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Improvement of all-optical switching performance based on azo dye-doped polymer film using two cross-linearly polarized pump beams

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ABSTRACT

We propose a method for improving the characteristics of all-optical switching based on azo dye-doped polymers. Using alternately two cross-linearly polarized beams (532 nm, continuous light wave (CW)) to pump azo dye–ethyl red (ER) doped polymer methyl methacrylate (PMMA) film, the modulation depth of the all-optical switching reached 96% at the pump powers of 4.8 mW and 1.6 mW and the modulation frequency of 1000 Hz. For comparison, we used respectively the single linearly polarized beam (4.8 mW) and the alternately linear–circular polarized beams (4.8 mW and 1.6 mW) to pump the film at the modulation frequency of 1000 Hz, the obtained modulation depths of the all-optical switching were 36% and 45.8%, respectively. Furthermore, the experimental measurement and analysis showed that the turn off speed of the all-optical switching could be obviously increased by use of our pump method.

1. Introduction

All-optical switching based on azo dye-doped polymers has become a study hotspot of optical switching at present because it offers possibilities for the applications in optical communications, optical information processing, and other optoelectronic devices [1–5]. Currently, an urgent problem of all-optical switching based on polymers needs to solve is, how to improve pump-probe method of the all-optical switching to achieve a fast switching response speed and a large modulation depth at low pump power, and there have been a few reports of this. Traditionally, a single pump beam is used in the all-optical switching and the switching signal has commonly larger background. Two pump beams (a linearly and a circularly polarized) were used for increasing the switching modulation depth [6,7]. In this study we present the all-optical switching pumped alternately with the two cross-linearly polarized beams, and the experimental results of the three different pump methods were compared, in which the single linearly polarized beam, the alternately linear–circular polarized beams and the two alternately cross-linearly polarized beams were used as pump beams, respectively. The new pump method exhibits a noticeable improvement of the all-optical switching characteristics at low pump power and high modulation frequency.

2. Samples and experimental setup

The azo dye–ethyl red (ER) doped methyl methacrylate (PMMA) polymer film was prepared by the sol-gel process and the cyclohexanone was used as solvent, and the weight ratio of ER dye and PMMA was 10 wt%. The thickness of the films was about 70 μm, the absorption peak of the sample was at 540 nm. The preparation method was given in our previous work in detail [8].

The experimental setup of the all-optical switching pumped by the two cross-linearly polarized beams is shown in Fig. 1. A semiconductor laser (532 nm, CW) was used as a pump beam and divided into two beams by a beam-splitter BS_2. One of the two beams used as a linearly polarized pump beam B_1 was modulated with a chopper C and passed through polarizer P_3, reflected by a mirror M_2 and a beam-splitter BS_1, and then illuminated on the film sample. The other beam used as a linearly polarized pump beam B_2 was reflected by a mirror M_1, after passing through the chopper C and polarizer P_4, and then reflected by a mirror M_3 and illuminated on the film sample. One of the beams B_1 and B_2 passed C and the other was blocked by C at anytime, thus the two beams B_1 and B_2 were modulated with same frequency and had a phase difference of 180°. A He–Ne laser (632.8 nm, CW)

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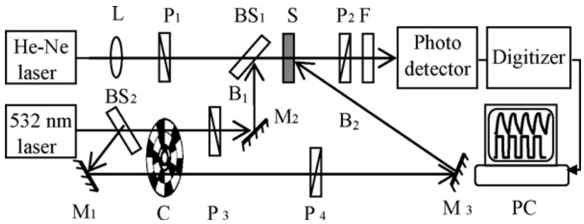

Fig. 1. Experimental setup of all-optical switch pumped by two cross-linearly polarized beams. P's: polarizer; M's: mirror; L: lens; S: sample; BS's: beam splitter; F: 632.8 nm filter; C: chopper; PC: computer.

was used as the probe beam passed through polarizer P_1 and the beam-splitter BS_1, then illuminated on the sample and transmitted the polarizer P_2. The filter F (632.8 nm) was used to stop the pump beam and transmitted the probe beam. The transmitted probe beam was detected by a silicon photocell and a pre-amplifier and then recorded automatically with a high-speed digitizer (Model NI5102) and a computer. The angle between the polarization directions of polarizer P_1 and P_3 was 45°. The polarization direction of the polarizer P_2 was perpendicular to that of polarizer P_1, and the polarization direction of P_3 was perpendicular to that of polarizer P_4, thus the polarized beams B_1 and B_2 were the two cross-linearly polarized beams. In addition, when blocking the beam B_2, the signal of the all-optical switching used a single linear polarized pump beam can be measured. In the experiment of the all-optical switching used alternately linear–circular polarized beams, a quarter wave plate was placed between the polarizer P_4 and M_3, the optical axis of the quarter wave plate was adjusted to be 45° with respect to the polarization direction of the polarizer P_4, thus the beam B_2 became a circularly polarized beam and was reflected by mirror M_3, then shot to the sample.

3. Results and discussions

For the film sample with doping concentration 10 wt% and at modulation frequency of 100 Hz and room temperature 25 °C, the all-optical switching characteristics are shown in Fig. 2. Fig. 2(a) shows the signal of all-optical switching pumped by the single linearly polarized pump beam (4.8 mW), Fig. 2(b) shows the signal of all-optical switching when the linear polarized beam (4.8 mW) was used as the pump beam and the circular polarized beam (1.6 mW) was used as the erased beam, Fig. 2(c) shows the signal of all-optical switching pumped by the two cross-linearly polarized beams B_1 (4.8 mW) and B_2 (1.6 mW), Fig. 2(d) and (e) express the signals of the chopped pump beams B_1 and B_2 as a functions of time, the modulation depths of switching M corresponding Fig. 2 (a), (b) and (c) were 36.7%, 57.3% and 98%, respectively, which were calculated by $M = I_p/I_m$, where I_p and I_m are the peak to peak and the maximum values of the intensity of the transmitted probe beam, respectively. When the modulation frequency f_m was increased to 1000 Hz and at the same pump powers mentioned in Fig. 2, the signals of all-optical switching are shown in Fig. 3(a), (b) and (c), and the corresponding modulation depths of the switching were 36%, 45.8% and 96%, respectively. The experimental results shown in Figs. 2 and 3 indicate that under higher modulation frequency and lower pump power, the low signal background and the large modulation depth of switching can be obtained by using alternately two cross-linearly polarized pump beams.

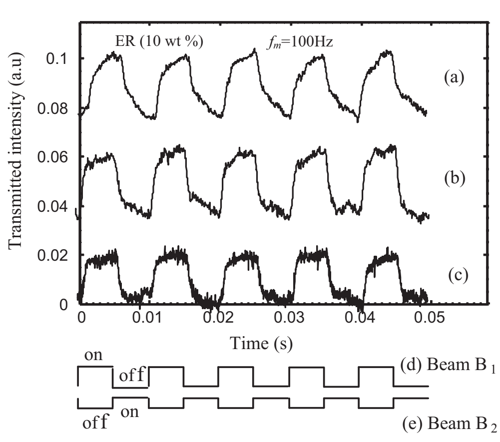

Fig. 2. The relative intensity of the transmitted probe as a function time under different pump beams: (a) single linearly polarized beam (4.8 mW), (b) linearly polarized beam (4.8 mW) and circularly polarized beam (1.6 mW), (c) two cross-linearly polarized beams (4.8 mW and 1.6 mW). Modulation frequency f_m = 100 Hz.

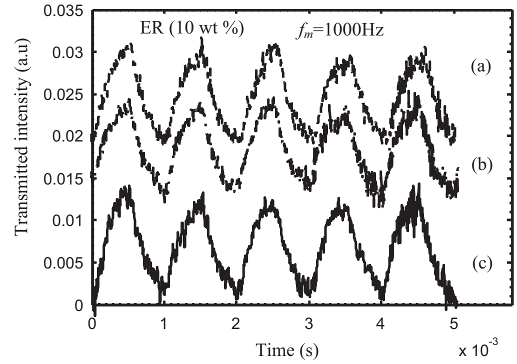

Fig. 3. The relative intensity of the transmitted probe as a function time under different pump beams: (a) single linearly polarized beam (4.8 mW), (b) linearly polarized beam (4.8 mW) and circularly polarized beam (1.6 mW), (c) two cross-linearly polarized beams (4.8 mW and 1.6 mW). Modulation frequency f_m = 1000 Hz.

In order to specify that using our pump method can significantly reduce the background signal, we performed the following experiments to observe the decay processes of the transmitted probe intensity by using the different exciting methods. The experimental setups were similar to that in Fig. 1 and but the chopper C was removed. In the following each experiment, the sample was first illuminated by the linearly polarized beam B_1 (4.8 mW) and then after the transmitted probe intensity *I* increased to the stable value, the beam B_1 was turned off and the beam B_2 (1.6 mW) was turned on to illuminate the sample. Fig. 4(a) shows the decay process of *I* after only using the beam B_1 to illuminate the sample. Fig. 4(b) shows the decay process of *I* after the B_1 was turned off and the circularly polarized beam B_2 was turned on. Fig. 4(c) shows the changed process of *I* after the B_1 was turned off and the cross-linearly polarized beam B_2 was turned on, which shows a rapid

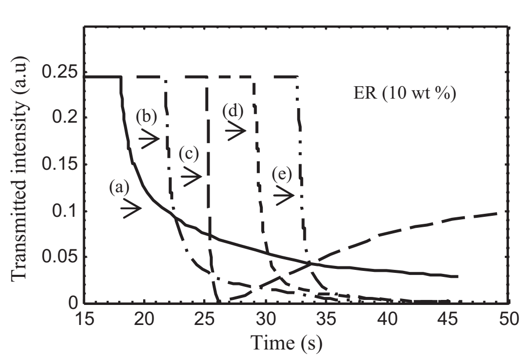

Fig. 4. The decay processes of transmitted intensity for the illuminations of the different beams B_2 after the linearly polarized beam B_1 illuminate the sample and the transmitted intensity reaches maximum value and then beam B_1 turn off.