Diffraction efficiency enhancement of transient holographic gratings in nematic liquid crystals doped with Disperse Red 1

Hongjing LI[1, a], Changshun WANG[1, b]*

[1] State Key Lab of Advanced Optical Communication Systems and Networks,
Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, 200240, China

[a]email: lhjnet2012@sjtu.edu.cn, [b]email: cswang@sjtu.edu.cn

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Abstract. The diffraction properties of transient holographic gratings recorded by two 532 nm laser beams were investigated in nematic liquid crystals doped with Disperse Red 1. A nearly 30-fold enhancement of the first-order diffraction efficiency as a function of heating time was obtained when the sample temperature was close to the clearing point in the nematic phase. A peak shift of diffraction efficiency with the increase of recording light intensity was observed, which was attributed to laser induced photochemical nematic-isotropic phase transition.

Introduction

Azo dye doped nematic liquid crystals have been actively investigated due to their promising applications in display technology, optical storage, optical limiting and nonlinear optical devices [1-4]. Disperse Red 1 (DR1) doped nematic liquid crystals have been regarded as one of the most potential materials for application in transient holographic display because of the fast response time of several milliseconds and no need for external electric field [5-7]. However, the lower diffraction efficiency is not beneficial to the development and its practical application. It is well known that azo dye molecules can undergo *trans-cis-trans* photoisomerization process after absorbing suitable optical energy, which exerts intermolecular torque to align liquid crystals perpendicular to the polarization of incident light [8-11]. The reorientation of nematic liquid crystals caused by photoisomerization process of azo dye molecules plays an important role in the refractive index modulation of holographic grating. On the other hand, the refractive indices of nematic liquid crystals are closely related with temperature especially near the phase transition temperature.

In this paper, we report the temperature-dependent diffraction efficiency of photo-induced grating in DR1 doped liquid crystals under continuous wave (CW) 532 nm laser interference. The first-order diffraction signal intensity has an obvious enhancement near the nematic-isotropic phase transition temperature with homogeneous alignment. A peak shift of diffraction efficiency toward lower temperature can be observed with the increase of recording light intensity.

Experiments

The material used in the current work was a mixture of a nematic liquid crystal (5CB) doped with DR1 molecules. The homogenous mixture was injected into an empty cell by capillary. The sample was sandwiched by two indium-tin oxides (ITO) glass substrates to maintain the cell gap with 50 μm thick spacers, and the two ITO glass substrates were precoated with polyvinyl alcohol (PVA) and rubbed in the same direction to obtain homogeneous alignment, which was confirmed using polarizing microscope. The sample has a strong absorption maximum in the visible spectral range near 510 nm that corresponds to the n-π^* electronic transition of *trans* isomer of DR1 molecule [19]. The differential scanning calorimetry (DSC) data showed that the sample's clearing temperature was 35.08 °C.

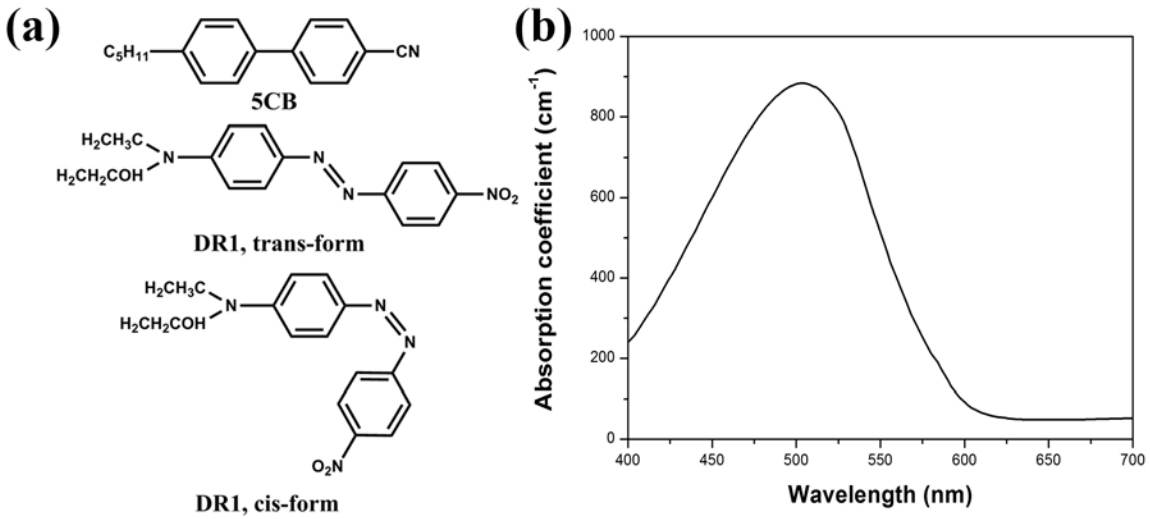

Figure 1. (a) Chemical structures of 5CB and DR1; (b) absorption spectra of nematic liquid crystals doped with 1 wt. % DR1.

Figure 2 illustrates the experimental setup for investigating the temperature-dependent diffraction of photoinduced grating. Two s-polarized recording beams with the same diameter of 2 mm were both derived from a CW Nd:YAG laser ($\lambda = 532$ nm), intersected at an angle of $\theta \sim 3°$ in the sample. These two beams had the equal-intensities and were overlapped on the sample. The sample was placed in a temperature-controlled chamber with glass window, to enable the recording beams transmitted. The heating rate of the chamber was precisely controlled at 0.5 °C/s by a temperature controller (HCS302, Instec Co.). The intensities of the first-order diffraction with temperature variation were simultaneously detected by a photodetector and recorded by a digitizing storage oscilloscope (Tektronix DPO2014).

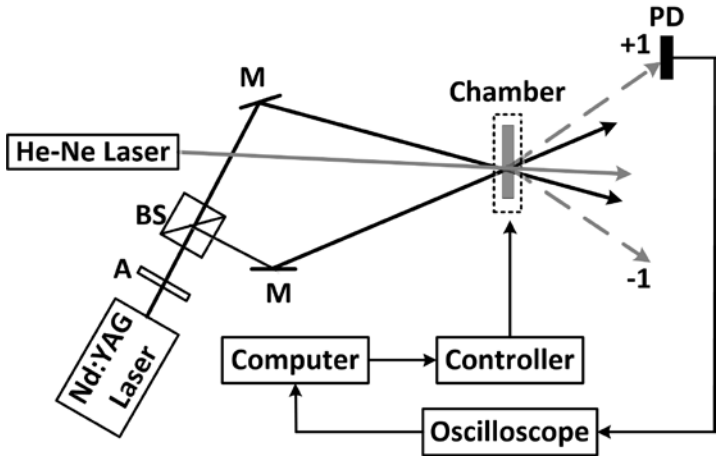

Fig. 2. Schematic diagram of the experimental setup; A: attenuator, BS: beamsplitter, M: mirror, PD: photodetector.

Results and discussion

Figure 3 shows the first-order diffraction efficiencies as a function of heating time with different recording light intensities. The chamber was heated for 36 s at 0.5 °C intervals from 27 °C to 45 °C. Different recording light intensities, 65 mW/cm^2, 128 mW/cm^2, 192 mW/cm^2, 260 mW/cm^2, were used to investigate the diffraction properties. The dynamic responses of diffraction efficiency to different light intensities showed similar behaviors. For the recording intensity of 260 mW/cm^2, there is a nearly 30-fold enhancement of the first-order diffraction efficiency was obtained when the chamber temperature was heated up to 34.8 °C. At the same time, second-, third-order diffractions were gradually generated. The typical self-diffraction pattern with the recording intensities of 260 mW/cm^2 at 34.8 °C is shown in Fig. 4. As the chamber temperature exceeded 34.8 °C, the diffraction efficiency decreased sharply to a stable value, which was smaller than that at room

temperature.

In order to study the temperature dependence of the first-order diffraction efficiency, we found the minimum transmitted zero-order beam powers are happened when the diffraction efficiency peaks can be observed. It is well known that the transmitted power is the maximum in the isotropic phase where light scattering is minimal. One can deduce the diffraction efficiency peaks are happened near the clearing point in nematic phase. The diffraction efficiency enhancement occurring in the sample near the phase transition is a critical effect, which is accompanied by strong fluctuation of density and order parameter that could lead to large refractive index variation of the sample and enhance the diffraction efficiency of holographic gratings in DR1 doped liquid crystals.

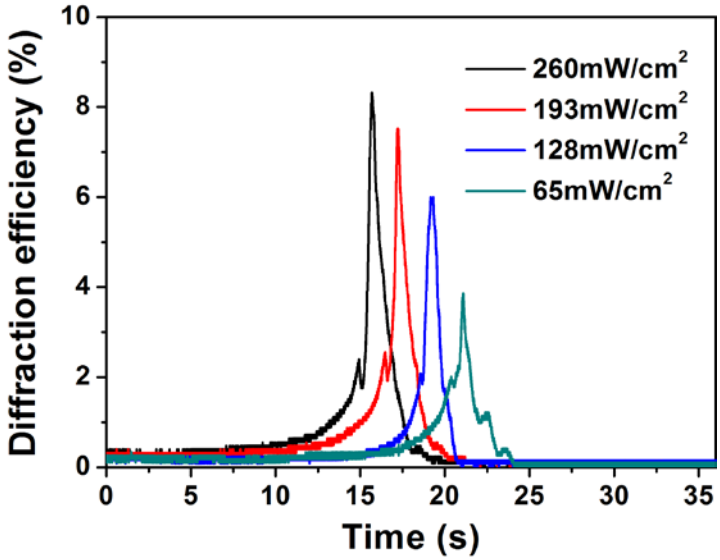

Fig. 3. First-order diffraction efficiencies as function of heating time with different recording light intensities.

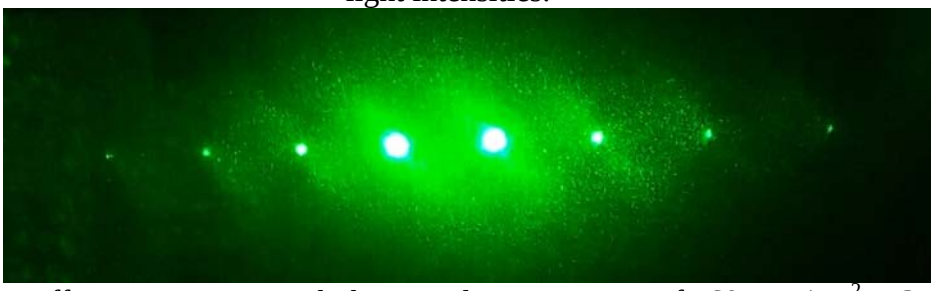

Fig. 4. Diffraction patterns with the recording intensities of 260 mW/cm^2 at 34.8 °C.

There is a peak shift of diffraction intensity toward lower temperature with the increase of recording light intensity in Fig. 3. The temperature variation of the peak diffraction efficiency for 65 mW/cm^2 and 260 mW/cm^2 is about 2.5 °C, indicating that the increasing recording light intensity might result in the sample temperature variation. However, the sample temperature was precisely controlled by the temperature controller. In the experiment, when the recording light intensity is increased, the fraction of *cis* states of azo dye molecules increases. The reaction of azo dye molecules reduces the order parameter of the nematic phase. The photochemical disordering is increased at elevated temperatures below the clearing temperature of liquid crystal. This effect is similar to the thermal effect.

Conclusion

We have investigated the diffraction properties of holographic gratings in DR1 doped liquid crystals with homogeneous alignment using two 532 nm laser beams interference. The first-order diffraction efficiency as a function of heating time in our experiments can reach nearly 30-fold enhancement when the sample temperature is close to phase transition temperature. The peak shift of diffraction efficiency towards the lower temperature was observed with the increase of recording light intensity, which was attributed to laser induced photochemical disordering.

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