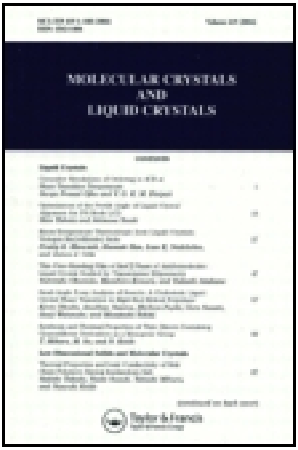

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Modified Williams' Domains in Liquid Crystals

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MODIFIED WILLIAMS' DOMAINS IN LIQUID CRYSTALS

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ABSTRACT: Far-field diffraction patterns of radiation transmitted through a negative liquid crystal in a cell with rubbed parallel alignment reveals two groups of domains, at equal angles to the rubbing direction. The vortex motion is not circular, as has been reported earlier, but spiral, with translation in opposite directions in neighbouring domains. The effect of voltage and frequency changes is reported.

Liquid crystals with negative dielectric anisotropy show at low voltages and low frequency an electrohydrodynamic instability which is revealed by the appearance of light and dark stripes in transmitted light. These stripes, or Williams' domains, are caused by vortex motion setting up a roughly parallel array of cylindrical lenses, and the characteristics of the effect were well documented some 10 years ago. We wish to report results which show marked differences from the earlier observations[1,2].

The cells used, squares of side 2.5 cm, were of thickness between 6 and 12 microns, with rubbed PVA alignment on both surfaces. They were driven AC, and held in the beam from a helium-neon laser about 25 cm from a screen. The rubbed direction was vertical. The far-field diffraction pattern could thus readily be observed and photographed. A typical pattern from Merck Licrystal Phase 5A is shown in Figure 1. The output from an RMS voltmeter is recorded on the left hand side of the figure. The dot pattern develops from diffuse lines in the first ten to twenty seconds, and then changes more slowly.

Our results are unexpected in three ways. First, the existence of such a defined diffraction pattern, with as many as nine orders, reveals a high degree of order. Published pictures of Williams' domains[3] show variations in parallelism and direction - a typical micrograph of our cells is shown in Figure 2, and the uniformity of the domains is clear. Second, Williams' domains are at 90° to the rubbing direction for cells with planar alignment whereas our domains are at an angle $90-\alpha$. In Figure 1 α is about 20°. Third, there are generally two sets of domains, and α can be positive or negative. On first application of the field the two arms of the diffraction pattern are of equal intensity, but gradually one becomes dominant. The other can be found in different regions of the cell. The micrograph in Figure 2 was taken after the field had been switched on for several minutes. Earlier two or three zones of each type would be visible in the field of view.

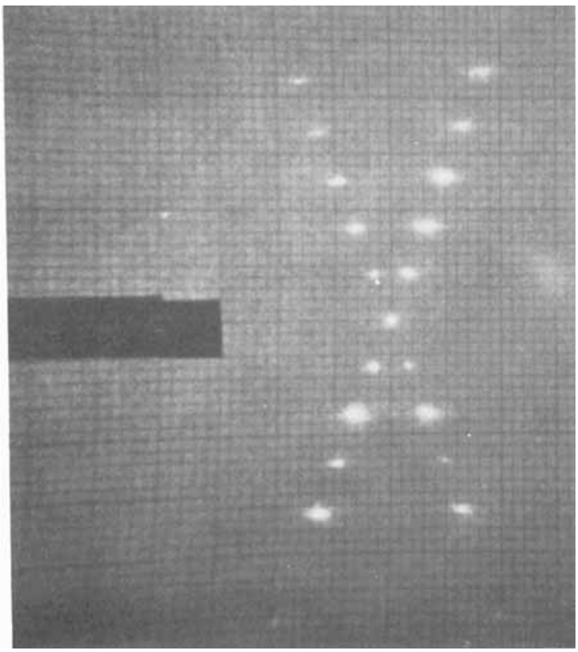

FIGURE 1 Far-field diffraction pattern, 6 micron cell, Licrystal Phase 5A driven at 5.39 v, 50 Hz. Photograph taken 60 secs after field applied.

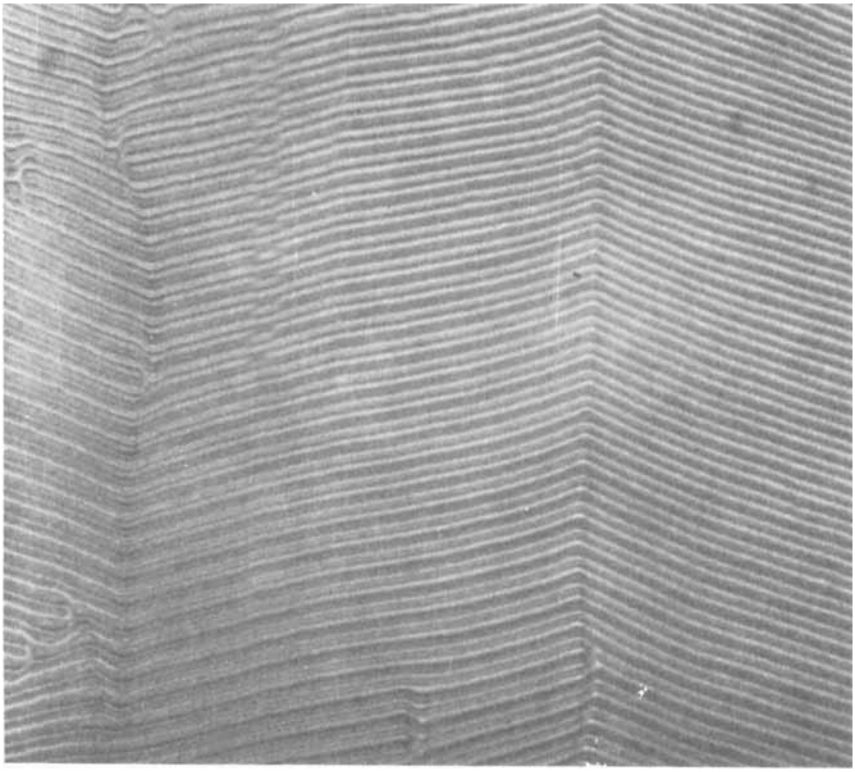

FIGURE 2 Micrograph of cell as in Figure 1. Separation between dark bands in lower part of picture approximately 14 microns. [The sequence is dark-light-grey-light-dark] The alignment direction is up the page.

The diffraction pattern for a cell containing MBBA is shown in Figure 3. The two arms are clearly visible, but α is only 4^{o}. A less sensitive method of observation might well miss the degeneracy, and conclude the domains were at 90^{o} to the rubbing direction. It should be emphasised that the materials we have found to show a large value of α were not available at the time of Williams work.

The two-armed diffraction pattern could be observed over only a limited voltage range, which for Phase 5A was about 1 v. For a typical cell the threshold voltage for appearance

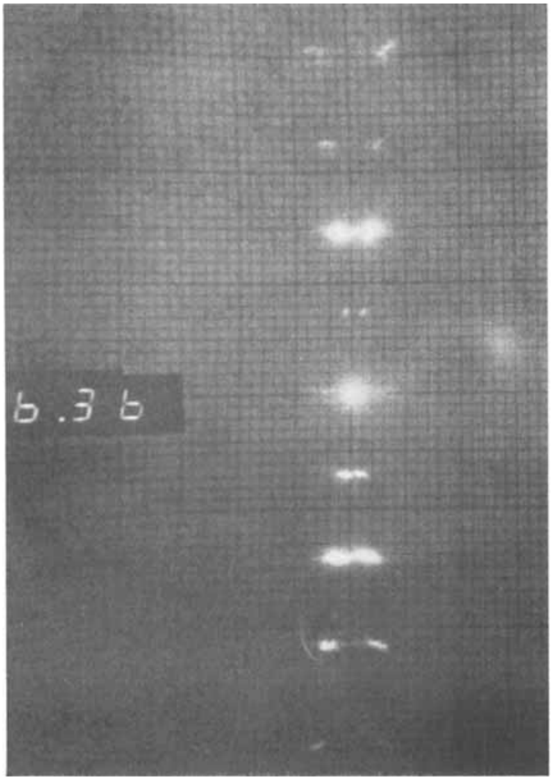

FIGURE 3 Far-field diffraction pattern, 6 micron cell, MBBA, driven at 6.36 v, 50 Hz. Photograph taken 210 secs after field applied.

was 5.7 volts at 50 Hz, and at 6.6 volts a more complex series of spots appeared (Figure 4). These spots could take the form of an array with hexagonal symmetry. The corresponding micrographs showed a network of fine squares or hexagons, similar to the gridded pattern recently reported by Kai and Hirakawa[4]. At still higher voltages dynamic scattering sets in. The variation of the threshold voltage, V_T, and the voltage at which the diffraction pattern becomes complex, V_M, is shown as a function of frequency in Figure 5. V_T can be found precisely, since the appearance of the spots is reproducible. The minimum at 10 Hz is noteworthy, since it has not been reported previously. V_M cannot be defined so accurately, and it varies by perhaps 0.1 volts with time. A similar behaviour is observed for

MBBA, but for our heavily doped sample the minimum V_T, 6.17 v, occurred at 70 Hz, and the two-armed pattern could still be obtained at 1 kHz.

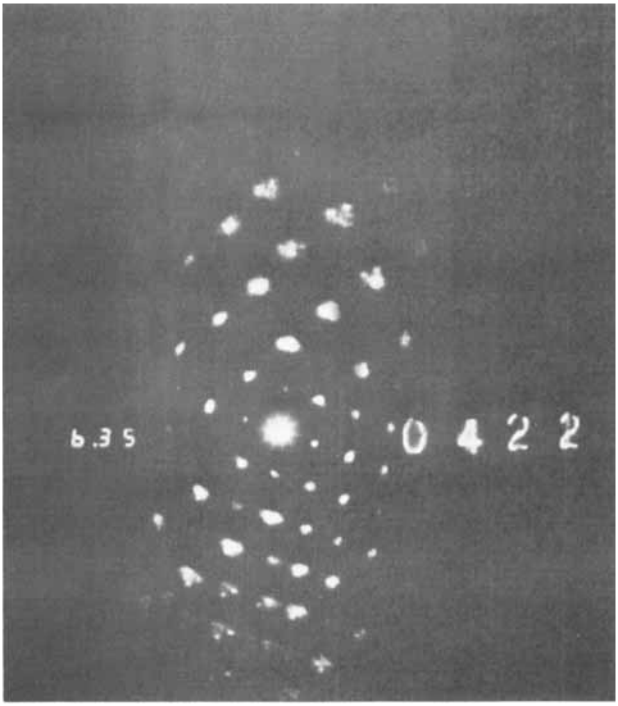

FIGURE 4 Cell as in Figure 1, driven at 6.35 v, 30 Hz, 422 secs after field applied.

The angle α was a function of both voltage and frequency, usually tending to decrease as either increased. A typical Phase 5A cell operated at 50 Hz had $\alpha = 25^{\circ}$ at 5.1 v and 18° at 5.6 v. At the higher frequencies there was a tendency for α first to increase with volts and then decrease. The diffraction pattern can be used to deduce the domain separation, and to observe any variation with voltage and frequency. There was no observable variation with voltage, and only a 20% decrease with an order of magnitude increase of frequency.

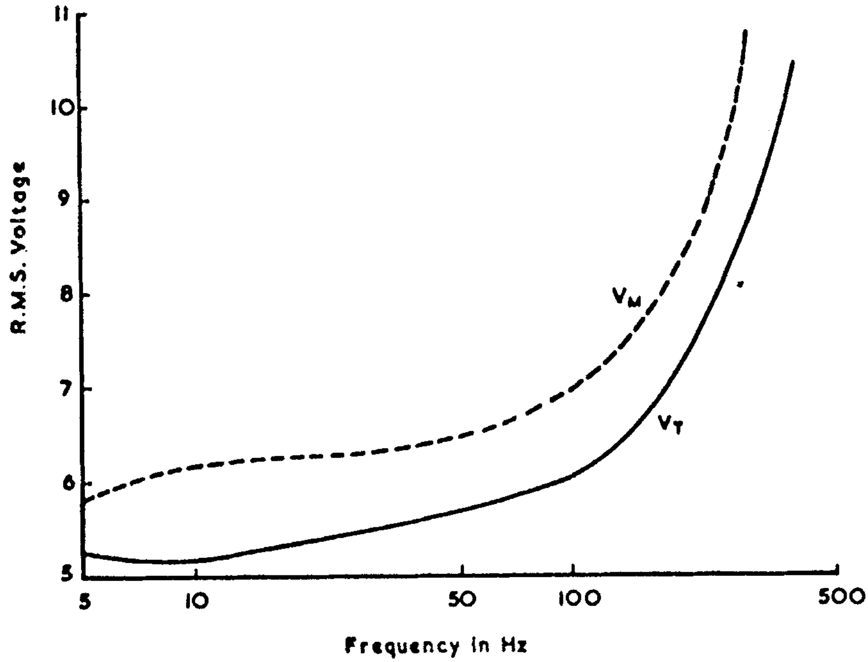

FIGURE 5 Variation of V_T and V_M with frequency for 6 micron, Phase 5A cell.

It has earlier been assumed that the vortex motion in Williams' domains is planar, the molecules moving in circles in the plane defined by the direction of the field and the direction of rubbing. Microscope studies of our Phase 5A cells showed that the motion was helical, particles being translated across the field of view while confined to the domain channel. The direction of motion was reversed in neighbouring channels, but was unaltered in crossing a boundary between domains of opposite signs of α.

First experiments with a number of other materials with negative anisotropy shows that the two-armed diffraction pattern is general, and that α is usually larger than 10°.

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