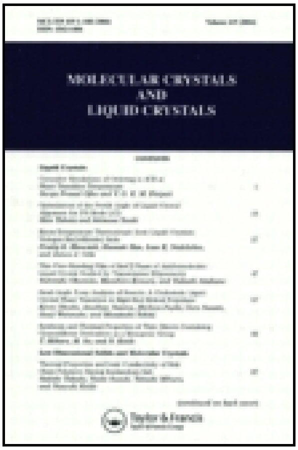

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Optical Effects in Polymer-Dispersed Liquid Crystal - Fibre Optic Devices

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Optical Effects in Polymer-Dispersed Liquid Crystal - Fibre Optic Devices

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Optical effects in PDLC - fibre optic systems have been studied. The main attention is devoted to intensity modulation based upon electrically driven transmittance and switching effects based upon grating structures in PDLC films. Obtained results are discussed from application point of view.

Keywords: fibre optic devices; PDLC; light modulators; diffraction gratings

INTRODUCTION

PDLC structures are very interesting due to optical, electro-optical, anchoring and dimensional effects. The most important electro-optical effect observed in case of nematic-containing PDLC is electrically driven transmission, i.e. transition from scattering to transparent state[1], which is used for a construction of information displays and light modulators.

There have been also attempts to apply PDLC in fibre optic devices due to their following features:

- possible aperture much larger than in case of solid crystal devices,
- relatively low cost,
- technology compatible with fibre optic one,

- possibility to obtain elastic devices.

The very first studies have concerned a simple intensity modulator, i.e., switchable light valve using the above effect[2]. In the present paper the results obtained for a similar system are also presented but the main attention is paid to in-plane light modulator and effects observed in PDLC films with periodically differentiated structure. The latter structures contain areas with different size and concentration of nematic droplets and, for this reason, act as Bragg diffraction gratings[3,4]. Those gratings can be permanent or switchable, depending on the method of creation. Theoretical description of observed effects will be published separately[5].

EXPERIMENTAL

Photopolymerisation induced phase separation (PIPS) has been used as PDLC preparation method due to its well known advantages, i.e. simplicity, excellent control of LC droplet diameter and fast processing[6,7]. Photocurable mercaptoester resin NOA-65® (Norland Optical Adhesives) has been chosen as a polymer matrix material. Two nematic mixtures based upon cyclohexylisothiocyanates with code numbers W-486 and W-602, respectively, (Institute of Chemistry MUT) have been selected as liquid crystals. The solubility of these materials in cured NOA-65 is close to zero securing proper refractive index matching[8] in contrary to the third LC mixture (W-801) based upon alkylbiphenyls.

PDLC structures has been obtained in glass cells with deposited ITO electrodes. In case of simple intensity light valve the whole PDLC film has got uniform structure 9 or 14 mm thick. The respective measuring set-up is shown in Figure 1.

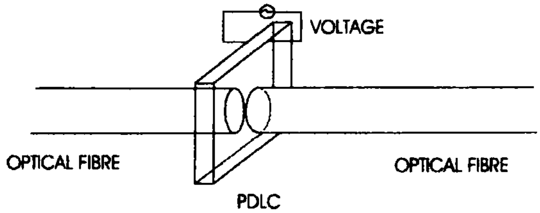

FIGURE 1 Measuring set-up in case of simple PDLC light modulator.

Another modulator configuration has been obtained when optic fibres have been co-linearly placed into PDLC cell before curing. Then UV curing with mutual hydrodynamic flow parallel to fibres has been adopted. In this way elongated ellipsoidal droplets with almost uniform optical axes parallel to fibres have been obtained[9] (transparent state). An application of electric field could switch this structure to scattering state (see Figure 2).

LC droplet eccentricity was 5 to 10 and their longer axes were 3 to 6 μm. The distance between fibres was less than four fibre core diameter. The above distance guaranteed minimisation of fibre coupling loss. Such a construction of the system secures the uniform PDLC layer thickness equal to fibre diameter. Th crucial problem in this case is to mount fibres in order to conserve their adjusted positions during shearing of the upper glass plate relative to the lower one. Measuring set-up is shown in Figure 3.

Striped periodic PDLC structures have been obtained by selective polymerisation method [4,10]. LC - prepolymer systems have been UV illuminated through lithographic masks consisted of black stripes 23 or 25 μm wide separated by transparent stripes 17 or 8 μm wide, respectively. As a result striped periodic structure of PDLC film has been obtained in which more transparent stripes (larger LC droplets of lower concentration) have been separated by more scattering stripes (small droplets of higher concentration).

An example of obtained structure and measuring system are presented in Figures 4 and 5, respectively. Grating efficiency was about 0.3. A semiconductor laser or laser diode with wavelength from the range 630-680 nm have been used as a light sources.

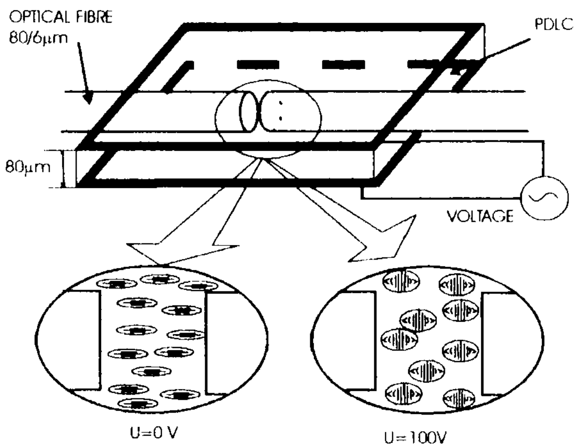

FIGURE 2 The principle of action of in-plane light modulator.

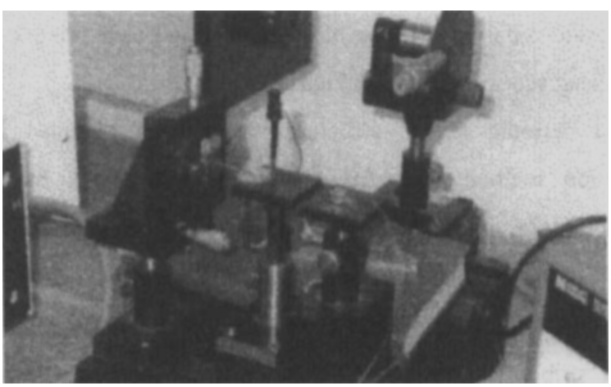

FIGURE 3. Photography of measuring set-up in case of in-plane system.

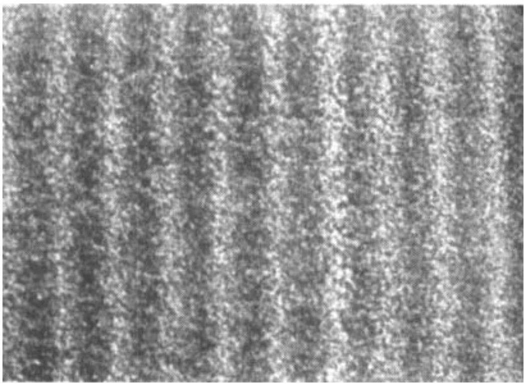

FIGURE 4 Periodic structure of PDLC film obtained by selective polymerisation.

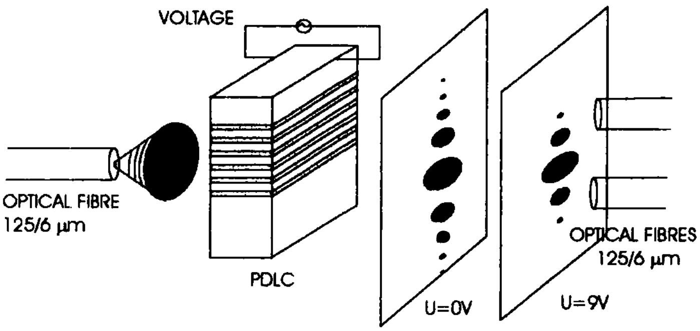

FIGURE 5 Measuring set-up in case of system for grating coupler.

RESULTS AND DISCUSSION

Simple modulator

In Figure 6 an example of static electro-optical characteristic of PDLC sample is presented. Normally scattering PDLC modulator is switched to transparent state, therefore light intensity in output fibre increases with applied electric field following PDLC transmittance. The crucial problem is to increase optical contrast ratio CR by reducing haze in on-state and decreasing transmission in off-state. CR depended also on optical coupling, i.e. distance between input and output fibres. The results are gathered in Table 1.

TABLE 1 Approximated CR values for simple modulator systems

LC	CR 9 μm	CR 14 μm	Comments
W-486	70	100	best refractive index matching, T_{on} = 85% for 14 μm
W-602	60	90	low solubility in uncured NOA-65,
W-801	35	60	bad refractive matching, T_{on} = 75% for 14 μm

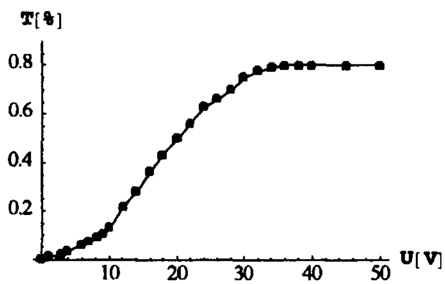

FIGURE 6 Static PDLC characteristic for PDLC sample 14 μm thick containing 20 per cent by weight of W-602.

In-plane modulator

In this configuration normally transparent modulator is switched to opaque state; dielectric reflections do not exist, light absorption is reduced, haze in transparent off-state is lower due to lower effective cross-section of LC droplets and mechanical stability of the system is improved. For above reasons

CR can be higher in this case in comparison with simple modulator if LC droplet diameter is not to large, so optical coupling is conserved. The main disadvantage of this system is much higher driving voltage due to larger thickness of PDLC film equal to fibre diameter, i.e. 80 μm. In Figure 7 an example of static electro-optic characteristic of this system is presented. Results obtained for different distance between fibres are gathered in Table 2.

TABLE 2 Approximated CR values for in-plane modulator systems

LC	CR 20 μm	CR 35 μm
W-486	100	120
W-602	75	95
W-801	40	55

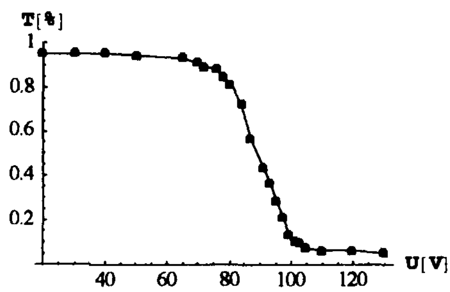

FIGURE 7 PDLC cell transmission measured between fibres for a sample containing 26 per cent by weight of W-486 nematic mixture.

Switchable grating modulator

Periodic differentiated PDLC structure acts as mixed phase-amplitude diffraction grating. After an application of sufficiently high electric field and reorientation of LC director in droplets this grating changing its character between phase and amplitude type. For this reason, instead of 5-8 orders of diffraction fringes observed in off-state one can see only the first order diffraction fringes.

In Figure 8 relative light intensity in fibres attached to the first (upper curve) and the second order diffraction fringes (lower curve), respectively, are presented. An application of electric field results in switching light energy from farther fringes to the first order fringe. Such the effect can be adopted to construct switchable coupler for fibre optic devices.

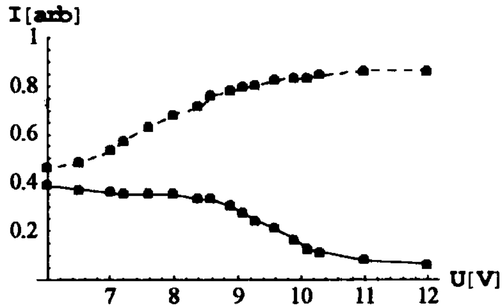

FIGURE 8 Light intensity in fibres attached to grating modulator vs applied voltage for NOA65 - W486 system.

CONCLUSIONS

1. PDLC can be successfully adopted as controlled intensity light modulators in fibre optic systems. In-plane modulator seems to be better solution than simple one due to enhanced contrast ratio and less sensitivity to mechanical stress, however switching voltage should be reduced.

2. The interaction of light with periodic structure of PDLC allows to construct a new generation of opto-electronic devices, which can be used as switchable couplers for fibre telecommunication application.
3. For a professional application in fibre optic devices PDLC require careful optimisation of their electro-optical properties, especially reduction of haze to increase contrast ratio and reduce light losses.

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References

[1.] J. W. Doane, in *Liquid Crystals: Applications and Uses*, ed. B. Bahadur, Singapore, London, New York, 1990, Chap.14.
[2.] A. Karppinen, H. Kopola and R. Myllyla, *Proc. SPIE*,**1455**, 179 (1991).
[3.] R. L. Sutherland, V. P. Tondiglia, L. V. Nataranjan, T. J. Bunning and W. W. Adams, *Appl. Phys. Lett.*, **64**(9), 1074 (1994).
[4.] S. J. Kłosowicz, *Opto-Electronics Review*, **2'94**, 58 (1994).
[5.] L. R. Jaroszewicz, S. J. Kłosowicz and E. Nowinowski-Kruszelnicki - to be published
[6.] Y. Hirai, S. Niiyama, H. Kumai and T. Gunjima, *Proc. SPIE*, **1257**, 2 (1990).
[7.] A. J. Lovinger, K. R. Amundson, and D. D. Davis, *Chem. Mat.*, **6**, 1726 (1994).
[8.] S. J. Kłosowicz, *Proc. SPIE*, **2372**, 258 (1995).
[9.] S. J. Kłosowicz, *Opto-Electronics Review*, **4**(1/2), 62 (1996).
[10.] S. J. Kłosowicz, O. Francescangeli and I. Pepe, submitted to *Mol. Cryst. Liq. Cryst.*