Dynamic Surface In-plane Switching Property using the Ferroelectric Liquid Crystal on the surface

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Abstract

In-plane switching characteristics of PI rubbed ITO sandwich cell with low molecule FLC (ferroelectric liquid crystal) surface was investigated. FLC on the surface is governed by the applying frequency and surface condition. By controlling the Ps (spontaneous polarization) direction of dual FLC surfaces, switching characteristics are improved without change of cell structure.

1. Introduction

Based on the phenomena of ferroelectric liquid crystal (FLC) switching[1-2] and dynamic commanding surface switching using photo re-arrangement of polymers[3-4], a novel in-plane switching concept[5-6] of electrically dynamic surface was introduced. FLC switching on the surface makes it possible bulk nematic liquid crystal with negative Δε to get in plane switching under vertical electric field due to the cone shape switching by coupling of electric field and spontaneous polarization (Ps). And other groups also introduced similar concepts with experimental results. However, the reported results have been limited to the proof switching itself or idea. And the switching mechanism is little studied. In this letter, we investigated switching properties as applied electrical conditions, in cell structures with more practical cell conditions and electrical driving range using low molecular FLC material.

2. Results

We investigated the switching phenomena as driving frequencies. Firstly, we applied 12V DC electric filed. As result, the optical switching occurred due to the surface rotation of FLC layer. Because bulk layer was filled with negative Δε liquid crystals, the planar state of liquid crystal molecules was strengthened under vertical electric field and liquid crystals rotate in plane. However, the optically switched white state disappeared and went back to the initial black state within short time under DC electric field still applied. On the contrary, as we applied AC electric field about 60 Hz the white state did not disappeared, but the white ON state was unstable and showed random domain and motion of state. And unstable optical oscillation of dynamic switching was shown. (FIG 1)

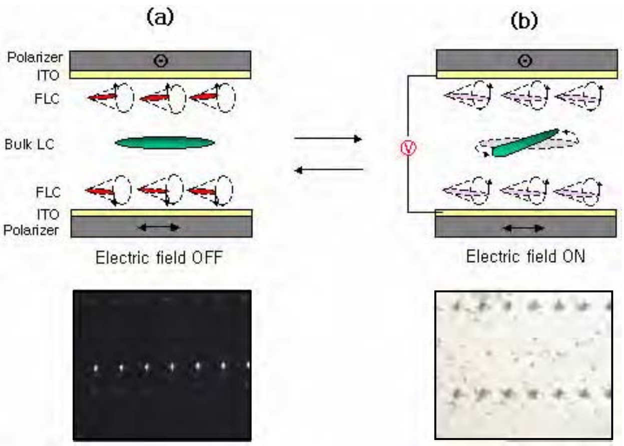

FIG1. Schematic FLC dynamic surface switching and polarized optical images. (a) OFF state , (b) ON state : As increasing the electric field, FLC molecule rotate and induce rotation of nematic molecules.

We also checked electro-optical properties varying applied frequency. The optical oscillations were different as driving frequency of applied AC electric field as shown in FIG 2. This oscillation occurred periodically and this was matched with frequency time. [FIG 2 (c)] And the brightness of optical image was also different as driving frequency. [FIG 2 (a)]

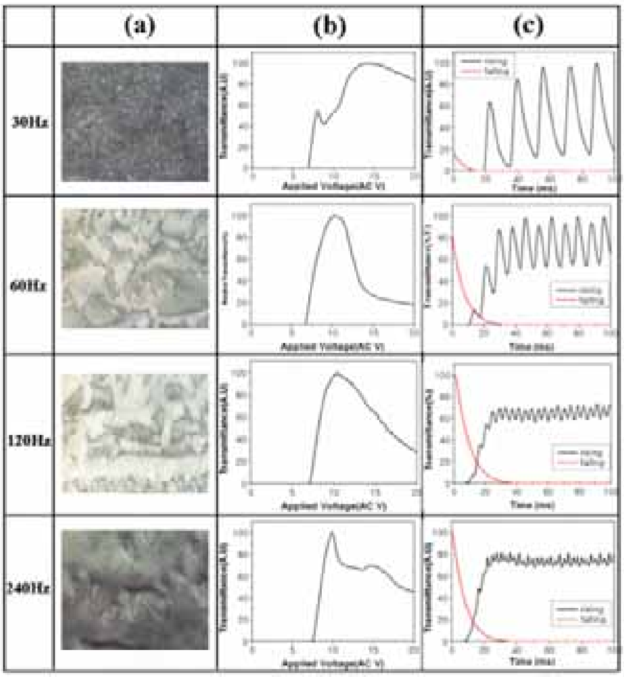

FIG2. Switching characteristics as driving frequencies. (a) Polarized optical images of On-State, (b) Average transmittance as applied voltage, and (c) Dynamic Responding Properties of On-Off switching (0V – Tmax Voltage)

Therefore, we thought that this unstable and periodical switching oscillation could be related with surface switching behaviors as applied electric field. Considering the dynamic response, it was considered that once liquid crystal rotate as the applied electric field and then re-rotate to initial positions surface. These optical oscillations were periodical and dependent on applied signal. The repeating optical switching matched with a half period of applied signal frequency and subsequent switching was observed at every polarity inversion of signal as shown FIG2. The brightness of optical image was also different depending on applied frequency of signal. Around 100~120Hz the transmitted brightness was maximum, but decreased at lower or higher frequency. Hence, it can be considered that this critical switching characteristic is related with dipole properties and conditions of FLC surfaces. Initially FLC layers on both substrates were aligned same direction, but after cell assembly the Ps directions of FLC layers are placed to opposite directions each other.

To compare the effect of surface condition, three different samples were prepared. First sample as shown in FIG 3 (a), was prepared with same ferroelectric surface and had opposite Ps direction, second one had single FLC surface and opposite surface was just conventional rubbed polyimide surface FIG 3 (b), and third one as shown in FIG 3 (c) had FLC surface on both substrates, but DC electric field was applied during N*→ Sc* Phase transition to induce parallel Ps direction.

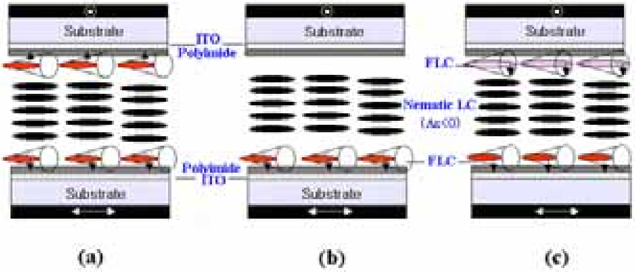

FIG. 3. Three cell structures of different FLC dynamic layers. (a) Cell has dual FLC surfaces, but the Ps (spontaneous polarization) directions are opposite to each other, (b) cell consists of single FLC surface on polyimide alignment layer and the opposite surface of polyimide alignment layer. (c) Cell has dual FLC surfaces and the Ps directions are induced to have same direction by DC induction process. As result, both FLC surfaces have same sensitivity.

Considering transmittance equation (*eq*.1) of in plane switching, the transmittance is dependent on average rotation angle (θ) of liquid crystal optic axis and effective retardation ($d\Delta n$ effective). Where 2θ is the director rotate angle from crossed polarizer, d is thickness of liquid crystal and Δn is the birefringence of liquid crystals.

$$Transmittance = \sin^2(2\theta)\sin^2\left(\frac{\pi d\Delta n_{eff}}{\lambda}\right) \qquad (eq.1)$$

Comparing single and dual FLC surface, the cell with single FLC surface showed higher transmittance than dual FLC surfaces shown as FIG 4 (a), (b). However, the voltage of maximum transmittance (~12V) and VT curve profiles were similar. This indicates that the retardation effect of nematic LC ($d\Delta n_{eff}$ in eq.1) contributes to the difference of transmittance between single FLC surface cell and dual FLC surfaces cell dominantly. Because planar aligned liquid crystals with negative Δε could not change director out of plane and rotate in plane under vertical electric field, Δn was assumed to be not dependent on applied electric field. Therefore, it can be considered that the difference of transmittance between FIG 4 (a) and (b) are caused by the change of the effective liquid crystal layers between FIG 4 (a) and (b). For the case of FIG.3 (a), FLC layers on both substrates were formed equally. But after cell assembly, two FLC layers get to face each other and Ps (spontaneous polarization) directions of FLC layers get opposite to each other. As result, each dynamic FLC surface director get sensitive to opposite polarity of electric field and the switching of each surface hindered the switching of opposite surface. Because two FLCs were sensitive to opposite signal polarity, switching and hindering roles were alternated whenever inversion of signal polarity occurred. This hindering force caused switching oscillations and get to increase as the switching force increased with respect to applied voltage. FIG.4 (c)&(f) show the effect of FLC surface control. Considering electro optical results, the cell after DC induction process showed higher transmittance, lower driving voltage and lower threshold.

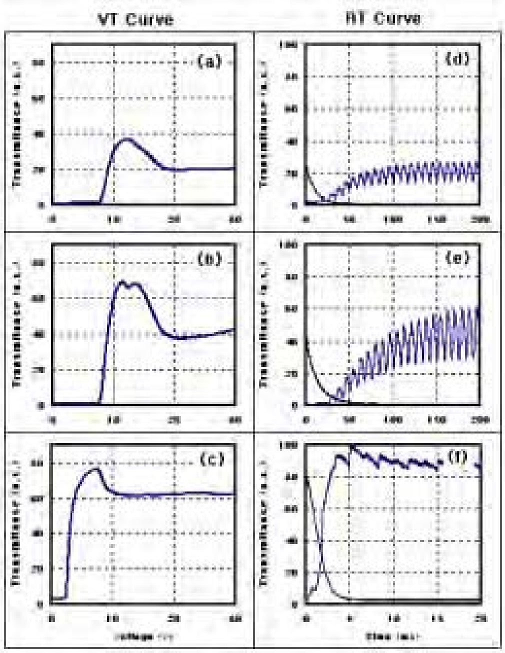

FIG. 4. Electro optical results of three cell that have different structures of FIG 4. (a) (b) and (c) is the VT curves of dual FLC surfaces structure without DC process, single FLC surface structure and dual FLC surfaces structure with DC process, respectively. (d), (e) and (f) is RT curves of dual FLC surfaces structure without DC process, single FLC surface structure and dual FLC surfaces structure with DC process, respectively.

In addition, dynamical switching oscillation was minimized and the response time was also improved to be $\tau_{on} \approx 2$ms and $\tau_{off} \approx 2$ms. Considering that these two cells had the same cell structures and liquid crystals, it could be considered that induction of parallel Ps made it easier to switch at the surface and liquid crystal rotated effectively. From these results, we thought that switching could be improved by just controlling dipole properties of facing dual FLC surfaces without any change of cell structure.

In summary, the switching characteristics by FLC commanding surface switching were investigated using commercial low molecular FLC material. Due to the dipole property of FLC surface, FLC commanding surface switching is dependent on the applying frequency.

Uncontrolled two FLC surfaces in cell structure strongly hindered switching each other and deteriorated cell performances. On the contrary, well control of spontaneous polarization could remove hindering effect of FLC surfaces and improved cell performances were observed.

3. Conclusion

Conventional IPS mode has a critical defect of low pixel aperture ratio due to the electrode structure for in plane field. As a solution of this we thought the idea of using ferroelectric liquid crystal (FLC) alignment layer as dynamic layers. FLC switching makes it possible to get in plane switching without in-plane electrode due to the cone shape switching by coupling of electric field and spontaneous polarization (Ps).

Due to the dipole property of FLC surface, FLC commanding surface switching is dependent on the applying frequency. Well control of spontaneous polarization could remove hindering effect of FLC surfaces and improved cell performances were observed.

4. References

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