Optical Bistability of Poly(3-octylthiophene)/Polymethylmethacrylate Composite Waveguides Prepared by Spin Coating*

Jayaraman RAMAJOTHI, Kenzo KOJIMA, Teruyoshi MIZUTANI and Shizuyasu OCHIAI*1

*1Department of Electrical Engineering, Aichi Institute of Technology, Toyakusa, Toyota, Aichi-470-0392, Japan

(Received October 30, 2009, Accepted February 15, 2010)

Poly(3-octylthiophene)/Polymethylmethacrylate (P3OT/PMMA) composite waveguides were prepared by spin coating method as composing a prism-coupling waveguide. The UV-vis spectrum of P3OT/PMMA thin film was recorded in the range 300–900 nm using spectrophotometer to determine the optical absorption property of the composite thin film. The prepared P3OT/PMMA waveguide was treated with organic gas for 25 hrs to smoothing the surface of the thin film. An 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 optical bistability measurement. The optical bistable characteristics of prism coupling waveguide comprising with P3OT/PMMA composite thin film was measured for different laser power intensities using optical bistable measuring equipment. The measured optical bistability displaced good stability and hysteresis characteristics. The input power dependence of optical bistability was observed and the switching on-off position shifted with the increase of input power intensity. In addition, the effects of organic gas treatment on the optical bistability of P3OT/PMMA composite waveguides were analyzed.

1. Introduction

The study of optical bistability and bistable devices is an important and interesting subject in nonlinear optics due to its potential applications in optical memory, logic gates and optical switches1–3. Many experimental schemes have been carried out to obtain optical bistability and several relevant theories were proposed to explain them. In a Fabry-Perot cavity or in a one dimensional super lattice, the related physical parameter is the wavevector mismatch detuning from the resonant condition such as optical bistability belongs to the wavevector mismatch mechanism, classified into two categories: absorptive and dispersive type; the former originates from intensity-dependent nonlinear absorption, whereas the later is due to intensity-dependent nonlinear refraction.

After organic gas treatment for 25 hrs in 1, 2–dichloroethane vapor, the third-order nonlinear susceptibility of a tertiary butyl vanadyl phthalocyanine [t-Bu]$_2$O$_2$Pc]/PMMA composite thin film was found to increase significantly because the phase morphology of the composite thin film is changed from phase I to phase II. Also the optical bistability displayed excellent stability and hysteresis characteristics. However, in the input power dependence of optical bistability was observed and the switching on-off position shifted according to input power intensities. Our aim to obtain optical bistability with less on-off position shift and stable bistable characteristics. Already we have systematically investigated and reported the optical bistability of Ter-thiophene/Polymethylmethacrylate and P3HT/PMMA composite waveguides. In the present paper, the optical bistability of P3OT/PMMA composite thin film for different input power intensities and the effect of organic gas treatment for 25 hrs on the optical bistability of composite waveguide have been reported.

2. Experimental

Regioregular Poly(3-octylthiophene) (RR-P3OT) and Polymethylmethacrylate (PMMA) with two different molecular weight (9980 and 23000) from Aldrich and 1, 1, 2, 2–Tetrachloroethane from WAKO Chemicals were purchased. The P3OT/PMMA composite solution was prepared by dissolving of P3OT (0.30 wt %) and PMMA (6.92 wt %) in 1, 1, 2, 2-tetrachloroethane at ambient condition. The P3OT/PMMA composite thin film was fabricated on the top of the triangular prism arranged in a spin-coater with the speed of 1200 rpm and the spin-coating time is 120 s. Using the same conditions totally four P3OT/PMMA waveguides were prepared and the thickness of spin-coated composite film was measured to be 3 μm using surface profile measuring system. The prepared P3OT/PMMA composite thin film was treated with organic gas for 25 hrs to determine the effect of organic gas treatment on the optical bistability. A glass container was arranged with special modifications suitable for organic gas treatment of the P3OT/PMMA waveguide. The glass container was filled with 1, 1, 2, 2-tetrachloroethane. Then, the quasi-waveguide constructed with a triangular prism and P3OT/PMMA composite film was inserted with a hanger into a saturated organic-gas-filled glass container for 25 hrs. The organic gas treatment was performed at room temperature (20°C)

UV-vis spectrum of P3OT/PMMA composite film was recorded in the range 300–900 nm using UV-visible spectrophotometer to determine the optical absorption property (Fig. 1). The morphology and surface roughness of the P3OT/PMMA composite thin film was investigated by dynamic-mode atomic force microscopy.

---

* Presented as a contributed talk at the 50th annual symposium of the Vacuum Society of Japan, Nov. 6, 2009
*1 E-mail: ochiai@aitech.ac.jp

---

(Received October 30, 2009, Accepted February 15, 2010)
Fig. 1 UV-Vis spectrum of P3OT/PMMA (PMMA Mw – 9980) composite film.

Fig. 2 DFM image of P3OT/PMMA composite film.

Fig. 3 DFM image of P3OT/PMMA composite film after organic gas treatment for 25 hrs.

(DFM; SPI4000, SII Nanotech. Inc.). An 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 this experiment to determine the optical bistable behavior of the P3OT/PMMA quasi-waveguide. The input power intensity was adjusted using an attenuator. Photodiodes (S5971–Hamamatsu Photonics) attached with pinhole (100 μm) were used to detect the reference and output beams. The input and output photodiodes were connected with digital oscilloscope (2.5 GS/s) to observe the bistable behavior of the quasi-waveguide.

3. Results and Discussion

The P3OT/PMMA composite thin film has strong absorption in the visible region around 550 nm (Fig. 1). 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 polymer compounds. Figure 2 shows a DFM image of spin-coated P3OT/PMMA composite thin film within an area of 5 μm². The obtained roughness of the P3OT/PMMA composite thin film was about 30 nm, indicating film smoothness at the molecular level. The Fig. 3 shows a DFM image of P3OT/PMMA composite thin film after organic gas treatment for 25 hrs. In this image it is clearly indicates the surface roughness of the film is decreased considerably than before organic gas treatment. It reveals that the composite film exposed to organic gas has better molecular orientation, homogeneous and smooth surface than untreated thin film. The optical bistability of the P3OT/PMMA (PMMA, Mw ~ 9980) composite waveguide was measured for different (0.16, 0.20, 0.24, and 0.26 GW/m²) input power intensities. Input intensity dependence of optical bistability was observed and switching on-off position of the optical bistability shifts according to the increase in input power intensity. This indicates that when P3OT/PMMA composite film is irradiated with laser light, thermal expansion occurs in the film. Therefore, the refractive index of the composite film irradiated with laser light changes according to the increase in input power intensity. The shift of the on-off position of the optical bistability measured with different input power intensities is attributed to the change in the refractive index of P3OT/PMMA composite film irradiated with laser light. Figure 4 shows the input laser intensity dependence of the optical bistable characteristics measured for P3OT/PMMA composite waveguide treated with organic gas for 25 hrs for the same input power intensities. As shown in the figure, in the input laser power dependence of optical bistability, the switching on-off position shifted with the increase in input laser power intensity. The shift of the on-off position according to the input power is decreased compared to that before being treated with organic gas. The on-shift width between input laser.
The optical bistability measured for the quasi-waveguide constructed with a triangular prism and P3OT/PMMA composite thin film after organic gas treatment for 25 hrs (PMMA, $M_w \approx 9980$).

Figure 5 shows the optical bistability measured with the quasi-waveguide composed of a triangular prism and P3OT/PMMA (PMMA, $M_w \sim 23000$) composite waveguide for different input power intensities. The on-shift width between input laser power intensities of 0.24 GW/m$^2$ and 0.26 GW/m$^2$ is 0.01 GW/m$^2$. The off-shift width between the same-input power intensities is very small and it does not change much with input power intensities. It is considered that the on-off shift of the P3OT/PMMA composite waveguide is decreased according to the increase in PMMA molecular weight and organic gas treatment.

4. Conclusion

The P3OT/PMMA composite thin film was prepared by the spin-coating method and the optical absorption property was investigated using UV-vis spectroscopy. 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 in input laser power intensity. The optical bistable behaviors are stable for P3OT/PMMA composite film after exposure to organic gas. It suggests that composite film exposed to organic gas has larger grain size, better molecular orientation, homogeneous and smooth surface than before organic gas treatment.

Acknowledgement

The present work was partially supported by a grant from the Frontier Research Project (Continuation) “Materials for the 21st Century-Development of Novel Devices Based on Fundamental Research of Materials Development for Environment, Energy and Information” (for fiscal years 2007 – 2009) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

9) J. Ramajothi, K. Kojima, T. Mizutani and S. Ochiai: The Institute of Electrical Engineering of Japan (IEEJ) (Accepted).