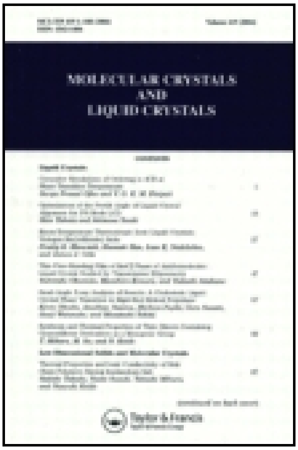

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Photoconducting Polymer - Nematic Liquid Crystal Hybrid Structures the Promising Choice for Optical Information Processing

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We present recent progress in development of liquid crystalline optically addressed spatial light modulator, its characterisation and performances. The spatial light modulator is based on photoconducting polymer – nematic liquid crystal hybrid structure and is used in various configurations of holographic recording and reconstruction. The refractive index gratings arising in a system with photoconducting electrode layer are tilted and phase shifted with respect to the light intensity pattern therefore allowing for an extremely efficient energy transfer between the incoming beams. Depending on optical systems used, several useful optical devices have been constructed by us, like: phase conjugate mirrors, Fourier optical correlators for pattern recognition, coherent light amplifiers, incoherent-to-coherent light converters. Their performances are directly linked with physical properties of used materials and the principal photorefractive mechanism which will discussed.

Keywords: liquid crystal; spatial light modulator; real-time holography

INTRODUCTION

Optical information processing is nowadays inherently linked with non-linear optical properties of materials. During the last decade we observe a consequently increasing importance of organic materials used for construction of active photonic devices. The leading role is played by polymeric composites and liquid crystals[1]. Molecular reorientation of planarly ordered nematic liquid crystal leading to index modulation, among many other possible processes[1-5], can be induced by intrinsic photoconductivity of the liquid crystal mixture[6,7] or via use of semi-transparent photoconducting electrodes and evanescent electric field coming from surface charge density[8]. The latter solution, in opposition to that employed in designing photorefractive polymers, splits electrical and optical functions among two more suitable media being in contact with each other. Photoconducting polymer performs task of creation of charge density which maps the incoming light interference pattern and liquid crystal, being a highly non-linear optical material which changes its optical properties according to evanescent electric field, performs a role of an efficient light refractive medium.

DIFFRACTION GRATINGS IN PHOTOCONDUCTING POLYMER - NEMATIC LC HYBRID STRUCTURES

Let us consider liquid crystalline cell as shown in Figure 1.
The cell shown in Fig. 1 has the photoconducting layer deposited directly onto ITO covered glass. We used soluble polythiophene derivative with attached chromophore commercially known as Disperse Red 1 (DR1). This layer simultaneously performs a dual function - that of partially transparent but photoconducting layer and of a planar alignment inducing layer in nematic liquid crystal filling the cell[9]. Polymer layer when excited with absorbed laser light of 514 nm or 532 nm wavelength shows photoconducting properties. Conventional degenerate two-wave mixing technique was used to study performance of the described structure. Two coherent p or s-polarised laser beams crossed inside the sample formed sinusoidal light intensity pattern with the spacing $\Lambda = \dfrac{\lambda}{2n\sin(\theta)}$ which could be changed by changing the angle 2θ between the two writing beams. We observed an efficient self-diffraction for hybrid photoconducting polymer - LC sample only at

oblique light incidence angle (preferentially Ψ_{tilt} = 45^{o})[10], no diffraction was seen for $\Psi_{tilt} = 0^{o}$. Moreover for p-polarised beams an efficient exchange of energy between the inciding beams was observed and direction of energy transfer was controlled by sign of an externally applied voltage.

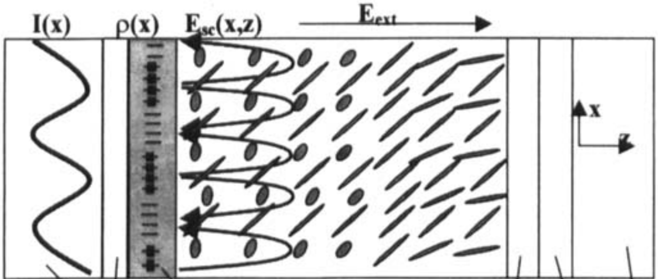

FIGURE 1 A schematic depiction of the liquid crystal panel described in the present studies and reorientation of LC molecules along the lines of electric field formed as result of evanescent field coming from surface charge distribution in polymeric layer and applied external electric field. The light intensity pattern assumed here is $I = I_0(1 + \cos(qx))$.

The time constants of grating recording and erasing ranged from several ms to several hundreds of ms. Light diffraction efficiency could be as high as 30 % which is close to the theoretical limit for thin phase (Δn) gratings (typical LC layers thickness were 6 - 15 μm).

The tentative mechanism of diffraction grating recording in a presented structure we understood in the following way. Sinusoidal light intensity pattern creates in a thin photoconducting polymer electrons and holes only in the bright regions. The charges move from the place of their generation due to diffusion and drift in the electric field. Part of them depending on their mobilities and lifetimes reach either ITO electrode or LC layer, part are trapped either in the bulk of the polymeric layer or at the LC-polymer interface. As result of these processes certain distribution of surface charge $\rho(x) = \rho_m \cos(qx + \delta)$ being a replica of I(x) is obtained. Spatial electric charge density modulation generates an electric field E_{SC} which in LC layer can be shown to have a form[11]:

$$E_x^{LC} = E_o \exp(-qz)\sin(qx)$$
$$E_z^{LC} = E_o \exp(-qz)\cos(qx) \quad (1)$$

where $E_o = \frac{2\pi\sigma_m}{\varepsilon_{LC}}$ with σ_m being the amplitude of the surface-density modulation of charges. Superposition of evanescent fields with external field E_{ext} will reorient the NLC director at the spatial frequency of q according to a torque τ_E [1]:

$$\tau_E = \frac{\Delta\varepsilon}{4\pi}(\hat{n}\cdot(E_{sc}+E_{ext}))(\hat{n}\times(E_{sc}+E_{ext})) \quad (2)$$

where $\hat{n}$ is a director. A grating which is the result of molecular reorientation in the simplest case can be described by a modulation of the dielectric permittivity tensor of the liquid crystal at the operation wavelength. The respective gratings are schematically shown in Fig. 2.

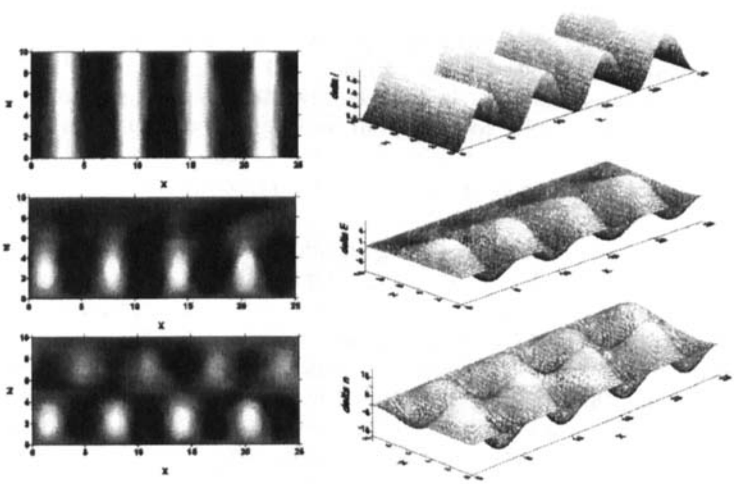

FIGURE 2 A schematic views, from the top and 3-D, of the gratings formed in planar nematic liquid crystal with polymeric photo-conducting electrode: sinusoidal light intensity pattern I(x,z), electric field inside LC layer E(x,z) and modulation of refractive index Δn(x,z).

The phase mismatch δ between light intensity grating and refractive index grating leads to an efficient energy transfer between the beams. One of the beams experiences gain g at the cost of the second one. The gain parameter *g* can be expressed as[10]:

$$g = \frac{I_{-0,+0}}{I_{-0}} = \frac{1+m}{1+me^{-\Gamma d'}} e^{-\alpha d'} \qquad (3)$$

where $I_{-0,+0}$ and I_{-0} are the beam intensities measured at 0 diffraction order in the presence of second beam and its absence in two-beam coupling experiment, α is the average absorption coefficient of a liquid crystal at the excitation wavelength, d' is the interaction length and Γ is the exponential gain coefficient.

EXAMPLES OF OPTICAL DEVICES EMPLOYING LC PANELS

The optical phenomena occurring in described above LC panels are frequently described in terms of real-time holography. The recorded refractive gratings are read by other laser beams thus allowing for parallel light processing.

In Figure 3a we show the scheme of a photorefractive beam amplifier where two beams of very different intensities are coupled and in Figure 3b we present the exponential gain coefficient measured in the LC panel in function of external voltage applied to the sample. This is one of the highest Γ ever measured (Γ = 3800 cm $^{-1}$ at 9 V)[12].

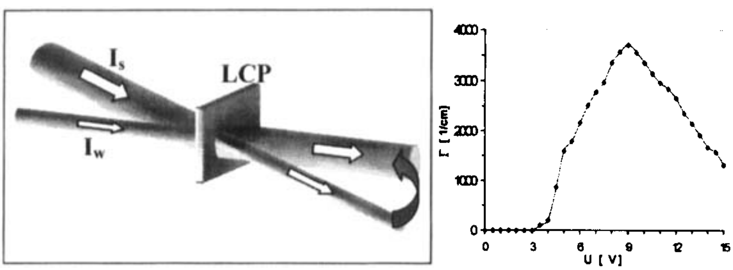

FIGURE 3 Simplified optical system realising coherent light amplification.

In Figure 4 we show the scheme of incoherent-to-coherent image converter. For that purpose we used a two wave mixing set-up (right side) and perturbed the refractive index grating by illumination of a third incoherent beam carrying an image (triangle, left side). As result the image is transferred from incoherent beam to coherent one. The experimental results are shown in Figure 4.

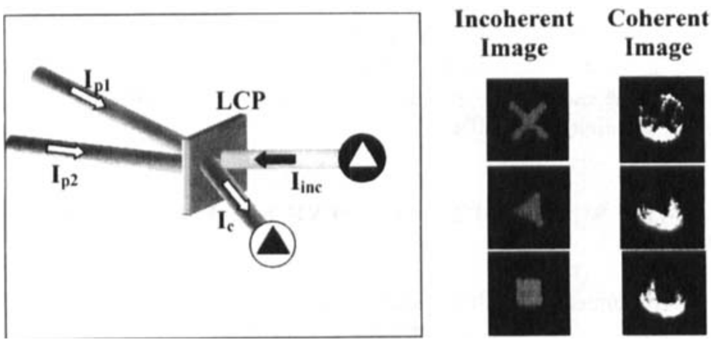

FIGURE 4 Incoherent-to-coherent image converter and results obtained for LC panel. Writing beams λ = 532 nm incoherent beam λ = 514 nm[13].

Next we assembled a system realising phase conjugated mirror (PCM)[14] . In Fig. 5 the interference of the probe I_p and the forward I_f pump beam writes a holographic grating in the LC, which is read by backward I_b pump beam and diffracted in the direction of the phase conjugate I_c beam. The maximum phase conjugate reflectivity R_{PC} = I_c/I_p obtained in 15 μm thick LC layer amounted to 2.5 %.

In Fig. 5 we show an example of abberation removal of our PC mirror. In the experiment we put small lens (A) between beam splitter BS and LC panel and observed the image of laser beam at distances X = 0.5, 1.5 and 2.5 m apart from BS. The similar experiment we performed replacing the PC mirror with a classical metallic one, which of course can not remove beam abberation.

Finally in Fig. 6 we present schematic view of joint Fourier transform optical correlator[15]. The object and group of various objects are superimposed onto a collimated laser beam I_o by use of transmissive type LC matrix display.

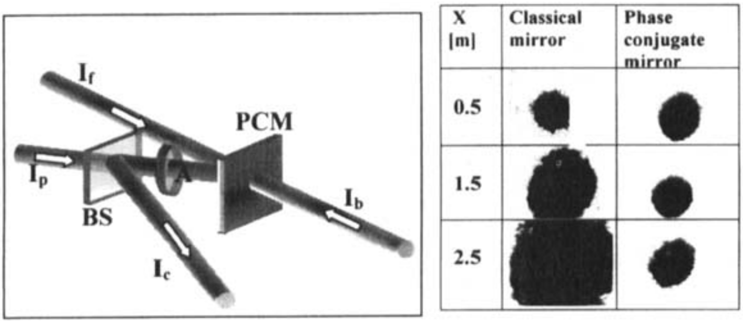

FIGURE 5 Schematic view of degenerate four wave mixing using our LC panel and its abberation correction properties.

A thin lens performs a Fourier transformation of all the objects. Depending on similarity of Fourier transforms diffraction gratings are formed. These gratings are read by another laser beam I_p and intensity of first order diffraction (so called correlation peaks) shows correlations between similar or identical objects. The system uses 40 ms for recognition cycle. In Fig. 6 an example of pattern recognition is given, further details were already published[15].

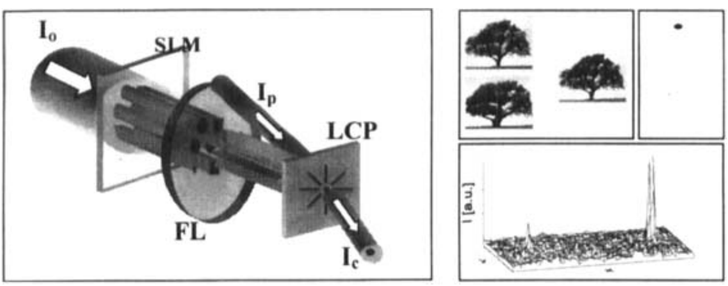

FIGURE 6 A scheme of joint Fourier transform optical correlator and an example of correlation result seen as correlation peaks obtained on described in the paper LC panel.

All presented above optical devices use the same nematic liquid crystal panel as the optically active element. The extremely high optical nonlinearities and photorefractive properties of this material are result of relatively complex mechanism leading to transformation of optical field into refractive index changes. The knowledge of involved processes (photogeneration and charge transport, molecular reorientation and relaxation) helps in designing of novel materials and panel constructions with still improved performances. Liquid crystals as a whole class proved to be very versatile materials for processing of optical information and number of papers devoted to their unique properties is progressively increasing.

Acknowledgements
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