Electro-optical Properties and Stabilities of Polymer Network Liquid Crystal Films with Polymer Wall Structure

Se-Yong Eom[1], Da-Som Yoon[2], Tae-Hoon Kwon[1] and Soon-Bum Kwon[1,2]

[1]Dept. of Electronic Display Engineering, Hoseo University, Asan, Chungnam 31499, Korea
[2]NDIS Corporation, Asan, Chungnam 31499, Korea
Keywords: PNLC, Plastic Substrate, Mechanical Stability, Smart Window, Light Shutter

ABSTRACT
In order to secure the mechanical stability of polymer network liquid crystal films based on plastic substrate, polymer wall structures were introduced into LC layers. Excellent electro-optical properties, mechanical and thermal stabilities were achieved by optimizing the material and process parameters of them. The details of the study are presented.

1 INTRODUCTION
Unlike typical polymer dispersed liquid crystals, polymer network liquid crystals (PNLC) have highly demanded normally transparent characteristics, transparent in off-state and opaque in on-state, so they have been expected to be widely used for transmittance variable devices such as smart windows and light shutters [1].

Recently, the needs for PNLC films based on plastic substrates have been increasing. To meet the needs, technologies for securing the mechanical stability of PNLC films, which is inherent challenge, must be applied.

As a way to secure the mechanical stability of PNLC films, our group applied the polymer wall technology [1-3]. The previous results were not very satisfactory in terms of electro-optical and mechanical properties. The reason for the insufficient properties was attributed to the fact that the phase separations of liquid crystal and the two types of monomers, which were used for the polymer wall and the polymer network, respectively, interfered with each other and degraded the properties.

We have found two types of monomers and liquid crystals that are efficiently phase separated with complementary interaction with each other. In this paper, we discuss the results of investigating the electro-optical properties and mechanical and thermal stabilities of PNLC films with varying concentration ratio of the materials and UV irradiation conditions, which affect phase separation behavior between liquid crystal and polymers.

2 EXPERIMENT
A polycarbonate substrate, a negative liquid crystal (Δn=0.256, $\Delta\varepsilon$ =-4), an acrylic monomer (M1) for polymer wall formation, a monomer (RM257) for polymer network formation, a vertical alignment layer, a ball spacer (Φ = 5μm) and a UV curing type sealant were used as materials to make PNLC films. The structure of PNLC cell with polymer wall (abbreviated as PWPNLC cell to distinguish it from normal PNLC cell) is shown in Fig. 1.

For the formation of the polymer wall and network in PWPNLC cells, a two-step UV exposure method based on a polymerization-induced phase separation technique was used [2]. A liquid crystal-monomers mixture consisting of the negative LC, M1 and RM257 was coated on a bottom substrate with a printed seal line. A top substrate with adhesive spacers was laminated to the bottom substrate to fill the liquid crystal mixture up in the cell. The cell was irradiated with UV light two times in sequence: the first UV irradiation through a patterned photo-mask to form the polymer wall, and the second full irradiation to form the polymer network. High-pressure mercury lamp with a peak wavelength of 365nm was used for the phase separation processes. Two types of photo-masks with stripe pattern (pitch=200μm, line width=10μm) and hexagonal pattern (pitch=274μm, line width=7μm) were used.

Voltage-transmittance curves of the PWPNLC cells were measured with a luminance colorimeter consisting of BM-7 and EOMS-250 programs. Mechanical stability testing of PWPNLC cells was performed by placing a vial and pendulums of various weights on the cells and then observing if an unrecoverable change in liquid crystal orientation occurred. To evaluate the high temperature stability of PWPNLC cells, we compared the electro-optical properties of them before and after applying a thermal shock the cells at 110℃ and 130℃ for 1 hour.

3 RESULTS
According to our previous experimental results, the proper concentration of monomer M1 and UV irradiation conditions to stably form the polymer walls in the vertically aligned liquid crystal cells were 15 to 20% and 5 to 15 minutes of irradiation time in the intensity range of 5 to 15mW/m^2, respectively. In addition, the concentration of RM257 and UV irradiation conditions for obtaining excellent electro-optical properties of PNLC cells were 8 to 16% and 1 minute irradiation time in the intensity range of 5 to 10mW/m^2. In order to find conditions that provide the excellent electro-optical properties and mechanical stability of the PWPNLC cells, the parameter dependence of the properties was investigated in the above-mentioned variation ranges. An experiment example of the parameter dependent

electro-optical properties of PWPNLC cells is shown in Fig. 2. In this case, the UV irradiation intensity and time were 6mW/m^2 and 5 minutes for the primary irradiation through the photo-mask and 6mW/m^2 and 1 minute for the secondary irradiation. It can be seen that the PWPNLC cell with RM concentration of 14% has the best electro-optical property (T_{off}=82.8%, T_{on}=10.2%) with little difference from that of the optimized PNLC cell (T_{off}=86.2%, T_{on}=11.3%). It should be noted that the electro-optical properties of PWPNLC cells were almost the same regardless of whether the polymer wall shape was stripe or hexagonal.

Fig. 3 shows the microphotographs of an optimized PWPNLC cells with stripe and hexagonal patterned polymer walls. This result shows that the polymer walls were formed well in PWPNLC cells with two shaped polymer walls.

Fig. 4 shows the mechanical stability test method and the test results for an optimized PWPNLC cell. It can be seen that the PNLC cell was damaged at a weight of 500 g, while the PWPNLC cell was not affected even at a weight of 1 kg. This result indicates that the optimized PWPNLC has sufficient mechanical stability.

Fig. 5 shows the electro-optical properties of a PWPNLC cell before and after thermal shock at 110℃ and 130℃ for 1 hour. This result shows that after the PWPNLC was thermally shocked, the driving voltage was slightly lowered but there was little change in transmittance in the on- and off-states. Besides, it can be seen that the thermally stabilized effect might exist because the difference of the voltage-transmittance characteristics of the PWPNLC cell after thermal shocks at 110℃ and 130℃ was very small. Fig. 6 shows microphotographs of PWPNLC cells with stripe and hexagonal patterned polymer walls after thermal shock at 130℃ for 1 hour. It can be seen that the polymer walls were not damaged after the thermal shock. Fig. 5 and 6 imply that the optimized PWPNLC cell has thermal stability up to 130℃.

4 CONCLUSIONS

Using two types of monomers (M1 and RM257) that complement a negative liquid crystal, we developed polymer network liquid crystal film with excellent electro-optical property (T_{off}=82.8%, T_{on}=10.2%), good mechanical and thermal stabilities. Optimal material concentration ratio and UV irradiation conditions to provide the best performance were found as follows: material concentration ratio of LC, M1 and RM257 was 81:5:14, two step UV irradiation intensities and times are 6mW/m^2 and 5 minutes for the first polymer wall formation and 6mW/m^2 and 1 minute for the second polymer network formation.

ACKNOWLEDGEMENT

Following are results of a study on the "Leaders in INdustry-university Cooperation +" Project, supported by the Ministry of Education and National Research Foundation of Korea

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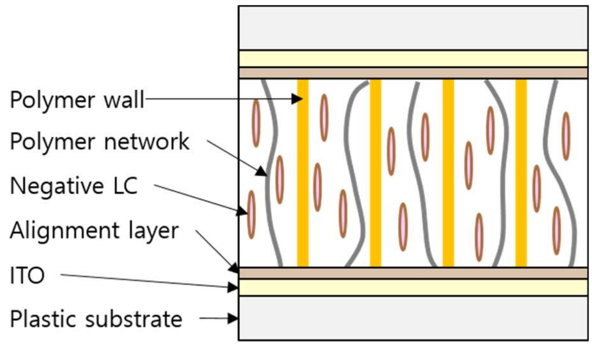


Fig. 1 Cross-sectional structure diagram of PWPNLC cells

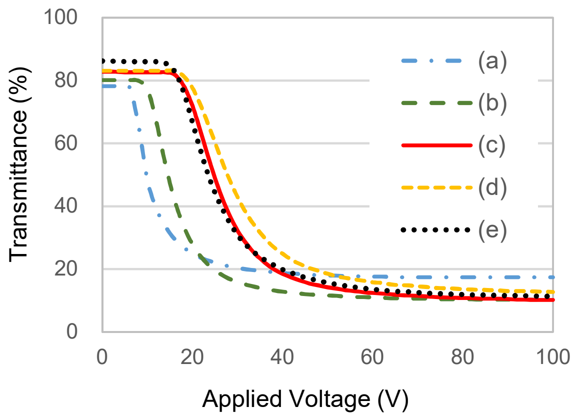


Fig. 2 Electro-optical properties of PWPNLC cells with different concentration ratios of LC, M1 and RM257: (a) 85:5:10, (b) 83:5:12, (c) 81:5:14, (d) 79:5:16, and (e) an optimized PNLC cell

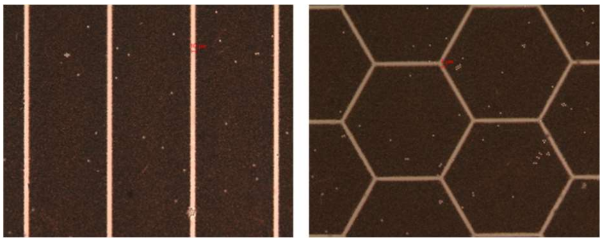


Fig. 3 Microphotographs of PWPNLC cells with stripe (a) and hexagonal (b) patterned polymer walls (200x magnification)

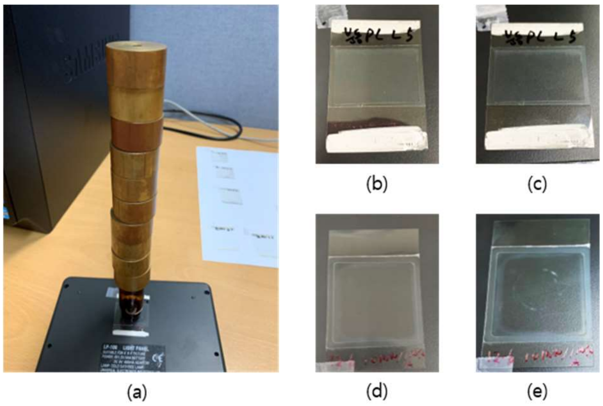


Fig. 4 Photos of a mechanical stability test method (a) and PWPNLC cells with no pendulum (b) and pendulums of 1kg (c), and PNLC with no pendulum (d) and pendulums of 500g (e)

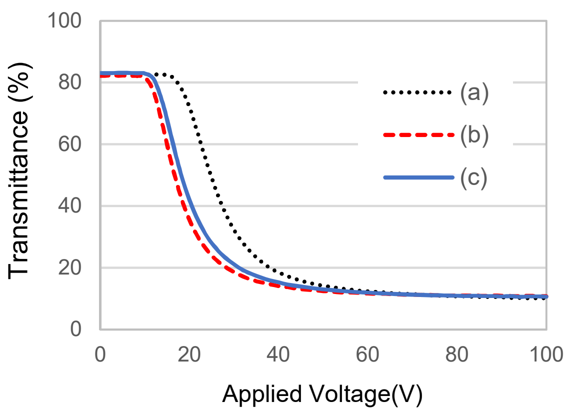
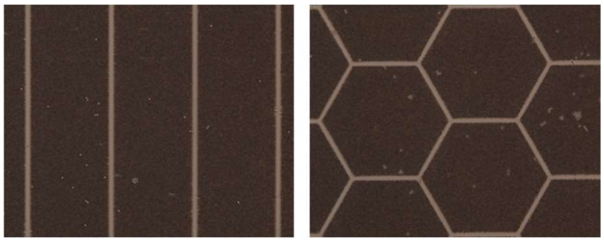


Fig. 5 Electro-optical properties of a PWPNLC cell before (a) and after 1 hour's thermal shock at 110°C (b) and 130°C (c)



(a) (b)

Fig. 6 Microphotographs of PWPNLC cells with stripe (a) and hexagonal (b) patterned polymer walls after 1 hour's thermal shock at 130°C (200x magnification)

(a) (b)

Fig. 7 Photos of a PWPNLC sample with active area size of 158mmx90mm in off-state (a) and on-state (b)