



All optical switching in azo-polymer planar waveguide

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ABSTRACT

In this paper all optical switching in planar methyl red doped poly (methyl methacrylate) (MR/PMMA) waveguide and the effects of different parameters on this process are presented. Switching was achieved by a 488 nm Ar ion laser (pump beam) on a 633 nm He–Ne laser (probe beam) when passed through the waveguide. The effect of temperature and pump intensity, polarization and chopping frequency on switching is investigated. The switching process is attributed to trans–cis–trans photoisomerization of azo dyes in the polymer host. By studying the absorption spectrum of the sample, it is shown that both pump and probe laser beams are effective on the switching process.

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1. Introduction

Different properties of light such as intensity, polarization, and wavelength may be applied for information processing and photonic switching devices [1]. Nonlinear optical effects in dye doped polymer systems offer many possibilities for the production of versatile and highly effective optical and opto–electronical devices [2]. Azobenzene derivatives with two phenyl ring separated by an azo ($-N=N-$) bond with a possibility of switching the configuration of this bond in a controlled fashion [3–7] are attractive for second and third order nonlinear optical effects and polarized-light induced anisotropy [8]. This class of materials offers promising applications in optical processing, switching, modulating, data storage, display and telecommunications due to their response to polarized light [9–23]. Irradiating the medium with linearly polarized light may induce trans–cis photoisomerization in azobenzene which eventually ends with molecular orientation in the direction perpendicular to the incident beam polarization. This alignment results in some order of birefringence and dichroism in the medium. Cis–trans isomerization can occur thermally and photochemically [13], and can be observed as a change in the absorption spectrum of the sample [24–29]. Fig. 1 shows trans–cis–trans isomerization.

The control over the direction and the magnitude of the induced anisotropy is important for different applications [30]. In photoinduced and photoassisted poling [31], isomerization is used to help the alignment and to obtain nonlinear effects. Upon isomerization, there can be significant changes to the optical, geometric, mechanical and chemical properties of azobenzene molecules [5]. The first report on this application was published in 1992 by Sekkat and Dumont. The value of

the anisotropy achieved in different azo containing polymers depends on the concentration and type of the azo chromophores, and the polymer structure that influences the mobility of the azobenzenes and the rate constant of the isomerization process; it also depends on the intensity of the exciting light and temperature [32].

Azo dye polymer waveguides can be used to change the guided light intensity due to, the change in birefringence after the photoisomerization process in the dye molecules which is sufficient for opto–optical switching. This photoisomerization is rapid, reversible, and of high quantum yield [5]. The time constant of this effect can be as low as 0.001(s) [33]. In 1983–1984 Todorov, Nikolova, and Tomova reported the first optical application of photoinduced dichroism and birefringence in holography. Luckemeyer and Franke reported the possibility of obtaining opto–optical switching using trans–cis isomerization of azo dyes in PMMA waveguides and Tomov and Voitenkov reported all optical modulation in the azo dye polymer waveguide.

In this paper we present the detailed study of the switching of the guided laser light. The effect of the temperature and other parameters on the laser induced anisotropy and the resultant switching property is reported. Also by studying the absorption spectrum of the sample it is shown that both lasers are effective on the switching process.

2. Experimental

2.1. Sample preparation

Poly (methyl methacrylate) (PMMA) (from Aldrich) and Methyl Red (MR) (from LOBA) at 0.2 weight percent were dissolved in dichloromethane (DCM). The mixture was then filtered to make a clear solution. A standard microscope slide was used as a substrate after precise cleaning. A thin film of MR/PMMA was made by dip coating from the solution. The sample was dried for 8 h at 60 °C. The thickness of the sample was around

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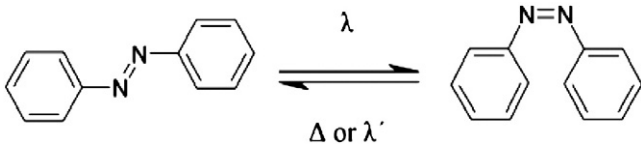


Fig. 1. Trans–cis–trans photoisomerization in azo dyes.

5 μm as measured by Dectak 8000. Fig. 2 shows the absorption spectrum (Ocean Optics HR4000 & USB2000 spectrophotometer) of the prepared sample.

2.2. Experimental set up

Fig. 3 shows the experimental set up for all optical switching experiment on the MR/PMMA planar waveguide [34–36]. The structure of the waveguide was: glass substrate/PVA as the clad layer/PMMA doped with MR as the core layer/PVA as the top clad layer. The refractive index of the core was about 1.52 and that of clad was about 1.48. The thickness of the core layer was about 2 μm and that of the clad layers was about 1 μm . Argon ion laser at 488 nm (1.5 mm beam waist) is used to induce the changes in the sample and He–Ne laser light is used to travel across the waveguide in order to probe the photoinduced changes. In order to achieve waveguiding, prism coupling is used [37–42]. The He–Ne laser was polarized at 45° relative to TE polarization direction then focused by a lens ($f=5$ cm) onto the sample via the first prism. The prisms were a right angle with a flat top and a refractive index of 1.78. The distance between the prisms was about 5 mm. The outgoing light from the second prism was passed through a polarizer orthogonal to the first one and then focused on the detector. The intensities mentioned in the diagram refer to the output probe intensity detected by the detector. The waveguide was multimode due to the thickness of the film; therefore m-lines (3 TE and 3TM) were expectable. These number of m-lines was in agreement with the theoretical predictions according to the refractive index and the thickness of the layers. The most intense m-line was separated by a diaphragm for detection.

Ar ion laser beam was focused by a lens ($f=4$ cm) then passed through a chopper and after re-collimating with another lens (6 cm), the beam was passed through a polarizer to determine the polarization of the switching laser light for illuminating the sample.

3. Results and discussions

All optical switching in these experiments happens due to the refractive index alteration of the sample during molecular alignment due to cis–trans photoisomerization by absorbing polarized pump laser beam. In this case, the situation is similar to what happens in refractive index alteration by the intensity dependent refractive index which leads

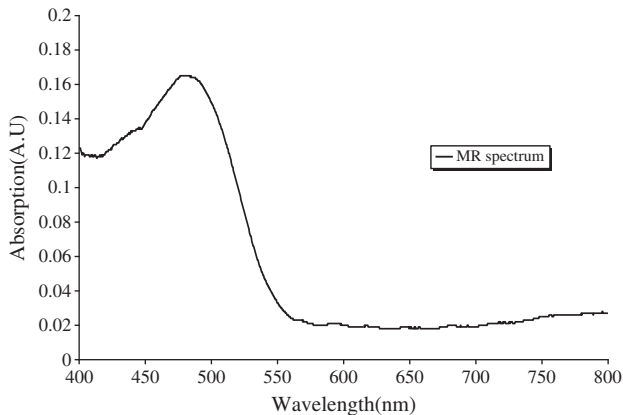


Fig. 2. Absorption spectrum of the MR/PMMA film.

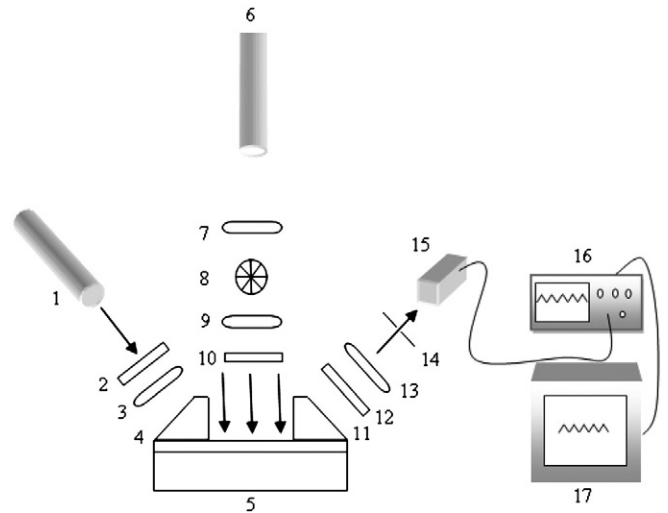


Fig. 3. Experimental set up for all optical switching: 1–He–Ne laser, 2–Polarizer, 3–Lens, 4–Prism, 5–Waveguide, 6–Ar ion laser, 7–Lens, 8–Chopper, 9–Lens, 10–Polarizer, 11–Prism, 12–Polarizer, 13–Lens, 14–Slit, 15–Detector, 16–Oscilloscope and 17–PC.

to mode coupling between TE and TM modes, driven by the perturbation from the pump beam [43]. Here, the mechanism of the refractive index alteration is the resonant interaction of the pump beam with the sample and therefore happens at much lower intensities of the pump beam and off course at a lower speed, as compared with other non-resonant mechanisms. At first the behavior of the detected probe intensity during switching the Ar ion laser on and off was studied. Fig. 4 shows the result for applying linearly polarized pump beam. After switching the pump on, a decrease in the signal can be seen. Then it was switched off which followed by a slower increase in the signal. The decrease in the detected probe intensity is a measure of the induced anisotropy in the waveguide. Therefore, illuminating the sample with pump beam must induce some sort of alignment in the molecules. Molecular orientation in this class of materials after absorbing laser light may be attributed to trans–cis–trans isomerization. The isomerization process is induced by the electronic excitation of an electron from either the highest occupied non bonded orbital (n) or the highest occupied π orbital to the lowest unoccupied π^* orbital (π^*). Since the trans ground state lies lower in energy than that of the cis isomer, any cis species created, returns to trans via the photochemical and/or thermal process [32]. Depending on the angle between the direction of the electric field of the pump beam and the direction of the dipole of the chromophore, the molecules absorb the pump beam. It results in these molecular orientations perpendicular to the direction of the light electric field. Illuminating the sample, may be considered as burning a hole in the angular distribution of the trans molecules (Angular Hole Burning) [44,45]. More specifically the

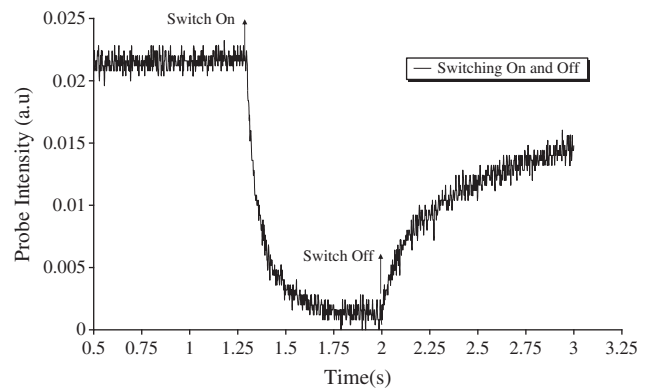


Fig. 4. Detected probe intensity during switching the Ar ion laser on and off for parallel polarization and 30 mw pump power.

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