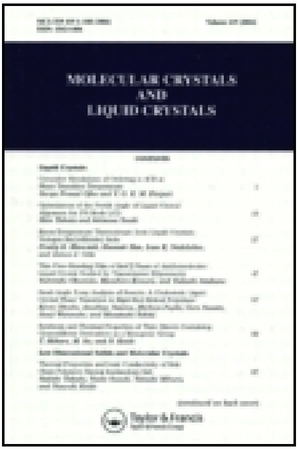

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Experimental Results on Optical Effects Induced in Epoxy Resin Based PDLC

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A thermosetting matrix based on a bifunctional epoxy resin was employed to realize a Polymer Dispersed Liquid Crystal (PDLC) system. Two different switching effects from an opaque to a transparent state have been observed: an electro-optical one occurring at a threshold value of the applied electric field and a self-switchi effect of thermal nature, occurring at a critical incident intensity in a PDLC. The experimental results showed promisi switching times with a rise time of 200 μsec and a decay time of 2.2 msec and an exceptionally high contrast ratio up to 430 for the electro-optical switch. The self-transparency effect is taking into account the beam profile variations of the light propagating inside such a medium. A three-dimensional analysis is reported.

Keywords: liquid crystals; PDLC; optical switching; electro-optical characterization

INTRODUCTION

During the last few years a high level of activity has characterized the field of research on PDLCs which are potentially useful for a variety of electro-optical applications including switchable windows, displays and light control applications.[1-4]

These materials consist of micron-sized nematic liquid crystal (LC) droplets dispersed in a polymeric matrix obtained by means of a thermally induced phase separation in a homogeneous solution of a nematic LC and monomer.

Their optical response can be induced both electrically and thermally. The electro-optical response is based on the electrically controlled light scattering properties of the droplets. An applied electric field aligns the molecular director inside the droplets to yield a non-scattering state. This happens because the LC is chosen so that its ordinary index of refraction is matched to the index of the polymer. Surface interactions at the droplet wall return the droplets to the original reorientation in the absence of the field to yield an opaque state. A competition between the applied field, and the elastic and viscous torques of the LC governs the response times and switching voltages of such light shutters. It is reported that the electro-optical properties of PDLC depend on LC concentration, film thickness, size and shape of LC droplets, and refractive index ratios of the LC and polymer. [5]

A similar behavior appears when the sample temperature increases and the LC inside the droplets undergoes a phase transition from the nematic state to the isotropic one.[6] Such a thermal effect can form the basis of an optical switch. This can be also induced increasing the incident light intensity, so that the initially opaque material becomes transparent. This optical phenomenon, is also termed a *self-transparency* effect.

In this paper we report experimental studies on both an electro-optical switching effect from an opaque to a transparent state occurring at a threshold value of the applied field and a self-switching effect occurring at a critical incident intensity in a PDLC.

EXPERIMENTAL

Materials

The epoxy prepolymer used in this study is the diglycidyl ether of bisphenol A (DGEBA) from Shell Italia S.p.A., commercially available under the trade name of Epikote 828. The methyl-5-norbornene-2,3-dicarboxylic anhydride (MNA) was used as hardener, and the 2,4,6-tris(dimethylaminomethyl)-phenol (DMP-30), was employed as initiator; both these products were Aldrich reagent grade, and were used without further purification. The weight ratio DGEBA/MNA/DMP-30 in the epoxy formulation was 0.53/0.46/0.01.

The epoxy-based PDLC was prepared by mixing the LC component (40% by weight) with the uncured epoxy matrix at 70°C, obtaining a complete homogenization of the mixture. The mixture was then sandwiched between two transparent conductive glasses spaced at 50μm by appropriate mylar spacers. The PDLC droplets were allowed to cure at 130°C reached with a heating rate of 2°C/min.

Morphological analysis

A preliminary investigation on the epoxy-based PDLC system has been presented in a previous work of the authors. [7]

Optical microscopy shows evidence of a separate LC phase in the form of birefringent droplets at compositions higher than 40 wt% of LC (see Figure 1A).

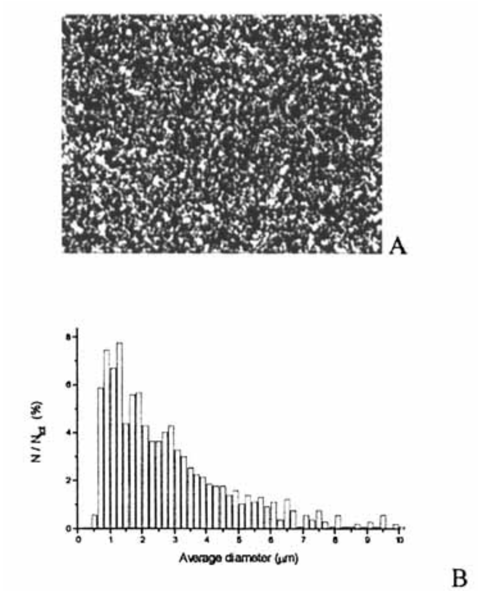

FIGURE 1. Optical micrograph at room temperature under polarized light of the 60/40 PDLC composition after curing; magnification 160x (A). Histogram of the particle size distribution inside the polymeric matrix (B).

A preliminary study of the above micrograph has been performed using a proper software of image analysis, and the results are reported in the histogram of Figure 1B. This distribution was evaluated by computerized image analysis from several SEM micrographs. In this case the particle size distribution is considerably narrower, with most of the domains ranging between 0.7 and 3 μm. The peak of the statistical distribution (exceeding 60 %) is located between 0.7 and 2 μm.

Electro-optical measurements: results and discussion

One of the potential application of PDLC is the realization of displays. Fabrication of displays requires knowledge of the switching voltage, response times, and optical properties of the materials employed.

The electro-optical characterization of our PDLC sample was performed by using the experimental set-up shown in Figure 2.

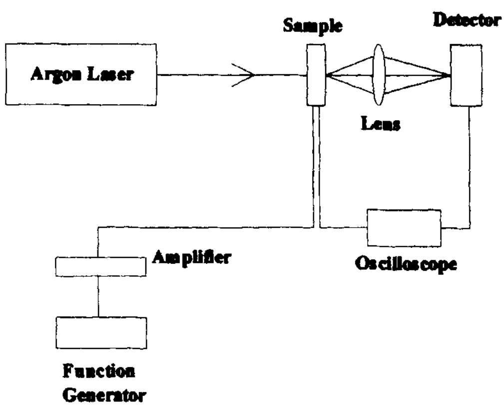

FIGURE 2. Experimental setup.

A linearly polarized, collimated beam from an Argon ion laser is directed normal to the film surface; the transmitted optical power is focused on to a silicon photodiode to get a small collection angle (<3°). The output of the photodiode is linear with light intensity over the range used. An electric field of known intensity and duration is provided by application of a voltage from a pulse generator and amplifier to transparent conductive electrodes. The voltage signal and optical response are monitored on a storage oscilloscope.

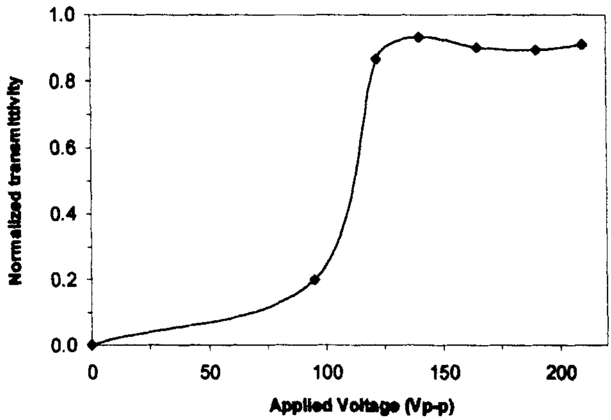

FIGURE 3. Applied voltage dependence of the transmittance of a PDLC cell 50-μm thick.

We measured transmittivity as a function of voltage from 0 to 250 V. Figure 3 shows the transmittivity as a function of the applied voltage of the PDLC cell at 50 Hz. Transmittance slightly increases with voltage up to approximately 90 V_{p-p}, and increases drastically in the range 90-

200 V_{p-p}. The voltage, at which a sharp increase in transmittance sets up, is the threshold voltage (V_{th}). In such a situation, when the applied voltage is lower than a threshold value (approximately 120 V), no distortion induced in the LC molecular director appears and the sample is in its OFF-state. When the voltage is increased above the threshold, the reorientation of nematic LC molecules occurs. In this case, there is a good index matching between the liquid crystal domains and the polymer matrix; this results in highly transmitted light, so that the sample is driven to the ON state.

In order to analyze the electro-optical behavior of our device, we changed the polarization states, the amplitude and frequency of the electric field. In all the tested configurations the field was driven by a square wave applied voltage. Over ν = 100Hz the optical signal was no more able to follow the driving field.

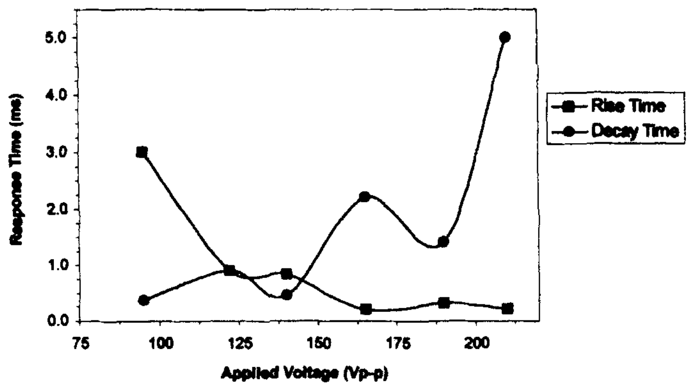

FIGURE 4. Response time as a function of applied voltage

We measured on and off response times using different values of the applied voltage to switch the cell. Figure 4 shows the rise time τ_{ON} (the time required for the composite to reach 90% of the ON-state transmission) and decay time τ_{OFF} (the time needed for a composite to reach 10% of the ON-state level) for the PDLC cell.

A set of photographs are presented in Figures 5(a) – 5(c) showing the traces at the oscilloscope of the driving signal (lower curve) and of the output signal (upper curve) in relation to various voltages applied at a frequency of 50 Hz. While the modulated electric field is in the low state the sample is OFF. But when the electric field is in the high state, light is transmitted and the device is ON.

In Table 1 we report in details the values of the response times and of the contrast ratio (ratio of the transmittivity in the switched state to that of the scattering state) for each applied external voltage.

Applied voltage (V)	τ_{ON} (ms)	τ_{OFF} (ms)	Contrast ratio
95	3	0.370	100
120	0.9	0.9	430
165	0.2	2.2	410

TABLE 1. Modulation characteristics of our PDLC sample

These characteristics indicate that PDLC cells can modulate depolarized light with very fast switching times and a very high contrast ratio up to 430.

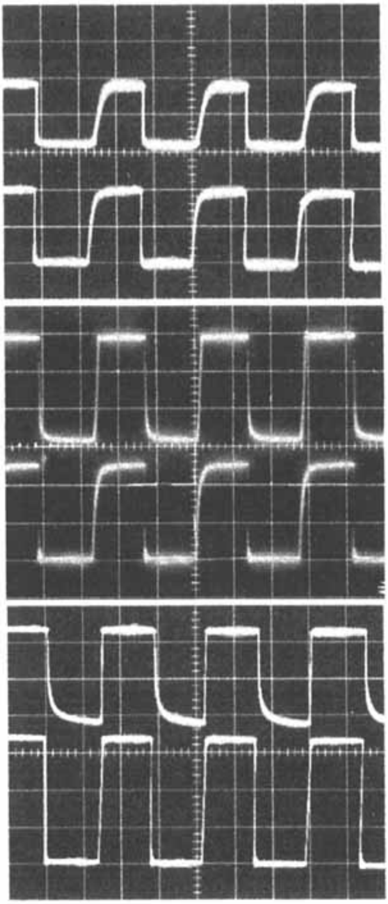

FIGURE 5. Optical response of our sample (upper traces): (A) $V_{p\text{-}p}$= 95V< V_{th} , (B) $V_{p\text{-}p}$ = 120V≈V_{th} and (C) $V_{p\text{-}p}$ = 120V>V_{th} . In the lower traces is shown the driving voltage whose frequency is 50 Hz. The time scale is 10ms/cm; the output voltage scale is 5V/cm; the driving voltage scale is 50V/cm.

Thermo-optical behavior

A self-switching appears when the sample temperature increases and the LC inside the droplets undergoes a phase transition from the nematic state to the isotropic one.

Such a thermal effect can form the basis of an optical switch. When increasing the incident light intensity, the initially opaque material becomes transparent.

This optical phenomenon, is also termed a *self-transparency* effect.

The thermo-optical response of this new kind of sample prepared by the authors exhibits interesting properties confirming the possibility to employ it for thermo-optical sensors or optical memory devices by thermal induced optical bistability.[8-9,6] Our results confirm that, when index matching occurs due to increasing light power, there is a defined threshold of the incident intensity at which the device passes from the scattering state to the transmitting one.

In order to analyze the light propagation through this material, and study the beam profiles changes induced by thermal nonlinearities, we used the experimental set-up described below.

The light beam from an Argon ion laser (λ = 514 nm) is normally incident on the sample, the transmitted optical power P_t is focused on a screen where the projected far-field image is collected by a profilometer to get a complete analysis of the three-dimensional spatial distribution of the output beam. A beam splitter just before the sample allows to monitor the incident power P_i.

In Figures 6a-6c three-dimensional profiles of the output laser beam at

T = 25°C for different values of the incident power P_i are presented: for P_i = 7mW< P_{th} only a weak scattered light beam is observed, while for P_i = 88mW > P_{th} an appreciable laser beam is transmitted whose Gaussian profile is easily recognizable. A clear switching effect is observed with a threshold value P_{th} = 20mW of the incident power.

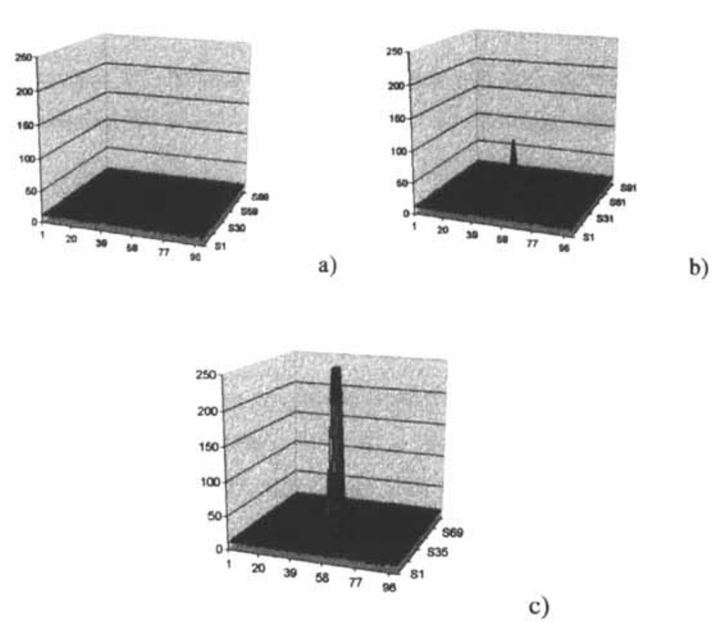

FIGURE 6. Three-dimensional profiles of a laser beam travelling through the PDLC at T=25°C for the increasing values of the incident power; a) P = 7mW, b) P = 20mW, c) P = 88mW.

CONCLUSIONS

In this paper we presented experimental results on electro-optical properties of a new kind of PDLC sample prepared by the authors. We estimated the rise time and the decay time as a function of the applied electric field, transmitted light vs voltage, and contrast ratio.

Contrast ratio is an important measure of the performance of an electro-optical devices. The experimental results showed fast switching times with a rise time of 200 μsec and a decay time of 2.2 msec and an exceptionally high contrast ratio up to 430. These performances are certainly appealing.

One of the aim of our work was to investigate also the thermo-optical behavior of the considered material. We analyzed the self-transparency effect which can occur in a highly scattering medium, with thermal nonlinear properties, when the increasing of the incident light intensity determines a local temperature variation of the material, necessary to switch from the opaque state to the transmission one. This mechanism is due to the competition of the components of the refractive indices of both the LC and the polymeric matrix.

The experimental observations, here presented, confirm the existence of such a type of effect in PDLC and show the self-confinement of the propagating laser beam inside the medium by the changes of the beam profiles.

In conclusion, we studied the self-action of a light beam propagating inside a PDLC and reported experimental evidence of light transmission from an OFF state to the ON one. Such an electrically/thermally switching, due to the index matching, of our PDLC indicates the possibility of employing this material to design thermal sensors or device working as optical switch.

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