# Analysis of Optical Performance Degradation in an Ion-doped Liquid Crystal Cell

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# ABSTRACT

We report an analysis of the optical performance degradation in an ion-doped liquid crystal cell. When an electric field is applied to the cell for a long time, the optical performance becomes non-uniform, and the haze value in the opaque state decreased. Based on the measurement of the optical and physical characteristics, we estimated that the degradation is caused by ionic materials.

## **1** INTRODUCTION

Recently, liquid crystal (LC) light shutter technologies have been actively studied for automotive, architecture, and display applications [1-4]. Among them, an ion-doped LC cell shows the haze-free transparent state because it does not contain any polymer structure. Moreover, it shows a very high-haze value in the opaque state thanks to the strong scattering of the incident light by the electrohydrodynamic instability [2,4]. Despite the excellent optical performance, reliability of an ion-doped LC device remains a critical issue [5]. The behavior of ions under an applied electric field can influence the optical performance, such as the decrease in the haze value and uniformity in the opaque state. To solve these critical issues caused by the ion material, investigation on the physical and optical parameter changes during the degradation is essential.

In this paper, we analyze the reason for degradation in the optical performance of an ion-doped LC cell. When an electric field is applied to the cell for a long time, the cell shows the decrease of the haze value and the non-uniform operation. As time goes on, uniformity becomes worse, and the haze value decreases. Degradation may be caused by a complicated mechanism related to the materials, such as the LC mixture, ionic material, and alignment layer. To analyze degradation with time, we tested reliability with different LC mixtures. As time goes on under an applied field, we found that the LC cell shows non-uniformity and the decrease of the haze value. We expect that the measurement of optical and physical characteristics can be used for the analysis of degradation in an ion-doped LC cell. It will offer an effective analysis method for enhancing the reliability of an ion-doped LC cell. 2 PRINCIPLE OF OPERATION AND CELL FABRICATION



Fig. 1 Structure and Operation of degradation in an ion-doped LC cell.

Fig. 1 shows the structure and operating principle of an ion-doped LC cell. In the initial transparent state, LC and dye molecules are aligned perpendicular to the two substrates. When the applied voltage is increased, turbulence caused by electro-hydrodynamic instability becomes stronger. In the opaque state, the incident light is strongly absorbed because most of the dye molecules are oriented parallel to the substrates and scattered strongly by randomly distributed negative LCs with small domains.

To analyze the degradation issue, we measured the optical and physical characteristics of an ion-doped LC cell as a function of time. We measured the haze value using a haze meter (HM-65W, MCRL). By measuring the impedance, an equivalent circuit can be estimated. The LC cell can be modeled as a parallel combination of a resistance  $R_{cell}$  and capacitance  $C_{cell}$  [6].

To confirm any change in a degraded ion-doped LC cell with time, we fabricated ion-doped LC cells using



Fig. 2 Photographs of the fabricated LC cells in the opaque states.

negative LC, dichroic dye, and ionic materials. We used two negative LCs; LC-1 ( $\Delta$ n: 0.20,  $\Delta$ ε: -4) for the mixture A and LC-2 ( $\Delta$ n: 0.25,  $\Delta$ ε: -4) for the mixture B. We mixed the same concentration of dichroic-dye and ion materials to each LC mixture. The top and bottom substrates were coated with the homeotropic alignment layer, and the cell gap was maintained at 10 µm. The mixture-A LC cell shows a uniform opaque state. However, the mixture-B LC cell shows a non-uniform opaque state, which changes with time. Fig. 2 shows photographs of the fabricated LC cells in the opaque state at t = 0, 20, 60 min. At the beginning, both cells show the uniform opaque state. The mixture-A LC cell maintains the uniform opaque state, but the mixture-B LC cell shows the non-uniform opaque state as time goes on.

#### 3 RESULTS AND DISCUSSION

To confirm the change of optical characteristics, we measured the haze value of the fabricated ion-doped LC cells as time is increased from 0 to 60 min. For the measurement, the amplitude and frequency of the applied voltage were set to 60 V and 60 Hz, respectively. Fig. 3 shows the measured haze value of the two LC cells. Initially, the LC cell was in a transparent state. When the applied voltage was increased, the haze value increased by electro-hydrodynamic instability. The mixture-B LC cell shows a non-uniform opaque state. As shown in the photographs of the fabricated cells, the degraded region is brighter than the normal region in the mixture-B LC cell. We measured the haze value in each region of the mixture- B LC cell. The measurement points are marked as dotted circles in the photographs of the LC cells in the opaque state. Fig. 3(a) shows the measured haze value of the mixture-A LC cell. When an electric field is applied for 10 min, the threshold voltage increased from 20 V to 25 V. The haze value was 88%, with a small deviation to the applied voltage time. Fig. 3(b) shows the measured haze value in the normal region of the mixture-B LC cell. In this region, the threshold voltage and maximum haze value were 5 V and 99% respectively, which did not change with time. Fig. 3(c) shows the measured haze value in the degraded region of the mixture-B LC cell. At t = 10 min, the threshold voltage increased from 5 V to 15 V. The haze value was 98.8% at t = 0 when the applied voltage was 60 V. The haze value was decreased to 90.8% at t = 60 min.

To confirm that the reason for decrease haze value in the mixture-B LC cell, an LC cell was observed using a polarized optical microscope (POM), as shown in Fig. 4. When turbulence in the cell has occurred, POM images show patterns called "dynamic scattering mode (DSM)" [7, 8]. In this state, when turbulence becomes stronger, the haze value has increased. As shown in Fig. 4(a), the mixture-A LC cell shows the uniformity of turbulence. However, the mixture-B LC cell shows the turbulence region is separated in the boundary between the normal region and degraded region, as shown in Fig. 4(b). In the degraded region, turbulence has not occurred when the applied voltage was 15 V.

We assume that the change of the optical characteristics is caused by ion accumulation in the alignment layer. Ionic molecules in the LCs are accumulated in the alignment layer with time. When the accumulated ion molecules in the alignment layer are increased, the number of ionic molecules in the LCs is decreased, which leads to the decrease in the current, reduction in the turbulence, increase in the threshold voltage, and finally the decrease in the haze value.



Degraded region of the mixture-B LC cell

Fig. 3 The measured haze value of (a) the mixture-A LC cell, (b) the mixture-B LC cell in normal region, and (c) the mixture-B LC cell in degraded region as a function of time.



Fig. 4 POM images of (a) the mixture-A LC cell and (b) the mixture-B LC cell in boundary between normal region (left) and degraded region (right).

When ionic molecules in the LCs are accumulated in the alignment layer, the current will decrease by the reduction of ionic molecules in LCs, which leads to an increase in the resistance of the degraded ion-doped LC cell. As shown in Table 1, we measured  $R_{cell}$  and  $C_{cell}$  of the fabricated LC cell as we vary the LC mixture and time. The measurement of  $R_{cell}$  and  $C_{cell}$  were carried out with an applied voltage of 60 V and 60 Hz.  $R_{cell}$  of the mixture-A LC cell shows no clear correlation with time. On the other hand,  $R_{cell}$  of the mixture-B LC cell increased from 2.037  $M\Omega$  to 3.010  $M\Omega$  when we applied an electric field for 60 min.  $C_{cell}$  of both cells shows only a small deviation with time.

# 4 Summary

In summary, we studied the degradation issue in an iondoped LC cell for light shutter applications. As time goes on, an ion-doped LC cell shows a decrease in the haze value and become less uniform as time goes on. To analyze the reason for degradation with time, we measured optical and physical characteristics with different LC mixtures. As time goes on, a degraded LC cell shows a decrease in the haze value and turbulence and an increase in the threshold voltage and resistance. By measuring the change of optical and physical characteristics of a degraded ion-doped LC cell, we estimated that degradation issue in an ion-doped LC cell is mainly caused by ion accumulation in the alignment layer.

Table	1.	The	measured	resistance	(R <sub>cell</sub> )	and			
capacitance (C <sub>cell</sub> ) of the fabricated LC cells.									

		0 min	10 min	20 min	30 min	60 min
Mixt ure A	R <sub>cell</sub> (ΜΩ)	2.569	2.472	2.472	2.569	2.675
	C <sub>cell</sub> (nF)	2.130	2.160	2.161	2.262	2.272
Mixt ure B	R <sub>cell</sub> (MΩ)	2.037	2.112	2.252	2.378	3.010
	C <sub>cell</sub> (nF)	1.413	1.295	1.256	1.536	1.599

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