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Biphotonic effect of azo-dye-doped liquid crystals using the sequential Z-scan technique

Hui-Chi Lin [a], Jyun-Ruei Wang [a], Wei-Yen Wu [a], Andy Ying-Guey Fuh [b,*]

[a] *Department of Physics, National Cheng Kung University, Tainan 701, Taiwan, ROC*

[b] *Department of Physics, and Institute of Electro-Optical Science and Engineering, National Cheng Kung University, Tainan 701, Taiwan, ROC*

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Abstract

This study investigates the biphotonic effect of azo-dye-doped liquid crystals (ADDLCs) using the sequential Z-scan technique. A spot on the sample is illuminated by a green light for 6 s, and then the same spot is illuminated simultaneously with a red light and a green light for 6 s. Measurements are made by scanning the sample near the beam waist of the green laser. The results show that the biphotonic effect is important to the nonlinear coefficient of the sample. The variations of the optical Kerr constant with intensity of red light are measured. Measurement results demonstrate that the molecular reorientation of liquid crystals induced by the photoisomerization of the azo dyes dominates at low red-light intensity, but the thermal effect compensates for the molecular reorientational nonlinearity of the sample at high red-light intensity.

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Keywords: Liquid crystals; Z-Scan; Azo-dye

1. Introduction

New materials with large optical nonlinear coefficients have recently received increased attention owing to their wide range of photonic applications. Nematic liquid crystals (NLCs) exhibit large nonlinearities, a high dielectric constant, conductive and optical anisotropies. NLCs have been used in display, image processing and optical switching [1,2]. Recently, dye-doped liquid crystals (DDLCs) have been extensively studied because of the increased nonlinearity of the host LC materials. One important cause of such high nonlinearity is the photo-induced reorientation of trans-form molecules.

The Z-scan technique is a simple, but highly effective means of measuring nonlinear coefficients [3,4]. Z-Scan has been used to measure the nonlinearities of nematic liquid crystals [5–8] and DDLCs [9–11]. Kosa et al. observed that the dye-induced enhancement of molecular reorientation in liquid crystals that were doped with anthraquinone dyes depends on the wavelength of the pump beam [9]. Esteves et al. found that the reorientation of LCs that are doped with anthraquinone dyes is a function of temperature, and is affected by the intensity of the optical field and by their nonlinear absorption coefficients [10]. The authors have described the thermal effect in azo-dye (DR1)-doped liquid crystal films using the biphotonic Z-scan technique [11]. Experimentally, a linearly polarized red light was focused in the z-direction onto the sample. A linearly polarized homogeneous green light was simultaneously used to illuminate the same spot of the sample illuminated. Experimental results demonstrate that the green light increases the sample temperature, increasing of the temperature gradient on the irradiated spot, and changing the nonlinearity of the sample [11]. In

* Corresponding author. Tel.: +886 62757575x65228; fax: +886 2747995.

E-mail address: andyfuh@mail.ncku.edu.tw (A.Ying-Guey Fuh).

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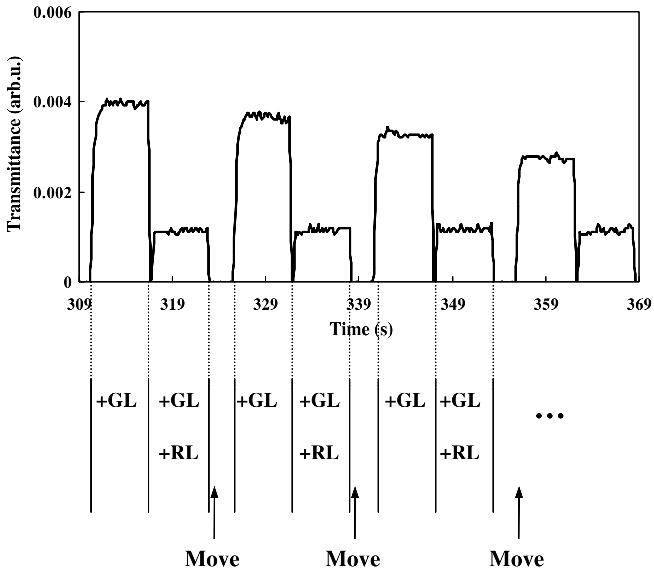

Fig. 1. Sequential Z-scan measurements using the setup presented in Fig. 2 made with detector 2. The sample is illuminated by green light from a DPSS laser (GL) only for 6 s initially, and then simultaneously illuminated by green light and red light (RL) from a diode laser for 6 s for a given sample location. Afterwards, the sample is moved through $\sim$1 mm along the z-axis to the next location, and the measurements are repeated for 61 positions around the beam waist of the green laser.

the present biphotonic experiment, the roles of the green and red lights are reversed: a linearly polarized green light is focused in the z-direction onto the sample of azo-dye (D2)-doped liquid crystal, which is scanned near the beam waist of the green laser. Sequentially, the sample is illuminated by a focused green laser only, and then simultaneously with a linearly polarized homogeneous red light (Fig. 1), in the "sequential Z-scan technique". The measurements reveal that the molecular reorientation of the liquid crystals that is induced by the photoisomerization of the azo dyes dominates at low red-light intensity, but the thermal effect compensates for the molecular reorientational nonlinearity of the sample at high red-light intensity.

2. Experimental method

The nematic liquid crystal and azo dye that are used in this experiment are E7 (from Merck) and D2 (from Sigma–Aldrich), respectively. The E7:D2 mixing ratio is 99:1 wt%. An empty cell is fabricated using two indium–tin–oxide (ITO)-coated glass plates, which are treated with polyvinyl alcohol (PVA) and rubbed to promote homogeneous alignment. The cell is 15 μm thick. The homogeneous mixture is then injected into an empty cell to from a homogeneously aligned azo-dye-doped liquid crystal film. The homogeneous alignment is verified using a conoscope.

Fig. 2 presents the sequential Z-scan setup. A linearly polarized CW diode pumped solid state (DPSS) laser (which emits green light at $\lambda = 532$ nm with a power $\sim$0.7 mW) is incident in the z-direction onto the sample. It is focused by a lens with a focal length of 5 cm. The sample is moved from a position $\sim$30 mm behind the beam waist (focal point) of the DPSS laser ($+z$ in Figs. 3 and 4) along the z-axis to $\sim$30 mm in front of the waist point (negative z in Figs. 3 and 4). A step-movement is $\sim$1 mm. When required, another linearly polarized CW diode laser, which emits red light at $\lambda = 670$ nm, is applied to the sample from its rear side at an angle of incidence of $\sim$25°. The diode laser has a beam radius $\sim$1.38 mm, which is much larger than that of the DPSS laser over the scanning range (<0.89 mm). Notably, the red diode laser and the sample are arranged on a stage (the square box in Fig. 2) such that the laser can be moved as the sample is z-scanned by the green laser beam. This setup ensures that the red-light illuminates the same spot of the sample during scanning. Experimentally, the incident angle of the diode laser in the setup of Fig. 2 should be as small as possible, so that the two beam overlap fully in the sample. Since the arrangement of the diode laser and the sample on a stage limits the incident angle of the diode laser onto the sample. The minimum angle that we can have is $\sim$25°. Under this condition, the beam center of the diode laser through the sample (15 μm thick) shifts a distance along x-axis (see Fig. 2) of $\Delta x \sim 7$ μm. Since the diode laser is approximate

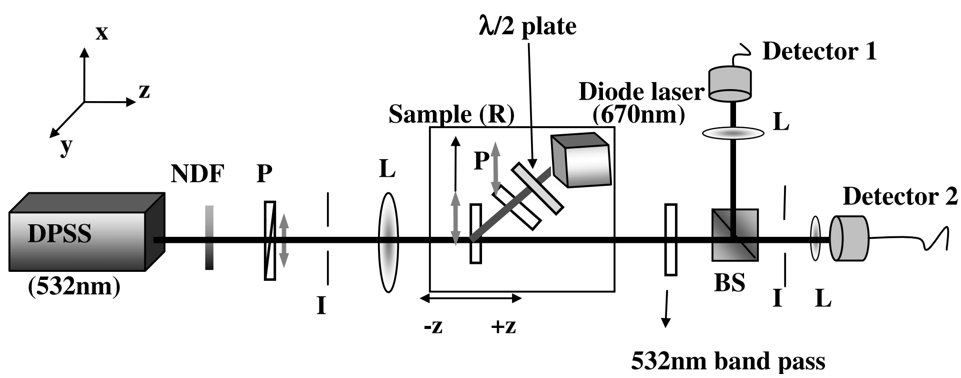

Fig. 2. Experimental setup; DPSS: diode pumped solid state laser, NDF: neutral density filter, I: iris, L: lens, P: polarizer, BS: beam splitter. The diode laser, $\lambda/2$ plate, polarizer and the sample are arranged on the same stage, delineated by a square.