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Fabrication of an initially-focal-conic cholesteric liquid crystal cell without polymer stabilization☆

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ABSTRACT

A dye-doped cholesteric liquid crystal (LC) cell with the focal-conic initial state is demonstrated. Although dye-doped LC/polymer composites have been widely used for LC light shutters, dye-doped LC cells with polymer structures suffer from the degradation of dichroic dyes during the UV curing process. To avoid this problem, we propose a dye-doped cholesteric LC cell using vertical alignment layers instead of polymer structures. We have shown that the focal-conic initial state can be obtained by homeotropic anchoring without the polymer structure. The proposed device not only provides the black color but can also hide objects behind a display panel in the focal-conic initial state without the degradation of dichroic dyes.

1. Introduction

Recently, see-through displays have attracted much attention as a promising next-generation display [1–3]. In particular, see-through displays using organic light-emitting diodes (OLEDs) have been widely studied [2,3]. However, see-through displays using OLEDs exhibit poor image quality because they can neither provide the black color nor hide objects behind the display panel. To overcome these problems, a light shutter can be placed on the backside of a see-through display panel. By switching the light shutter, a see-through display can be operated in the see-through mode or high-quality mode.

To realize a high-quality see-through display, it is necessary to use light shutters that not only hide objects behind a display panel by light scattering but also provide the black color by light absorption [4–6]. Light shutters using liquid crystals (LCs) are of great interest because they can simultaneously scatter and absorb incident light. Light scattering can be obtained using polymer structures in the LCs whereas light absorption can be obtained by doping dichroic dyes for LCs [4–19]. However, dye-doped LC cells fabricated using LC/polymer composites, such as polymer-dispersed LCs, polymer-stabilized LCs, and polymer-networked LCs, undergo a change in the absorption peak or the dichroic ratio of the dichroic dye.

As shown in Fig. 1(a), as the intensity of the UV light was increased, the measured specular transmittance of dye-doped polymer-stabilized cholesteric LC (PS-ChLC) cells for wavelengths between 400 nm and 600 nm increased because of the degraded dichroic dyes. Therefore, the UV-exposed cell cannot provide the black color, as shown in Fig. 1(b). We should note that the UV exposure changed not only the transmittance but also the color of the dichroic dye.

A cholesteric liquid crystal (ChLC) cell can be used to prevent degradation of the dichroic dye because it can scatter light in the focal-conic state without using polymer materials. However, a ChLC cell requires a complicated drive scheme for switching from the homeotropic state to the focal-conic state. To avoid this problem, Yu et al. have proposed a dye-doped ChLC cell with the initial focal-conic state by forming a polymer network structure [19]. However, it still includes the UV curing process, which may degrade the dichroic dye.

In this paper, we propose a dye-doped ChLC cell with the focal-conic initial state that does not include polymer structures. To obtain the focal-conic initial state, we use vertical alignment layers. The proposed ChLC cell with the focal-conic initial state not only provides the black color but also hides objects behind a display panel without degradation of dichroic dyes. We also confirmed that the degradation of the dichroic dyes is caused by the interaction between the photo-initiator and the dichroic dye during UV exposure. We expect that the proposed device can be widely used for see-through displays to hide objects behind a display panel and provide the black color.

2. Experimental

The structure of a dye-doped ChLC cell with vertical alignment layers is shown in Fig. 2. The focal-conic initial state can be obtained by homeotropic anchoring without the polymer structure. To evaluate the performance of the proposed device, a dye-doped ChLC cell using

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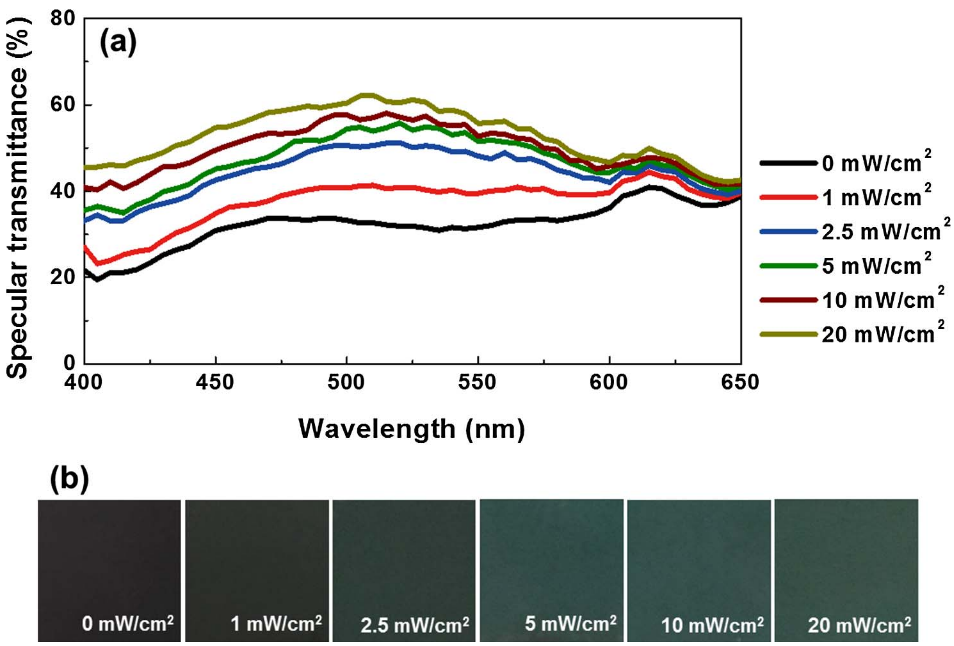

Fig. 1. Dependence of (a) specular transmission spectra and (b) images of dye-doped PS-ChLC cells on the UV intensity. Cell parameters; liquid crystals: E7, chiral dopant: S-811 (pitch: 1.25 µm), UV-curable monomer: RM 257 (2 wt%), photo-initiator: Irgacure 651 (0.1 wt%), black dichroic dye: S-428 (1 wt%), cell gap: 10 µm. The cell in the planar state was exposed to UV light for 10 min as we varied the intensity (0, 1, 2.5, 5, 10, and 20 mW/cm^2).

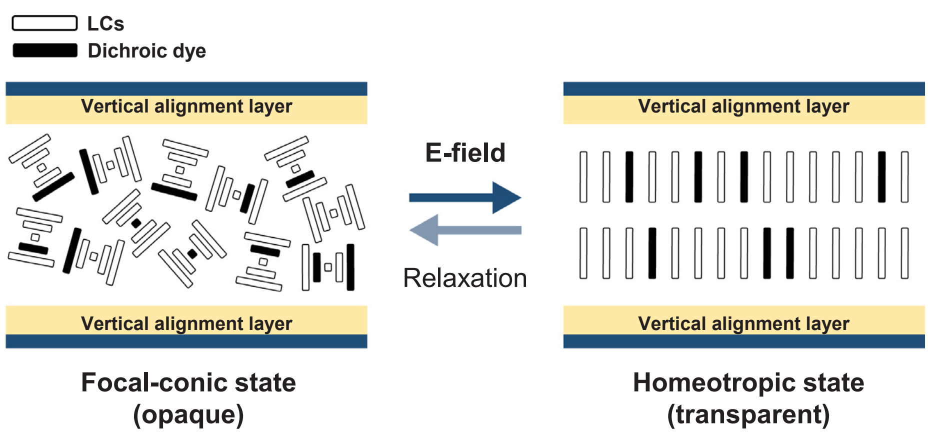

Fig. 2. Structure and operation of the proposed device.

vertical alignment layers was fabricated. We mixed positive LCs (E7, Δn: 0.223, $\Delta\varepsilon$: 13.5, Merck) with a chiral dopant (S-811, Merck) and 1 wt% of a black dichroic dye (S428, Mitsui). This mixture was stirred for 24 h, followed by application of an ultrasonic wave for 3 h. Polyimide SE-5662 (Nissan, Japan), a vertical alignment material, was spin-coated for 30 s at 3000 rpm on the top and bottom indium-tin-oxide glass substrates. The coated substrates were pre-baked at 100 °C for 10 min on a hot plate and annealed at 180 °C for 1 h. The mixture was then injected into a 10-µm-thick cell via capillary action.

We fabricated a dye-doped PS-ChLC cell [19] to compare the transmission characteristics with the proposed device. The amount of chiral dopant was chosen to reflect infrared light of wavelength 2000 nm (pitch: 1.25 µm). We doped ChLC with 2 wt% of UV-curable monomer (RM 257, Merck), 0.1 wt% of photo-initiator (Irgacure 651, BASF), and 1 wt% of black dichroic dye (S-428, Mitsui). The cell was exposed to UV light with an intensity of 10 mW/cm^2 for 10 min in the focal-conic state.

To confirm the scattering characteristics of the focal-conic initial state, we measured the specular transmittance and haze of the fabricated ChLC cells using a haze meter (HM-65W, Murakami Color Research Laboratory) as we varied the number of pitches. The specular [diffuse] transmittance T_s [T_d] refers to the ratio of the power of the beam that emerges from a sample cell, which is parallel (within a small range of 2.5°) [not parallel] to a beam entering the cell, to the power carried by the beam entering the sample. The total transmittance T_t is the sum of the specular transmittance T_s and the diffuse transmittance T_d. The haze H can be calculated as $H = T_d/T_t$.

3. Results and discussion

The focal-conic initial state can be obtained by homeotropic anchoring without the polymer structure [20–23]. The minimum helical pitch value for the homeotropic state can be expressed as

$$p_{th} = 2d\frac{K_{22}}{K_{33}}, \quad (1)$$

where d is the cell gap, and K_{22} and K_{33} are the twist and bend elastic constants, respectively. If the pitch is larger than the threshold pitch p_{th}, the chiral torque is too weak and the system is unable to twist, resulting in homeotropic alignment of the LCs. On the other hand, when the pitch is smaller than p_{th}, the chiral torque is sufficiently strong, and the focal-conic initial state can be achieved.

We measured the haze values of the ChLC cells with vertical alignment layers as a function of the number of pitches, as shown in Fig. 3. The number of pitches N can be expressed as d/p. Substituting Eq. (1) into the equation of number of pitches $N = d/p$, the minimum number of pitches for the homeotropic state can be expressed as $N_{th} = d/p_{th} = K_{33}/2K_{22}$. As we expected from N_{th}, the homeotropic