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Fabrication of a Mono-Domain Alignment Ferroelectric Liquid Crystal Device Using a Polar Self-Assembled Monolayer *

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A mono-domain ferroelectric liquid crystal device (FLCD) is fabricated using a novel method. The cell used in this method is an asymmetric cell, typically the combination of a polar self-assembled monolayer (SAM) for one substrate and a rubbed polyimide for the other substrate. A defect-free alignment of ferroelectric liquid crystal is fabricated without applying a dc voltage to remove degeneracy in the layer structure. The contact angles of self-assembled monolayer and PI-2942 are measured and the polarity of SAM is higher than the PI alignment. It is found that the polarity of self-assembled monolayer is a key factor in the formation of mono-domain alignment of FLC.

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Nematic liquid crystals are currently extensively used in various devices.[1−3] The respond time of liquid crystal devices using nematic liquid crystal is 2 ms, which is slow for some high-quality devices. Ferroelectric liquid crystal (FLC) with N*-SmC* phase transition shows half V-shaped switching and it is useful because of its advantageous characteristics such as high-speed respond, wide viewing angle, high contract ratio, gray-scale capability.[4,5] The optic characteristic is determined by the alignment of ferroelectric liquid crystal. However, it is difficult to obtain the homogeneous layer alignment, When the FLC is cooled down from the N* phase to the SmC* phase without an applied voltage, the number of deviation directions of the smectic layer is two. Thus two domains usually coexist in SmC* phase. Under crossed polarizers, a gray domain and a black domain can be seen. When positive voltage is applied, the gray domain responds, but the black domain does not. However, when negative voltage is applied, the black domain responds, but the gray domain does not. The two domains coexisting deteriorate the quality of displays seriously. Therefore, the mono-domain alignment FLC is important for display. In order to improve the FLC alignment quality, various methods have been investigated, such as polymer-stabilization ferroelectric liquid crystal, where a dc voltages is applied during photocuring of doped monomers,[6] applying an electric field in the cooling process when the cell at the temperature 2–3°C higher than the N*-SmC* phase transition temperature,[7] alkane-based and silane-based cinnamate self-assembled monolayer have been widely studied by rubbing and photoalignment,[8,9] and the contrast ratio is low. However, all of these methods need to apply an electric field in the cooling process. Recently, Okabe *et al.*[10] reported that a mono-domain alignment can be obtained using a polar liquid crystal polymer as an alignment without applying an electric field. In this study, we obtain a mono-domain alignment using polar self-assembled monolayer and rubbed polyimide without applying an electric field.

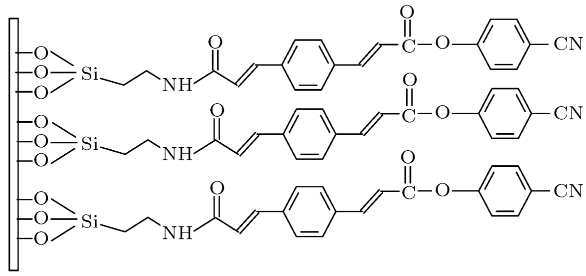

Fig. 1. Chemical structure of self-assemble monolayer.

A polar film was obtained by the self-assembled method. The surface of the cleaned substrate was modified with aminopropyltriethoxysilane in the way described in Ref. [11]. Then the substrate decorated with amino was immersed in 1% solution of photosensitive material used in this study in anhydrous toluene at room temperature and the method of synthesize was described in the Ref. [12]. Then the substrates were cleaned in toluene, ethanol and deionized water in an ultrasonic bath respectively for 2 min and finally dried in a nitrogen stream. Finally, a photosensitive

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self-assembled film was successfully prepared on the substrate. Then the self-assembled monolayer film was vertically irradiated at room temperature by LPUVL for 20 min. The structure of the self-assembled monolayer is shown in Fig. 1. Liquid crystal alignment layer was polyimide PI-2942 (Chisso Corporation). The polyimide was spin-coated on the substrate and prebaked at 80°C for 10 min then baked at 230°C for 30 min. A substrate with self-assembled monolayer and a substrate with rubbed polyimide were assembled as an asymmetric boundary cell, the cell gap was 2 μm. The structure of the asymmetric cell using the polar self-assembled monolayer is shown in Fig. 2. The phase sequences of FLC (R-2301: AZ electric materials) were as follows: isotropic 86°C-N*64.7°C-SmC* $-$ 4°C. FLC material was filled in the cell at the temperature of isotropic phase by capillary action and cooled down with cooling rate of 0.1°C/min. We compare the qualities of three FLC cells: the fist cell was fabricated with two rubbed polyimide, the second cell was fabricated with two SAM films, and the third one was asymmetric boundary cell. Any voltage was not applied in the cooling process of the three cells. Figure 3 shows the dark state micrographs of the three cells. All images were obtained under polarized microscope (BX-51, Olympus) with crossed polarizers. As shown in Figs. 3(a) and 3(b), two layer normal directions generated in the cells with two rubbed polyimide and two SAM substrates. Two domains, black and gray, can be obtained at room temperature. However, as shown in Fig. 3(c), in the asymmetric boundary cell, it is found that one domain is obtained without an applied voltage in the cooling process.

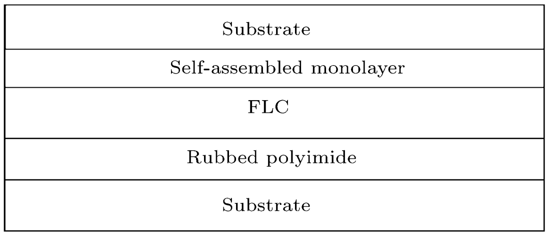

Fig. 2. Schematic drawing of asymmetric boundary cell.

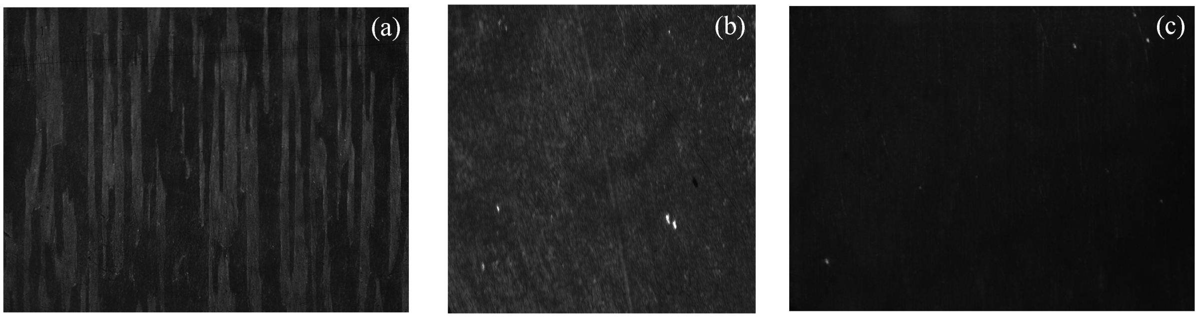

Fig. 3. Polarization microscopy images of the dark state at different boundary conditions: (a) rubbed cell, (b) SAM cell, (c) asymmetric boundary cell.

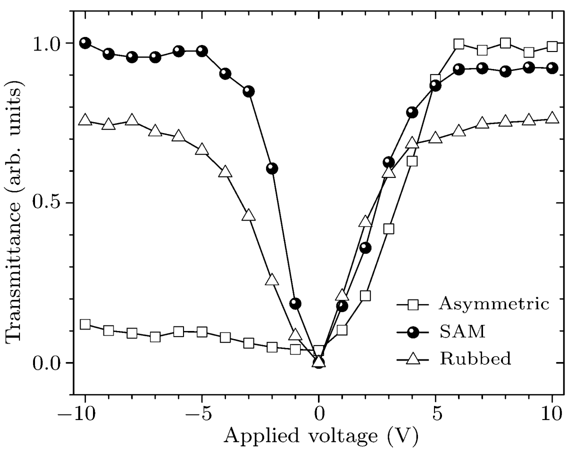

Fig. 4. Electro-optic response of FLC with rubbed cell; SAM cell and asymmetry boundary cell.

The electro-optic characteristic is shown in Fig. 4. There were two domains in the rubbed polyimide and SAM cells, one domain responded to negative voltages, the other responded to positive voltages, therefore the two domains alignment exhibited V-shaped switching. In the asymmetric cell, there was one domain. Ferroelectric liquid crystal only responded when the positive voltages were applied, the monodomain alignment exhibited half V-shaped switching. Contrast ratio is an important characteristic of FLC device and provides information about the alignment. It is defined as the ratio of maximum light transmission to the minimum light transmission through the sample set between crossed polarizers. Figure 5 shows the transmittance curve as a function of rotation angle. The contrast ratio of FLC in the asymmetric cell is up to 700. It is seen that the asymmetric cell using the self-assembled monolayer result a good dark state. It is believed that the self-assembled monolayer is the key material in the asymmetric cell. To clarify the reason for the different alignment films, the contact angles of self-assembled monolayer and PI alignment were measured. The contact angles experiments of water were performed at room temperature. To obtain reliable contact angle, three drops of water which were dispensed in different regions on the same film were measured and two films were used in the experiment. Thus, six contact angles were averaged for each kind of films. The contact angle of water on the self-assembled monolayer is 78° but that of water on PI-2942 is 92°. It is indicated that the polarity of the self-assembled monolayer is higher than that of PI. This is because the self-assembled layer is high ordered by the self-assembly method, the self-assembled monolayer has a CN group at the end of the chain and the CN group is high electrically negative. For planar boundary condition, the ferroelectric liquid crystal molecules have their dipoles pointing into the bulk of liquid crystal cell because this configuration minimizes the energy, this is claimed by experimental evidence.[13] The directions of Ps at bottom and top substrates are opposite in the rubbed polyimide and SAM cells. The FLC bulk alignment is aligned by the surface LC via molecule-molecule correlation through a surface-bulk transition region.[14] Thus, the directions of Ps in FLC bulk are decided by the competition of the two surfaces and two directions could coexist in bulk because the directions of Ps at the two surfaces are different. As soon as the temperature cool to the SmC*, the layer tilts along two different directions in the rubbed polyimide and SAM cells, two domains with opposite sign of polarization are obtained, as shown in Fig. 6(a). The interface between the self-assembled monolayer and ferroelectric liquid crystal is electrically negative because the CN group and the positive Ps of ferroelectric liquid crystal can be attracted by the polar self-assembled monolayer, which leads the Ps point into the substrate. Thus, the directions of Ps are the same in the cell by the attraction of the polar self-assembled monolayer, when the phase transition to SmC*, the layer tilts along one direction and a mono-domain alignment is obtained as shown in Fig. 6(b).

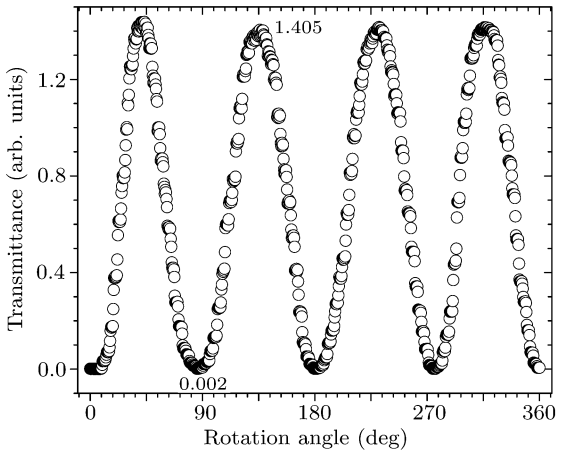

Fig. 5. Transmittance dependence of rotation angle of FLC with the asymmetric boundary cell.

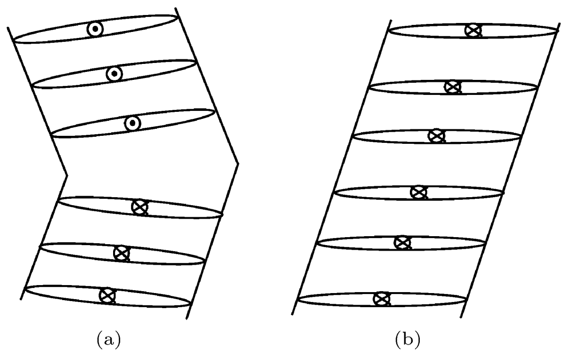

Fig. 6. (a) Two domains structure in rubbed cell and SAM cell; (b) mono-domain structure in asymmetry boundary cell.

In conclusion, we have investigated the alignment of FLC with the asymmetric cell, which combined of a polar self-assembled monolayer and a rubbed polyimide alignment film. A high contrast ratio and mono-domain alignment FLC is obtained in the asymmetric boundary cell without applying voltage. The polar material is very important for asymmetric boundary conditions. It is believed that the polar film is effective control of Ps direction by attracting positive Ps. Compared with applying a dc electric field during cooling process, the asymmetric cell with a polar self-assembled monolayer simplified the manufacturing processes.

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