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Light Diffraction by Laser Beam Created "Channels" in Nematic Liquid Crystals

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Light diffraction was found and studied on "Channels" i.e. cylindrical regions of isotropic liquid in the nematic phase of a liquid crystal, created along the path of a laser beam by heating. Reorientation of the director is shown to take place at the boundary of these channels.

INTRODUCTION

During our previous investigations on the Fredericks effect caused by the field of a light wave[1-3] in some cases in the nematic phase of liquid crystalline MBBA (*p*-*n*-methoxybenzilidene-*p*-butylaniline) a system of nearly equidistant rings could be observed on the screen behind the sample. The distance between two adjacent rings was found to depend on the laser power. A similar ring system was observed by Volterra and Wiener-Avnear[4] when they studied thermal lens effects in MBBA. No explanation has been given, however, for the appearance of this system of equidistant rings. The aim of the present work was therefore the detailed investigation of this phenomenon.

EXPERIMENTAL

The experimental setup was similar to that used earlier.[1-3] The samples used were sandwich like cells of homeotropically aligned nematic liquid crystals (NLC) of MBBA or OCB (octyl-cyano-biphenyl). The cells were placed in a temperature controlled chamber. The linearly polarized beam of an argon ion laser of 515 nm wavelength was focused into the sample with a good lens ($f = 270$ mm). The plane of polarization was rotated with a polarization rotator. The transmitted beam pattern could be observed or photographed on a screen at about 20 cm behind the sample. The wave vector of the incident light wave was always parallel with the director of the NCL. For the analysis of the transmitted light a polaroid sheet was placed between the crystal and the screen.

RESULTS

1. For OCB the equidistant ring system appeared at temperatures quite near to the clearing temperature; for MBBA it could be observed near to the clearing point only in fresh made samples, in older ones it occurred far from this temperature. In the case of old and deoriented samples it could be produced even at room temperature.

2. In the latter case—if the laser power was high enough—the ring pattern appeared practically instantly after switching on the laser. First the separation of the rings was rather large, but the distance between them decreased rapidly in time, the rings seemed to run to the center and then the picture was stabilized. The overall stabilization time was less than one second. At a given temperature and after stabilization, the higher the laser power, the smaller the ring separation. As an illustration, parts of the ring systems are given in Figure 1 photographed on the screen at increasing laser powers, using an old MBBA cell of 120 μm thickness at room temperature.

3. If a freshly-made and well oriented homeotropic NLC cell of OCB was illuminated with a constant laser power of about 100 mw and the cell temperature increased continuously and slowly, the following could be observed: at liquid crystal temperatures, some tenths of a degree centigrade below the clearing temperature, the characteristic aberrational ring system due to the optical Fredericks effect—the reorientation of the director by the light field—could be observed. By slowly further increasing the crystal temperature, the aberrational ring system

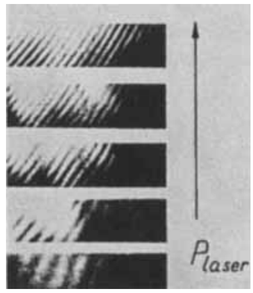

FIGURE 1 Photographs of equidistant ring systems at different laser powers.

becomes distorted (distortion time 3 ÷ 10 s) and quite near to the phase transition the equidistant ring system appears. The picture changes very rapidly; the rings run to the center and their separation decreases. In fractions of a second after the appearance of the equidistant rings, a new, complicated—cross shape—pattern can also be observed between crossed polarizers (see VH and HV pictures in Figure 2 where H and V denote the horizontal and vertical polarization directions, respectively). In this figure, the photographs of crosses for both MBBA (cell thickness 50 μm) and OCB (cell thickness 150 μm) are given.

The central part consists of a narrow black cross, surrounded by four bright quadrants which are again encircled by a series of bright and black, ring-shaped formations. The cross could be observed only with well oriented samples.

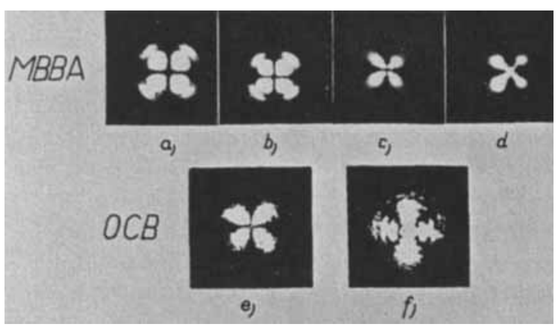

FIGURE 2 Photographs of the "crosses" at different laser powers (a) MBBA, VH, 90 mw; (b) MBBA, HV, 90 mw; (c) MBBA, HV, 150 mw; (d) MBBA, HV, 300 mw; (e) OCB, VH, 100 mw; (f) OCB, HH, 100 mw.

4. The actual intensity distribution inside the cross-like pattern depends on the laser power (at constant temperature) and on the temperature (at constant laser power). By increasing the laser power (or cell temperature) the central bright quadrants first decrease in size and then fully disappear, the narrow cross itself becomes broader and blurred, and the peripheral ring-shaped formations can no longer be observed (see Figure 2 b,c and d).

5. In the reverse process, i.e. when cooling the crystal from the isotropic phase to the nematic one, the pictures are reproduced in the opposite order.

6. With parallel polarizers (VV or HH setup) and with an OCB cell (150 μm thickness) between them, in the transmitted beam a rather complicated intensity distribution was observed reminiscent again of a cross; it was however bright and spread in the H direction (at the VV position) or in the V direction (at the HH position, see Fig 2 f).

7. By rotating the crossed polarizers together to a given angle, the crosses also rotated to the same angle.

DISCUSSION

We have already mentioned earlier,[1-3] that there is a difference between MBBA and OCB with regard to the appearance of the equidistant rings. For MBBA, it could be observed at temperatures far below the clearing point either after a relatively long (several hours) illumination of the sample with the laser light or with an aged sample. At a given laser power, the older the cell, the lower the temperature, where this pattern appeared. On the other hand, for OCB which absorbs much less light than MBBA at the argon laser wavelength, the equidistant ring system could be observed only near to the phase transition temperature.

It is therefore plausible to assume that the system of these practically equidistant rings originates from the diffraction on the "channels" "burned" into the liquid crystal by the laser beam. "Burning" means here an additional local heating of the NLC film along the path of the laser beam leading to a transition into the isotropic liquid phase in this region. Similar channels were observed earlier by Volterra and Weiner-Avnear[5] when studying liquid crystals with a microscope and irradiating them with strong laser radiation ($P > 180$ mW).

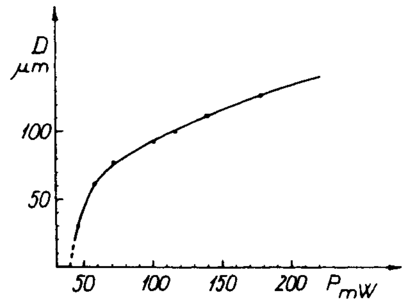

FIGURE 3 Dependence of the diameter of the "burned" channel on laser power.

It is obvious that from the observed diffraction pattern one can estimate the channel size using the simple relation:

$$D = \frac{\lambda}{\Delta\Theta}$$

where D denotes the channel diameter, λ the light wavelength and $\Delta\Theta$ the angular difference between two adjacent rings. Figure 3 shows the result of this calculation for an MBBA cell (120 μm, 36°C), giving the dependence of the channel diameter on the incident laser power. The shape of this curve and the channel size agree well with those of Volterra and Wiener-Avnear,[5] giving additional support to our assumption that the equidistant ring system originates from the diffraction of the laser light on the channel created by the beam itself.

Let us turn now to the origin of the crosses. The finite time interval between the disappearance of the aberrational ring pattern and the formation of the channels followed by the appearance of the crosses and also the fact that the crosses follow the angular position of the crossed polarizers, all seem to indicate that a reorientation of the director takes place in the illuminated region and the new distribution of the director has a cylindrical symmetry.

The pictures observed in the VV and HH positions indicate that the director has a radial orientation around the channels. Indeed, the spread of the bright crosses relative to the direction of the given parallel polarizer-analyser system shows that the radial polarizability of the emerging anisotropic structure is higher than the tangential one.[6] Furthermore, since for both OCB and MBBA $n_{eo} > n_o$, consequently the NLC molecules should be settled radially around the channels, i.e. at each point of the nematic near the boundary of the nematic-isotropic liquid, the director should be perpendicular to the boundary. It is known that there is orthogonal orientation of the director at the boundary of bubbles of nematic PAA formed at the isotropic liquid-nematic phase transition and swimming in the isotropic liquid,[7] and it has also been observed in bubbles of nematic Merck-IV, by cooling of emulsions of different constituents.[8]

In both of these cases the nematic was embedded into an isotropic liquid. In the present case, however, the isotropic liquid is surrounded by an oriented nematic. Regardless of the situation, for the orientation of the director, the most important factor is the existence of a boundary between the nematic and the isotropic liquid. It should be emphasized, that in our case the reorientation of the director could be observed only in initially well oriented samples. Our opinion is that this is because in disoriented crystals the orientational effect of the nematic-isotropic boundary is weaker than the elastic interaction forces.

Using parallel polarizers and analysers, extended bright crosses were observed earlier in spherulites;[6,9] in anisotropic media with different radial and tangential polarizabilities. It has been shown,[9,10] that after passing through a medium with different radial and tangential polarizability, the VH or HV picture of the light beam is a dark symmetric cross, whereas the VV or HH picture is an extended bright one.

SUMMARY

We have found and studied diffraction from cylindrical channels in a nematic liquid crystal in the isotropic phase. These channels arise due to additional heating of the nematic along the path of the laser beam. It was shown that in the case of an initially well oriented NLC, a reorientation of the director takes place at the boundary of the cylindrical isotropic liquid embedded in the nematic.

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