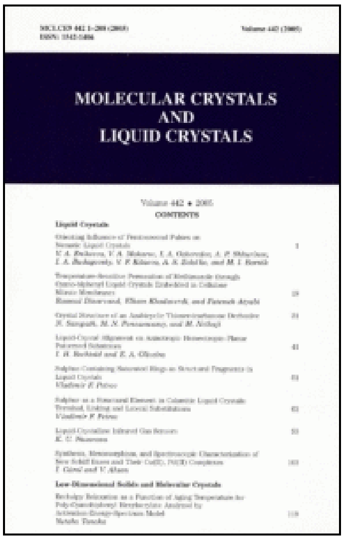

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Full Optical Control of Holographic Gratings Realized in Composite Materials Containing Photosensitive Liquid Crystals

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Full Optical Control of Holographic Gratings Realized in Composite Materials Containing Photosensitive Liquid Crystals

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We report on the characterization of an all optical switching effect that takes place when a UV light beam irradiates an azo-POLICRYPS diffraction grating. This high quality polymeric structure is utilized to confine and stabilize a well aligned nematic liquid crystal (NLC) film doped with a small percentage of azo-NLC molecules. The optical control of the grating diffraction efficiency is obtained by exploiting the photochemical phase transition between the nematic and the isotropic phases of the liquid crystal, based on the photoisomerization of the azobenzene guest molecules. The switch ON-OFF of the grating diffraction efficiency is triggered by a UV pump laser and is investigated by means of a low power red probe beam.

Keywords Diffraction gratings; liquid crystals; photosensitive materials

Introduction

Periodic structures in the micrometer and sub-micrometer range are in high demand for many applications ranging from electronics to photonics [1]. The possibility of developing electrically switchable holographic gratings based on polymer dispersed liquid crystals (PDLCs) has been widely explored in the last 15 years [2]. The reason lies in the possibility of obtaining reliable, cheap and commercially available elements for switchable holographic devices. Since good quality optical gratings need a sharp and uniform fringe morphology, a technique has been widely exploited which consists in exposing a pre-syrup of monomer, liquid crystal and curing agent to a visible (or UV) laser interference pattern, thus allowing a direct, single step, formation of the grating during the curing process [3].

Many studies [4,5] have been performed on optically controllable composite films which are attractive for applications in photonics or optoelectronics. Variations in the transmittance of systems can be achieved by exploiting a photochemical

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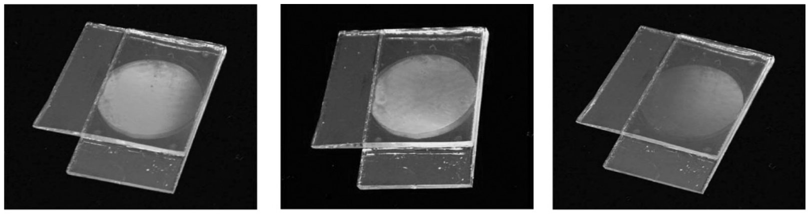
reaction of photochromic molecules, such as azobenzene and derivatives, incorporated into the LC domains inside the polymer matrix. These chromophores can undergo reversible *trans-cis* isomerization if acted on by light of suitable wavelength. The change in transmittance is due to a change in the molecule shape which leads to a phase transition. As in usual HPDLC, also in azo-HPDLC structures realization of a Bragg grating is based on a periodic modulation of the refractive index in the material, but the "ON-OFF" switching of the grating is now obtained optically. Indeed, photochromic compounds, such as azobenzene derivatives, provide a means to access, optically and isothermally, a Nematic to Isotropic (NI) transition which changes the refractive index of the PDLC droplets, thus modifying the refractive index modulation of the sample. The transition from the thermodynamically more stable trans to the cis conformation can be induced by irradiation with UV or visible wavelength and reversed upon heating or irradiation with visible light of longer wavelength. Combination of the dynamic optical properties of an azo-LC/LC mixture with the photonic properties of an HPDLC enabled realization of an optically switchable optical device. Systems of this kind are of great interest for possible applications, since they represent simple and flexible elements by which photoresponsive photonic crystals can be fabricated in a single-step process. In addition, it is envisaged that complex two- and three-dimensionally periodic HPDLC photonic materials utilizing azo-LC could be fabricated in the future to realize dynamic photonic crystals of any structure in a one-step process. As a matter of fact, however, the overall optical characteristics of recorded HPDLC or azo-HPDLC gratings exhibit some intrinsic drawbacks. Namely, if the droplet size of the nematic liquid-crystal (NLC) component inside the polymer matrix is comparable with the wavelength of light, the sample is strongly scattering.

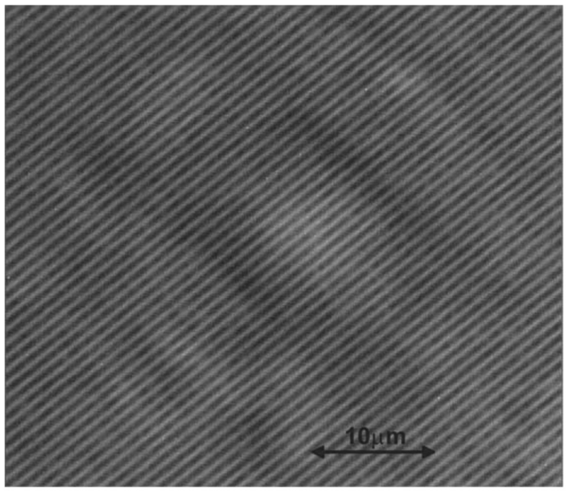
Few years ago, an attempt has been made to fabricate a new kind of holographic grating that exhibits a better optical quality [6]. The grating consists of polymer slices alternated with films of regularly aligned NLC [we called it "Polymer Liquid-Crystal Polymer Slices" (POLICRYPS) grating]. In this paper, we review recent results [7] obtained by combining the good quality and properties of POLICRYPS structures with the possibility of optically controlling (switching) holographic gratings realized in liquid crystalline composite materials which contain also a small percentage of an azo-compound.

Experiment

POLICRYPS fabrication has been realized by means of the UV holographic setup described in details elsewhere [6], implemented with a new technique for high stability curing [8,9]. For our experiments, a POLICRYPS grating with a periodicity $\Lambda = 1.6\,\mu m$ and thickness $d = 11.4\,\mu m$ has been realized, following the procedure of Ref. [6]. The mixture is composed by: 25% in weight of NLC (E7 by Merck), 5% in weight of azo-NLC (1005 by Beamco [10]) and 70% in weight of monomer (NOA61 by Norland). The initial mixture has been ultrasonic-treated to form a homogeneous solution and then injected by capillarity into the cell made of two glass slabs. A first, qualitative characterization, made with the help of a photo camera and an optical microscope, shows that also this azo-POLICRYPS exhibits good morphological characteristics (Figs. 1a and 1b). In particular, from Figure 1b we can infer the existence of a stable structure, made of alternated layers of pure polymer and pure LC, with the apparent absence of PDLC droplets. A spectrum has been



(a)



(b)

Figure 1. (a) Pictures of a POLICRYPS sample at different angles, (b) Photo of a POLICRYPS grating taken with 50X a objective equipped Olympus microscope.

recorded on this curing mixture using a spectrophotometer. The resultant spectrum over wavelengths of interest is displayed in Figure 2. The mixture (red curve) exhibits a high absorption in the $\lambda = 300$–400 nm range, while the grating (blue curve) shows a minimum in the transmission (a sign of a good diffraction efficiency) around $\lambda = 650$ nm. For this reason, the setup utilized for the characterization of the sample (Fig. 3) makes use of a blue pump laser of wavelength $\lambda = 409$ nm, in the high absorption range of the spectrum, and a red probe laser of wavelength $\lambda = 650$ nm, in the range that is of high efficiency for the grating.

Results

We have performed our first characterization by using an unfocused pump beam with a power of only 4.4 mW, which exhibits an oval shape with dimensions of the order of $2\,\mathrm{mm} \times 3\,\mathrm{mm}$. Figure 4 shows that a pump irradiation of duration $\tau = 20$ s operated by opening the UV laser shutter dramatically reduces the diffraction efficiency of the azo-POLICRYPS grating to less than 75% of its initial value in a time scale of few seconds; a slow increase towards the initial diffraction efficiency value is then observed when the shutter closes the beam. In order to explain this behaviour, we have to consider that when azo-NLC is embedded in a

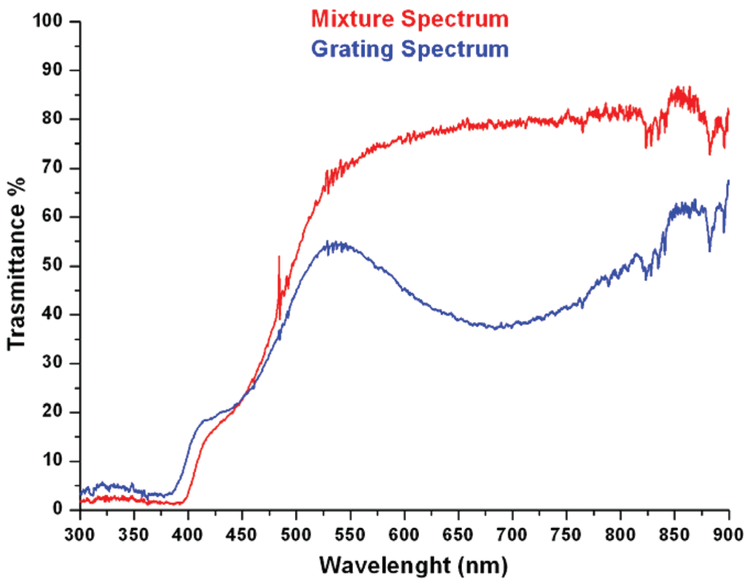


Figure 2. The transmission spectra of both the uncured mixture (red curve) and the realized grating (blue curve).

NLC, the two isomers produce different environments, which are characterized by the two different molecular shapes. The rodlike rigid molecule of the *trans* form is favorable for the stabilization of the LC phase, while the bent *cis* isomer tends to destabilize the nematic phase structure. Therefore, the ordered nematic phase is isothermally transformable into a disordered isotropic phase by the *trans–cis* photo-isomerization of the guest azo-NLC. This combination enabled realization of an

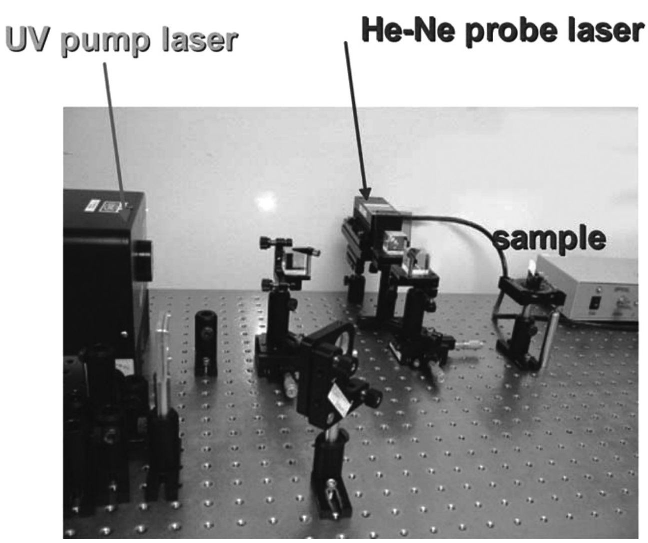


Figure 3. Experimental setup for the observation of all-optical processes in azo POLICRYPS.

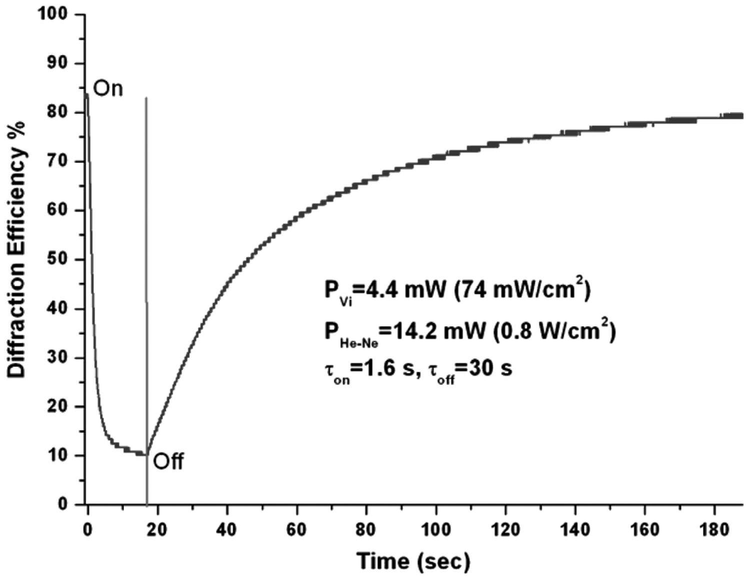


Figure 4. Dynamics of the diffraction efficiency of the probe 1-st order diffracted beam. The grating is irradiated by the pump laser beam for a time interval $\tau = 20\,s$; the probe beam is from a He-Ne laser. Beams are not focused.

optically switchable system. We have investigated this dynamics by varying the pump power while the probe power is kept constant (Fig. 5). The fall time of each curve is reported in Figure 6 as a function of the pump power: data are well-fitted

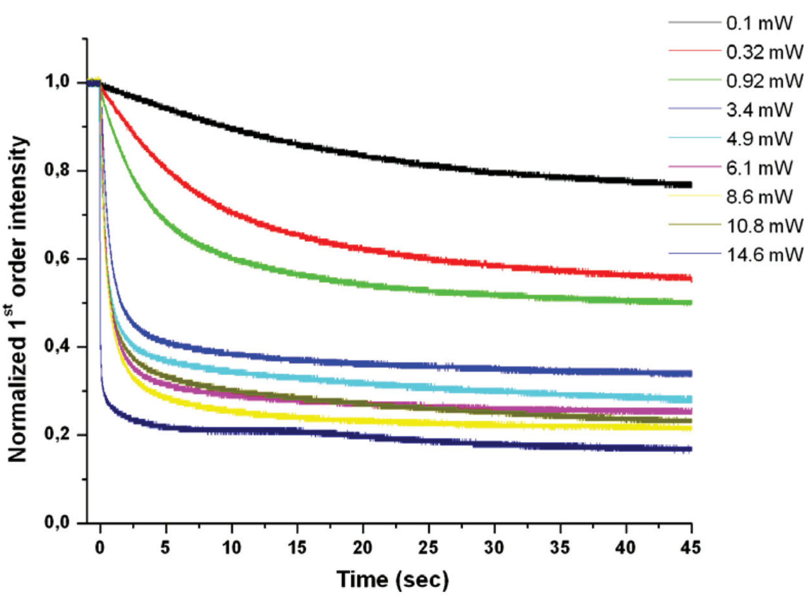


Figure 5. Dynamics of the grating diffraction efficiency observed for different value of the pump beam power; the probe beam power is kept constant ($P_{red} = 14.4\,mW$). Diffraction efficiency values are normalized to the initial ones.

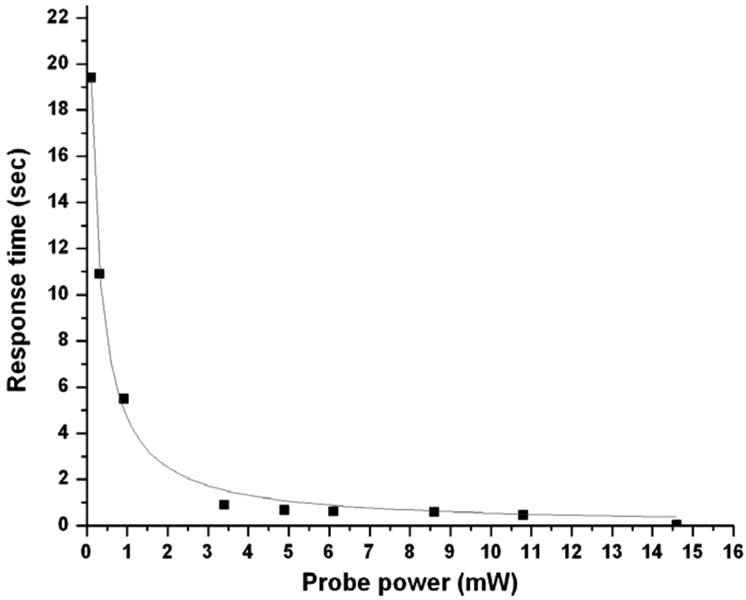


Figure 6. Response time of the azo-POLICRYPS grating vs the power of the pump beam.

by a negative exponential curve (red): $\tau_{SW} = \tau_0^{*e^{-(P-P_{min}/P_0)}}$ ($\tau_0 = 19.4$ s, $P_0 = 1.8$ mW, $P_{min} = 0.1$ mW). This behavior represents the most interesting result reported in the present paper. Indeed, keeping in mind that in our experiment the laser beam

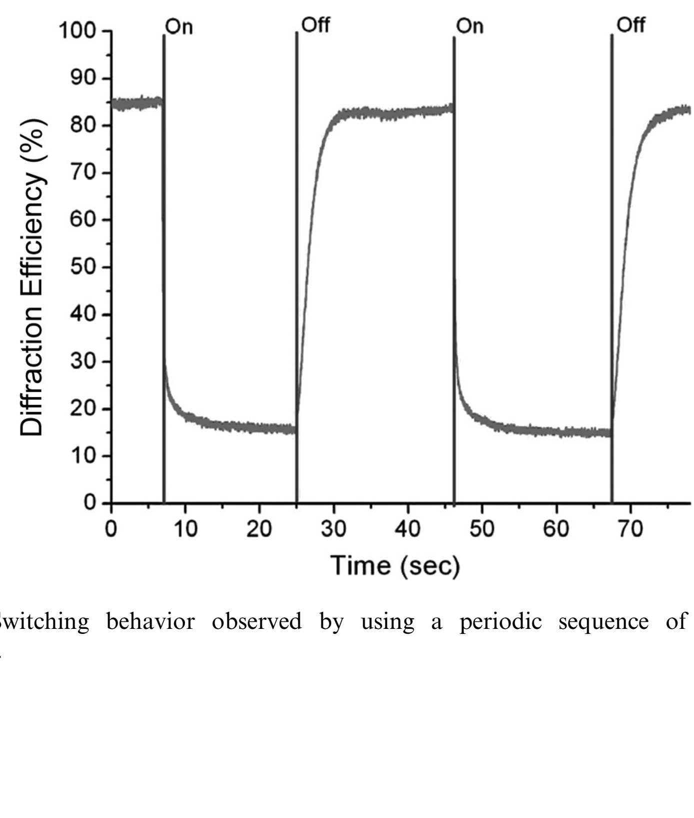


Figure 7. Switching behavior observed by using a periodic sequence of pump beam irradiations.

was not focused, we foresee that much shorter switching off times can be achieved for an azo-POLICRYPS grating irradiated by a focused beam, where a much higher power density is obtained with power levels even lower than those used in actual experiments. In order to verify this hypotesis, we repeated the experiment by using the same experimental values in Figure 4 by focusing the laser beams (0.5 mm spot diameter). Finally, we have observed that the switching behavior occurs periodically if a sequence of pump beam irradiations are used, as demonstrated in Figure 7.

Conclusions

We have reported the experimental characterization of an all optical control of an azo-POLICRYPS diffraction grating. This high quality periodic structure, realized in composite materials containing mesogenic azo-NLC molecules, is obtained in a single step by using a UV holographic setup. The switch ON-OFF of the grating is carried out by means of an all-optical setup and the response time are related to the impinging pump power density.

Acknowledgments

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