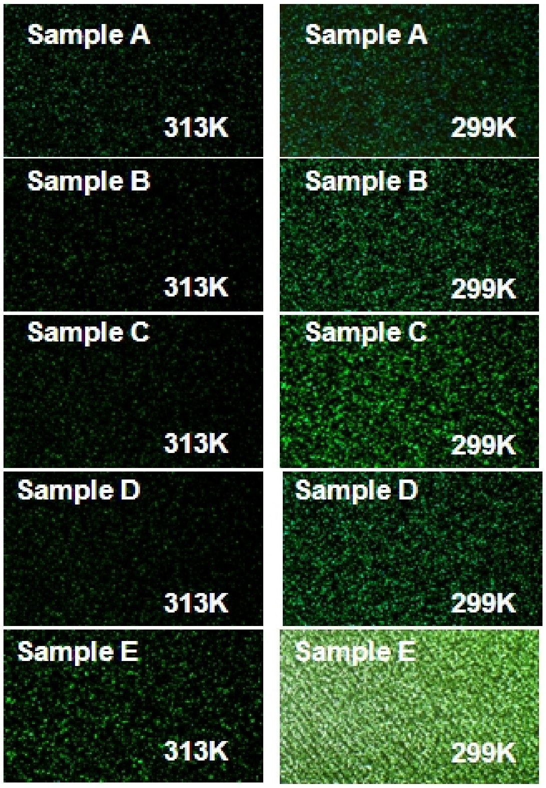

Fig. 1. Platelet texture of the PSBPLC samples under a polarized optical microscope (POM).

The blue phase temperature range of samples A, B, C, and D were all expanded to more than 70 K (263 K-338 K) after polymerization. In sample E, the phase transition from blue phase to chiral nematic (N*) phase appeared when the temperature was cooled down to 302 K. Among the samples, only the sample E cannot be stabilized well by the polymer network due to its monomer dopant, MP. Because MP is a non function monomer, it cannot be polymerized with other monomers and crosslinkers. Therefore the anchoring energy of polymer network in sample E is insufficient to stabilize the disclination line among the double twist cylinders (DTCs) of BPLC, resulting in a narrow temperature range. The results indicate that there is a threshold interface energy between the polymer network and the DTCs of PSBPLCs. Only if the anchoring energy of the polymer network is higher than the threshold interface energy, the BPLCs can be polymer stabilized effectively.

3.2. Driving Voltage

The voltage-dependent transmittance (*VT*) curves of the IPS cells were measured by applied a square wave voltage with 1 KHz frequency. Figure 2 shows the *VT* curves of the IPS cells at 633 nm. At room temperature (~299 K), the on-state voltage (V_{on}) of sample A, B, C, and D are 145V, 120 V, 105 V, and 90 V, respectively. Among the samples, the sample A has the highest V_{on} and the sample D has the lowest V_{on}. According to the Kerr effect, the birefringence of PSBPLC is induced by electric field. As the stiffness of the polymer system increases, the anchoring energy of polymer network increases. As a result, a higher electric field is needed to drive the LC molecules. Compare to the other samples, the sample A is harder to be driven, since the anchoring energy of polymer network formed by TMPTA, which is a tri-function monomer, is higher than that of the other polymers formed by mono-function monomers. The sample D shows the lowest V_{on} because the anchoring energy of sample D whose polymer network formed by a flexible linear mono-function monomer is the lowest one among the samples. The NVP and ACMO show similar chemical structure. Nevertheless, the V_{on} of sample B is larger than that of sample C because the anchoring energy of polymer formed by a five-membered ring is higher than that formed by a six-membered ring.

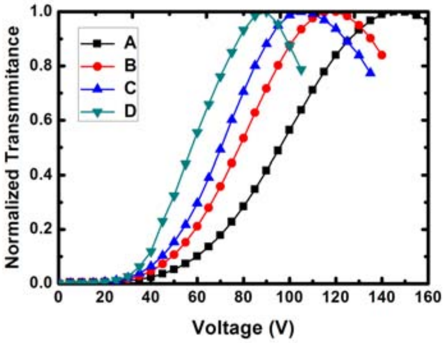

Fig. 2. Normalized VT curves of the samples. λ=633 nm and T=299 K.

3.3. Hysteresis

To investigate the effect of different polymer system on the hysteresis, the hysteresis of four samples were calculated with the measured hysteresis loops as illustrated in Fig. 3. Here, the hysteresis is defined as $\Delta V/V_{on}$, where ΔV is the voltage difference during the voltage-up and voltage-down scans at half of the peak transmittance and V_{on} is the on-state voltage.

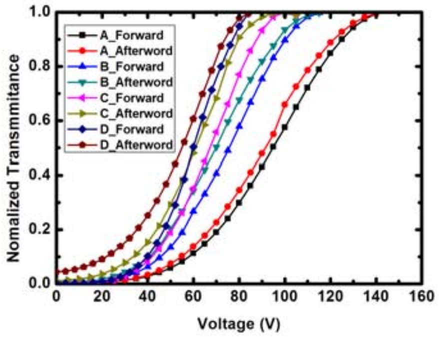

Fig. 3. The hysteresis loops of the samples. T=299 K and λ=633 nm.

Table II shows the calculated hysteresis of the PSBPLC devices. The hysteresis of samples A, B, C, and D are 2.4%, 4.8%, 5.6%, and 6.2%, respectively. Among the samples, the hysteresis of sample A is the lowest one due to the largest surface anchoring energy of the polymer system formed by TMPTA. As the applied voltage decreases, the LC molecules can recover to their original state by the large anchoring energy of polymer network. The relative larger hysteresis of the other samples result from the lower anchoring energy of the more flexible polymer network.

Table III. The calculated hysteresis of IPS devices

Samples	A	B	C	D
Hysteresis	2.4%	4.8%	5.6%	6.2%

3.4. Residual birefringence

To investigate the effect of polymer system on the residual birefringence, the measured residual birefringence of all the samples are shown in Fig. 4. Among all the samples, sample A shows the lowest residual birefringence and the sample D shows the highest residual birefringence. The residual birefringence results from the distorted lattice structure of PSBPLC. The lattice of PSBPLC can be distorted when the applied electric field exceeds a threshold electric field, in proportion to anchoring energy of polymer system. Then, if the applied electric field is removed, the lattice cannot recover to its original state. As shown in fig. 4, all the samples have the residual birefringence because the applied electric fields on all them exceed their threshold electric field. The residual birefringence of sample A is the lowest one because the anchoring energy of polymer network formed by TMPTA is larger than that of the other samples, and the larger anchoring energy can make the distorted lattice structure of PSBPLC recover to its original state after the applied electric field is removed. The highest residual birefringence of sample D is caused by the lowest anchoring energy of polymer network, which is formed by a flexible linear monomer, 12A. The distorted lattice cannot be recovered to its original state by the lower anchoring energy. In summary, the residual birefringence of PSBPLC appears when the PSBPLC device is driven by the electric field, which exceeds the threshold electric field. The residual birefringence decreases, as the anchoring energy of polymer network increases.

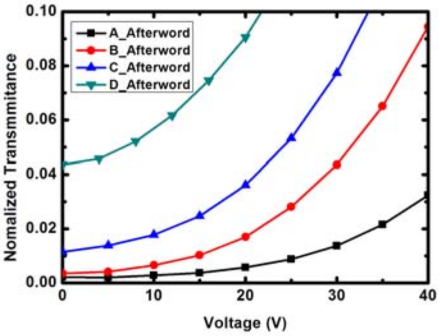

Figure 4. The residual birefringence of the samples.

4. Conclusion

The effects of polymer system on the thermal stability and electro-optic properties of PSBPLC are investigated. The experimental results indicate that the electro-optic properties of PSBPLC are affected by anchoring energy of polymer network. As the anchoring energy of polymer network decreases, the driving voltage of PSBPLC decreases, and the hysteresis and residual birefringence enlarges. In addition, there is a threshold energy between the polymer network and the DTCs of BPLC. When the anchoring energy of polymer network is less than the threshold energy, the BPLC cannot be stabilized well.

5. Acknowledgements

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6. References

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