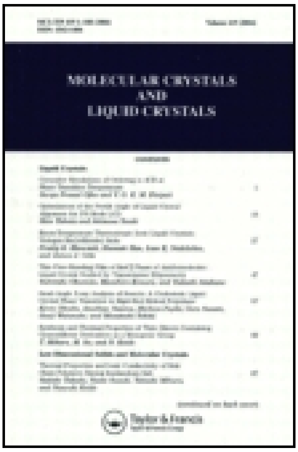

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Realization of Photoresponsive Diffractive Beam Splitters

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Realization of Photoresponsive Diffractive Beam Splitters

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We report on the realization of a light beam splitting effect based on a light sensitive diffractive structure. The periodic structure is realized in soft composite materials doped with an high performance light sensitive Liquid Crystal. The capability of the structure as tunable beam splitter, is monitored by combining its zero and first diffracted orders in a MC-Zehnder geometry interferometer. The fringe visibility of the interference pattern can be finely controlled by means of an external pump source. Low driving power and short response time are the main features of this light controlled beam splitter.

Introduction

Optical Beam Splitters (OBS) split a light beam into two coherent parts by reflecting and transmitting different fractions of the incident beam intensity. Different types of OBS exist, which are used for many different purposes, like dielectric mirrors [1], cube OBSs [2], and fiber optics OBSs [3]. Diffractive beam splitter are periodic structures that split the input beam into multiple diffractive orders; such kind of diffraction effects have been exploited to realize OBS in photonic technology [4]. They exhibit excellent polarizing properties and small absorption coefficients, along with a high power damage threshold [5, 6]. Liquid Crystals (LCs) are materials that can be efficiently used for this kind of application; being, indeed, highly responsive to different external stimuli like optical, magnetic and electrical fields, exhibiting large birefringence and low absorption coefficient [7]

Transmission gratings realized in Liquid Crystalline composite materials, like Holographic Polymer Dispersed Liquid Crystals (H-PDLC) [8], along with diffraction effects, allow to exploit the capability of Nematic Liquid Crystals (NLCs) of exhibiting a birefringence that can be varied an external control. HPDLC based devices, however, can show some intrinsic drawback due to the high light scattering caused by NLC microdroplets [9]. Recently, we have proposed a new class of periodic structures named POLICRYPS (acronym of POLymer LIquid CRYstals Polymer Slices), which are made of polymer slices alternated to films of pure and well aligned NLC [10]. These structures possess excellent optical and electro-optical properties; furthermore, we have combined the

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properties of NLCs with those of photoresponsive materials, realizing a particular structure, (azo-POLICRYPS), which can be switched ON and OFF by applying either an external electric field or an optical pump beam [11]; these devices exhibit response times that fall in the nanosecond range. This characteristic is of particular interest for applications, since fast light responsive devices can enable implementation of an on-chip technology where control beams can be engineered to travel together with signals with no need of electrodes and electric contacts.

In this paper, we show that azo-POLICRYPS structures are excellent candidates for the realization of a light controlled OBS where beams coming out of this innovative device can be combined to obtain an interference pattern, whose visibility can be finely varied by means of an external control beam impinging on the OBS; this effect is very useful for the characterization of a variety of photo-responsive materials.

Experiment and Results

An azo-dye named CPND-57 ((2-chloro-4-N-ethylpiperazinylphenyl) (synthesized by BEAM engineering) with a composition of 85% 5CB (Merck) and 15% of a mixture of the piperazine-based push-pull LC azo dyes CPND 5 and CPND 7 has been utilized. In Fig. 1 we report the transmission spectrum (ocean optics spectrometer) of CPND-57, which is red-shifted in comparison with the azo dye due to the high polarity of the liquid crystalline compound.Here, according to the technique described in ref. [12], we have infiltrated a passive polymer template with CPND-57. The experimental setup utilized to check the optically controlled azo-POLICRYPS based OBS is reported in Fig. 2, along with the apparatus that creates an interference pattern with a tunable fringe visibility. The probe beam is split into two parts (the transmitted an the diffracted orders, 0T and 1T respectively) by the azo-POLICRYPS grating. These are recombined in a Mach-Zehnder interferometer geometry, used to monitor the functionality of the OBS. The interference pattern (dark insets of Fig. 2) produced by overlapping 0T and 1T beams is detected by the photodiode PD mounted on a motorized translation stage. Geometrical parameters of

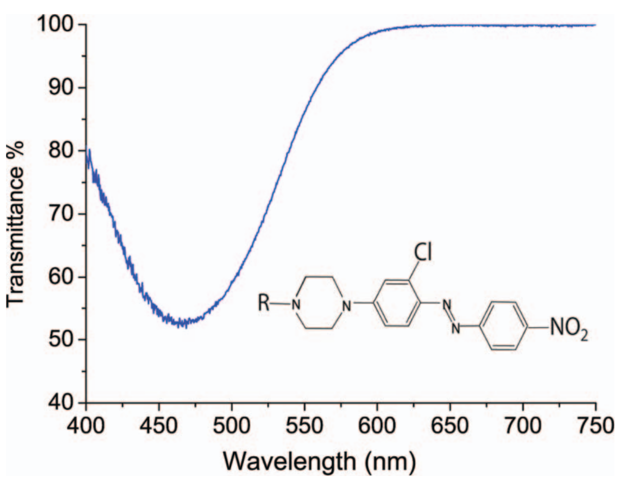

Figure 1. Visible spectrum of CPND-57 azo-dye in solvent. In the inset is reported the chemical structure.

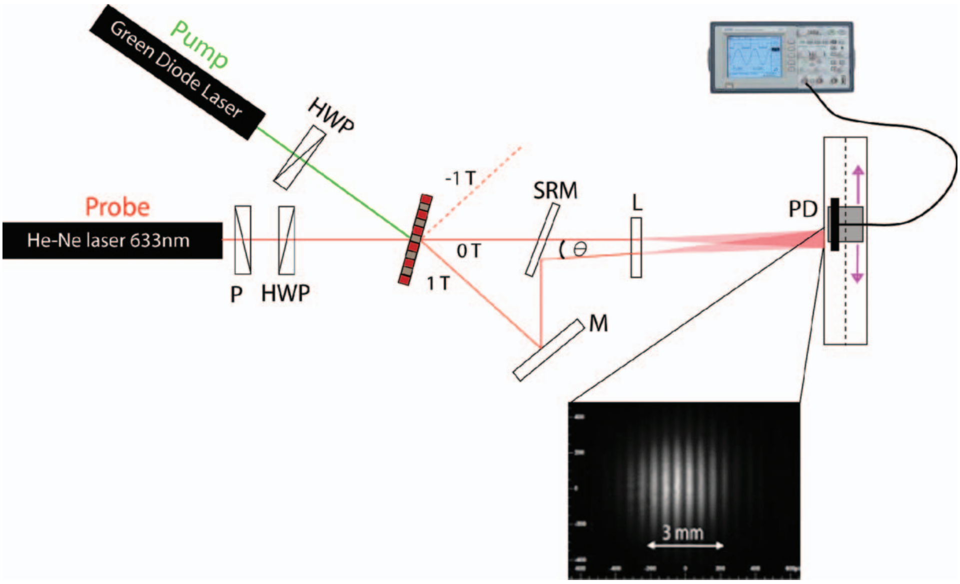

Figure 2. All-optical OBS and interferometer setup: P, polarizer; HWP, half-wave plate; SRM, semi-reflective mirror; θ, interference angle; PD, photo-detector; L, lens.

azo-POLICRYPS grating are L = 6.95 μm in thickness and Λ = 1.57 μm in fringe spacing; according to Kogelnik's theory [13], this grating operates in the Bragg regime with a characteristic parameter $\rho = \Lambda^2/\lambda L = 0.56$ (at $\lambda = 0.633$ nm). Figure 3a (blue curve) shows the detected interference pattern intensity versus the position of the translation stage. The intensity modulation is due to the intensity difference between bright and dark fringes of the interference pattern while Gaussian envelope of the signal reproduces the transverse intensity profile of the laser beam. The ratio $R = I_{1T}/I_{0T}$ of intensities of 1T and 0T beams is related to the diffraction efficiency (h) of the grating trough the equation:

$$\eta = I_{1T}/(I_{0T} + I_{1T}) = R/(1 + R) \quad (1)$$

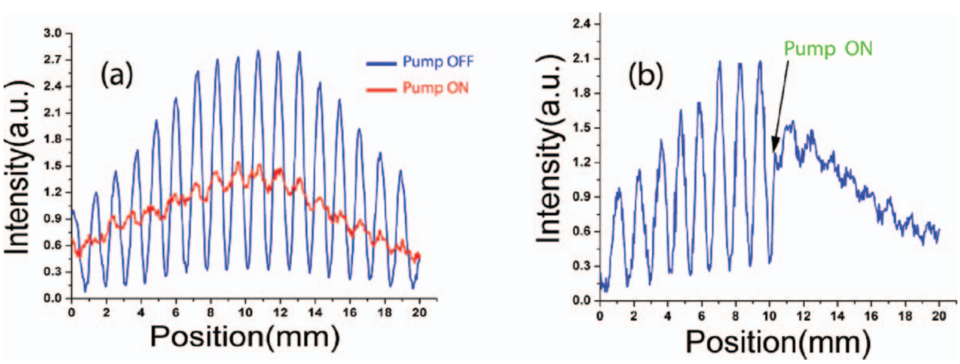

Figure 3. (**a**) Intensity profile versus the position of the motor stage; (**b**) Intensity profile before and after the pump irradiation.

On the other hand, the visibility V of the interference patter is related to diffracted beam intensity trough the equation:

$$V = [2(I_{0T}I_{1T})^{1/2}/(I_{0T} + I_{1T})]|\gamma| = [2(R)^{1/2}/(1 + R)]|\gamma| \quad (2)$$

The degree of coherence γ of the two beams [14] depends on the difference Δl of the optical path lengths of the two beams and on the coherence length l_c of the probe laser beam, which in our case is of the order of 10cm [HRP050 Thorlabs]. In our case, we have $\Delta l / l_c \sim 0$ within the experimental error and therefore $|\gamma| = (1- \Delta l / l_{c)} \sim 1$.The polarization of the probe beam and its incident angle have been adjusted to obtain a maximum diffraction efficiency [13] value $h_{max} = 50\%$, that is to say $R_{max} = 1$, when the pump beam is off.

The diffraction efficiency h of the azo-POLICRYPS grating is driven by an external pump source (green diode laser). In the guest-host system of the light responsive NLC, the optically induced trans-cis transformation of the azobenzene derivative (guest) locally disrupts the nematic order, and induces an isothermic Nematic to Isotropic phase transition. As a consequence a change in the refractive index of the NLC host material takes places: the index contrast vanishes and the structure becomes transparent to the impinging probe light. Therefore, by switching On the external pump source ($P_{pump} = 48$ mW/cm^2) as reported in Fig. 3b (red curve) and keeping switched On the intensity of the probe red beam ($P_{probe} =$ 0.55W/cm^2), the intensity contrast of the interference pattern is strongly attenuated. The behaviour of V versus fine variations of P_{pump} is reported in Fig. 4. The curve can be explained by considering that the rate of the trans-cis isomerization process depends on the number of excited molecules; therefore, the rate of concentration of photoisomerized azo-LC molecules is proportional to the pump power density. This phenomenon directly affects R and therefore V (equation 2), which varies from 0.94 to 0.2.

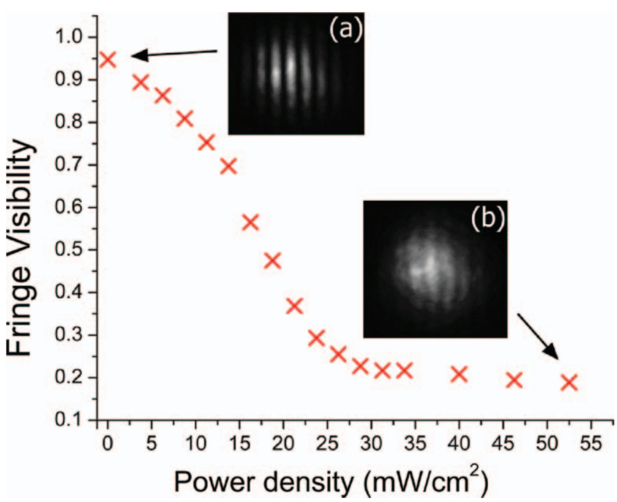

Figure 4. Fringe visibility versus the pump power density. Interference pattern acquired with a CCD camera is reported for V = 0.94 (**a**) and V = 0.2 (**b**). Experimental errors are the order of dot and cross dimensions.

Conclusions

We have reported on the realization of a light responsive optical beam splitter, which exploits the capability of an azo-POLICRYPS to be used as optically controllable diffractive element. The splitting ration can be controlled between 0.94 and 0.2, thanks to the high quality of the periodic structure containing a photosensitivity azo-NLC. The device can be easily integrated in an optical holographic setup.

Acknowledgements

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