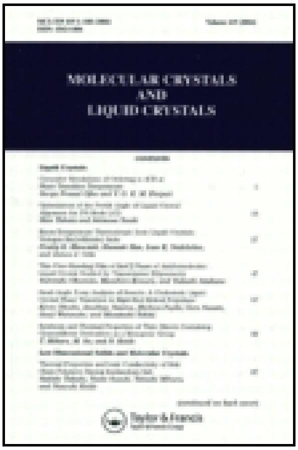

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Electro- and Magnetooptical Phenomena in Bulk Ordered Nematic Liquid Crystals

V. A. Tsvetkov [a] , O. V. Tsvetkov [a] & V. A. Balandin [a]

[a] Moscow State Academy of Instrument Engineering and Informatics, Stromynka 20, Moscow, 107846, Russia

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Electro- and Magnetooptical Phenomena in Bulk Ordered Nematic Liquid Crystals

V.A. TSVETKOV*, O.V. TSVETKOV and V.A. BALANDIN

Moscow State Academy of Instrument Engineering and Informatics,
Stromynka 20, Moscow, 107846, Russia

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Bulk ordered LC samples up to 3 × 3 × 8 mm (width × thickness × height) in size have been investigated. The restricting surfaces were rubbed or treated in order to achieve a homeotropic orientation. A concordent treatment of the surfaces leads to a perfect monocrystal. Orientation of two surfaces perpendicular to the other ones results in a deformed non-monocrystal structure. By application of the external electric or magnetic field as well as by variation of the temperature one can manipulate with the deformed structure and obtain information on the behavior in the boundary LC layers.

Keywords: bulk orientation; boundary; monocrystal; electric and magnetic fields

INTRODUCTION

It is known that many physical parameters of LC significantly differ depending on the proximity to the orienting surfaces[1]. Most of electrooptical observations and measurements were made in the samples whose medium layers were within 100–150 μm from the orienting layers, which means that the sample thickness did not exceed 300 μm.

EXPERIMENTAL

We made an attempt to make a LC bulk monocrystal 3 × 3 × 8 mm in size. The LC was placed into a cavity composed of two glass plates and 4 glass bars with a

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* Corresponding Author: e-mail: tsvet@pop3.mipt.ru

cross-section of 3 × 3 mm. Transparent electrodes were applied to two walls of the cavity. All the walls of the cavity were treated with a homeotropic orienting agent or rubbed in order to create conditions for formation of a bulk monocrystal. Thus, if four vertical walls are rubbed along the vertical to attain a planar orientation in the boundary layers with a homeotropic orientation of two horizontal walls, then a sufficiently perfect bulk monocrystal is formed whose optical axis is directed vertically. While observing such sample in rotating crossed polarizers one can see how the field of the sample either switches off or clears up depending on the orientation of the optical axis of the sample relative to the polarization planes of the polarizers. Such samples are very convenient in x-ray investigations.

The most interesting observations, however, were obtained for the case when all surfaces of the cavity were rubbed in a planar way, with four faces providing a horizontal planar orientation while two faces (left and right) vertical planar one (Fig. 1a). The distribution of the molecules orientation across cross-section *abcd* is shown in Fig. 1b.

It can be seen that in the central part of the sample all orienting faces orient concordantly. Near the lateral faces the LC molecules are subjected to the orienting action of the surfaces with mutually perpendicular orienting direction. Fig. 2a-d shows the sample in the crossed polarizers illuminated by a laser (0,63 μm) at 22–25°C (to get a more clear picture, the sample thickness is chosen 0,9 mm).

The LC mixture used was MBBA and ether nitriles with a nematic range of 4....65°C, the dielectric anisotropy being +2.

It is seen from Fig. 2a that in the central part of the sample there are clearly defined interference bands indicating a good monocrystalline structure of the sample. Near the lateral faces, where the LC molecules are subjected to the orienting action of the surfaces with mutually perpendicular directions and are forced to take a certain transient orientation, the interference bands are considerably curved.

When alternating voltage of over 50 Hz is applied to the lateral faces of the sample (hatched in Fig. 1a), then the interference bands smoothly (without any threshold) straighten (Fig. 2b). On attaining certain voltage, the bands become parallel (Fig. 2c) and remain unchanged with further growth of the voltage. If the driving voltage is switched off, some time later near the lateral faces of the sample there occur waves of the interference band curvatures which gradually propagate towards the central part of the sample. Fig. 2d shows the sample 7 minutes after switching off the voltage. About 1.5 ... 2 hours after switching off the voltage, the sample looks like it was before application of the voltage (Fig. 2a). A

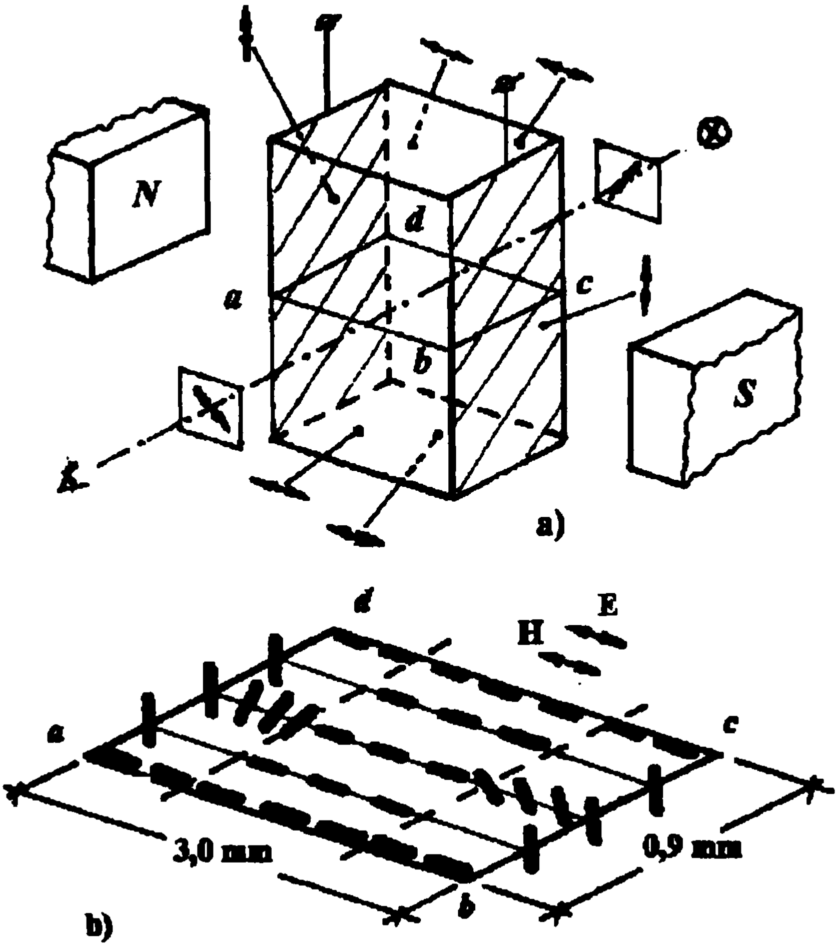

FIGURE 1 Diagram of measurements (a) and distribution of the LC molecules orientations across the *abcd* cross-section (b)

similar behaviour of the bands is observed when a magnetic field parallel to the electric field is applied to the sample.

RESULT AND DISCUSSION

The behaviour of the interference bands affected by the electric or magnetic field can be explained as follows. In the original state in the central part of the sample

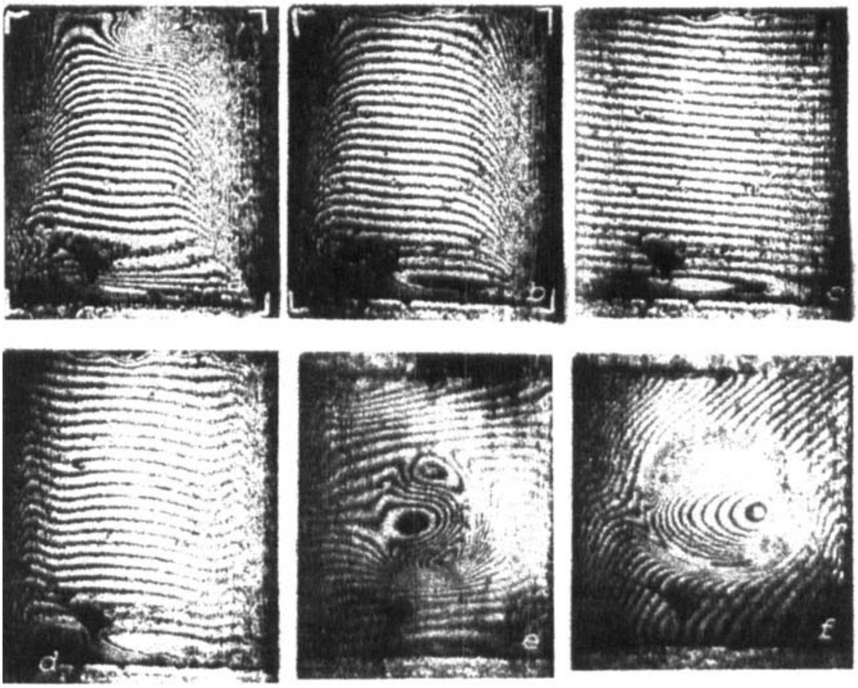

FIGURE 2 Appearance of the LC sample in crossed polarizers at various actions affecting the sample

where all orienting surfaces orient concordantly and horizontally, there is a perfect bulk monocrystal. Near the lateral faces which orient adjoining layers in the direction perpendicular to the remaining faces, there is an area with a transient orientation. It is this area that gives a picture of curved bands. The curving of the bands stops in the point of equilibrium between two competing orientations. Application of the electric or magnetic fields along one of the competing orientation directions suppresses the orienting action of the other orientation and disposes the equilibrium point (Fig. 2b) up to a complete suppression of its orienting action (Fig. 2c). When the external effect is stopped, the equilibrium point returns to the original state at a velocity typical for LC. For a fixed temperature this velocity is defined by the visco-elastic properties of the LC. The location of the equilibrium point is defined by the elastic properties of the LC and the orienting force of the surfaces.

Another interesting phenomenon is observed at heating of the sample. At the room temperature the sample looks like it is shown in Fig. 2a. As it is heated, the bands straighten in central part (as if under some external orienting action) and at a certain temperature (which was 31°C for our LC) straighten completely, i.e. the disorienting action of the lateral faces is suppressed and the sample looks as in Fig. 2c.

With further rise of the temperature up to 40°C the appearance of the sample practically remains unchanged. At the temperature of about 42°C – which is far from that of the transition to the isotropic phase (65°C) – in the central part of the sample there occurs circular curving of the bands (Fig. 2e). The area of the curved bands expands with further growth in the temperature (Fig. 2f, 55°C). On application of an external electric or magnetic field the bands straighten and then curve again on switching off the external fields. When the temperature of heating exceeds that of the isotropic point, all bands disappear. The phenomena taking place at variations of the temperature can be explained as follows.

At the room temperature the point of equilibrium of forces between four surfaces orienting horizontally and one lateral surface acting vertically is at some distance from the lateral face, specifically, in the place where the bands start to curve (Fig. 2 a). With heating the range of action of the orienting surfaces equally drops. As there are four surfaces orienting horizontally and only one vertically, the fraction of the horizontally oriented LC molecules grows, the « central » part of the sample extends (the bands partially straighten). On attaining a certain temperature, the bands straighten in full testifying about complete suppression of the orienting action of the lateral face. The further growth of the temperature does not affect the appearance of the bands up to such temperature at which the incident range of action of the orienting surface is still sufficient to orient throughout the entire thickness of the LC sample. Upon attaining a certain temperature, in the thickness of the central part of the sample, to which the orienting action of the surfaces does not reach, due to the thermal fluctuations there starts a disorientation of the LC molecules and the sample assumes an appearance shown in Figs. 2e, f, i.e. the one with curved bands in the central part. If the temperature remains the same, this appearance also remains unchanged. Explanation of the sample's condition, for instance, by partial transition of the sample to the isotropic phase would hold no critic by the following reasons.

1. The curving of the bands in the center starts at the temperature far from the isotropic point (by almost 20°C) and it is difficult to imagine such temperature gradient for the maximum thickness of the sample of 3 mm.

2. Application of external fields (either electric or magnetic) results in straightening of the bands throughout the entire sample which is an evidence of the existence of the LC phase throughout the entire volume of the sample and of the suppression of the thermal fluctuations disorienting the central part of the sample.

CONCLUSION

The above qualitative description of the processes optically observed in the bulk ordered sample opens extensive methodological possibilities of investigating LC physical parameters in bulk samples, specifically

1. To measure magnetic susceptibility by a simple method. The straightening of the bands occurs under the action of both electric and magnetic fields. The procedures for measurement of dielectric parameters of LC are well developed. From the known dielectric parameters for equal straightening action of the electric and magnetic fields one can calculate diamagnetic parameters. Thus, for the LC used, the intensity of the electric field of 1 V/cm is equivalent to that of the magnetic field of 4.8 oersted. The value of $\Delta\chi$ equal to 1.7×10^{-7} which is the same order of magnitude as for $\Delta\chi$ para-azoxycyanizole (1.73×10^{-7}).
2. From the curvature of the bands in the center of the LC cell it is possible to directly measure the temperature length of the coherence, i.e., the distance from the orienting surface at which due to the temperature fluctuations the surface does not exert any orienting action on the LC. In our experiment the temperature length of the coherence at 41.6°C is 450 μm (half of the sample thickness). In view of the fact that application of the electric or magnetic fields restores the orientation (as if the coherence temperature length were increased) and their magnitudes can be easily measured, having made an adequate calculator one can compute energetics of the temperature fluctuations and possibly the degree of ordering.
3. For a fixed temperature, the location of the equilibrium point of the forces of the surfaces orienting in two mutually perpendicular directions is defined by the LC elastic coefficients, the coherence temperature length and possibly by the LC molecule pre-tilt angle. The location of the equilibrium point is defined by magnetic and electric fields which can be easily measured, same as the coherence temperature length. Consequently, having created an adequate calculating device, it is possible to compute a number of elastic coefficients and the pre-tilt angle.
4. At least in two LC cells it was evidently found that the equilibrium point is at a different distance from the vertically orienting surface depending on the nature of the orienting surface, for instance, be it a rubbed polymer film or a skew evaporated film. Probably, the orienting ability of the planar orienting surfaces is different and can be estimated by the procedure proposed.

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