Scattering Linear Polarizer Based on a Polymer Blend of Photo-cross-linkable Polymer Liquid Crystal and Photoinactive Polymer

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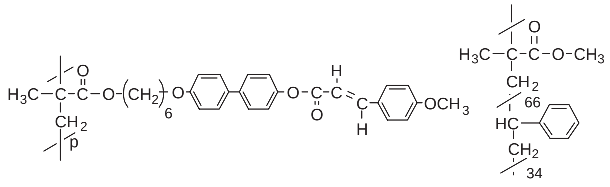
A polymer blend film of a photo-cross-linkable liquid crystal (PPLC) and an isotropic copolymer shows polarization-selective scattering generated by the photoinduced optical anisotropy of the PPLC.

Polarizers are widely used for optical devices to obtain polarized light. A conventional linear polarizer consists of oriented dichroic dye materials or iodine doped in the mechanically stretched polymer films, such as poly(vinyl alcohol). In this case, half of the incident light is absorbed by the oriented materials. To improve the transmission efficiency of the incident light beam through the polarizer, reflection-[1,2] or scattering-type[3–5] polarizers have been proposed. These new types of polarizers can be applicable to the backlight system for liquid crystal displays (LCDs) to improve the optical efficiency of the backlight system.[1,5]

A light beam can be scattered when it passes through phase-separated materials with different refractive indices. If the refractive indices between the two materials are same for one incident polarization direction, and are different for the other direction, polarization-selective scattering may occur. A mechanically stretched composite film with monomer liquid crystals doped in an isotropic polymer exhibits polarization-selective scattering because of the birefringence of the LC uniaxially oriented.[4] Stretching of a phase-separated blend film of a polyester derivative and an isotropic polymer also generates the polarization-selective scattering characteristics due to the mechanically induced birefringence of the polyesters.[5] This letter proposes a new process for the fabrication of scattering linear polarizer of a polymer blend, consisting of a photo-cross-linkable polymer liquid crystal (PPLC) and an isotropic copolymer. Our technique is based on the photoinduced reorientation of mesogenic groups of the PPLC, without any mechanical drawing.



P1 **P2**

We have reported that large in-plane reorientation of mesogenic groups was generated in a thin film of methacrylate PPLC with 4-(4-methoxycinnamoyloxy)biphenyl side groups (**P1**) by irradiation with linearly polarized ultraviolet (LPUV) light and subsequent annealing in the LC temperature range of the polymer, and the generated birefringence was 0.24.[6] In this case, refractive index (RI) parallel to the polarization (**E**) of the LPUV light is estimated to be 1.75, while that perpendicular is 1.51.[7] If the uniaxially oriented **P1** is dispersed in an isotropic polymer with RI of 1.51, polarization-selective scattering should occur, as illustrated in Figure 1. For this purpose, we synthesized a copolymer (**P2**) with methyl methacrylate and styrene in a copolymerization ratio of 66/34 (mol/mol-%).[8] The RI of **P2** is 1.52. Additionally, these polymers have no absorption in the visible region.[6]

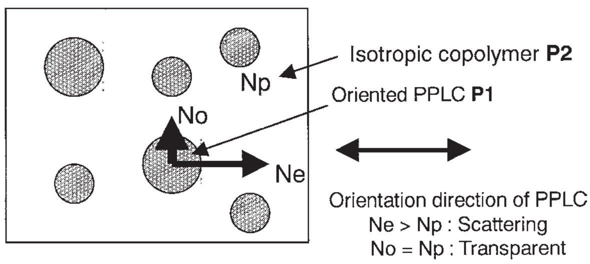


Figure 1. Schematic illustration of a blend film with oriented PPLC **P1** and an isotropic copolymer **P2**. No and Ne are ordinary and extraordinary RI of **P1**, respectively, and Np is RI of **P2**.

A thin blend film of these polymers was prepared by a spin-coating method on a quartz substrate from a chloroform solution of 25/75 (wt/wt) of **P1** and **P2**, resulting in a 1.3 μm-thick film. Figure 2 shows a transmission spectrum of the blend film before and after exposure to LPUV light for 300 mJcm^{-2}, and that following subsequent annealing at 150 °C for 10 min. Before exposure, the film is opaque due to the scattering in the visible region. Irradiation with LPUV light induces a small negative optical anisotropy ($T_{\parallel} > T_{\perp}$) around 300 nm due to the axis-

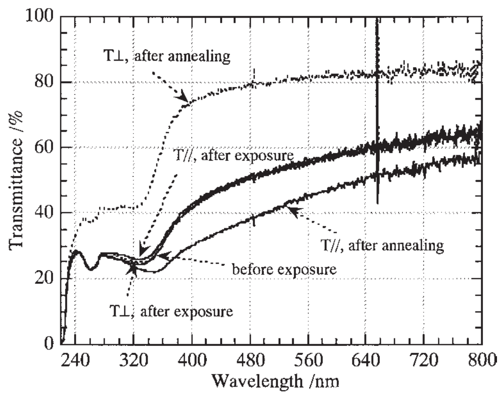


Figure 2. Polarized transmission spectra of a blend film.

selective photoreaction of the side groups of **P1**,[6] while the scattering property does not change. After annealing, great increase in the transmittance higher than 75% for $T_{\perp}$ is observed in the visible region. Since mesogenic groups in **P1** thermally reorients parallel to **E** of LPUV light,[6] the RI perpendicular to **E** should be decreased. Therefore, the increase in the transmission in the visible region for $T_{\perp}$ is a consequence that the RI perpendicular to **E** of the reoriented **P1** becomes close to that of **P2**. In contrast, the scattering property is increased for $T_{\parallel}$ after annealing. This is due to the increased difference in the refractive indices between the reoriented **P1** parallel to **E** and **P2**. Figure 3a displays the photograph of the polarization optical microscope (POM) observation, when the reoriented blend film is placed between crossed polarizers of the POM with an angle of 45° polarization to **E** of the exposed LPUV light. The clear droplets correspond to the reoriented **P1**, and the sizes of them are between 0.5 μm and 6 μm. In addition, the dark area corresponds to **P2**. On the other hand, when the film is rotated by 45°, the whole area becomes dark as shown in Figure 3b. These results confirm the uniaxial reorientation of **P1** in the blend film. Additionally, the polarizing efficiency, $\mathrm{PE} = (T_{\perp} - T_{\parallel})/(T_{\perp} + T_{\parallel})$, of the film is between 0.27 and 0.43, indicating that this blend film acts as a scattering linear polarizer, although PE value is smaller than that of other thick linear polarizers made by a stretching method.[5]

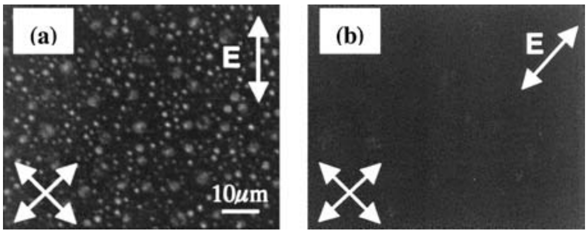


Figure 3. Photographs of the blend film after exposure and subsequent annealing placed between crossed polarizers of POM (a) Direction of the polarizer of POM is 45° to **E** of the film, (b) parallel to **E**. White arrow shows the reorientation direction of **P1**, and crossed arrows shows the direction of polarizers.

For the application to the backlight system in LCDs, backward scattering is more important than forward one, because the scattering light to the backward direction can be reused for the transmission. At present, the integrated transmittance and backward scattering of the blend film were evaluated by measuring the total transmittance using a He–Ne laser at a wavelength of 632.8 nm, as summarized in Table 1. The total transmittance for $T_{\perp}$ is close to the substrate, and is higher than that shown in Figure 2. This result indicates the existence of partial scattering of the incident light beam, caused by a small mismatching of refractive indices between the reoriented **P1** and **P2** in this polarization. For $T_{\parallel}$, total transmittance is much higher than that in Figure 2 because of the large amount of forward scattering. In this case, the forward scattering is estimated to be 31%,[9] and backward one is about 17%, i.e., when this blend film is used in the backlight system, optical efficiency will improve 8.5% by recycling the backward scattering light.

Table 1. Integrated forward transmittance and backward scattering of a quartz substrate, and a blend film of PPLC **P1** and copolymer **P2**[c]

	Forward/%	Backward/%
Quartz substrate	91	9
Transparent ($\perp$ to **E**)[d]	90	9
Scattering ($\parallel$ to **E**)[d]	79	17

[c]Measured at 632.8 nm using a He–Ne laser. [d]Because of a small amount of waveguiding mode of the scattered light into the substrate, sum of forward and backward light intensities is not 100%.

In summary, we demonstrate preliminary results of a scattering linear polarizer based on a polymer blend of the anisotropic PPLC and the isotropic polymer, in which the optical anisotropy of the PPLC is generated by a thermally enhanced photoinduced reorientation. By employing the photo-orientation process, a patterned scattering polarizer can be fabricated for new polarization devices. Since the current backward scattering of the film in this study may be small for the practical usage for the LCD, further study on fabrication of thick blend film, and control and simulation of the size of the phase-separation are in progress to improve the PE and the backward scattering.

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7 Refractive index (RI) of oriented **P1** film was measured by the Abbe's refractometer. $M_w = 6.8 \times 10^4$, $M_w/M_n = 3.1$.
8 **P2** was synthesized by a radical solution polymerization in THF. The copolymerization ratio was determined by ^{1}H NMR. $M_w = 2.3 \times 10^4$, $M_w/M_n = 1.5$.
9 The difference between the total transmission and the non-scattered transmitted light was 31%.