Three-dimensional multiplex micro-hologram using diarylethene-doped PMMA film

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Three-dimensional multiplex micro-hologram using diarylethene-doped PMMA film

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ASBTRACT
A large-capacity recording media is realized by three-dimensional micro hologram. In this research, we have succeeded in fabricating multiple micro holograms, and their diameters are the same as that of Airy disk ($\phi = 1.15\ \mu$m) of an objective lens. This result will provide a great improvement of the memory capacity.

KEYWORDS
Hologram; optical memory; confocal microscope

1. Introduction

Three-dimensional optical memory is regarded as an attractive recording system from the point of view of mass storage methods. Recording systems have been developed with various kinds of methods. Holographic memory, in particular, allows for recording and reading data as a batch of page [1]. The holographic memory will also provide quick access speed.

Micro holographic memory has more recording capacity than other holographic memory, since its pit size is reduced by use of an objective lens. The ability to read or write page data enables thousands of data to be dealt by a single shot of the recording beam through the lens [2].

In this research, we attempt to improve the recording capacity by means of a three-dimensional micro hologram.

2. Experiments

We describe spectrum properties of photochromic materials that we used for recording a micro hologram. Diarylethene-doped polymerylmethacrylate (PMMA) film (100 μm film thickness) is used as a record medium. A brief review of a preparation for a thick diarylethene (1,2-Bis(2,4-dimethyl-5-phenyl-3-thienyl)-3,3,4,4,5,5-hexafluoro-1-cyclopentene derivative)-doped PMMA (polymethylmethacrylate) film is as follows: mixing PMMA(MW:224,000) with cyclohexanone at a rate of 15 wt% and stirring them up sufficiently heating at 60°C; after PMMA dissolves completely, mixing diarylethene with the solution at a rate of 2.6% and making a stirring as same as the previous step; after diarylethene dissolves completely, making the resolution fall in drops on a glass plate and drying it up in a vacuum oven set at 60°C. This film has a thickness of about 100 µm.

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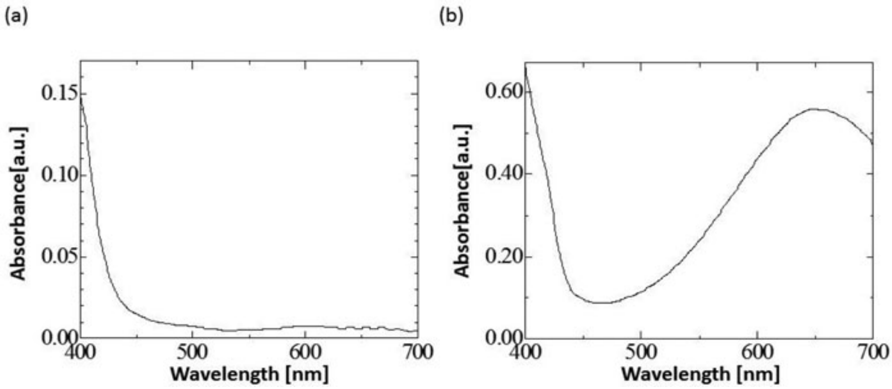

Figure 1. Profiles of absorbance spectrums of diarylethene; (a) in ring-opening structure., (b) in ring-clothing structure.

Diarylethene is a photochromic material. On exposure to UV light, hexatriene in the center of diarylethene will vary its ring-opening structure into a ring-closing structure. Then, when exposing to visible light, hexatriene will rechange in the opposite direction [3,4]. In this study, we utilize the difference between the absorption spectra of two isomers as a record (see Fig. 1). The difference arises from the structural change [5].

Next, we describe recording and reading methods of micro hologram. Figure 2 shows an optical system to fabricate and measure micro holograms. A blue laser of 473-nm wavelength is used for fabricating them; a LD laser of 633-nm wavelength is used for observing them. Two beams of blue laser that is split by a beam splitter focus on the sample through two objective lenses (NA = 0.5) being positioned nose-to-nose, on opposite sides of it. The resultant recorded hologram was observed in detail with a confocal microscopic optical system. The blue laser and the LD laser sources are incoherent with each other. The optical power of the LD laser source was set to weak enough not to undergo photobleach.

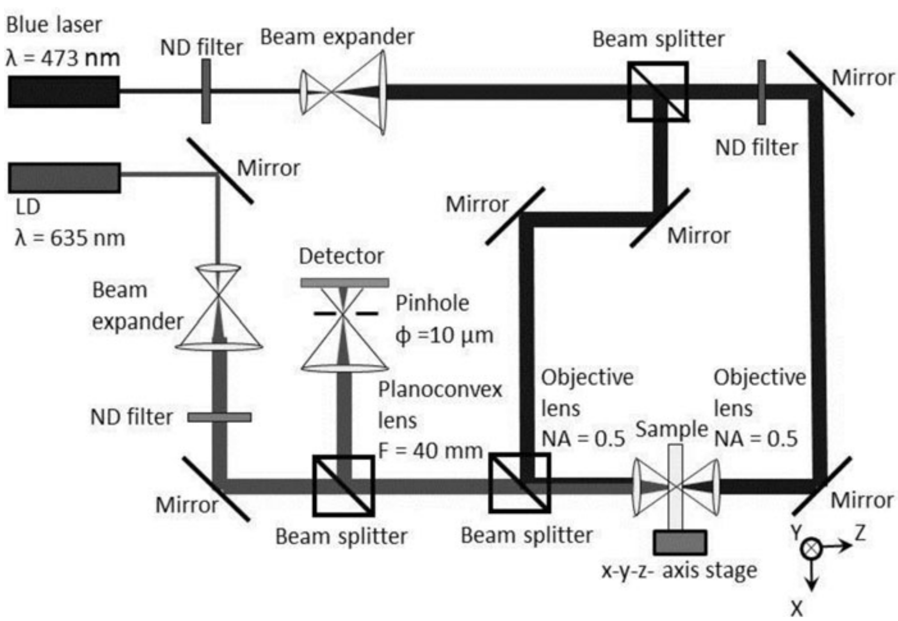

Figure 2. Optical system of two beam interference exposure with confocal microscope embedded.

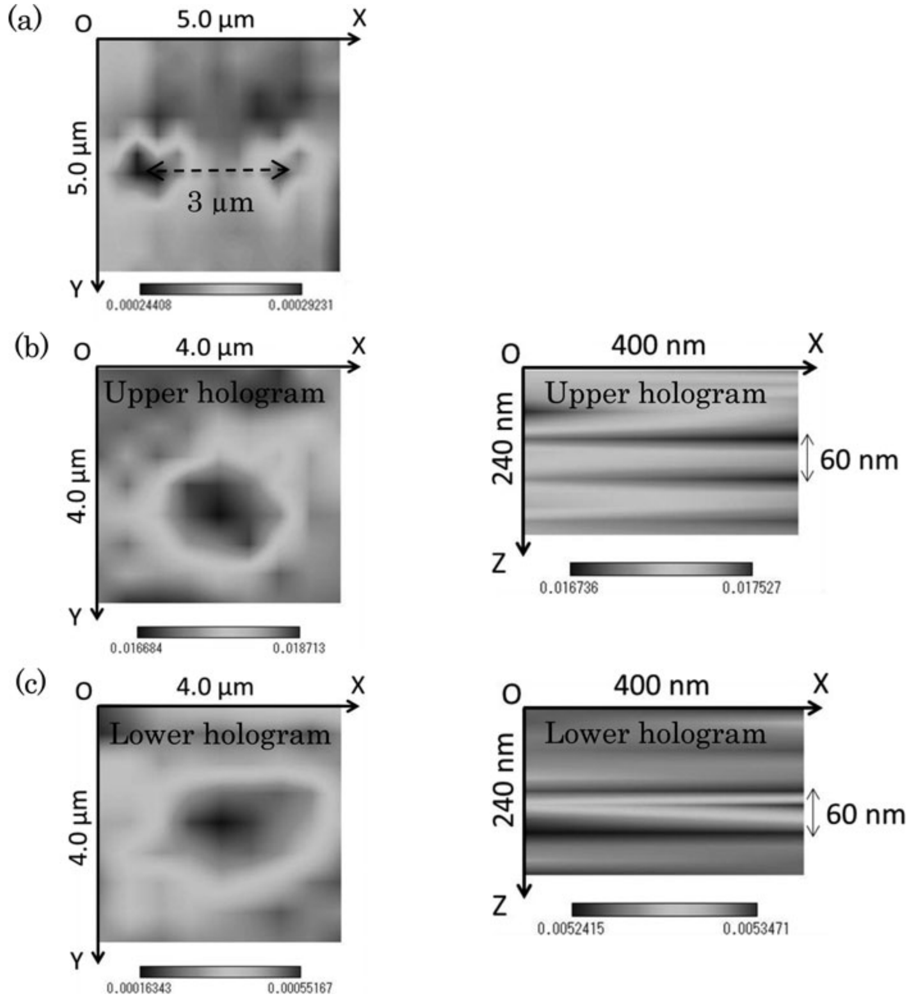

Figure 3. Confocal image of fabricated micro hologram. (a) Widely scanned image of a surface of the sample. (b) Top-view and cross-sectional images of upper micro hologram. (c) Top-view and cross-sectional images of lower micro hologram.

3. Results and discussion

We describe an internal state of the fabricated micro hologram. Fig. 3 shows the scanned images of the sample in which the micro holograms are recorded. First, one hologram fabrication was operated at the surface of the sample, then the other hologram was recoded at the point which is 5 µm (automated stage movement with the direction of optical z-axis) inside from the surface of the sample. The literal amount of movement was set to 3 μm. A duration of the recording exposure was set to 0.1 s. Peak exposure dose was 56 kJ/cm^2. Figure 3(a) shows an image of a widely scanned surface of the sample in the x-y plane of $5\ \mu m \times 5\ \mu m$ at a rate of 500 nm per step. This image indicates that the lateral shift-multiplexed recording was achieved in a distance interval of 3 μm. Figure 3(b) shows the top-view and cross-sectional images of upper micro hologram. Figure 3(c) shows the top-view and cross-sectional images of lower micro hologram. Two Figures on the left- side indicate that the size of each exposed spot was limited to about 1.15 μm. Now a diameter of Airy disk size is defined as

$$\varepsilon = 1.22 \times \frac{\lambda}{\mathrm{NA}}. \quad (1)$$

then it was calculated as $\varepsilon = 1.15\ \mu$m when $\lambda = 473$ nm and NA = 0.50. Thus it is evident that the range of nonlinear exposure was limited to the Airy disk size. This result provides the indication that the record of the hologram pit can be realized not with a heat mode but with a photon mode. Two Figures on the right-side show sample's cross-sectional images scanned each exposed spot in the x- z plane of 400 nm×240 nm at a rate of 20 nm per step. Note that linear absorption has an effect on these images. There are 5-μm intervals between the pits of the surface and the inside of sample. When scanning the recorded sample with an automated stage, we consider the refractive index difference between those of air n_0 and medium n_1. Thus, a moving distance of the automated stage should be converted into an optical distance. Defining the refractive index of the air as $n_0 = 1$, an equation is converted to

$$L_2 = L_1 \frac{\sqrt{{n_1}^2 - NA^2}}{1 - NA^2}. \quad (2)$$

where L_1 is the travel distance of the automated stage, L_2 is the optical distance, and n_1 is the refractive index of a medium ($n_1 = 1.51$) [2]. Hence, the above value is converted to 8.16 μm as an optical distance.

Next, we discuss the periodic structures of each micro hologram. The right-side figure indicates that both periods of the micro holograms measured with the automated stage were 60 nm. Applying the conversion (Eq. 2), the actual period is 150 nm. Here, theoretical period of diffraction grating is calculated by the following

$$\Lambda = \frac{\lambda}{2n}. \quad (3)$$

then it was calculated as $\Lambda = 157$ nm when $\lambda = 473$ nm and n = 1.51. But, this theory assumes the scanning in the medium that has a uniform refractive index profile, so there are some errors are in date when we scanned a medium with periodic structure of refractive index like the fabricated hologram pit. Hence, the period of diffraction grating which was obtained from the result is approximately equal with a theoretical value, which fact suggests that we were able to make micro holograms appropriately. The upper micro hologram is double exposed to the recording beams when the lower micro hologram is recorded. The upper one keeps high contrast after double exposure.

4. Conclusion

We have succeeded in fabricating multiplex micro holograms in the optical axial direction whose distance interval is 8.16 μm, and its diameter is the same as that of Airy disk of an objective lens. The photoisomerization structural change of diarylethene enables us to fabricate an optical periodic structure without physical layered structure. The upper one keeps high contrast after double exposure. By regulating exposure strength appropriately (in low power) for a recording medium, we control an exposure domain and the reversibility of the structural change at a relatively high accuracy. The results suggest that the optical memory enables high density recording with simple structure.

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