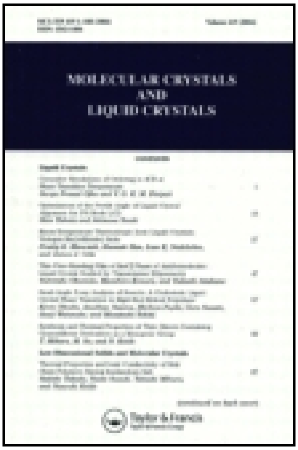

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

V-SHAPED SWITCHING: MODELS AND PHYSICAL REASONS

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 366, pp. 743-750
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V-Shaped Switching: Models and Physical Reasons

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It is shown that the surface plays a crucial role in the V-shaped switching and the inclinations of smectic planes from the normal to a substrate on sufficiently large angles δ may play the role of importance for the observed phenomena. The effects of bulk and surface domains, polarization charges and free ions are considered. The physical reasons for the V-shaped switching in new AFLCs are discussed.

Keywords: ferroelectric; antiferroelectric; switching; surface tension

OBSERVATIONS AND MODELS

The V-shaped switching takes place in a certain part of the temperature interval of existence of the ferrielectric and SmC* phases [1,2]. In some substances the formation of the striped texture along the smectic layer normal was observed during the switching, the smectic layers being approximately normal to a substrate [3]. The domains were visible optically in the absence of an applied electric field. It was discussed [3] that the surface effect plays a crucial role in the V-shaped switching. In the rubbing cell, the width of the domains is much narrower than in the temperature gradient cell. The light transmittance at zero voltage is quite low in the rubbing cell.

In other substances the mentioned striped texture and domains were not observed [4] but the X-ray diffraction investigations had shown the inclinations of smectic planes from the normal to a substrate on large angles δ (a chevron angle ~ $\pi/10$). It was suggested [5] that in the cell bulk the director distribution is homogeneous, while there is a director twisting in a thin subsurface layer near the substrate. It was shown [6,7] that the increase in amount of charged impurities resulted in the change of V-shape and in hysteresis phenomena.

The domains [3] are quite similar to the domains observed in the FLCs [8-10] (see Figure 1a). The inclinations of smectic planes in SSFLC were estimated by X-ray data [9,10] (see Figure 1b).

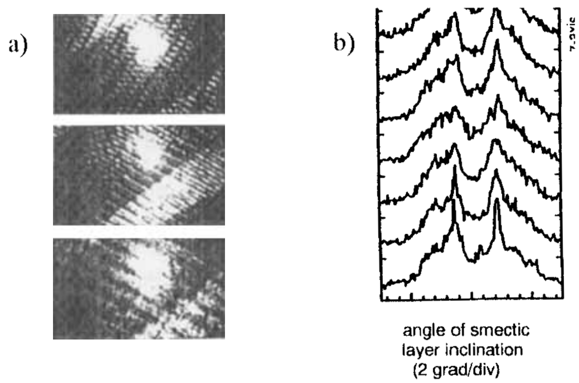


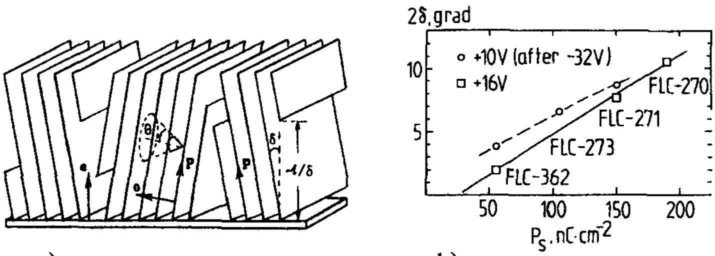
FIGURE 1. Domains and inclinations of smectic layers in the SSFLC materials: a) the temperature change in domain width [8], b) X-ray data on the layer inclinations [10]

The reported experimental data allow to make the conclusion that in the substances under consideration (AFLC mixtures) the charged dislocation walls related to the inclinations of smectic planes in SSFLC [8] may play the role of importance for the observed phenomena.

Really, the chevron angle δ is an inevitable consequence of effects at the interface FLC/substrate [9,10], the δ angle being dependent on the surface anchoring parameters (Φ,W), piezoelectric constant μ, tilt angle $\Theta(T)$, elastic constant K and dislocation core energy u:

$$\delta \propto \frac{\mu\Phi - W\Theta}{\sqrt{Ku}} .$$

The inclinations of both signs are equivalent. They inevitably result in the appearance of dislocation walls possessing the polarization charges (see Figure 2). The polarization charges are favorable for the SSFLC cell if the amount of free ions is enough to neutralize them.



a) b)

FIGURE 2. The surface-induced δ - inclinations of smectic planes: a model (a) and the X- ray data [9] (b)

In general, two systems of the domains were observed in ordinary FLC substances: the bulk and surface domains [8-11]. The surface domains exist in the subsurface double-electric layer.

The domains were seen in thick and thin films. The width of surface domains is larger. The domain widths do not depend of the cell thickness. But the temperature dependence of the domain width D is crucial: D rapidly decreases with temperature decreasing in the SmC* phase if T is not close to the SmA-SmC* phase transition temperature T_{AC} [8] (see Figure 1a). These facts are explained by the model of charged dislocation walls [8], accordingly to which we obtain $D \propto (1/\mu\delta)^2$. In considered temperature range, δ is proportional to the tilt angle $\Theta \sim (T_{AC} - T)^{1/2}$ that explains the observed dependence $D(T) \propto (T_{AC} - T)^{-1}$ [9]. The dislocation walls and ferroelectric domains are eliminated by a sufficiently strong field [9,12] (see Figure 3). The corresponding threshold dc field E_{th} is very sensitive to the FLC material parameters: $E_{th} \propto \mu^3\delta^2\Theta$.

When the ion mobility is high and the field change is slow the ions succeed the field change and the dislocation walls become unfavorable because of non-compensated polarization charges. Contrary, the low ion mobility and fast field change promote to the preservation of the dislocation walls since in such a case they are partially neutralized. The existence of the bulk domains results, in general, in a poor reversibility and hysteresis phenomena.

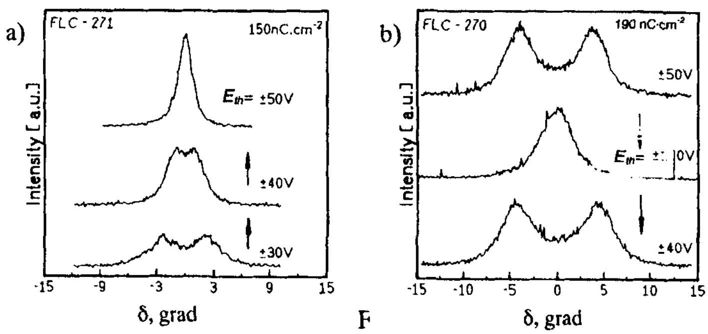


FIGURE 3. X-ray profiles in the 3 Hz-ac field [9]

The reversibility in non-high fields may be related to the large value of dc field E_{bst} in the effect of bistability, this critical value being necessary to preserve the orientation after the field switching off. The magnitude E_{bst} related to the wall [9] is proportional to

$$E_{bst} \propto \frac{\delta^4 \mu^3 \Theta}{K} \quad .$$

DISCUSSION OF RESULTS

Thus the domains observed in AFLCs [3] and FLCs [8-10] possess common features. A fairly high light transmittance in the temperature gradient cell with respect to the rubbing cell [3] is related to a smaller value of the δ inclination (because of a weaker surface anchoring) and, as a consequence, to a larger disturbance of the optical axis orientation in the cell bulk. A larger frequency (~1 Hz) of ac field results in a hysteresis in the V-shaped switching at low temperatures that can be explained by the presence of the bulk dislocation walls which possess large polarization charges only partially compensated during the polarization reversal.

The V-shaped switching was observed in AFLCs in the absence of the bulk domains [2]. It should be underlined that the bulk domains are not necessary for the reversible V-shaped switching. Contrary, such domains, trouble the reversible rotation of the polarization vector by an ac field. But the surface dislocation walls and ferroelectric domains must obviously appear because of the surface tension effects.

The reasons why the reversible V-shaped switching is observed in new AFLC mixtures may be following. Large values of the δ angle, which increases with the increase in piezomodulus μ and anchoring constant W [9], may result in large polarization charges, related to the surface dislocation walls, and in small domain widths. In FLCs this width is about several μm, while in the studied AFLC [3] it was much less, for instance in the rubbing cell. The measured δ [4,9] drastically differ, in the AFLCs δ being several times larger than in the FLCs.

The amount of free ions must be not large, to avoid the bulk domains. The polarization charges related to the surface walls are more strong than the charges which appear due to polarization twisting along the normal to a substrate in such a sub-layer. The surface walls increase promote to the reversibility of azimuth rotations in weak electric fields.

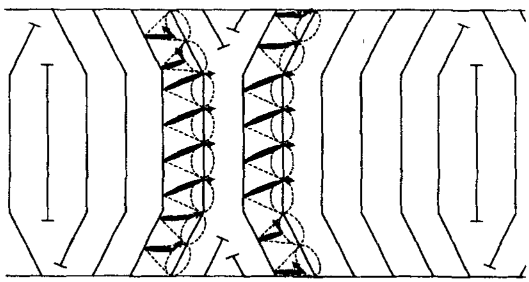


FIGURE 4. The distribution of director orientations when a sufficiently high ac field may eliminate the bulk walls at low frequencies, the surface dislocation walls are present

The bulk domains and dislocation walls must be absent for high values of δ and low concentrations of ions. A slow field change and a large ion mobility also promote to the disappearance of the bulk walls, but the surface walls must be present. In such a case the distribution of polarization vector and director in the cell is shown in Figure 4.

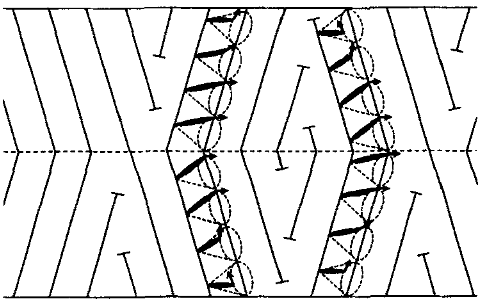


FIGURE 5. The distribution of the bulk walls and director orientations when a low ac field may preserve the bulk walls at high frequencies during the process of polarization reversal in the cell bulk

The polarization vector is parallel to the film surface at zero field value to avoid the appearance of a non-compensated polarization charge in the film bulk. Here a hysteresis phenomenon is less probable.

A fast field change and a low ion mobility promote to the preservation of the bulk walls in moderate fields, the polarization vectors on the inclined cones of directions being parallel to the film surface at zero field value as in the previous case. Figure 5 shows the corresponding distribution of the bulk walls and director orientations. Here a hysteresis phenomenon can take place.

CONCLUSIONS

It is shown by the comparative analysis of switching data on FLCs and AFLCs that the reversible V-shaped switching is due to the relatively strong anchoring at the cell surface, large piezoelectric effect, low content of free ions and due to the existence of narrow surface domains.

The hysteresis phenomena arise during the switching due to the increasing content of free ions and appearance of the bulk domains.

Acknowledgements
Financial support from Deutsche Forschungsgemeinschaft and from Russian Foundation for Basic Research (Grant 00-02-17801) is acknowledged. S.P. acknowledges the receipt of the research award of the Alexander von Humboldt-Stiftung.

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