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## Liquid Crystals

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## Optoelectronic polarizer by PDLC

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We present a new device based on Polymer Dispersed Liquid Crystals (PDLC). Applying a transverse low frequency electric field, the scattering cross section increases or decreases depending on the polarization of the impinging light. Depending on the choice of the refractive index of the polymeric matrix, such a device can be operated as a polarizer, or as an inverse shutter. In the first case one polarization component of an unpolarized beam is transmitted, while the other is scattered. In the second case an impinging polarized beam is totally scattered when an external electric field is applied and becomes partially transmitted when the external field is switched off.

Remarkable interest is growing about composite optical materials such as Polymer Dispersed Liquid Crystals (PDLC): liquid crystal droplets embedded in a polymeric matrix. Depending on manufacturing procedures, the droplet size, whose shape is usually spherical, may vary from a few tenths to some microns. Minimization of free energy yields a bipolar distribution of the liquid crystal molecules inside the cavity; most molecules are nearly parallel to a direction that is assumed as the droplet director. Droplets appear as optically uniaxial spheres with average ordinary and extraordinary refractive indices  $n_o$  and  $n_e$ , respectively. Due to the random droplet director distribution, if the droplet diameter is close to the wavelength of visible light, the PDLC generates high light scattering. To produce light valves, a sheet of PDLC is squeezed between two conducting (ITO coated) glass plates. When the liquid crystal is in the nematic phase, which has strong optical and electrical anisotropies, application of a high intensity, low frequency external electric field results in a reorientation of the droplet directors and of the molecular directors inside the droplets. In this situation light impinging orthogonally on the PDLC surfaces is affected only by the ordinary refractive index of the liquid crystal and, if this is equal to that of the polymer matrix, refractive index mismatch disappears and the device becomes transparent. The intensity of the light scattering can be controlled by the applied electric field intensity. This well known effect [1] is the basis of many applications [2, 3].

Usually both the electric field and the wavevector of the impinging light beam are orthogonal to the sample

surface, so that the refractive index mismatch, and therefore the transmitted light intensity, is independent of the polarization of the impinging beam. Let us call this the O-beam. In this paper we present a new experimental configuration with the external field applied at right angles with respect to the beam wavevector. In this configuration, the light scattering is greatly affected by light polarization. In fact, if we apply a 'vertical' electric field, a horizontally polarized light beam behaves as before, since, for a high applied field, it sees only the ordinary refractive index of the liquid crystal and hence there is no mismatch. On the other hand, a 'vertically' polarized light beam, for high applied voltage, sees only the extraordinary refractive index of the liquid crystal, and therefore it is scattered more than before. In this configuration, when an external field is applied, refractive index mismatch increases or decreases depending on the polarization direction of the light. The device presented here behaves as an optoelectronic polarizer. Note that it is based on anisotropic scattering instead of absorption, so that it can work with higher light intensities without producing unwanted device heating.

In our experiment we prepared the PDLC sample by polymerization induced phase separation (PIPS). We made a homogeneous solution of 25.6 wt % of fluid pre-polymer EPON 815 (Shell Chemical Company), 7.9 wt % of MK107 (Wilmington Chemical Corporation), 29.7 wt % of Capcure 3-800 (Diamond Shamrock), 3.7 wt % of B-component (BOSTIK) and 33.0 wt % of liquid crystal mixture E7 (Merck Ltd). The sample cell was made by placing two metallic spacers between two glass plates, as shown in figure 1. The volume between the two glass plates and confined by the two metallic spacers (thickness 15  $\mu\text{m}$ ) was filled with

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the homogeneous solution. Curing was performed in an oven at 60°C for 16 h. While the reaction proceeded, the average molecular weight of the polymer increased and the liquid crystal droplets separated. Droplet diameter is determined by the curing rate which, in our case, was slow enough to give diameters comparable with the wavelength of visible light and therefore to produce light scattering in the absence of an applied electric field.

The experimental arrangement is shown in figure 2. We aimed to study the optical transmittance of the sample for impinging light beams with their polarization planes both parallel and orthogonal to the applied electric field. Since in our configuration, the electric field is applied along the vertical direction, we call these the V- and the H-beam, respectively. Transmittance of both beams was studied as a function of the intensity of the applied low frequency electric field. The HeNe laser used to generate the impinging beam was positioned so that its polarization plane was at 45° with respect to the direction of the low frequency electric field, while the polarization plane at the sample was determined by polarizer  $P_1$ . This configuration allowed rotation of the

polarization plane of the impinging beam without changing the incidence point. A reference beam was sent by the beam splitter BS to the photodiode  $D_2$ , checked by the oscilloscope F. The beam was focused by the lens L onto the sample S. Beam width was of the order of 20  $\mu\text{m}$ , while the distance between the metallic spacers was around 150  $\mu\text{m}$ , so that the beam was almost completely transmitted for a transparent sample. Voltage was applied to the metallic spacers by the function generator FG through the amplifier A. Finally the beam was detected by the photodiode  $D_1$ . Noise and background signal were cut off by the chopper C and lock-in amplifier LI configuration.

An analyser  $P_2$  was used in the preliminary measurements to ensure that light emerging from the sample was still linearly polarized in the same direction. Figure 3(a) shows the H- and V-polarized components

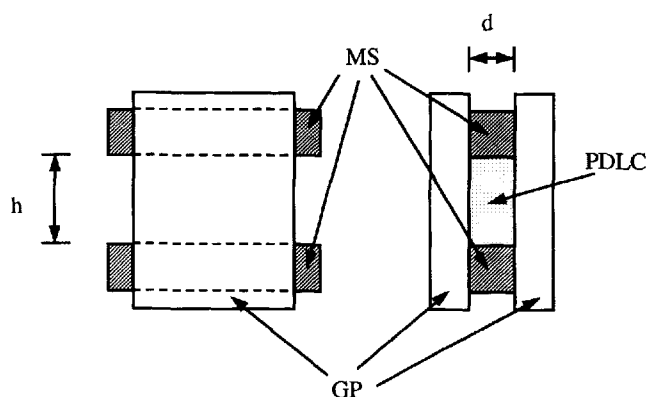


Figure 1. Sample frontal view and cross section. GP: glass plates; MS: metallic spacers; PDLC: Polymer Dispersed Liquid Crystal.

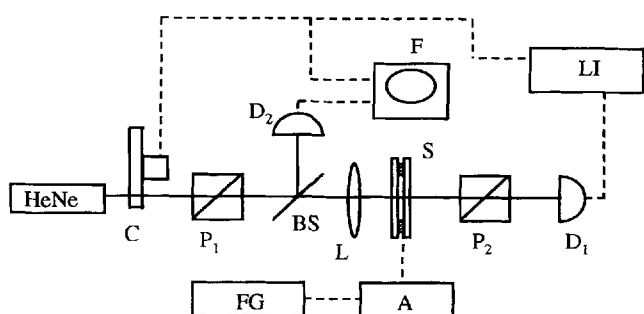
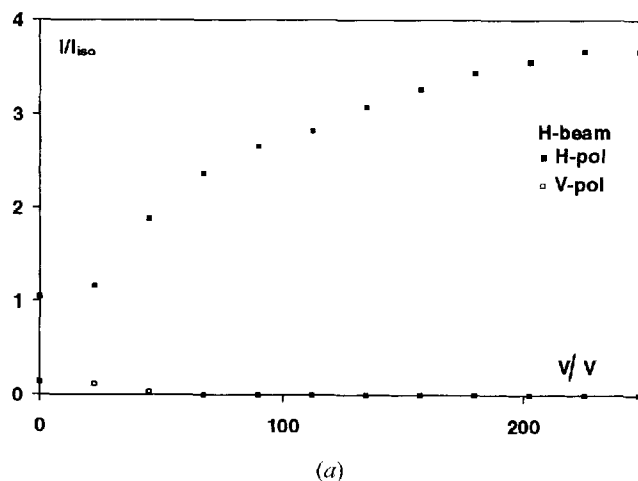
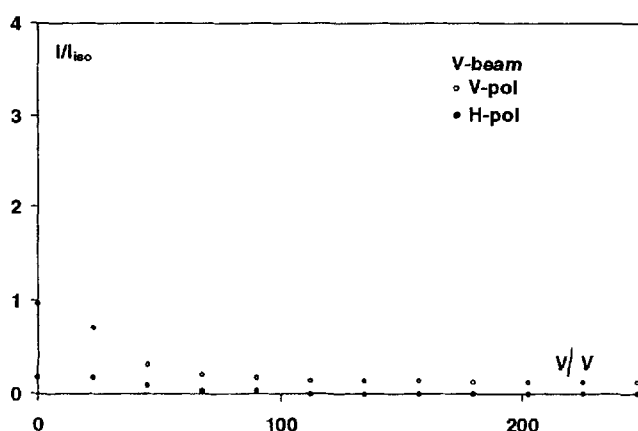


Figure 2. Experimental set-up. HeNe: He-Ne laser; C: chopper;  $P_1$ ,  $P_2$ : polarizers; BS: beam splitter;  $D_1$ ,  $D_2$ : photodiode detectors; L: lens; S: sample; F: oscilloscope; LI: lock-in amplifier; FG: function generator; A: amplifier.



(a)



(b)

Figure 3. H- and V-polarization components for H-beam (a) and V-beam (b).

(full and open squares, respectively) of the transmitted beam corresponding to an impinging H-beam. As can be observed, when no electric field is applied, there is a slight energy transfer from the H- to the V-polarization direction; however when the field is above the threshold value, the sample behaves like a uniaxial medium. A similar result was observed on examining the H- and V-polarized transmitted components (full and open circles, respectively) for an impinging V-beam, figure 3(b).

Experimental results are shown in figure 4. As can be seen, when the electric field is applied, sample isotropy is lost and it behaves as a polarizer; the transmittance of the H-beam (full squares) increases from 0.17 to 0.71 while the V-beam (open circles) is completely scattered. The H- to V-transmittance ratio changes from unity at zero applied field to 59.4 at high values of the applied field. The reason for this behaviour is clear. The applied field reorients the droplet directors so that the refractive index mismatch, initially equal for the two beams, increases for the V-beam and decreases for the H-beam. A complete theoretical description of the sample behaviour with respect to the applied voltage is quite a difficult task and is beyond the scope of this preliminary communication.

The transmitted beam intensity is

$$I = I_0 \exp(-N_v d \langle \sigma \rangle_s), \quad (1)$$

where  $N_v$  is the number of droplets per unit volume,  $d$  is the sample thickness,  $\sigma$  is the droplet scattering cross section and the angle brackets mean an average over the sample. If no field is applied, the droplets are randomly oriented so that H- and V-beams behave as an O-beam ( $\langle \sigma_H \rangle_{s[E=0]} = \langle \sigma_V \rangle_{s[E=0]} = \langle \sigma_O \rangle_{s[E=0]} = \langle \sigma \rangle_s^{\text{iso}}$ ) which has already been studied [4, 5]. The sample scattering cross section can easily be computed

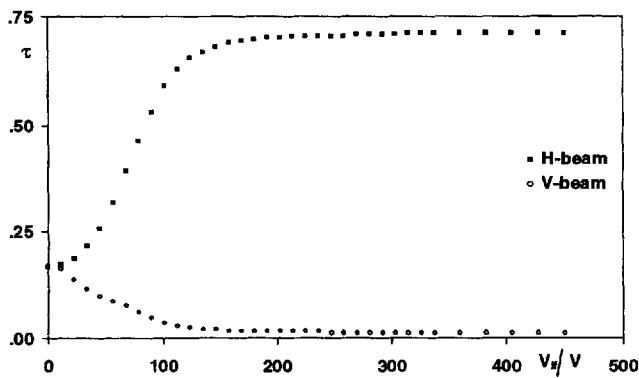


Figure 4. PDLC transmittance for H- and V-beams versus low frequency applied voltage.

from the experimental data:

$$\langle \sigma \rangle_s = \langle \sigma \rangle_s^{\text{iso}} \frac{\ln\left(\frac{I}{I_0}\right)}{\ln\left(\frac{I_{[E=0]}}{I_0}\right)}. \quad (2)$$

Using the data shown in figure 4, we obtain  $\langle \sigma_V \rangle_s^{\text{sat}} = 13.0 \langle \sigma_H \rangle_s^{\text{sat}}$ . Therefore, in saturation conditions there is one order of magnitude difference between the scattering cross sections for the H- and the V-beam.

Finally we observe that the maximum contrast between the transparent and the opaque states for our device is higher than would be possible by traditional use of a PDLC. Moreover, for an impinging polarized beam, it is possible to realize a reversed shutter; i.e. high scattering when the voltage is applied and a high transmittance when the voltage is turned off. The advantage of this configuration is to have the transmitting state in the case of failure. The difficulty is in achieving a high transmittance in the isotropic state. Perhaps this result can be achieved for thin films and an appropriate value of the refractive index of the polymer binder. Further work is in progress to develop a mathematical model giving a more accurate description of the device presented. When developed, it will be used for projection purposes.

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