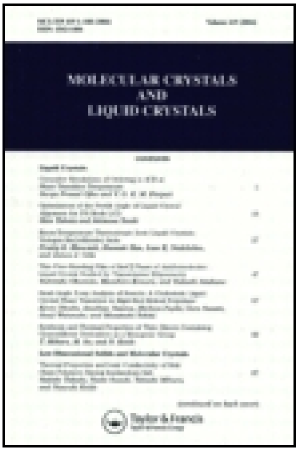

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Polymer Dispersed Liquid Crystal Thin Films for Optical Processing

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POLYMER DISPERSED LIQUID CRYSTAL THIN FILMS FOR OPTICAL PROCESSING

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Abstract A shape-controlled bistable hysteresis is observed for thin polymer dispersed liquid crystal films when inserted in feedback systems where the applied voltage depends on the intensity of the light transmitted by the film. A control of the hysteresis width is possible by acting on the parameters of the feedback circuit. The possibility of obtaining bistable regions of different width can be very useful in view of the application of PDLC as optic memory elements or binary data transmission devices.
An investigation on the use of these films as optical switches for fiber interconnects is also performed and the preliminary results are reported. Technical improvements are suggested in order to increase the on/off contrast ratio of the switching behavior.

INTRODUCTION

Polymer Dispersed Liquid Crystals (PDLC) are composite materials consisting of a liquid crystal dispersed in the form of micron-sized droplets in a transparent and optically isotropic polymer binder[1-3].

The optical properties of PDLC with droplet size close to the light wavelength are dominated by a strong light scattering[4-5], which gives the sample a translucent white appearence. In fact, in the absence of an externally applied field, the liquid crystal directors are randomly oriented in the droplet's volume and the incident light probes a range of refractive index between $n_\perp$ and $n_{//}$, i.e. the ordinary and extraordinary refractive index of the liquid crystal, respectively.

External fields may be used to control the alignment of the liquid crystal in the inclusions in order to induce a molecular order and reduce the strong optical anisotropy exhibited by the microdroplets. For instance, subject to the influence of an electric field of sufficient intensity, a preferred direction can be observed, along which most of the directors of the liquid crystal align themselves. As a consequence, in the case of positive dielectric anisotropy, the droplet director N_d, defined as the unitary vector which gives the average orientation of the liquid crystal director within the inclusions, aligns parallel to the applied field. In this state all the liquid crystal microdroplets offer a unique refractive index to an incident wavelight propagating parallel to the electric field, i.e. the ordinary one. Therefore, if the refractive indexes of the polymer and the liquid crystal are properly choosen, the PDLC film may be switched from the opaque scattering state to the clear transparent one.

The classical example of PDLC used for linear light modulation is the one containing a nematic liquid crystal, realizing a field controlled light scattering device.

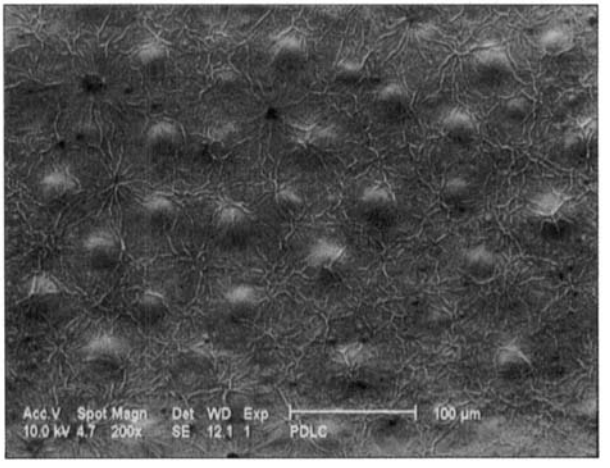
The electro-optic behavior has suggested a lot of new applications of PDLC for optical processing, from a new generation of displays to optical storage devices[6].

In this paper we report a detailed study of the optical bistability in PDLC in view applications of these materials as binary optical memories and we discuss preliminary data concerning a new application of PDLC as optically active interconnections for fiber optics.

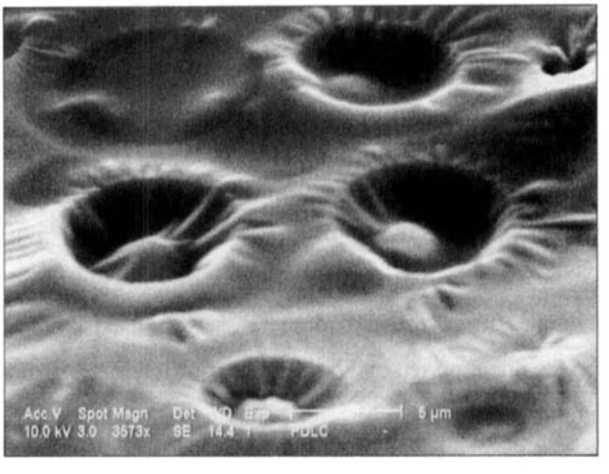
OPTICAL BISTABILITY

The investigated PDLC films were prepared by UV curing of a mixture of the liquid crystal E7 (50%) and the optic adhesive NOA 65 (50%); the sample thickness of 23 μm was fixed by Mylar spacers. Approximately 50% of the film volume was occupied by the liquid crystal dispersed in the form of uniformly distributed droplets with average radius of a few microns, as shown in figs 1, where photos of the sample taken by Scanning Electron Microscope (SEM) are reported.

The electro-optical response of our samples is reported in fig. 2. It shows a threshold-voltage of about 25 volts which separates two saturation regions with different transmitted signal levels corresponding to the absence and the presence of a perfect molecular alignment, respectively.



(a)



(b)

FIGURES 1 SEM photos of the sample surface.

(a) Magnification 1x200. (b) Magnification 1x3600.
See Color Plate IV.

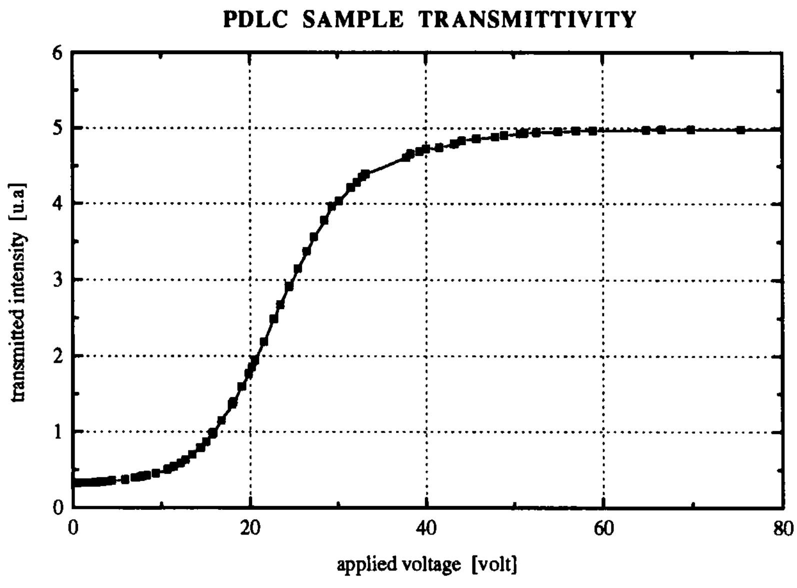


FIGURE 2 PDLC sample transmitted intensity vs applied voltage.

The nonlinear dependence of the transmittance on the applied voltage is responsible for the PDLC film bistable behavior in a feedback system. In fact, whenever an electric circuit exhibits two stable working states separated by an unstable one, an hysteresis cycle may be observed after inducing two sample response jumps between the two stable states[7].

A schematic diagram of the experimental set-up used to study the optical bistability, similar to the one reported by Kim and Palffy-Muhoray[8], is shown in figure 3. The sample is orthogonally illuminated by a 5 mW He-Ne laser linearly polarized beam. The incident light is detected by photodetector 1 to give the reference signal. The intensity of the incident light is varied by rotating the polarizer placed between the polarized laser beam and the sample, while the intensity of the transmitted light is measured by photodetector 2. The feedback circuit generates a voltage which is a linear function of the detector output; this voltage is used to modulate the output of a signal generator which drives the voltage applied to the sample. After realizing the above mentioned amplitude modulation, a constant offset voltage was added to a 1kHz sinusoidal output signal from the wave form generator. A properly amplified modulated signal is applied to the sample, closing a positive electric feedback.

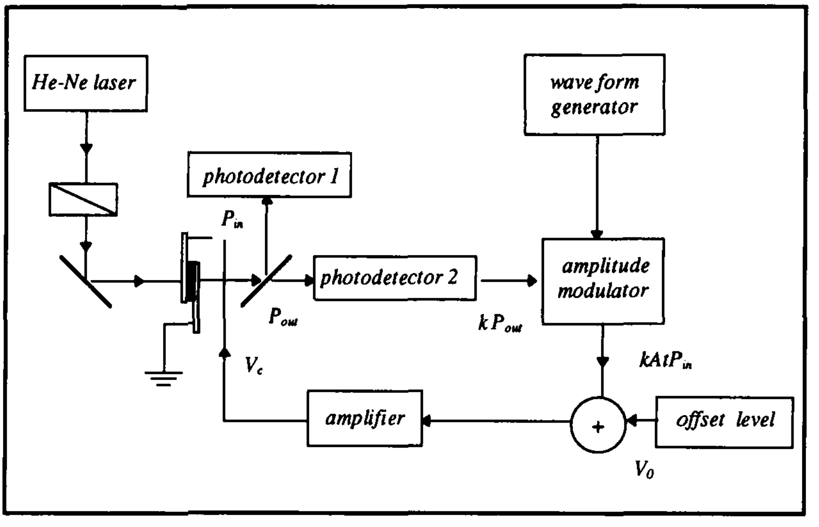


FIGURE 3 Experimental set-up used to study the bistable behaviour of a PDLC film.

Two parameters, namely the amplitude of the sinusoidal signal and the offset, can be varied in order to analyze the induced changes in the PDLC hysteresis profile. By a proper choice of the feedback circuit parameters, two stable states with different transmittance values can be obtained, separated by an unstable one.

The power P_{out} transmitted by the sample is given by

$$P_{out} = t\,P_{in} \quad (1)$$

where t is the transmittance and P_{in} is the incident power.

The output voltage of detector 2 is proportional to P_{out} through the constant k, and the voltage across the sample is a linear function of the detector output so that

$$V_c = G\,(\,V_0 + k\,A\,t\,P_{in}\,) \quad (2)$$

where V_0 is the offset level, G is the gain of the feedback circuit (which coincides with the applied constant amplification) and A is the amplitude of the sinusoidal signal.

In the t-V_c plane eq.(2) represents a straight line which can intersect the sample transmittance curve in three points, depending on the values of offset V_0 and of the incident power P_{in}. These intersections make it possible to find the stable and unstable states of the system and to point out the transmission hysteresis, which takes place by varying the incident power P_{in}. In fact, at high incident intensity, V_c begins to grow until reaching the threshold voltage which causes the sample to switch from the opaque scattering state to the transparent one, corresponding to the first sample jump from the lower stable state to the upper stable one. When V_c reaches its saturation value, t is essentially constant and P_{out} is proportional to P_{in}. On the contrary, as the incident power is decreased, V_c decreases too, thus reducing the film transmittance until an abrupt change in P_{out} is induced, caused by the PDLC transition to the opaque scattering state.

The measured response of the system with positive feedback (G>0) is shown in figure 4.

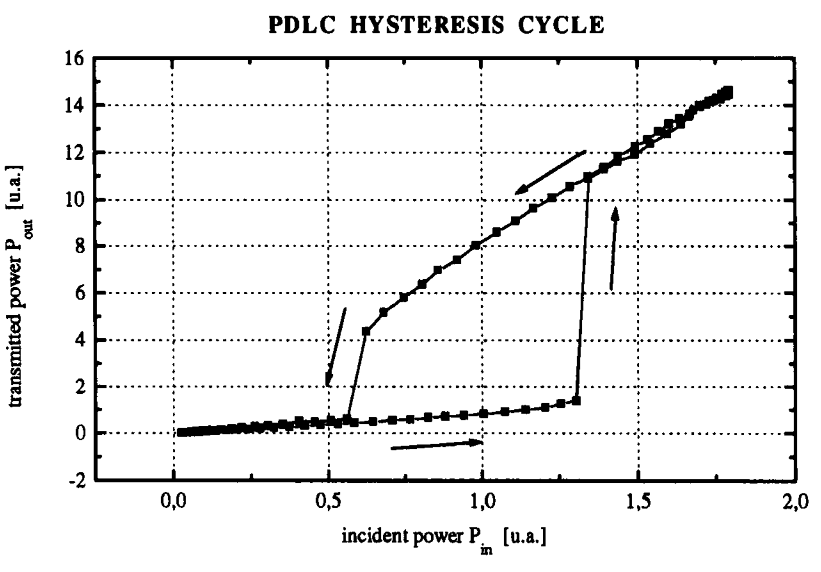


FIGURE 4 PDLC hysteresis for a particular choice of feedback circuit parameters.

Because of the instability of the intermediate state, any perturbation in V_c, or more exactly in P_{in} , leads the system to one of the other states, which are both stable. However, hysteresis and bistability exist in the regime where the values of V_o and A allow three intersections of the straight line (eq.(2)) with the sample response curve.

In order to study how to control the bistable behavior we have independently varied the two above mentioned parameters. We define the hysteresis loop width as

$$W = (I_1 - I_2)/ I_2 \tag{3}$$

where I_1 and I_2 represent the incident light intensities corrisponding to the two jumps. Figures 5 and 6 show the behaviour of W as function of V_0 and A, respectively.

We observe that, an increase of either V_0 or A produces the same effect on W, namely a reduction of the hysteresis range. This behavior, which confirms the simple model for bistability described above, is quite interesting since it offers the possibility of an external control of the bistability region. Such a possibility can be used to obtain high capacity optical memories as well as binary data transmission.

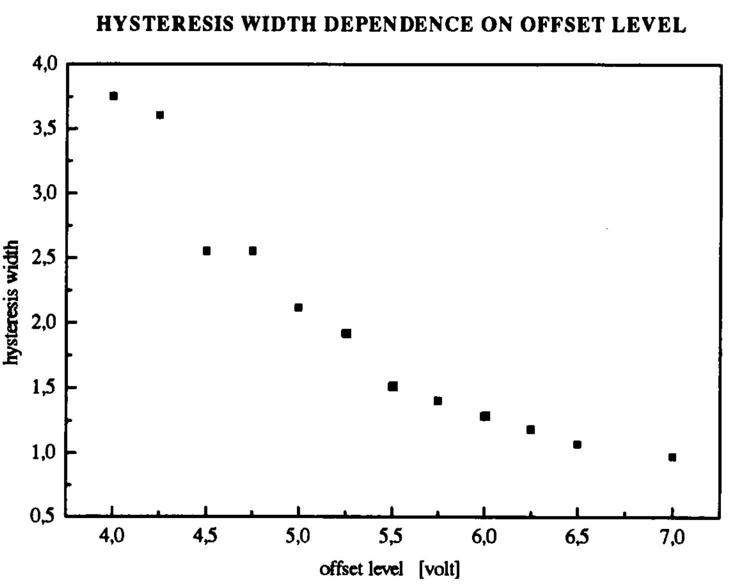


FIGURE 5 Hysteresis width as function of the introduced offset level.

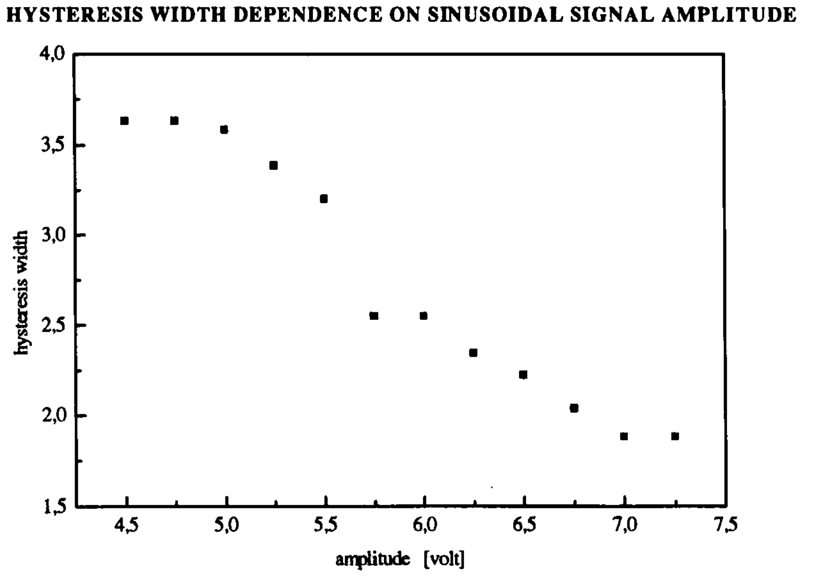


FIGURE 6 Hysteresis width as function of the sinusoidal signal amplitude that modulates the transmitted intensity.

FIBER OPTIC INTERCONNECTIONS

Preliminary experiments on the use of PDLC as fiber optic interconnections have been carried out using the following configuration. Two identical 1 cm long pieces of optical fiber have been glued in symmetric positions onto the parallel plane boundaries of a PDLC sample prepared as described above. The fibers were glued by using the optic adhesive NOA 65, to get good index matching with the glass slides of the sample. The symmetric positioning of the two fibers was assured by a careful observation through optical microscope while gluing them to the glasses (figure 7).

According to the experimental arrangement, an unpolarized attenuated beam from a 5 mW He-Ne laser is focused in the first fiber input and at the same time it is detected by a photodetector.

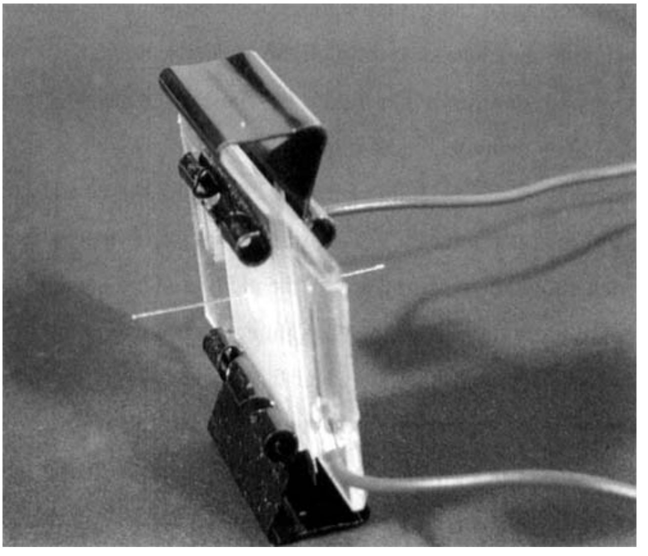


FIGURA 7: Optic switch realized with a PDLC film placed between two similar pieces of fiber. See Color Plate V.

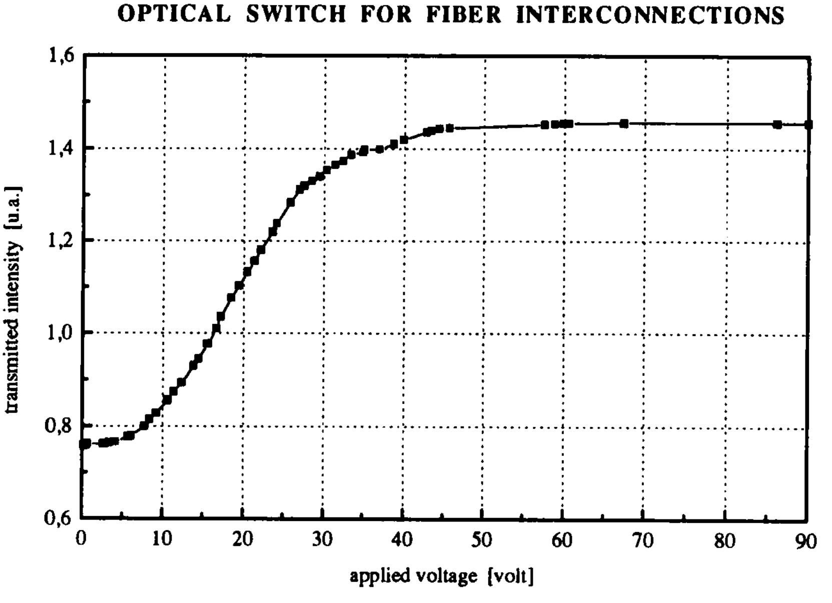


FIGURE 8 On-off light switch for fiber interconnections, obtained by inducing the PDLC transition from the opaque scattering state to the clear transmitted one.

The optical switching of the guided light is obtained inducing the PDLC transition from the opaque state to the clear state through the applied voltage.

This result is well summarized in figure 8. These data have to be considered as preliminary results, since many technical improvements are possible in order to increase the on/off contrast ratio of the swicthing behavior. By using the configuration described above, the main improvements which are possible concern: (i) the perfect alignment of the two fibers which should be performed with the aid of a video camera system allowing three dimensional observation during the gluing procedure; (ii) index matching optimization between fibers and glasses, which needs best choice of fibers and optical glues. Besides that, tecnical improvements of this device may involve: (i) direct interconnection between fibers without using supporting glasses; (ii) reduction of the overall size of the PDLC sample; (iii) use of plane waveguides.

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REFERENCES

1. P. S. Drzaic, J. Appl. Phys., 60, 2142 (1986).
2. J. W. Doane, A. Golemme, J. L. West, J. B. Whitebread, Jr, and B. G. Wu, Mol. Cryst. Liq. Cryst., 165, 511 (1988).
3. G. P. Crawford and J W. Doane, Condensed Matter News, 1, 5 (1992).
4. J. W. Doane, N. P. Vaz, B.-G. Wu, and Zumer, Appl. Phys. Lett., 48, 269 (1986).
5. G. P. Montgomery, Jr and N. A. Vaz, Phys. Rev. A, 40, 6580 (1989).
6. F. Simoni, Nonlinear Optical Properties of Liquid Crystals and Polymer Dispersed Liquid Crystals (World Scientific Publishing Co., Singapore, 1996).
7. F. Simoni, G. Cipparrone and C. Umeton, Mol. Cryst. Liq. Cryst., 207, 231 (1991).
8. J. Y. Kim and P. Palffy-Muhoray, J. Appl. Phys., 66, 362 (1989).