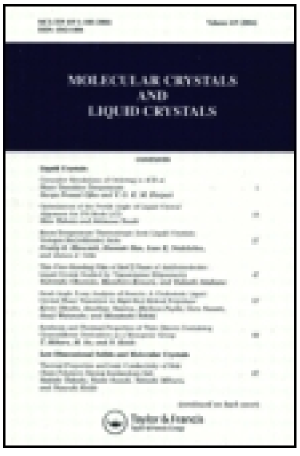

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Time-Resolved X-Ray Studies of Layer Behaviour During Operation of a Ferroelectric Device

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TIME-RESOLVED X-RAY STUDIES OF LAYER BEHAVIOUR DURING OPERATION OF A FERROELECTRIC DEVICE

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Abstract Time-resolved small angle x-ray diffraction experiments have been undertaken for the first time throughout the switching cycle of a ferroelectric liquid crystal device. The x-ray data show that during switching with a low electric field the chevron structure adopted by the layers distorts, changing the chevron angle. Further, a rotation of the layers in the plane of the device is observed, coincident with the change in chevron angle. The motion of the layers takes place on a ten microsecond time scale and the angular rotation of the layers is approximately 1°.

INTRODUCTION

Studies of electric field induced switching processes in surface stabilised ferroelectric liquid crystal (FLC) devices [1] have primarily concentrated on the director motion, since this is responsible for the optical behaviour of the device. However, the smectic layers are intrinsic to FLC devices and therefore contribute inherently to the device geometry and to the switching mechanisms. The most obvious method of probing smectic layering is via small angle x-ray scattering. Indeed the chevron structure adopted by the layers within FLC devices was first elucidated by x-ray measurements [2]. Although there have been many similar studies on the fully switched arrangement of these layers in devices subjected to static fields [3,4] here we report time-resolved studies of the layer behaviour during switching. In this paper experimental x-ray measurements with microsecond time resolution are presented, detailing the layer motion in two orthogonal places which occurs as part of the switching process.

EXPERIMENTAL

The experiments were carried out at the Synchrotron Radiation Source, Daresbury U.K. [5] where the combination of high x-ray flux and rapid response time area detectors allowed the time resolved experiment to be performed. The apparatus used is similar to that described previously [6] and the experimental arrangement is shown schematically in

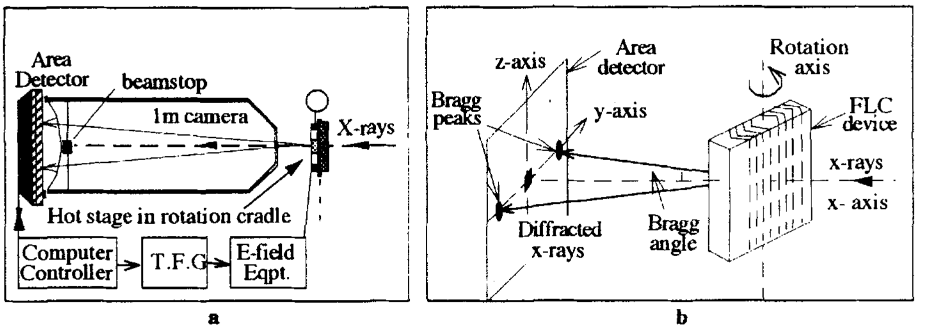

FIGURE 1 a) The experimental setup b) The experimental geometry. The device rotates about the z-direction to give Bragg diffraction off the chevron structure.

Figure 1a. The device is held in a temperature controlled environment (stability ±1°C) and a 1mm x 1mm beam is incident on it. The device is oriented such that the x-rays fulfil the Bragg condition for the chevron structure within the device (Figure 1b). The FLC device configuration investigated was a chevron structure with a low pre-tilt triangular director profile[7]. The 4 μm thick devices were constructed using 100μm thick ITO coated glass and the FLC mixture, SCE13[8]. Good alignment of the liquid crystal was obtained by cooling slowly through the high temperature nematic and smectic-A phases. A switching voltage of ±6 V, 1.5 kHz (square wave) was used in the experiments; high fields are known to cause an irreversible change from a chevron to a bookshelf structure[9] and the selected voltage had been established, by independent experiments not reported here, to be below that necessary to cause such a deformation (8 - 10 V in this device). The sample temperature was maintained at 54.5°C, (i.e.~6°C below the S_C^* to S_A phase transition) where the tilt angle is 15°. The temperature and switching voltage were chosen to give a convenient switching time of 200 ±10 μs.

The timing of the experiment is controlled by a programmed time frame generator (TFG) which defines the data acquisition sequence and provides a trigger for the application of the switching voltage to the device. The timing is discussed in detail in reference 10. X-ray diffraction patterns were acquired at 30 μs intervals throughout the switching cycle. Good signal-to-noise ratios were obtained by repeating the experiment and accumulating data in each interval. In order to simplify data analysis, the FLC device was rotated about the x-axis such that the UP state (defined in Figure 2) was on the equator (y-axis).

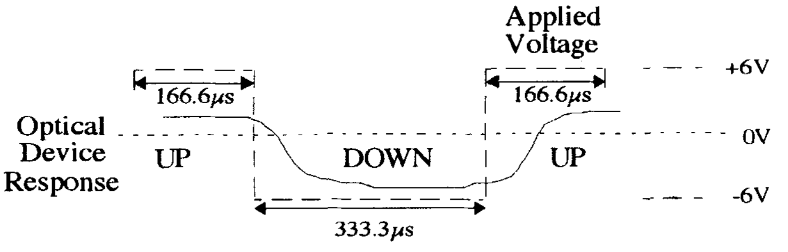

FIGURE 2 A schematic of the electro-optic response, device states and the triggered square wave voltage.

An area detector was used in these experiments, allowing several complementary levels of information to be obtained. In particular, it was possible to:

1. Deduce the layer spacing from measurement of the Bragg angle. In these experiments, no resolvable variation in layer spacing was observed;
2. Measure qualitative changes in the chevron angle as the intensity of the diffraction peak reduces if the layers move out of the Bragg condition;
3. Study the structure of the Bragg peak, deducing information about layer integrity during switching;
4. Determine the direction of the layer normal in the device from the angular position of the diffraction peak with respect to the equator (y-axis) of the detector.

RESULTS

The integrated intensity of the Bragg peak as a function of time is shown in Figure 3. The intensity clearly reduces ~60 μs after field reversal, then rises back to the pre-switched level. The only obvious mechanism that would account for the fall in intensity of the Bragg peak is a change in chevron angle during switching. Contour plots of the Bragg peak in the UP and DOWN states are shown in Figure 4. A detailed analysis of the Bragg peak distribution during switching shows that although the peak position on the detector changes, the intensity distribution within the spot does not change significantly, indicating that the bulk of the layers rotate together during switching and without a spread of layer spacing being introduced. The apparent structural differences in the contour plots are due to the combination of noisy data and large contour step sizes. The angular position of the peak does change however, and this change was quantified, as a function of time, by calculating the centre of area of the

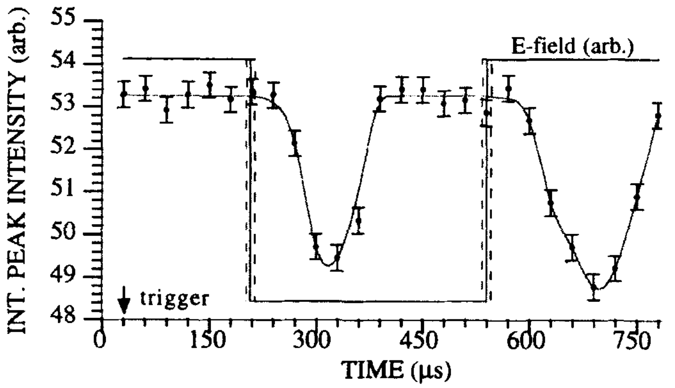

FIGURE 3 The integrated Bragg spot intensity versus time. Each data point represents the accumulated intensity in the preceeding 30 μs.

diffraction peak centre, Figure 5. The angular separation of the layer direction between the UP and DOWN states is ~1°. Whenever the field direction is changed the layers first

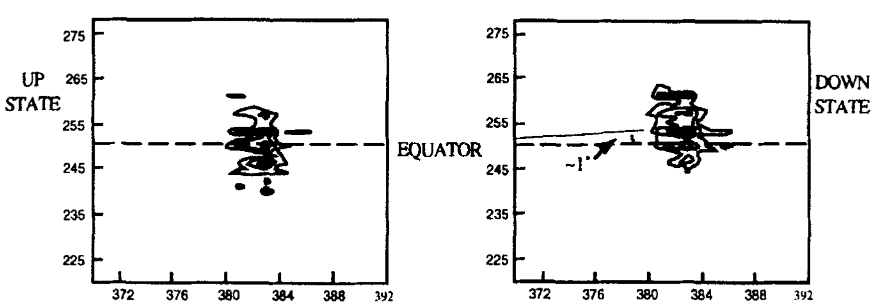

FIGURE 4 Contour plots showing the distribution of intensity of one of the Bragg peaks in the UP and DOWN switched states. The numbers on the diagrams refer to the pixel and raster numbers of the area detector.

rotate in such a direction as to increase this angular separation. The 75 μs period for which this occurs on switching from UP to DOWN is marked AS (Ante-Switch) in Figure 5. Following the AS period the layers reverse their direction of rotation and rotate towards the new stable state. There is an overshoot, marked PS (Post-Switch), lasting for ~100 μs as the layers rotate past the second stable state. The orientation of the layers in the DOWN switching state is stable 220 μs after field reversal, which is

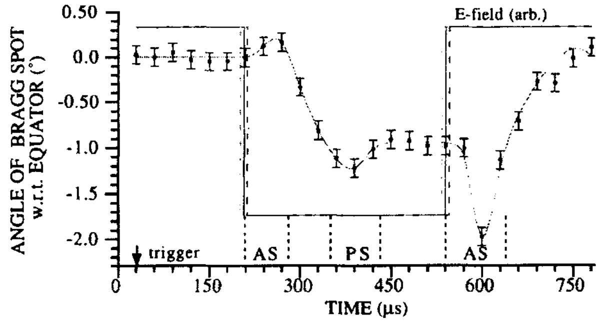

FIGURE 5 The angle of the Bragg spot relative to the equator, as a function of time. Each data point represents the accumulated intensity in the preceeding 30 μs.

consistent with the device's optical response time. A comparison of the angular rotation in the two AS periods shows an asymmetry in the maximum rotation of the layers from the stable state value; ~0.2° for UP to DOWN, and ~1.0° in the opposite case.

DISCUSSION

The data clearly indicate motion of the layers in two orthogonal planes during the switching process. In addition to the change in chevron angle, indicated by a reduction in the Bragg peak intensity, two further aspects of the data must be explained: the initial rotation of the layers away from the direction of the next stable state in the AS period; and the 1° difference in the directions of the layer normals in each state. The layer rotation during both AS and PS periods can be explained qualitatively by backflow effects[11], although it is difficult to quantify the extent to which backflow might contribute to the switching in the absence of information about viscoelastic coefficients of SCE13. Further experiments are currently underway at different temperatures which may help determine the possible influence of backflow. The asymmetric switching observed here is commonly observed optically and may be explained with reference to surface anchoring directions and energies[12].

We believe that the reversible change in chevron angle observed during switching and the 1° difference between the layer normal directions in the UP and DOWN states are linked and there are two possible explanations for these effects. The mechanism may be analogous to that which causes a change from chevron to bookshelf geometry at high field strength. When the field is initially applied the polarisation vector aligns with it and it and the chevron angle reduces due to torque on the layers. This torque reduces during switching[13] so the chevron angle increases temporarily, before again decreasing in the second switched state. The 1° layer tilt would occur to conserve layer spacing. The alternative explanation is based on the switching model proposed by Hartmann[14] in which the director moves parallel with the substrates throughout the sample during switching. This requires motion of the tilt cone axis away from the chevron apex, achieved by a slight increase in chevron angle. The Hartmann model therefore also explains the observed change in chevron angle and while it does not predict the 1° layer rotation in the plane of the cell, we believe this must occur, again to conserve layer spacing.

The layer motion during switching is clearly complex. On application of an electric field to a FLC device the rotation of the director around the tilt cone is facilitated by motion of the chevron structure and by a simultaneous rotation of layers in the plane parallel to the device face. Further time-resolved x-ray investigations using different device orientations and driving signals are underway to examine in more detail the layer motion in the device during switching.

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