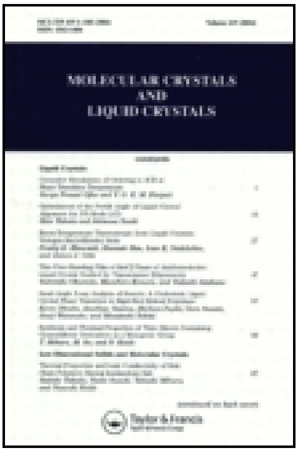

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Effects of UV Irradiation in Memory-Type PDLC Films Formed by a Photo-Induced Phase Separation

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EFFECTS OF UV IRRADIATION IN MEMORY-TYPE PDLC FILMS FORMED BY A PHOTO-INDUCED PHASE SEPARATION

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Abstract We have studied the relationship between the UV irradiation time and electrooptical properties in the UV curable polymer dispersed liquid crystal (PDLC) film. Memory-type PDLC films are prepared with various terms of UV irradiation and the changes of transmittance, capacitance and resistance of the PDLC film are measured while the phase separation is advanced. The driving voltage increases in the PDLC film which is made with an insufficient or excessive UV irradiation. The memory transmittance also depends on the UV irradiation time.

INTRODUCTION

Polymer dispersed liquid crystal (PDLC) films which are composed of liquid crystal (LC) microdroplets dispersed in a polymer matrix can be switched electrically from a light scattering state to a transparent state.[1-3] Recently, highly transparent memory states have been reported in the PDLC film[4,5] and a thermal addressing has been demonstrated by using a laser beam or a thermal printer head.[6,7] Some PDLC films including the memory-type PDLC film are formed from ultraviolet (UV) curable prepolymres. It is well known that their electrooptical properties depend on the UV intensity or the cure temperature because the morphology, for example, the size of LC droplet, is affected by them.[8-10]

Furthermore, the amount of UV irradiation should be very important in this UV curable PDLC system. It is expected that the prepolymer remains if the UV irradiation is insufficient, or the polymer and/or LC may be decomposed if it is excessive. Electrical properties of LC phase and polymer matrix change in either case, therefore the electrooptical property of the PDLC film also changes.

In this study, we first propose a term of UV irradiation as a cure parameter in the UV curable PDLC system. Memory-type PDLC films are prepared with various

UV irradiation times. The transmittance, capacitance and resistance of the PDLC film are monitored as a function of time in the process of the phase separation and the relationship between the UV irradiation time and the electrooptical properties are discussed.

EXPERIMENTAL

A nematic LC used in this study is a mixture of K15 (50 wt%) and E7 (50 wt%). A monomer, HEMA, (produced by Nippon Kayaku) contains a photoinitiator of 3 wt%. The homogeneous mixture is made up of the liquid crystal (50 wt%) and the monomer (50 wt%). It is sandwiched between indium-tin-oxide (ITO) coated glass substrates with rod glass spacers of 10μm diameter. An area of ITO electrode is 1 cm^2.

Figure 1 shows the setup for irradiating the UV light to the sample and simultaneously measuring the transmittance, capacitance and resistance of it. The UV intensity was 5 mW/cm^2. After the UV irradiation was ended, the sample was left in the dark and the measurement was continued. The sample was kept at 25°C using a peltier stage. A frequency for the measurement of electrical properties is 1 kHz.

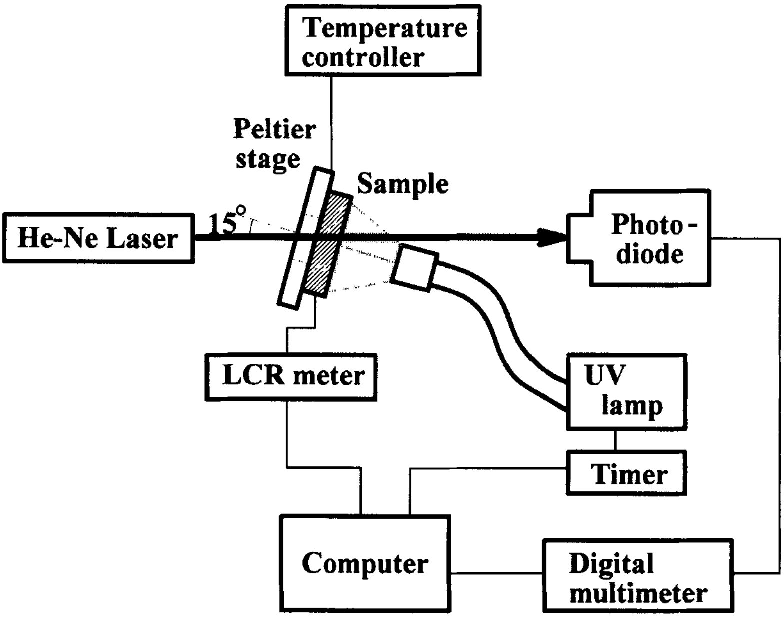

FIGURE 1 Experimental setup for UV curing and measuring the optical and electrical properties of the PDLC cell while the phase separation is advanced.

Electrooptical properties of samples were measured using a He-Ne laser beam which is normal to the substrate and a silicon photodiode. The beam intensity with no sample in place corresponds to 100% transmittance. The collection angle of transmitted light is about 1°.

RESULTS AND DISCUSSION

Figure 2 shows the capacitance and the resistance of HEMA in the process of polymerization as a function of time. The UV irradiation is started at time t=0 s and is ended at 500 s. The capacitance decreases and a small peak is observed at 60 s. The resistance increases rapidly after this time and continuously increases after the UV irradiation is ended. The polymerization may begin at 60 s. The variation of capacitance is very small after 200 s, whereas the resistance still increases.

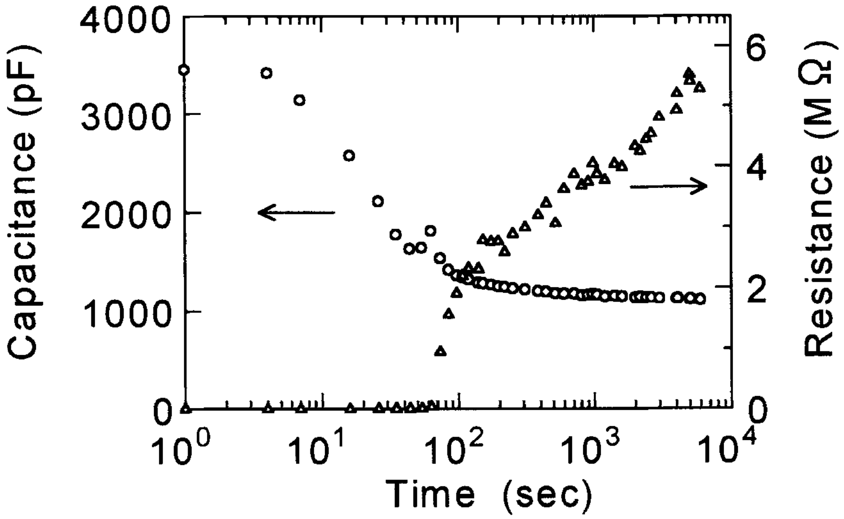

FIGURE 2 The capacitance and the resistance of HEMA in the process of polymerization, as a function of time. The UV irradiation is started at t=0 s and is ended at t=500 s.

A pure LC and a LC mixed with the photoinitiator were also irradiated with the UV light. The changes of resistance were measured and shown in Figure 3. The resistance of LC mixed with the photoinitiator of 3 wt% decreases linearly with the UV irradiation time. On the other hand, that of pure LC starts decreasing at 300 s. It is considered that the LC and the photoinitiator are decomposed by the UV light. After the UV irradiation is ended at 500 s, the resistance of pure LC increases and returns to the original value and that of LC mixed with the photoinitiator slightly increases but not return to the original value.

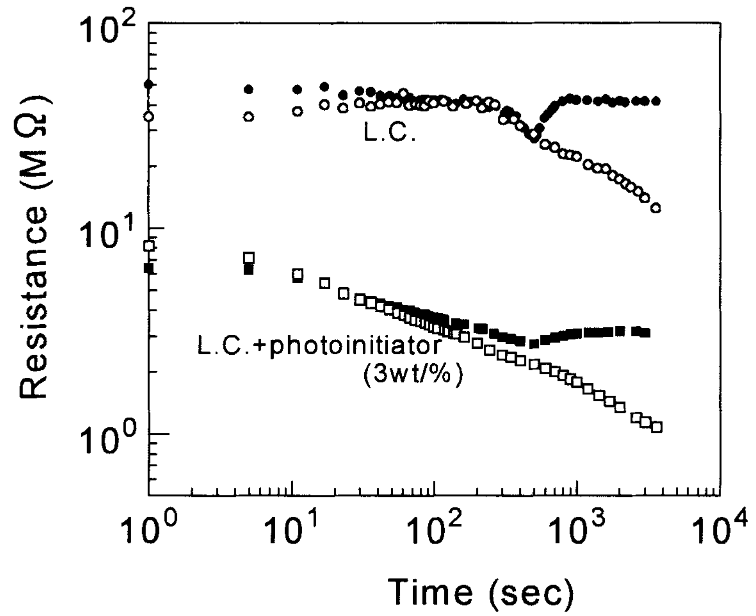

FIGURE 3 The UV irradiation effect on the resistance of liquid crystal. Closed symbols and open symbols show the cases where the UV irradiation is ended at t=500 s and 3600 s, respectively.

Figure 4(a) shows the transmittance of the PDLC film in the process where the homogeneous mixture separates into the polymer phase and the liquid crystal phase by the UV irradiation, as a function of time. The phase separation begins and the transmittance starts decreasing at 20 s. In the case where the UV irradiation is ended at 50 s, the phase separation is in progress at this time and still advances slowly from 50 s to 1200 s, after then it develops rapidly. The UV irradiation is also ended immediately before the completion of phase separation (at 100 s), or after the completion of phase separation (at 500 s and 1000 s). For changes of the capacitance in Figure 4(b), we can see peaks at 20 s which show the start of polymerization of HEMA. The transmittance and the capacitance are constant after the completion of phase separation. The resistance of samples increases with the progress of polymerization as shown in Figure 4(c). However they decrease after 200 s in the samples which are irradiated with the UV light for 500 s and 1000 s.

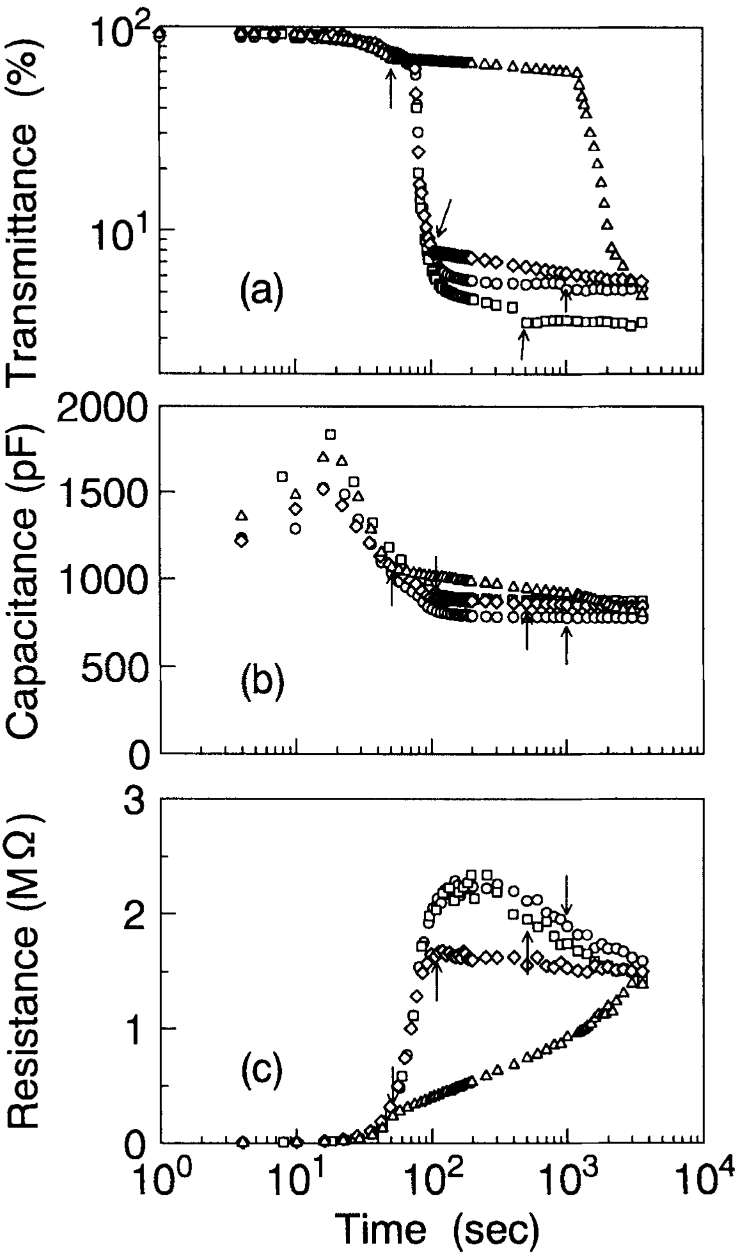

FIGURE 4 Properties of (a) transmittance, (b) capacitance and (c) resistance as a function of time in the process of phase separation for the PDLC film. Each arrow shows the time when the UV irradiation was ended (△:50 s, ◇:100 s, □:500 s, ○:1000 s).

Polymer structures of PDLC films with different terms of UV irradiation were observed by scanning electron microscopy. Polymer-particles of about 1 μm diameter connecting each other are observed in all films and the morphology is independent of UV irradiation time.

Figure 5 shows transmittance versus voltage curves for increasing and decreasing voltage in the PDLC film made with the UV irradiation for 500 s. The transmittance increases with increasing the voltage and does not return to the initial level when the voltage decreases to zero. This transparent memory-state is retained over a period of months. The memory-state can be converted to the initial scattering off-state by heating the PDLC film up to T_C which is defined as a temperature of LC phase transition from a nematic phase to an isotropic phase, and cooling down without the voltage.

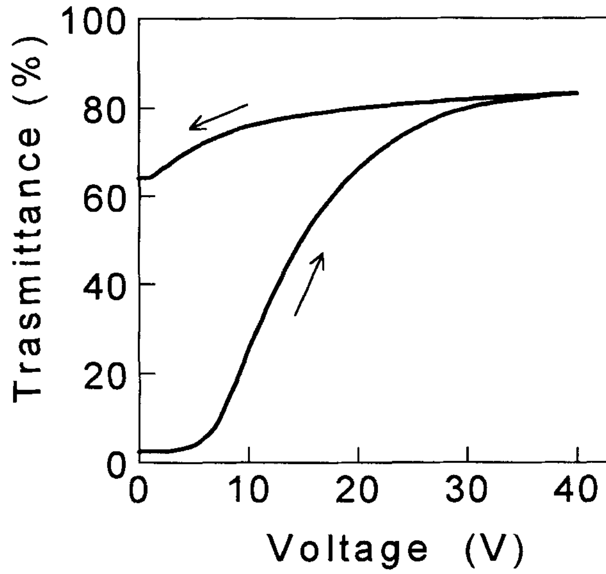

FIGURE 5 Transmittance versus voltage curves for increasing and decreasing voltage.

Electrooptical properties in the on-state and the memory-state are shown in Figure 6 for the PDLC films which are made with the UV irradiation for 50 s and 500 s, respectively. This figure shows that the electrooptical property depends on the term of UV irradiation. In the PDLC film with the UV irradiation of 50 s, the threshold voltage and the saturation voltage are higher and the saturated level of memory transmittance is lower as compared with the film with the UV irradiation of 500 s.

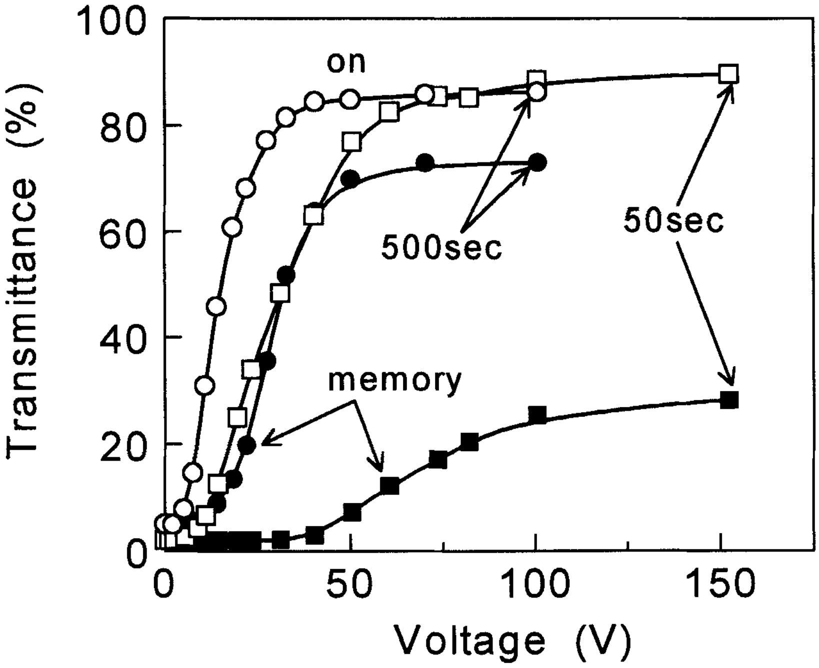

FIGURE 6 Electrooptical properties in the on-state and the memory-state as a function of applied voltage. PDLC films are made with the UV irradiation for 50 s (■,□) and 500 s (●,○).

Tramsmittances in the off- and on- and memory-state versus UV irradiation time are plotted in Figure 7. Transmittances in the off-state and the on-state are almost independent of the irradiation time. However, transmittances in the memory-state are very low in the PDLC films which are made with the UV irradiation for less than 100 s. The situation of polymer-particle interface and the adsorption of LC on it in the PDLC films made with insufficient UV irradiation are different from those in the films with enough UV irradiation.

Figure 8 shows the relationship between the driving voltage and the term of UV irradiation in the PDLC films. The values of V_{10} and V_{90} in the on-state and the memory-state become minimum in the PDLC film made with the UV irradiation for 500 s. This result shows that the insufficient or excessive UV irradiation increases the driving voltage of the PDLC film, because the prepolymer dissolves in the LC phase or the polymer, photoinitiator and/or LC are decomposed, and these impurities decrease the resistance of the LC phase.

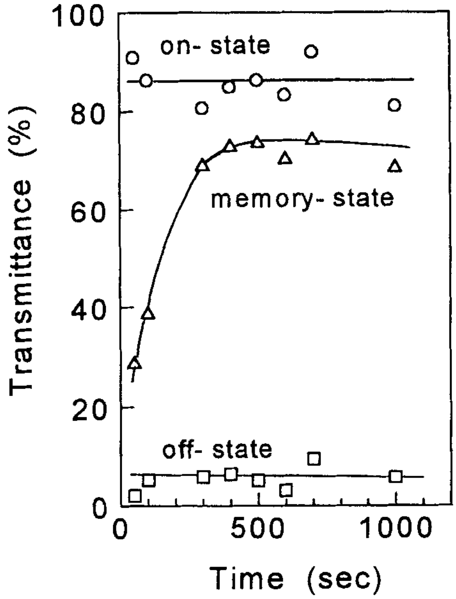

FIGURE 7 Transmission properties in the off-, on- and memory-state as a function of UV irradiation time.

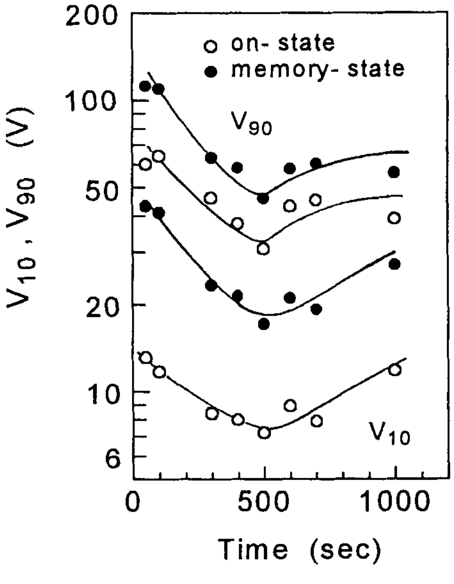

FIGURE 8 Threshold voltage V_{10} and saturation voltage V_{90} in the on-state and the memory-state as a function of UV irradiation time.

CONCLUSIONS

Relations between the term of UV irradiation and the electrooptical property in the UV curable PDLC film have been studied. The transmission and electrical properties have been revealed in the process of the phase separation. The memory effect and the driving voltage depend on the UV irradiation time and we can clarify the optimum time of ending the UV irradiation. It is shown that the term of UV irradiation is very important as a cure parameter.

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