

Fast Response and Scattering Free Optically Isotropic Liquid Crystal Device for Flexible Display Applications

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Abstract

We demonstrated a novel optically isotropic liquid crystal (OILC) mixture with acrylate type of functional group monomers. By controlling the ratio of LC to monomer and UV intensity, an excellent transparent OILC composite is obtained and the in-plane field driven device exhibits a higher transmittance by 49% and a faster response time by 40% than those of OILC with thiol-ene based monomers. This high level black state and its flexibility can be applicable to flexible TFT-LCDs.

Author Keywords

Optically Isotropic Liquid Crystal; Monomer; High Transmittance; Flexible LCD.

1. Introduction

The optically isotropic liquid crystal (OILC) mixture is newly emerging in liquid crystal displays (LCDs) because the composite with birefringent LC is transparent in the visible light and LC droplets are imbedded in the polymer composite or encapsulated as a capsule. Then the composite under crossed polarizers exhibits a clear dark state and its birefringence is induced by the in-plane field, giving rise to a bright state. In addition, the LCD with adoption of this composite could show wide-viewing-angle, fast response time even without using any surface treatment for LC alignment. Further if the device can show a fast response time less than 1 ms, it can be applicable to full color field sequential displays and also flexible LCDs because there is no fixed predetermined macroscopic LC orientation and fluid LC is kept in nano-sized droplet in a surrounding medium [1]. In the OILC composite, two different mediums LC droplets and polymer matrix exist and the Rayleigh cross-section scattering is given by [2].

$$\sigma_{\text{avg}} \propto k^4 D^6$$

Where k is $2\pi n_p/\lambda$, and D is a droplet size of LC in OILC. Therefore, in order to obtain the free scattering instead of blue wavelength scattering, the droplet size is smaller than visible light wavelength. However, if the D is too small, the field-induced LC reorientation requires high electric energy such that an operating voltage will be very high so that an optimization of the D with acceptable scattering level is very important if the device can be driven with conventional driver IC.

The electro-optical properties are highly dependent on the network morphology that can be controlled by optimizing the LC to monomer ratio and controlling the polymerization kinetics associated with UV exposure intensity.[3] although its detail network formation mechanism and corresponding electro-optical properties were still unclear and not studied in detail [4].

In this report, we attempt to develop the OILC film based on a polymerization induced phase separation method [5,6] while controlling UV intensity for curable reactive monomer and the ratio of monomer to LC. In this study, we have tested two different monomers NOA65 and PN393 which comprises a thiol-ene and acrylate functional groups, respectively. Electro-optics of the OILC composites with two different monomers were compared. The OILC film with PN393 exhibits much transparency which gives rise to an excellent dark state and good transmittance in on state.

2. Experiment

The prepared OILC composites consist of the commercially available high dielectric constant nematic LC mixture, MLC2053 ($\Delta\epsilon = 46.2$, $n_e = 1.7472$, $n_o = 1.5122$, $\Delta n = 0.235$ at 589.3 nm, 20 °C, from Merck Advanced Technology in Korea) and an UV curable monomers. We used two types of polymers: one is a Norland Optical Adhesive 65 (NOA65, $n_p = 1.524$, thiol-ene based Optical adhesive) and the other is monomeric mixture PN393 ($n_p = 1.473$, from Merck Advanced Technology in Korea). The NOA65 is a thiol-ene based optical adhesive while PN393 is an acrylate based reactive monomers mixture. The PN393 is comprised of a different acrylates such as EHA (Acrylic acid 2-ethylhexyl ester), TMPTA (Trimethylolpropane triacrylate), Darocur4265 (Diphenyl(2, 4, 6-trimethylbenzoyl) phosphine oxide and 2-Hydroxy-2-methylpropiophenone), Ebercyl11810. The long alkyl chain in PN393 believed to provide more flexibility to the structure. The Polarized Optical Microscope (POM), Nikon ECLIPSE E600 (Nikon, Japan) equipped with Nikon DXM 1200 digital camera, was used to characterize the morphology of the phase separation under crossed polarizers. The electro-optical properties were measured as a function of the voltage by using a lab made set-up under crossed polarizers. The external field applied to the sample by using a function generator (Tektronix DPO 2024B) and transmitted light was detected by photo detector and oscilloscope (Agilent 33521A). The polymer network morphology was characterized by the Scanning Electron Microscope (SEM).

We optimized UV irradiation dynamics by controlling the monomer concentration to irradiation intensity and time duration as well. All kinds of the mixtures that have different UV intensities were prepared and tested. The representative prepared OILC mixtures are follows;

S-1: MLC2053 (40 wt.%) + NOA65 (60 wt.%) and curing with 150 mW/cm² for 5 sec

S-2: MLC2053 (50 wt.%) + PN393 (50 wt.%) and curing intensity 60 mW/cm² for 12 sec

S-3: MLC2053 (50 wt.%) + PN393 (50 wt.%) and curing intensity 70 mW/cm^2 for 10 sec

S-4: MLC2053 (50 wt.%) + PN393 (50 wt.%) and curing intensity 80 mW/cm^2 for 10 sec

A small amount of the photo-initiator, Irgacure651 (2,2-Dimethoxy-1,2-diphenylethan-1-one), was added to the S-1, while pre-dissolved Darocur4265 is the photo-initiators for S-2, S-3, and S-4. The obtained homogeneous mixture was injected into the IPS cell by capillary action. The IPS cell has comb like interdigitated ITO patterned electrodes on the bottom substrate with its electrode width and the distance between them are both $4 \mu\text{m}$ while no electrodes on the top substrate. The cell gap was fixed to $10 \mu\text{m}$. The cells were exposed as mentioned above.

3. Results

We have prepared several samples using both LC and PN393 with different UV intensity such as 60 mW/cm^2 , 70 mW/cm^2 , 80 mW/cm^2 and their dark state have observed as can be seen in polarizing optical microscopic images. The POM images were taken under crossed polarizers while keeping the backlight intensity unchanged for all samples, as shown in Figure 1. The measured intensity of black state or the relative light leakage was 18, 6.5, 5.8, and 5.6 for (a), (b), (c), and (d), respectively, indicating that the obtained black textures of the OILC films with PN393 is relatively scattering free.

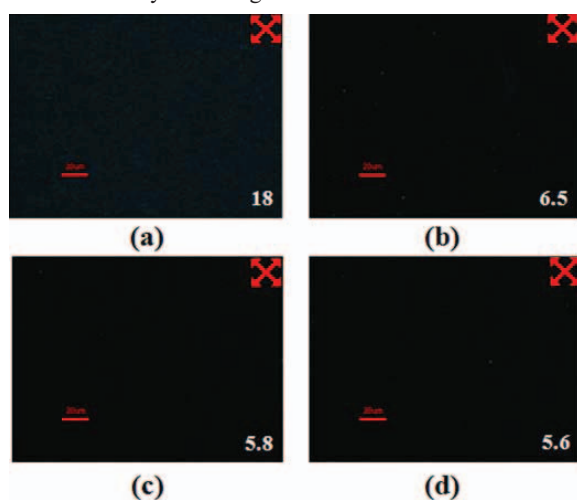


Figure 1. POM images obtained with OILC film under crossed polarizers in which all images were taken at $V=0\text{V}$: (a) S-1, (b) S-2, (c) S-3, and (d) S-4

The Figure 2 shows macroscopic scattering images of cells, and as expected, the S-1 sample shows severe scattering while OILC cell with PN393 has little scattering and the S-4 shows the least scattering which can be observed even by a naked eye. The results also imply that the D of S-4 might be the smallest among all samples.

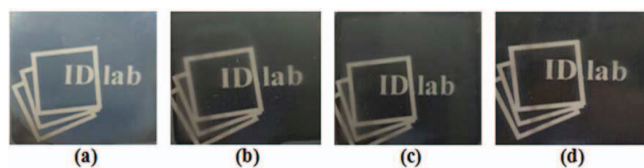


Figure 2. Macro images of all sample which indicate a level of scattering, all images were taken at $V=0\text{V}$: (a) S-1, (b) S-2, (c) S-3, and (d) S-4

A He-Ne laser light, 633nm , was probed and the transmitted light intensity was measured under the crossed polarizers at room temperature, as illustrated in Figure 3. The sample was driven with square wave field. The V_{th} and V_{op} are defined as the 10% and 90% transmittance change from a dark state, respectively. The measured V_{op} are 36V, 37.5V, 28.9V, and 29.3V for the S-1, S-2, S-3, and S-4, respectively. The corresponding transmittances are 12.3%, 18.3%, 13.6%, and 8.4% for S-1, S-2, S-3, and S-4. The field induced birefringence (Kerr constant) was saturated at high field. The response time was measured as a response to the applied square wave field, as shown in Figure 4. Here, the rise and decay times corresponds to 80% transmittance change from 10% (90%) to 90% (10%). The rise times for (a), (b), (c), and (d) were measured $600 \mu\text{s}$, $476 \mu\text{s}$, $384 \mu\text{s}$, and $395 \mu\text{s}$ and decay times for the same were 4.4ms, 2.65 ms, 1.7 ms, and 1.9ms, respectively. The decay response time is proportional to D^2 , such that the data imply that the droplet size of the S-3 and S-4 may be smaller than those of S-2 samples.

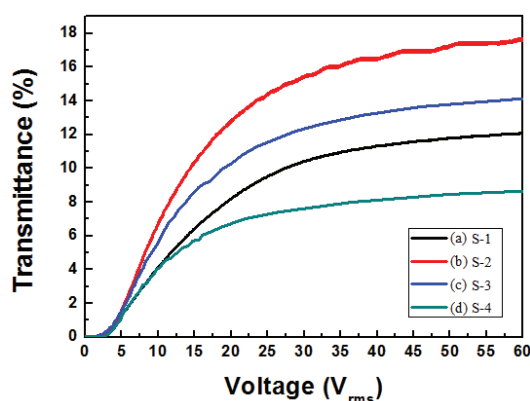


Figure 3. The measured Voltage-Transmittance curve.

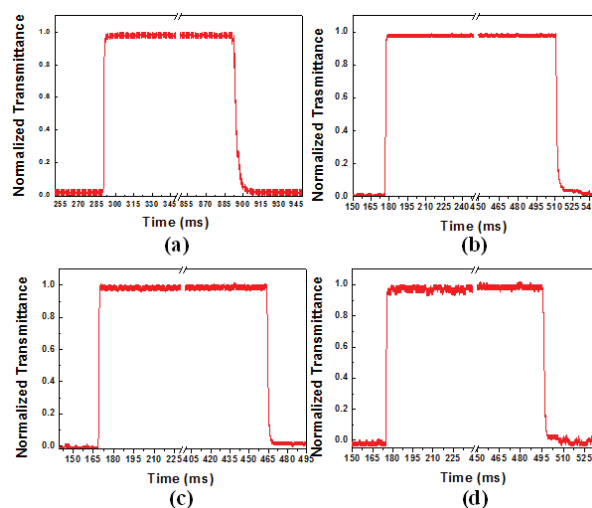


Figure 4. The measured response of the applied square wave filed for (a) S-1, (b) S-2, (c) S-3, and (d) S-4.

The formed polymer network morphology was studied by using the SEM, as indicated in Figure 5. We extracted the LC by keeping the LC cell in the hexane, and separated the two substrates with a sharp edge object. Because of the structural frame which is caused by solvent problem, the measured inner droplet sizes were 219nm, 243nm, 223 nm, and 207nm in average for the S-1, S-2, S-3, and S-4, respectively but further

measurement of polymer network in each case is under progress. The uniformly shaped and highly interconnected holes separated by the very thin polymer layer was obtained in acrylate based monomer network, while very small and isolated droplet obtained in thiol-ene based polymer network and even in the S-4. From Figure 3, we can expect that if the region of polymer matrix surrounding LC droplets is much richer than LC region, then the transmittance is quite low; however, if the embedded LC is surrounded by relatively thin polymer network imitating that the LC rich is larger than the polymer region, the birefringence is induced more at the same voltage and it increases more as the applied voltage increases.

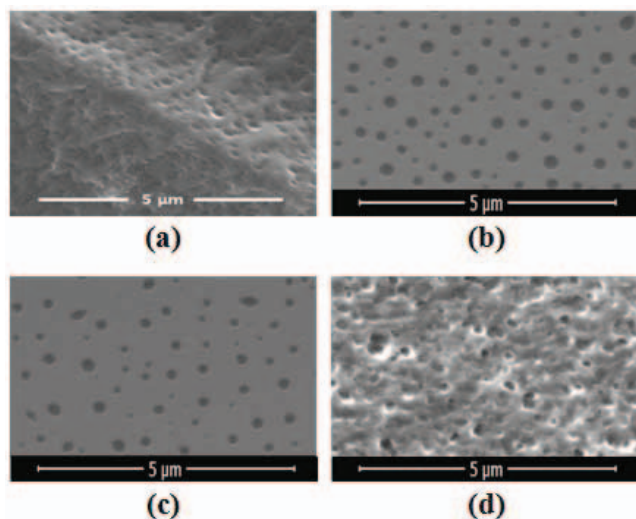


Figure 5. SEM images of the polymer network morphology of the sample (a) S-1, (b) S-2, (c) S-3, and (d) S-4. The images were taken normal to the substrate, no tilt was made. The LC holes have nano-size because cells show a least scattering, which confirms that the D is smaller than an incident visible wavelength.

4. Conclusions

We proposed a scattering free and fast response OILC cell compared with thiol group and acrylate functional group monomers. The proposed device is obtained high transmittance by 49% and fast response time by 40% than thiol-ene based previous work. The electro-optic properties were completely enhanced by optimized UV curing intensity. The proposed device exhibited higher transmittance and faster response time than thiol-ene based previous work.

5. Acknowledgements

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6. References

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