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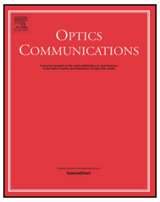

Dynamical thermo-optical switching based on nematic liquid crystals doped with push–pull azobenzene dyes

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ABSTRACT

Thermo-optical properties of push–pull azobenzene dyes doped nematic liquid crystals was investigated and experimentally demonstrated. The dynamical variations of transmission upon a CW Nd:YAG laser exposure at room temperature were determined by laser intensity, azobenzene dye concentration and sample temperature. Transmission behaviors at different temperatures were distinct, which resulted from oscillation transmittance performance of nematic liquid crystals with temperature variation and photoisomerization process of azobenzene dye. Our experimental results demonstrated that the dynamical thermo-optical change in azobenzene dye doped nematic liquid crystals could be a promising candidate for thermo-optical controller.

1. Introduction

Photosensitive liquid crystals are promising materials that can combine a high refractive index modulation, typical of liquid crystals, with high photosensitivity, due to the presence of photochromic molecules such as azobenzene and derivatives, which could achieve dramatic change in a controllable way by external stimuli, such as temperature, light, electric or magnetic field [1–4]. As one of photosensitive liquid crystals, azobenzene dye doped nematic liquid crystals have attracted much attention for their versatile applications in holography display, optical storage, optical limiting and nonlinear optical devices [5–9]. Nematic liquid crystals is a kind of thermotropic liquid crystals, whose refractive indices are strongly depend on the temperature of the sample. On the other hand, the reversible photoisomerization of azobenzene dye molecules exert intermolecular torques to align liquid crystals perpendicular to the polarization of incident light [10–13]. Therefore, the orientational order and subsequently the variation of refractive index in this material for the incident beam can be controlled by temperature and optical field [14,15]. Disperse Red 1 (DR1), a kind of push–pull azobenzene dye doped liquid crystals are regarded as one of the most promising materials for its application in dynamic holographic display because of its fast response time of few milliseconds and its elimination of external electric field [6,7]. However, the thermo-optical effect of this material is blurred, which is not beneficial to the development and practical application. It is necessary to research the thermo-optical properties in DR1 doped liquid crystals. Pump–probe measurement is an efficient method to investigate the photochemical processes in azo dye doped nematic liquid crystals by monitoring the change in optical transmittance of the sample [8,16,17]. In this paper, we report thermo-optical characteristics of azo dye doped nematic liquid crystals with the variation of laser intensity, azo dye concentration and temperature. The photoinduced transmitted responses of the sample at different temperature could be dynamically modulated, which shows the potential application in dynamical thermo-optical controller.

2. Experiments

The schematic of the proposed dynamical thermo-optical controller is presented in Fig. 1. A continuous light wave from a He–Ne laser ($\lambda = 632.8$ nm) was used to probe the transmission of the sample. The sample was placed between two crossed polarizers with the rubbing direction set at 45° to them. The transmitted intensities were simultaneously detected by a photodetector and recorded by a digitizing storage oscilloscope (Tektronix DPO2014). The heating rate of the sample was precisely controlled at 0.2 °C/s by a temperature controller (HCS302, Instec Co.). The sample was pumped by a s-polarized CW Nd:YAG laser ($\lambda = 532$ nm) with the diameter of 2 mm pass through a chopper.

The sample used were pentylcyanobiphenyl (5CB) doped with traces of a kind of push–pull azobenzene dye Disperse Red 1 (DR1). The homogeneous mixture was injected into an empty cell by capillary. The sample was sandwiched by two indium-tin oxides (ITO) glass substrates (20 mm × 10 mm) with 50 μm thick spacers in between, and the two ITO glass substrates were precoated with polyvinyl alcohol (PVA) and

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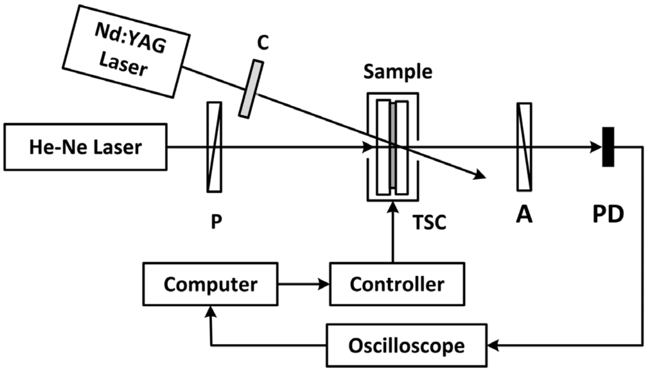

Fig. 1. Schematic diagram of the experimental setup; C: chopper, P: polarizer, TSC: temperature-stabilized optical chamber, A: analyzer, PD: photodetector.

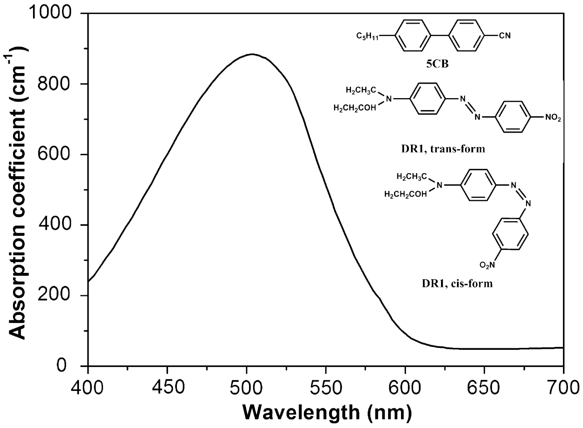

Fig. 2. Absorption spectrum of nematic liquid crystals doped with 1 wt. % DR1. Inset: chemical structures of the compounds.

rubbed in the same direction to obtain homogeneous alignment, which was confirmed using polarizing microscope. The absorption spectrum of the sample is shown in Fig. 2. The sample has a strong absorption maximum near 510 nm that is responsible for the $n - \pi^*$ electronic transition of trans isomer of DR1 molecule [18]. The result of differential scanning calorimetry (DSC) showed that the clearing temperature of the sample was 35.08 °C near the one of 5CB (35.5 °C).

3. Results and discussion

In Fig. 1, the transmittance change of He–Ne laser is associated with the variation of light polarization for the sample placed between crossed polarizers in response to CW Nd:YAG laser exposure. Although there is a photothermal effect resulted from the sample absorption at 532 nm, this effect is isotropic and cannot lead to the transmittance change of He–Ne laser [19]. Therefore, any changes in transmittance in response to the trans–cis photoisomerization of azo dye molecules in the sample could be measured by exposing the sample to pumping light. Fig. 3 presents the photo-optical behavior of DR1 doped liquid crystals at room temperature (27 °C). In Fig. 3(a), the decreases in transmittance increased by increasing the intensity of pump light. With the same pump light intensity (260 mW/cm^2), the decrease in transmittance increased with the azo dye concentration, shown in Fig. 3(b). The photo-optical behavior in Fig. 3 shows that azo dye doped nematic liquid crystals is an excellent photocontrollable materials. The number of trans–cis azo dye molecules upon pump light exposure determines the perturbation degree of liquid crystals aligned by rubbed surfaces in the cell.

Based on the performance of nematic liquid crystals, we detected the variation of transmittance signal at different temperature, as shown in Fig. 4. The transmittance decreases at 27 °C when the sample is irradiated by pump light, however, the transmittance increases at 33 °C. Otherwise, we noticed the transmittance at 27 °C and 33 °C is different without pump light irradiation. That is a particular phenomenon.

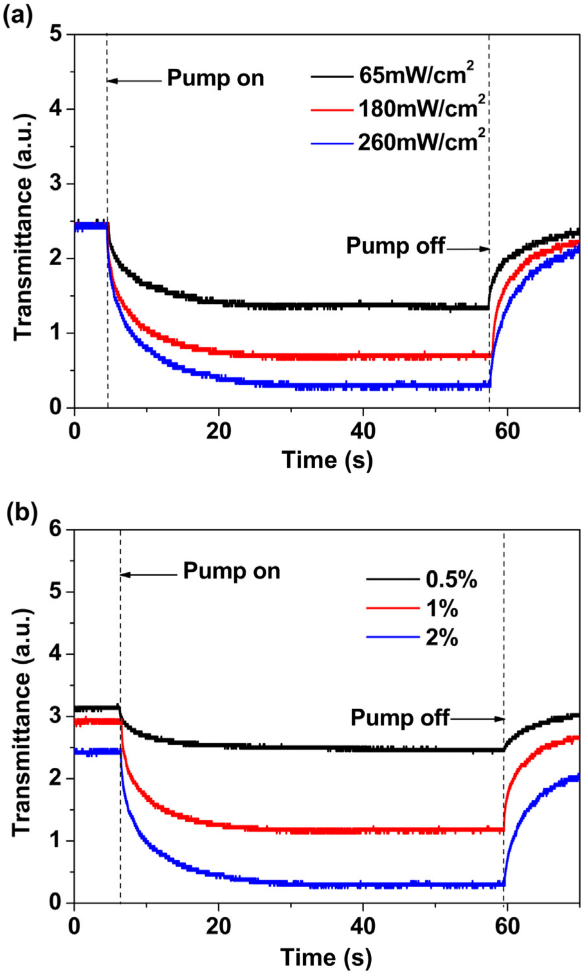

Fig. 3. Change in transmittance vs time for (a) a mixture containing 2% of azo dye exposed to different Nd: YAG laser intensities; (b) three mixtures containing different azo dye concentrations (0.5%, 1%, 2%) exposed to Nd: YAG laser (260 mW/cm^2).

In order to understand the photoinduced behavior of the sample with temperature variation, the transmittance of the sample between crossed polarizers with increasing temperature was detected. The sample was heated for 80 s from 27 °C to 42 °C. From the result shown in Fig. 5, an oscillation transmission of the system was observed during the temperature variation. Tabiryan et al. reported this oscillation transmission phenomenon was associated with the accumulation of cis isomers of azo molecules at the heating process results in decreasing order parameter [20]. However, we observed the similar oscillation transmission in pure liquid crystal between crossed polarizers with increasing temperature. For the oscillation transmission, Pieranski et al. and Olyaeefar et al. observed similar behavior in pure liquid crystals under magnetic field and applied voltage, respectively [21,22]. Liquid crystal molecules have consumed magnetic or electrical energy to rotate and result in the reorientation of liquid crystals. However, the explanation above for this oscillation phenomenon is blurry. In our experiment, azo dye doped liquid crystals were injected in the homogeneous alignment cell. The optical axis of the sample makes an angle of 45° with respect to the polarizer axis. Liquid crystal molecules swing in the rubbing direction as the sample temperature increases, which induce