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Optical bistability in second order nonlinear media: I. Nematic liquid crystals (experimental results)

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In the paper, some experimental results concerning optical bistability in a nematic liquid crystal are presented. A strong laser beam interacts nonlinearly with the material and influences a second (probe) beam in such a way that its transmitted part exhibits bistable dependence on the intensity and the polarization of the first beam.

1. Introduction

Optical bistability still belongs to the most important optical nonlinear effects [1], [2]. The basic mechanisms and means of its observing are numerous. Most of all optical bistable devices have been made in a Fabry–Perot cavity, in which the nonlinear material is situated. Depending on the nonlinearity of the material used, the power of the optical field required to achieve bistability varies in a wide range.

In this paper, we report on the observation of optical bistability created by a nematic liquid crystal film, without use of the Fabry–Perot interferometer [3]. Its role plays an NCL-film itself. A strong laser beam of polarized light changes the molecular orientation which, in turn, changes the conditions for appearance of the bistability. Such reoriented sample is then exposed to a second laser beam of much smaller intensity, which is partially transmitted. The behaviour of the last (outgoing) wave depends essentially on the geometry of the experimental setup and the parameters of the first (stronger) wave: its intensity and angle of polarization. Under some conditions there appears the bistability. More detailed description of them was the main aim of this paper.

2. Experiment

The experimental setup is shown in Figure 1. The beam indicated by 1 comes from the argon-ion laser (LEXEL 3500) operating at the 5145 Å green). Its power was varied from 0.05 W to 1.2 W. Additionally, by means of a linear polarizer we changed the wave polarization in the range 0°–90°. The angle 0° corresponds approximately to the vertical direction, parallel to the surface of the film considered. First measurements were performed without the use of the polarizer, but even then the beam was partially polarized by the laser itself.

The intensity of the red wave was kept constant. On the other hand, the intensity of the green (strong) wave was changed in a wide range.

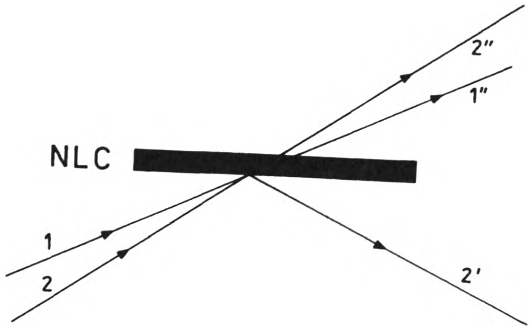

Fig. 1. Experimental setup

The beam 2 comes from the second (helium) laser of the power of the order of 40 mW, operating at $\lambda = 6320$ Å (red). It falls at the same region as the first (green) wave. Interaction of both waves – via the medium – leads to serious changes of the outgoing wave 2" of the intensity denoted further by P_2.

The liquid crystal film (NLC) was oriented by means of the dc electric field of the voltage 1.5 V, perpendicular to the film. Due to this field the molecules of the NLC had in general similar directions.

3. Results

The transmitted red light was a very sensitive function of the intensity of the original green beam. This dependence is presented in the subsequent three figures (Figs. 2, 3 and 4). Each curve corresponds to a definite angle of polarization Θ of the strong laser beam. In Figure 2, this angle was equal to 0; in Fig. 3, $\Theta = 30°$ and, finally, in Fig. 4, its value is $\Theta = 70°$.

It has been observed that P_2 grows abruptly with increasing P_1 at $P_1 \approx 0.6$ W. By decreasing P_1 a similar jump (down this time) appears at $P_1 \approx 0.5$ W. That means

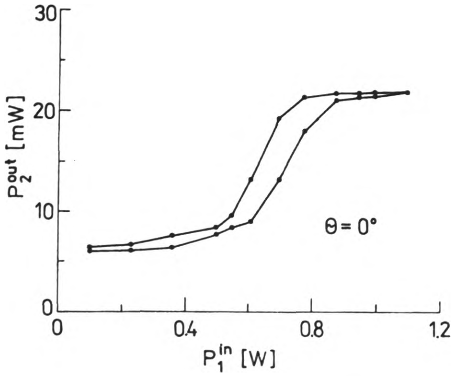

Fig. 2. Bistability loop for $\Theta = 0°$

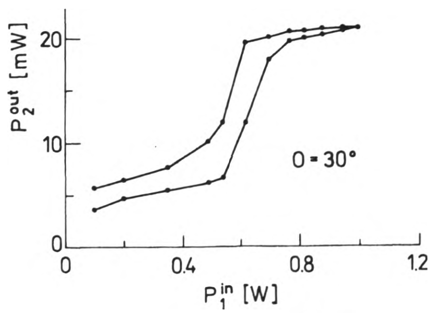

Fig. 3. Bistability loop for $\Theta = 30°$

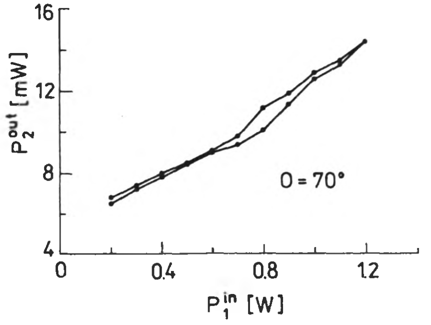

Fig. 4. Bistability loop for $\Theta = 70°$

that the width of the bistable loop is about 0.1 W. More spectacular is the height of this loop. In all the cases considered it reaches more than 50% of the initial value.

The polarization of the green light has significant influence on the shape of all curves. It was easy to see that the maximal intensity of outgoing red beam becomes smaller with increasing angle of polarization. For $\Theta > 60°$ the bistable loop practically disappears.

3. Discussion

The theory of effects described above is still unsatisfactory. There exist numerous papers on this subject ([2]–[6], and references therein), in which, however, only one wave is taken into account. In our experiment we had two beams going almost parallel, so that they may be treated as one composed wave which – in the first approximation – may be put in the formula derived for one wave. The total incident wave is effectively a variable of the green light only (the red beam shifts the $0x$ scale by a constant value). The total outgoing wave consists of two waves, but we extract the one which is relatively much more sensitive to changes in molecular network of the NCL film.

The most interesting result of our measurements is connected with a strong dependence of the bistable effect on the polarization of the incident green wave. First of all, the beam must be (linearly) polarized. Moreover, a very important role plays the angle of polarization. The loop monotonically diminishes with increasing this angle and disappears entirely above a value of the order of 60° with regard to the vertical direction.

Observed behaviour may be caused by two factors. First, the direction of the polarization vector of the green wave with regard to the surface of the NCL film and second – the reduction of the green beam caused by the polarizer itself. Relatively large size of molecules makes them unable to follow the temporal changes of the electric component $\boldsymbol{E}$ of the green wave.

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