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Ultrafast Reflection Control based on Photoinduced Complex Refractive Index Changes in Guided Mode Thin Films Containing Indium Phthalocyanine

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Ultrafast all-optical reflection control was achieved by complex refractive index changes upon photoexcitation of indium phthalocyanine in a guided mode geometry device. It gave a few microseconds response mostly characteristic to the lifetime of the excited triplet state.

Keywords: all-optical spatial light modulation; complex refractive index changes; photoexcitation of organic dyes; guided mode geometry; phthalocyanines; excited triplet state

INTRODUCTION

All-optical parallel switching devices and spatial light modulator (SLM) have attracted much interest especially in the fields of optical data communication and optical parallel data processing. However no practical devices have been developed except some prototypes or SLMs based on liquid crystals (LC). The response time of LC-SLM is controlled by the electric field-induced motion of LC and is not fast enough to make on-line optical correlation of mega-byte images. It is about a few hundreds of microsecond (μs) for ferroelectric LC and a

few tens of milliseconds (ms) for nematic LC.

Recently multiple-quantum-well (MQW) SLMs have been developed to show spatial resolutions of 5-7 μm and a response time of about 1 μs [1]. The MQW-SLM has very complex nano-structures, which can be prepared only by very expensive and high-vacuum facilities. We have proposed very recently a novel all-optical spatial light modulation using guided optical waves (guided mode) based on reflectivity increases as schematically shown in FIGURE 1 [2-7]. Our device is very simple and is composed of a prism and a metal-covered glass plate with a polymer film containing organic dyes. The changes of an imaginary part or a real part of the complex refractive index upon photoexcitation of an organic dye-doped polymer thin film cause the change of reflectivity or the shift of the guided mode resonance angle as shown in FIGURE 2 for calculated results. The complex refractive index of the polymer film can easily be controlled by absorption change and its Kramers-Kronig transformation upon excitation of organic dyes to from excited states or to cause various photoreactions such as photochromism and photoinduced electron transfer. The reflected light intensity or the phase of the probe beam thus can be two-dimensionally and all-optically controlled by the pump beam. In the present paper, indium tetra(tert-butyl)phthalocyanine chloride which was recently

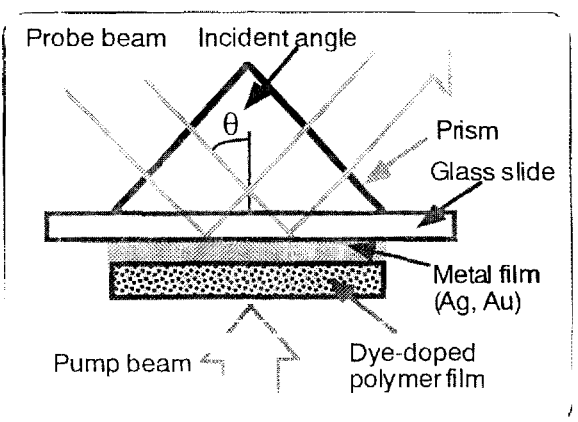

FIGURE 1 Schematic representation of all-optical reflectance control by complex refractive index of guided mode dye-doped polymer film

proved to work as a good optical limiter [8], was used to optically modulate reflectance.

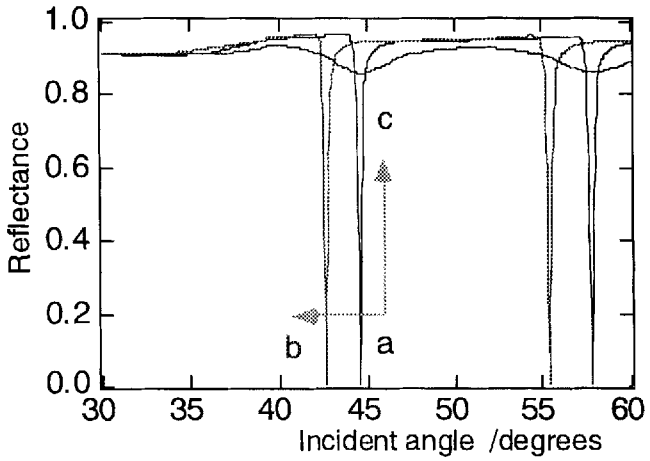

FIGURE 2 Calculated incident angle dependences are shown for changes of a real or an imaginary part of complex refractive index, a: n= 1.60, b: n= 1.58, c: n= 1.60 + 0.02*i*.

EXPERIMENTAL

A thin film of silver was vacuum evaporated onto a glass slide, on which indium tetra(tert-butyl)phthalocyanine chloride (InPc)-doped polystyrene (PS) films with a weight ratio of 1:50 were spin-coated. The structure of InPc is shown in FIGURE 3 with the ground state absorption spectrum. The sample plate was index-matched with a BK7 prism, which was set on a computer-controlled rotating stage. The writing beam was a ns OPO laser at 690 nm or the third harmonic (355 nm) of Nd:YAG laser; each with 8 ns pulse width, 0.03 - 2 mJ/pulse, and ca. 0.2 cm^2 beam area. He-Ne laser through a half-wave plate, a polarizer, and a chopper was used as a reading beam. The time dependence of a reflected intensity at a given incident angle upon excitation with different powers was detected with a photomultiplier and was recorded by a digital oscilloscope terminated with 50 ohm.

RESULTS AND DISCUSSION

Upon excitation with a fs laser at 400 nm, transient absorption spectra shown in FIGURE 4 were observed. Transient absorption spectra with peaks at 450 and 600 nm due to S_1-S_n absorption gradually changed

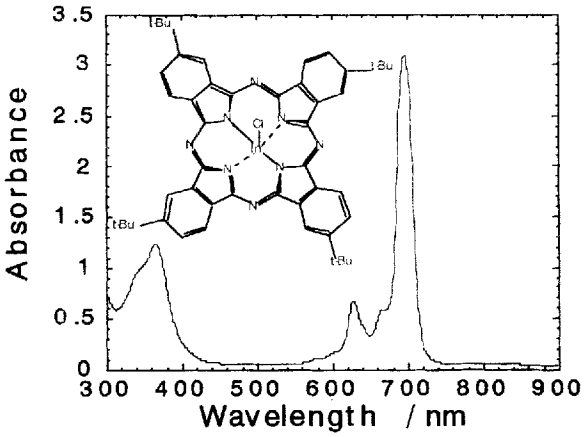

FIGURE 3 Structure of InPc and its absorption spectrum in toluene.

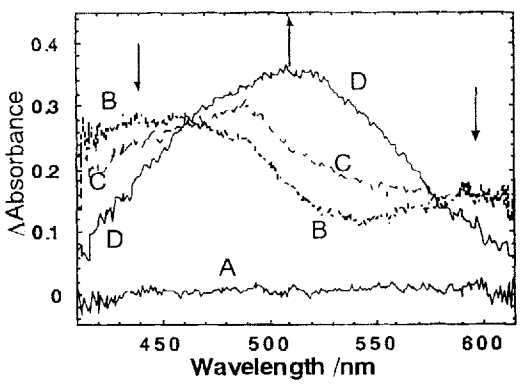

FIGURE 4 Transient absorption spectra upon fs laser excitation of InPc.

with a 450 ps time constant to that with a peak at 510 nm. The latter was attributed to the formation of the excited triplet state of InPc [8].

From FIGURES 3 and 4 together with comparison with the previous result in ZnPcS [5,7], it was shown that only the imaginary part of complex refractive index changes at 543.5 nm upon excitation. Thin polystyrene (PS) films containing InPc were spin-coated on a thin silver film, which showed sharp guided mode resonance at specific incident angle(s) depending on the thickness. The time dependence of reflected light intensity was observed at the incident angle of 51.2 degrees upon ns laser excitation at 690 nm. It increased very rapidly with a rise time of less than 20 ns as shown in FIGURE 5, which was controlled by the laser pulse. The decay was expressed with a double exponential with lifetimes of 3.8 μs (69 %) and 15 μs (31 %) as shown in FIGURE 5 for excitation at 0.6 mJ. The transient absorption at 543 nm of the excited triplet of InPc at a similar excitation power also decayed double-exponentially with lifetimes of 4.4 μs (27 %) and 22 μs (73 %). Somewhat faster decay of reflectance as compared with transient absorption strongly suggested that the complex refractive index changed due most probably to photochemical and thermal effects during the lifetime of excited triplet state.

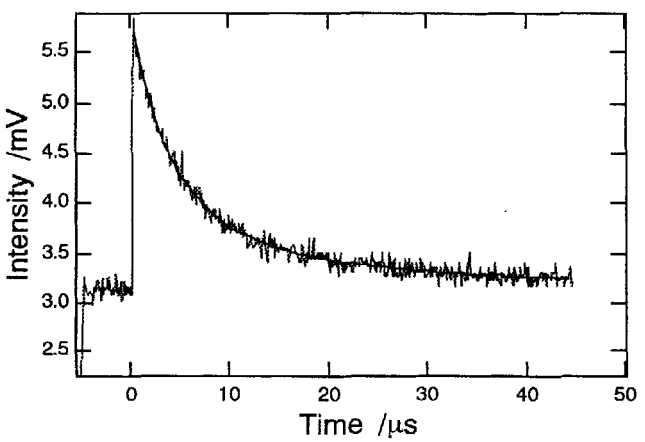

FIGURE 5 Time profiles of reflected light intensity at 543.5 nm and the incident angle of 51.2 degrees for guided mode films containing InPc upon ns laser excitation at 690 nm.

Much faster responses can be expected if we use excited states or charge-separated species with much shorter lifetimes. We have already reported 30 ns decay by using copper tetrasulfonatophthalocyanine in similar guided mode geometry [7]. The spatial resolution of two dimensional image written by a single shot ns UV laser was determinedto be about 4 μm by using a photochromic dye [7].

CONCLUSION

A few microsecond response was achieved for reflectance in guided mode geometry containing InPc upon excitation with ns laser. The present result will contribute a great deal to make ultrafast all-optical parallel processing such as on-line optical correlation.

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