

Electro-optical Properties of Polymer-Stabilized Nematic Pi Cells

Chi -Yen Huang, Ri -Xin Fung, and Ying -Ging Lin

Graduate Institute of Photonics and Department of Physics, National Changhua University of Education, Changhua, Taiwan 500, Republic of China

E-mail: *chiyen@cc.ncue.edu.tw*.

Keywords : liquid crystal, polymer network, bend

Abstract

We analyzed conditions for fabricating zero-bias polymer-stabilized liquid crystal (PSLC) pi cells. A high curing voltage and a very low curing intensity are effective in fabricating the cell with a high bright state, a low dark state and therefore a steep T-V curve. However, the response time of the cell is slow. Finally, a dual-frequency PSLC pi cell with fast response time is developed. The obtained result reveals that the dual-frequency PSLC pi cell has a fast response of under 1ms.

1. Introduction

Nematic liquid crystal (LC) devices are widely used as information devices or displays, owing to their advantages of low operation voltage, low power consumption, compact size and low fabrication cost. Various advanced LC display modes have been developed according to their applications.[1-2] However, the response time of nematic liquid crystal displays (LCDs) is not sufficiently short for TV and video applications with fast moving objects. Recently, it has been reported that an optically compensated bend (OCB) mode, or a pi cell, exhibits the shortest switching speed among nematic LCDs.[3-7] Additionally, it can be compensated using optical films to obtain a wide viewing angle and a high contrast.

A polymer-stabilized liquid crystal (PSLC) is a promising material for flexible display devices, owing to its rugged polymer structure. To eliminate the splay-to-bend transition, cells with polymer structures have been proposed.[8-11] Recently, Kim and Chen have reported that a high monomer concentration or high curing voltage stabilizes LCs in the stable bend state without a bias voltage; however, it confers a poor steepness in a transmission versus applied voltage (T-V) curve because of the excessive alignment strength

of the polymer structures.[10] In this study, we further examined the electro-optical characteristics of the PSLC pi cell. The external voltage applied to the cell while measuring the electrooptical characteristics is greatly higher than that in the experiment of Kim and Chen.[10] As a result, the effects of monomer concentration, curing voltage and curing intensity on the electrooptical characteristics of the PSLC pi cell were apparently revealed.

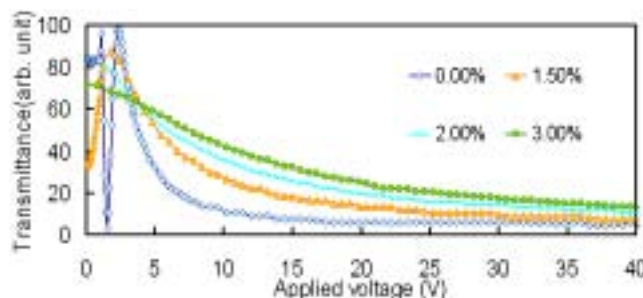


Fig. 1: Measured T-V curves of cells at various monomer concentrations. The curing intensity is $\sim 0.4 \mu\text{W}/\text{cm}^2$ and the curing voltage is 2.5 V.

2. Experimental

In this experiment, the pi cell is made from a conventional homogeneous polyimide and has a pretilt angle of 2 degrees. The cell thickness is $5.7 \mu\text{m}$. The nematic LC used is E7 and the monomer used is RM257 (both from Merck). A small amount of the photoinitiator Irgacure 651 (from Ciba Additive Corp.) was added to the LC/monomer mixture to initiate the polymerization of RM257. The cell was filled with the LC/monomer mixture. Subsequently, the filled cell was polymerized at room temperature with a curing voltage, which is higher than the splay-to-bend transition voltage ($\sim 2.03 \text{ V}$) of the cell filled with pristine E7. A He-Ne laser (632.8 nm) was used to characterize the electrooptical properties of the cell.

The cell was positioned between a pair of cross polarizers, with the rubbing direction at 45 degrees to the transmission axes of the polarizers. The T-V curve, switch-on response time (rise time) and switch-off response time (fall time) of the cell were measured. The rise time (fall time) of the cell is defined as the time taken for the transmitted intensity to change from 90% (10%) to 10% (90%) with a supplied voltage pulse.

3. Results and discussion

Figure 1 shows a plot of the measured T-V curves of the cell at various monomer concentrations. The curing intensity is $\sim 0.4 \mu\text{W}/\text{cm}^2$ and the curing voltage is 2.5 V. The results resemble those obtained by Kim and Chen[10]: After polymerization, LCs align at a balance state determined by the anchoring forces from the rubbed PI film and formed polymer networks. The anchoring force from the rubbed PI film aligns the LCs parallel to the substrate surface, and that from the polymer networks prevents the LCs from relaxing in a direction parallel to the substrate surface. When the monomer concentration exceeds 2 wt%, the LCs are stabilized at zero bias in the stable bend state with retardation under $\lambda/2$. The high monomer concentration is mainly responsible for the low bright state, high dark state and slow varying T-V curve of the cell. In this experiment, because the supplied voltage (40V) is high, our results clearly reveal that the dark state of the cell increases and the slope of the T-V curve decreases when the monomer concentration is increased. The bright state indicates the maximum transmittance and the dark state indicates the minimum transmittance in the T-V curve of the cell. Additionally, the switching characteristics of the cells with the monomer concentrations of 0 and 2 wt% in the bend states, in which the cells induce retardation under $\lambda/2$, were investigated. The voltage that yields 90% (10%) of the maximum transmittance, at which the cells induce retardation under $\lambda/2$, is defined as the threshold voltage (saturation voltage). The rise and fall times between the threshold voltage and saturation voltages were measured. The cell filled with pristine E7 has a short rise time of ~ 0.5 ms and a short fall time of ~ 1.8 ms. The cell with the monomer concentration of 2 wt% has a short rise time of ~ 0.5 ms and a long fall time of ~ 20 ms. The short rise times of both cells are due to the strong external electric torque applied to the LCs, and the long fall time of the cell with the monomer concentration of 2 wt% is due to the hindrance of LC reorientation by the

formed polymer networks when the applied voltage is switched off.[12]

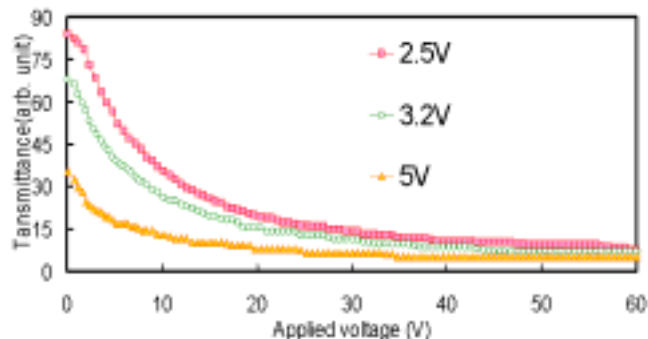


Fig. 2: Measured T-V curves of cells at various curing voltages. The monomer concentration is 2 wt% and the curing intensity is $\sim 0.4 \mu\text{W}/\text{cm}^2$.

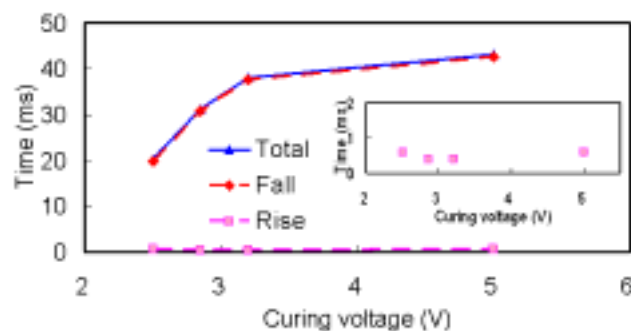


Fig. 3: Measured rise, fall, and total response times of cells at various curing voltages. The monomer concentration is 2 wt% and the curing intensity is $\sim 0.4 \mu\text{W}/\text{cm}^2$. The inset shows a plot of the rise time on an expanded scale.

Figure 2 shows the measured T-V curves of the cell at various curing voltages. The monomer concentration is 2 wt% and the curing intensity is $\sim 0.4 \mu\text{W}/\text{cm}^2$. As shown in the figure, a high curing voltage effectively aligns the LCs and monomers perpendicular to the substrate surface, and hence aligns the LCs and polymer networks homeotropically and uniformly following polymerization, thus making the cell the low dark state and approaching the saturation voltage rapidly. However, the bright state simultaneously decreases owing to the decreased effective birefringence. Notably, it is revealed in the figure that the dark state of the cell clearly decreases with increasing curing voltage. The response times of the cells in the bend states were also studied. As shown in Fig. 3, the short rise time of ~ 0.5 ms is independent of curing voltage, owing to the strong external electric torque applied to the LCs. The fall time markedly increases with curing voltage. This is

because the high curing voltage provides a strong anchoring force from the polymer networks that aligns the LCs homeotropically, preventing the LCs from relaxing in a direction parallel to the substrate surface when the applied voltage is switched off.

As discussed above, the high monomer concentration markedly increases the dark state and reduces the bright state and the steepness in the T-V curve of the cell. The high curing voltage markedly reduces the dark state of the cell; however, it is accompanied by the drawbacks of a low bright state. These drawbacks markedly limit the development of PSLC pi cells. Recently, it has been reported that the low UV curing intensity generates sparse polymer networks, because few free radicals are produced during polymerization and hence few propagation chain ends, resulting in polymer networks with high molecular weights of cross-linking.[13-14] To determine the effect of curing intensity on the electrooptical characteristics of the PSLC pi cell, PSLC pi cells with different curing intensities were fabricated. In this experiment, a high curing voltage of 5V makes a PSLC pi cell a low dark state. As shown in Fig. 4, when the curing intensity is high, the bright state of the cell is low. However, when the curing intensity is decreased significantly, the bright state of the cell markedly increases. This marked increase in bright state is attributed to the sparse polymer networks formed at the very low curing intensity, decreasing the anchoring force generated from the polymer networks that aligns the LCs homeotropically. The decreased anchoring force increases the bending degree of the LCs, increasing the effective birefringence and the associated bright state, such that the cell has a steep T-V curve. The response times of the cells were also investigated. As shown in the inset, the short rise time of ~ 0.5 ms is independent of curing voltage, as expected. However, the fall time is long and increases with curing intensity. This is because when the curing intensity is high, the formed polymer networks are dense and thus the generated anchoring force is high.

As discussed above, a high curing voltage and a very low curing intensity are effective in fabricating the cell with a high bright state, a low dark state and therefore a steep T-V curve. However, the response time of the cell is slow. Therefore, a special dual-frequency driving scheme that switches both on and off the dual-frequency PSLC pi cell using an electric torque is proposed to achieve a short response time. The dual-frequency nematic used is MLC-2048. Figure 5 presents the proposed dual-frequency driving

scheme and the measured electro-optical response of the dual-frequency PSLC pi cell (4.2 wt% monomer concentration). The dual-frequency driving scheme resembles the conventionally adopted single-frequency (1 kHz) driving scheme, except in that a high-frequency voltage pulse (50 kHz, 5 V) is inserted before the applied voltage is dropped to the threshold voltage. As shown in this figure, the inserted high-frequency voltage pulse rapidly changes the dielectric anisotropy of the LCs from positive to negative, generating a strong electric torque that returns the LCs perpendicular to electric field, yielding a short fall time of ~ 0.36 ms. The sudden increase in voltage generates a short rise time of ~ 0.46 ms, as expected.

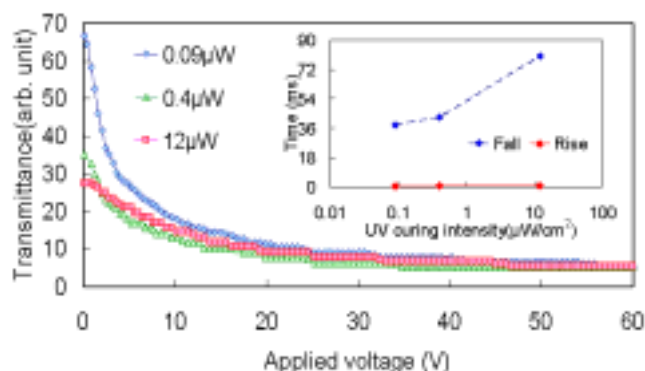


Fig. 4: Measured T-V curves of cells at curing intensities of 0.09, 0.4 and 12 $\mu\text{W}/\text{cm}^2$. The monomer concentration is 2 wt% and the curing voltage is 5 V. The inset shows the measured rise and fall times of the cells.

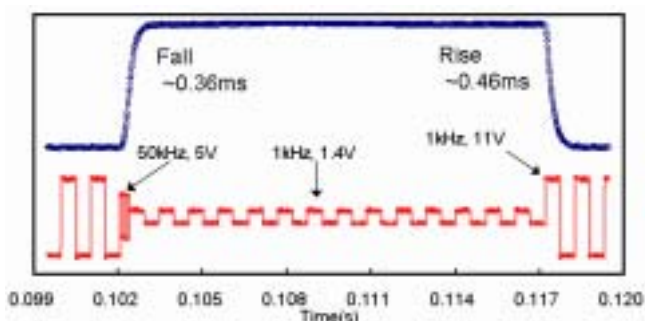


Fig. 5: Measured electro-optical response and dual-frequency driving scheme of dual-frequency zero-bias PSLC pi cell at monomer concentration of 4.2 wt%.

4. Summary

In conclusion, the methods of optimizing the electro-optical properties of PSLC pi cells were discussed. A high curing voltage makes a PSLC pi cell

a low dark state and approaches the saturation voltage rapidly. A very low curing intensity generates sparse polymer networks, increasing the bending degree of LCs and therefore increasing the effective birefringence and associated bright state of the cell. A high curing voltage and a very low curing intensity are found to be effective in fabricating a zero-bias PSLC pi cell with a high bright state, a low dark state and a steep T-V curve. The fall time of the cell is long because the formed polymer networks impede LC reorientation. Finally, a dual-frequency PSLC pi cell is fabricated. Under a proposed dual-frequency driving scheme, based on the electric torque driving mechanism, the dual-frequency PSLC pi cell exhibits a short response time of under 1 ms.

5. References

1. E. Lueder: *Liquid Crystal Displays, Addressing Schemes and Electro-optical Effects* (John Wiley and Sons, New York, 2001).
2. S. T. Wu and D. K. Yang: *Reflective Liquid Crystal Displays* (John Wiley and Sons, New York, 2001).
3. F. S. Y. Yeung and H. S. Kwok: *Appl. Phys. Lett.* **88** (2006) 063505.
4. P. J. Bos and K. R. Koehler/Beran: *Mol. Cryst. Liq. Cryst.* **113** (1984) 329.
5. S. Onda, T. Miyashita, and T. Uchida: *Mol. Cryst. Liq. Cryst.* **331** (1999) 383.
6. E. J. Acosta, M. J. Towler, and M. D. Tillin: *J. Appl. Phys.* **97** (2005) 093106.
7. X. J. Yu and H. S. Kwok: *Appl. Phys. Lett.* **89** (2006) 031104.
8. T. Konno, T. Miyashita, and T. Uchida: *Proc. 15th IDRC*, 1995, p. 581.
9. H. Kikuchi, H. Yamamoto, H. Sato, A. Kawakita, K. Takizawa, and H. Fujikake: *Jpn. J. Appl. Phys.* **44** (2005) 981.
10. S. H. Kim and L. C. Chien: *Jpn. J. Appl. Phys.* **43** (2004) 7643.
11. Y. Asakawa, K. Yokota, M. Nanaumi, N. Takatuka, T. Takahashi, and S. Saito: *Jpn. J. Appl. Phys.* **45** (2006) 5878.
12. C. Y. Huang, Y. S. Chih, and S. W. Ke: *Appl. Phys. B* **86** (2007) 123.
13. Y. K. Fung, D. K. Yang, S. Ying, L. C. Chien, S. Zumer, and J. W. Doane: *Liq. Cryst.* **19** (1996) 797.
14. G. P. Crawford and S. Zumer: *Liquid Crystals in Complex Geometries* (Taylor and Francis, London, 1996) p. 113.