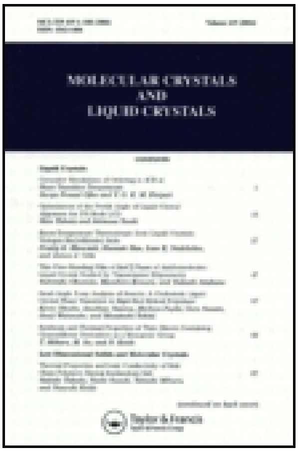

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The Effects of Ionic Fields and Previous Switched States on Domain Formation in Pulse Addressed Ferroelectric Liquid Crystal Cells

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THE EFFECTS OF IONIC FIELDS AND PREVIOUS SWITCHED STATES ON DOMAIN FORMATION IN PULSE ADDRESSED FERROELECTRIC LIQUID CRYSTAL CELLS

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Abstract

We discuss the large extent to which ionic impurities and previous states influence the switching of ferroelectric liquid crystal cells. In particular we see that the ionic field built up in response to the molecular dipoles causes switching to correlate with the previous state. This memory effect is not erasable even when the cell is fully reset into a uniform state. Also the strength of the reset pulse influences the ionic field and generally causes enhancement of partial switching in the opposite direction. There also exists an anomalous region where this enhancement doesn't occur. This is apparently due to variation in the elastic stability even when the cell appears to be in a uniform relaxed state.

INTRODUCTION

There is interest in the use of ferroelectric liquid crystals (FLCs) for display applications because of their advantages over nematics, including faster switching, a wider viewing angle and the potential for passive addressing due to the existence of bistable states. It is the bistability of FLCs however that is also a major drawback due to the difficulty in achieving an analogue grey scale. The problem can be overcome by the use of either temporal or spatial dither[1] but multiple addressing and sub pixellation increase the complexity of a display. A more simple solution would be to use partial switching of a pixel to obtain controllable proportions of bright and dark domains[2–5]; this would effectively be spatial dither within a single pixel.

Accurate control of the proportion of up and down domains is not easily achieved. Domain switching is very sensitive to device structure, alignment layers, ionic impurities and applied fields. A full understanding of the influences of all these parameters must be obtained in order to be able to predict the behaviour of devices. Ionic impurities play a significant role and previous workers have described their effect on bulk switching[1,6–8], indicating that ions are the cause of reverse switching in high Ps materials. We would expect these ionic effects to have an even greater impact on the more critically field dependent partial switching regime. Maltese et al. observed that the previous state of the pixel and previously applied pulses both influence domain switching and indicated these effects may be due to ionic interactions[5]. In order to fully erase these effects they found it necessary to apply complicated reset pulse sequences and superimpose a high frequency field. In this paper we explore these ionic phenomena and consider not only memory and enhanced switching effects but also elastic interactions which in certain circumstances can be significant and lead to seemingly anomalous results.

EXPERIMENTAL TECHNIQUE

The cell used here is 2μm thick and is filled with the FLC material ZLI4655–000 (E. Merck) which has a spontaneous polarization of $7\,\mathrm{nC\,cm^{-2}}$ at 20°C (Note: figure 3 illustrates results with a similar cell filled with ZLI4655–100 which has Ps = $22.6\,\mathrm{nC\,cm^{-2}}$). Ionic impurities were not deliberately introduced (i.e. the material is not doped), so the device is typical of a display structure using this type of material. Before assembly the cell surfaces were treated to produce a near planar low surface pre–tilt (around 2°) resulting in a chevron structure in the smectic layering and a director profile where the director at the top surface is constrained to lie approximately in the surface alignment direction and at the top of the smectic cone, while the director at the bottom surface is similarly aligned and constrained to the bottom of the smectic cone. This has commonly been termed the C2 structure[9]. The two relaxed switched states with the director taking the two allowed positions at the chevron interface then have a net spontaneous polarization either 'up' or 'down', and can be switched between by the application of voltage pulses across the cell in either direction. The cell can then be arranged between crossed polarizers so that these states appear 'bright' and 'dark'.

The extent of domain growth was monitored using polarized stroboscopic microscopy. A charge coupled device camera connected to a computer frame store is used to obtain an image of the cell (placed between crossed polarizers) that has been magnified by a x10 microscope objective (thus the region studied is ~ 0.5mm across). Before data were taken the cell position was adjusted in order to find a uniform defect free area for study. Having obtained an image of the device an image processing package was used to determine the percentage of area switched. This is done by thresholding the image to separate the 'bright' and 'dark' areas, and calculating the number of pixels in the image above and below this threshold. These numbers are subsequently divided by the total number of pixels in the image to determine the switched areas, which we generally refer to (idealistically) as the 'black' and 'white' areas. Images were generally taken 500ms after the pulse sequence was applied which is near equilibrium in the switching process.

RESULTS

In order to study partial switching in a device, a pulse is applied which is sufficient to nucleate and grow domains but not sufficient for the domains to coalesce and cover the whole pixel. The extent of domain growth is very sensitive to variation in applied pulses and initial state, and therefore for repeatable results the switching must occur from a uniform elastic state. To achieve this a pulse large enough for a full reset to occur is applied prior to the partial switching pulse, with a long enough delay between the two pulses for the director profile to relax to its equilibrium state (on the order of 1–2ms).

It has been observed however that these reset pulses do not eliminate dependence on previous switched states. For example a region that was originally white tends to switch white again even if a white switching pulse is preceded by a black reset pulse. The same white region will tend to remain white (i.e. not switch) if the switching pulse is towards black (and preceded by a white reset pulse). This memory effect is shown in figure 1, where each partial switching pulse is applied to an opposite uniform reset state. Any elastic stress caused by the reset pulse relaxes during the 2ms delay between pulses and therefore previous state bias is caused primarily by ionic impurities within the cell. Figure 2 demonstrates how this bias is set up by ions that drift to stabilize the current state of the molecular dipoles. This stabilizing field builds up with the cell shorted for several seconds, therefore when the cell is reset and shorted for only a few ms between the pulses there is not enough time for the ions to drift to stabilize the new uniform state of the pixel before the switching pulse is ap-

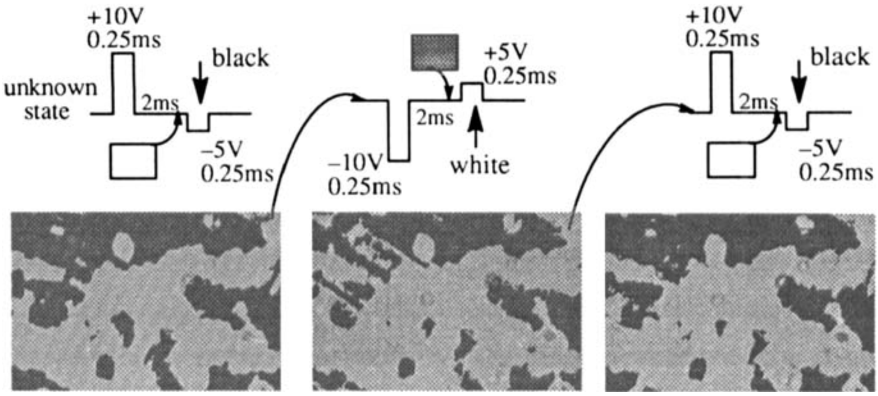

FIGURE 1 Sequences of images showing the ionic memory effect. Areas that were previously white have a white stabilizing ionic field (and correspondingly for the black areas). Therefore the previous state has a similar influence on the outcome of future switching, regardless of the polarity of the switching pulse.

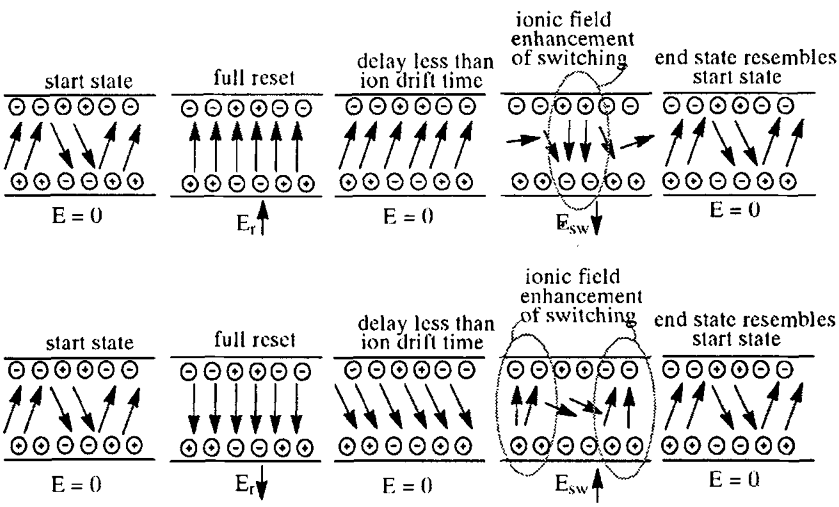

FIGURE 2 Demonstration of ionic memory effect. In both cases above a full reset is made but the previous ionic stabilizing field remains. The subsequent switching pulses are then enhanced in areas that previously had the dipoles pointing in the same direction as the switching pulse.

plied. The switching pulse is therefore enhanced (or inhibited) by the ionic fields in areas that were previously in the same (or opposite) direction as the pulse.

As shown in figure 2 the ions drift to stabilize the field set up by the molecular dipoles. Therefore one would expect this stabilizing field to be larger for higher Ps materials. This is unfortunate because although higher Ps materials often switch faster, the larger ionic stabilizing fields will make switching even more history dependent. This is clearly illustrated in figure 3 which shows that it is not possible to switch a similar cell containing a Ps =

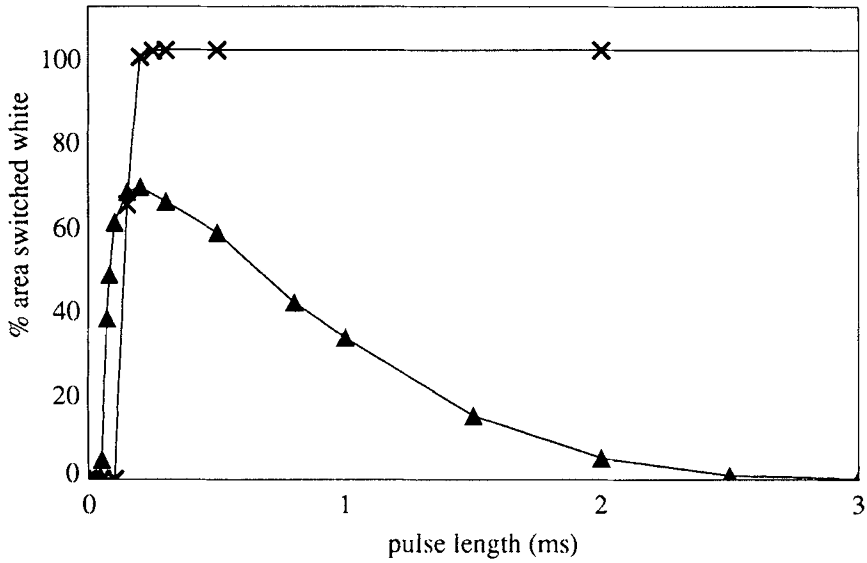

FIGURE 3 The effect of Ps on switching. The cell with Ps = 7nC cm^{-2} (x) can be fully switched between states with a single 10V pulse ranging in duration from 0.25ms – 6ms. However the cell with Ps = 22.6 nC cm^{-2} (▲) cannot be fully switched with a single pulse because ionic field induced reverse switching occurs even with pulses of durations too small to establish elastically stable states.

22.6 nC cm^{-2} material between states with a single 10V pulse. The higher Ps material does begin to switch partially at shorter pulse lengths but after shorting the cell reverse domains appear and grow in the switched areas **even with pulses that do not switch the entire pixel**. Increasing the pulse length to perform a full switch during the pulse application adds to the ionic reversal field and causes even more reversing domains to appear. As a result this material is never fully latched into a uniform opposite state. This is because the ionic stabilizing field built up while the cell was in one state is substantial (in response to the large dipole field) and the switched areas are not elastically stable enough to remain switched once the cell is shorted. The smaller Ps material however has a correspondingly smaller ionic stabilizing field and does not exhibit reverse switching unless an external field has been applied for long enough to build up a significant reversing ionic field. Therefore a range of pulse durations exist (between 0.25ms – 6ms for 10V applied) which latch the Ps = 7 nC cm cell into the opposite state whereas the Ps = 22.6 nCcm^{-2} cell is never fully latched.

Although for the low Ps devices there exist a range of reset pulses that switch the pixel into equivalent elastic states the strength of these pulses will still affect the ionic field and therefore the outcome of future partial switching. This is illustrated in figure 4 where a 4ms

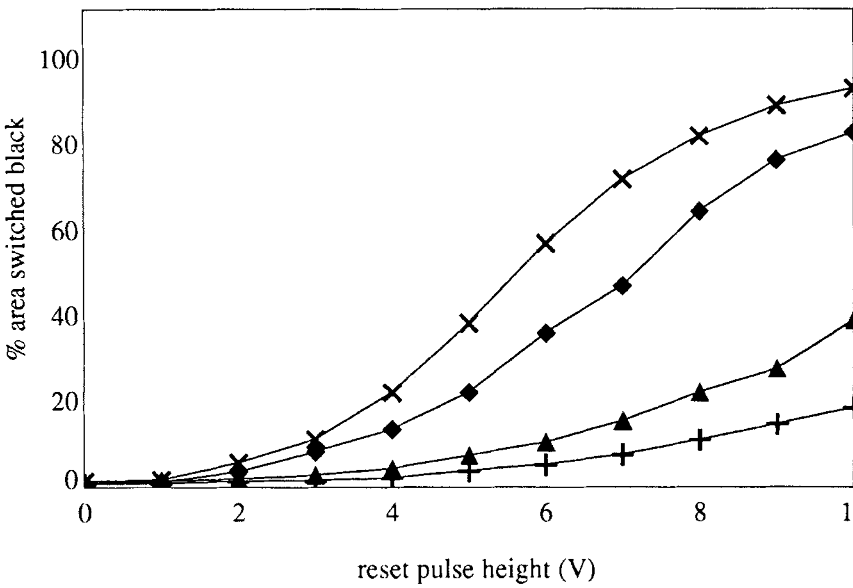

FIGURE 4 Area switched black by a +6V, 0.3ms pulse as the height of a 4ms reset pulse is increased. This is an ionic effect which decreases as the ions drift to stabilize the newly reset state, thus by increasing the delay between the reset pulse and the switching pulse, the switched area decreases. We show the results for delays of 1ms (x) 10ms (◆) 100ms (▲) and 500ms (+).

duration white–reset pulse is applied to the cell in the relaxed white state followed by a variable delay and a +6V, 0.3ms black switching pulse. Note that with no reset pulse applied the subsequent pulse is not capable of switching a significant proportion of the cell, but as the reset pulse is increased in amplitude the effectiveness of the switching pulse also increases. This is occurring even though the cell is in the uniform relaxed white state prior to the black switching pulse for all four delays shown. Figure 5 demonstrates how application of a reset

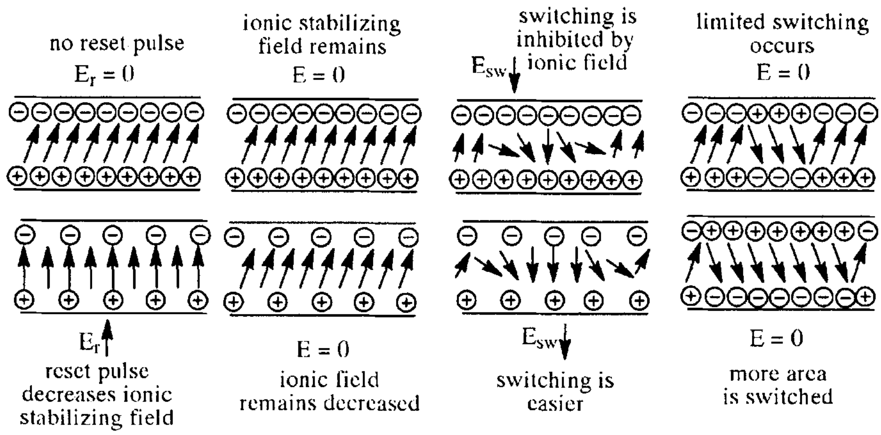

FIGURE 5 Demonstration of ionic enhancement of switching when a large reset pulse is applied. The top series shows the result of a switching pulse applied to a uniform relaxed state with no reset pulse applied. The bottom series shows that when a reset pulse is applied in the direction of the relaxed state the ionic stabilizing field is decreased. The subsequent switching field is stronger and a larger area is switched.

pulse decreases the ionic stabilizing field which subsequently causes enhancement of the partial switching pulse. This effect decreases as the delay between reset and switching pulses is increased, allowing the ions more time to drift back to stabilizing the white state, but even after a 500ms delay there is still an effect (figure 4).

A similar reset pulse enhanced switching effect should be seen when the start state is relaxed black, provided a true reset has been achieved and the cell is in a stable white state prior to the switching pulse. Figure 6 however shows this is not always the case: there are in fact three regions of interest. In region 1 the reset pulse is not large enough to fully switch the cell. With zero reset the pixel which was relaxed black will of course be fully switched black by the partial switching pulse. However as the reset pulse is increased in amplitude and it switches more area white the partial switching pulse becomes less effective in switching it back to the black state. Therefore a decrease in switched area versus reset pulse height is seen in this region. When the reset pulse height is 3.7V however the entire pixel becomes switched to the white state (this state is stable and will remain white if no partial switching pulse is applied). From this point on (3.7V – 10V) the partial switching pulse is always switching from the same uniform relaxed white state. The plot of area switched vs reset

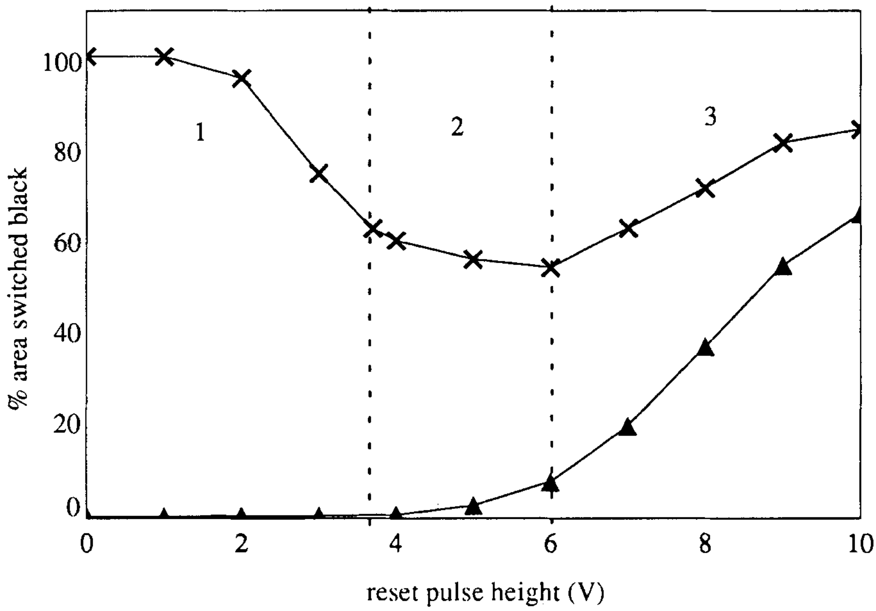

FIGURE 6 The effect of reset pulse strength on a +5V, 0.3ms duration switching pulse (2ms delay between pulses). When the start state is relaxed black (x) there are three regions of interest. In region 1 the switched area decreases as the amount of area switched white by the reset pulse increases. In region 2 however, the switched area continues to decrease even though the reset pulses are all sufficient to perform a full switch to a uniform white state. In region 3 the strength of the reset pulse is enough to cause enhancement of the switching as in the case of a relaxed white start state (▲).

pulse height should at this point begin to follow the trend shown in the lower plot for which the device was initially in the relaxed white state (and therefore always fully reset white before switching). The only difference in the state of the cell just prior to the partial switching pulse would be expected to be the strength of the ionic field. This should increase with increasing reset pulse height and cause an increase in the switched area (as in figure 4 and in the lower plot of figure 6). **Region 2 however shows an anomalous decrease. Thus there must be some further elastic stabilization of the white reset state for reset pulses in the 4–6V range even though the state appears to be the same beyond 3.7V.** In region 3 the ionic effects take over as expected and cause increasing enhancement of the partial switching.

In order to investigate the above anomalous effects the transmission through the cell (between crossed polarizers) was monitored during the switching process. In the anomalous region 2 the transmission after the reset pulse was seen to decrease faster for the higher voltage case, as expected due to a larger build up of the ionic reversal field. However, after the partial switching pulse was applied the lower reset voltage case resulted in lower transmission (and therefore more area switched black as seen in figure 6). Because the bulk of the cell appears to respond to the ionic field as expected we hypothesize that there is some **slight surface switching which is not apparent in average transmission measurements.** This surface switching increases for the larger reset pulses and **inhibits the future partial switch** for a small regime where the ionic fields are not large enough to dominate.

CONCLUSIONS

We have illustrated the significant influence both ionic and elastic effects can have on partial switching of FLC devices. The control of partial switching is difficult because the combination of these effects causes similar pulse sequences to produce radically varying results. Firstly we see that simply switching a cell from an equivalent elastic start state is not sufficient for well defined results. The ionic impurities stabilize previous domain areas and cause memory effects that last for several 100's of ms after the application of a reset pulse. Secondly the response of the ionic distribution to externally applied fields causes variation in switching even from equivalent elastic and ionic memory states. While the variation of the ionic fields is in most cases the largest influence there exists a small region where elastic stability dominates the results of switching even after bulk relaxation has occurred. These elastic states which have a significant effect on the results of partial switching pulses are not distinguishable in average transmission measurements (and we propose are due to a slight surface switching).

Interactions between ionic fields and elastic states along with their different timescales add complexity to the design of partial switching schemes. A complete model of switching must include the previous state of the ionic field distribution across the pixel, the current elastic state of the bulk and some not so well defined surface switching. Even with a complete model however it may not be possible to overcome the ionic memorization of previous switched states and sensitivity to previously applied fields since the decay time of these effects is much larger than the frame time of a display (>500ms as opposed to 40ms). It has been indicated that some of the unwanted ionic effects may be eliminated by using a high frequency bias field and multiple reset pulse erasure[5]. These high fields would effectively cause a uniform redistribution of the ionic content making the drift due to the small dipole field insignificant. However as we have shown here a uniform ionic field is also not sufficient for repeatable results as reset pulses that must switch from unknown elastic states do not always produce uniform states with equivalent elastic stability even though these states appear the same in average transmission measurements.

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REFERENCES

1. J. Dijon, in Liquid Crystals, Applications and Uses – Vol 1 , edited by B. Bahadur (World Scientific, USA, 1991), Chap. 13, pp. 305–360.
2. D. Armitage, Mol. Cryst. Liq. Cryst., 199, 97 (1991)
3. M. Kimura, H. Maeda, C.M. Gomes, M. Yoshida, B.Y. Zhang, H. Sekine, and S. Kobayashi, Proc. of the SID, 31, 139 (1990)
4. W.J.A.M. Hartmann, J. Appl. Phys., 66, 1132 (1989)
5. P. Maltese, J. Dijon, T. Leroux, and D. Sarrasin, Ferroelectrics, 85, 265 (1988)
6. C. Escher, H.R. Dübal, T. Harada, G. Illian, M. Murakami, and D. Ohlendorf, Japan Display, 348 (1989)
7. K.H. Yang, T.C. Chieu, and S. Osofsky, Appl. Phys. Lett., 55, 125 (1989)
8. Z. Zou, N.A. Clark, and M.A. Handschy, Ferroelectrics, 12, 147 (1991)
9. N. Itoh, M. Koden, S Miyoshi, and T. Wada, Jap. J. Appl. Phys., 31, 852 (1992)