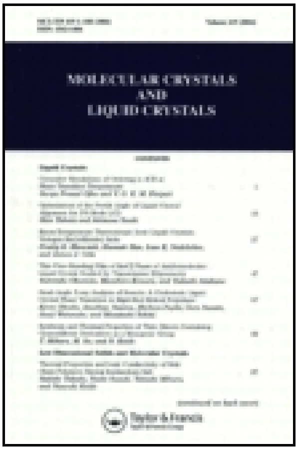

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Ferroelectric liquid crystal devices are notoriously susceptible to mechanical damage. Engineering approaches have reduced flow and shear effects using a polymer wall to maintain the cell spacing across the panel[1]. This was used to produce a 6" video rate display with 64 grey levels and a resistance to mechanical shock which is comparable to commercial STN panels[2]. However, a fundamental understanding of the mechanical damaged structure and its relation to the FLC physical properties is required. In this work X-ray diffraction is used to determine the smectic layer structure arising from mechanical damage.

Keywords: ferroelectric liquid crystals; mechanical damage; x-ray diffraction

INTRODUCTION

Ferroelectric liquid crystal displays (FLCDs) are a strong contender for large area, high information content display applications. Exploitation of the bistable nature of FLCDs allows passively addressed devices to be constructed without a costly active matrix array of thin film transistors. It is the chevron layer structure of surface stabilised FLCDs which results in device bistability, but this also increases the susceptibility to permanent performance degradation due to mechanical disruption of the layer structure. Recently FLC panels have been constructed, using polymer wall spacers, which have a resistance to mechanical damage equivalent to commercially available nematic devices[2]. Understanding the physical processes underlying mechanical damage may allow device improvements in terms of either reduced production cost or increased device performance. In this work x-ray scattering has been used to study the layer perturbations caused by mechanical stress.

MECHANICAL DAMAGE

Damage Tests

Two types of damage test have been used to simulate the mechanical stress which an FLC panel might experience. In the first the pressure applied by a pointed probe was continuously increased (Figure 1a). In the second a rapid (~0.7ms) blow of measured impulse was administered by a Dytran Inc. hammer fitted with a nylon tip (Fig 1b). The severity of the damage resulting from a test was evaluated by microscopic examination of the damaged FLC texture. In this study these tests were applied to two types of 2x2cm cells. One type had normal 1.1mm thickness glass walls, the other type was made with 100μm glass wall to allow X-ray measurement of the smectic layer structure.

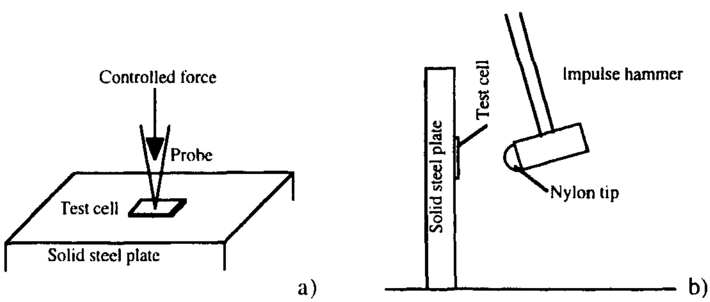

FIGURE 1 a) Hammer and b) Continuous pressure mechanical damage tests.

Damage Processes.

The typical damage processes resulting from a continuous pressure test are shown in Figure 2. The pressure leads to a reduction in the cell gap and so FLC material must flow out of the compressed region. Flow past obstacles (spacers, alignment defects, etc.) nucleates zigzag defects[3] (Figure 2b). Once flow stops the lower energy of the C2 relative to the C1 chevron state tends to cause the C1 zigzags to shrink away. Initially therefore the undamaged C2 FLC texture can recover. However after prolonged or repeated flow some perturbation of the smectic layering remains even after the zigzag defects shrink away (Figure 2c). This leads to a permanent degradation in the FLC switching characteristics. Further flow results in even more severe disruption of the smectic layer structure, giving rise to a damage texture which gives a zero volt optical extinction parallel to the rubbing direction (Fig 2d). Since the damage processes resulting from the pressure test are caused by flow the damage is concentrated in directions parallel to the smectic layering, the easy directions for flow.

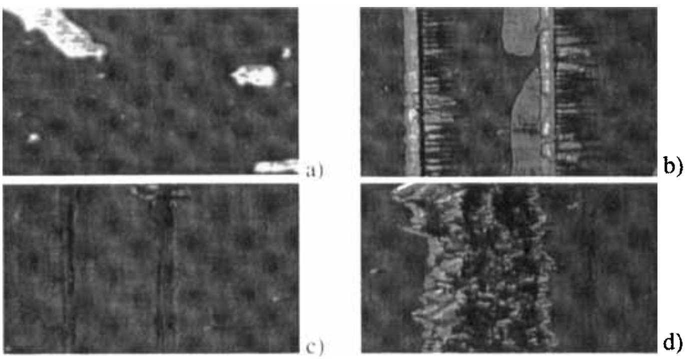

FIGURE 2 Typical damage processes for a pressure test. a) Initial texture, b) Zigzag defects nucleating due to flow past obstacles, c) Zigzag defects shrink away but leave perturbed smectic layering, d) Further flow causes extensive damage texture.

The typical damage processes resulting from a hammer blow are illustrated in Figure 3. The first sign of damage is a patch of needle defects formed in the negative rubbing direction from the point of impact (Figure 3b). For a larger blow a more symmetrical damage pattern forms (Figure 3c) with approximately circular patches of damaged FLC texture plus surrounding needle defects. For still larger blows the patches of damaged texture give extinction parallel to the rubbing direction (Figure 3d). This 'butterfly' pattern of damage, where the damage occurs in directions parallel to the rubbing direction, has been attributed to shear of the FLC layer[4].

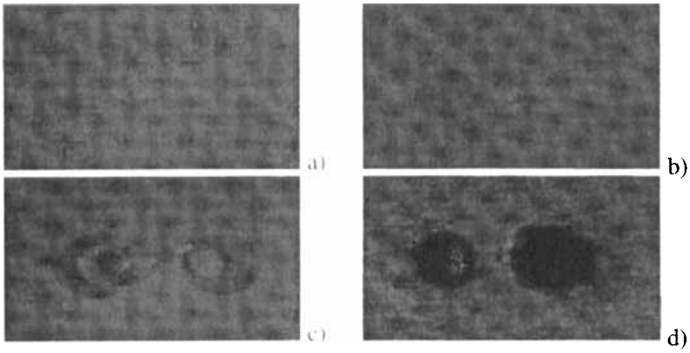

FIGURE 3 Typical damage processes for a hammer test. a) Initial texture, b) 0.028Ns blow, needle defects formed in the negative rubbing direction, c) 0.083Ns blow, symmetrical damage pattern forms, d) 0.121Ns blow, damaged texture gives extinction parallel to the rubbing direction.

Both types of damage test result in damage textures giving a zero volt optical extinction parallel to the rubbing direction. Knowledge of the smectic layer structure of these damage textures is important for understanding the mechanisms by which mechanical damage occurs in FLC panels. Therefore the smectic layer structures of these damage textures have been studied by x-ray diffraction.

DETERMINING FLC LAYER STRUCTURE.

X-ray Diffraction.

X-ray diffraction measurements were made using station 2.1 of the Daresbury laboratory synchrotron radiation facility[5]. Plane polarised x-ray radiation, of wavelength 1.54Å, illuminated a 0.8mm by 2mm sample area and a two dimensional detector recorded the diffracted intensity pattern at multiple orientations of the sample. Ionisation detectors were used to monitor the total intensity of radiation incident on and transmitted by the liquid crystal cell which allowed normalisation of data, and accurate determination of the orientation of the sample with respect to the incident beam. An optical system was also used to enable accurate positioning of cells in the x-ray beam, and to allow viewing of the alignment texture under examination.

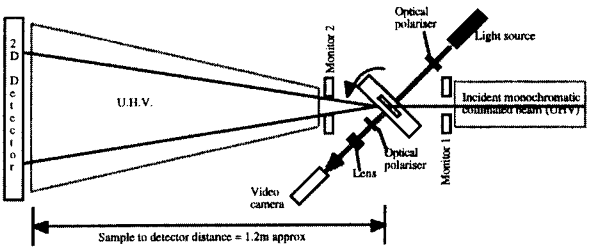

FIGURE 4 X-ray diffraction experimental set-up.

X-ray Data Analysis

Azimuthal analysis of data allowed the in-plane twist and out of plane tilt angle distributions of the smectic layer structure to be determined. Reciprocal space diffracted intensities were converted into layer tilt (δ) and twist (γ) distributions via[6]:

$$\delta = \sin^{-1}\left(\sin\theta_B \cos\phi_r - \cos\theta_B \sin\phi_r \sin\phi_a\right) \quad (1)$$

$$\gamma = \tan^{-1}\left(\frac{\tan\theta_B \sin\phi_r}{\cos\phi_a} + \cos\phi_r \tan\phi_a\right) \quad (2)$$

where θ_B is the Bragg angle, ϕ_a is the azimuthal angle of the data bin and ϕ_r is the angle between the cell normal and incident beam as defined in figure 5. Samples were rocked from -35° to +35° in 0.25° steps, and each acquired data frame contained 256 x 256 data points. Photographs of the mechanically damaged texture were taken before each experimental run.

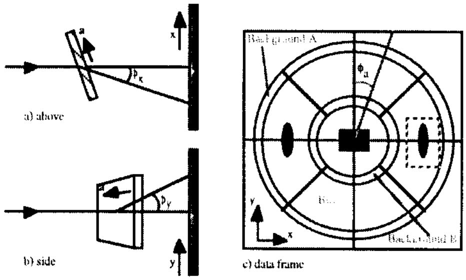

FIGURE 5 Azimuthal analysis of two dimensional x-ray data.

RESULTS

Figure 6 shows the textures induced by continuous pressure and hammer blows in $1cm^2$ active area x-ray cells, with and without active area spacer beads, and a cell with a 3mm by 10mm active area. For the cell with a 3mm by 10mm active area shear damage was not observed due to the proximity of the

Damage	Cell X279 10mmx10mm active area	Cell X280 10mmx10mm active area Active area beads	Cell X283 10mmx3mm active area
Shear by pressure			Damage not possible
Flow by pressure	Damage not possible		
Shear by hammer			Damage not possible

FIGURE 6 Mechanical damage texture of x-ray test cells (rubbing direction right to left).

edge seal to the active area. The cells were filled with the FLC material SCE13, which has a cone angle of approximately 25° at a temperature of 30°C. The undamaged texture was mainly C1 with some C2 zig-zags. X-ray diffraction data from these textures are given in figure 7.

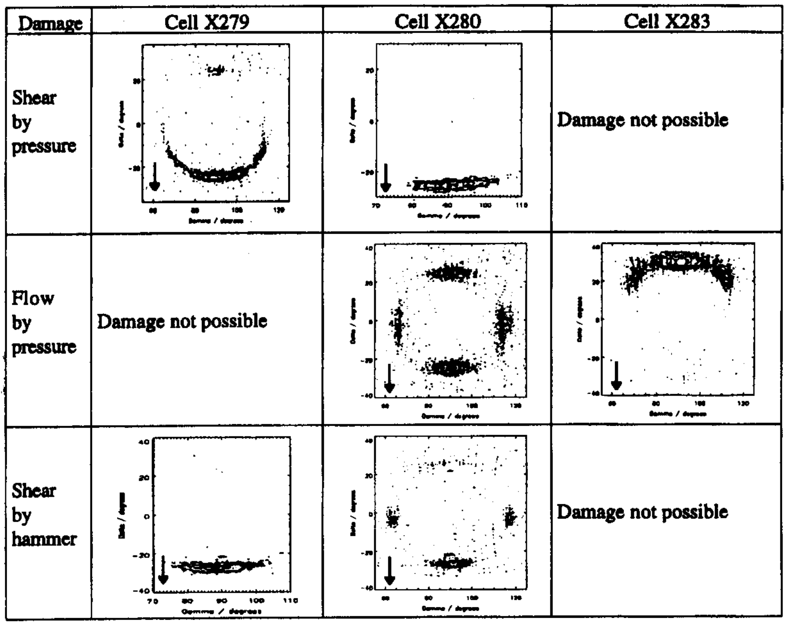

FIGURE 7 Azimuthal data plots of mechanically damaged cells.

After collection of mechanical damage data the cell was heated into the S_A phase and slowly cooled into the S_C phase. All S_A and realigned S_C data show the expected bookshelf and chevron layer structures.

DISCUSSION

For all types of damage shown in Figure 7 the diffracted x-ray peaks lie on a locus of layer twists and tilts at approximately the cone angle to the $\delta = 0$, $\gamma = 0$ point. This corresponds to the liquid crystal director lying parallel to the rubbing direction and the smectic layer normal being orientated at the cone angle to this direction. The director lying along the rubbing direction is the lowest energy configuration. However it does not normally occur in the s_C phase of an FLC cell because, once the smectic layers have formed at the N-S_A transition, the layer pitch is pinned at the cell walls. It appears from the results in Figure 7 that the effect of mechanical stress on the FLC cells is to unpin the smectic layers at the cell walls. The liquid crystal director can then relax to its lowest energy configuration and the smectic layers take up a structure commensurate with that director configuration.

Looking in more detail at the results in Figure 7 it can be seen that shear, either produced by pressure or a hammer blow, leads mainly to a smectic layer structure which is uniformly tilted by the cone angle with respect to the cell walls. This UTL structure is consistent with the model[4], illustrated in figure 8, that shear of the FLC layer initially causes the chevron interface to be displaced towards one of the cell walls. Once the shear exceeds the value which causes the chevron interface to reach the cell wall the smectic layers must become unpinned. The detail of the damage structure caused by flow is less consistent. For cell X283 a UTL structure formed. However for cell X280 both the chevron peaks remained, although reduced in intensity. In addition two new peaks appeared with approximately zero tilt, but twisted out at the cone angle to the rubbing direction. This damage texture therefore appears to be a mixture of a chevron structure and a periodically twisted quasi-bookshelf structure.

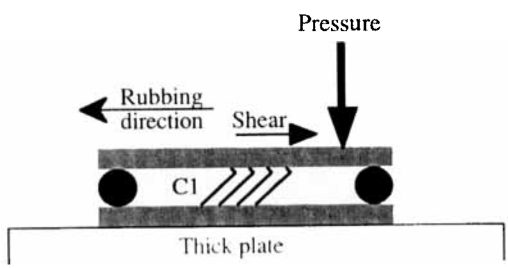

FIGURE 8 Illustration of shear forces producing a UTL structure.

CONCLUSIONS

X-ray scattering studies have shown that mechanical stress on FLC test cells causes a damage texture with a consistent smectic layer structure. This layer structure fulfils the two conditions of the director lying parallel to the rubbing direction and lying on the cone of the smectic layers. Layer structures which fulfil this condition include a UTL and a periodically twisted quasi-bookshelf structure. Both of these have been observed. The detail of the layer structure which forms as a result of mechanical stress depends on the cell construction and the method of stressing. In all cases in this study shear stress gave rise to a UTL structure.

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