FEMTOSECOND PHOTONICS FOR THREE-DIMENSIONAL HIGH DENSITY OPTICAL DATA STORAGE

Yoshimasa Kawata, Masatoshi Tsuji, Wataru Inami

Abstract:

We have developed a high density optical data storage by using two-photon absorption process. We have developed a multilayered medium in which photosensitive layers and transparent pressure-sensitive adhesives layer were piled up alternately. We also demonstrate the development of compact high power fiber laser as a light source of high density optical data storage system.

Keywords: *femtosecond pulse laser, two-photon absorption, confocal microscopy, optical memory.*

1. Introduction

Femtosecond laser is a very promising tool for opening new applications [1],[2]. It is possible to fabricate inside of transparent materials, produce three-dimensional fine structures with photosensitive resin, study dynamics of very fast response of materials. Many applications are proposed and have been developed by using femtosecond lasers.

We have developed three-dimensional (3D) optical memory for ultra-high data storage as an application of femtosecond photonics [3]-[8]. Because 3D optical memory can achieve high recording capacity as much as the numbers of recording layers, it is possible to overcome the density limit determined by the diffraction of light [9]. We have developed a multilayered medium in which photosensitive recording layers and transparent layers are piled up alternately in order to increase signal to noise ratio. We have developed the fabrication technique of multilayered mediums using pressure sensitive adhesive.

2. Fabrication of Multilayered Medium

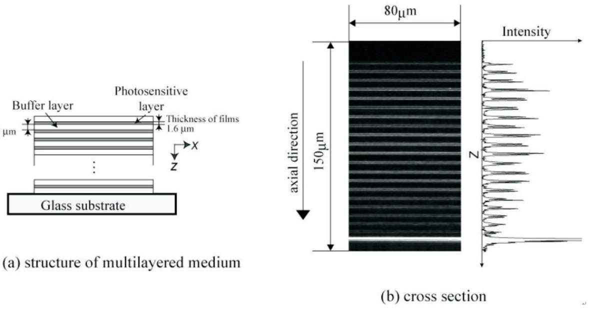
We fabricated multilayered medium by wet coating and laminating process using pressure sensitive adhesives (PSAs). First, the photosensitive layer and the PSA as buffer layer were deposited on release liner films. Coating solutions were cast on release liner films, and then solvents were removed in a dryer. The photosensitive layer and the PSA were laminated together. The two layered sheets are superposed on each other continually up to 20 layers. 1,3,3-trimethylindolino-6'-nitrobenzopyrylospiran was used as photosensitive materials.

We observed the axial distribution of the fabricated multilayered medium. Figure 1(a) shows the structure of the 20-layered medium we fabricated. Thickness of photosensitive layers was 1.6 μm and thickness of transparent layers was 4.6 μm. Figure 1(b) shows observation result and the cross section of readout signal with a reflection confocal microscope. We confirmed that each photosensitive layer could be observed clearly, without decreasing signal intensity in deep region.

By fabricating layered structures in a recording medium, we can control the spatial frequency distribution of recorded bit in the axial direction, and optimize it for a readout system of the multilayered optical memories [4]-[6]. Extension of the spatial frequency distribution in the axial direction is advantageous for the readout system of the multilayered memories. The distribution is given by convolution of the frequency distribution of the bit intensity and that of the multilayered medium. As a result, because each individual bit in the multilayered medium contains higher spatial frequency components in the axial direction, the spatial frequency distribution of a bit recorded in the multilayered medium easily overlaps the coherent transfer function (CTF) of the reflection confocal microscope which is used as readout system.

The recording density can also be increased by using the multilayered medium. When a bit is recorded in a multilayered medium, its size may be confined in a volume smaller than that of the focused spot. It is possible to reduce the interval between individual bits in the axial direction.

We demonstrated to record and read bit patterns in the multilayered medium fabricated by laminating process. Figure 2 shows recording and reading results. Random bit patterns were recorded in twenty layers and read out without crosstalk. We recorded the 3D bit patterns with a Ti:sapphire laser (Spectra-Physics: Mai Tai) at 800 nm in mode-locked pulse laser operation and used an oil immersion lens with a NA of 1.3 to decrease spherical aberration produced by refractive index mismatch between the air and the medium. The exposure time is 125 ms. The layer interval between neighboring photosensitive layers was 6.2 μm. The most adjacent bit distance in plane direction is 2.0 μm.



(a) structure of multilayered medium

(b) cross section

Fig. 1. The cross section of the 20-layered medium fabricated by laminating process (a) Schematic diagram of multilayered medium (b) axial response read with a reflection confocal microscope.

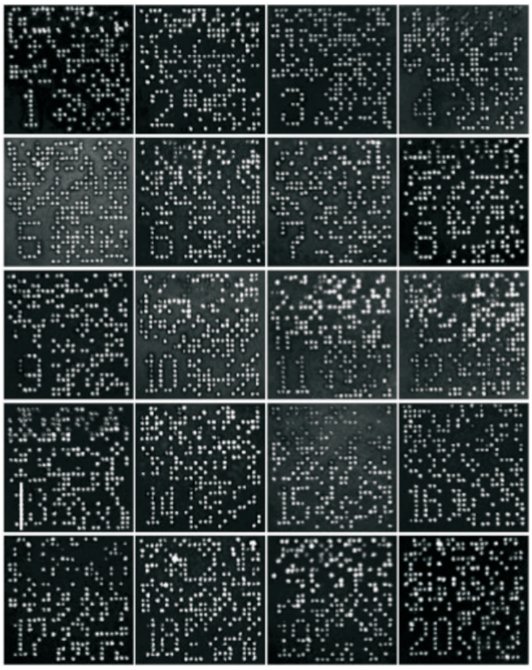


Fig. 2. *Recording and reading results of twenty-layers data.*

3. Compact and High-Power Mode-Locked Fiber Laser for Three-Dimensional Optical Memory

We also have developed compact femtosecond fiber as a light source of femtosecond photonics. Mode-locked pulse lasers are very promising as alight source in many applications, such as nonlinear spectroscopy, high-resolution micro-processing, multi-photon microscopy and optical memory, etc. Currently, bulk solid-state lasers such as Ti-Sapphire laser are widely used but their applications are limited because of the large size and worse stability.

Recently, passively mode-locked erbium-doped fiber laser is developed. Fiber lasers have potential to be compact and stable light source which can replace bulk solid-state lasers in the near future [10], [11]. Moreover, the spatial property of output beam from fiber lasers is circular profile and very stable.

We have developed high-power erbium-doped fiber ring laser using the stretched-pulse mode-locking. The fiber laser is very promising to replace a Ti-Sapphire laser that is used for three-dimensional optical memory. In this paper, we introduce compact and high-power erbium-doped fiber (EDF) ring laser for three-dimensional optical memory.

Figure 3 shows the configuration of compact high-power fiber laser. The laser cavity was composed with EDF and single mode fiber (SMF). EDF had positive dispersion and SMF had negative dispersion at 1.56 μm. Two 980 nm laser diodes (LDs) were combined by polarization beam combiner (PBC) and were used as pump laser. The power of each LD was 450 mW. EDF was pumped through the wavelength division multiplexing (WDM). Output of 1:99 coupler was used as monitor which connect with spectrum analyzer and oscilloscope.

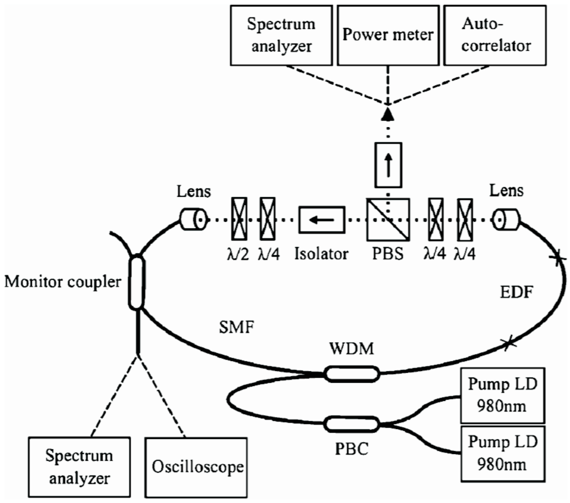


Fig. 3. *Experimental setup of mode-locked fiber laser.*

Figures 4 shows the spectrum of the output pulse measured the output from the coupler. The vertical axis is output power and the transverse axis is wavelength. A Gaussian shape spectrum was obtained in the developed fiber lasers. Figure 5 shows a pulse train of the laser output. The repetition rate of pulse was 40 MHz and the pulse width was supposed as several picoseconds. By chirped pulse compensation, it was conpressed the pulse width to nearly 100 fs. Averaged power was measured by PBS and was about 30 mW. The peak power was estimated to be 0.75 nJ from the averaged power and the repetition rate. The output power is enough for the application of three-dimensional optical memory.

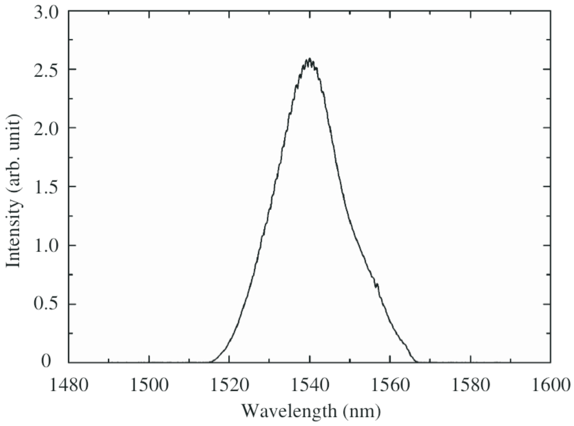


Fig. 4. *The spectrum of output pulse from monitor port.*

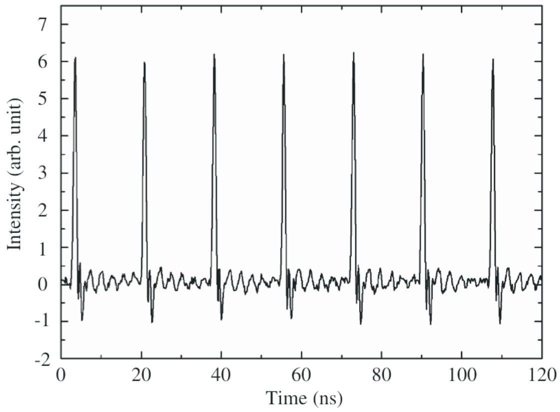


Fig. 5. *Pulse train of the developed fiber laser.*

4. Data Recording of Three-Dimensional Optical Memory

Figure 6 shows the 3D recording demonstration of photochromic materials by using the fiber laser we have developed. Two layers was recorded and readout. Figure 6(a) shows the 1st layer and (b) is the 2nd layer. Letter "A" and "B" were recorded in bit sequence for each layer respectively. The spacing between the layers is 40 µm. The recording power used was 4.7 mW with an exposure time of 1/125 s focused into the media. The cross talk in the 2nd layer was observed due to the detection system do not incorporate confocal system. The confocal readout system can improve the contrast of readout data.

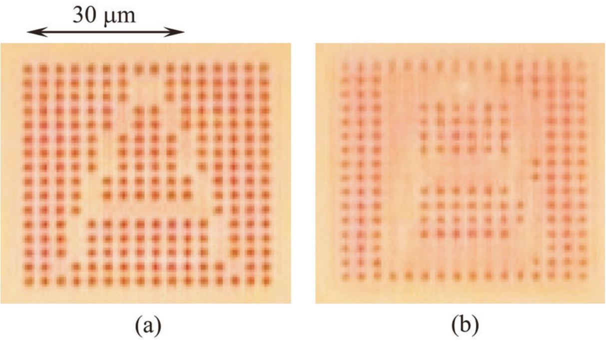


Fig. 6. Three-dimensional recording result. (a) 1st layer and (b) 2nd layer.

5. Conclusions

We have succeeded in recording and reading of bit data in a 20 layers medium fabricated by wet coating and laminating process. We are now developing a hundred layers recording media. It was confirmed that each photosensitive layer could be observed clearly without decreasing the signal intensity by the reflection confocal microscope. Random bit patterns were recorded in ten layers and read out without crosstalk. Asa conclusion we may say that the multilayered medium fabricated by wet coating and laminating process is advantageous as the medium of optical memory.

We also have developed the compact and high-power fiber ring laser [12]. We can achieve about 30 mW and pulsed-operation of 40 MHz repetition rate. The fiber configuration has potential to approach 100 mW averaged power and 100fs pulse width by adjustment of the wave plates and the fiber length. The fiber laser is very promising as a light source for three-dimensional optical memory.

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