Optical Properties of Nematic Liquid Crystal/ Polyfluorene Gel Devices

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ABSTRACT

The relationship between light transmittance and the induced gel network structure in liquid crystal (LC)/ polyfluorene gel was investigated. LC cells were fabricated at different polyfluorene concentrations and cooling rates; these parameters strongly affect the induced network structure, contrast ratio, and response time.

1 Introduction

The demand for smart windows, which can adjust the intensity of transmitted light in response to an applied voltage, has been increasing for applications in various fields. It is well known that polymer dispersed liquid crystal (PDLC) and polymer network liquid crystal (PNLC) devices exhibit good light switching properties, and they have been developed to a practically applicable level. Their light-switching function is a result of light scattering induced by the refractive index mismatch between the liquid crystal (LC) monomer and the polymer matrix.

A similar light scattering effect can be obtained using LC gel devices [1, 2]. Generally, the threshold voltage of operation in PDLC and PNLC devices tends to be elevated by the formation of a polymer matrix or network. On the other hand, the driving voltage of LC gel devices is occasionally similar to that of pure nematic LC devices, that is, a few volts. Furthermore, the gel structure of the so-called physical gels can be easily destroyed and constructed via a heating and cooling process using appropriate heating and cooling rates. This reform function of the gel structure is attributed to the relatively weak forces of interaction between the polymer molecules, such as π interactions and hydrogen bonding. Hence, physical gels are more advantageous than chemical gels, which are formed by cross-linking via covalent bonding.

Considering the above features, LC gel devices are prospective candidates for smart window applications. In this study, the gel structure of prepared LC/ polyfluorene gel was first observed using polarization and fluorescent microscopes to study the spatial distribution of the polyfluorene network. Next, the transmittance and voltage characteristics were measured to determine the optimum polyfluorene concentration and cooling rate for good light switching properties. Finally, the response times of the fabricated devices were estimated.

2 Experimental Details

The LC cells were constructed by sandwiching an LC gel layer between a pair of indium tin oxide/ glass substrates. We used a polyimide film (SE2170, Nissan Chemical Corp.) as the alignment layer and E7 (LCC) as the nematic LC. The cell gap was controlled using a glass rod spacer (diameter: 10 μm).

The LC gel was prepared as follows: 1) A small amount of polyfluorene powder was mixed in the E7 solvent to obtain polyfluorene concentrations of 1 and 2 wt%. 2) The solution was heated up to 150–160 °C and then stirred (300 rpm) until the polyfluorene powder was completely dissolved. 3) The heated solution was injected into a heated empty cell, and heating was maintained during the injection process. 4) The filled cell was cooled to room temperature at different cooling rates. Gradual cooling (30 °C/h) was achieved by controlling the cooling rate using an electric furnace. For rapid cooling, the filled sample was placed on a laboratory table (natural cooling).

During the experiment of light transmission properties, a He-Ne laser (633 nm) was incident on the LC cell. The polarization direction of the laser coincided with the rubbing direction. The transmitted light was detected using a photodiode (area of 10 mm × 10 mm) placed at a distance of 200 mm from the examined LC cell.

3 Results and Discussion

Figures 1(a) and 1(b) show the polarization micrographs of 1- and 2-wt% cells, respectively, when no voltage was applied. The color originates from the birefringence of the nematic LC in polarized light. Doping with polyfluorene produces a network structure, as observed in the 1-wt% cell (Fig. 1(a)). A relatively dense network is observed in the 2-wt% cell (Fig. 1(b)). The LC orientation in the dense network is not completely random (partially oriented), because the same color, which originates from the birefringence of the LC, is observed in this image.

Fluorescence microscopy was used to determine the spatial distribution of the polyfluorene network. Figures 1(c) and 1(d) show the fluorescence micrographs of the 1- and 2-wt% cells, respectively. The black and blue areas indicate LC and polyfluorene, respectively. A coarse network structure of polyfluorene is formed when the concentration is 1 wt%, as shown in Fig. 1(c). In contrast, an almost uniform blue image is obtained for the 2-wt% cell (Fig. 1(d)). This suggests that the polyfluorene network is very densely tangled, even in the direction vertical to the cell plane.

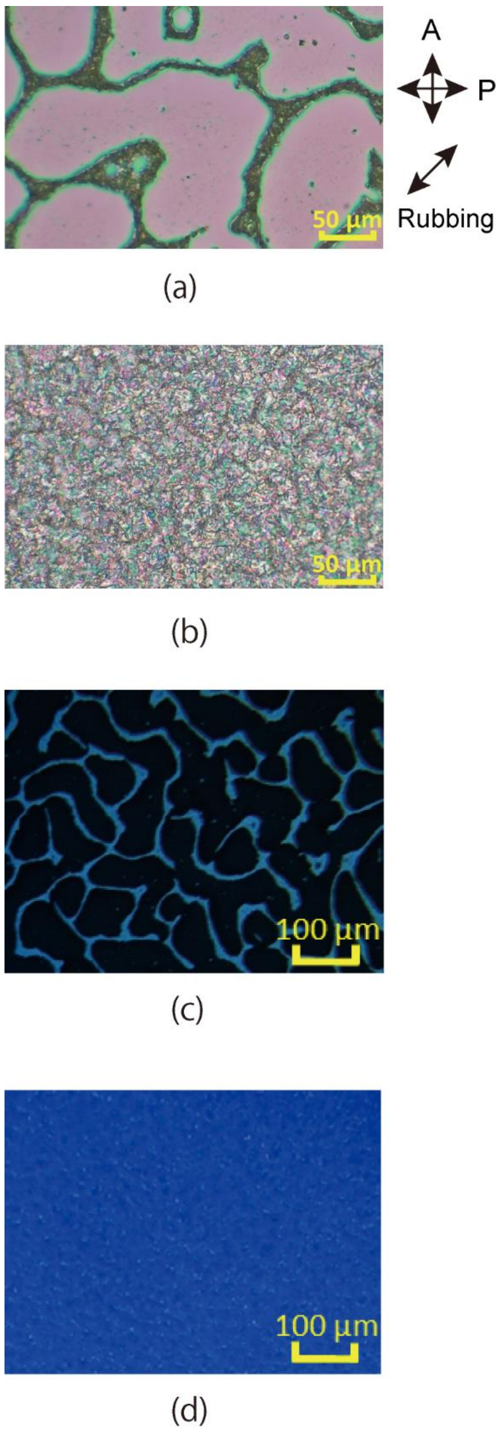

Fig. 1 Polarization and fluorescence micrographs of (a, c) 1-wt% cell and (b, d) 2-wt% cell, respectively. No voltage was applied while recording the micrographs.

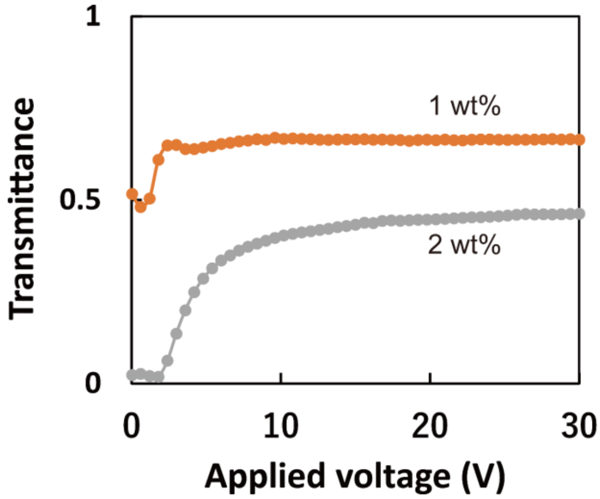

Fig. 2 Relationship between transmittance and applied voltage.

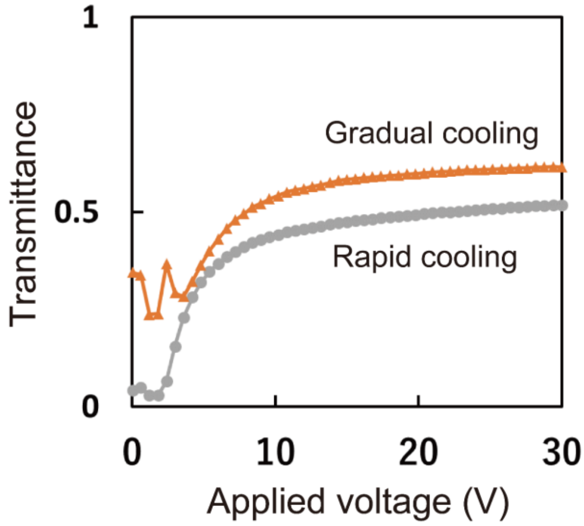

Fig. 3 Relationship between transmittance and applied voltage of the LC cells fabricated at different cooling rates.

Figure 2 shows the relationship between the transmittance and applied voltage of the LC cell fabricated using the rapid-cooling process. As evident from Fig. 2, the transmittance increases with increase in the applied voltage, suggesting that the index mismatch is reduced as the LC director becomes perpendicular to the substrate plane. The contrast ratio (on/off ratio) of the 2-wt% cell is higher than that of the 1-wt% cell. Furthermore, the threshold voltage of the 2-wt% cell is almost the same as that of the undoped LC cell (1 V).

We also investigated the effect of cooling rate on the transmittance–voltage characteristics. Figure 3 shows the relationship between the transmittance and voltage of the two LC cells fabricated at different cooling rates. It is evident that the cooling rate significantly affects the transmittance. These results suggest that the structure of the induced polyfluorene network strongly depends on the cooling rate.

We briefly evaluated the response time (rise time) of the fabricated LC cells by applying an AC voltage (5 V, 1 kHz, sinusoidal wave) across the LC cells (rapidly cooled). The rise times of the 1- and 2-wt% cells are almost the same, 20 ms, while the undoped LC cell exhibits a rise time of 5 ms. These results indicate that the polyfluorene network hinders the smooth movement of the LC molecules when the voltage is increased.

4 Conclusions

LC/ polyfluorene gel was prepared at different polyfluorene concentrations and cooling rates; these parameters strongly affected the induced network structure and the transmittance–voltage characteristics. Specifically, the 2-wt% cell exhibited a good contrast ratio (on/ off ratio) for light switching. Furthermore, the response time of the fabricated LC cells depended on the polyfluorene concentration. This is because the polyfluorene network hindered the smooth movement of LC molecules.

References

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