Ion-doped Liquid Crystal Light Shutter Switchable among Transparent, Haze-free Opaque, and High-haze Opaque States

Ho-Jin Sohn, Jae-Won Huh, Jeong-Ho Seo, Seung-Won Oh, Sang-Hyeok Kim, and Tae-Hoon Yoon

Department of Electronics Engineering, Pusan National University, Busan 46241, Korea

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ABSTRACT

Tristate switching of a liquid-crystal (LC) cell among the transparent, haze-free opaque, and high-haze opaque states is proposed. Owing to its simple switching process, the proposed LC cell is promising for the development of a multipurpose switchable window.

1 INTRODUCTION

Recently, smart window technologies have been widely studied to provide privacy protection and to control the heat transfer from sunlight [1-2]. LC devices have been actively studied as they can be used to simultaneously control the haze and transmittance. Dye-doped cholesteric LC (ChLC) [3] and dye-doped phase grating device [4] have been developed to control the transmittance and haze individually in a single device. They are switchable among the transparent, haze-free opaque, and high-haze opaque states. However, ChLC devices may have disadvantages, such as a low haze in the high-haze opaque state and the complicated switching process. Although a dye-doped phase grating device has a high haze value in the high-haze opaque state, it requires a complicated electrode structure. Moreover, both devices are initially opaque, which may limit their applications [3, 4].

In this presentation, we report an ion-doped LC cell, which is switchable among the initial transparent, haze-free opaque, and high-haze opaque states. It can be switched among the three states simply by changing the magnitude of the applied voltage. To obtain the haze-free opaque state, we apply a low voltage to the cell [5]. In this state, LCs and dye molecules are twisted so that the incident light is absorbed without light scattering. We can obtain the high-haze opaque state simply by further increasing the applied voltage. In this state, LCs and dye molecules are randomly oriented by the electro-hydrodynamic instability (EHDI) [6-8]. Thanks to the its simple switching process, simple structure, and excellent optical performance, the proposed LC cell can be used as smart windows for energy saving and privacy protection.

2 OPERATING PRINCIPLE AND CELL FABRICATION

The operating principle of the proposed LC cell is illustrated in Fig. 1. In the initial transparent state, the LC and dye molecules are aligned perpendicular to the substrate, and most of the incident light passes through the LC cell without either light scattering or absorption. When a low voltage is applied to the LC cell, the negative LC and dye molecules tend to align parallel to the substrate, and twisted by chirality. In this state, dye molecules could absorb the incident light without light scattering. As the applied voltage increases, randomly oriented LC and dye molecules results in strong light scattering and absorption. When the applied voltage is removed, the LCs relaxed to the initial transparent state.

To verify the transmission characteristics, we fabricated an LC cell doped with ionic and chiral materials and dichroic dye. We mixed a negative LC (Δn: 0.230, $\Delta\varepsilon$: −9.6) with the chiral dopant (S-811, Merck). For EHDI, we mixed the LC mixtures with 0.1 wt% of an ionic material (tetra-n-butylammonium bromide). For light absorption, we mixed the LC mixture with 2 wt% of black dichroic dye (X12, BASF). Owing to the dichroism of the dye molecules, they strongly [weakly] absorb the incident light polarized parallel [perpendicular] to their absorption axis [9].

We fabricated dye-doped polymer-stabilized LC (PSLC) and ChLC cells [10] for comparison with the proposed cell. For a PSLC cell, we mixed negative LCs (Δn: 0.200, $\Delta\varepsilon$: −5.5) with 2 wt% of reactive mesogen (RM257, Merck) and 1.5 wt% of the dichroic dye (X12, BASF). To form the polymer structure in the cell, UV light with an intensity of 10 mW/cm2 was exposed to the cell for 10 min. For a ChLC cell, we mixed positive LCs (Δn: 0.237, $\Delta\varepsilon$: 14.1) with 10 wt% of the chiral dopant (S-811, reflection wavelength: 1600 nm) and 1.5 wt% of the dichroic dye (X12, BASF). The cell gap of both cells was maintained at 10 μm using silica spacers.

3 EXPERIMENTAL RESULTS

To confirm the optical performance of the fabricated cell in the transparent, haze-free opaque, and high-haze opaque states, we measured the specular transmittance, total transmittance, and haze using a haze meter (HM-

65W, Murakami Color Research Laboratory), as shown in Fig. 2. The specular [diffuse] transmittance T_s [T_d] is the ratio of the intensity of the light that emerges from an LC cell, which is parallel (within a small angle range of 2.5°) [not parallel] to the beam entering the cell, to the power of the beam entering the cell. To measure the diffuse transmittance, the light diffused or scattered by the cell was collected by an integrating sphere installed in the haze meter. And the total transmittance T_t is the sum of the specular transmittance T_s and diffuse transmittance T_d. The haze H can be calculated as $H = T_d/T_t$.

The measured total, specular transmittances and haze value of the proposed LC cell are shown in Fig. 3. In the initial state, the total transmittance, specular transmittance, and haze of the fabricated LC cell were 63.2%, 63.1%, and 0.2%, respectively. When the applied voltage was 20 V, the total and specular transmittances were decreased to 29.9% and 29.7%, respectively and the haze did not increase. When the applied voltage was 64 V, the total, specular transmittances and haze were decreased to 19.2% and 0.8% and increased to 95.6%, respectively.

Fig. 4 shows the images of the proposed LC cell placed on a printed logo. We can clearly identify a printed logo in the transparent state. In the haze-free opaque state, we can observe the printed logo with reduced brightness. In the high-haze opaque state, the fabricated cell can hide the objects behind it and provide the black color by the Simultaneous control of the haze and transmittance. The proposed LC cell can be switched among the three states simply by controlling the applied voltage.

The optical performance of the proposed LC cell is compared with those of ChLC and PSLC cells in Table 1. A PSLC cell is not switchable among the three states although it has a high-haze value in the opaque state. The haze value of the PSLC cell in the high-haze opaque state was 82.7%, but it has shown a hazy transparent state with a haze value of 4.3% due to the index mismatch between the LC and polymer. A ChLC cell has a low haze value in the transparent state. But the haze value of the ChLC cell in the high-haze opaque state was just 70.0%. In our proposed cell, it can implement tristate, transparent state, haze-free opaque state and high-haze opaque state. The haze in the transparent state of the proposed LC cell was less than 1%. In addition, the high-haze opaque state shows a very high-haze value of 95.6%.

4 SUMMARY

We proposed an LC cell switchable among the initial transparent, haze-free opaque, and high-haze opaque states. We doped the chiral material to the LC mixture for the haze-free opaque state, and ionic materials for the high-haze opaque state. Simply by controlling the applied voltage, we could switch the cell among the three states. In addition, the proposed LC cell has shown a clear transparent state with little haze. These results demonstrate that the proposed LC cell is very promising for smart window applications.

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Table 1 Measured total transmittance and haze values of the PSLC, ChLC, and the proposed LC cells.

	Transparent		Haze-free opaque		High-haze opaque	
	Total T (%)	Haze (%)	Total T (%)	Haze (%)	Total T (%)	Haze (%)
PSLC cell	62.9	4.3	-	-	31.4	82.7
ChLC cell	62.9	0.5	18.3	1.9	24.3	70.0
Proposed LC cell	63.3	0.3	29.9	0.6	19.2	95.6

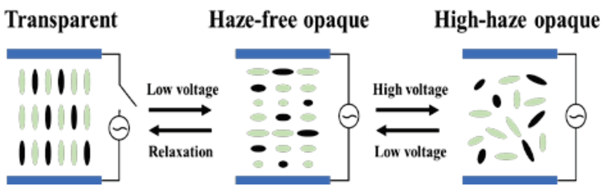

Fig. 1 Operation principle of the proposed LC cell.

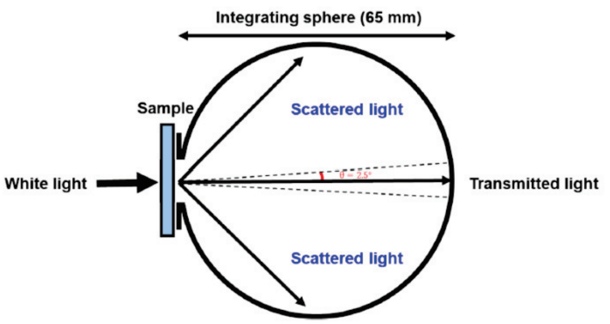

Fig. 2 Experimental setup for evaluation of the optical performance of the fabricated LC cells.

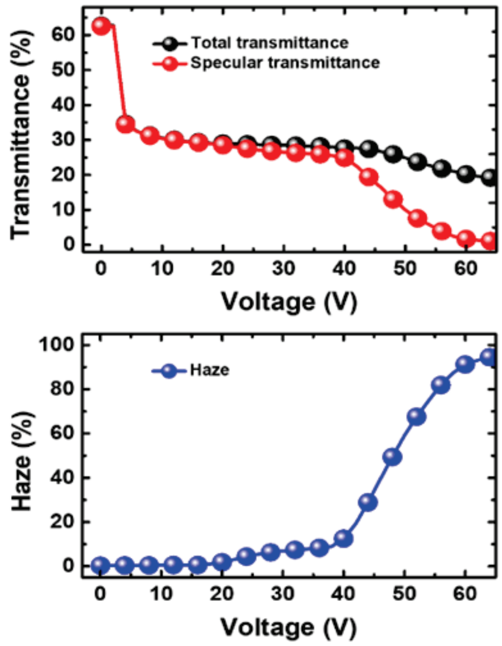

Fig. 3 Measured total transmittance, specular transmittance, and haze of the fabricated LC cell.

Fig. 4 Photographs in initial transparent, haze-free opaque, and high-haze opaque states of the fabricated LC cell.