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Preliminary Communications

Microsecond studies of layer motion in a ferroelectric liquid crystal device

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Small angle X-ray scattering has been employed to study dynamically the layer motion in a ferroelectric liquid crystal device on application of low electric fields. Microsecond time resolution was achieved and the use of an area detector in the experiment allowed the examination of layer motion in two orthogonal planes. The X-ray data show that during switching the chevron structure adopted by the layers distorts, implying a variation in the chevron angle. A rotation of the layers in the plane of the device is also observed, coincident in time 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°.

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 intrinsic to FLC devices contribute inherently to the device geometry and therefore to the switching mechanisms. The most obvious method of probing smectic layering is via small angle X-ray scattering, and 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 [3, 4], there have, to date, been no time-resolved studies of the layer behaviour during switching. Here, experimental X-ray measurements with microsecond time resolution are presented, detailing the layer motion in two orthogonal planes which occurs as part of the switching process.

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. The device is held in a temperature controlled environment (stability ± 1°C) and a 1 mm × 1 mm beam is incident upon it. The device is oriented such that the X-rays fulfil the Bragg condition for the chevron structure within the device. The FLC device configuration investigated was a chevron structure with a low pre-tilt triangular director profile [7]. The devices were constructed using 100 μm thick ITO coated glass, were 4 μm thick, employed a polyvinyl alcohol alignment layer and contained 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 previously been established to be below that necessary to cause such a deformation (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 was controlled by a programmed time frame generator (TFG) which defined the data acquisition sequence and provided a trigger for the application of the switching voltage to the device. The timing of the experiment is detailed in figure 2. The TFG allowed only 26 time frames of minimum duration 10 μs to be defined, allowing a single switching cycle to be studied. Each time frame comprised a 10 μs wait period and a 20 μs data capture period, allowing good time resolution throughout the switching cycle. The experiment was repeated many times allowing about

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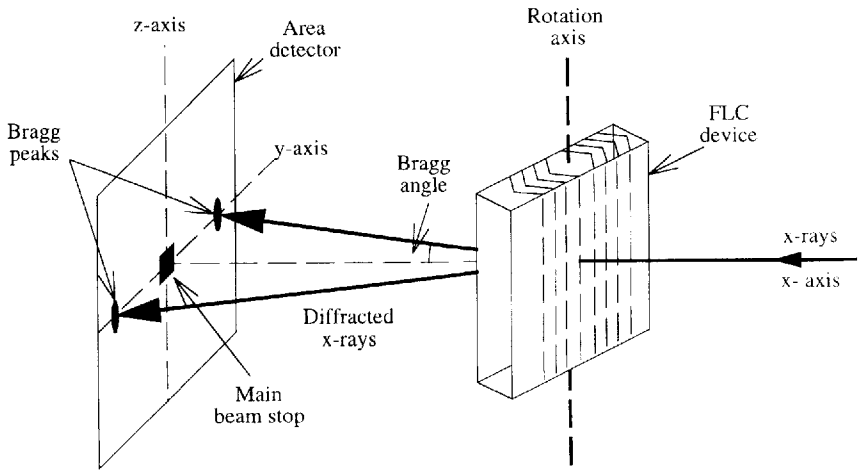

Figure 1. The experimental geometry; the device rotates about the z-direction to give Bragg diffraction off the chevron structure.

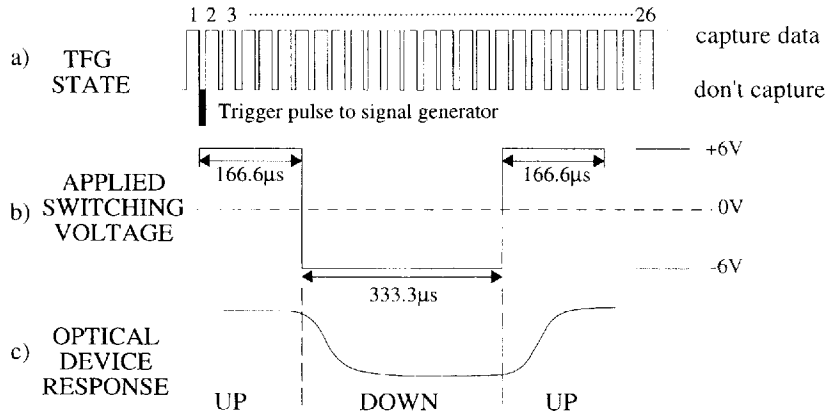

Figure 2. (*a*) Time frame generator settings, the 26 time frames each have a 20 μs data capture period followed by a 10 μs non-capture period; (*b*) the triggered square wave voltage; (*c*) a schematic of the electro-optic response and the device states.

2 seconds of data to accumulate in each time frame to gain acceptable signal intensity levels. In order to simplify data analysis, the FLC device was rotated about the x-axis such that in the UP state (also defined in figure 2) the Bragg peak was on the equator (y-axis).

The use of an area detector allowed several complementary levels of information to be obtained regarding the layer motion during the experiment. 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.

Consider first the intensity of the Bragg peak. Figure 3 shows the integrated X-ray intensity of the peak as a function of time during switching. It clearly reduces after ~60 μs of 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. It is clear from the figure that the position of the Bragg peak changes in each of the states. Figure 4 also seems to indicate that the structure of the Bragg peak changes in the switching process, though a detailed analysis of the progression from the UP to DOWN states as a function of time shows the structure in the Bragg peaks to be attributable to the cut-off points of each of the contour levels (i.e. an artefact of the plot), and not due to scattering off different domains in the sample with slightly different orientations, which

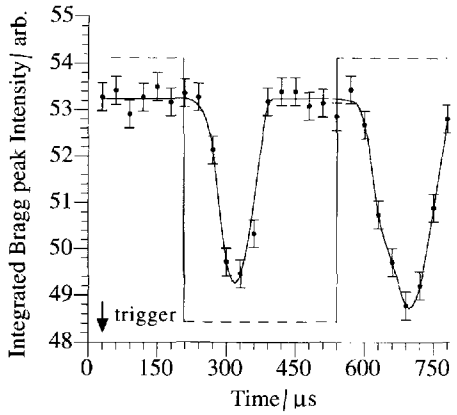

Figure 3. The integrated Bragg spot intensity versus time; Each data point represents the accumulated intensity in the preceding 30 μs.

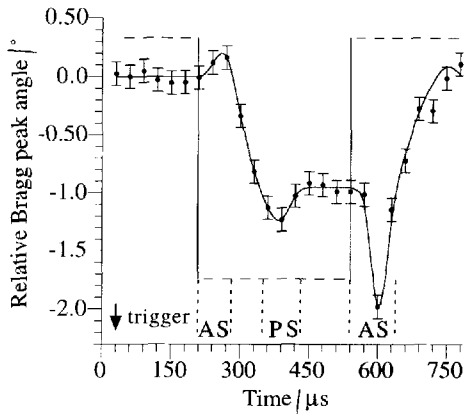

Figure 5. The angle of the Bragg peak relative to the equator, as a function of time; each data point represents the accumulated intensity in the preceding 30 μs.

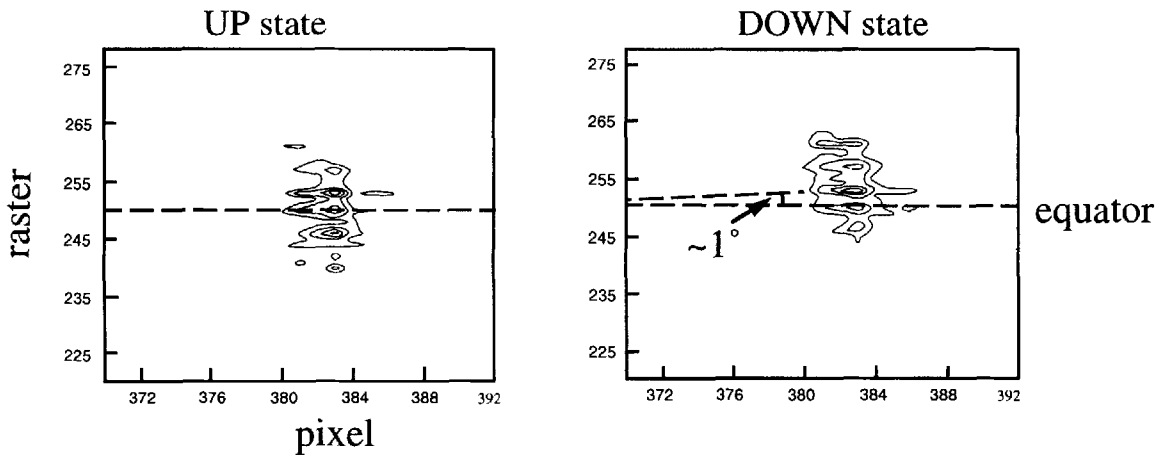

Figure 4. Contour plots showing the distribution of intensity of one of the Bragg peaks in the UP and DOWN switched states; the numbers on the diagrams refer to the pixel and raster numbers of the area detector.

might give rise to a similar structure in the Bragg peak. This was confirmed by optical microscopic analysis of the area from which the data were taken, which showed it to be a monodomain. It is possible to gain useful information from the contour plots by examining the angular position of the peak during switching, which indicates the direction of the projected layer normal. The change was quantified by calculating the position of the centre of mass of the diffraction peak centre as a function of time, figure 5. The angular separation of the layer direction between the UP and DOWN states is $\sim 1°$. Whenever the field direction is changed the layers first 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 consistent with the optical response time of the device. 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: $\sim 0{\cdot}2°$ for UP to DOWN, and $\sim 1{\cdot}0°$ in the opposite case.

The data clearly indicate motion of the layers in two orthogonal directions 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 initial layer rotation (AS period) can be explained qualitatively by

either soft mode switching [10] which is fast compared to the polarisation response, or to backflow effects [11]. The soft mode is expected to have a reasonable contribution to the switching at this temperature, relatively close to the smectic C* to smectic A phase transition, and field induced change in tilt angle could well cause rotation of the layers in the observed direction. 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. However, further experiments are currently underway at different temperatures that may help to distinguish between the two mechanisms. Both soft mode switching and backflow may also account for the behaviour in the PS period. 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 that 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 polarization vector aligns with it and the chevron angle reduces due to torque on the layers. This torque reduces during switching [3], 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 [13] 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 an 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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