37.3: Optimization of Photo-Aligned Asymmetric Ferroelectric Liquid Crystal Display Performance: Effect of Planar Layer

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Abstract

Photo-aligned ferroelectric liquid crystal (FLC) display reveals a perfect alignment in case of asymmetric boundary conditions, when the competition in aligning action of two solid surfaces is avoided. In this case a stable uniform photo-alignment on one of the cell substrates spreads out to the other, which is prepared to sustain planar alignment with a degenerate azimuthal direction. In the paper, a thin polyimide film was involved to improve smoothness of planar substrate, resulting in the better electrooptical properties of FLC display. A contrast ratio of 300:1 in a static addressing mode and 82:1 in a multiplex mode was demonstrated together with a perfect bistable switching of FLC display in static and multiplex addressing regimes.

1. Introduction

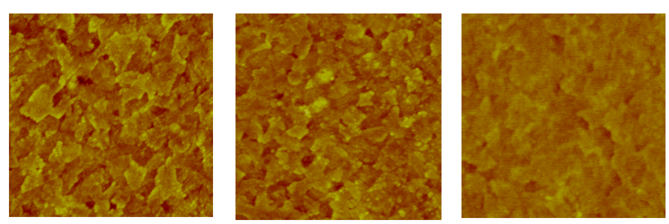
The phenomenon of the defects formation and bistability degradation in ferroelectric liquid crystal (FLC) displays aligned with traditional rubbing technique has been reported [1]. Homogeneous, reproducible and steady FLC alignment is very important for FLC bistable switching. A new non-contact alignment technique, photo-alignment, looks very promising for FLC display, due to its advantage of avoiding mechanical damage, electrostatic charges and impurities. Homogeneous, reproducible and steady FLC alignment is very important for FLC bistable switching. Various kinds of aligning surfaces, including polyimide (PI) films and photochemical layers were studied, to improve FLC alignment quality. A hybrid of linearly photopolymerized photo-alignment (LPP) with liquid crystal polymer (LCP) layers provides a very good alignment of deformed helix ferroelectric (DHF) FLC with the contrast ratio more than 200:1 as well as the electrooptical response time less than 200 μs [2]. The photo-alignment proves to be useful also for polymer-stabilized V-shape and half-V-shaped FLC displays due to a low operation voltage [3]. A normal sufficiently long UV-illumination on PI film was shown to promote defect-free alignment of surface-stabilized FLC layer due to a possible generation of low pretilt angle of FLC on the substrates [4].

An azobenzene sulfuric dye, SD-1, has been recently synthesized and successfully tested for the alignment of FLC displays. A remarkable property of this azo-dye is pure reorientation of molecular absorption oscillator perpendicular to UV light polarization without any photochemical transformations [5]. This property gives a good chance to provide a high photo-alignment quality of FLC using the azo-dye layer [6,7]. In the previous works, asymmetric boundary condition of FLC cell was applied in order to avoid a competition in aligning action of solid surfaces of the cells and provide the best alignment uniformity [6]. That was, only one ITO surface of FLC cells was covered with photo-aligning layer, while another one was simply washed in N,N-dimethylformamide (DMF) [6,7]. The ITO substrate washed in DMF, provides a planar azimuthally degenerated alignment, where all directions in the plane of the substrate are energetically equivalent. On the contrary, the photo-aligning substrate provided a preferable direction for the alignment of FLC molecules. The existence of preferable direction in just one surface minimizes the density of defects, if another solid surface provides the degenerated planar alignment.

In the asymmetric boundary structure, it was found not only the quality of photo-aligning layer, but also the roughness of ITO surface affected FLC alignment. As FLC alignment strongly depended on the qualities of substrates, a uniform photo-aligning layer or smooth ITO surface would lead to the better electrooptical performance of FLC display. In the paper, a method involving an additional polyimide layer was applied to smooth ITO substrate, in order to achieve smaller roughness and better quality, thus considerably improving FLC display characteristics.

2. Experiment

The polyimide PMDA-ODA (polymeric dianhidride and 4,4'-oxydianiline) with high purity, PI-10, was used in the experiment. It was dissolved in DMF, at the ratios varying from 1:70 to1:10. The PI-10 solutions were spin-coated on ITO surfaces instead of pure DMF washing, and then baked on 230°C for 90 minutes. Figure 1 shows the Atomic force microscopy (AFM) pictures of the samples with different concentrations, in comparison with the highly rough ITO surface, which was only washed by DMF. As the PI-10 concentration increases, the thickness of PI-10 also increases and the roughness of ITO surface becomes smaller.



(a) (b) (c)

Figure 1. 2.5×2.5μm^2 AFM pictures of ITO surface with (a) DMF washed, (b) 1:40 PI-10/DMF covered and (c) 1:10 PI-10/DMF covered. The sizes of the contours are: (a) 25.335nm, (b) 15.728nm, and (c) 12.129nm.

The photo-alignment was obtained by covering 0.4% SD1/DMF solution on glass substrates and then exposing the substrates by linearly polarized UV light with the wavelength of 365nm and the intensity of 6mW/cm^2. After the treatments, the PI-10 covered ITO substrates together with the photo-aligning ITO substrates

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were used to fabricate FLC cells. Such modified asymmetric boundary conditions of the FLC layer have been arranged in the framework of the present investigation as shown in Figure 2.

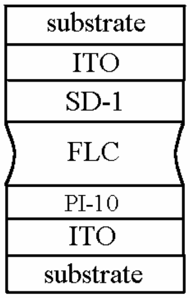


Figure 2. Asymmetric boundary structure of the photo-aligned FLC cells.

An FLC mixture FLC-408A from P. N. Lebedev Physical Institute of Russian Academy of Sciences was injected into the cell in an isotropic phase by a capillary action, with the cell gap of 1.5 µm. Figure 3 shows the FLC textures in the cells with different concentrations of PI-10 used for the preparation of the planar layer. It was found that with the PI-10 concentration of 1:40 and 1:50, the aligning layers were the most uniform and highly qualified.

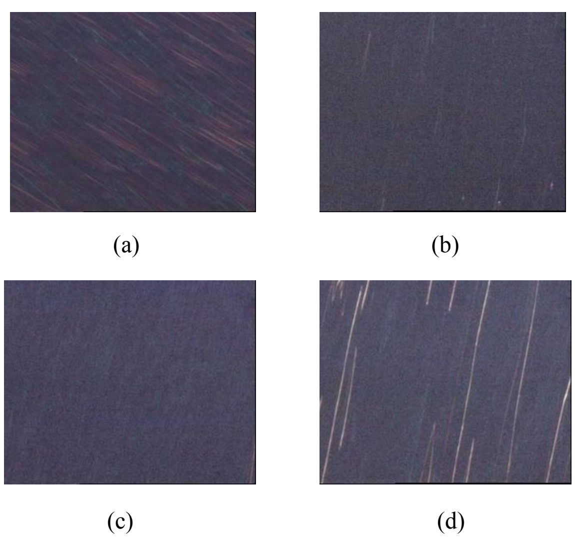


Figure 3. FLC textures of the cells with different concentrations of PI-10, used to prepare the planar layer: (a) 1:60, (b) 1:50, (c) 1:40, and (d) 1:30.

3. Electrooptical performance of FLC cells

The electrooptical properties of FLC display were measured in the multiplexing mode. Figure 4 shows the contrast ratio (*CR*) and multiplexing steadiness parameter, noise/signal ratio (*N/S*) of the FLC cells prepared with different PI-10 concentration, in comparison with FLC cell prepared without the treatment. The *N/S* ratio was defined, as the ratio of the FLC transmission response to the switching pulse to this one of the cross-talking pulses [6]. It was found that, in 1:50 PI-10/DMF case the FLC cell could achieve an electrooptical response with the highest contrast ratio *CR* of 82:1 and low *N/S* ratio of 0.05; while in 1:40 PI-10/DMF case, *CR* of 75:1 and the lowest *N/S* ratio of 0.035 were obtained. The FLC display exhibited the best performance in these two cases, because the FLC alignment was highly uniform as shown in Figure 3.

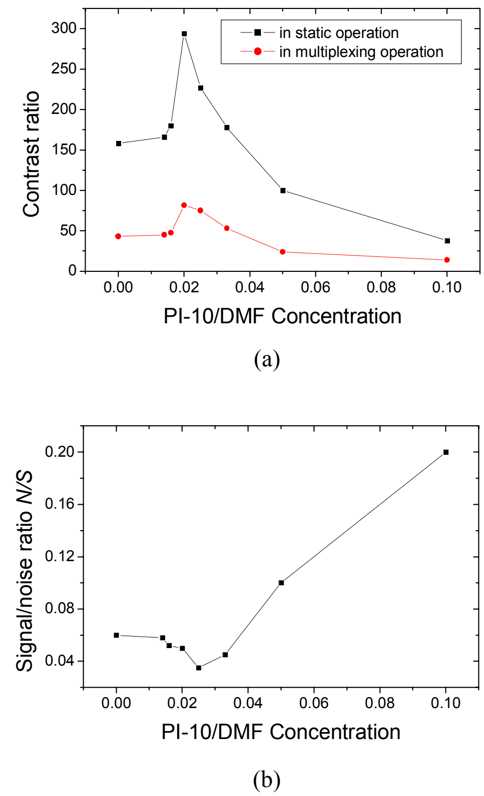
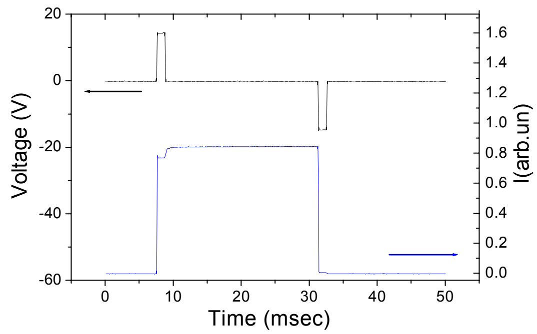
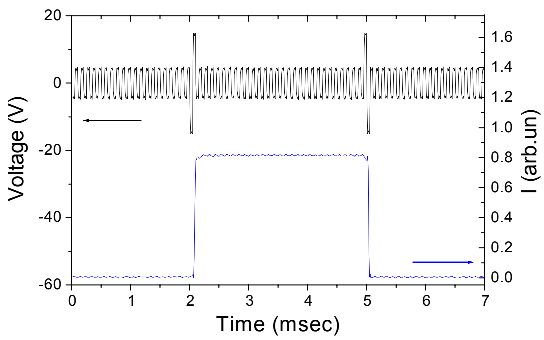


Figure 4. Contrast ratio and (b) multiplexing steadiness parameter *N/S* ratio of the FLC cells with different PI-10 concentrations, under the static and multiplex addressing

Figure 5 shows the electrooptical response of FLC cell with 1:40 PI layer under the static and multiplex addressing. The FLC cell was driven in a static regime by a pulse with 15V amplitude and 1ms duration. Ordinary Seiko-standard multiplexing scheme [1] was applied as multiplexing addressing, providing the addressing and cross-talking pulses at a ratio of 3:1 in amplitude. The driving device provided ±10 V and ±5 V bi-polar pulse for the row and the column of the FLC cell respectively. With the Seiko addressing scheme, the resulting voltage across the pixel was ±15 V for selecting state and ±5 V for non-selecting state. Due to the low *N/S* ratio obtained in Figure 4(b), the bistable switching under the multiplexing operation was steady and excellent, almost as same as the performance under the static mode. When the PI-10 concentration was larger than 40:1, the cell optical performance drastically changed to the worse. When the PI layer was too thick, the parasitic capacitance of the PI smoothing layer became to high, thus efficiently screening the electric field applied to the FLC cell [1]. The latter resulted in a poor contrast ratio and high *N/S* value. Thus it has been obtained that for PI–10 concentration of 1:40~50, a uniform thin layer onto ITO surface was formed, which would result in excellent electrooptical performance on the photo-aligned FLC displays with asymmetric boundaries.



(a)



(b)

Figure 5. Electrooptical response of photo-aligned 1.5 µm FLC-408A cell with 1:40 PI layer under (a) static and (b) multiplex operations.

Through the above improvement of photo-aligned FLC cell fabrication, a good electrooptical performance had been obtained, including perfect bistable switching, high contrast ratio, and high multiplexing steadiness. The FLC dark and bright states were memorized stable after the driving voltage was switched off. Figure 6 shows the 1.5um photo-aligned FLC-497 display under static operation. Its contrast ratio was high and the viewing angle was wide enough to be 80°.

Figure 6. 1.5 µm photo-aligned FLC-497 display with good bistability and wide viewing angle after the driving voltage was switched off.

Some FLC cells with thicker cell gaps of 5 µm or 7 µm, were also made in comparison with the traditional 1.5 µm FLC cells. It was observed that, higher FLC layer thickness would lead to increase of bistable and multiplex operation steadiness. Besides, its main advantage is easier fabrication and manufacturing. The mentioned effect occurs generally at the expense of an increase of *N/S* ratio in the multiplexing mode, but this drawback could be overcome via a proper selection of an optimal driving waveform. Figure 7 shows the 7 µm 64×64 passively addressed photo-aligned FLC display, under the multiplexing operation. The display matrix was 33×33mm^2. The generation and memorizing of images during several days after switching off the driving voltage has been observed. So, photo-aligned FLC display cells exhibited remarkable properties and the production of passively addressed bistable display devices is envisaged.

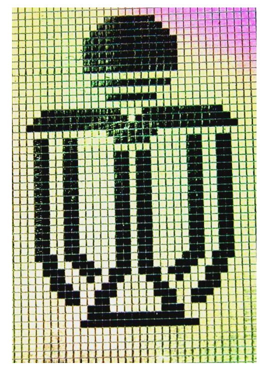


Figure 7. The image generated by 7 µm 64×64 passively addressed photo-aligned FLC display, which is memorized after the driving voltage is switched off.

4. Conclusions

The effect of planar layer on electrooptical performance of asymmetric photo-aligned FLC display was investigated. The asymmetric boundary conditions were obtained, when only one substrate of FLC cell was covered a photo-aligning layer with some preferable direction; while another one with a thin PI-10 layer to provide a planar azimuthally degenerated alignment. An addition of PI-10 layer with optimal thickness could reduce the roughness of ITO surface and make the planar layer smoother. The PI layer on ITO surface should not be too thick; otherwise a large parasitic capacitance worsens the optical performance. A highly uniform alignment of FLC cell with superior electrooptical response was obtained by this treatment. A contrast ratio of 300:1 in a static addressing mode and 82:1 in a multiplex mode was demonstrated together with a perfect bistable switching of FLC display. The minimal noise from cross-talking pulses in a multiplexing mode was shown to be less than 3.5% under the Seiko-standard addressing scheme. The new photo-alignment technique could be a decisive factor of the promotion of new FLC devices to the display market.

5. References

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