Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

Highly transparent memory states in polymer dispersed liquid crystal films

R. Yamaguchi[a]; S. Sato[a]
[a] Department of Electronics, Akita University, Akita City, Japan

To cite this Article Yamaguchi, R. and Sato, S.(1993) 'Highly transparent memory states in polymer dispersed liquid crystal films', Liquid Crystals, 14: 4, 929 — 935
To link to this Article: DOI: 10.1080/02678299308027800
URL: http://dx.doi.org/10.1080/02678299308027800

LIQUID CRYSTALS, 1993, VOL. 14, NO. 4, 929–935

Highly transparent memory states in polymer dispersed liquid crystal films

by R. YAMAGUCHI* and S. SATO
Department of Electronics, Akita University,
Tegata gakuencho 1–1, Akita City, 010 Japan

Electro-optical properties of polymer dispersed liquid crystal (PDLC) films which have reversed morphology are investigated. Highly transparent memory states, for which transmittances exceed more than 80 per cent, are observed in these PDLC films. The saturation voltage V_{90} can be decreased by a PTF (a phase transition with a field) operation and becomes 10 times lower than that without PTF operation. A contrast ratio of more than 600 is obtained in the memory state of a thick PDLC film.

1. Introduction

Polymer dispersed liquid crystal (PDLC) films can be switched electrically from a light scattering 'off state' to a highly transparent 'on state' [1–3]. In PDLC films which have reversed morphology, memory states in which transparency is preserved after the voltage is removed have been reported [4, 5]. In addition, highly transparent on and memory states are obtained by a phase transition from an isotropic to a nematic state with an applied field (PTF operation) [6]. Based upon such a memory type PDLC film, thermally and/or electrically addressable and erasable display devices have been proposed [7]. In this paper, PDLC films which show highly transparent memory states are prepared and the electro-optical properties investigated.

2. Experimental

A cyanobiphenyl nematic liquid crystal, K15 and the mixture E7 were used in this work. A UV-curable material consisting of a methacrylate monomer was prepared as a polymer matrix. The monomer and the liquid crystal were mixed in the ratio 1 : 1 by weight and then sandwiched between indium tin oxide (ITO) coated glass substrates. UV light of $5\,\mathrm{mW\,cm^{-2}}$ was used to irradiate the film at room temperature and the PDLC film was formed by polymerization induced phase separation. Electro-optical properties were measured using a He–Ne laser (1 mW) and a silicon photodiode at room temperature. The beam intensity with no sample in place corresponds to 100 per cent transmittance. The distance between the sample and the detector was 10 cm and the effective area of the detector was $6{\cdot}6\,\mathrm{mm}^2$. The driving frequency was 1 kHz.

3. Results and discussion

3.1. *Electro-optical properties in the on states and the memory states*

Transmission properties for the on state and the memory state (off state) of the PDLC film are shown in figure 1 as a function of applied voltage. The liquid crystal used in this PDLC film is a mixture of K15 and E7 in the ratio 1 : 1 by weight and the cell

---

* Author for correspondence.

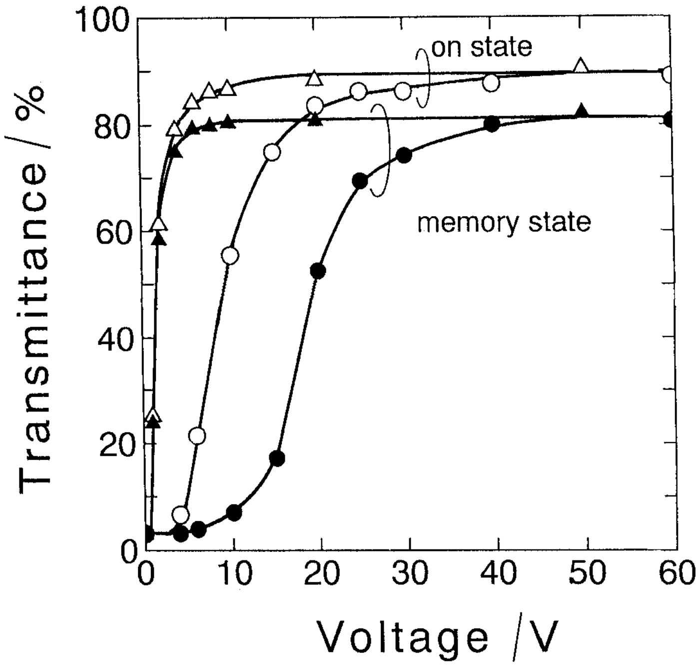


Figure 1. Transmission properties of the PDLC film in the memory state and the on state as a function of applied voltage. Open and filled circles represent normal operation, without PTF, and open and closed triangles represent PTF operation.

thickness is controlled using rod spacers of 5 μm diameter. The transmission properties were measured as follows: a small voltage was applied for enough time to level off the transmittance (on state); then it was removed and the transmittance in the memory state was measured. After that, the next higher voltage was applied. The transmittance increases with increasing applied voltage and reaches about 90 per cent in the on state. When the voltage is removed, the transmittance does not return back to the initial level, but rather is maintained at a level of about 80 per cent. The curve in the memory state does not depend on its history at lower voltages. This transparent memory state is preserved over a period of months. Moreover, saturation voltages in the on states and the memory states can be decreased by heating the film to the isotropic phase and cooling it back to form the nematic phase with an applied AC field (PTF operation; this is shown as open and closed triangles). The memory state can be converted into the initial scattering off state by heating the film to the clearing temperature (T_c) of the liquid crystal and cooling it down without applying a field.

3.2. *Dependence on the mixing ratio of K15 and E7*

PDLC films were prepared using liquid crystal mixtures of K15 and E7. The cell thickness was 5 μm. Figure 2 shows the relationship between the birefringence Δn and the transmittance in the off states, the on states and the memory states as a function of the mixing ratio (weight per cent) of K15 and E7. Transmittances in the on states and the memory states were obtained by applying a saturation voltage. The birefringence, Δn, increases with increasing concentration of E7. The transmittance in the off state decreases with increasing concentration of E7 as the mismatch of n_p (the refractive index of the polymer matrix) to n_e increases. The transmittance in the on state depends

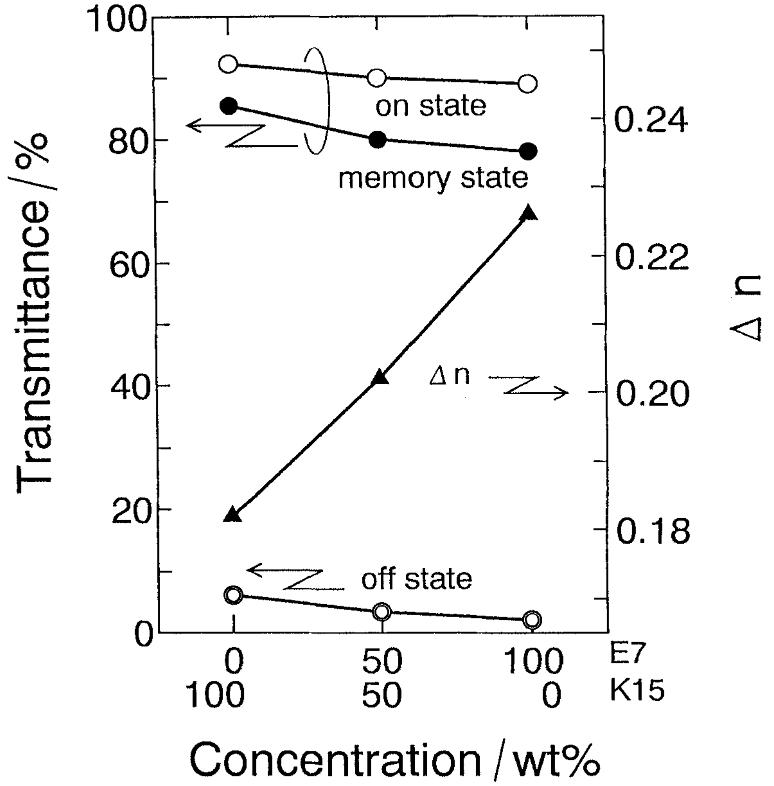


Figure 2. Birefringence of the liquid crystal Δn and transmittances in the off, on and memory states as a function of mixing ratio of K15 and E7. The cell thickness of all PDLC films is 5 μm.

on the matching of n_p to n_o, and that in the memory state may be affected by both the refractive index matching and the Δn of the liquid crystal. In this study, the highest memory transmittance 85 per cent was obtained for the PDLC film prepared using K15 only.

The polymer structure of these PDLC films shows a reversed morphology [8] where many polymer particles of less than 1 μm diameter are connected to each other. The liquid crystal exists continuously in gaps or interstices in the complex polymer structure.

Figure 3 shows the saturation voltage V_{90} in the on states and the memory states with and without PTF operation as a function of the mixing ratio of K15 and E7. The saturation voltage is defined as the applied voltage at which the transmittance reaches 90 per cent of the saturated transmittance. The saturation voltage increases with increasing concentration of E7 in each state. In addition, it can be decreased by PTF operation and becomes 10 times lower than that without PTF operation in the memory state. It can also be decreased by a factor of 4 in the on state; that is, PTF operation is more effective in the memory state than in the on state.

3.3. *Dependence on the cell thickness*

Figures 4 (*a*) and (*b*) show the dependence on the cell thickness of the electro-optical properties in the on states and the memory states without PTF operation. These PDLC films were prepared using E7. It is seen that the threshold voltage increases and the

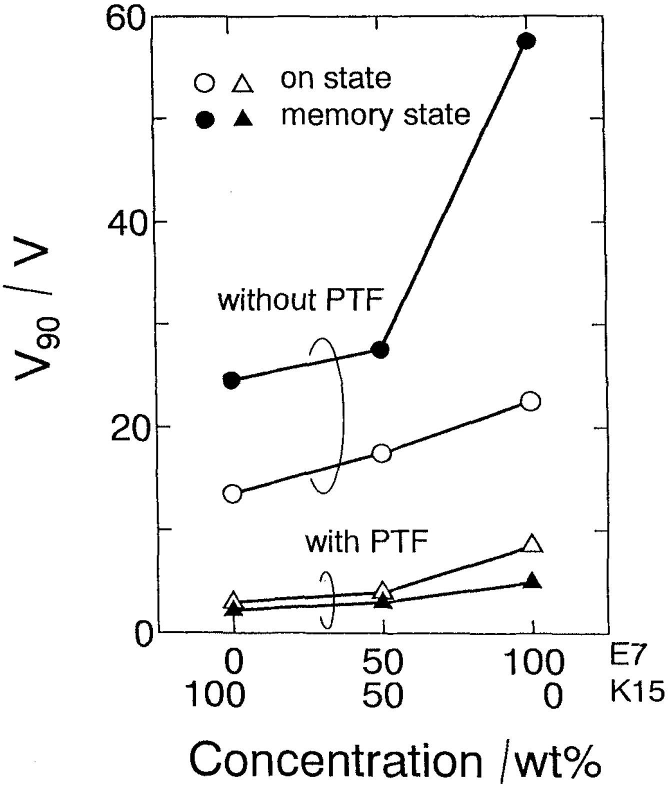
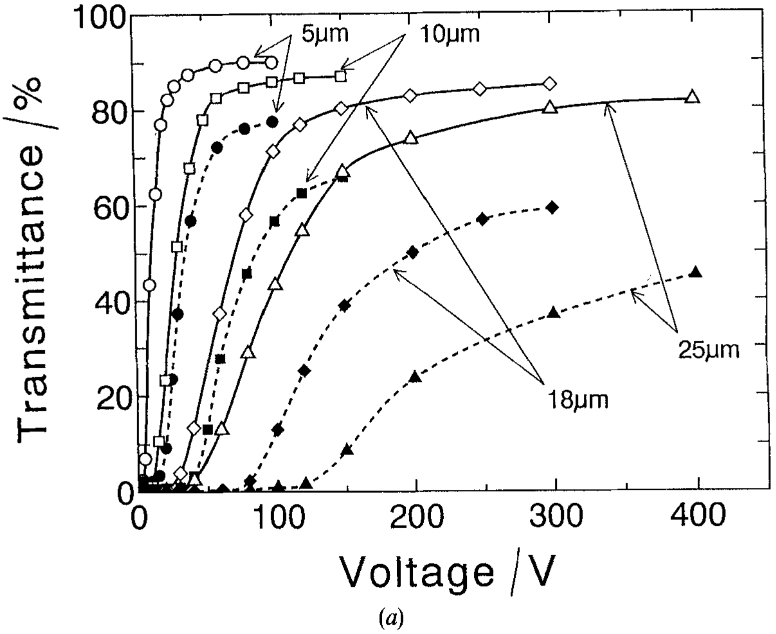


Figure 3. Saturation voltage V_{90} in the on and memory states with and without PTF operation as a function of mixing ratio of K15 and E7. The cell thickness of all PDLC films is 5 μm.

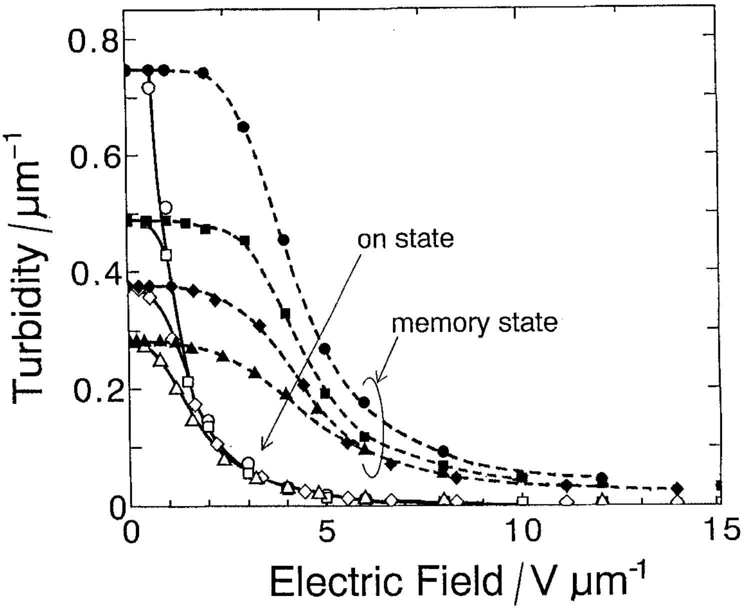
saturated transmittance decreases with increasing cell thickness. In figure 4(*b*), the transmittance is converted to the turbidity τ which is defined as

$$I = I_0 \exp(-\tau d), \tag{1}$$

where I_0 and I denote the intensity of the incident light and the transmitted light, and d is the thickness of the film. In figure 4(*b*), the electric field is plotted instead of the voltage. Although the turbidity is independent of the film thickness if the light scattering properties are determined only by the morphology and refractive index mismatching of the liquid crystal ($n_{\mathrm{l.c.}}$) and polymer (n_{p}), the turbidity in the off state increases with decreasing cell thickness. The dependence of the turbidity on cell thickness is explained as follows: the average value of the refractive index of the liquid crystal, $\bar{n}_{\mathrm{l.c.}}$, in the regions within the bulk of the PDLC film is assumed to be about $(2n_0+n_e)/3$, because of the random orientation of the liquid crystal molecules. However, $\bar{n}_{\mathrm{l.c.}}$ near the grass/film interface becomes larger than that in the bulk of the film since the liquid crystal molecules tend to align parallel to the interface. Then, stronger light scattering is caused by the larger refractive index mismatching $\bar{n}_{\mathrm{l.c.}} - n_{\mathrm{p}}$ at the interface, rather than within the film. This effect is more marked in thinner films than in thicker films. In the on state, the turbidity does not depend on the cell thickness above an applied field of 2 V μm^{-1} since the liquid crystal molecules near the interface tend to align perpendicular to the glass substrate. The dependence of the turbidity on the cell thickness is also observed in the memory state.



(*a*)



(*b*)

Figure 4. Dependence on the cell thickness of the electro-optical properties in the on (open symbol) and memory (filled symbol) states without PTF operation. (*a*) Transmittance *versus* applied voltage and (*b*) turbidity *versus* electric field with cell thicknesses of 5 μm (○, ●), 10 μm (□, ■), 18 μm (◇, ◆) and 25 μm (△, ▲).

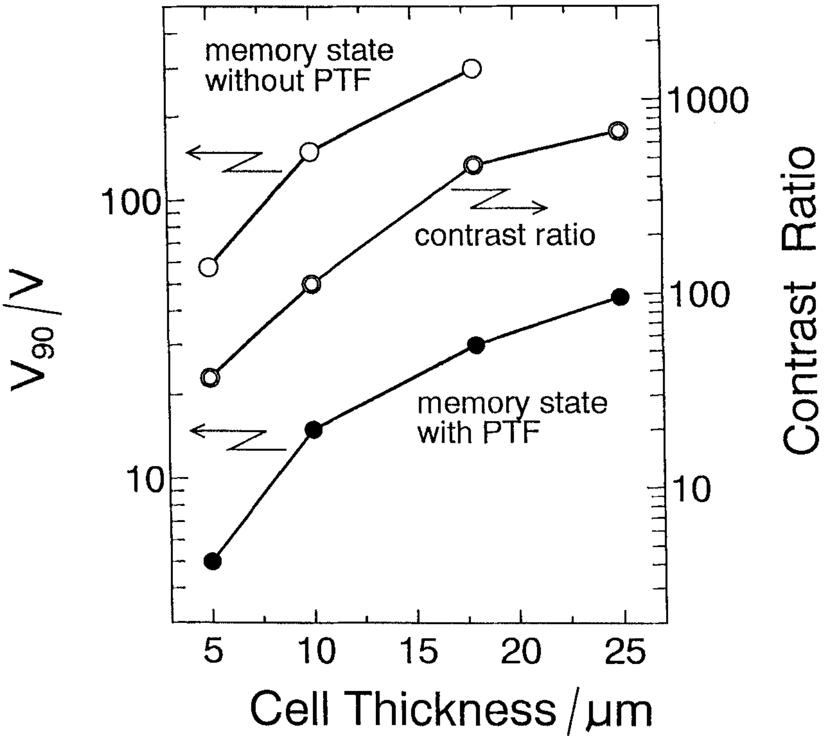


Figure 5. The saturation voltage V_{90} and the contrast ratio in the memory state as a function of cell thickness.

In addition, we observed the morphology in thin (5 μm) and thick (25 μm) films, and at both sides of the film surface by SEM. The same morphology and size of the polymer particles were observed. Therefore the morphology of the films is independent of film thickness and of the direction of UV irradiation in this study.

Figure 5 shows the saturation voltage V_{90} and the contrast ratio in the memory state as a function of cell thickness. It is seen that the saturation voltage with PTF operation can be decreased, and it becomes 10 times lower than that without PTF operation for each cell thickness. The contrast ratio CR

$$\mathrm{CR} = \exp\left[(\tau_{\mathrm{off}} - \tau_{\mathrm{memory}})\, d\right], \qquad (2)$$

where τ_{memory} is obtained by applying a saturation voltage with PTF operation and d is the cell thickness, increases with increasing cell thickness. PDLC films with higher contrast ratios show higher values of V_{90} and a similar tendency is shown in figures 2 and 3.

4. Conclusions

PDLC films which have reversed morphology were prepared and the electro-optical properties measured in the off state, the on state and the memory state. The highest memory transmittance of 85 per cent was obtained in this study. The relationship between the turbidity and the cell thickness in each state was measured, and it is found that turbidities in the off and the memory state increase in thinner PDLC films. A contrast ratio of more than 600 was obtained in a thick PDLC film. The saturation voltage V_{90} with PTF operation is 10 times lower than that without PTF operation in the memory state.

References

[1] Drzaic, P. S., 1986, *J. appl. Phys.*, **60,** 2142.
[2] Doane, J. W., Vaz, N. A., Wu, B. G., and Zumer, S., 1986, *Appl. Phys. Lett.*, **48,** 269.
[3] Yamaguchi, R., and Sato, S., 1990, *Trans. IEICE*, J73-C-II, p. 348.
[4] Yamagishi, F. G., Miller, L. J., and van Ast, C. I., 1989, *S.P.I.E. Liquid Crystal Chemistry, Physics, and Applications*, **1080,** 24.
[5] Yamaguchi, R., and Sato, S., 1991, *Jap. J. appl. Phys.*, **30,** L616.
[6] Yamaguchi, R., and Sato, S., 1992, *Jap. J. appl. Phys.*, **31,** L254.
[7] Yamaguchi, R., and Sato, S., 1992, *Jap. J. appl. Phys.*, **31,** L1093.
[8] Vaz, N. A., 1989, *S.P.I.E. Liquid Crystal Chemistry, Physics, and Applications*, **1080,** 2.