Polarization multiplexing holographic optical recording of a new photochromic diarylethene

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Abstract. A new unsymmetrical photochromic diarylethene **1a** is synthesized, and the photochromic properties of it are also investigated. The compound exhibits good photochromism with UV/visible light irradiation. Compound **1a** in polymethyl methacrylate (PMMA) film changes color upon 313-nm light irradiation from colorless to blue, in which the absorption maximum is observed at 587 nm. Photon-mode polarization multiplexing holographic optical recording is performed successfully using this compound as a recording medium. In the diarylethene **1b**/PMMA film, polarization multiplexing hologram recording and retrieval, and a combination with the angular multiplexing scheme, are demonstrated systematically. The results indicate that recording capacity can be significantly improved with the combined method of polarization and angular multiplexing holographic recording.
[DOI: 10.1117/1.2890426]

Subject terms: Diarylethene; polarization multiplexing holographic recording; optical materials; optical properties; photochemical technology.

Paper 070774LR received Sep. 19, 2007; revised manuscript received Jan. 11, 2008; accepted for publication Jan. 16, 2008; published online Mar. 13, 2008.

1 Introduction

Optical memory, which allows the storage of large amounts of information, is one of the most desired targets for computing technology, since society continues to demand better tools to communicate more data at higher rates.[1] Holographic optical recording is regarded as one of the very promising approaches to increase recording density because of its advantages of large capacity and high recording speed.[2]

For a long time, the lack of suitable recording materials has been a significant obstacle to the development of holographic optical recording. For a holographic recording system, the recording media must satisfy stringent criteria, including high dynamic range, dimensional stability, rapid response time, etc.[3] Generally, there are two main classes of materials used for holographic recording, *i.e.*, photorefractive materials and photosensitive polymerizable acrylic materials.[4] Each kind of material has its advantages and disadvantages. For instance, photorefractive materials exhibit high dynamic range, and photopolymer materials are sensitive to light throughout the visible spectral region. However, slow response times for photorefractive materials and special fixing information after recording for photosensitive polymerizable acrylic materials pose major disadvantages.[2] These disadvantages can be overcome by using photochromic compounds as holographic recording media, and one of the most promising photochromic candidates is diarylethene. Recently, the family of 1,2-diarylethenes has attracted much attention regarding their good thermal stability, remarkable fatigue resistance, and high sensitivity.[5] To date, diarylethenes have been used as recording media for various optical memories, such as multiwavelength recording,[6] two-photon 3-D recording,[7] holographic recording,[8] etc. However, publications concerning polarization multiplexing holographic optical recording using diarylethenes as recording media are very rare. In this work, a new unsymmetrical photochromic diarylethene compound, 1-(2-methyl-5-phenyl-3-thienyl)-2-[2-methyl-5-(3-trifluoromethylphenyl)-3-thienyl]perfluorocyclopentene (**1a**), was employed to investigate its application in polarization multiplexing holographic optical recording.

2 Experimental

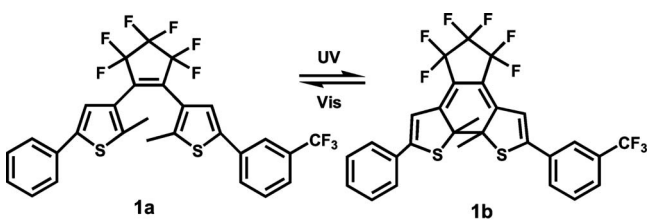
The recording medium was prepared by solubilizing ultrasonically 10 mg of diarylethene 1(a) and 100 mg of polymethylmethacrylate (PMMA) in chloroform (1 ml), then spin coating the homogeneous solution on a glass substrate ($20\times20\times1$ mm) with a spin rotation speed of 1500 rpm. The thickness of the film was about 15 μm. The film was dried in air, kept in darkness at room temperature, and colored homogeneously by irradiation with 313-nm UV light to convert the open-ring isomer 1(a) to the closed-ring isomer 1(b) before carrying out holographic recording. The initial coloration step for the diarylethene **1b**/PMMA film is performed by irradiation of a UV light ($\lambda=313$ nm) for about 2 min at the power of 8 W.

Polarization holographic recording and multiplexing experiments were carried out in the setup illustrated in Ref. 9. The method for different types of polarization holographic recording was described in detail by Yao et al.[10]

3 Results and Discussion

3.1 *Photochromism in Polymethyl Methacrylate Film*

The photochromism of diarylethene **1** is illustrated in Fig. 1, and a synthetic method will be reported elsewhere. Figure 2 shows the absorption spectral changes of diarylethene **1** by photoirradiation in PMMA film (10% w/w). Upon irradiation with 313-nm light, the color of **1a** (λ_{max}



Scheme 1.

Fig. 1 Photochromism of diarylethene **1**.

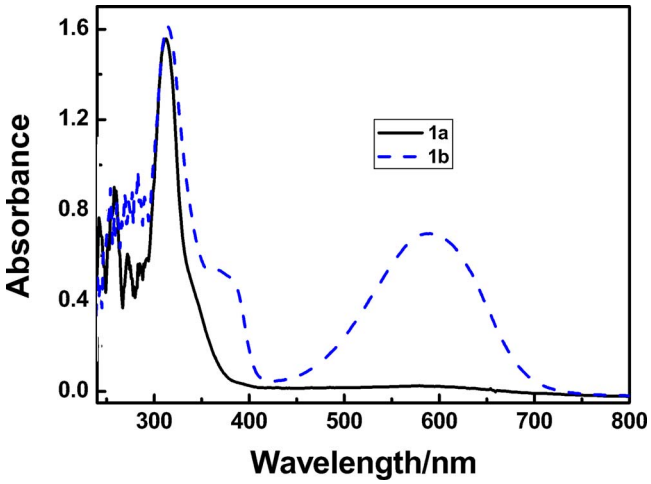


Fig. 2 Absorption spectral changes of compound **1** in PMMA film.

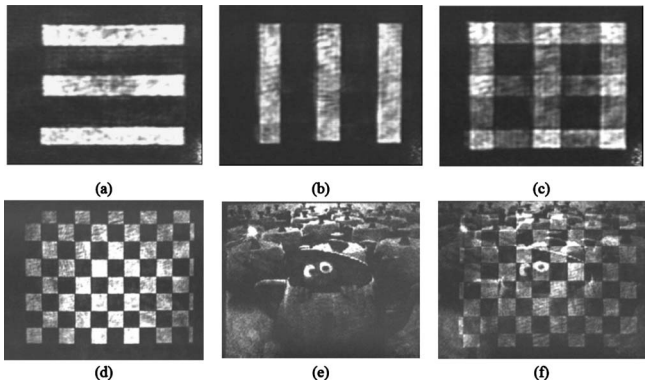


Fig. 3 Retrieved images from the polarization multiplexing holograms. (a) Parallel circular polarization hologram at 0 deg; (b) orthogonally circular polarization hologram at 90 deg; (c) overlapping retrieved image at 45 deg; (d) parallel linear polarization hologram at 0 deg; (e) orthogonally linear polarization hologram at 90 deg; and (f) overlapping retrieved image at 45 deg.

=314 nm) changed from colorless to blue with the appearance of a new broad absorption band at λ_{max}=587 nm, which was assigned to the formation of **1b**. The colored PMMA film could return to colorless upon irradiation with appropriate visible light ($\lambda > 450$ nm). The coloration-decoloration cycle could be repeated more than 100 times, and it showed no remarkable photodegradation, indicating that it possessed good photochromic behavior.

3.2 *Polarization Multiplexing Holographic Recording*

3.2.1 *Polarization multiplexing holograms*

Because there is a photoinduced anisotropic phenomenon accompanying the photochromic reaction of diarylethene, holographic gratings can be recorded on diarylethene media not only by polarization modulation but also by intensity modulation.[11] The polarization multiplexing scheme is based on the multiple polarization hologram recording in polarization-sensitive materials by alternating the object and reference waves with parallel and orthogonal polarization, either in linear or in circular polarization. Using diarylethene **1b**/PMMA film as a recording medium, we carried out both circular polarization and linear polarization multiplexing tests, as shown in Fig. 3. The features of these tests are that the hologram recording and reconstruction are in the same optical setup; the readout of the two object images is controlled by selectively setting the polarization angle of the polarizer P. In Fig. 3, the retrieved images [Figs. 3(a)–3(c)] from circular polarization multiplexed holograms were recorded in the same region in a **1b**/PMMA film, while the retrieved images [Figs. 3(d)–3(f)] from linear polarization multiplexed holograms were recorded in the same region in another **1b**/PMMA film. The reference wave is kept in left-hand circular polarization during recording, and the object wave of the first image [Fig. 3(a)] is set to be left-hand circular polarization and the second image [Fig. 3(b)] to be right-hand circular polarization. In the reconstruction process, a single left-hand circularly polarized beam is used to reconstruct the two orthogonally circularly polarized images simultaneously. The quarter-wave plate Q_3 transforms the circularly polarized light into linearly polarized light. As a result, the two object images are discriminated by possessing orthogonally linearly polarized states. Thus, by rotating the polarization angle of the polarizer P, different images can be selectively read out. From Figs. 3(a) and 3(b), it can be seen that the two object images can be fully separated and viewed independently as long as the polarization angles of P are 0 and 90 deg, otherwise an overlapped image appears, as in Fig. 3(c). Similarly, the same phenomena appeared in linear polarization multiplexing, as shown in Figs. 3(d)–3(f). The results showed that parallel linear polarization holographic recording achieved high diffraction efficiency and high scattering noise when the intensity of the recording and the readout wave were both fixed [Fig. 3(d)]. However, the orthogonal linear polarization holographic recording possessed low diffraction efficiency as well as low scattering noise [Fig. 3(e)]. When the readout linear polarization angle is 45 deg, an overlapping image appears as in Fig. 3(c). By changing the polarization angle of the polarizer P, different polarization images can be hidden in the pattern and recorded on the recording medium, resulting from the photochromic and photoinduced anisotropic properties of this diarylethene compound. The hidden images can be read out separately only when the polarizer P locates on a certain polarization angle. This characteristic may possibly be applied in camouflage technology.[9] Comparing the results of the two types of polarization multiplexing, we can see that each image of circular polarization multiplexing has approximately equal intensity, while that of linear polarization multiplexing has not. From this point of view, circular polarization multiplexing is better than linear polarization multiplexing when diarylethene **1b**/PMMA is used as the recording medium.

3.2.2 *Polarization plus angular multiplexing holograms*

To further increase the memory capacity of the holographic recording, we propose to combine the angular multiplexing scheme with the polarization multiplexing scheme according to the ability of the polarization multiplexing of diarylethene **1b**/PMMA film described before. In the combined multiplexing scheme, the principal multiplexing scheme is angular multiplexing and the secondary scheme is polarization multiplexing. The retrieved holograms of the combined multiplexing scheme are shown in Fig. 4. For

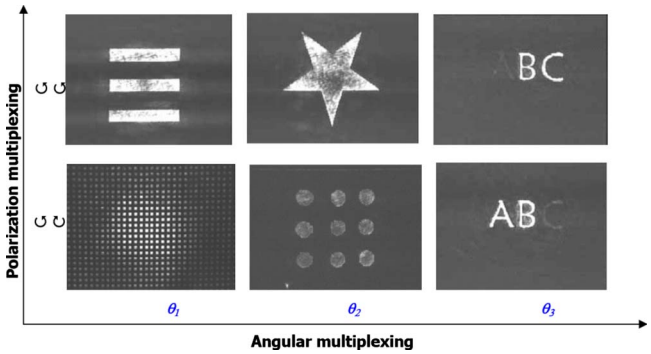


Fig. 4 Experimental results for angular multiplexing scheme combined with polarization multiplexing scheme in diarylethene **1b**/PMMA film.

each angle of the reference beam, two polarization holograms, *i.e.*, parallel circular polarization hologram and orthogonal circular polarization hologram, were recorded on diarylethene **1b**/PMMA film. A He-Ne laser (633 nm, 3 mW) was used for recording and readout beams. The object beam size on the sample plane is about 100 μm in diameter. The intensities of the object beam and the reference beam are both 14 mW/cm^2 on the diarylethene **1b**/PMMA film. The exposure time for each hologram recording is 8 sec. With 4 deg angular separation, three angles of reference beam were used in this experiment. Therefore, six holograms were recorded in the same region of the diarylethene **1b**/PMMA film. From Fig. 4, it can be seen that the six holograms were retrieved without cross talk, which is very important for successful realization of multiplexing holographic recording. Compared with the single angular multiplexing scheme, the holographic recording density can be doubled when using this combined multiplexing scheme. Therefore, the combined multiplexing scheme will lead to a higher data capacity than the single angular multiplexing method. In addition, experimental tests showed that the hologram recorded in the diarylethene **1b**/PMMA film is stable at room temperature in darkness. We also tested the fatigue resistance of diarylethene **1b**/PMMA film, indicating that the coloration-decoloration cycle was repeated more than 100 times and no remarkable photodegradation was found.

4 Conclusion

We synthesize a new unsymmetrical photochromic diarylethene and investigate its photochromic properties. Using this compound as recording medium, we combine the polarization multiplexing scheme with the angular multiplexing scheme to improve the information capacity of the holographic recording technique. The results illustrate that diarylethene has attractive properties for polarization holographic optical recording, such as high photosensitivity, excellent fatigue resistance, and a polarization-sensitive response. It is hoped that this work will be helpful in accumulating evidence to realize high-density polarization holographic optical recording using photochromic diarylethenes as recording media.

Acknowledgments

This work was supported by the Projects of National Natural Science Foundation of China (20564001, 60678023), the Project of Jiangxi Youth Scientist, and the Natural Science Foundation of Jiangxi, China (0620012).

References

1. A. Bianco, C. Bertarelli, J. F. Rabolt, and G. Zerbi, *Chem. Mater.* **17**, 869 (2005).
2. Y. Chen, C. M. Wang, M. G. Fan, B. L. Yao, and N. Menke, *Opt. Mater. (Amsterdam, Neth.)* **26**, 75 (2004).
3. H. J. Coufal, D. Psaltis, and G. T. Sincerbox, *Holographic Data Storage*, p. 167, Springer-Verlag, New York (2000).
4. L. Dhar, A. Hale, H. E. Katz, M. L. Schilling, M. G. Schnoes, and F. C. Schilling, *Opt. Lett.* **24**, 487 (1999); A. Akella, S. L. Sochava, and L. Hesselink, *Opt. Lett.* **22**, 919 (1997); and V. P. Pharm, G. Manivannan, and R. V. Lessard, *Opt. Mater. (Amsterdam, Neth.)* **4**, 467 (1995).
5. M. Irie, *Chem. Rev. (Washington, D.C.)* **100**, 1685 (2000); H. Tian and S. J. Yang, *Chem. Soc. Rev.* **33**, 85 (2004); S. Z. Pu, G. Liu, L. Shen, and J. K. Xu, *Org. Lett.* **9**, 2139 (2007); and N. Xie and Y. Chen, *J. Mater. Chem.* **16**, 982 (2006).
6. K. Uchida, M. Saito, A. Murakami, T. Kobayashi, S. Nakamura, and M. Irie, *Chem.-Eur. J.* **11**, 534 (2005); and S. Z. Pu, F. S. Zhang, J. K. Xu, L. Shen, Q. Xiao, and B. Chen, *Mater. Lett.* **60**, 485 (2006).
7. Y. J. Zhou, H. H. Tang, W. H. Huang, A. D. Xia, F. Sun, and F. S. Zhang, *Opt. Eng.* **44**(3), 035202 (2005).
8. S. Z. Pu, T. S. Yang, B. L. Yao, Y. L. Wang, M. Lei, and J. K. Xu, *Mater. Lett.* **61**, 855 (2007); and G. D. Liu, Q. S. He, D. H. Ding, M. X. Wu, G. F. Jin, and S. Z. Pu, *Chin. Phys. Lett.* **20**, 1051 (2003).
9. B. L. Yao, Y. L. Wang, M. Lei, N. Menke, and G. F. Chen, *Opt. Express* **13**, 20 (2005).
10. B. L. Yao, Z. W. Ren, N. Menke, Y. L. Wang, Y. Zheng, M. Lei et al., *Appl. Opt.* **44**, 7344 (2005).
11. B. L. Yao, Y. L. Wang, N. Menke, M. Lei, L. Y. Ren, and S. Z. Pu, *Proc. SPIE* **6343**, 63432Z (2006).