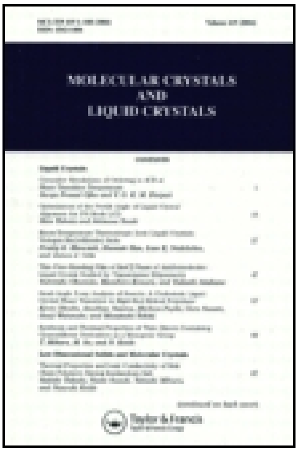

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Optical Switching and Bistability in Polymer Dispersed Liquid Crystals

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OPTICAL SWITCHING AND BISTABILITY IN POLYMER DISPERSED LIQUID CRYSTALS

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Abstract We report detailed measurements performed on a sample of a dye doped Polymer Dispersed Liquid Crystal (PDLC). It is shown that the laser induced phase transition of the liquid crystal droplets to the isotropic state can be exploited to get an optical switching and an optical bistable behavior. These effects can be satisfactory explained within the theoretical framework of an absorption which increases with the degree of excitation of the material.

INTRODUCTION

Polymer Dispersed Liquid Crystals (PDLCs) consist of nematic liquid crystals randomly dispersed as micrometer size droplets in polymer films. The droplets have an optical anisotropy which depends on the local director of the nematic liquid crystal. These materials produce strong light scattering and appear opaque but their optical characteristics can be strongly varied either by means of an electric or an optical perturbation. They exhibit thus several peculiar optical properties which have been investigated with growing interest[1]. The main feature which has been shown is that by applying an external voltage it is possible to obtain optical switching to a high transmission state and this effect has been explained as due to the induced matching of the ordinary refractive index of the droplets with that one of the polymeric matrix[2].

Recently also nonlinear properties of PDLCs have been investigated trying to figure out how the properties of the used liquid crystal affect the nonlinear optical behavior of these new compounds. While reorientational phenomena appear to be weak[3], thermal effects seem to be the most important in determining the nonlinear optical behavior of PDLCs. We have reported several nonlinear optical effects induced in PDLCs, namely: self transparency, opto-optical modulation, four wave mixing[4-5]. Other authors have reported optical bistability in a hybrid configuration[6].

In this paper we present a series of measurement concerning the effect of all optical bistability recently reported by us[7] with a detailed discussion of the experimental data.

EXPERIMENT

The sample preparation was made by using the polymer induced phase separation method[8] which we have already used and described[4]. Before the preparation, the E7 nematic liquid crystal by British Drug Houses (BDH) was mixed with a 0.2 % in weight of the D2 orange dichroic dye by BDH: the aim was both to increase the light absorption of the sample and to obtain a different absorption for different director orientations within the nematic droplets. Here the dye molecules have an average alignment parallel to the liquid crystal director **n** and therefore, if the direction of **n** varies, a dichroic effect must be expected, according to the relation

$$A_{\parallel} / A_{\perp} = 10 \quad (1)$$

(as given by BDH for the D2 dye), where $A_{\parallel}$ and $A_{\perp}$ are the absorption parallel and perpendicular to the molecular axis. The mixture was finally sandwiched between two transparent conducting glasses spaced by appropriate Mylar spacers 30 μm thick.

The index of refraction of the used materials are the following:

n_e=1.736 and n_o=1.525 for the E7 liquid crystal, n_p=1.550 for the polymeric matrix.

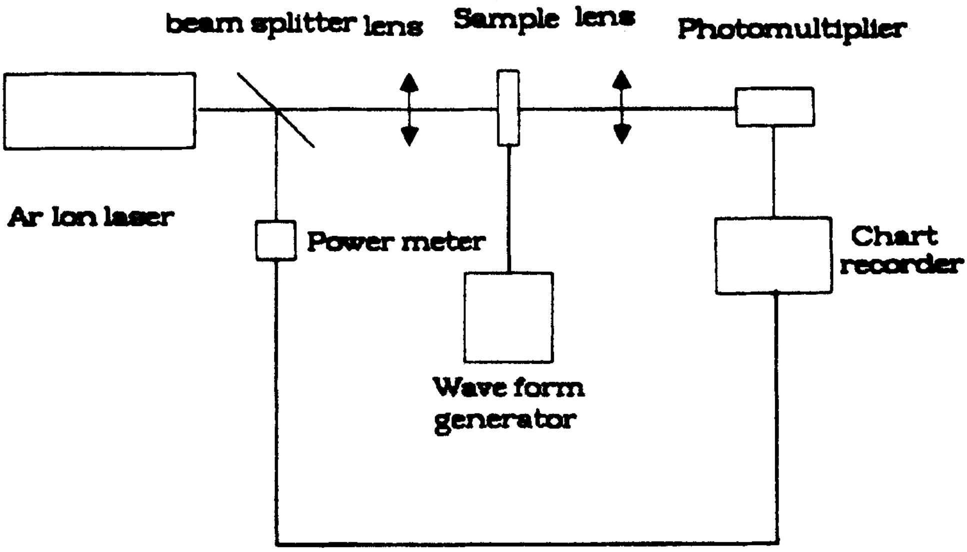

FIGURE 1. Sketch of the experimental set-up.

The experimental set up is sketched in fig. 1. The light beam from an Argon Ion laser (λ = 5145 Å) was linearly polarized and focused (f = 100 mm) on the dye doped PDLC sample at normal incidence; the transmitted optical power was detected by a photomultiplier and sent to a chart recorder. A beam splitter placed before the sample enabled us to measure the impinging light power P_i. An a.c. (10 KHz) voltage was applied to the sample conducting glasses in order to switch the sample to the low scattering state.

At low optical impinging power, the output signal S_t was detected for several values of the applied voltage V; the obtained transmission characteristic vs V, reported in fig. 2, shows a smooth switching from low to high transmission, which is typical of PDLCs.

For each V value reported in fig. 2, we have performed different experimental observations of the optical behavior of the sample: in each case, P_i was increased and then decreased; S_t was detected vs P_i. The whole measurement was performed by changing the impinging power very slowly (from 0 to 25 mW in about 1800 sec) in order to be sure that no other phenomena could affect the data, and the stability of the signal transmitted at a given intensity was checked several times.

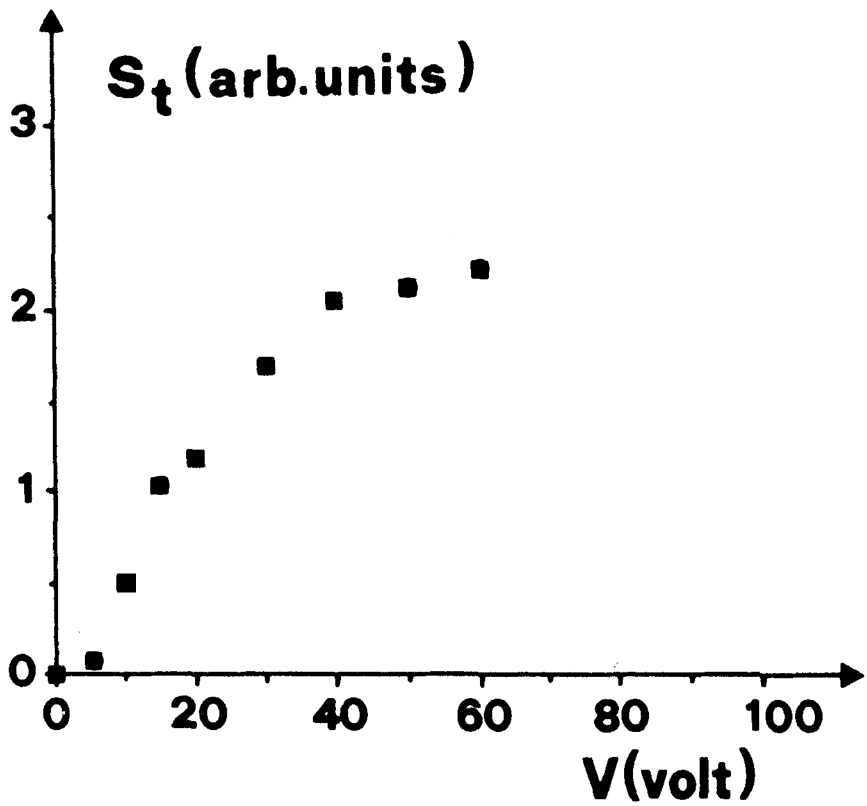

FIGURE 2. Transmission characteristic of the sample vs the applied voltage V.

RESULTS

We report in fig. 3 the curves detected at V = 10, 15, 20 and 50 volt. Increasing the voltage we observe the rise of a bistable behavior with a loop which reaches the maximum width at V = 50 volt, which corresponds to the complete alignment of the droplets as we can infer from fig. 2.

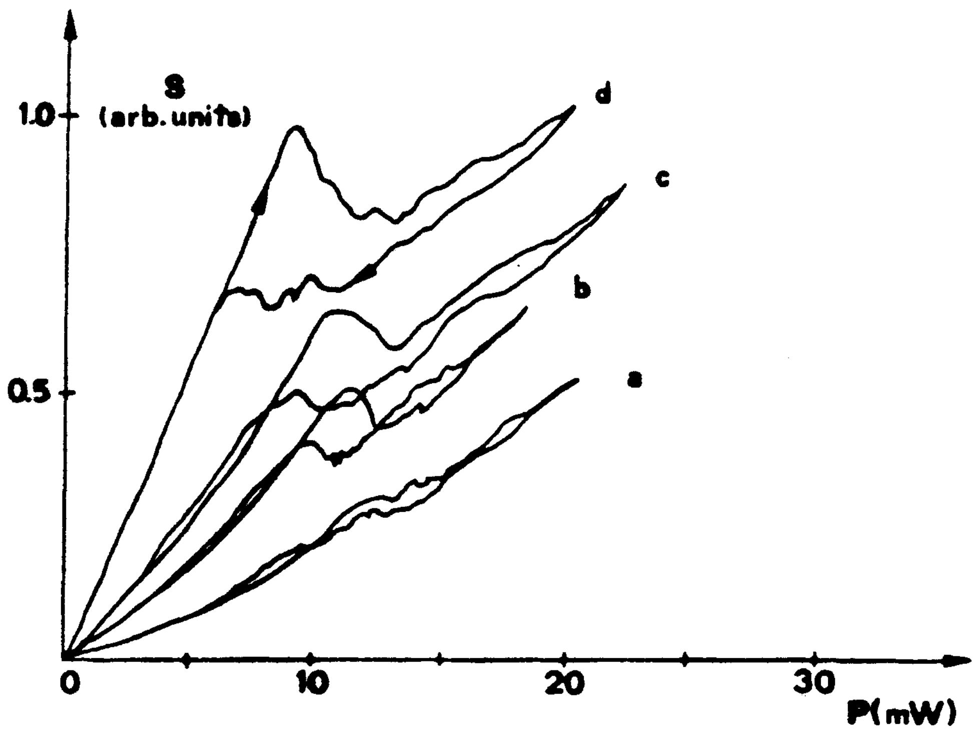

FIGURE 3. Optical characteristic of the sample vs the input power for four different values of the applied voltage: V = 10 volt (a); V = 15 volt (b); V = 20 volt (c); V = 50 volt (d).

In the increasing direction of P_i, the bistability starts as a smooth switching - off of the sample to a lower transmission state at a determined value of P_i; in the decreasing direction of P_i, a similar switching - on effect is noted. We call P_{down} and P_{up} the values of P_i at which the switching - down and switching - up effects have come to an end (as indicated in fig. 4).

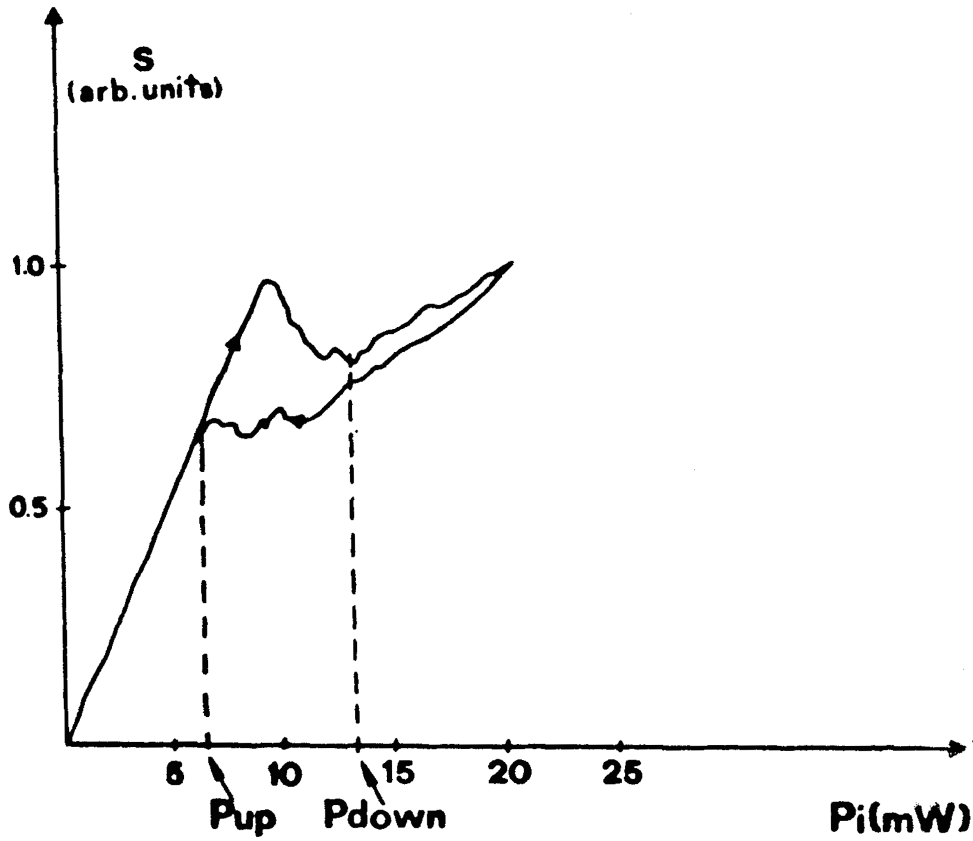

FIGURE 4. Optical characteristic of the sample vs the input power for the applied voltage V = 50 volt.

Some interesting remarks must be done on fig. 3. The slope of each curve decreases from the low to the high optical power regions, moreover the slope in the high optical power region is the same for each curve. These slopes are, of course, proportional to the light transmittivity. Calling T_i and T_f respectively the initial and the final value of the transmittivity we get: T_i/T_f = 1.12 (b), 1.58 (c), 2.54 (d). Also notice that the self transparency[4] affects the initial slope of the curves correspondent to lower voltages giving a slightly nonlinear increase of the transmittivity.

The observed behavior is satisfactory interpreted by taking in to account the dichroism of the dye molecules. In fact, the reason for a decrease in transmittivity may be found in an increase of scattering and/or in an increase of absorption. Anyway, the nonlinear optical response is mainly due to heating of the liquid crystal up to the transition to the isotropic state, therefore the scattering should not exhibit strong variations: we start from a low scattering state which is due to static field alignment of the molecules and we end in a low scattering state which has been always observed for isotropic droplets in PDLCs[4]. Then the change in transmission may only be induced by a strong increase of light absorption of the dye molecules. In fact by supposing that at V = 50 volt the liquid crystal droplets are completely aligned by the electric field (fig. 3, curve d) we can write the absorption A_1 in the low optical power region as:

$$A_1 = S'A_\perp + (1 - S')\left(\frac{2A_\perp + A_\parallel}{3}\right) \tag{2}$$

Here, S' = 0.6 is the order parameter of the dye molecules. When the droplets become isotropic the absorption A_2 simply equals the isotropic absorption A_{iso} :

$$A_2 = A_{iso} = \frac{2A_{\perp} + A_{\parallel}}{3} \qquad (3)$$

therefore $A_2 > A_1$. For the other cases of fig. 3 (curves a, b, c), the initial absorption A_1 is higher than the one expressed by eq. (2) because of the only partial alignment of the liquid crystals, while the final absorption is still expressed by eq. (3) .Therefore, by increasing the applied voltage, we expect a bigger variation of absorption (and as a consequence of transmittivity) from the low to the high optical power region. The effect is clearly shown in fig. 3. This fact explains also the variation of the width of the bistability region $W = (P_{down} - P_{up}) / P_{down}$ which is reported in figs. 4 and 5.

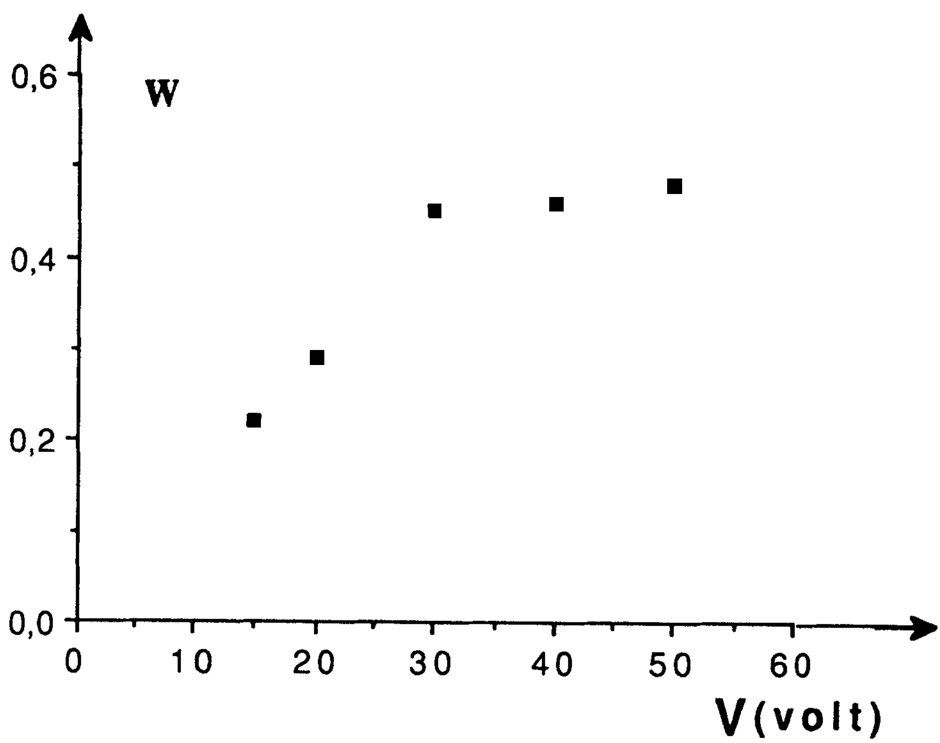

FIGURE 5. Width W of the bistability loop vs the applied voltage V

THEORETICAL INTERPRETATION

The previous remarks are the keys to explain the bistable behavior. The discussion of the model has been illustrated elsewhere[7]; here it is only sketched and it is applied to the case of fig. 3, curve d (W = 0.50). There by using eq. (2) and eq. (3), recalling relation (1), we get: $A_2/A_1 = 1.82$. This ratio accounts for the observation of optical bistability due to increasing absorption within the theoretical framework proposed by D.A.B. Miller[9]. We assume that the absorption A of the material increases with the degree of excitation of the material N which depends on the absorption:

$$N = \eta A P_i$$

where η is a constant and P_i is the incident power. Supposing N is the temperature variation Δt of the material, we can write for A(N) the step function

$$\begin{cases} A(N) = A_1 & \text{for } N < N_0 \\ A(N) = A_2 & \text{for } N \geq N_0 \end{cases} \qquad (4)$$

where $N_o = t_c - t_r$, being t_r the room temperature and t_c the transition temperature to the isotropic state for the droplets.

Indicating by k an irrelevant constant which allows for the almost unvarying scattering, we can write $T = k(1 - A)$ for the transmission of the sample and give a graphic solution of the problem by plotting

$$T = k(1 - N / \eta P_i)$$

versus N. Denoting by P_{i1} and P_{i2} the critical input powers for the switch to low transmission and to high transmission, there is a region $P_{i2} < P_i < P_{i1}$ where we have three solutions for T(N), that is three values for the output power $P_o = TP_i$. This is a bistability region whose width

$$W = (P_{i1} - P_{i2}) / P_{i1}$$

is trivial to calculate. For $N = N_o$ we must have

$$P_{i1} = N_o / \eta A_1 \quad \text{and} \quad P_{i2} = N_o / \eta A_2.$$

Therefore:

$$W = 1 - P_{i2} / P_{i1} = 1 - A_1 / A_2.$$

By substituting $A_2 / A_1 = 1.82$, we get: $W = 0.45$ in satisfactory agreement with the experimental value $W = 0.50$.

CONCLUSIONS

In conclusion, we have reported detailed measurements performed on a dye doped PDLC. We have shown that the laser induced phase transition of the liquid crystal droplets to the isotropic state yields an optical switching and an optical bistable behavior. These nonlinear effects are interpreted within the theoretical framework of an absorption which increases with the degree of excitation of the material.

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