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p4

NONLINEAR TOTAL INTERNAL REFLECTION IN NEMATIC LAYERS

L. CSILLAG, I. JÁNOSSY, V.F. KITAEVA*, N. KROÓ and N.N. SOBOLEV*

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

*Lebedev Physical Institute
Moscow, USSR

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Abstract: It is shown that nonlinear total internal reflection can be realized in deformed nematic layers at a few mW input power. Experimental results on 5CB are presented.

In the recent years it was demonstrated that nematic liquid crystals show strong nonlinear optical properties at low light intensity levels [1,2,3]. The origin of the nonlinearity is the reorientation of the nematic director by the optical field. In typical experiments the optical changes are observed as the increase of the divergence of the transmitted beam. This increase is due to self-focusing.

Another possible nonlinear optical effect is the light induced switch from a state where total internal reflection (TIR) occurs to a transmitting state [4]. This effect is usually realized at an interface of a linear and a nonlinear medium. Khoo demonstrated that uniformly oriented nematics can be used as the nonlinear medium [5].

In the present letter we show that in the case of nematics, using suitable non uniformly oriented samples, TIR may occur inside the sample. In this situation switch to the transmitting state can be induced by a much lower intensity level as in the case when TIR occurs at the interface.

Let us see the condition for TIR in uniaxial nematics. As reorientation effects can be induced only by the extraordinary component of the light beam [2], we consider only this component. We investigate a sandwich cell, where the director varies only in the direction normal to the boudaries (z direction). For a fixed parallel component of the wave vector ($\underline{k}_\parallel$) the possible values of the normal component (k_z) can be determined from the Maxwell equations in the standard way. As it can be shown, k_z has an imaginary component (i.e. the light field is evanescent) if

$$n_o^2 k_o^2 - k_\parallel^2 < \frac{\gamma(\underline{n}_\parallel \underline{k}_\parallel)^2}{1 + \gamma n_z^2} \quad \text{with } \gamma = \frac{n_e^2 - n_o^2}{n_e^2} \qquad (1)$$

where n_e and n_o are the extraordinary and ordinary refractive indices resp.; $n_e > n_o$. $\underline{n}_\parallel$ and n_z are the parallel and normal components of the director.

Non uniform orientation of the sample in which (1) is not satisfied near the boundaries, but is satisfied near the half plane of the sample can be produced e.g. by deforming a homeotropic sample with a magnetic field. The magnetic field is in the plane of incidence. The angle between the director and the z axis, Θ, is zero at the boundaries and has a maximum value, Θ_m, at the half plane. TIR occurs inside the layer if

$$0 < n_o^2 k_o^2 - k_\parallel^2 < k_\parallel^2 \gamma \frac{\sin^2\Theta_m}{1 + \cos^2\Theta_m} \qquad (2)$$

Θ_m can be varied with the magnetic field between 0 and $\pi/2$. Ineq.(2) can be realized whenever the angle of incidence of the light beam (β) is chosen such, that in the undeformed homeotropic sample TIR occurs for the ordinary component but dos not occur for the extraordinary one. To realize this situation the nematic layer must be sandwiched between two glass prisms, the refractive index of the glasses being larger than n_o.

Figure 1 shows the effect of the magnetic field on the transmission coefficient at low light inten-

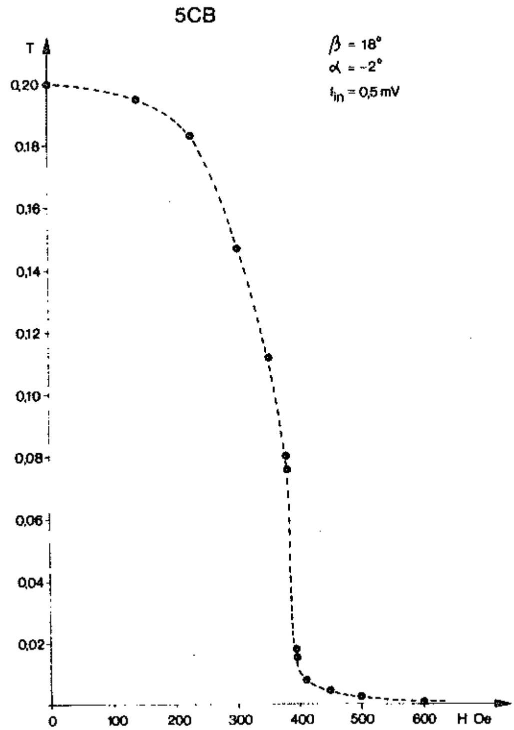

Fig. 1. Transmission coefficient as a function of the magnetic field at low light intensity. Material: n-pentyl cyano biphenyl (5CB). Sample thickness 150 μm, room temperature. α is the angle between the magnetic field and the boundaries.

sity levels. There is a rather sharp transiton from the transmitting state to the TIR state. This transition is discussed in detail in [6].

Now let us consider the effect of the optical field. The light induced reorientation always promots the formation of the transmitting state. This can be understood qualitatively by the following argument. TIR occurs when the effective refractive index reaches a lower limit. However the light field tries to orient the molecules into the direction where the effective refractive index has a maximum, because the interaction energy is minimum in this case. Consequently we expect that increasing the light in-

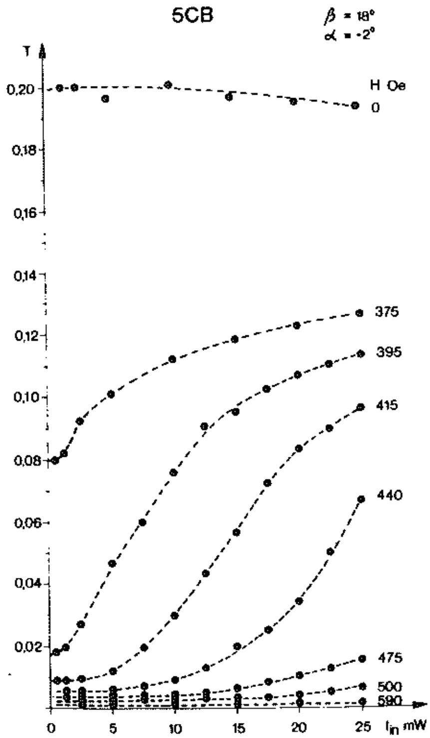

Fig. 2. Transmission coefficient as a function of the input intensity at different magnetic fields. The 514.5 nm line of an Ar^+ laser was used. Spot diameter 65 μm (FWHM). To avoid the influence of self-focusing the transmitted beam was carefully collected and focused onto the detector by a lens. Spectra Physics Model 404 power meters were used to measure intensities.

tensity at a fixed magnetic field, transition from the TIR state to the transmitting state can be induced.

Figure 2 shows the transmission coefficient as a function of the incoming intensity. With an approprietly chosen magnetic field the predicted transition takes place at a few mW input intensity. As it can be seen, the transmission changes about an order of magnitude. We note as a comparison, that at the same spot size ∿200 mW is needed to induce the same transition at the interface [6].

As it can be seen the light induced transition is rather gradual. The reason of this is the spatial distribution of the light beam. The reorientation does not go homogeneously within the beam, so when the centre of the beam is transmitted, the outer parts are still reflected. It was found also, that even relatively strong optical fields coud not compensate completly the magnetic field induced decrease of the transmission coefficient (see Fig. 2). For 5CB only 65 % was regained of the transmitted light. The reason of this effect is not yet clear for us.

To sum up, we have demonstrated, that nonlinear TIR can be produced in nematics at low light intensity levels. This effect leads to strongly nonlinear transmission vs. input power curves, which may be used in optical transistors.

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