Driving Voltage in Reverse Mode Cell Using Reactive Mesogen : Effect of UV Absorption of Liquid Crystal

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We have proposed reverse mode liquid crystal (LC) cells by using a polymer stabilized LC technology. A reactive mesogen was dissolved in the LC and was polymerized by UV light from an Hg lamp (313 nm) and a UV-LED (365 nm) light sources. LC materials with and without UV absorption at each wavelength were prepared and electro-optical properties of the reverse mode cell were measured. It was found that the electro-optical property strongly depended on the UV absorption of the LC. Next we mixed LCs with and without UV absorption to adjust the UV intensity profile in the bulk of the LC cell. We successfully reduced the driving voltage by changing the absorption coefficient of LC mixtures.

Keywords: Liquid crystal, Polymer stabilized, Reverse mode, Light scattering, UV absorption, Smart window

1. Introduction

A nematic LC / polymer composite system has been studied as a novel electro-optical material. The most typical composite cell is a polymer dispersed liquid crystal (PDLC) [1-3] which shows a light scattering voltage off-state and a transparent on-state. On the other hand, a reverse mode LC cell has the transparent off-state and the light scattering on-state, which is attracting the attention for a smart windows and automotive applications. A typical reverse mode cell has a high driving voltage, because LCs with negative dielectric constant anisotropy are used [4,5]. The homogeneously aligned reverse mode cell using a photo reactive mesogen (RM) and LCs with positive dielectric constant anisotropy has been proposed by Hikmet [6,7]. We have also investigated reverse mode cells with different LC materials and orientations to reduce the driving voltage [8-12]. Those studies indicated that the polymer morphology control is key technology to reduce the voltage.

In this study, reverse mode LC cells have been prepared using a high pressure Hg lamp (313 nm) and a UV-LED (365 nm) for the polymerization process. An electro-optical property was investigated in the cell by controlling the UV absorption of the LC mixture at both UV wavelength. A relation between the polymer morphology and the driving voltage has been discussed through different UV intensity profiles in the LC cell.

2. Experimental

We used the RM of ARLM-002 (Osaka organic chemical industry) and nematic LCs of E7 (Δn=0.204, Δε=13.3), MLC2053 (Δn=0.235, Δε=34.3) and ZLI4792 (Δn=0.09, Δε=5.3) from Merck. The RM was dissolved in the LC at concentration of 5 wt%. The mixture was homogeneously oriented in the cell. The cell thickness was 10 μm. We prepared UV-LED (λmax=365 nm) and the super high pressure Hg lamp with short-pass filter (SHX350 Asahi spectra, cutoff: 350 nm, λmax=313 nm). The cell was irradiated with UV lights of 2 mW/cm² for 3000 s at room temperature.

An electro-optical property was measured using a polarized semiconductor laser beam (635 nm) and a silicon photodiode. The frequency of
applied voltage was 1 kHz. A collection angle of scattered light was about 2°. The transmittance of 100% was defined as the light intensity detected without the cell.

3. Results and discussion

Figure 1 shows absorption spectra of LCs dissolved in a Hexane solvent and emission spectrum of the UV-LED used in this study. MLC2053 and E7 have the absorption at 313 nm of the Hg lamp and ZLI4792 hardly absorbs the UV light. Figure 2 shows UV transmission spectra of homogeneously aligned LC bulks after polymerization of the RM. The bulk thickness is 10 μm. ZLI4792 is transparent at 313 and 365 nm. The UV light at 313 nm is almost absorbed in cells using E7 and MLC2053. Absorption of the UV light at 365 nm is small in the cell using E7. On the other hand, the transmittance at 365 nm is about 50% in the cell using MLC2053. The influence of the UV intensity profile cannot be ignored for the polymerization process of RM in the LC because the polymer morphology is strongly affected by the

Table 1. Absorption coefficient of LCs.

<table>
<thead>
<tr>
<th></th>
<th>313 nm α//</th>
<th>313 nm α⊥</th>
<th>365 nm α//</th>
<th>365 nm α⊥</th>
</tr>
</thead>
<tbody>
<tr>
<td>E7</td>
<td>60×10³</td>
<td>12×10³</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>MLC2053</td>
<td>440×10³</td>
<td>90×10³</td>
<td>1.1×10³</td>
<td>420</td>
</tr>
<tr>
<td>ZLI4792</td>
<td>80</td>
<td>16</td>
<td>40</td>
<td>8</td>
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![Fig. 1. Normalized absorption spectra of LCs and emission spectra of the UV-LED and the Hg lamp.](image1)

![Fig. 2. UV transmission spectra of reverse mode cell.](image2)

![Fig. 3. Intensity profile of unpolarized UV light at 313 and 365 nm in LC cells.](image3)

Polarized UV absorption spectroscopies of LCs and those optical densities have been reported by S.-T. Wu [13]. Referring their data and our measured data shown in Fig. 1 and Fig. 2, we roughly estimated UV absorption coefficient of LCs at 313 nm and 365 nm, as shown in Table 1. Next we calculated unpolarized UV intensity profiles at 313 and 365 nm in the bulk of the cell as an average of ordinary and extraordinary UV light, as shown in Fig. 3. The UV light intensity at 313 nm rapidly decreases and becomes to zero at about 1 and 5 μm respectively in the depth of the LC cell using MLC2053 and E7. The UV light intensity at 365 nm gradually decreases to 56% at the exit side of the cell using MLC2053.

Figure 4 shows electro-optical properties of LC cells. The reverse mode property can be obtained in all cells. Almost the same curve was obtained in cells using ZLI-4792 which were irradiated with UV lights of the Hg lamp and the UV-LED, as shown in Fig. 4(a). It indicates that almost the same polymer morphologies are formed in both cells because ZLI4792 has no UV absorption at 313 nm and 365 nm. On the other hand in cells using E7 and MLC2053, the transmission curve in the cell irradiated with the Hg lamp is very different from that irradiated with the UV-LED, as
shown in Figs. 4(b) and 4(c). The driving voltage is very low and, however, the light scattering is very weak in the cell using E7 and the Hg lamp. The polymerization reaction mainly occurs near the UV irradiation side of the substrate because of the short penetration depth of the UV light. Therefore, the polymer concentration becomes low at the exit side of the UV light. Such a poor polymer layer causes the low driving voltage and the weak light scattering [14].

The light scattering does not occur by increasing the applied voltage in the cell using MLC2053 and the Hg lamp, as shown in Fig. 4(c). The UV light dose not pass through the LC bulk because of the strong UV absorption of the LC. Therefore, almost the RM dissolved in the LC is polymerized only near the incident side of the substrate and the light scattering does not occur in the bulk of the cell. The UV light of 365 nm is absorbed in the MLC2053 to a certain degree and, however, reaches to the exit side of the substrate. Therefore, polymerization occurs in the whole cell layer and the strong light scattering occurs. The driving voltage is the lowest in cells prepared in this study because Δε of MLC2053 is the highest in three LCs.

Next, we mix LCs with different UV absorption coefficient to change the UV intensity profile and improve the reverse mode property. Figure 5(a) shows the electro-optical property in the cell by using the LC mixture of E7 of 75 wt% and ZLI-4792 of 25%. We have reported that the driving voltage in the cell using E7 and ZLI-4792 mixture was lower than that using only E7 or ZLI-4792 [15]. In this case, the UV-LED was used to polymerize the RM. We found that the polymer morphology changed from “smooth network” type

![Fig. 4. Electro-optical properties in reverse mode cells.](image)

![Fig. 5. Electro-optical properties in reverse mode cells using LC mixtures.](image)
to “rice grain like” type, which caused the low driving voltage. In this study, moreover, the driving voltage can be reduced and the strong light scattering was obtained in the on-state by using the Hg lamp.

Figure 5(b) also shows that the driving voltage in the cell using the LC mixture of MLC2053 of 50 wt% and ZLI-4792 of 50% is successfully reduced by changing the UV light source from the UV-LED to the Hg lamp.

Figure 6 shows a schematic model of the polymer structure with large and small LC domains. It is well known that the weak UV intensity makes large LC domains in the PDLC system [16-20]. When the UV intensity decreases with passing through the LC bulk, the LC domain size becomes larger. Therefore, we simply suggest the polymer layer structure, that is, a polymer rich layer with small LC domains and a poor polymer layer with large LC domains. Large and small LC domains result in a high and low voltage to reorient LC molecules, respectively. When the applied voltage is up to the threshold voltage in the large domain and LCs in the small domain do not reorient yet, as shown in Fig. 6(b), the refractive index mismatching occurs between large and small LC domains. Therefore, the light is scattered between domains with different sizes. This light scattering mechanism causes the low driving voltage, comparing to the index mismatching between the polymer matrix and LC domains. If whole LC domains in the cell are large by using weak UV light intensity, the driving voltage is naturally low and however the light scattering becomes weak. The appropriate UV intensity profile makes the polymer morphology with different LC domain size, which can manage both the low driving voltage and the strong light scattering as shown in Figs. 5(a) and (b).

4. Conclusion
Absorption spectra of LCs were investigated and UV intensity profiles at 313 nm and 365 nm were estimated in LC cells. Reverse mode cells were prepared using different UV absorption LCs and the relationship between UV wavelength and electro-optical property of the cell was investigated. The driving voltage was successfully reduced by using suitable UV intensity profile which forms non-uniform polymer network with different size of LC domains in the cell.

References

Fig. 6. Model of polymer structure with large and small LC domains.