Study of Optimized Condition for Bend State in Polymer Stabilized Pi-cell with Compensation Films

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Abstract

The pi-cell [1] is known as one of the candidates for a fast response time and a good viewing angle characteristics due to a self-compensated configuration and can be a replaceable mode instead of the current TN mode and the IPS mode for moving picture in future. This paper shows the optimized condition to maintain bend state instead of splay state, which is mortal demerit for good optical properties in a pi-cell, by using the polymer stabilized method [2]. The good electro-optical characteristics are also obtained by optimizing the various factors, which are monomer concentration in a LC, UV intensity, curing time, curing voltage, and curing temperature, and by using retardation film. We use a scanning electron microscope to study the structures of the polymer stabilized polymer network in a pi-cell as a key to figure out why bend state is occurred.

1. Introduction

The optically compensated bend mode has been introduced to try to improve the narrow viewing angle and response time. The pi-cell mode of LCD used nematic liquid crystal has the most possibility for a video application because of fast switching [3] and a wide viewing angle. Nevertheless, the problem of pi-cells is the instability of the desired bend director configuration at lower driving field. More stable splay configuration appears first and a long warm-up period is needed to transform the pi-cell from the splay to the bend state. The LC molecules in bend configuration is required a bias voltage. The problem of the instability of the bend configuration can be solved by using negative dielectric anisotropy, high pretilt angles (typically ~85°) [4,5], and polymerization by addition of a small amount of UV curable monomer to the LC material and curing with an applied voltage across the cell [2].

In this paper, polymer network were formed for stabilizing the liquid crystals director in the bend configuration, making it more stable, and preventing to change splay form bend state. We also studied electro-optical characteristics of a polymer stabilized pi-cell related with monomer concentration and UV curing conditions at different wavelengths with A-plates and polymer network morphology which makes liquid crystals stuck in the boundary of the polymer network.

2. Experimental Details

ITO coated glass substrates were treated with polyimide (pretilt angle ~5°, Nissan SE7492) and rubbed to obtain a necessary homogeneous alignment. Cells were fabricated keeping the rubbing directions parallel to each other and the cell thickness was controlled by using glass fibers. We prepared each 1.5wt%, 2wt%, 3wt%, and 5wt% of diacrylate monomer RM-82(from Merck) concentration of liquid crystal ZSM-5247 (Chisso, Tni=87.5℃, Δn=0.149, $\Delta\varepsilon$=12, K33/K11=1.674). To initiate the photo-polymerization process, 1% of BME (bezoin methyl ether, Polysciences Inc.) was added to the LC mixture. To generate a network, samples were irradiated by using a UV light with an applied electric field across the cells. Before UV irradiation, initial warm-up voltage was applied to the pi-cells for about 1 minute to convert the liquid crystal totally in its bend configuration. The curing temperature was controlled by Mettler thermostat.

3. Results and discussions

Figure 1 schematically summarizes the process. Pi-cell liquid crystal director can be aligned in bend configuration at 2 voltages. Photo reactive monomers were dissolved in a LC before polymerization and polymer network was stabilized the LC orientation after polymerization with UV irradiation [6]. We expected that the liquid crystal still formed a bend

configuration after the polymerization without an electric field applied due to the polymer network. Our recent results obtained by scanning electron microscopy experiments showed that this expectation matched. As a curing voltage, we chose the bias voltage of 2V and higher voltage of 4.5V(1kHz, square wave).

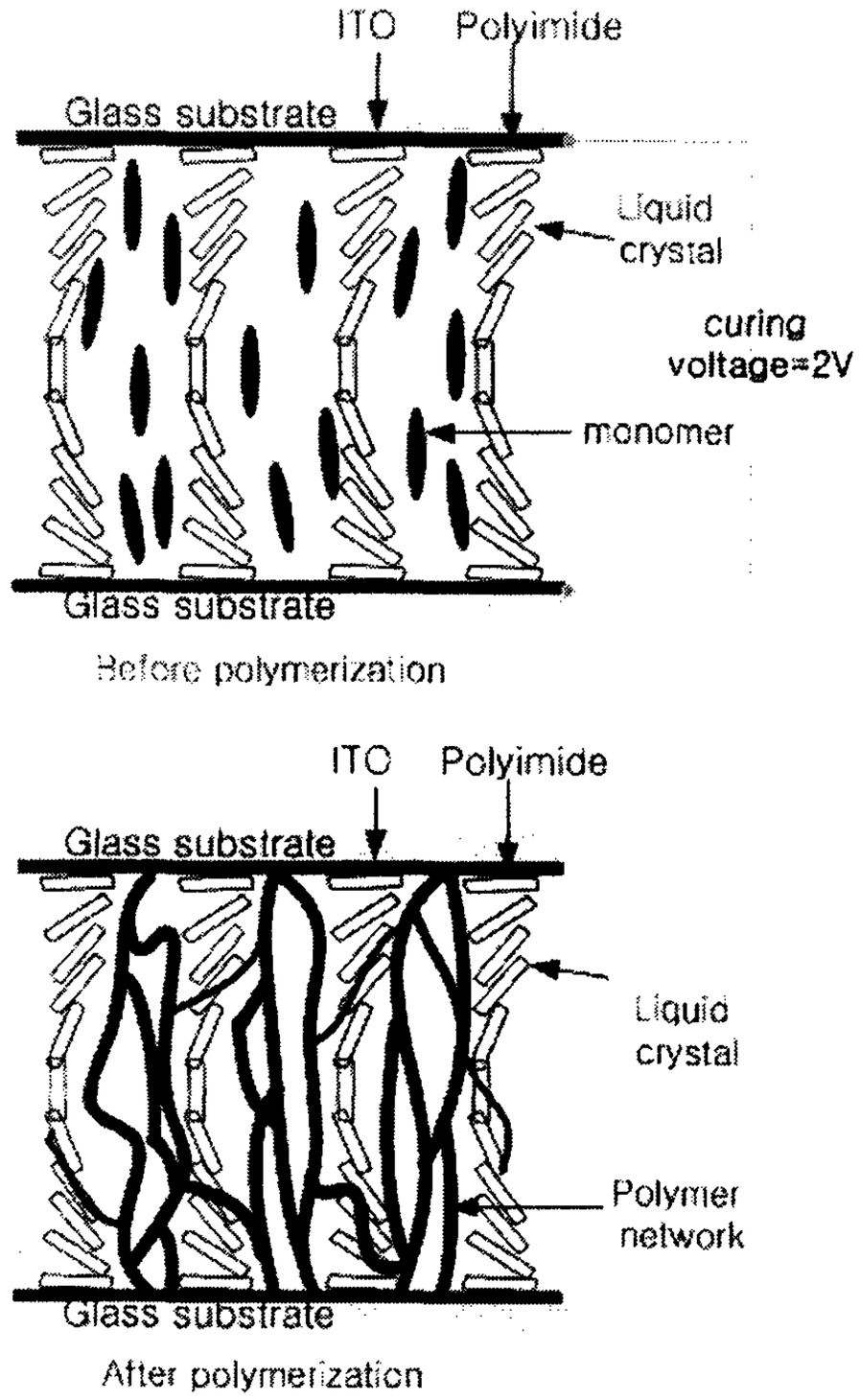


Figure 1. Photo reactive monomers dissolved in a LC before polymerization (top) and a polymer network stabilizing the LC orientation after polymerization with UV irradiation (bottom).

The electro-optics properties of cells were measured with a 633nm He-Ne laser. The pi-cells were positioned between crossed polarizers with the alignment direction at 45° to their polarization axes.

Figure 2 shows experimental results of the voltage-dependent light transmittance of the pi-cell before and after polymerization (UV intensity is 1mW/cm^2, irradiation time is 30 minutes with 2V and the temperature of polymerization is 50℃). As we can see from the figure, the transition states disappear in the polymer stabilized pi-cell.

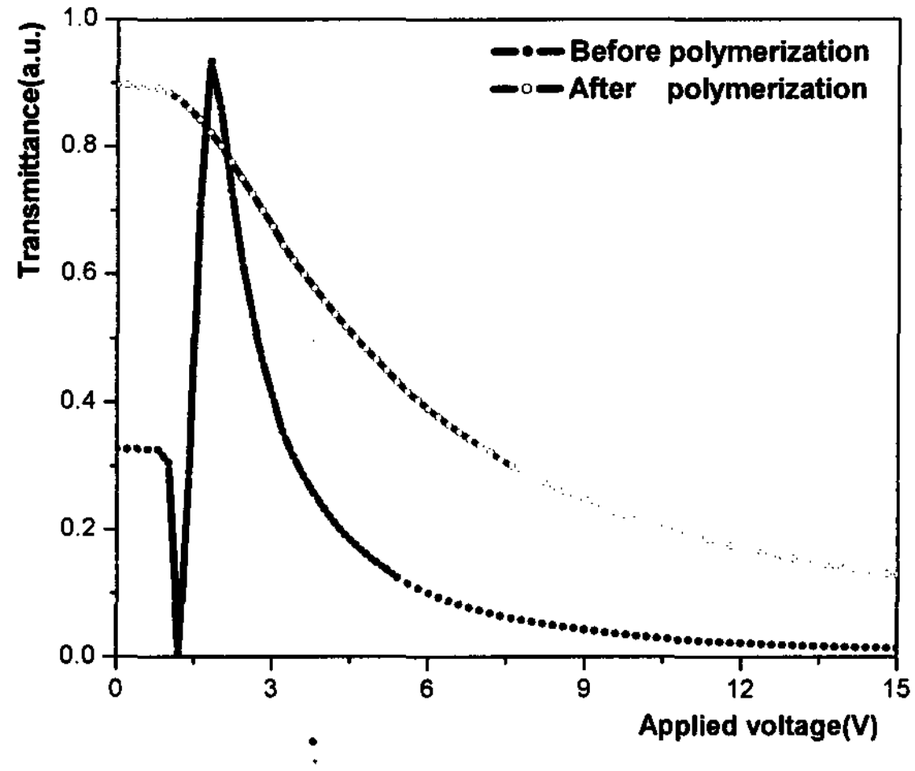


Figure 2. 3wt% - Transmittance vs voltage of a polymer stabilized Pi-cell before and after polymerization. (curing voltage is 2V, curing temperature is 50℃)

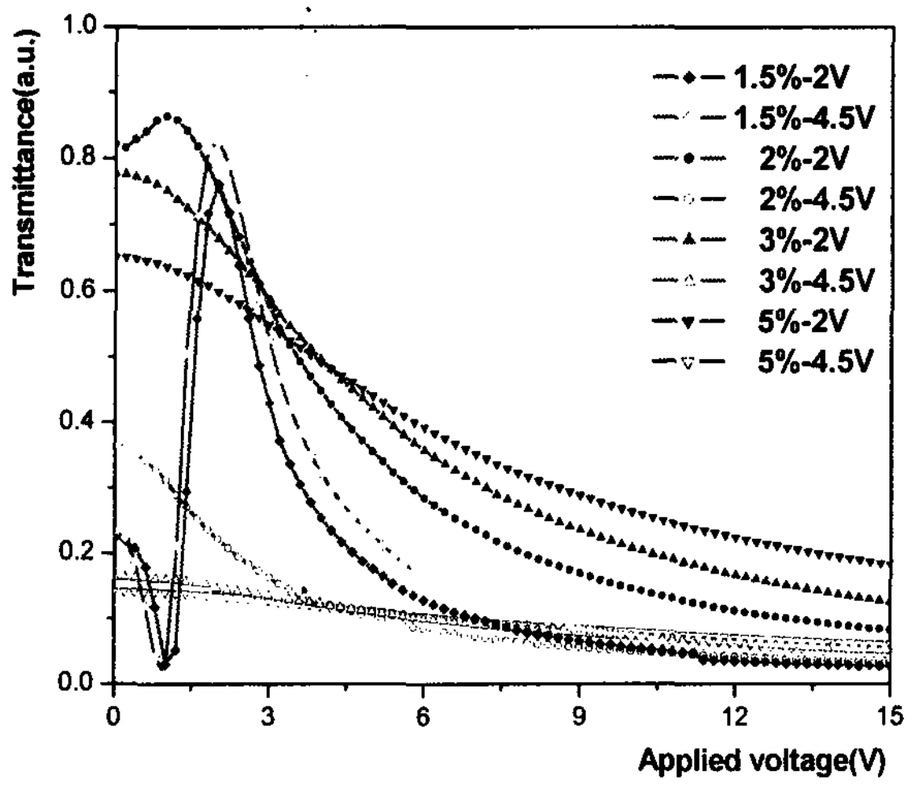


Figure 3. Transmittance vs voltage for pi-cells made using different monomer concentrations and curing voltages. (curing temperature is room temperature)

We have found that the polymer concentration and voltage applied to the cell during the polymerization influence drastically the resulting polymer network structure in the cell. The optimum concentration of the polymer in our case was about 3wt.%. Figure 3 showed that when the polymer concentration is 1.5wt%, we have not observed any indication of

stabilization of the bend state. On the other side, 2wt% is still low monomer amount and the whole cell was not indicated stabilization of the bend state. At higher concentrations, noticeable light scattering occurs when electric field is applied to the cell. Also the LC molecules stabilized in a state more close to a homeotropic state rather than in a bend state at curing voltage of 4.5V at any polymer concentration except of 1.5wt%.

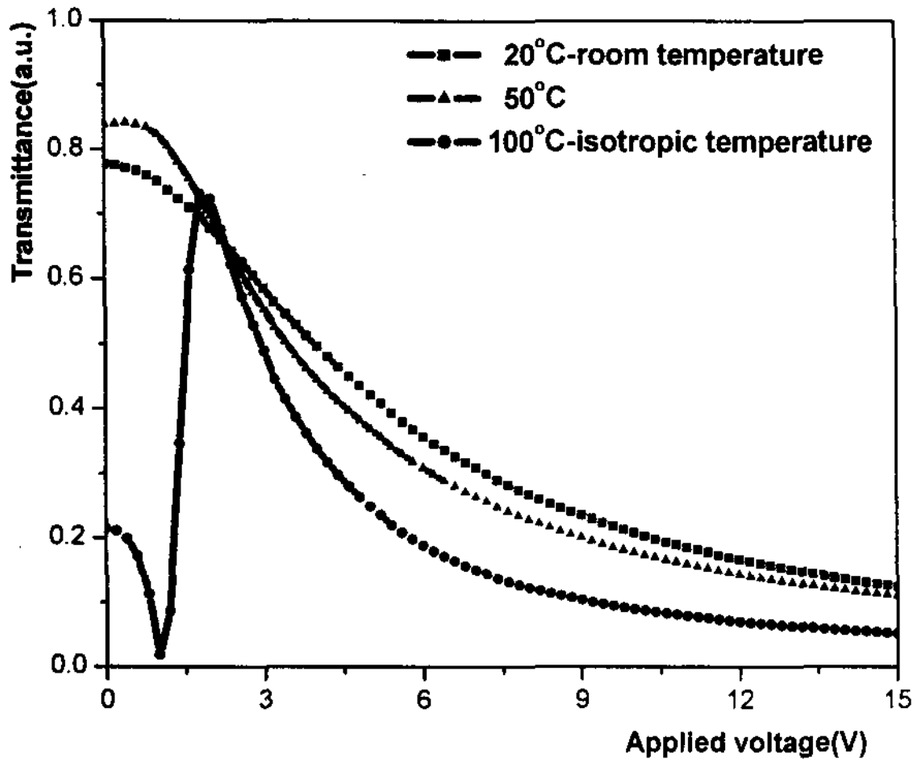


Figure 4. 3wt% Transmittance vs voltage of a different curing temperature. (UV intensity is 1mW/cm^2, curing time is 30minutes)

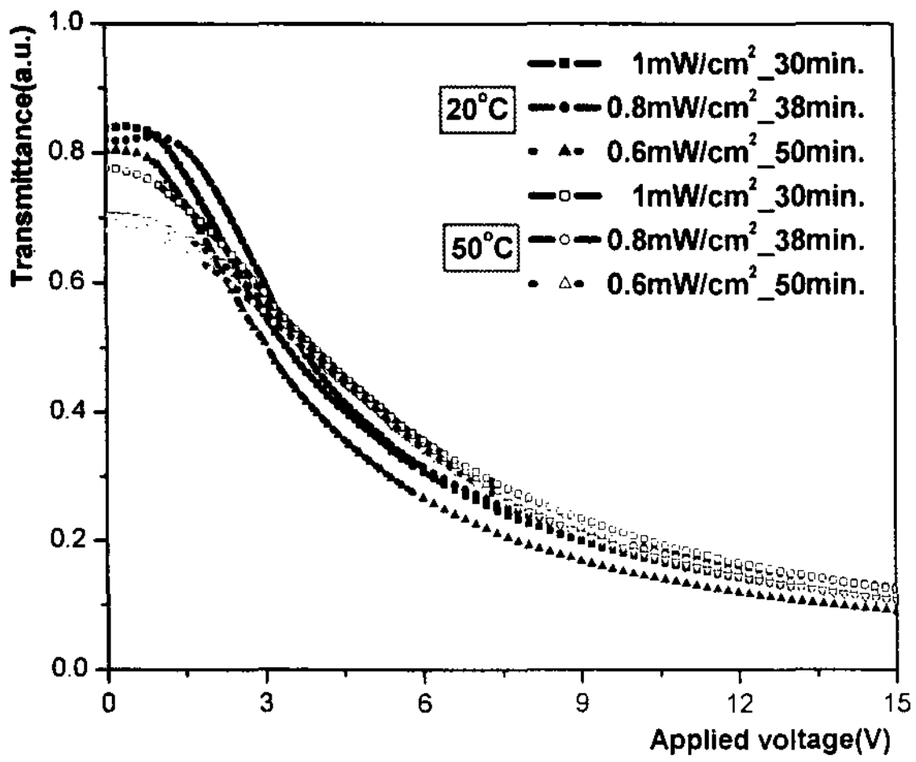


Figure 5. 3wt% Transmittance vs voltage at same UV energy.

At a curing temperature of 50℃ polymer-stabilized pi-cells have a higher contrast ratio, lower driving voltage, and lower V_{90}-V_{10} than the cell polymerized at room temperature. But we could not get polymer-stabilized pi-cell in isotropic phase since the molecules were randomly oriented for UV irradiation (Figure 4). We have found that the best results may be achieved when the intensity of polymerization is about 0.6-1 mW/cm^2 (Figure 5).

Transmittance-voltage curves showed that pi-cells could not get a dark state at a high voltage without a retardation film. This light scattering was due to the presence of the network, keeping LC molecules in the vicinity of the polymer strands in their original orientation, while the bulk material reoriented under field application. Later we could get the dark state at about 5.5 voltage with using a compensation film.

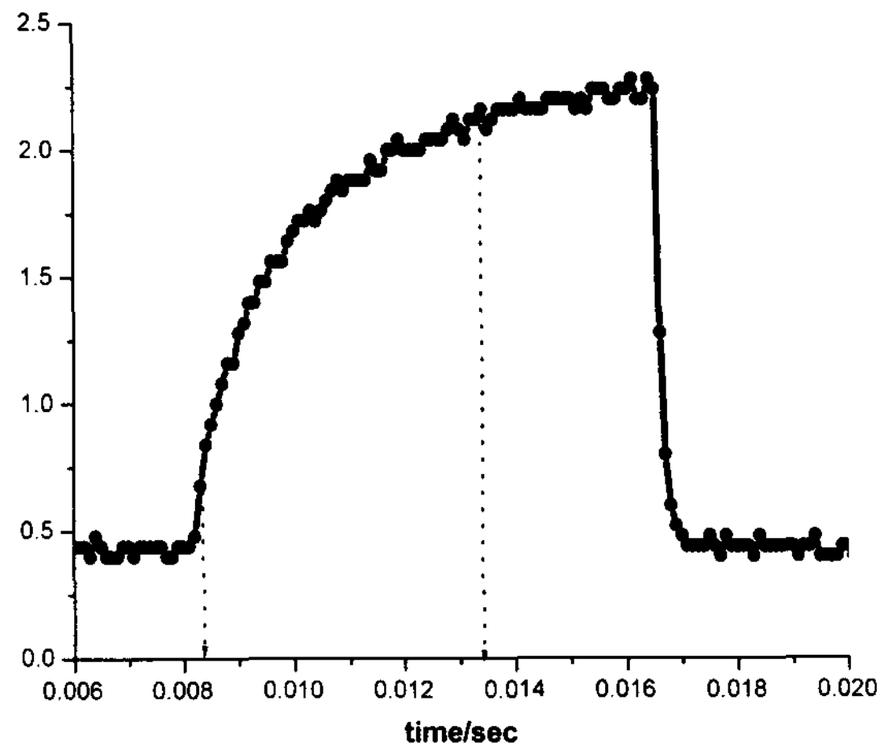


Figure 6. Response time of a polymer stabilized pi-cell.

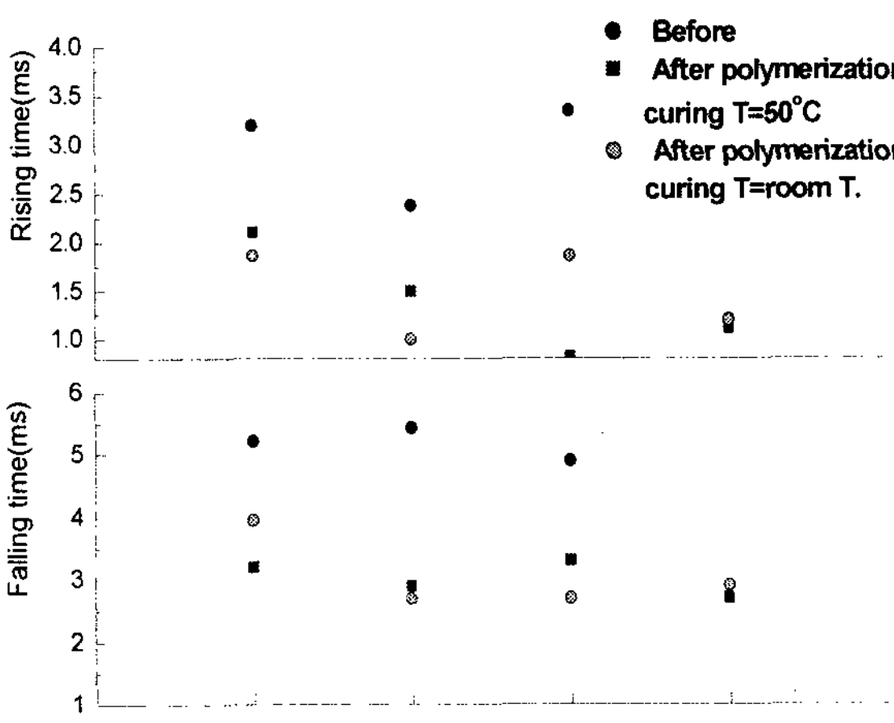
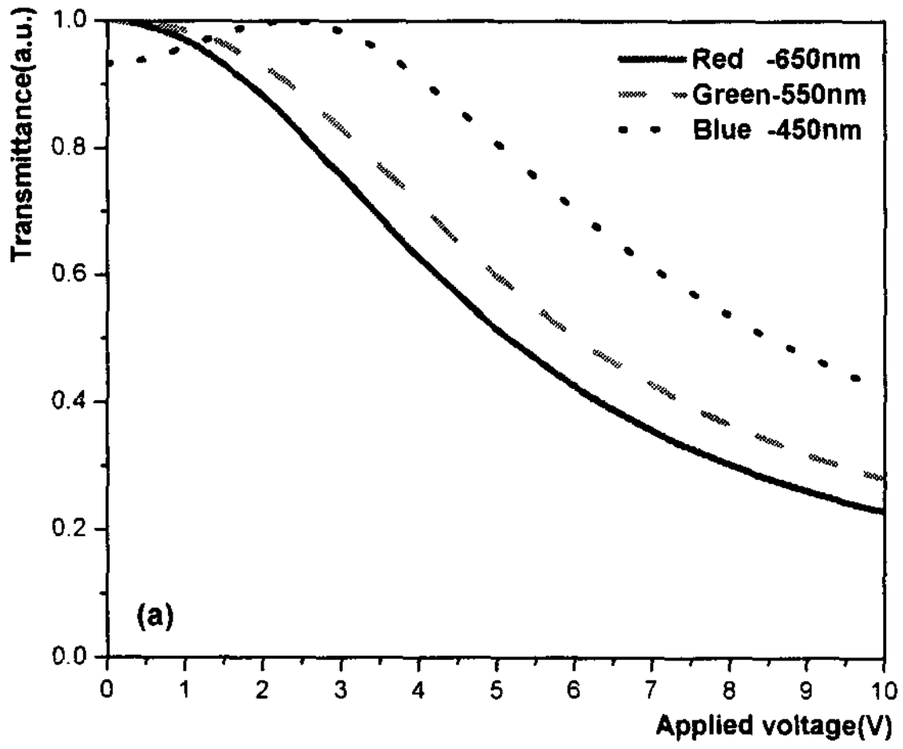
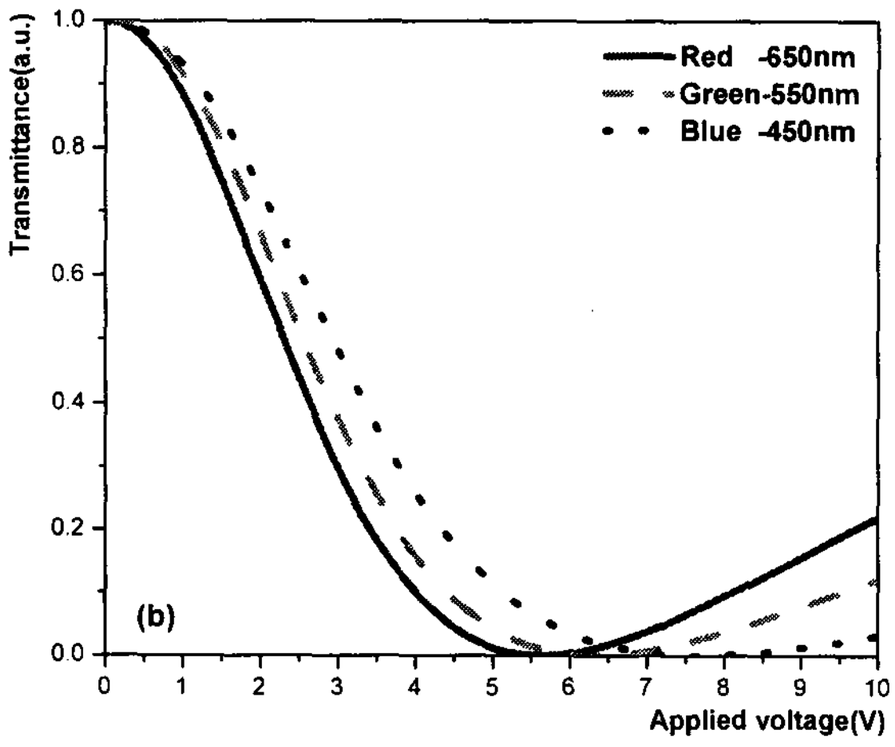


Figure 7. Response time of cells before and after polymerization (3wt% polymer stabilized Pi-cells).





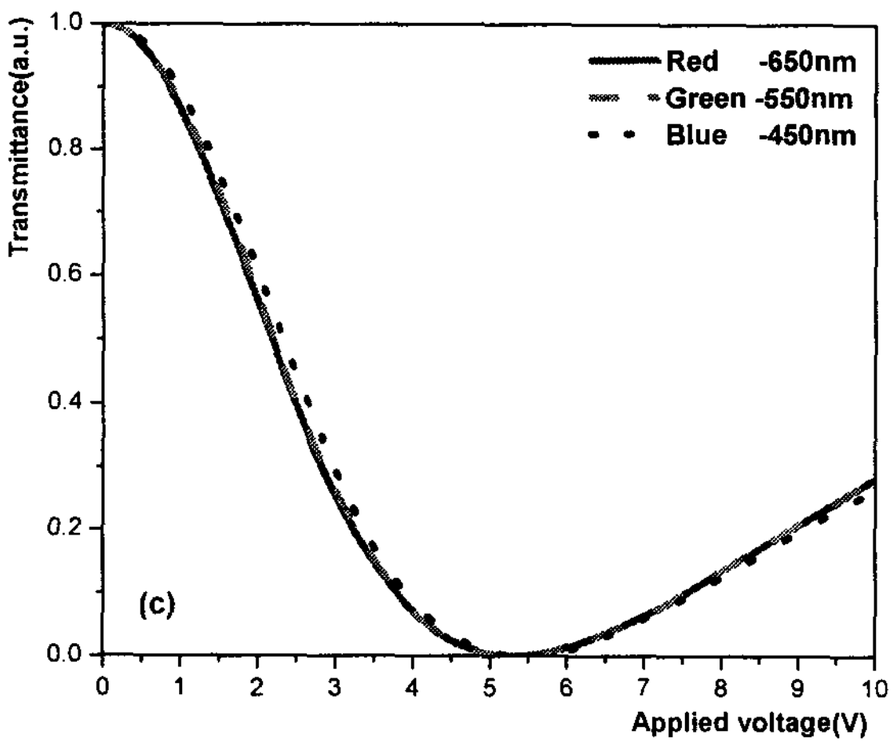


Figure 8. Transmittance-voltage properties of the polymer- stabilized pi-cell for different color. Red=650nm (straight), Green=550nm (dash), Blue=450nm (dot). (a) with no compensation film. (b) with quarter-wave plate (c) with 146nm compensation film.

Secondly, we compared switching times for a cell before and after polymerization. Polymer-stabilized samples showed "On + Off " electro-optic switching times of the order of 5ms, that was a little faster than before polymerization of the samples (Figure 6 and Figure 7).

In order to reduce the dark state voltage, we added a phase compensation film. Retardation value got from

$$I_{//} = kCos^2\left(\frac{\pi\delta(V)}{\lambda}\right)$$

$$I_{\perp} = kSin^2\left(\frac{\pi\delta(V)}{\lambda}\right)$$

where $\delta(V)$ denoted the total retardation of liquid crystal and film, k was a constant, and λ was a wavelength.[7] The values of $\delta(V)$ must be changed at least form $\lambda/2$ to 0 to obtain transmittance from 100 to 0%.

		Contrast	Driving Voltage	Dark voltage
Without	R	2.97 : 1	1.46 V	
	G	2.5 : 1	1.86 V	
	B	1.7 : 1	3.42 V	
Quarter-wave plate	R	97 : 1	0.9 V	5.66 V
	G	109 : 1	1.1 V	6.25 V
	B	118 : 1	1.18 V	7.62 V
146nm	R	19.4 : 1	0.85 V	5.3 V
	G	25.4 : 1	0.85 V	5.3 V
	B	44.2 : 1	0.96 V	5.45 V

Table 1 Comparison of contrast, driving voltage and dark voltage without compensation film and A-plate films.

Generally, at high voltage it was impossible to get dark state because of polymer. Retardation films compensate residued retardation of the liquid crystal layer in the black state. It was expected the improvement of contrast ratio after optimization and application of compensation film. From Fig. 8(a), without a compensation film, the transmittance oscillated as the voltage was increased. No common

dark state for the RGB wavelengths was obtained. Dark state showed at 5.66V, 6.25V, and 7.62V each red, green and blue wavelength by using a quarter-wave plate, Fig. 8(b). Figure 8(c) showed that the R, G, B-light intensities of the polymer-stabilized pi-cell were adjusted to similar value about 5.4V by using 146nm retardation film. Table 1 were given contrast ratio, driving voltage, and voltage of dark state with and without any compensation film.

Finally, we studied polymer network structure in polymer-stabilized pi-cell. We selected cells of 3wt% and 5wt%, which were irradiated with UV light of intensity 1mW/cm^2 for 30 minutes. The cell was immersed in hexane and CH_2Cl_2 for 4 days.

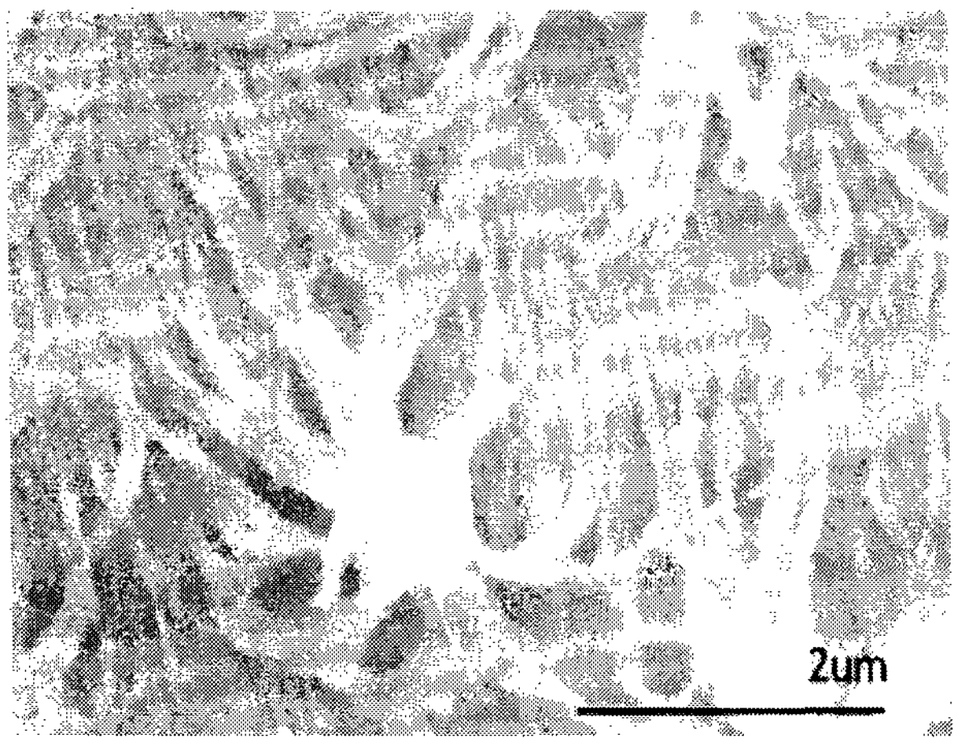


Figure 9. 3wt% - SEM picture of the polymer network formed in the room temperature.

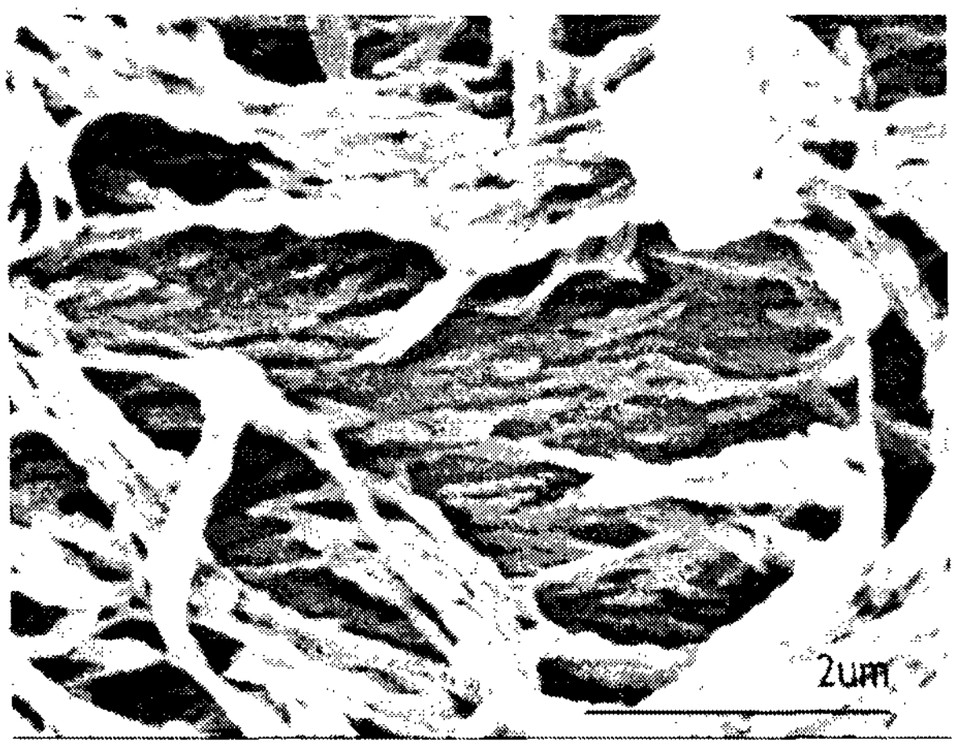


Figure 10. 3wt% - SEM picture of the polymer network formed in the 50℃.

After the liquid crystal was removed, we took the top and bottom glass plates apart. The polymer was sputtered with a thin layer of Au for SEM study. Then the polymer network was studied by scanning electron microscopy, which showed clearly that the polymer networks were oriented along the same direction as the liquid crystal curing the polymerization. As polymer network could be used in turn to align the liquid crystal polymer during polymerization prevented to change to the twist and splay in pi-cell. The aligning effect of the polymer was a bulk effect

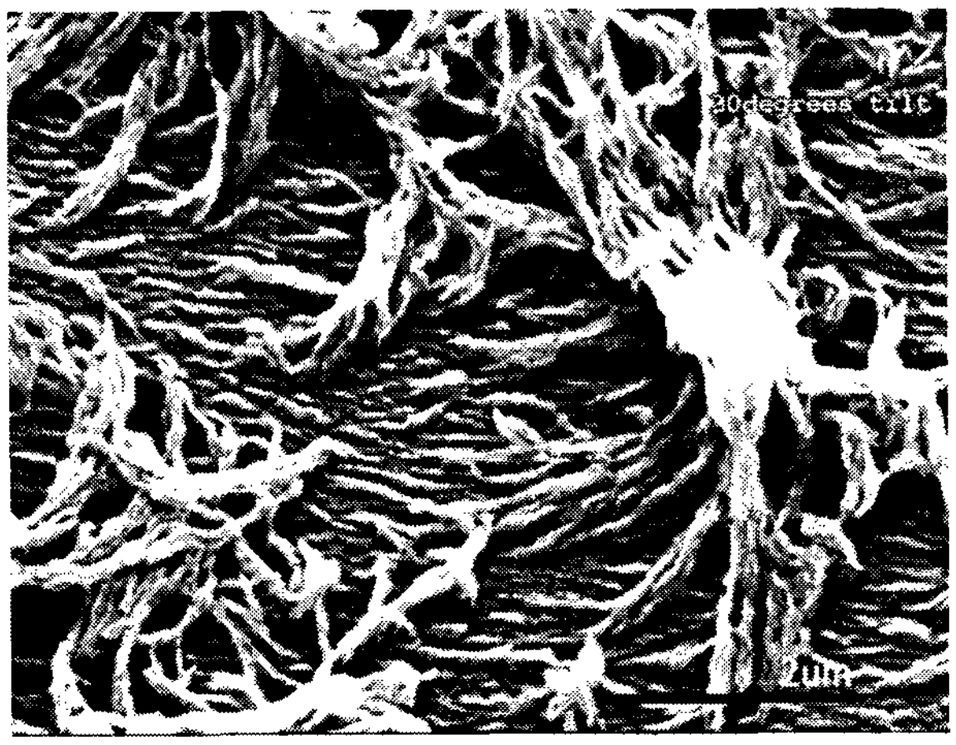


Figure 11. 3wt% - SEM picture of the polymer network formed in the 50℃. The normal of the substrate was tilted a 30°away from the incident beam.

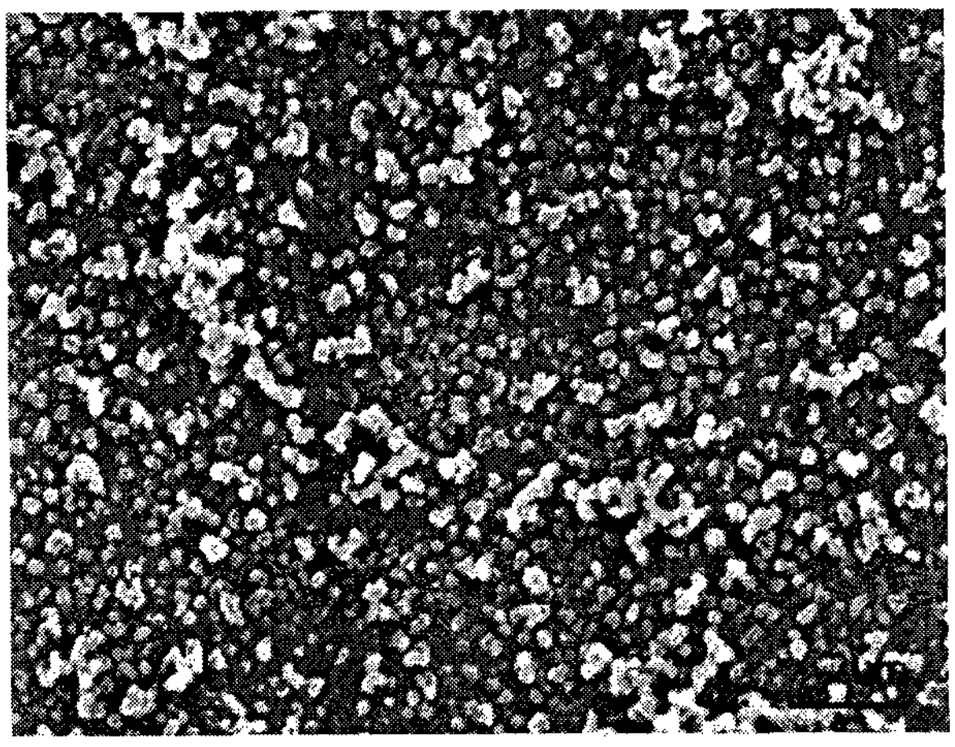


Figure 12. 3wt% - SEM picture of the polymer network formed in the isotropic state.

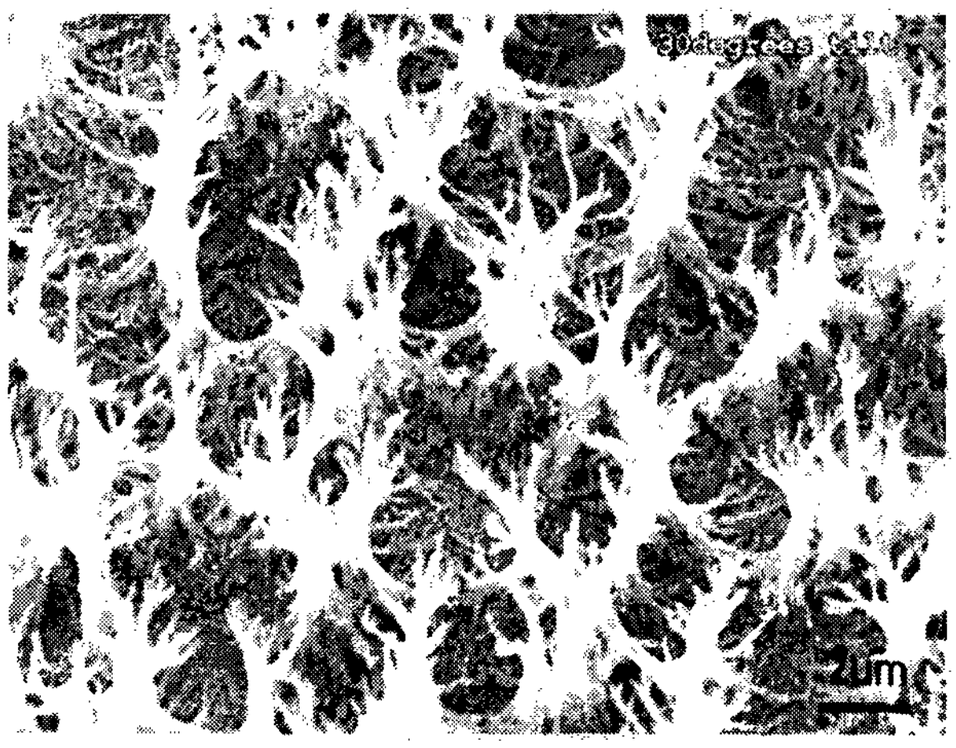


Figure 13. 5wt% - SEM picture of the polymer network formed in the room temperature. The normal of the substrate was tilted a 30° away from the incident beam.

That it could be used to achieve the desired director configuration of liquid crystals [6-8].

As our expectation, we could see bended polymer network that consisted of polymer strands oriented along the direction of the liquid crystal director (Fig. 9, 10, 11, and 13). The monomer was polymerized at 100℃ at which the material was in the isotropic phase, since the molecules were randomly oriented, the polymer network was also randomly an oriented and formed globule as shown in Fig. 12. This result matched transmittance-voltage curve as previously stated.

4. Conclusion

The polymer-stabilized pi-cell did not need to operate between a bias and saturation voltage as in conventional pi-cells. Also this had the advantage of having faster switching times than the conventional pi-cells. Polymer network formed stabilizing the liquid crystals director in the bend configuration making it more stable and prevent to change splay form bend state. This fact was proved by transmittance-voltage measurements. Also the transmittance-voltage curves of the polymer-stabilized pi-cell for red, green, and blue light were rather different to each other, but we could get the dark state at lower voltage by using compensation films. Clearly, that the good matching of monomer and liquid crystal materials will greatly improve the performance of the polymer stabilized pi-cells.

5. References

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