Fast switching of long-pitch cholesteric liquid crystal device

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Abstract: We propose a long-pitch cholesteric liquid crystal (ChLC) device capable of operation in both the dynamic mode and the memory mode. Fast switching between the homeotropic state and the focal conic state allows the display of moving pictures at a low operating voltage. In addition, we can write text messages on the proposed ChLC device by applying an external pressure locally to switch it from the focal conic state to the planar state.

OCIS codes: (230.0230) Optical devices; (230.3720) Liquid-crystal devices.

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1. Introduction

Cholesteric liquid crystals (ChLCs) are candidates for various optical devices because of their bistable and reflective properties [1–13]. A ChLC has two stable states of planar and focal conic states at zero electric field, and one transient homeotropic state in the presence of an applied electric field. The planar and focal conic states show Bragg reflection by helical molecular structure and light scattering due to randomly distributed molecular domains,

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respectively [14,15]. Due to their bistability, ChLC devices can be operated in memory mode with low power.

Currently, ChLCs reflecting visible wavelengths have been utilized. To display moving pictures in the dynamic mode, the planar and homeotropic states can be employed as bright and dark states, respectively. However, relaxation from the homeotropic to the planar state takes about 300 ms when the applied electric field is eliminated, which may be too slow for operation in the dynamic mode [7,14]. Moreover, a voltage higher than 50 V is usually required for switching from the planar state to the homeotropic state [5,14]. For current practical application to transparent devices such as sub-panel displays and light shutters [10,11], the homeotropic state is necessary, wherein the high operating voltage causes high power consumption.

Recently, we proposed a ChLC device with a long pitch [12,13] wherein the planar state is transparent for all visible wavelengths because of Bragg reflection at infrared wavelengths. The focal conic state scatters ambient light; thus, achromatic reflection and an omni-directional viewing angle can be obtained. The required power for the homeotropic state and for switching between two bistable states is much lower than that required for a conventional ChLC device. In this study, we propose a ChLC device that can be operated in both the dynamic mode and the memory mode. Since we use switching between the focal conic state and the homeotropic state instead of slow switching between the planar state and the homeotropic state in a conventional ChLC device, fast operation for the dynamic mode can be realized. Both the dynamic mode and memory mode can be achieved at a low voltage by using the long pitch structure. In addition, the proposed ChLC device can be used as both an output device and an input device since we can write text messages on the device by applying external pressure.

2. Principle and experiments

The operation of the proposed ChLC device is shown schematically in Fig. 1. The focal conic state scatters the ambient light (see Fig. 1(a)), whereas the planar state reflects infrared light through Bragg reflection (see Fig. 1(b)). Therefore, transparency at visible wavelengths (380 to 780 nm) can be obtained. Switching between the two stable states can be applied to a switchable reflector or a reflective display [12,13]. Since the two states are stable at zero electric field, the device can be operated with very low power [12].

In a conventional ChLC device that reflects visible light, operation in the dynamic mode by switching between the homeotropic state and the planar state is difficult because relaxation from the homeotropic state to the planar state takes a long time (about 300 ms). Switching between the homeotropic state and the planar state cannot be used in the long pitch ChLC device since both states are transparent for visible wavelengths. Instead, we used the homeotropic and focal conic states for operation in the dynamic mode (see Figs. 1(a) and 1(c)). Switching from the homeotropic to the focal conic state takes only a few ms [14]; thus, the proposed ChLC device can achieve fast operation for the dynamic mode. In addition, the device can be switched to the transparent planar state by applying external pressure to the proposed ChLC device in the focal conic state, as shown in Fig. 1(d). Thus, an input device that is writable without applying an electric field can be realized. The proposed device can also be applied to writable boards and outdoor displays [16].

To confirm the electro-optical characteristics of the proposed ChLC device, we fabricated a ChLC cell. A homogeneous polyimide (H-PI) alignment layer (PIA-5310, Nissan Chemical) was spin-coated onto the top and bottom of indium-tin-oxide (ITO) glass substrates, followed by a baking process for the polyimidization of the H-PI. Rubbing or any other treatment was not made on alignment layers. The device was then assembled, maintaining a cell gap of 7 μm by using silica spacers. The positive liquid crystal (E7, Δn: 0.2255, $\Delta\varepsilon$: 14.1, Merck) was mixed with a chiral material (S811, Merck). The mixing ratio was chosen to reflect infrared light of 1000 nm, and the mixture was injected into the empty cell.

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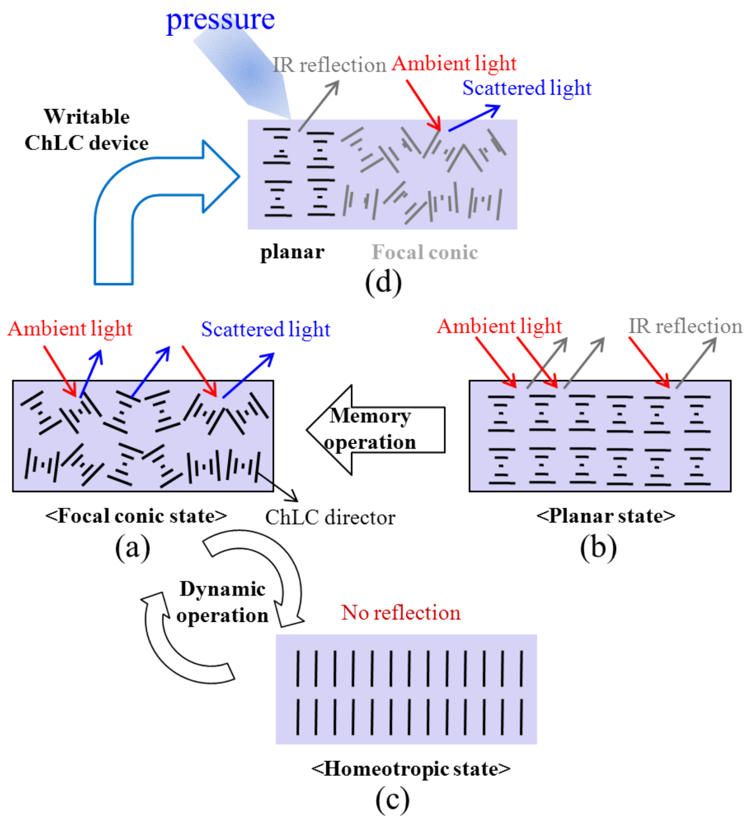

Fig. 1. Operation of a long pitch ChLC device. (a) Focal conic state. (b) Planar state. (c) Homeotropic state. (d) Switching from the focal conic state to the planar state by applying an external pressure.

3. Results and discussion

Transmittances of the fabricated long pitch ChLC device operating in memory mode are shown in Fig. 2 as a function of the amplitude of the applied voltage pulse. The width of the addressing voltage pulse was fixed at 40 ms. Transmittance was measured after the removal of the addressing voltage pulse. When the ChLC cell was in the initial planar state, it maintained the initial state for an addressing voltage smaller than 6 V. When the addressing voltage was increased to 7 V, the cell became opaque because focal conic domains began to scatter the incident light, and therefore the transmittance decreased. When a voltage between 12 and 15 V was applied, focal conic domains were predominant over entire regions of the ChLC cell so that the lowest transmittance was observed. The ChLC cell was switched to the homeotropic state for an addressing voltage higher than 18 V, and began to relax back to the planar state as soon as the addressing pulse was removed. High transmittance could be obtained due to transparency of the planar state at visible wavelengths.

When the ChLC cell was initially in the focal conic state, it maintained the state for an addressing voltage of less than 18 V; thus, the cell still showed low transmittance. When the addressing voltage was higher than 21 V, the cell could be switched completely to the homeotropic state and then relax to the planar state. The required addressing voltages for the homeotropic state and the focal conic state were much lower than those of the conventional ChLC cell [5,12]. The inset boxes show the images of the fabricated ChLC cell at each addressing voltage. At the bottom of the cell, we placed a sheet of paper printed with “PNU.” The text “PNU” was not readable when the focal conic domains were dominant. The switching behavior of the fabricated long pitch ChLC cell is shown in Fig. 3.

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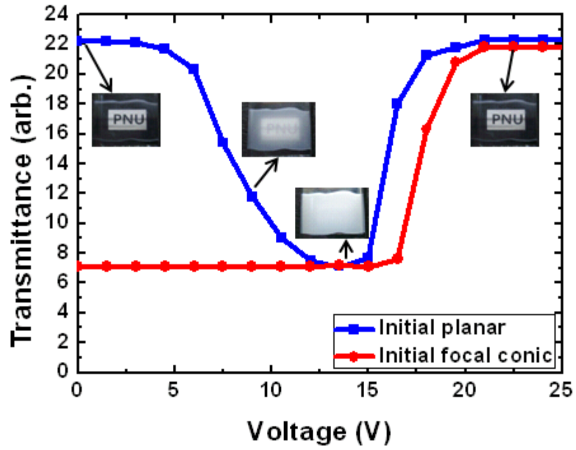

Fig. 2. Transmittances of the fabricated long pitch ChLC device operating in the memory mode as functions of the amplitude of the applied voltage pulse.

As shown in Fig. 3(a), the planar state can be switched to the homeotropic state by applying a voltage pulse with an amplitude of 25 V. Since both states are transparent for visible light, the fast turn-on process was not distinguishable. When the applied electric field was turned off, the mixture of the focal conic and planar textures were observed temporarily. Finally, it relaxed to the transparent planar state in about 450 ms. Although a conventional ChLC cell can be operated in the dynamic mode using switching between the planar and homeotropic states, it is too slow to display moving pictures

As shown in Fig. 3(b), the focal conic state could be switched to the homeotropic state in less than 2 ms when 25 V was applied to the cell. The homeotropic state could be switched back to the focal conic state in around 11 ms when a 15 V voltage pulse was applied to the cell. As opposed to the conventional ChLC cell that uses the homeotropic and planar states for operation in the dynamic mode, the long pitch ChLC device employs the homeotropic and the focal conic states. This is why fast dynamic response can be achieved in the proposed ChLC device. We expect that further studies of the optimization of cell parameters such as the pitch length, and use of a curable polymer, can be applied to accelerate the response time.

To confirm the possibility of the proposed ChLC device as an input device, we fabricated a 3.2 inch prototype panel. The cell conditions were the same as the aforementioned ChLC cell. It is also possible to use the panel as an output device by switching electrically among three states using passive matrix addressing [12]. To write a text message, we can apply an external pressure locally to the surface of a panel in the focal conic state. An external pressure applied to the surface induces the flow of LCs. Then, the regions where the external pressure is applied are switched to the transparent planar texture because the free energy of the planar state is lower than that of the focal conic state [14]. Examples of text messages written with a stylus pen are shown in Fig. 4. The line width of the written text and the gray scales can be controlled by the level of applied pressure. To remove the written text, we applied a voltage of 14 V to the panel to return it to the focal conic state. Although boundary regions are not very clear, it is expected that clearer images can be obtained by using a plastic substrate instead of a glass substrate. We measured the reflection using a chroma meter (Konica Minolta CS-100A) while the while light incident from a cold-cathode fluorescent lamp array at a fixed angle of −30° was shined to the panel. On-axis reflected light intensities were 73.15 cd/m^2 in the focal conic state (bright) and 4.84 cd/m^2 in the planar state (dark). Thus, the measured contrast ratio is higher than 15: 1.

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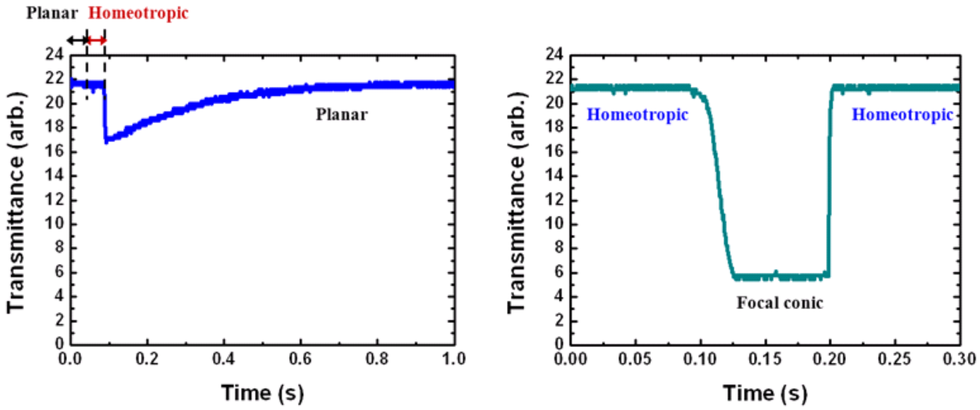
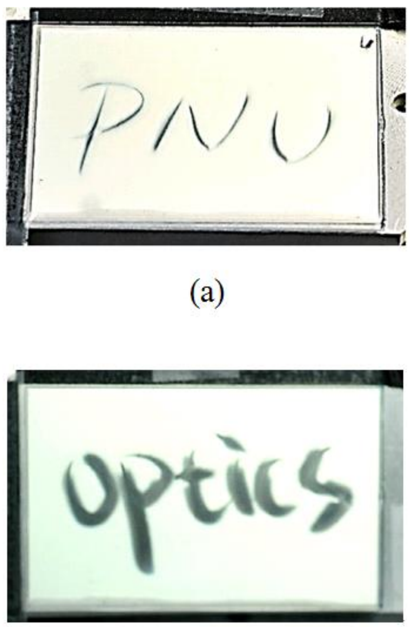


(a) (b)

Fig. 3. Operation of the fabricated long pitch ChLC device in the dynamic mode. (a) Switching between the planar and the homeotropic states. (b) Switching between the homeotropic and the focal conic states.



(a)

(b)

Fig. 4. Text messages written on a prototype long pitch ChLC panel. (a) "PNU" (Media 1). (b) "Optics" (Media 2).

4. Conclusions

In conclusion, we proposed a long pitch ChLC device capable of operation in the dynamic mode, which employs the focal conic state and the homeotropic state. Moreover, text messages can be written on the ChLC device by applying external pressure. We expect that the proposed device could be applicable to outdoor displays that require operation in both the dynamic mode and the memory mode.

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