

Optical Bistability of Spin Coated Poly(3-hexylthiophene)(P3HT)/PMMA Composite Thin Film

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In the present work, Poly(3-hexylthiophene)/Polymethylmethacrylate [P3HT/PMMA] composite thin film was prepared using spin coating method on the top of triangular prism as composing a prism coupling waveguide. The optical bistable characteristics of prism coupling waveguide comprising with P3HT/PMMA composite film was measured for different input laser power intensity using optical bistable measuring equipment. Also the effect of organic gas treatment on the optical bistable behavior of P3HT/PMMA quasi-waveguide has been investigated. The measured optical bistabilities have excellent stability and hysteresis characteristics. In the input laser power dependence of optical bistability, the on-off position shifts with the increase of input laser power intensity. A Nd:YAG laser with a wavelength of 1064 nm, a pulse width of 5 ns and a repetition frequency of 10 Hz was used for this measurement.

Key Words: Optical bistability, Polymer materials, P3HT/PMMA, Spin coating, Waveguide.

1. Introduction

Optical bistability in nonlinear periodic media is a powerful phenomenon which plays a crucial role in realizing the future all-optical technology. Optical bistability has been one of the continuously interesting subjects from the points of both physics and applications. In large capacity communication networks, optical-optical conversion devices are required in order to increase the information transmission speed. In the field of semiconductors, optical bistability has been extensively studied for preparing optical devices, such as optical switching, memory, modulation and logic elements. Bistability (or multistability) is a phenomenon in which the system exhibits two (or more) output intensities for the same input intensity. Optical bistability has been predicted and experimentally realized in various settings, including a Fabry-Perot resonator filled with a nonlinear material, layered periodic structures and nonlinear couplers with external feedback mechanisms.¹⁻⁴⁾ Winful et al. have demonstrated the optical bistability phenomena in the nonlinear distributed feedback structures.⁵⁾ Subsequently Hojoon et al. have compared the nonlinear switching performances between uniform and phase shifted Fiber Brag Grating (FBG). They showed that the optical bistability hysteresis loop exist for nonlinear switching curve of FBG in a certain range of input intensity and detuning.⁶⁾ Optical bistability in InSb and GaAs has been studied extensively, both theoretically and experimentally, and advances in the understanding of the underlying process that give rise to the large third-order nonlinearity in the semiconductors have been reported.^{7,8)} Optical bistability can be established in all-optical signal processing in large capacity optical transmission devices. However, the switching speed of an optical switch fabricated with inorganic semiconductor is on the order of nanosecond.

On the other hand, highly functionally organic materials have a π -electron conjugated systems like polymers, thus optical device fabricated from these materials are expected to have a switching speed on the one order of the femtosecond, and 1000 times higher than those of optical devices fabricated with inorganic materials. Therefore, organic and polymer systems are expected to be appropriate materials in this studies.⁹⁾

In the recent years, special attention was turned to the studies of optical bistability in thin films because of its potential applications in optical computing and integrated optics. The study of optical bistability and bistable devices is an important and interesting in nonlinear optics due to its many potential applications in various fields. In an optical system/structure, if the output fields were a nonlinearly dependent function with an oscillating from of the related physical parameter, it would exhibit optical bistable behavior in the presence of positive feedback under suitable conditions. Recently, the optical bistabilities of the optical devices (quasi-waveguide) composed of a prism and a dye/PMMA composite thin film mixed with dye molecules and PMMA were investigated.¹⁰⁾

Optical bistable behavior in a quasi-waveguide interferometer with third-order nonlinearity in the guiding film composed of soluble poly(diacetylene) (poly-4BCMU) was demonstrated. This device shows input-output behavior analogous to that of a nonlinear Fabry-Perot resonator. Also, in the ultra-fast optical bistable behavior of quasi-waveguides and waveguides prepared with vanadyl phthalocyanine doped polymer films was observed. After organic gas treatment for 25 h in 1,2-dichloroethane vapor, the third-order nonlinear susceptibility of a tertiary butyl vanadyl phthalocyanine [(t-Bu)1.45 VOPc]/PMMA composite thin film was found to increase markedly because the phase morphology of the composite thin film is changed from phase I to phase II.

Also the optical bistability displayed excellent stability, high sensitivity, and effective reproducibility. However, in the input laser dependence of optical bistability, the switching on-off position shifted according to input laser power intensity. This indicates that by changing the input laser power intensity, the composite thin film can be heated, leading to the phase transition of the composite film causing the optical refractive index of the composite film to subsequently increases.⁹⁻¹¹⁾ In the present paper, the optical bistability of P3HT/PMMA composite thin film for different input laser power intensity and the effect of organic gas treatment for 25 h on the optical bistability of composite thin film have been reported.

2. Experimental

The materials P3HT and PMMA were purchased from Aldrich and 1,1,2,2-Tetrachloroethane was purchased from WAKO Chemicals. The materials were used in this experiment as such as purchased without further purification. The P3HT/PMMA mixed solution was prepared by dissolving of P3HT (0.37 wt%) and PMMA (5.9 wt%) in 1,1,2,2-tetrachloroethane solvent. Then the mixed solution was warmed at 80°C using ultrasonic vibrator cum heater for uniform concentration in the entire volume of the solution. Before spin coating of the solution, the prism was cleaned in the sequence of acetone, ethanol and deionised water by ultrasonic cleaner. To fabricate P3HT/PMMA composite thin film waveguide, the mixed solution was dropped using micro-syringe on the top of the triangular prism arranged in a spin coater. Then the thin film was coated with the speed of 1500 rpm and the spin-coating time was 130 s. The thickness of spin coated composite thin film was measured approximately as 2.5 μm , using surface roughness meter (Dektak IIA, Sloan Tech. Corporation). The structure of the fabricated optical quasi-waveguide is schematically shown in Fig.1. The prepared P3HT/PMMA composite thin film was treated with organic gas for 25 h to find out the effect of organic gas treatment on the optical bistability. Figure 2 shows the schematic diagram of apparatus (glass container) used for organic gas treatment of P3HT/PMMA thin film waveguide. As shown in Fig.2, the glass container was filled with 1,1,2,2-tetrachloroethane gas and closed tightly without air transaction. Then the quasi-waveguide constructed with a prism and P3HT/PMMA composite film was inserted in a saturated organic gas filled glass container for 25 h. The organic gas treatment was performed at room temperature

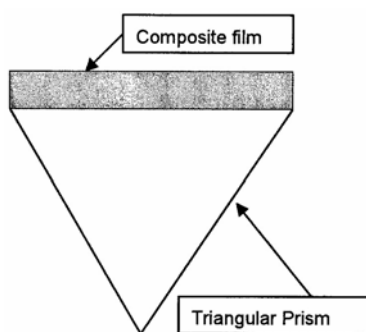


Fig.1. Quasi-waveguide comprised with prism and film.

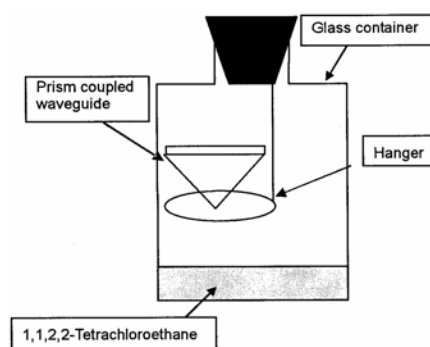


Fig.2 Schematic diagram of apparatus used for organic gas treatment.

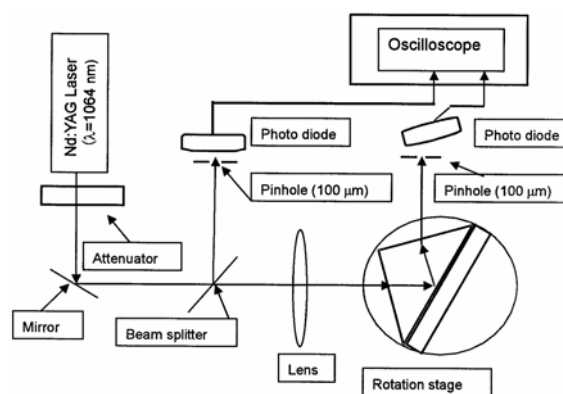


Fig.3 Experimental setup for optical bistability measurement.

(20°C).

The UV-Vis absorption spectrum of P3HT/PMMA composite films was recorded in the range 300-900 nm using UV-Visible spectrophotometer (UV-2450 Shimadzu Corporation) to find out its optical absorption property. The optical bistability experimental setup is schematically shown in Fig.3. A Nd:YAG laser beam having the wavelength of 1064 nm, a pulse width of 5 ns and a repetition rate of 10 Hz was used as a source in the experiment to determine the optical bistable behavior of the P3HT/PMMA quasi-waveguide. As shown in Fig.3, the laser beam was splitted into two beams using beam splitter. In the splitted beams, one beam was used as reference light and another beam was irradiated to the quasi-waveguide through a concave lens with a focal length of 150 mm, exciting the transverse magnetic (TM) modes. The input laser power intensity was adjusted continually using an attenuator. A pinhole and photodiodes (S5971-Hamamatsu Photonics) were used for reference beam and output beam detection. The input and output photodiodes were connected with a digital oscilloscope (2.5 GS/s) to observe the input and output bistable behavior of the quasi-waveguide. The incident angle of the composite film coupled with a prism was adjusted by turning the rotation stage, which has a measurement accuracy of 1 min. The same experimental procedure was followed for organic gas treatment film to observe its optical bistable behavior.

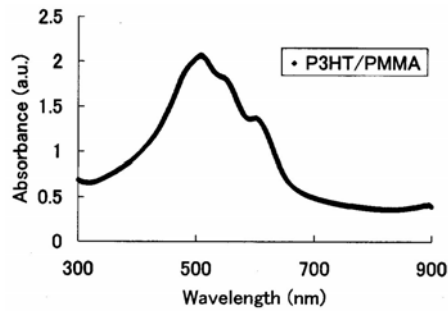


Fig.4. UV-Vis optical absorption spectrum of P3HT/PMMA composite film.

3. Results and Discussion

Before measuring the optical bistability of quasi-waveguide prepared by a prism and P3HT/PMMA composite film, the optical absorption property was measured (Fig.4). When molecules absorb lights of an appropriate wavelength, an electron can be promoted to a higher energy orbital. Ultraviolet and visible light has sufficient energy to cause electronic transition. The higher energy electronic transition is promotion of an electron from a π bonding molecular orbital into π antibonding molecular orbital, known as π - π^* transition. The P3HT/PMMA composite film has strong absorption in the visible region around 515 nm. The absorption peak in this region is due to the strong interaction (π -bonding) or aggregation between the polymer chains and these are generally influenced by molecular packing in the polymer compounds.

Figure 5 shows the optical bistability measured with the quasi-waveguide composed of a triangular prism and a P3HT/PMMA composite film. Concerning the input power intensity dependence of optical bistability, the switching on-off position of the optical bistability, measured with input power intensities, shifts according to the increase in input power intensity. This indicates that when the P3HT/PMMA composite film is irradiated with laser light, thermal expansion occurs in the film. It is supposed that the change in the on-off position with the input laser optical power intensity dependence of optical bistable behavior is vary likely to be the thermal expansion due to the laser irradiation. Therefore, the refractive index of the composite film irradiated with laser light changes according to the increase in laser intensity. The

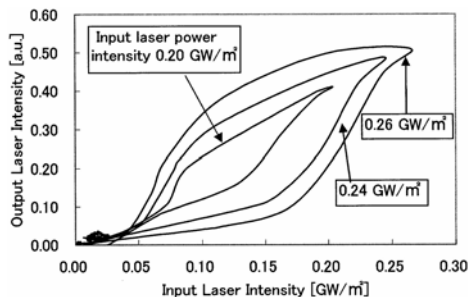


Fig.5 Input laser power dependence of optical bistability characteristics of P3HT/PMMA composite thin film.

shift of the on-off position of the optical bistability measured

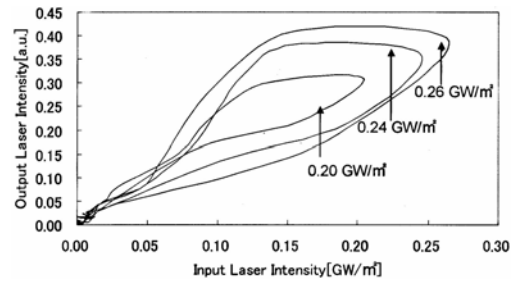


Fig.6. Optical bistability measured for the quasi-waveguide constructed with triangular prism and P3HT/PMMA composite film after organic gas treatment for 25 h.

with different input laser power intensities is attributed to the change in the refractive index of P3HT/PMMA composite film irradiated with laser light. Because the effect of the transition giving a compound film from the heat treatment is the same as organic gas treatment. Figure 6 shows the input laser intensity dependence of the optical bistable characteristics measured for P3HT/PMMA composite film treated with organic gas for 25 h. On the input power dependences of optical bistability, the switching on-off position of the optical bistability, shifts according to the increase of input power intensity. The shift of the on-off position according to the input laser power is markedly higher than that of before being treated with organic gas. In the input laser power dependence of optical bistability, the switching on-off position shifted with the increase of input laser power intensity. The bistable behaviors are very stable for P3HT/PMMA composite film exposed to organic gas.

In Fig.5, the on shifting width between the input laser optical power intensities 0.24 GW/m^2 and 0.26 GW/m^2 is 0.03 GW/m^2 . The off shifting width between the input laser optical power intensities 0.24 GW/m^2 and 0.26 GW/m^2 is 0.02 GW/m^2 . In Fig.6, the on shifting width between the input laser optical power intensities 0.24 GW/m^2 and 0.26 GW/m^2 is 0.05 GW/m^2 . The off shifting width between the input laser optical power intensities 0.24 GW/m^2 and 0.26 GW/m^2 is 0.02 GW/m^2 . Therefore the shift of the on-off position shown in Fig.6 is better than that shown in Fig.5. This indicates that the P3HT/PMMA composite film after being exposed to organic gas is improved with larger grain size, better molecular orientation, homogeneity and surface smoothness than that of before being organic gas treatment.

4. Conclusion

The optical bistability of optical device fabricated using a prism and an organic composite film (P3HT/PMMA) was performed and investigated for different input laser power intensities. The measured optical bistability displaced excellent stability and hysteresis characteristics. In the input laser power dependence of optical bistability, the switching on-off position shifted with the increase of input laser power intensity. The optical bistable behaviors are very stable for P3HT/PMMA composite film after exposed to organic gas. It suggests that the composite film exposed to organic gas has larger grain size, better molecular orientation, homogeneous bulk and smooth surface than that of before organic gas treatment.

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