

Polymer-Dispersed Liquid Crystal Displays with Low Driving Voltage

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ABSTRACT

A nematic LC and thermal-curable mixtures were cured by thermal polymerization. We investigated their effects on the electro-optical performance and the morphology. The thermally induced polymer dispersed-liquid crystal displays showed strong scattering behavior despite low cell gap and low driving voltage ($< 20V$).

1 INTRODUCTION

Polymer-dispersed liquid crystal displays (PDLCDs) consisted of nanometer-sized, birefringent nematic liquid crystal (NLC) droplets dispersed in a transparent polymer network have many potential opportunities from smart window to information display. Such inhomogeneous polymer-NLC hybrid composite devices for optical device applications scatter incident light because of varying refractive index, which can be fabricated very easily, typically by a wet coating and curing method. [1-11] These PDLCDs have distinct advantages and disadvantages compared to normal LCDs, because LC molecules dispersed in a cured polymer matrix.

Most PDLC devices are opaque in the absence of an electric field, and have a disadvantages of high driving voltage and slow response times due to adjacent polymer network.

Recently, research and development of these PDLCDs have been carried out in the fields of (1) reverse-PDLCDs for transportation (automobile, train, airplane, yacht, and military vehicle) and building exterior, (2) color PDLCDs for advertisement and interior, and (3) PDLCDs having low driving voltage for applications in limited power sources.

At previous studies [12-14], we demonstrated the thermal-induced and photo-induced PDLC devices having a specific color, fast driving switching times ($< 85ms$) and a low driving voltage ($< 50V@60Hz$), which were devised by means of doping color dyes into curable polymer precursors. We next developed new decap and lamination methods to stack the fabricated PDLCD with an OLED to achieve a reflective/emissive display.

Figure 1 shows the driving images of the color PDLCDs and the reverse PDLCD without vertical alignment layers developed by ETRI.



(a) Color PDLCDs



(b) Reverse PDLCDs

Fig. 1 PDLC devices developed by ETRI

In this study, we have developed the PDLC devices that use thermal curing reaction above the phase transition temperature of the NLC. The obtained PDLC devices showed a high haze value despite the low cell gap ($2.5\mu m$) at power-off state, and showed fast response times and low driving voltage.

2 EXPERIMENTAL

2.1 PDLC devices Fabrication

The nematic LC BHR32100-100 ($T_{NI}=98^{\circ}C$) was supplied from Beijing Bayi Spacer LCD Technology Co., Ltd. Dielectric anisotropy($\Delta\epsilon$) of BHR32100-100 is

+30.17, and parallel and perpendicular indices are 37.15 and 6.98, respectively. Flow viscosity at 20 °C is 64 v[mm²/s]. Refractive anisotropy (Δn) is 0.235, and extraordinary and ordinary indices are 1.752 and 1.517, respectively.

Two di-acrylate monomers were used as the curable polymer precursor, and 0.5~2 wt% of AIBN was used as the thermal initiator. The dispersion ratio of the BHR32100-100 and the polymer precursor was fixed at 5:5.

The test devices for evaluating the performance of the PDLC displays were fabricated by dispersing 2.5 μ m glass beads onto a glass substrate (size, 30X30mm²) with ITO electrode (sheet resistance, 10ohm/sq), and then assembled using a thermosetting sealant. The thermal curable mixtures are injected into the sandwiched empty devices by mean of capillary action method at 40 °C.

After the injection, the polymer-NLC reactants were heated at 90~110°C (above phase transition temperature of BHR32100-100) for 2 minutes to perform the curing reaction, and then slowly cooled to room temperature to obtain stabilized NLC distribution.

The morphology of BHR32100-100 analyzed using SEM showed a dependence on the polymerization rate, the composition ratio between the reactants, and the concentration of AIBN.

The fabrication steps of the PDLC device can be summarized as shown Fig. 2.

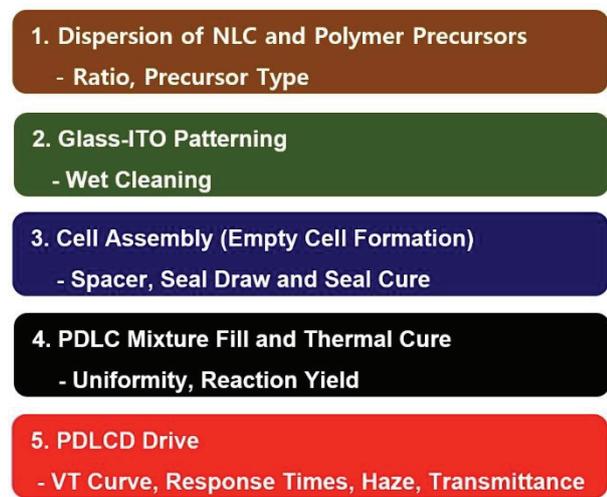


Fig. 2 Fabrication steps for the PDLC device used in the study

2.2 Characterization

After the thermal reaction was completed, the obtained PDLC layer was separated from the glass substrate. BHR32100-100 was dissolved in n-hexane for 48 hours at 25°C, dried, and analyzed by SEM.

The electro-optical characteristics of the devices were

measured using Otsuka LCD-5200 instrument system (using the standard illuminant D65). The LCD-5200 system consists of a white light source, 25cm below the stage where the PDLC device is placed, and a photo detector is positioned 25cm above the stage. (figure 3) [11-14]

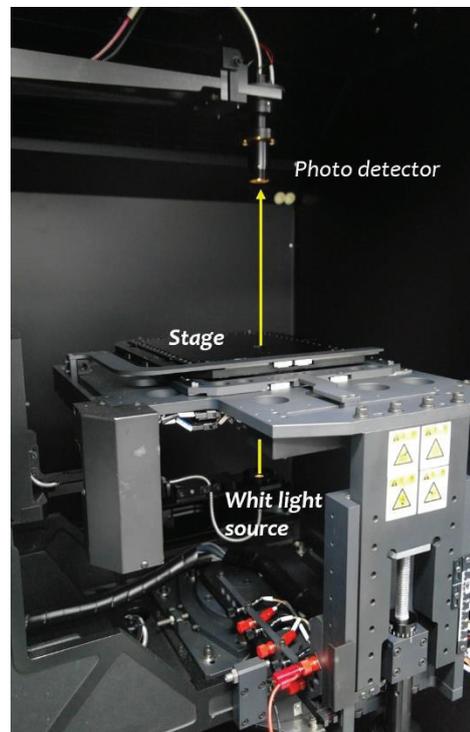


Fig. 3 Measurement stage and optical system of LCD-5200 instrument

We defined 100% transmittance as the transmittance of the incident light through air and evaluated the changes of transmittance through the PDLC device by the applied electric field.

As shown in Fig. 3, the incident light passes through the PDLC device vertically from the bottom to the top, the transmitted light amount of the incident light shows the typical characteristics of normal-PDLC device, which gradually increases as the electric field increases. The applied voltage - transmittance (VT) curve, contrast ratio, rising time (T_r) and falling time (T_f) were measured. [11-14] Halogen lamp was used as the incident light source and the change of transmittance at 550nm was measured.

3. RESULTS AND DISCUSSION

We evaluated the electro-optical behavior of the PDLC devices according to the curing temperature (reaction time, 2 minutes). As shown in Fig. 4, as the curing temperature increases, the threshold voltage moves to the high voltage direction, and the turn-off

transmittance decreases, and the CR (contrast ratio) increases. CR values were approximately 3, 14, and 34 at 90, 100, and 110°C, respectively.

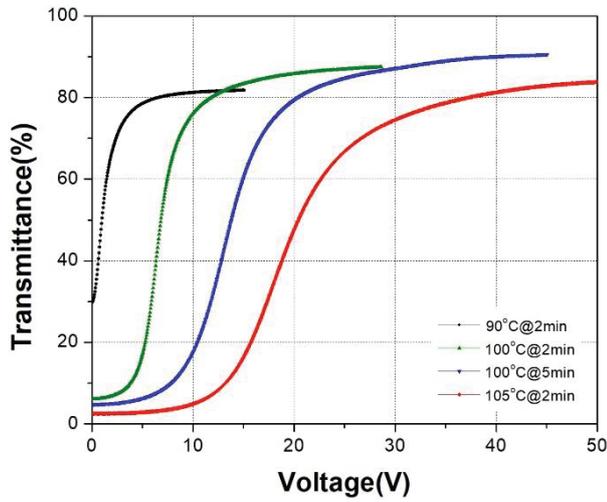


Fig. 4 The electro-optical characteristics of the PDLC device according to curing temperature

The SEM images (Fig. 5) of these PDLC devices showed that the polymer cured at 90°C had a network structure connected like a spider's web and showed various shapes by location. In contrast, the polymer network cured at 110°C showed a denser network structure.

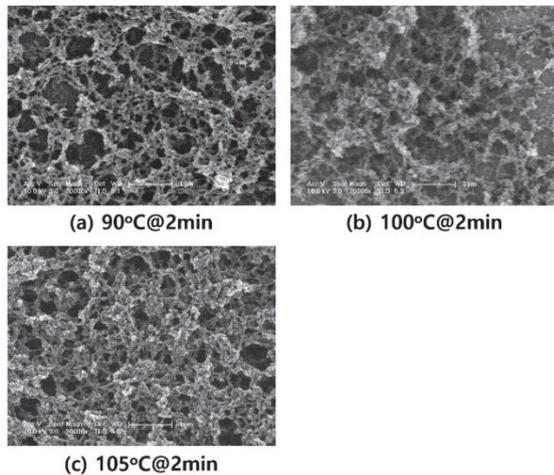


Fig. 5 SEM microscopy of the PDLC devices according to curing temperature

This difference in SEM images seems to be due to the miscibility between BHR32100-100 and the polymer, the phase transition temperature (TNI, 98°C) of BHR32100-100, and the higher temperature reaction appears to result in smaller NLC space.

However, despite these differences in the polymer

network structure, the response times of Tr and Tf were similar to those of 38~45ms.

Next, curing conditions (temperature and time) are fixed at 100°C for 2 minutes, and the PDLC devices are manufactured while changing the concentration of the initiator from 0.5% to 2%, and then the characteristics of these devices are evaluated.

As shown in Fig. 6, as the concentration of initiator is increased, the Vth moved to the high voltage direction, but showed a low driving voltage (<20V).

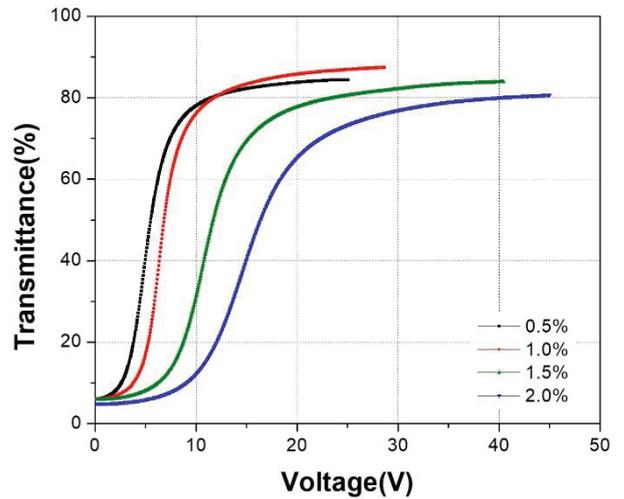


Fig. 6 The electro-optical characteristics of the PDLC devices according to the initiator content

The response times shows that the Tr and Tf are gradually slowed down as the concentration of the initiator increases. This result seems to be due to the difference in the reactivity of the polymer rather than the shape difference of the NLC particles. Figure 7 shows the response times results for different the initiator concentration.

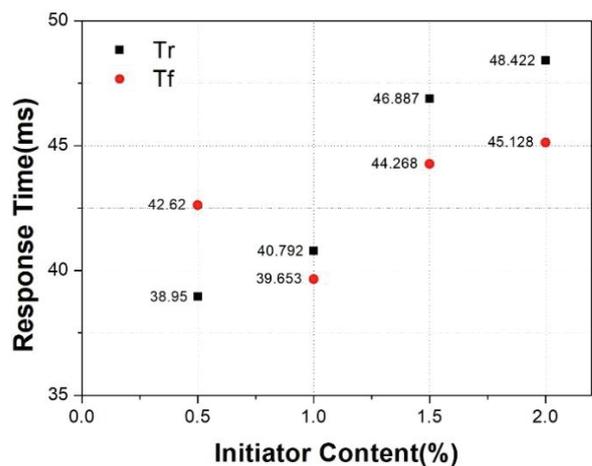


Fig. 7 The electro-optical response of the PDLC devices according to the initiator content

4. CONCLUSIONS

Although the V_{th} of the PDLC device is dependent on NLC properties, polymerization rate, curing conditions, and polymer resistance, it is most affected by cell gap. Therefore, the PDLC device was prepared using the thermal reaction method to obtain good electro-optical properties even at low cell gap (2.5 μ m).

Thermal reaction can proceed above the phase transition temperature of the NLC, and the efficiency of the thermal-initiator is higher than the photo-initiator have the advantages that the unreacted or low molecular reactant did not remain in the NLC to minimize the effects on the NLC relatively.

Thermally induced PDLCDs showed high haze (> 80%), low drive voltage (< 20V) and fast response times (38~45ms) despite low cell gap (2.5 μ m). The electro-optical characteristics of the devices showed dependence on the concentration of AIBN, the type and the mixing ratio of the polymer precursor, the curing temperature, and the NLC properties. These devices are expected to be used in large area billboards and displays, automotive and aircraft windows due to their price advantages.

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