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Reflection-Mode All-Optical Parallel Switching in Guided Wave Geometry Including Photochromic Compounds

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Reflection-Mode All-Optical Parallel Switching in Guided Wave Geometry Including Photochromic Compounds

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A novel all-optical parallel switching device was demonstrated by using photoinduced changes of a complex refractive index in a guided mode thin film composed of silver and polymer containing photochromic dyes. An incident angle of a probe beam was set at a value corresponding to the minimum reflection due to the guided mode. Pulsed laser excitation caused changes of absorption of the polymer films due to photochromism, which resulted in the increase of reflection because the guided mode condition was changed. According to the Kramers-Kronig relationship the real part also changes, which results in the shift of the minimum. Appropriate wavelength can be selected for all-optical switching in this geometry. We used photochromic spiropyran dispersed in polystyrene. Self-held parallel switching was achieved upon UV or visible laser excitation with response times less than 20 ns.

Keywords: all-optical parallel switching; complex refractive index changes; guided mode thin film; spiropyran; pulsed laser excitation

INTRODUCTION

All-optical parallel switching devices and spatial light modulator (SLM) have attracted much interest especially in the fields of very fast optical data communication and optical parallel data processing. In order to construct molecular photonics system which can make such optical parallel processing with ultimate spatial resolution, we have been studying ultrafast, picosecond (ps) - femtosecond (fs), colour changes and highly sensitive detection of steady and transient absorption changes

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by the optical waveguide method. [1-4] Recently we have proposed a novel all-optical light modulation and self-held parallel optical switching based on complex refractive index changes upon photoexcitation of an organic dye-doped polymer thin film. [5-8] The present system is very unique as compared to the previously proposed "all-optical" light modulation systems. [9,10] In principle fs response can be achieved in this system, because we use resonance shifting of the guided optical waves in the ATR geometry based on the changes in an imaginary part of the refractive index due to transient absorption upon photoexcitation of a dye. The main advantages using guided optical waves (guided mode) are (1) its high sensitivity to small changes in refractive index and thickness, and (2) its sensitivity to both p- and s-polarized light. In the present paper, we will make some discussion on characteristics and possible applications of this all-optical parallel self-held switching based on photochromism.

EXPERIMENTAL

The principle and the structure of the present novel device were reported previously. [5-8] An increase in imaginary or real parts of complex refractive index of a polymer film increases the reflectance at the guided mode resonance angle or shifts the resonance angle to a higher value. Thus very fast light modulation or switching is possible at the incident angle corresponding to such guided mode resonance under appropriate combination of a pump (writing) beam, a probe (reading) beam and a dye in the guided wave geometry based on transient or persistent absorption changes due to various mechanisms. The rise time will be fs order, in principle, and the fall time can be controlled over a wide range from ps to infinity depending on the nature of photogenerated species.

Photochromic 1,3,3-trimethylindolino-6'-nitrobenzopyrylospiran showed two stable species, spiropyran (SP) and colored photomerocyanine (PM), which are reversibly formed by irradiation at two different wavelengths. The quantum yields of photoreactions from SP to PM, and from PM to SP are reported as 0.6 and 0.15, respectively. [11] Spectra of extinction coefficient and refractive index changes ((a) Δk and (b) Δn) of polystyrene thin film containing SP upon UV excitation are shown in Figure 1. The former (a) in Figure 1 is based on the

observed difference absorption spectra before and after UV irradiation. The latter (b) was calculated from the extinction coefficient Δk by Kramers-Kronig transformation. Large refractive index changes with different signs can be seen near strong absorption changes. The extinction coefficient and/or refractive index changes over a wide wavelength range approximately from 400 nm to 800 nm can be utilized to operate a wide range all-optical switch.

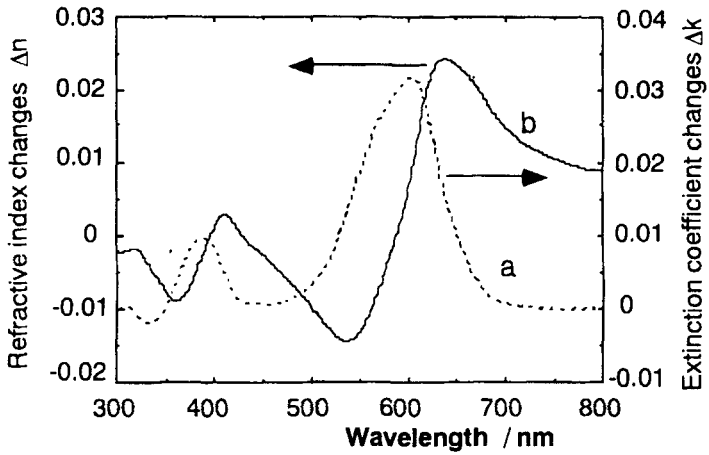

FIGURE 1 Spectra of (a) extinction coefficient (broken line) and (b) refractive index (solid line) of polystyrene thin film containing SP upon UV irradiation.

RESULTS AND DISCUSSION

From time profiles of reflectance upon excitation with a single shot laser at 355 nm or at 600 nm, the response time of this system was less than 20 ns for both switching ON and OFF operation as previously reported, which was controlled by the time resolution of our system. [6,7] Much better switching is expected if a picosecond laser and the experimental set up with much better time resolution are used, since the rise time of transient absorption of a polystyrene film containing spiropyran was reported as about 200 ps upon ps laser excitation. [12] These results

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indicate that this fast reflectance decrease was caused by the reverse photochromic reaction from PM to SP, and not by the thermal reaction.

Figure 2 shows the incident angle dependences for the guided mode geometry with 50 nm silver and 264 nm SP-doped polystyrene with a weight ratio of 1:10 observed at 543.5 nm (a) before and (b) after excitation with a single shot of ns laser at 355 nm, 2.5 mJ/pulse. The minimum of reflectance was increased and shifted to lower angles as expected from Figure 1. Calculated dependences are also shown for the same polystyrene film containing SP without a silver film (normal ATR mode) based on the same refractive index values. The reflectance value at 50.76 degrees increased by 17 times in the guided mode. Meanwhile it decreased by about 1.5 times in the normal ATR mode. These results clearly demonstrated that higher contrast can be achieved in the guided mode.

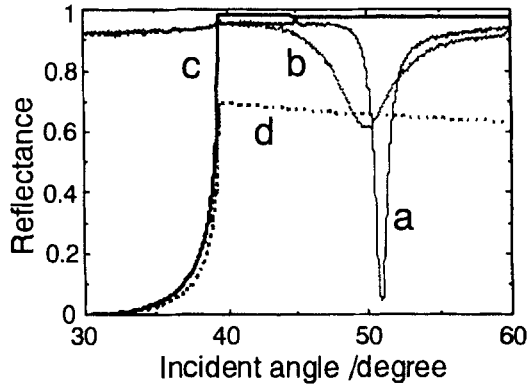

FIGURE 2 Incidenct angle dependences for (a,b) the guided mode and (c,d) the normal ATR mode; (a,c) before and (b,d) after excitation at 355 nm.

The incident angle dependences of measured reflectance of a probe beam were further studied at several wavelengths using the same guided mode geometry as shown in Figure 2. Observed dependences at 594 nm and at 694 nm are shown as curves "**a**" in Figure 3 (A) and (B). Curves "**b**" were observed after excitation with a single shot of ns Nd-YAG laser at 355 nm, 1 mJ/pulse. The guided mode dip shifted to

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smaller angles with increasing the wavelength as expected. After excitation, the incident angle dependence showed very different behavior at 594 and 694 nm as shown in Figure 3. At 594 nm, the reflectance increased dramatically with a very small shift of the minimum reflectance (dip) angle after excitation.

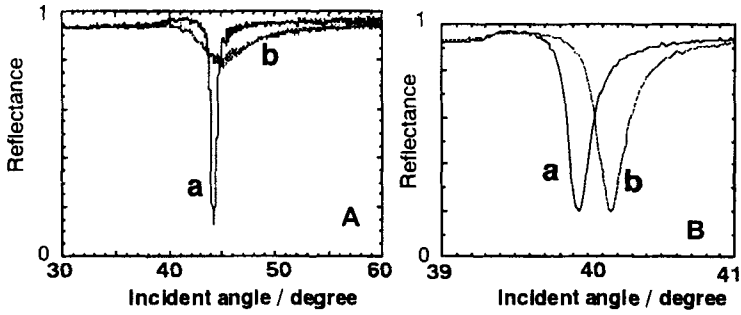

FIGURE 3 Incident angle dependences of reflectance at (A) 594 nm and (B) 694 nm for SP-doped polystyrene film (a) before and (b) after excitation with a single shot of ns Nd-YAG laser at 355 nm, 1 mJ/pulse.

Meanwhile, the dip angle shifted to larger angles without changing the reflectance value at 694 nm. These behaviors well corresponded with the dependences of Δn and Δk on the wavelength as shown in Figure 1. At 594 nm, Δn is very small and Δk is very large, whereas Δk is almost zero and Δn is a large positive value at 694 nm. Wavelength dependences of the refractive index and the extinction coefficient changes evaluated from reflectance changes upon pulsed laser excitation in the polystyrene film containing SP corresponded well with the spectra of extinction coefficient and refractive index changes estimated from steady photolysis as shown in Figure 1. These results confirmed the mechanism responsible for the reflectance changes in guided wave geometry and also demonstrated the wide range of operation wavelength of the present all-optical device.

In addition to very fast photoresponses, it is essential to be able to write and read a two-dimensional image pattern for the optical parallel data processing. An image of a mask was recorded in the reflected light by a single shot excitation at 355 nm as previously reported. [6,7] The

spatial resolution of the SP-doped polystyrene film in guided wave geometry was evaluated to be better than 161 line pairs/mm or about 3 μm by using the USAF test target.

CONCLUSION

An all-optical ultrafast parallel processing device was proposed and demonstrated based on complex refractive index changes of thin films containing photochromic dyes in a guided wave geometry. The reflected intensity of a reading beam was switched very rapidly and two-dimensionally. A combination of the present all-optical switch and the photon-mode spatial light modulator reported previously will contribute a great deal to construct ultrafast parallel processing devices such as an all-optical correlator.

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