

# Electro-Optic Devices Based on Ferroelectric Liquid Crystals/ Polymer Composite Films

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## Abstract

*We have achieved an improved stability of an analog electro-optic effect in FLC/polymer composite films. The optimization of device depends on both the composition of the FLC/polymer mixture and the energy of UV irradiation. This device exhibits continuous gray scales and the mechanical stability against external forces.*

## 1. Introduction

Many researches have been presented for utilizing intrinsic features of ferroelectric liquid crystals (FLC) such as fast optical switching and wide viewing properties for display applications. For example, a surface-stabilized (SS) FLC device has very fast response and wide viewing characteristics. However, in order to obtain gray scales, it needs more complex method such as a time- or space-averaging technique. Moreover, it is very sensitive to the external mechanical deformation. This is one of critical issues of commercializing FLC devices [1].

Recently, a phase separated composite films (PSCOF) structure has been proposed [2]. Unlike polymer dispersed LC (PDLC) devices that operate in the scattering mode in the presence of LC droplets, the PSCOF technique can produce an interfacial layer between LC and polymer which parallel to the cell surface by means of a phase-separation process. It has the several advantages over conventional FLC devices such as ease of fabrication, and the stability against external forces. Among them, the most important benefit is the gray scale capability.

In this work, we describe how the electro-optic characteristics can be modified during the FLC/polymer phase separation process under various fabrication conditions. Especially, we focus on the PSCOF device and measure the electro-optic properties. In order to find the optimum condition for preparing PSCOF, the composition of the polymer-

liquid crystal mixture and the energy of UV irradiation were varied. Using an optical polarizing microscope and a scanning electron microscope, the state of the phase separation in the FLC/polymer mixture were examined. In order to study the stability improvement against the external forces, the electro-optic characteristics of the PSCOF device were compared to those of PDLC and SSFLC devices.

## 2. Experimental

The FLC material used in this study is CS1024 of Chisso, which has Ch-Sm A-Sm C\* transitions and a long pitch ( $> 20\mu\text{m}$ ) in the Sm C\* phase. The matrix material is NOA 65 (Norland Products, Inc.). The LC concentration was varied in the range from 10 % to 90 % in volume. The sample cells were made with patterned indium-tin-oxide coated glasses. The cell gap was maintained by glass spacers of  $3\mu\text{m}$ . One of two surfaces was coated with Nylon 6 (Aldrich Chemical Company, Inc.) and unidirectionally rubbed so that LC has homogeneously uniform alignment. The FLC/prepolymer mixture was filled into the sample cell in the isotropic state of FLC ( $110^\circ\text{C}$ ). In order to diminish the nonuniformity of the composition over the cell, it was maintained at the same temperature for about 10 minutes followed by UV curing. The sample cell was exposed to UV light through the substrate surface with no alignment layer. The UV intensity was varied from  $10\text{ mW/cm}^2$  to  $100\text{ mW/cm}^2$ .

## 3. Results and discussion

As shown in Fig 1, the formation mechanism of the PSCOF structure can be explained by 'anisotropic phase separation process' including the light absorption, slow polymerization, phase separation, and fast diffusion of small molecules [3]. When the process was finished, the solidified polymer is

accumulated to the surface of UV irradiance, and the LC is diffused to the opposite side and aligned to the rubbing direction.

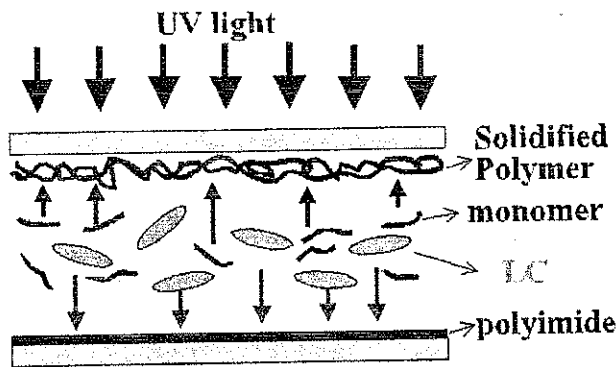


Figure 1 Schematic of the PSCOF process.

The fabricated FLC-PSCOF device shows the uniform alignment. Fig. 2 shows the FLC-PSCOF texture under an optical polarizing microscope. The dark spots are due to the locally solidified polymer-droplet. Note that these polymer droplets do not affect electro-optic characteristics of LCs macroscopically aligned over the whole sample.

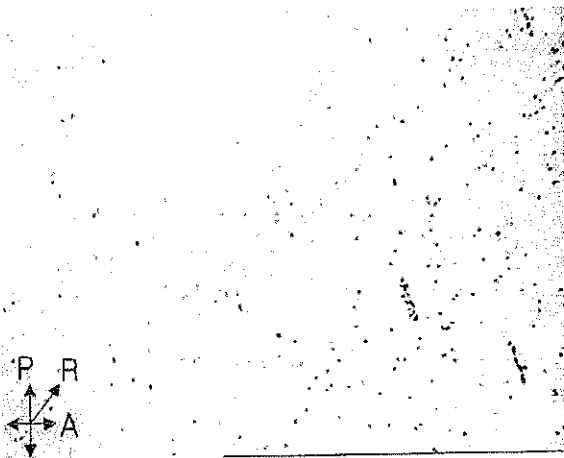


Figure 2 FLC-PSCOF texture under the polarized microscope, P, A: Polarizer direction, R: Rubbing direction.

In order to investigate the polymerization state inside the sample cell, we examined the substrate in the side where the UV exposure was executed after

disassembling the cell. When the polymer fraction was over the 30 %, the sample cell showed a typical PDFLC structure. In this structure, LCs were confined in the polymer matrix. Moreover, at more than 80 mW/cm<sup>2</sup> of the UV intensity, the PDLC structure was formed. In the cell substrate, very large spherical domains (more than 10  $\mu$ m in diameter) were observed. The PDLC structure can be switched from an opaque to a transparent state by the application of an external electric field [4,5]. When the polymer was mixed relatively in small amounts (< 10%), the mixture exhibited a polymer-network structure. This structure is known to have the stability due to elastic interactions between the polymer network and LC [6]. Therefore, for obtaining the PSCOF structure, 40 ~ 60 % of the prepolymer fraction is required. The PSCOF structure was observed in the wide range of UV power (20~80 mW/cm<sup>2</sup>). However, two limiting cases exist, one of them is very weak power region (< 20 mW/cm<sup>2</sup>) where it is not enough to initiate each of prepolymer and LC to diffuse to opposite side. Therefore, phase separation process occurs slowly in the whole bulk region, resulting in the PDLC structure. In the other case, in the regime of strong UV exposure enough for diffusion process, the polymerization process is so fast that most of the prepolymer cannot be moved to the substrate near the substrate side where the UV exposure was executed. Again, the PDLC structure was obtained in this case. From surface morphology of the PSCOF obtained by SEM the tiny polymer droplets were. The droplets are much smaller than the wavelength of the visible light. This is due to the locally inhomogeneous phase separation or defects. Generally, the scattering efficiency in the most PDLC structure depends on the droplet size of the polymer and the wavelength of the incident light. As smaller the size of droplet is, the better the efficiency of scattering becomes. Since the polymer droplets are very small and rare over the whole sample, the total forward transmission is not much affected by them. This means that the PSCOF structure acts like an electrically controlled birefringence film.

The electro-optic response of the sample to an external electric field was measured by monitoring the change in the transmitted light intensity through the sample cell between crossed polarizers. An He-Ne laser of 632.8 nm, a digitizing oscilloscope (TDS420, Tektronix), a motorized rotary stage (495A, Newport) and an arbitrary waveform generator (75, Wavetek)

were used as shown in Fig. 3. All the measurements were carried out at room temperature.

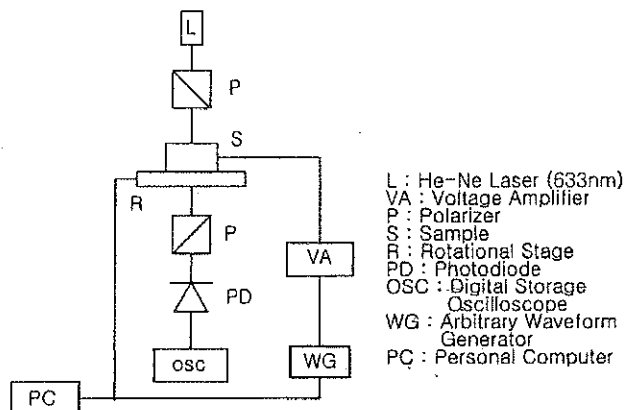


Figure 3 The set-up for measuring electro-optic response.

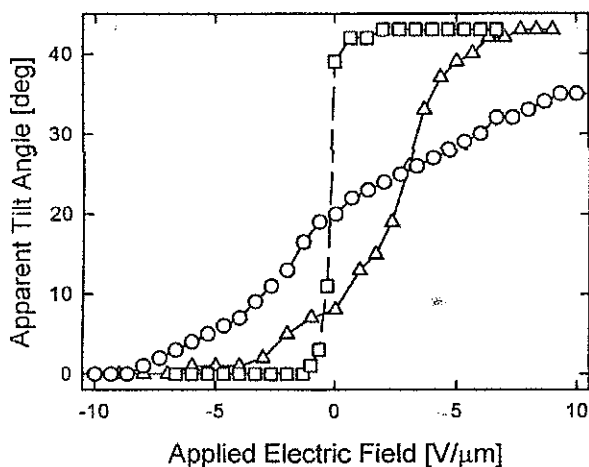


Figure 4 Apparent tilt angle variation as a function of the applied field (□ : SSFLC, ○ : PDFLC, △ : PSCOF).

Figure 4 shows the macroscopic molecular tilt angle variation as a function of the applied electric field. The FLC/prepolymer compositions of PDFLC and PSCOF were 30:70 at the UV exposure of 40 mW/cm<sup>2</sup> and 50:50 at 40 mW/cm<sup>2</sup>, respectively. The optic axis of the sample was fixed to have the lowest value at -10 V/μm. The SSFLC sample shows the well-known bistability. The optic axis switches between only two states. PDFLC shows the continuous response to an external electric field. Because of the FLC droplets surrounded by polymer, the electric field for saturation

is higher than that of SSFLC. The tilt angle of PSCOF increases monotonically with increasing the applied electric field. This means PSCOF also has gray-scale capability due to the locally formed FLC domains.

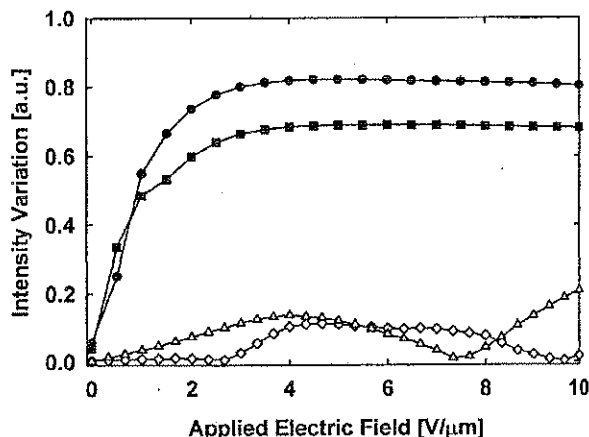


Figure 5 Intensity variation (● : SSFCS after thermal shock, ■ : SSFLC after mechanical shock, △ : PSCOF after thermal shock, ◇ : PSCOF after mechanical shock).

Figure 5 shows the intensity variation after external forces to the sample cell. For applying the mechanical shock to the sample cell, each sample cell was dropped on a rigid plate from a height of 1 m. For thermal shock, each sample was cooled very rapidly from the isotropic temperature (110 °C) to room temperature. As seen in Fig. 5, SSFLC is very sensitive to the external mechanical and thermal shocks. This is mainly due to the breaking of FLC layers, resulting in the formation of local FLC micro domains. This has been one of the main problems to commercializing the SSFLC devices. However, in the PSCOF, the stability against external mechanical deformations is greatly improved due to the polymer bonds to the substrate adjacent to the LC, producing the rigidity and strength. As a result, the change in the transmittance is greatly reduced in comparison to the SSFLC case.

#### 4. Conclusion

We experimentally showed an improved stability of the FLC/prepolymer films by means of the anisotropic phase separation. Depending on the power of UV irradiation and the FLC/prepolymer composition, the PSCOF structure can be formed. Our PSCOF sample shows analog gray scale capability due to the locally

formed FLC domains. Moreover, in the PSCOF, the sensitivity to the mechanical and thermal shock is greatly reduced. It is expected that PSCOF is a promising solution to overcome the intrinsic problem to commercialize the FLC devices.

### 5. Acknowledgements

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