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Magneto-optical Imaging by Scanning Near-field Optical Microscope Using Polarization Modulation Technique

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A polarization modulation technique has been applied to a scanning near-field optical microscope (SNOM), in order to improve sensitivity and resolution of a magneto-optical (MO) imaging. Polarized light modulated by a photoelastic modulator (PEM) was introduced into a bent-type optical fiber probe operated as an AFM cantilever, and transmitted MO signals were detected using a lock-in amplifier. Ar ion laser (488 nm) was used as a light source. By using this technique, images of recorded marks on a Pt/Co disk were successfully obtained, which were written by a magnetic field modulation method with a length of 1μm and a track pitch of 1.6 μm on a multilayer of Pt (0.8 nm) / Co (0.3 nm) with thickness of 15 nm. A resolution of approximately 90 nm was obtained in the MO imaging.

Key words: magneto-optical imaging, scanning near-field optical microscope. polarization modulation technique, PtCo. optical fiber probe

1. Introduction

The magneto-optical (MO) storage devices have been developed as an attractive alternative to traditional magnetic disks. In view of a research of materials, development of the characterization method on magnetic properties. as well as the imaging technology, in mesoscopic size is strongly required to attain the higher recording density. As observation techniques. Lorentz electron microscope,[1] spin-polarized scanning electron microscope (SP-SEM),[2] magnetic force microscope (MFM),[3] spin-polarized scanning tunneling microscope (SP-STM) and scanning near-field optical microscope (SNOM) have been developed.

Magneto-optical imaging using the Faraday effect or the Kerr effect is attractive since it provides a direct image of magnetization of samples. However the resolution in optical measurement is generally governed by the diffraction limit. We chose the SNOM which can provide a resolution with subwavelength by utilizing the near-field optics.

Until now, there are several reports on the MO imaging using optical fiber probes. Betzig et al. succeeded in the MO recording as well as observation in subwavelength scale by using the SNOM technique with a straight-type fiber probe.[4,5] In our preceding paper we reported MO imaging technique using SNOM with the bent-type fiber probe.[6] In both cases. the crossed polarizer method has been applied to obtain MO images, although different feedback techniques for levitation of the probe was utilized.

In this paper. we report the MO imaging by SNOM with a polarization modulation technique, which has been developed for the MO spectroscopy.[7,8] This technique has an advantage to obtain the sub-wavelenghth-scale MO images with high sensitivity and high resolution.

2. Experimental Setup

The schematic diagram of the near-field MO microscope is illustrated in Fig.1. This apparatus is based on a commercially available AFM unit (model SPI3700, Seiko Instruments).[9] A sharpened and bent optical fiber probe was mounted beneath a bimorph and vibrated at the resonant frequency (typically 10-40 kHz). The distance between the probe and the sample was controlled by the dynamic feedback technique to approximately 20 nm. Light of 488 nm from an argon ion laser was coupled into the cleaved end of the optical fiber probe. The beam was modulated by an acousto-optic (AO) modulator at the vibration frequency to improve the signal-to-noise ratio of the optical signal. The retardation of the light was modulated at p = 50 kHz by a photo-elastic modulator (PEM) to obtain the MO signal. To compensate the anisotropic polarization state of the beam emitted from the probe, a quarter-wave (λ/4) and a half-wave (λ/2) plates were placed in front of the input fiber coupler. The transmitted light from the sample was detected by a photomultiplier tube through a collimation lens, a reflective mirror, an optical filter and an analyzer. The signal from the photomultiplier was demodulated and amplified by a lock-in amplifier. The MO image was visualized using the modulating frequency component p(=50 kHz) of the detected signal. In principle, the p and $2p$ components of the detected signals are corresponding to

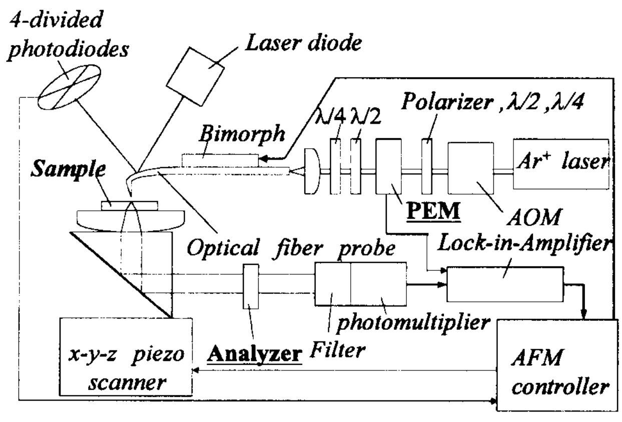

Fig. 1 Schematic illustration of the near-field magneto-optical microscope using polarization technique.

the magneto-circular dicroism (MCD) and the Faraday rotation, respectively, if an ideal polarization property is maintained during transmission through the fiber probe.

3. Results and Discussion

3.1 Polarization properties of fiber probes

The polarization properties of the light emitted from the aperture were measured at a far-field region to obtain the polarization effect of the fiber probe separately avoiding any interaction between the aperture and the sample. Figure 2 shows the relation between the rotation angle of the polarizer placed in front of the fiber coupler and the polarization extinction ratio of the light emitted from the aperture of the probe. Here the extinction ratio is defined as the ratio of the maximum to the minimum intensity of the signal on rotating the analyzer. It is found that the bent optical fiber acts as if it were a wave plate, due to the optical anisotropy induced by bending. The transmission characteristics of a polarized light through the bent probe varied from sample to sample depending on the fabrication process, i.e., at present the fabrication technology of the probe is not completely optimized as far as polarization properties are concerned. Consequently, some of the probes showed less satisfactory characteristics leading to poor MO images as far as the conventional crossed polarizer method is employed. In order to overcome this situation and improve the sensitivity of MO imaging, we utilized the polarization modulation technique with the PEM, which has been applied to the mageto optical spectroscopy.

3.2 MO imaging of recorded marks

An MO-disk using a Pt (0.8 nm) / Co (0.3 nm) multilayer with thickness of 15 nm as a recording layer was employed for the measurement. The disk has a tracks pitch of 1.6 μm and a groove-depth of 0.08 μm. The marks were recorded by a magnetic-field modulation recording method with a length of 1 μm on the tracks. Faraday rotation and MCD spectrum were measured with a conventional polarization modulation technique, and angles of Faraday rotation and MCD at 488 nm were determined to be 0.27° and 0.45°, respectively.

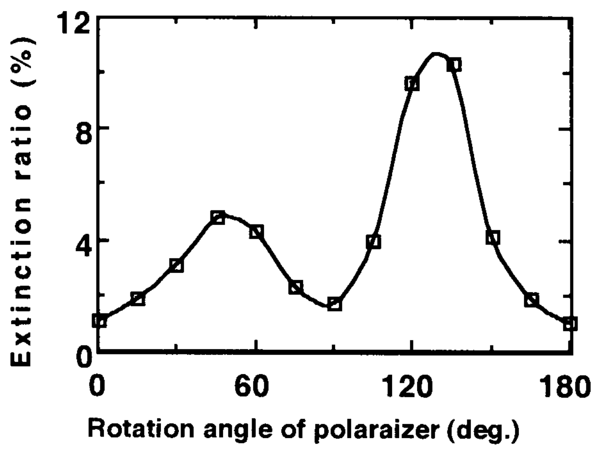

FIg. 2 Extinction ratio of light emerging from the aperture of the fiber probe.

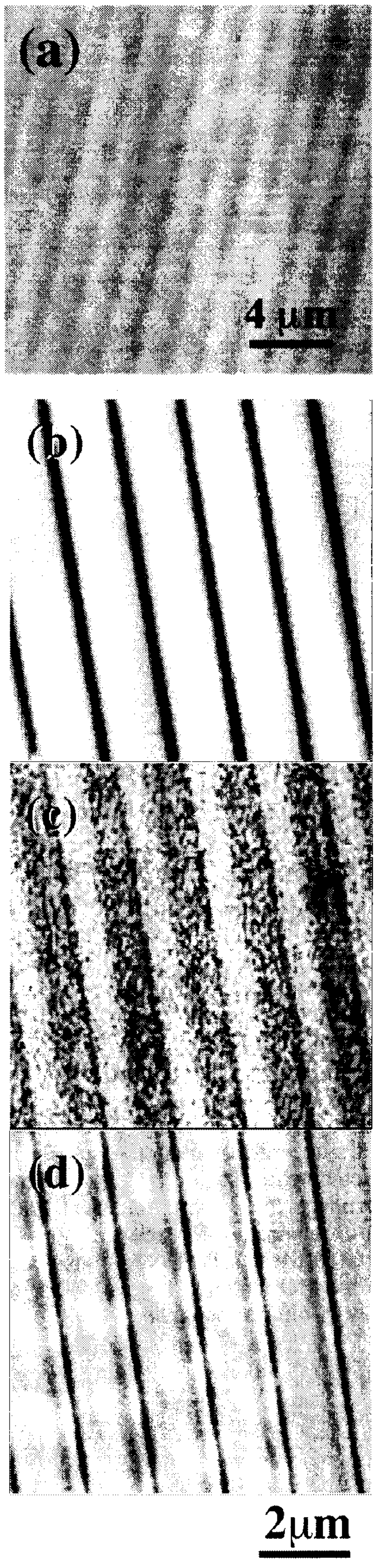

Fig. 3 A magneto-optical image (a) observed by conventional optical microscope. A topographic image (b), an optical image (c) and a magneto-optical image (d) measured by SNOM.

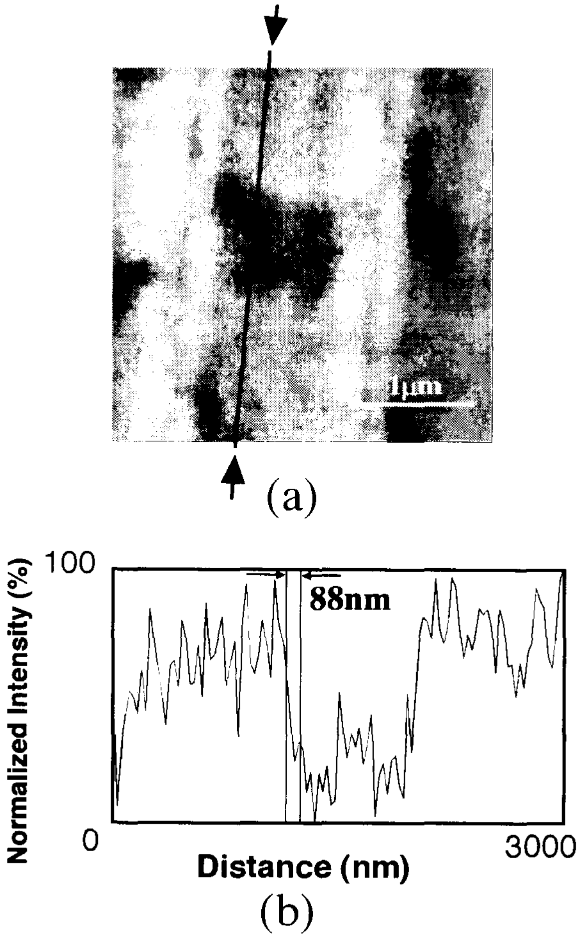

Fig. 4 An enlarged image for an bit (a) and a line scan (b).

With a conventional optical microscope with a crossed Nicol method it is difficult to resolve a shape of recorded marks clearly as shown in Fig. 3(a). Figures 3(b), 3(c) and 3(d) show an AFM topographic image, an unpolarized SNOM image and an MO image, respectively. No structures corresponding to the recorded marks were found on the tracks in the topographic image shown in Fig.3(b) and the optical image shown in Fig. 3(c), although the grooves of the disk were clearly observed. The MO-images of the recorded marks of ~1 μm in length were successfully obtained as shown in 3(d). Figure 4 shows an enlarged image for a mark, in which the "crescent-shaped mark characteristic of the magnetic field modulation is clearly resolved. The figure also shows a line scan on the MO imaging, from which a resolution of approximately 90 nm was obtained.

Since these MO images were obtained by using the p (= 50 kHz) component of the signal detected, they are expected to correspond the MCD in an ideal case. However, it may suffer a considerable mixing with the signal of the Faraday rotation due to a poor polarization properties of the fiber probe. For further understanding of this effect, the relation between the polarization properties of the optical fiber probe and the MO images should be elucidated. This problem is still under investigation.

4. Conclusions

By applying the polarization modulation technique to the SNOM, images of marks recorded on a Pt/Co disk were successfully obtained. The recorded marks of ~1 μm length were clearly observed on the tracks. A resolution of approximately 90 nm was obtained in the MO imaging. The sub-wavelength MO imaging was thus successfully performed in this experiment.

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References

1) J. N. Chapman, A. B. Johnson and L. J. Heyderman: *J. Appl. Phys.* **76**, 5349 (1995).
2) K. Koike and K. Hayakawa: *Jpn. J. Appl. Phys.* **23**, L187 (1984).
3) D. Rugar, H. J. Maimin, P. Guethner, S. E. Lambert, J. E. Stern, U. Mc-Fadyen and T. Yogi: *J. Appl. Phys.* **68**,1169 (1990).
4) E. Betzig, J. K. Trautman, R. Wolfe, E. M. Gyorgy, P. L. Finn, M. H. Kryder and C. -H. Chang: *Appl. Phys. Lett.* **61**, 142 (1992).
5) E. Betzig, J. K. Trautman, J. S. Weiner, T. D. Harris and R. Wolfe: *Appl. Optics* **31**, 4563 (1992).
6) Y. Mitsuoka, K. Nakajima, K. Homma, N. Chiba, H. Muramatsu, T. Ataka and K. Sato: *J. Appl. Phys.* **83**, 3998 (1998).
7) K. Sato: Jpn. *J. Appl. Phys.* **20**, 2043 (1981).
8) K. Sato, H. Hongu, H. Ikekame, Y. Tosaka, M. Watanabe, T. Takanashi and H. Fujimori: *Jpn. J. Appl. Phys.* **32**, 989 (1993).
9) N. Chiba, H. Muramatsu, T. Akata and M. Fujimura: *Jpn. J. Appl. Phys.* **34**, 321 (1995).