KFKI-1982-58

REORIENTATION OF LIQUID CRYSTALS BY SUPERPOSED OPTICAL AND QUASISTATIC ELECTRIC FIELDS

L. Csillag, N. Éber, I. Jánossy, N. Kroó
V.F. Kitaeva*, N.N. Sobolev*

Central Research Institute for Physics
H-1525 Budapest 114, P.O.B. 49, Hungary

*Lebedev Physical Institute
Moscow, USSR

Submitted to Molecular Crystals and Liquid Crystals

HU ISSN 0368 5330
ISBN 963 371 944 5

ABSTRACT

The electric field of a CW laser beam can reorient a nematic liquid crystal. Experiments on the influence of a superposed quasistatic electric field are reported showing that this can reinforce or weaken the laser induced reorientation depending on the substance and geometry.

АННОТАЦИЯ

Переориентацию нематических жидких кристаллов можно осуществить электрическим полем пучка лазера непрерывного действия. Показано, что добавочное квазистатическое электрическое поле усиливает или ослабляет этот ориентирующий эффект оптического поля в зависимости от свойств жидкого кристалла и от геометрии образца.

KIVONAT

Folytonos üzemü lézernyaláb elektromos tere átorientálhatja a nematikus folyadékkristályokat. A fénnyel egyidejüleg alkalmazott kvázisztatikus elektromos tér esetében megmutattuk, hogy ez erősiti ill. gyengiti a lézerfény átorientáló hatását, az anyag sajátságaitól, ill. a minta geometriájától függően.

Recently a couple of theoretical and experimental work has been published on orientational nonlinearity and optical field induced Fredericks transition in nematic liquid crystal layers [1-5]. These effects are due to the orienting action of the electric field of the light beam passing through the sample. Experimentally one observes a power dependent increase of the divergence of the light beam and a ring system appearing in it.

It is well known that the orientation of a nematic layer can be influenced by external magnetic or quasistatic fields too. Thus it can be expected that the orientational deformation caused by a light field can be controlled by external fields. The aim of the present letter is to report experimental results on such an effect.

In our experiments the external field was an electric field with f = 10 kHz. It was applied perpendicularly to the boundaries of the cell with the help of transparent indium oxide coatings as electrodes. The light field was produced by focusing a polarised argon ion laser beam on the sample into a spot with a radius of 40 μm. The sample thickness was in all experiments 150 μm. We confined ourselves to the case of normal incidence. The measurements consisted of determining the divergence of the laser beam as a function of the laser power and the applied voltage. As a measure of the divergence the angular diameter of the outest dark ring was measured.

The response of the nematic layer to a low frequency electric field depends crucially on the sign of the anisotropy of the static dielectric constants, $\varepsilon_a^{(S)} = \varepsilon_{\parallel}^{(S)} - \varepsilon_{\perp}^{(S)}$, where $\varepsilon_{\parallel}^{(S)}$ and $\varepsilon_{\perp}^{(S)}$ denote the dielectric constants in the direction parallel and perpendicular to the nematic director. Depending on whether $\varepsilon_a^{(S)}$ is positive or negative, the applied field tries to orient the molecules parallel or perpendicularly to itself, respectively. The light field always tries to orient the molecules parallel to the direction of the polarisation. In the case of normal incidence the light field and the applied field are normal to each other. Thus if $\varepsilon_a^{(S)} > 0$ the two fields weaken, while if $\varepsilon^{(S)} < 0$ they reinforce each other.

To study the case $\varepsilon_a^{(S)} > 0$ we chose octyl-cyano-biphenyl (OCB) which has a strong positive dielectric anisotropy (at $T = 35\ ^{o}C\ \varepsilon_{\parallel} = 12.5;\ \varepsilon_{\perp} = 5.7$ [6]); the case $\varepsilon_a^{(S)} < 0$ was studied on p-n methoxybenzilidene-p-butylaniline (MBBA) for which at $T = 30\ ^{o}C\ \varepsilon_{\parallel} = 4.6,\ \varepsilon_{\perp} = 5.0$ [7]. Three different cells were investigated.

1. HOMEOTROPICALLY ALIGNED OCB

As discussed in detail in Ref. [5], in this case the alignment becomes instable at a threshold laser power. The applied field tries to stabilize this alignment, consequently the threshold power increases as the applied field is increased. In *Fig. 1* an

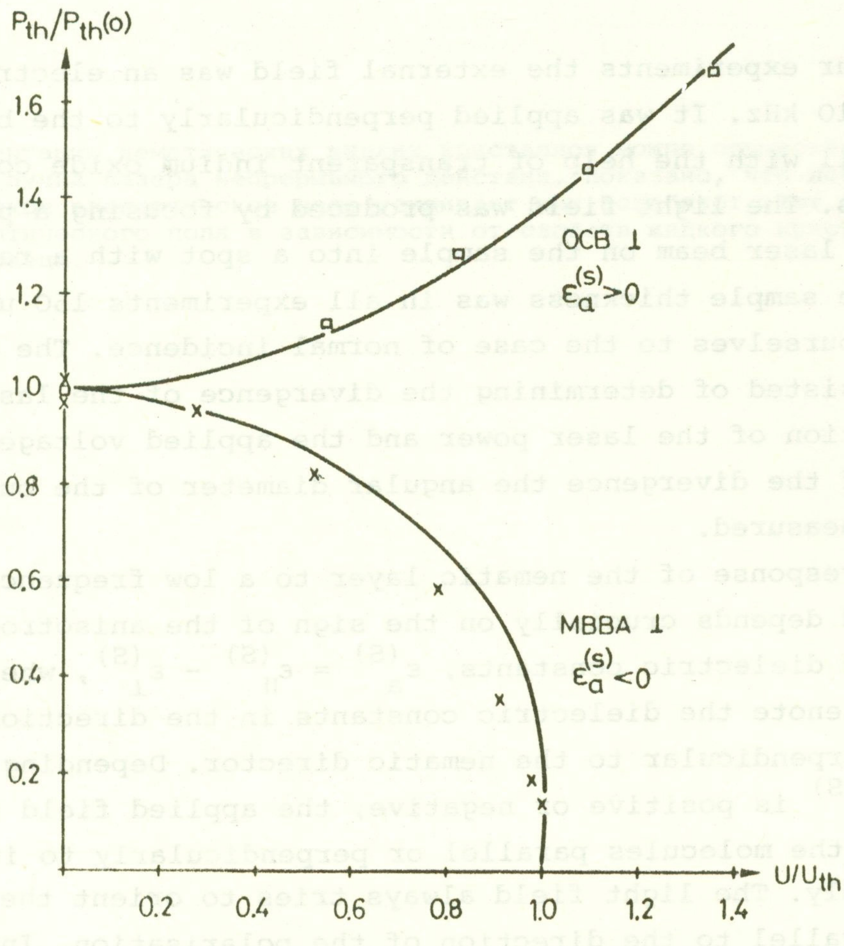

Fig. 1. The threshold power as a function of the applied voltage. For OCB $P_{th}(0) = 58$ mW, $U_{th} = 0.93$ V; for MBBA $P_{th}(0) = 41.5$ mW, $U_{th} = 3.86$ V

experimental curve is presented. In *Fig. 2* the beam divergence is shown as a function of the applied field at a fixed laser power. As it can be expected, the divergence monotonically decreases and becomes zero at a critical field strength.

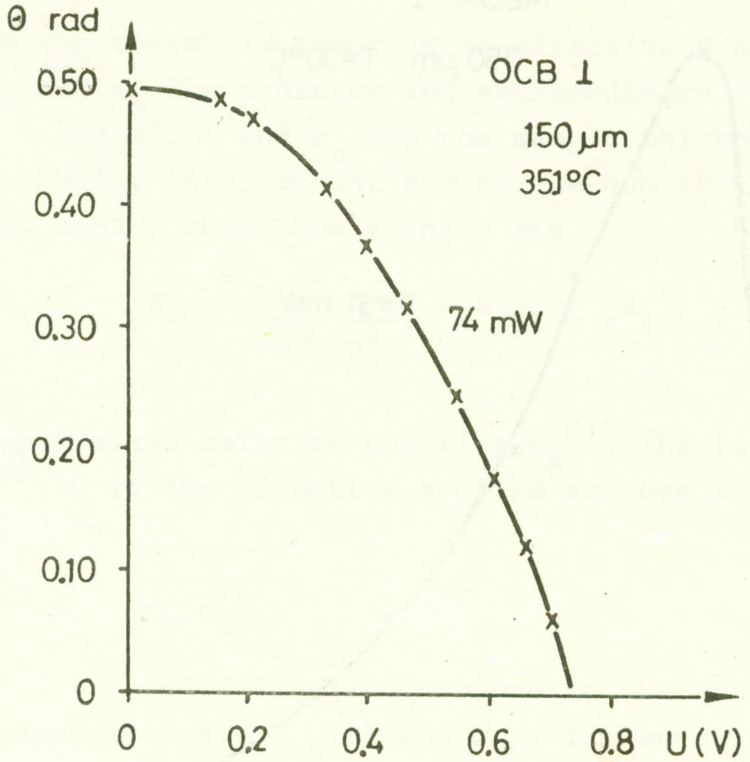

Fig. 2. The beam divergence as a function of the applied voltage for homeotrop OCB

2. HOMEOTROPICALLY ALIGNED MBBA

In this case as $\varepsilon_a^{(S)} < 0$, the threshold power decreases as the applied field is increased, as shown in *Fig. 1*. The threshold power becomes zero when the applied voltage is high enough to destabilize alone the alignment.

The divergence of the laser beam as a function of the applied field at a fixed power is shown in *Fig. 3*. This curve, exhibiting a sharp maximum, can be explained qualitatively by remembering that the divergence of the laser beam is due to the inhomogeneity of the deformation within the laser spot. At low voltages the applied field increases this inhomogeneity. At high fields however the director becomes almost parallel to the surfaces in the *whole* cell. Thus the sample becomes again homogeneous and the ring system disappears.

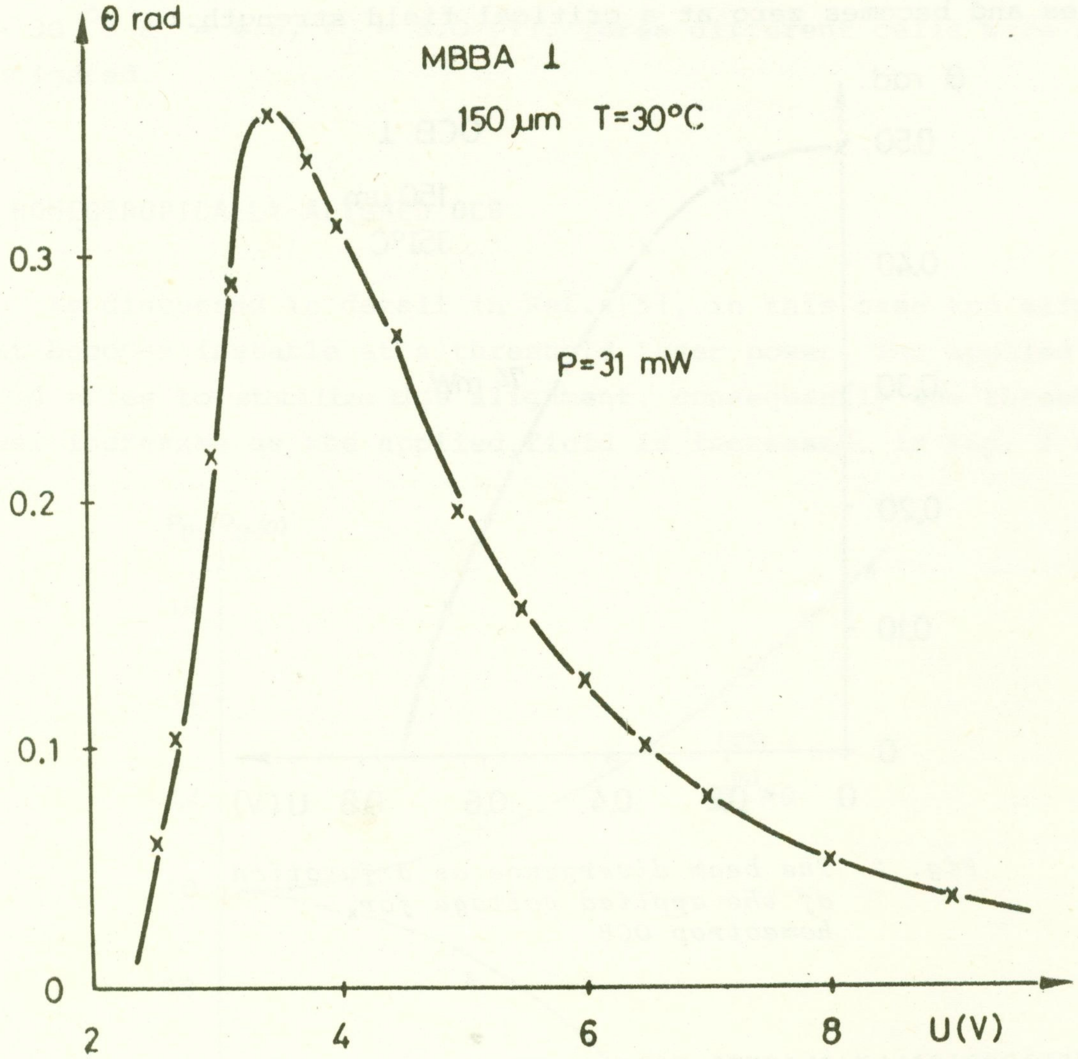

Fig. 3. The beam divergence as a function of the applied voltage for homeotrop MBBA

The variation of the threshold power as a function of the applied field in the two cases discussed above can be given theoretically by a slight modification of the theory given in [5]. As it is shown there the threshold power can be determined from the equation

$$\gamma \frac{J_o'(\gamma)}{J_o(\gamma)} = \varkappa \frac{K_o'(\varkappa)}{K_o(\varkappa)} \qquad (1)$$

where J_o and K_o denote the O-order Bessel and modified Hankel functions. For zero applied field

$$\gamma^2 = P_{th}\varepsilon_o\varepsilon_a \frac{n_o}{n_e^2}\frac{1}{\pi c K} - \frac{\pi^2}{\ell^2} r_o^2; \quad \kappa^2 = \frac{\pi^2}{\ell^2} r_o^2$$

where P_{th} is the threshold power, K an effective Frank elastic constant, n_o and n_e the ordinary and extraordinary refractive indices, $\varepsilon_a = n_e^2 - n_o^2$; ℓ and r_o are the sample thickness and spot radius resp. Taking into account the torque due to the applied field we get Eq.(1) again, where now γ and κ are

$$\gamma^2(U) = \gamma^2(O) \pm \frac{r_o^2}{\ell^2}\frac{U^2}{U_{th}^2}; \quad \kappa^2(U) = \kappa^2(O) \pm \frac{r_o^2}{\ell^2}\frac{U^2}{U_{th}^2}$$

where the upper signs refer to positive $\varepsilon_a^{(S)}$, the lower ones to negative $\varepsilon_a^{(S)}$. U is the effective applied voltage and

$$U_{th} = \pi\sqrt{\frac{K}{\varepsilon_o|\varepsilon_a^{(S)}|}} \qquad (2)$$

In *Fig. 1* the solid lines correspond to the above theory. The fitted parameters are $P_{th}(O)$ and U_{th}. The agreement between the experimental curve and the theoretical one is satisfactory for both material. From $P_{th}(O)$ and U_{th} two separate values of the "effective" elastic constants can be calculated. The measurements provide for OCB $K = 0.63 \times 10^{-11}$ N and $K = 0.53 \times 10^{-11}$ N; for MBBA $K = 0.62 \times 10^{-11}$ N and $K = 0.54 \times 10^{-11}$ N resp. (for the refractive index data see [2,5]). The consistency of these data and their agreement with independently measured values of elastic constants [8,9] can be regarded satisfactory taking into account the simplifications in the theory and the uncertainities in the determination of the *absolute* value of the laser power.

3. PLANAR CELL OF OCB

As discussed in [2], in the case of planar orientation and normal incidence of the polarised light beam, deformation does not occur. The extraordinary component stabilizes the planar configuration, while the ordinary does not interact with it.

The applied field, due to the positive static dielectric anisotropy of OCB, destabilizes the planar orientation above a threshold voltage (≈ 1 V [10]). Thus applying a voltage higher then 1 V, a ring system can be produced by a laser beam with extraordinary polarisation, because the light field reorients the molecules within the spot. The beam divergence as a function of the applied field at different laser powers is given in *Fig. 4*. In accordance with the above considerations the beam divergence goes to zero at approximately 1 V, independently from the laser

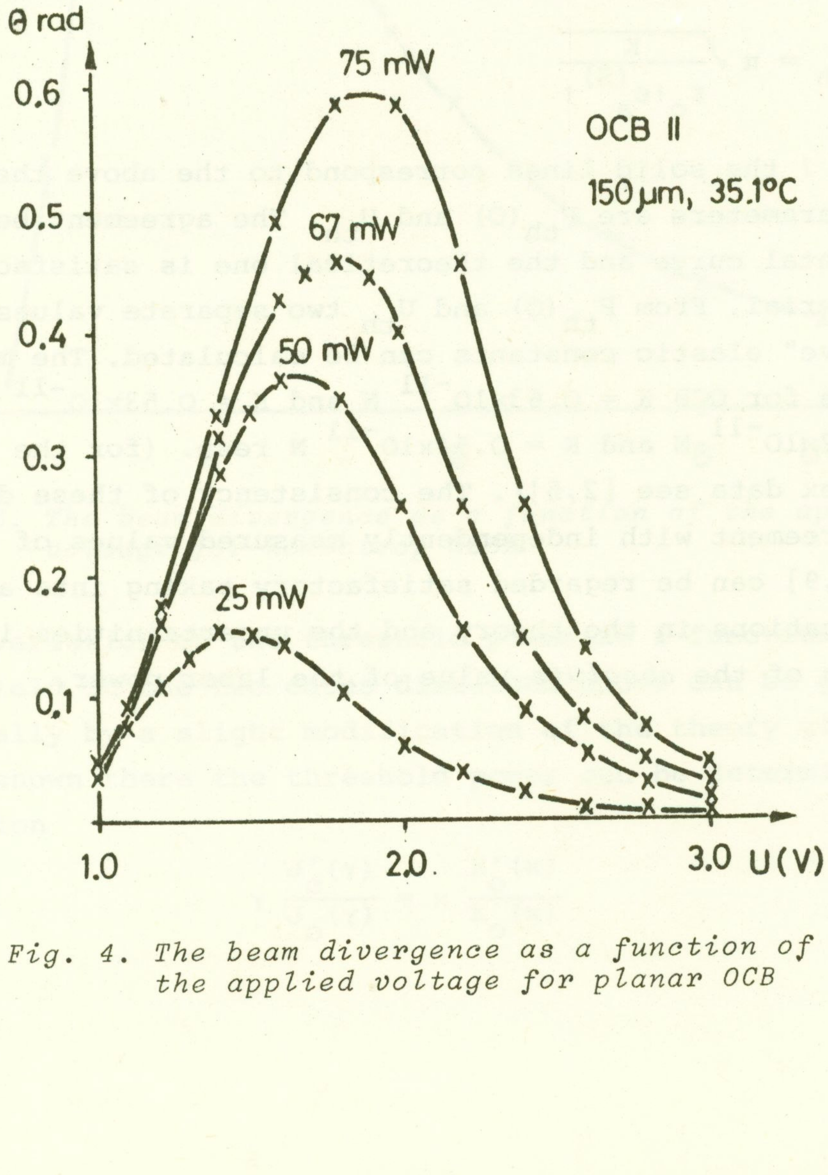

Fig. 4. The beam divergence as a function of the applied voltage for planar OCB

power. The decrease of the divergence at high voltages can be explained similarly as in the case of homeotropic MBBA. In the present case the high electric field removes the inhomogeneity of the deformation by orienting the molecules in the whole sample perpendicularly to the boundaries.

The result of the investigations described above fit well into the interpretation of the laser field induced reorientation of nematics, given in our earlier papers. The possibility of controlling the beam divergence by an external field may find some practical applications.

REFERENCES

[1] A.S. Zolot'ko, V.F. Kitaeva, N. Kroó, N.N. Sobolev, L. Csillag, Pisma v ZhETF, 34 (5), (1981) 263 (in russian)

[2] L. Csillag, I. Jánossy, V.F. Kitaeva, N. Kroó, N.N. Sobolev, A.S. Zolot'ko, Mol. Cryst. Liq. Cryst., 78 (1981) 173

[3] N.F. Pilipetski, A.V. Sukhov, N.V. Tabiryan, B.Ya.Zel'dovich, Optics Comm., 37 (4), (1981) 280

[4] S.D. Durbin, S.M. Arakelian and Y.R. Shen, Optics Letters, 6, (1981) 411; Phys. Rev. Lett., 47 (1981) 1411

[5] L. Csillag, I. Jánossy, V.F. Kitaeva, N. Kroó, N.N. Sobolev, Mol. Cryst. Liq. Cryst., 84 (1982) 125

[6] L. Bata and A. Buka, Acta Phys. Pol., A54 (1978) 635

[7] I.P. Zhuk and L.E. Golovither, Acta Phys. Pol., A55 (1979) 575

[8] P.P. Karat and N.V. Madhusudana, Mol. Cryst. Liq. Cryst., 40 (1977) 239

[9] P. de Gennes, The Physics of Liquid Crystals, Clarendon Press, Oxford, 1974, p. 66

[10] I. Jánossy and L. Bata, Acta Phys. Pol., A54 (1978) 643