Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Surface Deformation and Walls in the Conduction Regime of Nematic Liquid Crystals

R. W. H. Kozlowski [a] & E. F. Carr [a]
[a] Department of Physics, University of Maine Orono, Maine, 04469, USA
Version of record first published: 20 Apr 2011.

To cite this article: R. W. H. Kozlowski & E. F. Carr (1981): Surface Deformation and Walls in the Conduction Regime of Nematic Liquid Crystals, Molecular Crystals and Liquid Crystals, 64:9-10, 299-304

To link to this article: http://dx.doi.org/10.1080/01406568108072015

Mol. Cryst. Liq. Cryst. Vol. 64 (Letters), pp. 299-304
0140-6566/81/6409-0299$06.50/0

Printed in the United States of America

SURFACE DEFORMATION AND WALLS IN THE CONDUCTION REGIME OF NEMATIC LIQUID CRYSTALS

R.W.H. KOZLOWSKI and E.F. CARR
Department of Physics, University of Maine
Orono, Maine 04469 USA
Submitted for publication: March 2, 1981

Abstract: Reflection of a laser beam from the free surface of a nematic liquid crystal shows that the surface is periodically deformed when a high electric field (conduction regime) is continuously applied. Walls which appear to be of the alignment-inversion type have also been observed for these fields. These results are associated with flow cells that were discussed earlier.

A model[1] (reproduced in Fig. 1) was proposed to explain molecular alignment and material flow due to applied electric fields. Much of the evidence[1,2] in support of this model involved measurements that were made shortly after an electric field (conduction regime) had been applied to a nematic material that was initially well aligned. The work presented here supports the model for high electric fields continuously applied to bulk samples exhibiting negative dielectric and positive conductivity anisotropies.

A photograph of the surface of a sample of MBBA (cutoff frequency = 200 Hz) in the presence of a 5000 V/cm dc electric field is shown in Fig. 2a. Walls (defects) can be seen extending out from the electrodes to more than one-half the distance between them. The walls appear to be similar to the alignment-inversion walls discussed by Helfrich[3]. The direction of maximun flow velocity and the flow cell width are indicated in Fig. 2b. Because of the difficulties in photographing walls only a few are shown in Fig. 2a. These walls can be observed with the naked eye and they appear to be reasonably well spaced over the surface of the sample. Even though walls are being destroyed and created they appear quite stable. Photographs involving a time exposure of several seconds shows evidence of walls even though the maximun flow velocity is greater than 1 cm/sec. This implies that an element of volume of the sample could make many rotations in the flow cell while the photograph was being taken. While the walls appear stationary the material making up

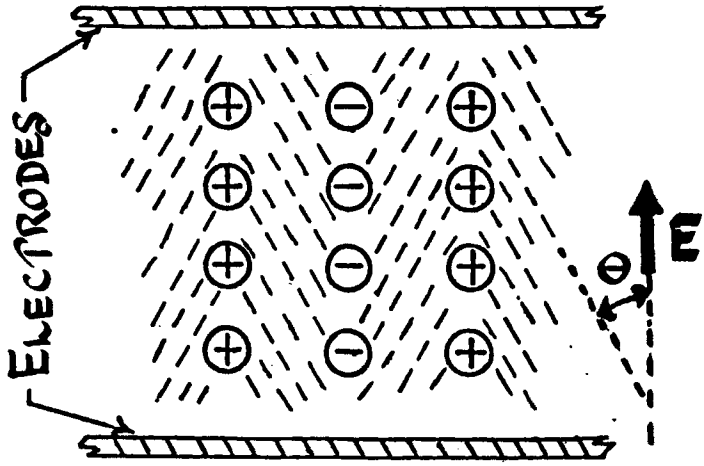

FIGURE 1. Model for molecular alignment and material flow due to an external electric field. Charges accumulate at the walls (defects) which are perpendicular to the electrodes and the plane of the paper. Forces due to the interaction of the electric field with the space charge at the walls (defects) tend to shear the sample. Because of shear flow, the director associated with the sample between the walls is turned toward the electric field giving rise to the "flow alignment-angle" Θ. Although the walls should appear to be stationary, the material making up the walls is constantly changing. For further discussion see reference 1.

the wall is constantly changing and moving with the maximum fluid velocity. The material making up the wall moves into the wall as it leaves the electrode and leaves the wall as it approaches the opposite electrode.

Figure 3 shows patterns obtained from the reflection of a laser beam (0.5 mw) making an angle of 14^{o} with respect to the surface of a sample of MBBA. A large sample was necessary to avoid any curvature of the menicus at the center of the sample that would give rise to magnification. This also meant that the sample holder had to be level and contain the correct amount of sample.

Figure 3b is a photograph of the laser beam after reflection from the flat surface of the sample with no applied field. Figure 3c is a photograph of a pattern with an applied dc field of 3300 V/cm. Approximately five flow cells were responsible

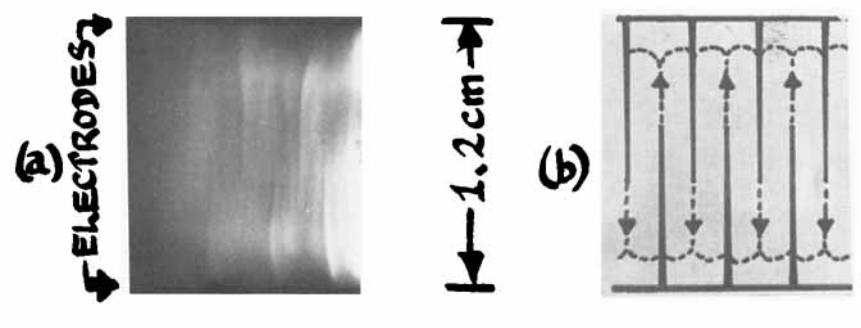

FIGURE 2. (a) Walls due to a continuously applied 5000 V/cm electric field at the free surface of MBBA. (b) Schematic diagram for the material flow.

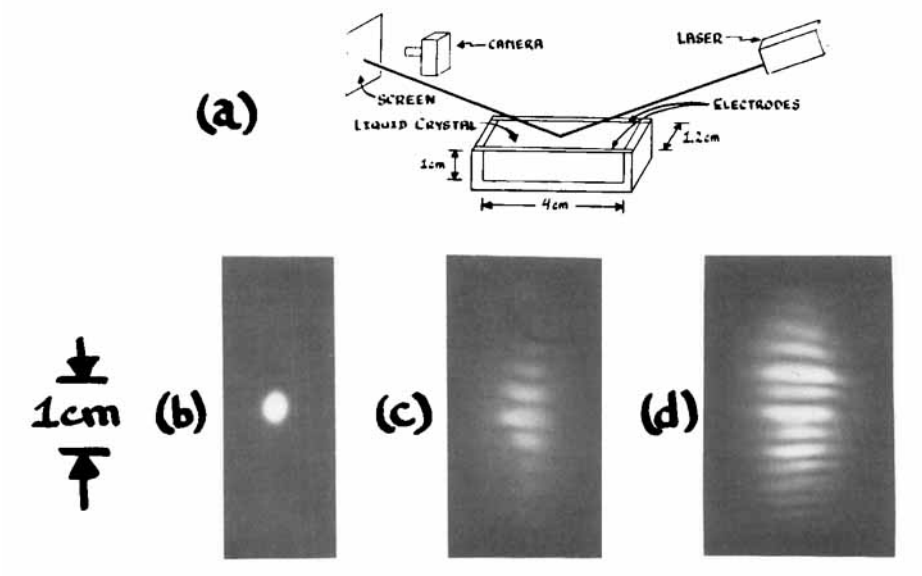

FIGURE 3. Diffraction patterns due to the reflection of a laser beam from the free surface of MBBA: (a) Schematic diagram of the experimental setup, (screen is 150 cm from the sample), (b) Electric Field E=0, (c) E=3300 V/cm, (d) E=5000 V/cm.

for this pattern. This pattern is caused by the reflection from the surface of the sample which is no longer flat (Bernoulli Effect) due to the variation of the velocity across the flow cell. Since the velocity can vary by as much as 1 cm/sec, a variation in height of a few microns is expected. If this pattern is a diffraction pattern, it should become larger and contain more maxima and minima if the field is increased, and Fig. 3d shows this to be the case. Previous work[1] had indicated that the flow velocity varied approximately as the square of the electric field intensity. Since Figs. 3c and d are diffraction patterns, small fluctuations in the flow cells produce drastic changes in these patterns. Hence, these patterns are not as stable as those shown in Fig. 2 although the contrast is much better which facilitates photography.

The photographs in Figs. 3c and d show some horizontal magnification. This is to be expected because when looking in a direction perpendicular to the electrodes the crest of the distortion should be level whereas the trough of the distortion (where the fluid velocity is greatest) should be concave. The model in Fig. 1 may imply that all the flow parallel to the electrodes takes place very near the electrodes, but observation of the movement of dust particles indicates that the fluid velocity is greatest midway between the electrodes. This concave shape would require that the rays from the laser cross after reflection from the surface of the sample and if the screen is far enough away a magnification should result. By cutting off part of the laser beam while observing the pattern we were able to show that this was the case. Since the extremes of the patterns (3c and d) are primarily due to regions in the flow cell that were higher than the trough we would expect the observed narrowing of the pattern.

A detailed analysis of the diffraction pattern (Fig. 3) is not attemped at this time because of uncertainty as to the surface's contour. One might assume a sine curve, but the model (Fig. 1) indicates that some areas of the surface should have a parabola-like nature. Also the shape of the surface should vary some as one moves from the center of the sample towards the electrodes. It should also be noted that good patterns with different numbers of maxima and minima were also obtained for a given value of the field intensity. Variations in flow velocity and flow cell width would be effective in bringing about these changes. The most interesting aspect of these patterns is not

the analysis of them, but rather the fact that the mechanism involving molecular alignment and material flow is such a well behaved mechanism that patterns like those in Fig. 3 are even possible.

Conclusion: Previous work had supported the model in Fig 1 and had indicated that the model also applied to dynamic scattering, but there was not much evidence as to how the walls were being created or destroyed in the presence of continuously applied electric fields. The work discussed here shows that there are walls and they are quite stable. The results indicate that the material making up the walls moves into the wall as it leaves the region near the electrode and leaves the wall as it approaches the opposite electrode. The structure of the walls is not known, but when a sheet of polaroid is placed in front of the microscope the walls are clearer for light polarized perpendicular to the electrodes. This implies that the walls have a twist associated with them as in twist walls. More work on the stability of walls for electrode separations less than 0.5 cm is needed. In thinner samples the presence of other defects and the small flow cell size make walls much more difficult to identify.

At the free surface the walls are perpendicular to both the electrodes and the surface. However, in the body of a sample in which the depth is much greater than the electrode seperation, the model only requires the walls to be perpendicular to the electrodes. In earlier work[1] (depth was two times the plate seperation), where the initial conditions were a well ordered sample and observations were made shortly after turning on the field, the results indicated that the walls tend to extend to the bottom of the sample. Results are not available for wall depths when high electric fields are continuously applied.

The model (Fig. 1) predicts that in a large portion of the sample, the director should align at an angle of Θ with respect to the electric field and the angle can be related to the flow-alignment angle[4]. This angle was observed by Tarr and Carr[5] in MBBA using NMR techniques. Although there are small deviations due to dielectric and conductivity anisotropies, an angle associated with flow-alignment was measured as a function of temperature. We believe that these results are also excellent evidence in support of the model.

It now appears that the patterns, which were used for earlier work[6] to determine the flow cell width as a function of the electric field intensity, were due to walls. Also the work of some other investigators may be related to the work discussed here even though their experimental setups were quite different.

Acknowledgments: The authors are greatful for helpful discussions with G.C. Krueger, W.N. Unertl, and J.S. Hutchison.

REFERENCES

1. E.F. Carr, Liquid Crystals and Ordered Fluids III,]65, (eds. J.F. Johnson and R.S. Porter) Plenum Press (]978).

2. E.F. Carr, P.H. Ackroyd and J.K. Newell, Mol. Cryst. and Liq. Cryst. 43, 93 (1977); E.F. Carr and R.W.H. Kozlowski, Liquid Crystals (ed. S. Chandrasekhar) pp. 287-295, Heyden, London (1980).

3. W. Helfrich, Phys. Rev. Lett. 21, 1518 (1968).

4. F.M. Leslie, Arch. Ration. Mech. Anal. 28, 265 (1968).

5. C.E. Tarr and E.F. Carr, Solid State Commun. 33, 459 (1980).

6. E.J. Sinclair and E.F. Carr, Mol. Cryst. and Liq. Cryst. 37, 303 (1976).

7. Houg Sup Lim amd J. David Margerum, J. Electro. Chem. Soc., 123, 837 (1976); R. Chang, Mol. Cryst. and Liq. Cryst., 20, 276 (1973); P.P. Karat and N.V. Madhusudana, Pramana, Suppl., No.1, p.285 (1973); S. Kai, K. Yamaguchi and K. Hirakawa, J. Phys. Soc. (Japan) 40, 267 (1976).