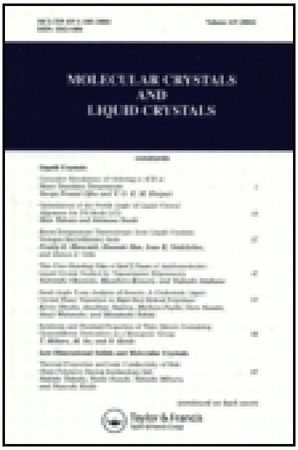

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Influence of the Alignment Process on the Switching of High Contrast Antiferroelectric Liquid Crystal Displays

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Influence of the Alignment Process on the Switching of High Contrast Antiferroelectric Liquid Crystal Displays

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In this paper we investigate the causes of poor alignment in antiferroelectric liquid crystal devices making use of spin coated and rubbed polyimide. We found that poor alignment is due to the deviation of the layer normal from the rubbing direction. By optimising the skew between the rubbing direction on opposite substrates we found that a high quality and stable alignment can be obtained. Quantitative experimental results showing a static extinction ratio higher than 3000:1 and dynamic contrast ratio higher than 2000:1 are presented.

Keywords: antiferroelectric liquid crystals; high quality alignment; skewed rubbing; switching

INTRODUCTION

Antiferroelectric liquid crystals (AFLCs) are very promising materials for large passively driven displays thanks to their fast tristable switching and in-plane optics. However, two major problems hamper the introduction of AFLCs to the marketplace: (i) the pretransitional regime [1] which is responsible for partial transmission when a holding voltage and crosstalk data are applied; (ii) the present quality of the alignment of the AFLCs which is still not satisfactory for full colour displays, where contrasts larger than 100:1 are demanded.

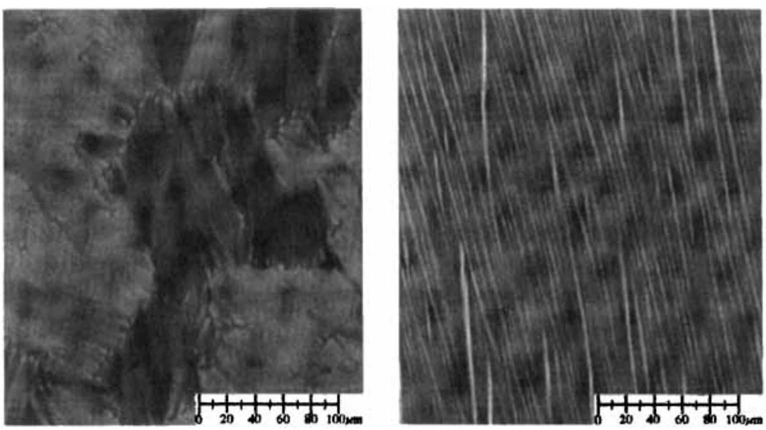
Micrometer scale defects exist and, in cells having both the substrates rubbed along the same direction, there is a coexistence of two preferred directions of orientation both differing from the rubbing direction. When the devices are placed with the optic axis of the ground antiferro state (AF) parallel to one of a pair of two crossed polarisers, an undesired transmission results. The existence of these two directions of orientation can be avoided by rubbing only one of the substrates [2]. In parallelly rubbed and in single rubbed cells a low frequency triangular waveform can improve the contrast [3,4]. However this treatment, similarly to the equivalent treatment used for quasi-bookshelf ferroelectric (QBS) [5] and deformed helix ferroelectric (DHF) [6,7], is likely to produce thermodynamic instability [8]. Undesired variation of the electrooptic performance could be observed by the display user. Similarly, the use of untreated substrates and the temperature gradient method is unsuitable for applications due to a pronounced tendency for layer rotation [9,10,11] which would destroy the contrast of the display.

We have systematically investigated the cause of poor alignment and found that there exists an optimum angle between the rubbing direction on the two substrates which provides a unique orientation of the normal to the smectic layers. This simple and stable alignment process improves the contrast of AFLC devices well beyond the values needed in high quality displays.

EXPERIMENTAL

We have filled by capillary action several cells and small patterned displays with the liquid crystal mixture Chisso 4000 while in the isotropic phase (at 120°C) and let them cool slowly. The alignment material is a polyimide, JALS 212 R2 (diluted 1:2) which has been spin coated directly on the indium tin oxide and rubbed with a velvet cloth wrapped onto a rotating cylinder. This polyimide produces a pretilt of $\leq 5°$, when measured with antiparallel rubbed cells filled with the nematic liquid crystal E7. The thickness of the test cells is controlled via bead spacers dispersed in the glue and is in the range 1.5 to 2.5 μm. Commercially available parallelly rubbed low pretilt cells (EHC) have also been used (2.7 - 3.3 μm thick).

Previous investigations of the cooling process in parallelly rubbed cells show that two directions of orientation are nucleated when the smectic ordering is first formed [12]. They deviate in opposite directions from the rubbing direction, and each of these regions appears to be seeded on one of the opposite rubbed substrates. After some minor reorientation two distinct types of regions remain. These regions are characterised by differing orientations of the layer normal (the directions of best extinction between polarisers) and some residual orientation spread. Also several diamond-shaped defects are created when small regions of isotropic phase are trapped between two larger regions of differing orientation. This is illustrated in Figure 1(a). The application of a low frequency triangular waveform is an effective way to remove these diamond-shaped defects [2]. The differences between the directions of maximum extinction are frozen in when entering the AFLC phase and are not affect by DC-balanced voltages. However it appears that the rubbing process affects these differences: in commercial cells it is $\approx 17°$, while in our devices it is $\approx 10°$, thus producing a lower transmission in the AF state. We have found that the application of a low frequency triangular waveform (1 Hz 15V/μm) in the high temperature range of the AFLC phase produces a partial merging of these two regions as shown in Figure 1(b).



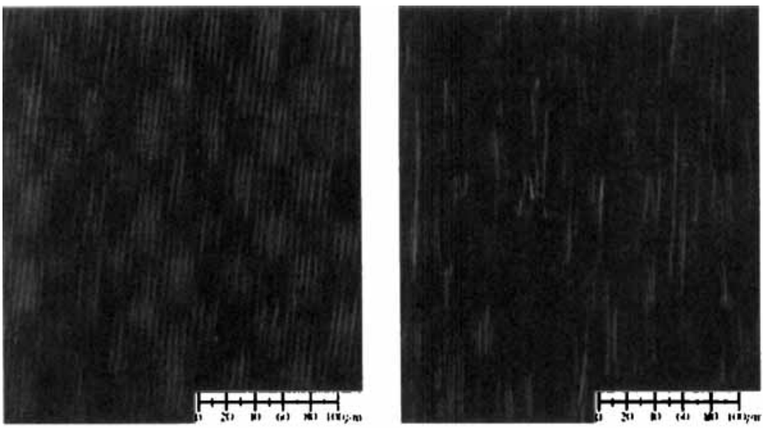
(a) (b)

FIGURE 1 Texture in untreated (a) parallelly rubbed cells and (b) after the low frequency electrical treatment.

A superior quality of the alignment has been achieved with devices having both substrates coated with polyimide but only one of them rubbed, as illustrated in Figure 2(a). However, we have found that the layer normal (i.e. evaluated as the direction of best extinction in the AF state) deviates 13°±3° from the rubbing direction. Interestingly this orientation is formed as soon as the first of the smectic phases is nucleated from the isotropic phase and is not altered whatsoever by further cooling (to room temperature) across the range of smectic phases.

This deviation may seem a negligible inconvenience, as it can be compensated by correctly placing the polarisers. However, after repeated switching from the AF to the F state with a simple *symmetric* DC-free triangular waveform we have observed a further apparent rotation of the layer normal, which can be seen by looking at the direction of best extinction in the absence of an applied field (i.e. in the ground AF state). This second deviation is in the same direction as the first one. This process is further enhanced when the temperature is increased up to 5-10°C below the transition to the higher temperature phase. Under such conditions, several degrees of rotation can be produced in a few minutes only. The original alignment direction can be recovered only by heating the device above the clearing point and cooling again. This second rotation is highly undesired in real displays. It prevents the writing of different information on the pixel on the two branches of the hysteresis loop and, more importantly, the black state would be significantly degraded making the display unusable.

Thus, two rubbed substrates seem to be needed for a stable alignment under symmetric switching conditions. Hence we have systematically investigated the effect of skewing the rubbing directions on opposite substrates. Here, the skew angle is defined as the angle between the rubbing direction on each surface and the desired direction of the layer normal (i.e. half of the difference between the rubbing directions when projected onto the same plane). We have found that the optimum skew angle is be very close to the apparent deviation angle which is measured in devices having one rubbed surface only (12°). Furthermore in these skewed devices, the nucleation of the smectic phases appears more regular with reduced splay in the alignment direction and no diamond-like defects. When cooling from the higher temperature smectic phase into the AFLC phase only a few needle defects appear (evidence of a tilted smectic phase). The texture of alignment with optimised rubbing is illustrated in Figure 2(b). However, the very high quality of the alignment cannot be fully appreciated simply by looking at the pictures due to the limited grey scale resolution (8 bits) of the imaging system used. Neither can the high contrast can be measured accurately using the focused light of a polarising microscope. We have therefore carried out quantitative measurements with a He-Ne laser (632.8 nm). The static extinction ratio, defined as the ratio between the maximum and the minimum transmission of the antiferroelectric ground state measured by rotating the cell between crossed polarisers, and the dynamic contrast ratio, defined as the ratio between transmission in the field-induced ferroelectric states and the ground state, while minimising the transmission of the latter, are here measured.



(a) (b)

FIGURE 2 (a) Texture in cells with only one substrate rubbed and (b) in cells with optimised skewed rubbing. The light intensity has been increased compared to Figure 1.

The quantitative difference between the static extinction ratios (Figure 3) and the dynamic contrast (Figure 4) are due to the difference between the optical anisotropy in the antiferro and ferro state (seen by the light impinging perpendicular to the cell), as well as to the less than ideal field induced in-plane tilt (27.1°) of this AFLC mixture. Furthermore, in some thicker cells the $\lambda/2$ condition is exceeded in the field induced ferroelectric state.

Finally, we have verified the stability of the alignment in the devices with optimised skewed rubbing. No layer rotation occurs when repeatedly switching the devices using symmetric waveforms.

However, it should be noted that a minor increase in the density of needle defects does take place, although these defects do not significantly affect the high quality of the dark state. After the test, the static contrast ratio remains higher than 1400:1.

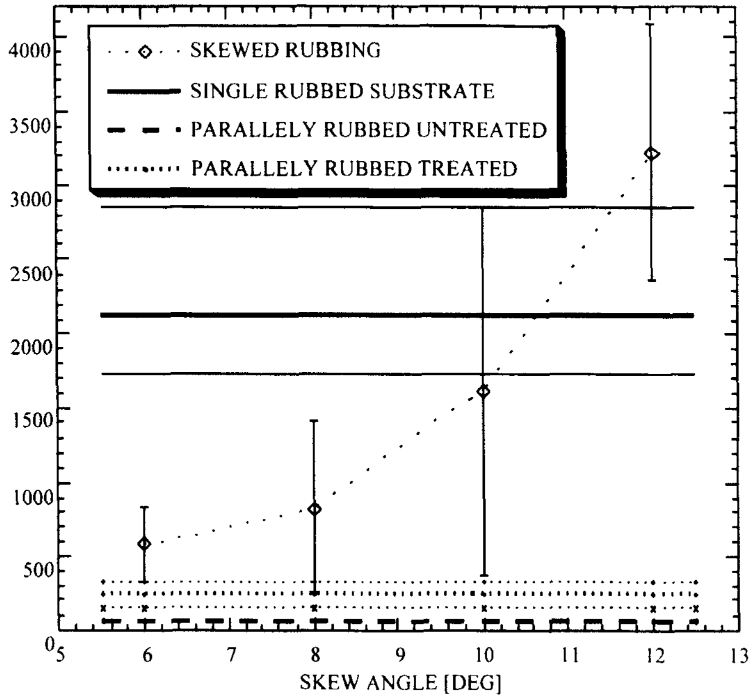


FIGURE 3 Static extinction ratio measured between crossed polarisers for the minimum and maximum transmission (when the cell is rotated by ~ 45°). For skewed devices, error bars describe statistical deviations within a device and among devices. For single and parallelly rubbed cells minimum, average (thick line) and maximum are shown by separate lines.

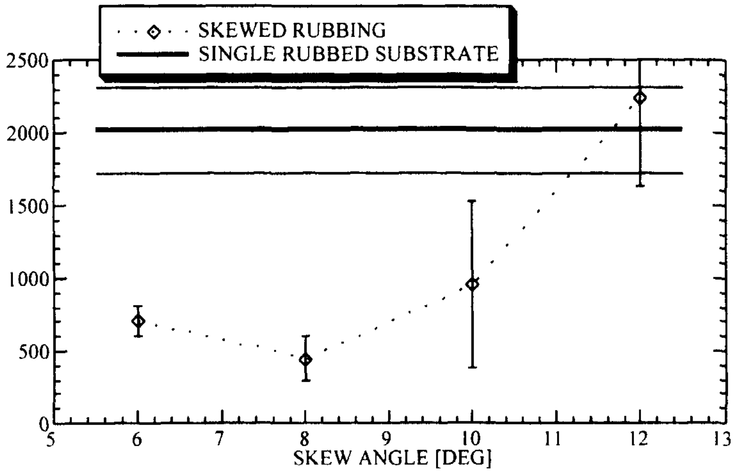


FIGURE 4 Dynamic contrast measured between the F states and relaxed ground state under driving conditions. For skewed devices, error bars describe statistical deviations within a device and among devices. For single rubbed cells minimum, average (thick line) and maximum are shown by separate lines.

CONCLUSIONS

In this paper a simple and effective technique for the production of high quality alignment AFLC devices is presented. By using a spin-coated polyimide and skewing by an optimum angle the rubbing directions of the top and bottom substrate we have produced very high quality display devices with static extinction ratio and dynamic contrast ratio in excess of 3000:1 and 2000:1, respectively. Our tests also show that our skewed alignment prevents undesired layer rotation which takes place, under symmetric DC-free voltage conditions, in devices having one rubbed substrate only.

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References

[1] R. Beccherelli, S. J. Elston, *Liquid Crystals,* **25,** No. 5, pp 573–577 (1998).
[2] K. Itoh, M. Johno, Y. Takanishi, Y. Ouchi, H. Takezoe, A. Fukuda, *Jpn, J. Appl. Phys.,* **30** pp. 735–740 (1991).
[3] B. Verweire, J. Fornier, G. Cnossen, *Ferroelectrics,* **213** pp. 133–141(1998).
[4] K. Nakamura, A. Takeuchi, N. Yamamoto, Y. Yamada, Y. Suzuki, I. Kawamura, *Feroelectrics,* **179,** pp 131–140 (1996).
[5] C. Echer, G. Illian, A. Kaltbeitzel, J. Manero, D. Ohlendorf, H. Rieger, N. Rösch. H. Schlosser, P. Wegner, R. Wingen, *Proc. SPIE,* **1665,** pp. 90–101 (1992).
[6] J. Fünfschilling and M. Schadt, *J. Appl. Phys.,* **66** No. 8, pp. 3877–3882 (1989).
[7] J. Fünfschilling and M. Schadt, *Proc.SID,* Vol **31/2** pp. 119–122 (1990).
[8] G. Cnossen, *SID Digest,* Vol. XXVII, pp. 695- 698 (1996).
[9] M. Ozaki, H. Moritake, K. Nakayama and K. Yoshino, *Jpn, J. Appl. Phys.,* **33,** No. 11B, L1620–1623 (1994).
[10] H. Moritake, M. Ozaki, K. Nakayama and K. Yoshino, , *Ferroelectrics,* **178,** pp. 277–285(1996).
[11] K. Nakayama, M. Ozaki and K. Yoshino, "Control of layer arrangement by electric field in ferroelectric and antiferroelectric liquid crystals", *Jpn, J. Appl. Phys.,* **36,** No. 9B pp. 6122–6124 (1997).
[12] R. Beccherelli and S. J. Elston, submitted to *Displays.*