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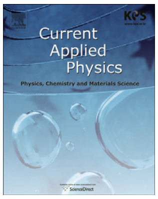

Electro-optical properties of smectic liquid crystal-polymer composite with a negative dispersion of birefringence

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ABSTRACT

Two-dimensionally self-organized smectic liquid crystal (LC)-polymer composite has been reported to show a negative dispersion of birefringence [H. Lee and J.-H. Lee, Opt. Lett. 39, 5146 (2014)]. In this paper, we separately measured the extraordinary and ordinary refractive indices n_e and n_o of the pure LC and LC-polymer composite and simulated the dependence of the transmittance and the color on the viewing angle for the display application. The LC-polymer composite with the negative dispersion property showed a wider viewing angle and a smaller color shift compared to the pure liquid crystal with a positive dispersion of birefringence.

1. Introduction

Generally, the liquid crystal (LC) materials in nature shows a positive dispersion (PD) of birefringence, i.e., $\Delta n \equiv n_e - n_o$ decreasing with a longer wavelength of light λ, where n_e and n_o are the extraordinary and ordinary refractive indices of LC, respectively [1]. The PD medium inevitably results in the mismatch of the optical phase retardation $\Gamma = 2\pi\Delta nd/\lambda$ at different λ and this limits the bandwidth of the optical retarders [1,2]. There have been many reports to obtain a negative dispersion (ND) retarder, i.e., Δn is increasing with longer λ [3–12]. The traditional method to obtain the ND retarder is stacking multi-layers which have different dispersion of refractive indices [3–7]. Meanwhile, a single layer approach using copolymers with cylindrical and discotic substituents [8–10] or biaxial reactive mesogen molecules were also reported [11].

Recently, we demonstrated another method to obtain ND of birefringence using a two-dimensionally self-organized smectic LC-polymer composite single layer [12]. The polymers absorbing longer wavelength of light than the host LC were located at the inter-layer space of LC and the dispersion property was gradually converted from PD to ND with more fraction of polymers [12]. We should mention that the smectic LC-polymer composite system has been also referred as a polymer-stabilized ferroelectric liquid crystal (PSFLC) [13–16]. The PSFLC has been known to have a wide viewing angle property due to its in-plane switching of the optic axis. However, the effect of the ND of birefringence has not been considered yet for the wide viewing angle characteristics. We showed that the ND property of the LC-polymer composite system could enhance the viewing angle property better than the conventional in-plane switching mode of the LC materials with PD.

We separately measured the refractive indices n_e and n_o of the pure LC and LC-polymer composite and simulated the dependence of the transmittance (TR) and color on the viewing angle. The LC-polymer composite with ND property showed a wider viewing angle and a smaller color shift compared to the pure LC with PD. To estimate the performance of the LC-polymer composite for the display device application, we experimentally measured the contrast ratio (CR) and the response time of the LC-polymer composite. The CR value was 130:1 and both the rising and falling time was 280 µs at 10 V applied state.

2. Materials and methods

A commercial smectic LC mixture FELIX018/100 was mixed with a mixture of reactive monomers triallyl-1,3,5-triazine-2,4,6(1h,3h,5h)-trione (triallyl, Aldrich), 1,6-hexanediol diacrylate (HDDA, Aldrich), and photoinitiator Irgacure651 (Ciba Chem) at a

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weight ratio 62:38. LC is electrically ferroelectric and shows the cone mode in-plane switching [13–16]. The mixtures were injected into an empty cell whose substrates were coated with a planar alignment polyimide PIA-X189-KU1 (JNC). The cell gap *d* was maintained to be 2.1 μm for the half-wave retardation of the pure LC at 550 nm. The substrates were rubbed with a cotton cloth and assembled in an antiparallel fashion. The mixtures were injected at 100 °C. Then, the sample was cooled to 25 °C and exposed to a UV light of 30 mW/cm^2 for 1 m.

We separately measured n_e and n_o of the pure LC and the LC-polymer composite with an Abbe refractometer. To obtain a homogeneous orientation of LC for the refractive index measurements, the same polyimide was coated on the prism and then rubbed. The refractive indices were measured at different λ from 450 to 650 nm with a separation of 20 nm. The data was then interpolated using Cauchy's equation given by $n(\lambda) = A + B/\lambda^2 + C/\lambda^4 + D/\lambda^6$, where A, B, C, and D are the fitting parameters. The corresponding fitting parameters of the n_e of pure LC were 1.57, 1.59×10^4 nm^2, 2.93×10^6 nm^4, and -5.06×10^{10} nm^6, respectively. Those of the ne of LC-polymer composite were 1.57, -6.09×10^3 nm^2, 1.15×10^9 nm^4, and 2.81×10^{10} nm^6, respectively. The optical simulation was done with a commercial display simulator Techwiz LCD (Sanayi). The polar pretilt angle of the LC director was 2° from the surface plane and the rubbing direction was antiparallel. The azimuthal pretilt angle at dark state was at −22.5° parallel to the transmission axis of the polarizer. The LC molecules were assumed to be uniformly oriented with the same azimuthal and the polar angle through the sample. To measure the experimental value of the CR and the response time, a probe light (632 nm) was consecutively passed through a polarizer, the sample, an analyzer, and into a detector. For the experimental measurement of the CR and the response time, the polarizer was set to parallel to the optic axis of the sample in the absence of the electric field. 100 Hz bipolar voltage was applied across the sample.

3. Results and discussion

Fig. 1(a) and (b) show n_e and n_o of the pure LC and the LC-polymer composite, respectively, measured with the Abbe refractometer. Δn of the pure LC was decreased with longer λ, thus showing PD of birefringence [Fig. 1(a)]. The refractive index of the pure polymer n_p was smaller than n_e and larger than n_o of the pure LC [Fig. 1(a)]. n_e was decreased after mixing the polymers, whereas n_o was increased after mixing the polymers [Fig. 1(b)]. Meanwhile, the slope of n_e, $|dn_e/d\lambda|$ was decreased while that of n_o, $|dn_o/d\lambda|$ was increased in the LC-polymer composite sample, thus showing ND of birefringence [Fig. 1(b)]. Fig. 1(c) shows **Γ** of the pure LC and the LC-polymer composite deduced from the n_e and n_o data in Fig. 1(a) and (b). The magnitude of **Γ** of the LC-polymer composite was smaller than the pure LC due to the fraction of the optically isotropic monomers. On the other hand, the slope $|d\Gamma/d\lambda|$ of the LC-polymer composite was decreased compared to the pure LC. Fig. 1(d) shows the normalized Γ whose Γ(550 nm) was set to be π by varying *d*. The dashed blue line (in web version) indicates the ideal achromatic half-wave retarder. It is clearly seen that the LC-polymer composite shows better achromaticity than the pure LC sample.

Using the data in Fig. 1, we calculated TR at various viewing angles. Fig. 2 shows the optical simulation results of TR vs. viewing angle at bright state. The cell gap of the pure LC and LC-polymer composite were set to be 2.1 and 4.3 μm to obtain half-wave retardation at λ = 550 nm. The LC molecules were assumed to be uniformly oriented with the same azimuthal and the polar angle. The projected optic axis on the surface was at 22.5°. The transmission axis of the polarizer and analyzer was at −22.5° and 67.5°,

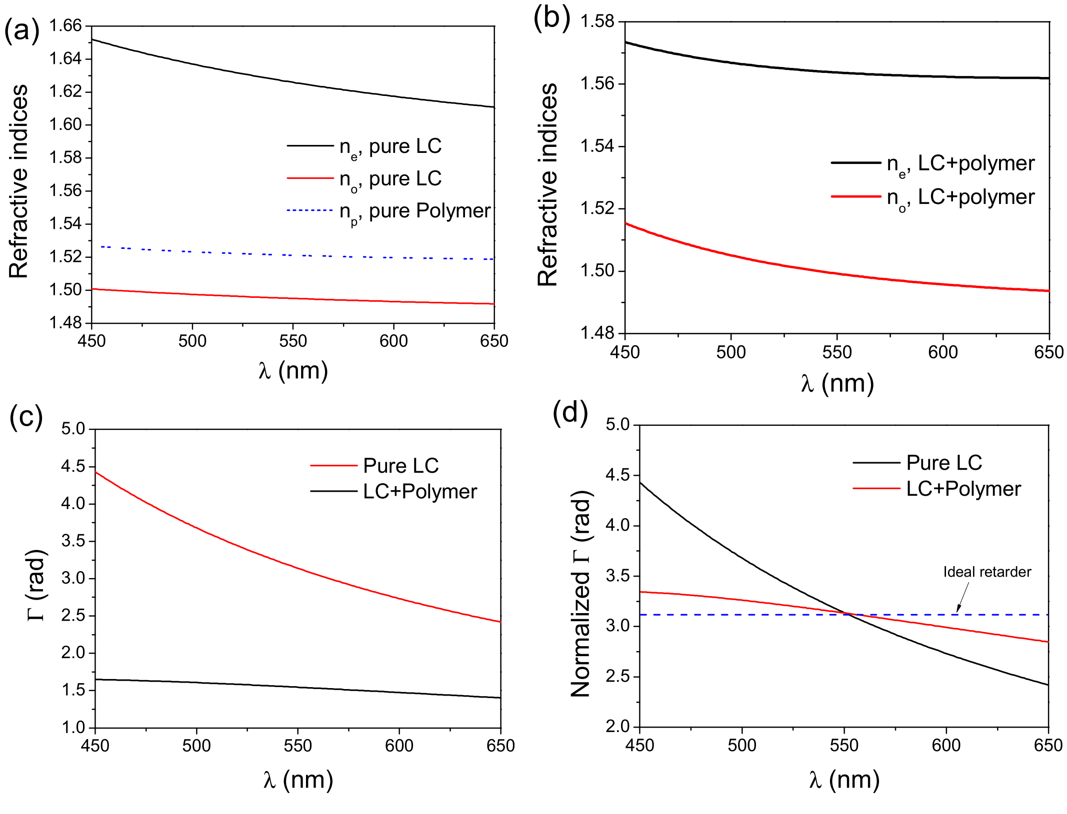

Fig. 1. (a) The extraordinary and ordinary refractive indices n_e and n_o of pure LC and polymer. (b) n_e and n_o of the LC-polymer composite. (c) Phase retardation Γ of the pure LC and the LC-polymer composite (d) Normalized Γ of the pure LC and the LC-polymer composite whose Γ(550 nm) was set to be π by varying *d*.