

Switching of polymer-stabilized vertical alignment liquid crystal cell

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Abstract: This work investigates the switching characteristics of the polymer-stabilized vertical alignment (VA) liquid crystal (LC) cell. The experimental results reveal that the fall time of the cell declines as the monomer concentration increases because the vertically-aligned polymer networks accelerate the relaxation of the LC molecules. Furthermore, the formed polymer networks impede the growth and annihilation of LC defects, suppressing the optical bounce in the time dependent transmittance curve of the cell when the voltage is applied to the cell, substantially reducing the rise time of the cell. A step-voltage driving scheme is demonstrated to eliminate completely the optical bounce and hence improve further the rise time of the VA LC cell. The rise times of the pristine and the polymer-stabilized VA LC cells under the step-voltage driving scheme are less than 50% of those under the conventional driving scheme.

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1. Introduction

Liquid crystals (LCs) are widely employed in display devices owing to their low operating voltage, low power consumption and small size. [1-2] However, the LC display performance is unsatisfactory because of a narrow viewing angle and a slow response time. Various advanced LC modes, such as associated with a birefringence film, domain-divided twisted nematic, in-plane switching, multi-domain vertical alignment (MVA) and patterned vertical alignment (PVA) have been proposed to improve the viewing angle. [3-5] Among them, the MVA and PVA (VA-type) cells have a very high contrast ratio because the LC is almost vertically aligned against the substrate at zero voltage, providing the cell an extremely good dark state under crossed polarizers. However, the in-plane propagation of the LC alignment gives the VA-type cells a long response time. [6] The optically compensated bend mode (pi cell) may offer a wide viewing angle and fast response time. Unfortunately, it is associated with difficulties in controlling the LC conformation. [7-9]

Recently, liquid crystal polymer dispersions have been exploited in flexible display devices because of the excellent mechanical stability of polymer structures. Pi cells with polymer structures have been demonstrated to eliminate the splay-to-bend transition. [10-11] However, the formed polymer networks inhibit the reorientation of the LCs such that the response time of the cell is long. The dual-frequency driving scheme that both switches on and switches off the polymer-stabilized liquid crystal pi cell using electric torque has been presented to provide a sub-millisecond response time. [12] Likewise, cells with polymer structures which sustain a pretilt angle at the substrate surface have been demonstrated to reduce the rise time of the VA-type LC displays, but the sustained pretilt angle leads to a somewhat long fall time. [6, 13] Adding chiral material has been also demonstrated to reduce the response time of the VA-type cell. [14]

Recently, a VA pi cell fabricated from homeotropically-treated substrates with parallel rubbing has been demonstrated to have a faster response time and a more symmetrical viewing angle than conventional VA cells with anti-parallel rubbed substrates. [15, 16] This work explores the switching characteristics of the polymer-stabilized VA pi cell. The obtained results show that the formed polymer networks in the cell significantly reduce the response time of the cell. The fast switching mechanism of the cell is discussed.

2. Experimental

A cleaned indium tin oxide (ITO) glass substrate was coated with [3-(trimethoxysilyl)propyl]octadecyl-dimethylammonium chloride (DMOAP), which was adopted to produce the homeotropic alignment layer. The VA pi cell was assembled from two identical DMOAP-coated substrates. The top and bottom substrates of the cell were rubbed in parallel. The rubbing process generated a small deviation of the LC director from the substrate normal in the field-off state, by less than 1 degree. The cell thickness was 4.25 μm . The nematic LC was ZLI-2806 and the monomer was RM257 (both from Merck). A little photoinitiator Irgacure 651 (from Ciba Additive Corp.) was added to the LC/monomer mixture to initiate the polymerization of RM257. The empty cell was filled with the LC/monomer mixture and then polymerized at room temperature under UV irradiation. The curing intensity was $\sim 4 \text{ mW/cm}^2$ and the curing time was 2 hours. Notably, there was no clear evidence or additional proof for the claim of pi cell structure under the formation of polymer networks. A He-Ne laser (632.8 nm) was used to characterize the electrooptical properties of the cell, which was positioned between a pair of cross-polarizers, with the rubbing direction at

45 degrees to the transmission axes thereof. The transmittance versus applied voltage (T-V) curve, the field-on response time (rise time) and the field-off response time (fall time) of the cell were measured. The rise time (fall time) was defined as the time taken for the transmitted intensity to change from 0 % (90 %) to 90 % (10 %) when a pulse-voltage was supplied.

3. Results and discussion

At the beginning of this experiment, the switching characteristics of the VA pi cell and the conventional VA cell, which was fabricated using two DMOAP-coated substrates that were rubbed in anti-parallel, were studied. The obtained results are similar to those in another work [15]: the rise time of the VA pi cell is similar to that of the conventional VA cell, but the fall time of the VA pi cell is slightly less than that of the conventional VA cell, because the LCs that neighbor the bottom and top substrates of the VA pi cell have the same flow direction, which accelerates the relaxation of the LCs on the falling edge of the pulse-voltage. Then, the switching characteristics of the polymer-stabilized VA pi cell are investigated. Figure 1 presents movies of the pristine VA pi cell and the polymer-stabilized VA pi cell under a polarized optical microscope (POM). As presented in Fig. 1(a), when a voltage is applied to the cell, a complex defect structure comprising umbilical and Schlieren defects grows. The neighboring defects attract each other and thereby slowly annihilate each other. However, in the polymer-stabilized VA pi cell, the formed polymer networks substantially inhibit the growth and annihilation of the LC defects, as displayed in Fig. 1(b).

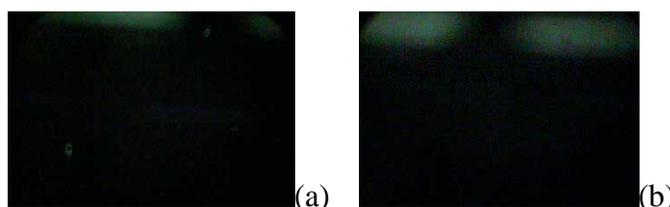


Fig. 1. (3.65 MB) POM movies of (a) pristine VA pi cell and (b) polymer-stabilized VA pi cell with 0.2 wt% monomer. The amplitude of the applied voltage is 10V.

The complex defect structure significantly influences electro-optical response of the VA pi cell. Figure 2 displays the measured switching characteristics of the pristine VA pi cell and the polymer-stabilized VA pi cell. As displayed in Fig. 2(a), in the pristine VA pi cell, when the 5 V pulse-voltage is applied to the cell abruptly, a small bounce appears on the optical response curve of the cell. As the amplitude of the pulse-voltage increases, the optical bounce and associated rise time of the cell increase significantly. Comparing Figs. 1(a) and 2(a) reveals that the generation of optical bounce is attributed to the growth and annihilation of the complex defect structure. However, as presented in Fig. 2(b), in the polymer-stabilized VA pi cell, the cross-linked polymer networks disturb the flowing of the LCs, suppressing the optical bounce of the LC cell and thereby effectively reducing the associated rise time of the cell.

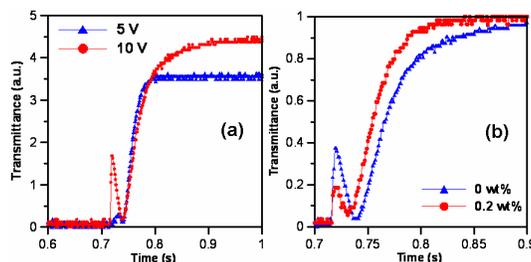


Fig. 2. (a) Switching characteristics of pristine VA pi cell under applied pulse-voltages of 5 V and 10 V; (b) Switching characteristics of pristine VA pi cell and polymer-stabilized VA pi cell with 0.2 wt% monomer. The amplitude of the applied pulse-voltage is 10 V.

The response time is a critical consideration for LC cells. A short response time improves the performance of the LC device. The rise time τ_{on} and fall time τ_{off} of the LC device depend on the cell thickness d , the viscosity γ_1 and the effective elastic constant k_{eff} : [17]

$$\tau_{on} = \frac{\gamma_1 d^2}{\epsilon_0 |\Delta\epsilon| V^2 - k_{eff} \pi^2} \quad (1)$$

$$\tau_{off} = \frac{\gamma_1 d^2}{k_{eff} \pi^2}$$

Figure 3 plots the measured voltage dependent rise, fall and total response times of the polymer-stabilized VA pi cells at various monomer concentrations. As shown in Fig. 3(a), when the amplitude of the pulse-voltage is low (such as less than 5V), the effects of the LC flow and associated optical bounce are negligible, and the amplitude of the pulse-voltage dominates the rise time of the cell. Accordingly, the rise time declines as the amplitude of the pulse-voltage increases. However, when the amplitude of the pulse-voltage exceeds 5 V, the rise time of the cell increases with the amplitude of the pulse-voltage, suggesting that the growth and annihilation of the LC defects and the associated optical bounce dominate the rise time of the LC cell. Interestingly, if the amplitude of the pulse-voltage is high, then the rise time of the cell also substantially declines as the monomer concentration increases, because the formed polymer networks effectively inhibit the optical bounce of the LC cell. Notably, when the amplitude of the pulse-voltage is low, the formed polymer networks do not significantly impede the reorientation of the LCs on the rising edge of the pulse-voltage. Hence, the rise time of the cell is almost independent of monomer concentration. Figure 3(b) plots the measured fall time of the polymer-stabilized VA pi cell. As shown in the figure, the fall time of the cell increases slightly with amplitude of the pulse-voltage because the reorientation angle is increased. The fall time also decreases as the monomer concentration increases, because vertically-aligned polymer networks are formed during polymerization. [18] The anchoring force generated by the vertically-aligned polymer networks accelerates the relaxation of the LCs on the falling edge of the pulse-voltage, markedly reducing the fall time of the cell. Figure 3(c) plots the measured total response time (rise time + fall time) of the cell. The total response time of the polymer-stabilized VA pi cell with 0.5 wt% monomer is ~ 25% of that of the pristine VA pi cell when the amplitude of the applied pulse-voltage is ~ 6 V.

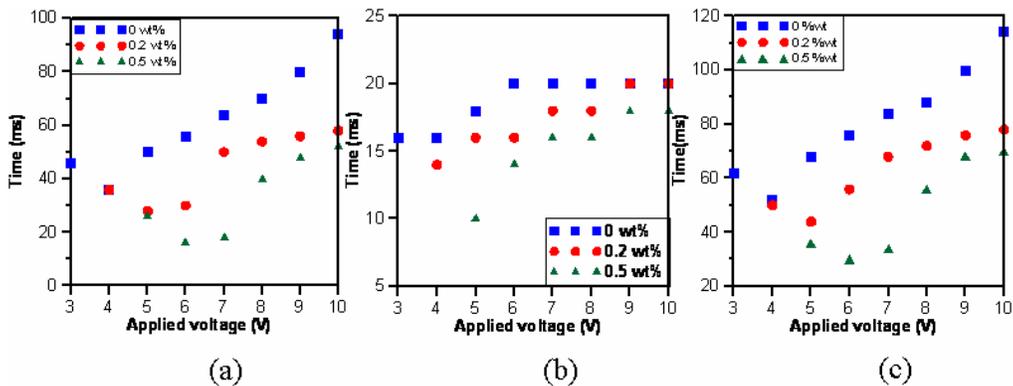


Fig. 3. Voltage-dependent (a) rise, (b) fall and (c) total response times of polymer-stabilized VA pi cells at various monomer concentrations.

As revealed by the above results, the dynamics of the LC defect structure and the associated optical bounce substantially increase the rise time of the VA pi cell. Adding monomers and the formation of polymer networks throughout the cell effectively inhibit the optical bounce and thereby reduce the rise time of the cell. However, the suppression of the optical bounce is not total. Therefore, a new driving scheme is demonstrated to eliminate completely the optical bounce and hence further improves the rise time of the VA pi cell. Figure 4 plots the optical responses of the pristine VA pi cell and the polymer-stabilized VA pi cell under the conventional pulse-voltage scheme and the proposed step-voltage scheme. As presented in Fig. 4(a), the conventional pulse-voltage scheme drives the pristine VA pi cell by directly applying a high voltage of 10 V, which produces a significant optical bounce and thus gives the cell a slow rise time of ~ 95 ms. However, under the proposed step-voltage scheme, the rise time is reduced significantly to 35 ms. The proposed step-voltage scheme involves the low step-voltage of 5 V, following the driving-voltage of 10V. The initially low step-voltage effectively prevents the generation of an optical bounce and thus markedly reduces the rise time of the cell. The amplitude of the low step-voltage is slightly smaller than the voltage that will generate an optical bounce in the cell. A similar result is also obtained in the polymer-stabilized VA pi cell with 0.2 wt% monomer. As shown in Fig. 4(b), the rise time of the cell determined using the conventional pulse-voltage scheme is ~ 60 ms. However, the rise time determined using the step-voltage driving scheme is ~ 30 ms. Notably, the step-voltage driving method in the pristine VA pi cell is more effective than that used in the polymer-stabilized VA pi cell, because the LCs in the pristine VA pi cell have more obvious flow motion.

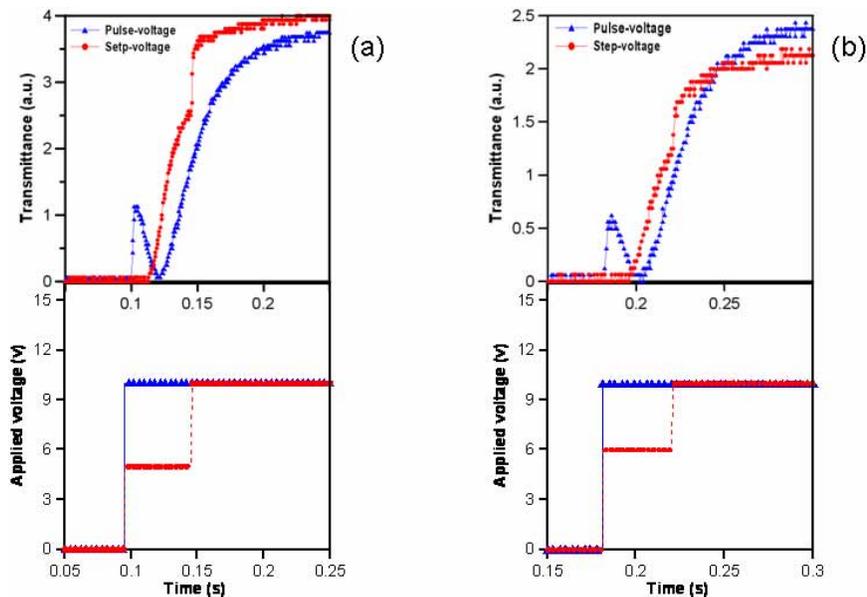


Fig. 4. (a) Optical responses of pristine VA pi cell under conventional pulse-voltage and proposed step-voltage; (b) optical responses of polymer-stabilized VA pi cell with 0.2 wt% monomer under conventional pulse-voltage and proposed step-voltage.

4. Conclusions

Earlier studies have demonstrated that VA cells fabricated with polymer sustained alignment technology at the substrate surface markedly improve the rise time of the cell. [6, 13] However, the fall time of the cell is long. This paper investigates the switching characteristics of the polymer-stabilized VA pi cell. The obtained results show that the rise time of the cell at

high voltage is reduced by the suppression of the optical bounce of the LC cell by the formed polymer networks. The fall time of the cell declines because the vertically-aligned polymer networks accelerate the relaxation of the LC molecules on the falling edge of the applied pulse-voltage. The formed polymer networks slightly disturb the alignment and reorientation of the LC molecules, causing the cell to have a tiny dark state light leakage and to have a higher threshold voltage. Finally, a new driving scheme is demonstrated to improve further the rise time of the VA-type cell. The rise time of the pristine VA pi cell determined using the proposed step-voltage driving scheme is ~ 30% of that determined using the conventional pulse-voltage scheme. The rise time of the polymer-stabilized VA pi cell determined using the proposed step-voltage driving scheme is ~ 50% of that determined using the conventional pulse-voltage scheme. The proposed driving scheme can also be applied to a cell in which the flow of LCs increases the field-on response time of the LC cell. The detailed polymer network morphology, the relationship between the polymer networks and the motion of the LCs are studied. Further study of the optimization of the cell will result in the development of a polymer-stabilized VA pi cell for rapid switching and flexible display applications.

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