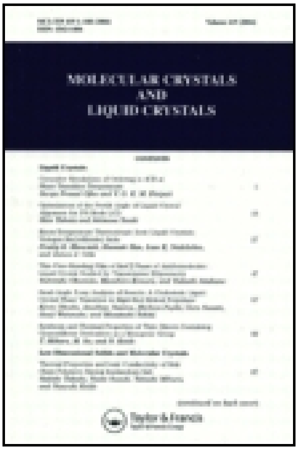

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Characterization of Organic Photochromic Materials as 3-D Optical Data Storage Media

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Characterization of Organic Photochromic Materials as 3-D Optical Data Storage Media

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We present our work on data storage and characterization in photochromic materials, and have succeeded in recording data at a total of 26 overlapping layers. The effect of bit depth and bit size were investigated by varying exposure time of the sample to the laser pulses. Bit size and bit depth were found to increase with exposure time and optimizing their values would increase the density of the possible number of data stored in a photochromic medium.

Keywords: photochromic materials; NSP; B1536; 3-D optical data storage; bit size; bit depth

INTRODUCTION

3D optical digital data storage allows for the recording of Terabit data, due to its volumetric data storage capability [1]. Recent work on this subject has been done on photorefractive crystals [2, 3, 4], a photorefractive polymer [5], photopolymerizable [6], photobleaching [7] and photochromic materials [8,9,10,11]. This article presents our work on 3-D optical data storage in photochromic materials, namely, 1,3,3-trimethylindolino-6'-nitrobenzopyrylospiran (NSP) and *cis*- 1,2-dicyano-

1,2-bis(2,4,5-trimethyl-3-thienyl)ethene, or B1536.

Photochromic materials offer the advantage of low cost in processing and easy incorporation in a polymer matrix. These materials exhibit a characteristic absorption spectrum in its initial trans- state. Illumination of the material with a wavelength within the absorption band of the trans- state transforms it to a cis- state, and vice versa. Figure 1 shows the photochromic reaction that occurs in NSP, and the corresponding change in its absorption spectrum (Figure 2). Figure 3, on the other hand shows the absorption spectrum of B1536 before and after illumination with UV light.

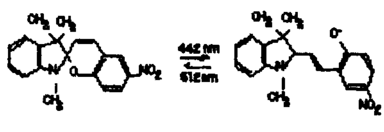


FIGURE 1 Photochromic reaction of NSP.

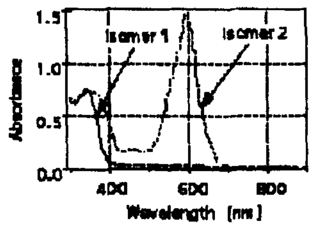
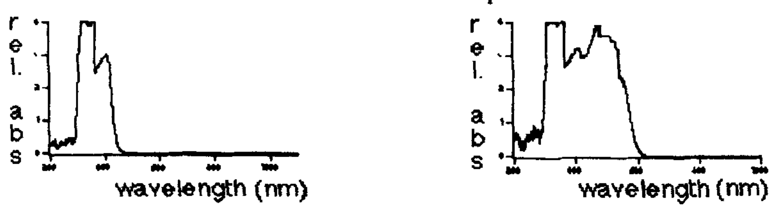


FIGURE 2 Absorption spectra of isomers A and B.



A. *B.*

FIGURE 3 Absorption spectra of the B1536 sample before (A) and after (B) illumination with a 4W U.V. lamp.

We performed experiments on NSP using one photon absorption for writing data and two-photon absorption on B1536. Figure 4 shows the difference between 1-photon and 2-photon absorption in a photochromic material. For 1-photon absorption, a photon with frequency f_1 is absorbed by the photochromic molecule, transforming it from isomer A to B. 2-photon absorption on the other hand involves the absorption of two photons with frequencies f_1 and f_2 via a virtual intermediate state.

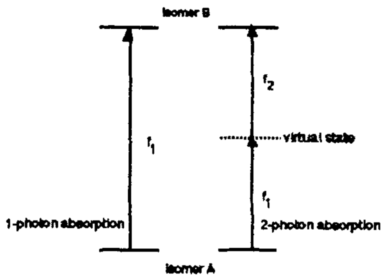


FIGURE 4 Schematic representation of 1-photon and 2-photon processes.

METHODOLOGY

Bit patterns were stored in the NSP sample which was approximately 100 um thick, using the experimental set-up presented in Figure 5. The wavelength of the "writing" laser used was 442 nm and had an output power of 2.8 mW. Bits were stored at an interval of 5 um and a layer distance of 70 um. A near-IR laser-scanning differential contrast microscope (Figure 6) was used to read the stored data.

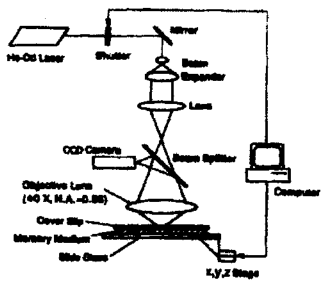


FIGURE 5 Experimental setup for 1-photon 3-D optical data storage used for NSP [10].

2-photon optical data storage experiments were performed on the poly(methyl methacrylate) film doped with the B1536 photochromic molecule. This material was found to be stable at 80°C for more than three months and thermal backreaction (from the red to yellow state) does not occur even at 300°C [12]. 3-D bits were written in the photochromic sample in its trans- state. A mode-locked, 760 nm Ti-Sapphire laser which produces 150 fsec pulses at a repetition rate of 76 MHz was used for two-photon writing. The output of the laser was measured to be 40 mW at the focus of a 1.4 NA objective lens. Such a high NA objective lens was used so that the 2-photon absorption process occurs only at the focus position as manifested by a written bit. The sample used had a thickness of 1.2 mm, which is the typical thickness of a CD (compact disc). Figure 7 shows a schematic diagram of the experimental setup used.

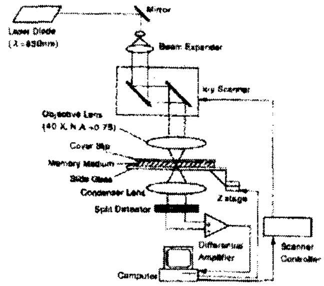


FIGURE 6 Schematic diagram of a near-IR laser scanning differential contrast microscope used in the experiment [10].

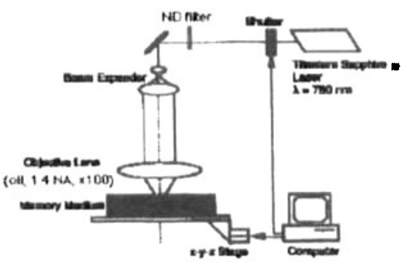


FIGURE 7 Schematic diagram of the 3D optical data storage system.

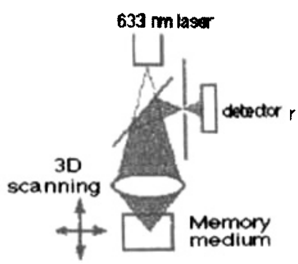


FIGURE 8 Schematic diagram of a reflection confocal microscope.

A reflection confocal microscope (Figure 8) was used to readout the recorded bits, wherein the illumination light was from a 633 nm He-Ne laser, and the reading objective had an NA of 1.4. 633 nm was chosen as the reading wavelength since the photochromic material showed little absorption at this wavelength for both the trans and cis-isomer.

EXPERIMENTAL RESULTS

Figure 9 shows two overlapping layers of 24 by 24 bit patterns read from the NSP photochromic material by a near-IR laser-scanning differential contrast microscope. The bits were recorded at a bit interval of 5 um and a layer distance of 70 um [10].

Studies on the B1536 photochromic material however, showed more promising results as far as data storage density is concerned. Figure 10 shows reflection confocal images (100x magnification) of bits stored in the B1536 photochromic sample in a previous work [11]. A total of 26 overlapping layers were recorded, with minimal crosstalk, at a bit spacing of 2 um and a layer interval of 5 um.

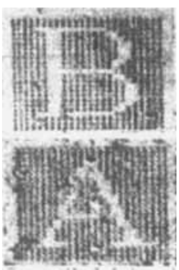


FIGURE 9 Two layers of bit patterns stored in the NSP photochromic material [10].

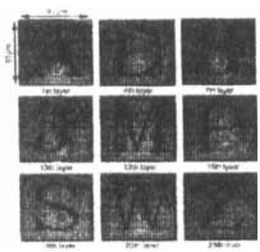


FIGURE 10 Reflection confocal images (100x magnification) of stored data at different layers in the B1536 photochromic sample [11].

In order to increase the density of stored data in the photochromic medium, it is imperative to characterize the effect of experimental parameters on the stored bits. Figure 11 shows a plot of bit size vs. exposure time. A linear increase in bit size is observed with exposure time, while ablation occurs after 200 msec exposure. The ablation dots were determined as the dots which remained in the sample even after illuminating the sample with an expanded beam of a 5 mW, 532 nm Nd:YAG laser, for 10 minutes. It should be noted that ablation should be avoided during the recording process.

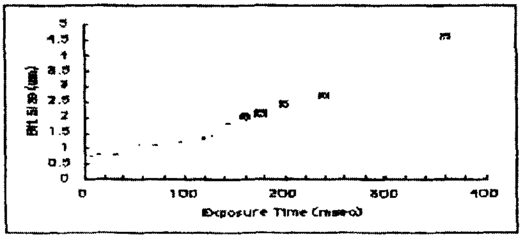
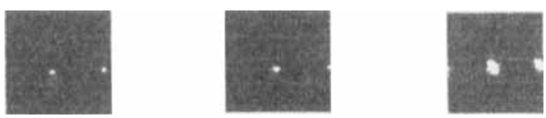


FIGURE 11 Plot of bit-size vs. exposure time (X indicates ablation).

Figure 12 shows reflection confocal images (100x magnification) of some resultant dots at different exposure times. It was observed that the minimum dot size of .72 um was achieved at the minimum exposure time setting of 8 msec, and this presents the possibility of storing bits at distances less than 2 um.

Figure 13 presents the plot of bit depth vs. exposure time. The depth of the ablation dots are observed to deviate from the linear behavior.



8 msec exposure time (.72 um)	56 msec exposure time (1.1 um)	240 msec exposure time (.81 um)

FIGURE 12 Reflection confocal images (100x magnification) of recorded dots at different exposure time.

An increase in the depth of the non-ablation dots indicate a possibility of the worsening of crosstalk if storage is done at different overlapping layers. The minimum bit depth of 2.4 um achieved at an exposure time of 8 msec, presents the possibility of storing data in overlapping layers at an interlayer distance less than 5 um.

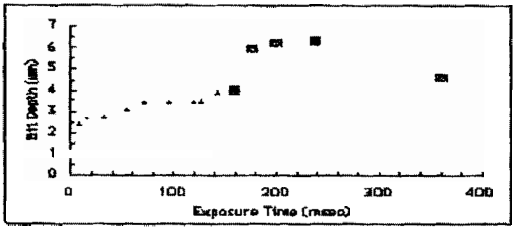


FIGURE 13 Plot of bit depth vs. exposure time (X indicates ablation).

Our group has attempted bit erasure using one-photon excitation, on stored bits in the B1536 photochromic sample, with a 543 nm laser [11], the result of which is presented in Figure 11. The arrows on the right figure indicate the portion at which bits were erased.

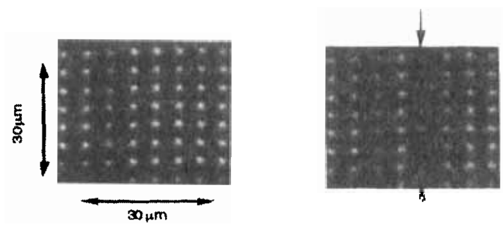


FIGURE 14 Reflection confocal images of bits before (A) and after (B) erasure with a 543 nm laser.

CONCLUSION

We have presented out studies on two photochromic materials, namely, 1,3,3-trimethylindolino-6'-nitrobenzopyrylospiran (NSP) and *cis-* 1,2-

-1,2-bis(2,4,5-trimethyl-3-thienyl)ethene, or B1536. Of the two materials investigated, B1536 showed more promise as a practical medium for 3-D optical data storage, owing to the simplicity of the optical system necessary for reading recorded data. The results presented show that for the given parameters used in our experiments, the optimum exposure time for 2-photon bit recording was 8 msec, which resulted in bit sizes of .72 um with an axial depth of 2.4 um. Reducing bit distance to less than 2 um and bit layer interval to less than 5 um is therefore possible, and could lead to an increase in data storage density.

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