P-156: Alignment of Ferroelectric Liquid Crystals with the Substrates Processed by Plasma-Beam

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Abstract
Plasma beam procedure earlier adapted for alignment of nematic liquid crystals and reactive mesogens is successfully applied for alignment of ferroelectric liquid crystals. Highly uniform alignment of "chevron" structure (before electrical treatment) and "quazi bookshelf" structure (after electrical treatment) are realized. In the latter case, the contrast of bistable switching is larger than 350:1 for 650 nm wavelength. This makes the non-contact plasma alignment procedure especially attractive for high contrast bistable LCD on LCOS base particularly used in PDA and E-books. Fast switching and realization of gray scale in the plasma beam aligned FLC cells makes this technique also promising for full color displays including color TV LCD.

1. Introduction

Because of bistable switching, ferroelectric liquid crystals (FLC) excel in fast electrooptic response and ultra-low power consumption. This makes them especially promising for fast switchers, high-contrast economy-type LCD for portable devices, and LCD for color television.

These applications require FLC layers of good alignment uniformity. However, good alignment of FLC can not be easily attained, as in case of nematic LC, because of layered helical structure. The alignment force shall not only provide uniform alignment of FLC layers, but also suppress helix of the vector of spontaneous polarization. In practice this problem is solved either by introduction of the aligned polymer networks [1] or by proper treatment of boundary substrates confining FLC film. In the latter case, in parallel with traditional rubbing, alternative alignment processes has been considered. Among them are photoalignment [2, 3], vapor [4, 5] and ion beam sputtering deposition [6] of SiO_x layers.

In the present paper we consider novel approach of improving alignment quality of FLC films. It consists in anisotropic etching of the alignment substrates by the obliquely incident beam of accelerated ions or plasma. Recently, this process was successfully applied for alignment of conventional nematic LC [7, 8] and "passive" LC like reactive mesogens and semiconducting LC used in optical films and surface electronics [9]. This technique provides excellent alignment uniformity of LC on macroscopic and microscopic scale, wide range variation of pretilt angle and anchoring energy, and good electrooptic performance. The present paper shows that plasma beam alignment can also be successfully extended for FLC alignment.

The aligned by this method FLC films are of excellent uniformity and demonstrate high electro-optic contrast. The most effective applications of this procedure are discussed.

2. Experimental

2.1 Preparation of the substrates

As the bounding substrates we used films of polyimide AL3046 from JSR. The polymer layers were spin coated at 3000 rpm on glass slides (2x3 cm) containing patterned ITO electrodes and subsequently backed at 80^o C for 5 min and then at 180^o C for 1h. In following, the substrates were processed by the beam of plasma.

2.2 Treatment Procedure

For irradiations, we used anode layer source (ALS) with a race track shaped glow discharge area [7, 10]. In the beam mode, this source generates two "sheets" of accelerated plasma with a width of 25 cm (Fig. 1 a). The device operated in the regime of low energies (E=500-800 eV) and currents (j=5-20 μA/cm^2). The source was set for oblique irradiation. The incidence angle of plasma beam was about 70^o. The distance between discharge area

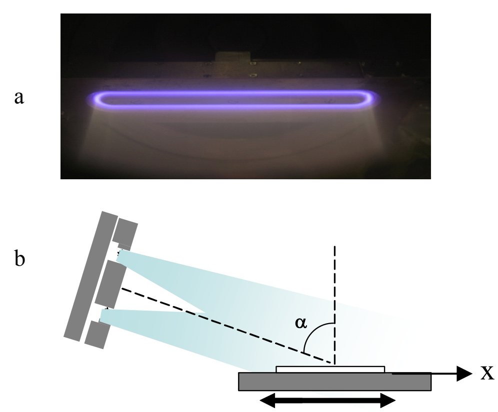

Figure 1: Photograph of ALS and generated plasma "sheets" (a) and geometry of plasma beam irradiation of alignment substrates (b).

and treated substrates was about 20 cm. The substrate's holder was moved with the PC controlled moving system providing cycling translation in the horizontal plane, as shown in Fig. 1b. The translation amplitude was 3 cm, while the translation speed was 2.5 mm/s. The translation regime of irradiation provided uniform treatment over the whole substrate area. The treatment time was varied between 1 and 30 min. Surface morphology of polyimide films was studied by using AFM device NanoScope IIIa from Digital Instruments working in tapping mode.

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2.3 FLC cells

For the alignment tests, the FLC cells were assembled with parallel alignment of plasma treated substrates on both sides. The cell gap was maintained with 3 µm spacers. The cells were filled with FLC material FELIX 017/100 from Clarian. Phase transition temperatures of this material are I 87°C N 77°C S_A 73 °C S_{C*} -28 °C X so that at the ambient temperatures this material is in a ferroelectric chiral smectic C mesophase. FELIX 017/100 has spontaneous polarization around 47 nC/cm^2. The FLC was filled in the cells in isotropic phase. After filling, the cells were slowly cooled down with a speed of 1-2 °C per minute up to room temperature.

2.4 Electro-Optics Measurements

Electro-optical measurements were carried out based on a He-Ne laser, DAQ board (PCI-MIO-16E-4 from National Instruments Corporation), voltage amplifier (Model: 7600 wideband amplifier from KROHN-HITE Corporation) and a rotating table for adjusting an angular position of the FLC cell placed between crossed polarizer's [11]. A special software program was developed for the calculation of experimental data.

3. Results

3.1. Nanotopology of alignment films.

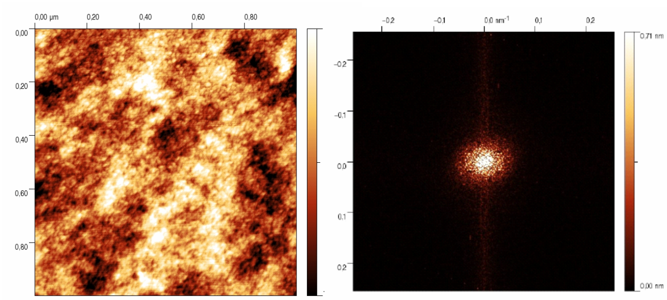


Figure 2: 2D AFM image (a) and its Fourier transformations (b) for nonprocessed polyimide film.

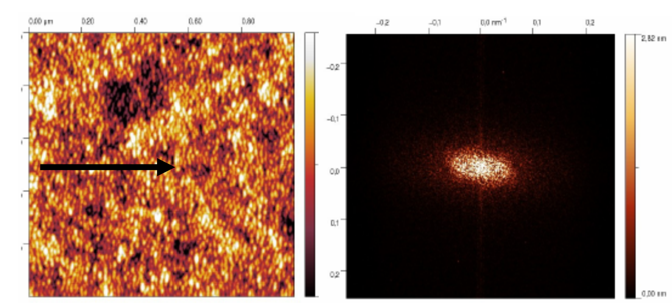
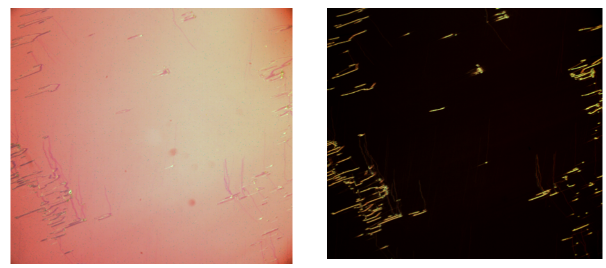


Figure 3: 2D AFM image (a) and its Fourier transformations (b) for the polyimide film obliquely processed by plasma beam during 20 min. Arrow in (a) shows surface projection of plasma beam.

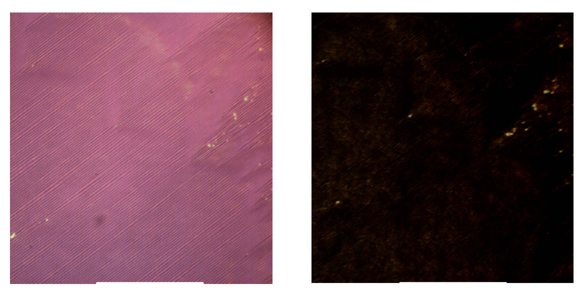
According to Figure 2, the unprocessed PI films have moderate roughness and isotropic topology. Plasma treatment strengthens surface roughness and induces relief anisotropy. The direction of minimal roughness was either in the direction of surface beam projection (low exposure doses) or in the perpendicular direction (higher doses). In the latter case, anisotropy of surface relief is especially pronounced (Fig. 3); a ripple structure arises similar to that which is usually formed on the surface of inorganic films [12]. As we checked, conventional *nematic* LC align in the direction of minimal roughness, i.e., in the direction of surface beam projection at low plasma fluences and in the perpendicular direction at higher doses. This is in full accordance with Berreman rule [13]. These alignment types of nematic mixtures we called the 1st and the 2nd alignment mode [7, 8].

3.2. Alignment of FLC



a b

Figure 4: Textures of FELIX-17 FLC layer aligned between two plasma beam processed PI substrates. (a) bright state; (b) dark state. No electrical treatment was preliminary applied.



a b

Figure 5: Textures of FELIX-17 FLC layer aligned between two plasma beam processed PI substrates. (a) bright state; (b) dark state. Cell is preliminary treated with electric field.

The FLC alignment on the plasma beam treated substrates was observed in the wide range of exposure doses. However, the alignment quality was considerably better for the higher doses, corresponding to the 2nd mode alignment of nematic LC. Because of this, high exposure doses were chosen in further work. Figure 4 shows a texture of FLC cells observed in polarizing microscope under crossed polarizers. This is a chevron texture with high alignment quality. The zigzag defects is this cell are practically eliminated. Presumably, smectic layers in this cell are in C1 geometry because of moderate values of azimuthal anchoring on plasma beam processed substrates [14]. Similarly to substrates subjected to other alignment treatments [6], we observed structural transition from chevron structure to quasi-bookshelf structure [15] after cell training in an electric field. The electrical treatment was done by applying for 5 minutes alternative voltage of rectangular wave form with amplitude10 V and frequency 10 Hz. The resultant quasi-bookshelf structure is shown in Figure 5.

3.3. Electro-optic performance

Figure 6 shows electro-optical response of FLC cell on the rectangular driving signal with amplitude 5 V and period 1 ms. The cell was not preliminarily treated with an electric field. There is evident that switching time is less than 200 µs. The treated cell shows similar response time.

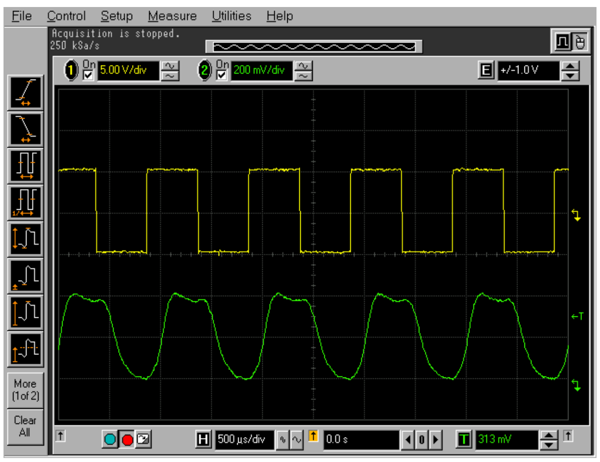


Figure 6: Optical response of FLC cell on the rectangular driving signal with amplitude 5 V and period 1 ms.

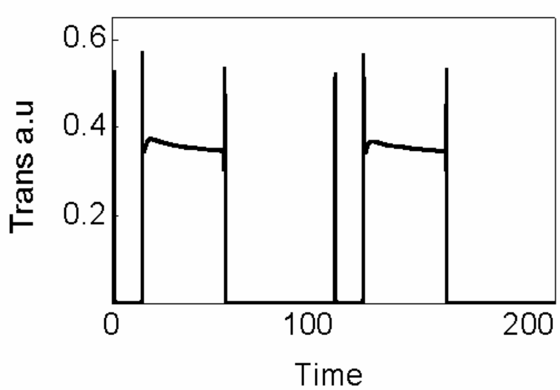


Figure 7: Optical response of the electrically treated FLC cell on the bipolar rectangular driving pulse with the amplitude of 20 V and duration time of 1 ms. Switching contrast is higher than 350:1.

On the next stage, the electro-optical response of FLC cell on the bipolar driving pulse with the amplitude of 20 V and duration time of 1 ms was measured. Figure 7 illustrates the response for the cell previously electrically treated. The contrast of the bistable switching is larger than 350:1 for 650 nm wavelength. Because mechanical contact with the alignment substrate is avoided, this method is especially attractive for the FLC displays on ALCOS base, particularly used in mobile phones, PDA and e-books. Due to new alignment procedure, in addition to high resolution, fast switching and low energy consumption, these displays acquire high electro-optic contrast. The electro-optic contrast of chevron texture is considerably lower (80:1), because C1 structure has much smaller switching cone angle than optimal 45^0.

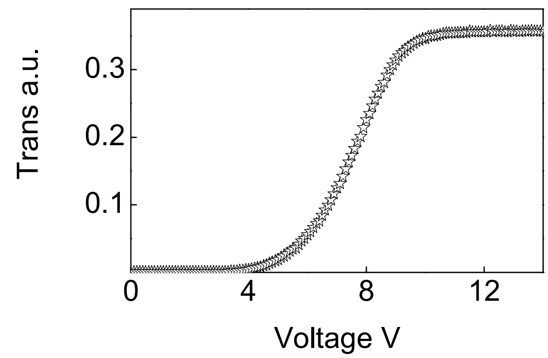


Figure 8: TVC dependence of FLC cell aligned by plasma beam etching process.

Finally, Figure 8 shows the TVC dependence of FLC test cells measured by varying the amplitude of bipolar driving pulse in the range 0~14 V. There is evident that sufficient amount of grey levels can be generated and stabilized. This opens perspectives of plasma beam alignment for full color displays, first of all those based on color sequential principle.

4. Conclusion

In conclusion, plasma beam deposited substrates yield highly uniform and defect free alignment of ferroelectric liquid crystals. Due to this FLC cells show high electro-optic contrast. Besides, they demonstrate fast switching and stable grey scale. This opens good perspectives for this alignment method in a number of known display applications of FLC, such as e-paper, small displays for mobile phones and PDA, and color TV LCD. As we believe, good alignment characteristics obtained by using anode layer source process are common for anisotropic etching processes, e.g. those based on ion beam from Kaufman source [14-16]. However, etching conditions should be thoroughly optimized, seemingly, much better than for nematic LC. According to our results, alignment characteristics of FLC are rather sensitive to surface topology of the alignment films. Excellent alignment on plasma beam treated substrates suggests that it provides anchoring conditions close to optimized for FLC.

5. Acknowledgements

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6. References

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