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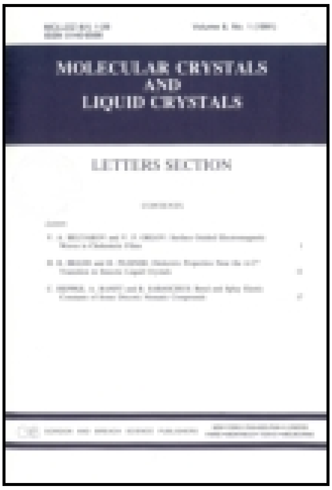

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Electro-Optical Properties of Electric Field-Induced-Polymer Stabilization at Blue Phase of Chiral Nematic Liquid Crystal

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Electro-Optical Properties of Electric Field-Induced-Polymer Stabilization at Blue Phase of Chiral Nematic Liquid Crystal

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Polymer stabilization of the blue phase induced a wide temperature range of more than 60 K, but the high driving voltage and the large switching hysteresis compared to the low molecular weight blue phase of the chiral nematic liquid crystal. In this study, we newly proposed electric field-induced-polymer stabilization of blue phase (EFIPSBP) which the electric field was applied to the blue phase during polymer stabilization and investigated the driving voltage and the switching hysteresis using various voltage-applied EFIPSBP cells. We confirmed that the driving voltage and the switching hysteresis of the EFIPSBP cell were decreased compared to those of conventional polymer stabilized BP at 8OCB chiral nematic liquid crystal mixture. This could be suggested as a potential method for improving the driving voltage and the switching hysteresis of conventional polymer stabilized BP.

Keywords Blue phase; chiral nematic LC; driving voltage; electric field-induced polymer stabilization; switching hysteresis

1. Introduction

Blue phases (BPs) are liquid crystal (LC) phases that appear in the temperature range between the chiral nematic phase and the isotropic liquid phase of chiral nematic LCs under high chirality condition. BP I and BP II possess a three-dimensional cubic structure with lattice periods that are several hundred nanometres in length [1–3] and therefore exhibit selective Bragg reflections in the visible and ultra-violet (UV) light range. Therefore, BPs possess great potential as fast light modulator due to the electrically controllable Bragg diffraction of visible light [4–7]. However, due to their narrow temperature range less than a few degrees Kelvin, the practical application of BPs has always been difficult. Recently, the polymer stabilized-BP (PS-BP) with a wide temperature range greater than 60 K reported as a high performance optical switch with a high speed electro-optical response time of the order of 10^{-4}s [8–14]. However, BP polymer stabilization resulted in high driving voltage and large switching hysteresis compared to the low molecular BP without polymer stabilization. Therefore, BP polymer stabilization has many difficulties in practical application.

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In this study, we proposed the electric field-induced-polymer stabilized-blue phase (EFIPSBP), in which the arbitrary voltage was applied during BP polymer stabilization, and investigated the driving voltage and the switching hysteresis using various voltage-applied EFIPSBP cells of 8OCB chiral LC mixture.

2. Experiment

2.1 Sample

JC1041XX (JNC Corp., Tokyo, Japan) and 4-cyano-4'-octyloxy-biphenyl (8OCB, Sigma-Aldrich Corp., St. Louis, MO, USA) were used as nematic LC materials, and ISO-$(6OBA)_2$ was used as a chiral dopant as shown in Fig. 1. Here, JC1041XX was used to improve the miscibility with ISO-$(6OBA)_2$. For polymer stabilization of the BP, RM257 (Merck & Co. Inc., Whitehouse Station, NJ, USA) and dodecyl acrylate (DA, Sigma-Aldrich Corp.) were used as reactive monomers and 2,2-dimethoxy-2-phenyl-acetophenone (DMPAP, Sigma-Aldrich Corp.) was used as a photo initiator as shown in Fig. 1.

2.2 Preparation of Electric Field-Induced-Polymer Stabilized-BP Cell

A 8OCB chiral nematic LC mixtures were prepared at 7.5 wt% at weight ratio of (8OCB:JC1041XX:ISO-$(6OBA)_2$:RM257:DA:DMPAP = 42.6:42.6:7.5:3.5:3.5:0.3). The 8OCB chiral nematic LC mixture was injected into the vacant space of a 5 μm gap in-plane

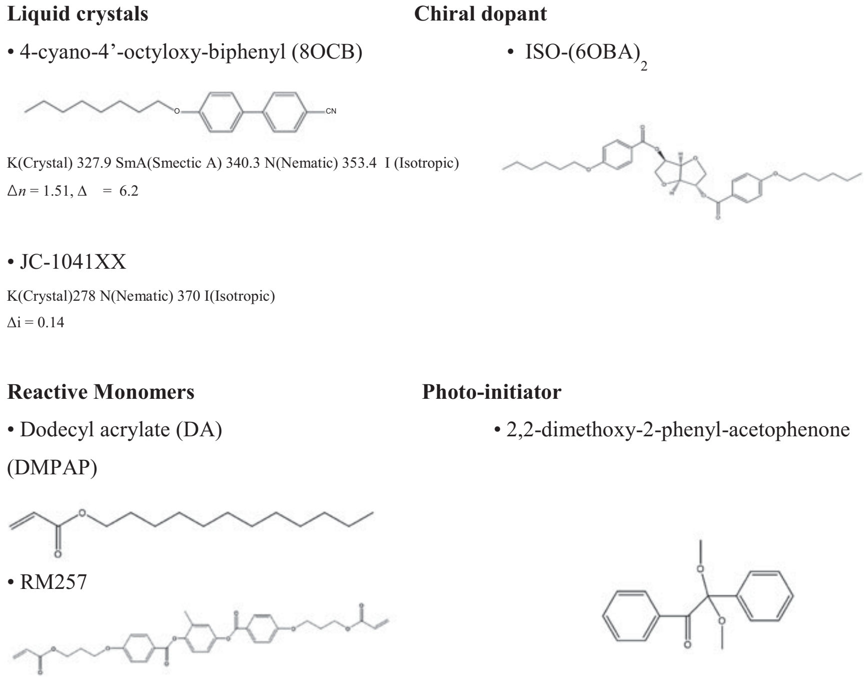

Figure 1. Chemical structures and physical properties of LCs, chiral dopant, reactive monomer, and photo-initiator.

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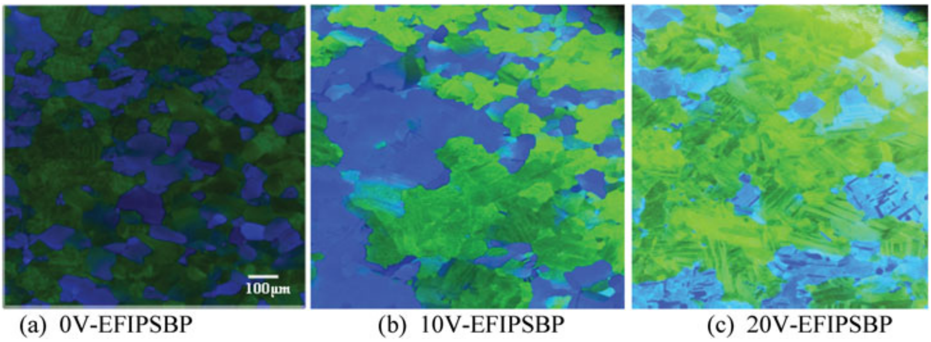
switching (IPS) sandwich cell without surface treatment. For the IPS cell, the top bare glass was not given any surface treatment, and the bottom ITO glass was patterned at 4 μm wide on the same plane. For the electric field-induced-polymer stabilized-BP, an alternative current voltage of 1 kHz was applied to the LC mixtures in the ITO IPS sandwich cell when 8OCB chiral LC mixture was maintaining a stable BP I. The irradiation of UV having maximum wavelength of 365 nm was then performed on the LC mixtures for 15 min at an intensity of 600 mW/cm^2. Three types of electric field ($V_{\text{p-p}}$), including 0 V, 10 V, and 20 V were applied to 8OCB chiral LC mixture during polymer stabilization by using a function generator (Tektronix, AFG3021B), a digital multi-meter (ADCMT, 7461A), and an amplifier (NF Corp., HAS 4051).

The BP temperature range of the EFIPSBP cell was evaluated from the optical texture of a polarized optical microscope (POM) (Nikon Co. Ltd.) observation. The EFIPSBP optical textures were observed using a POM equipped with a hot stage calibrated to an accuracy of ± 0.1 K (Linkam LK-600PM, UK) under crossed Nicols. The cooling and heating ratios of the cell were both set to 1 K/min.

2.3 Evaluation of Electro-Optical Properties of EFIPSBP Cell

The driving voltage and the switching hysteresis of the EFIPSBP cell were evaluated by measurement of the voltage-transmittance curve at T_c –10 K under crossed Nicols. Where T_c means clearing temperature being of phase transition temperature from BP to isotropic phase. The driving voltage was defined as the saturation voltage at maximum transmittance at voltage up and the switching hysteresis was defined as the voltage difference between voltage up and voltage down in respect of 50% transmittance.

An electro-optical response time of the EFIPSBP cell was evaluated by measurement of the time at which the transmittance is changed from 10% to 90% upon voltage on (rising time), or from 90% to 10% upon voltage off (decay time) at T_c –10 K in the cell. During the measurement of the electro-optic response time, the squared AC electric voltage of 1.0 kHz was applied for 1 s over 30 times. A He–Ne laser (λ = 633 nm) was positioned perpendicular to the sample cell. The transmitted light was detected by a photo diode (New Focus 1621 M), and was recorded with a digital storage oscilloscope (LeCroy WP950).



(a) 0V-EFIPSBP (b) 10V-EFIPSBP (c) 20V-EFIPSBP

Figure 2. POM observation photographs under crossed Nicols of 0 V-EFIPSBP, 10 V-EFIPSBP and 20 V-EFIPSBP for the 8OCB chiral LC mixture upon cooling.

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3. Results and Discussion

Figure 2 shows the POM observation photographs under crossed Nicols for the 0 V-EFIPSBP, 10 V-EFIPSBP, and 20 V-EFIPSBP cells of the 8OCB chiral nematic LC mixture upon cooling. Here, 0 V-EFIPSBP cell is similar with conventional polymer stabilized BP without applied electric field during polymer stabilization. The 20 V-EFIPSBP presented the brightest platelet texture of BP I, and the 10 V-EFIPSBP presented a brighter platelet texture of BP I than that of the 0 V-EFIPSBP. Table 1 shows the phase transition temperature evaluated by the optical texture of the POM observation of 0 V-EFIPSBP, 10 V-EFIPSBP, and 20 V-EFIPSBP for the 8OCB chiral LC mixture upon cooling. The 0 V-EFIPSBP presented a BP from 339.1 to 253 K, the 10 V-EFIPSBP presented a BP from 338.3 to 253 K and the 20 V-EFIPSBP presented a BP from 337.9 to 253 K upon cooling. In all cases, even though the temperature lowered to 253 K, the phase transition from BP to the chiral nematic phase was not observed upon cooling. Here, 253 K was the lower observable limitation temperature of our POM equipped with a hot stage, but was not phase transition temperature between the BP and chiral nematic phase. Namely, all EFIPSBPs of the 8OCB mixture presented a wide BP temperature range more than 60 K. However, the 20 V-EFIPSBP cell for the 8OCB chiral LC mixture presented an unstable BP which changed from BP to the chiral nematic phase at 298 K after one or two days. This result indicates that it is difficult to obtain the BP stability in EFIPSBP cell manufactured by the applied voltage more than 20 V during polymer stabilization at 8OCB LC mixture. In addition, the $T_{\mathrm{Iso}\rightarrow\mathrm{BP}}$ of EFIPSBP was lowered with an increase of voltage applied to the BP cell during the polymer stabilization. These results imply that when a higher electric field was applied to the BP cell, the BP stability was reduced.

Figure 3 shows the measurement results between the applied voltage (V) and transmittance (T) on the voltage up and voltage down of 0 V-EFIPSBP and 10 V-EFIPSBP for the 8OCB LC mixture. Unfortunately, we could not obtain the V-T result of 20 V-EFIPSBP cell because of instability of BP as mentioned at result of Fig. 2.

Table 2 shows the driving voltage and the switching hysteresis of 0 V-EFIPSBP and 10 V-EFIPSBP estimated from the results of Fig. 3. The driving voltage of 0 V-EFIPSBP presented 135 V and that of 10 V-EFIPSBP was 111 V; furthermore, the switching hysteresis of 0 V-EFIPSBP presented 14 V and that of 10 V-EFIPSBP was 6 V. These results indicate that the switching hysteresis and the driving voltage of EFIPSBP were reduced in comparison with the conventional PS-BP for the 8OCB chiral nematic LC mixtures, even though the EFIPSBP presented slightly high transmittance compared to the PS-BP at zero applied voltage.

Table 3 shows measured transmittance as a function of applied voltage for low molecular weight BP cell (before polymer stabilization), 0 V-EFIPSBP cell and 10 V-EFIPSBP

Table 1. Phase transition temperature of 0 V-EFIPSBP, 10 V-EFIPSBP, and 20 V-EFIPSBP for the 8OCB chiral LC mixture upon cooling

	Phase transition temperature (K)	
LC sample 8OCB LC mixture	$T_{\mathrm{Iso}\rightarrow\mathrm{BP}}$	$T_{\mathrm{BP}\rightarrow\mathrm{Ch}}$
0 V – EFIPSBP	339.1	<253
10 V – EFIPSBP	338.3	<253
20 V – EFIPSBP	337.9	<253

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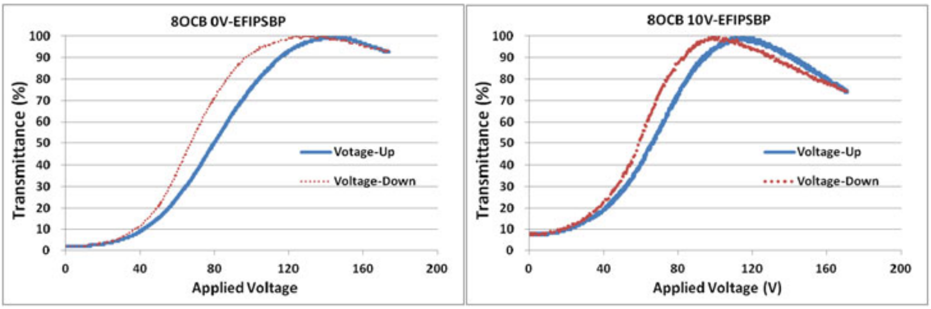

Figure 3. Measurement results of voltage and transmittance curve of 0 V-EFIPSBP and 10 V-EFIPSBP for the 8OCB chiral LC mixture.

cell of 7.5 wt% 8OCB chiral LC mixture at low applied voltage region on voltage up. From the Table 3, we can know that the 10 V-EFIPSBP cell shows 7.56 % of high transmittance compared to 2.02 % of transmittance of 0 V-EFIPSBP at 0 V. These results imply that the BP molecules aligned by electric field are increased with an increase of the applied electric field, and then these aligned BP molecules are partly fixed during polymer stabilization. And these results are supported by that the transmittance of low molecular weight BP cell before polymer stabilization is changed from 0.3% to 0.75% when the applied electric voltage to the BP cell is increase to from 0 to 10 V as shown in Table 3. However, it is not sufficient to explain the transmittance difference between 0 V-EFIPSBP and 10 V-EFIPSBP by only viewpoint of LC molecular alignment along to electric field because the transmittance of 10 V-EFIPSBP cell is 3.74 times large compared to that of 0 V-EFIPSBP cell at 0 V. Furthermore, we observed an increase of transmittance of the 0 V-EFIPSBP as well as the 10 V-EFIPSBP compared to the low molecular weight BP before polymer stabilization at 0 V as shown in Table 3. Therefore, we need additional explain about increase of transmittance for the 0 V-EFIPSBP cell as well as the 10 V-EFIPSBP cell compared to the low molecular weight BP cell at 0 V. As a possible mechanism, it is considered that the polymerization by UV exposure is started from interface between BP LC and glass in the cell during polymer stabilization and birefringence due to generation of polymer layer on the glass surface results in an increase of transmittance of the 0 V-EFIPSBP cell and 10 V-EFIPSBP BP cell compared to the low molecular BP cell at 0 V. Furthermore, for the 10 V-EFIPSBP cell, it is considered that the polymer layer on glass surface may be increased due to movement of reactive monomer into glass surface of the cell by applied 10 V

Table 2. Driving voltage, switching hysteresis, and response time of 0 V-EFIPSBP and 10 V-EFIPSBP for the 8OCB chiral nematic LC mixture

	8OCB LC mixture	
LC mixture	0 V-EFIPSBP	10 V-EFIPSBP
Driving voltage (V)	135	111
Switching hysteresis (V)	14	6
Rising time (μs)	559	988
Decay time (μs)	647	875

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Table 3. Measured transmittance as a function of applied voltage for low molecular weight BP cell, 0 V-EFIPSBP cell and 10 V-EFIPSBP cell of 7.5 wt% 8OCB chiral LC mixture at low applied voltage region. Here, the property of V-T for low molecular weight BP cell was measured at T_c –0.5 K

	Transmittance (%)		
Applied voltage (V)	Low molecular weight BP	0 V-EFIPSBP	10 V-EFIPSBP
0	0.30	2.02	7.56
5.5	0.32	2.02	7.56
10.0	0.75	2.02	8.40
16.5	1.52	2.83	9.24
22.0	5.14	3.64	10.08

electric voltage during polymer stabilization compared to the 0 V-EFIPSBP cell. However, this is not clear yet and we need further study using another samples and conditions.

The measurement results of the rising time and decay time of the 0 V-EFIPSBP and 10 V-EFIPSBP cells for the 8OCB LC mixture is shown in Table 2. The 10 V-EFIPSBP cell presented the slow rising time and decay time compared to 0V-EFIPSBP cell, while the total optical response time (which is the sum of the rising time and decay time) was around one millisecond at both cells.

Consequently, we confirmed that the EFIPSBP cell had the low driving voltage and switching hysteresis compared to the conventional polymer stabilized BP cell while the EFIPSBP cell had the fast response around 1 ms.

4. Conclusions

We found that the driving voltage and the switching hysteresis of polymer stabilized BP decreased when the electric field was applied to the BP cell during polymer stabilization for the 8OCB chiral LC mixture. The proposed method could, therefore, be suggested as a potential method for the improvement of the driving voltage and switching hysteresis of the conventional polymer stabilized BP.

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