Switching Field and Resolution of MFM Tips Prepared by Coating Fe/Co\textsubscript{50}Pt\textsubscript{50} Magnetic Films

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Abstract. Magnetic force microscope (MFM) tips are prepared by coating Fe(10 nm)/Co\textsubscript{50}Pt\textsubscript{50}(x nm)/Ru(5 nm) (at. %) films at 300 \degree C on Si-base tips of 4 nm radius. The thickness of CoPt layer, x, is varied in a range of 10 – 200 nm. The effects of coating thickness on spatial resolution and switching field of MFM tip are investigated. With increasing the thickness, the resolution deteriorates from 9.4 to 12.1 nm. The switching field increases from 0.675 to 2.025 kOe with increasing the coating thickness from 10 to 200 nm. A tip prepared by coating 100 nm thick Co\textsubscript{50}Pt\textsubscript{50} film which has high resolution and high switching field property is successfully applied to the observation of magnetization structure of high-Ku magnetic thin film with L\textsubscript{10}-ordered structure.

1. Introduction
Magnetic force microscopy (MFM) has been used to investigate the magnetization structures of magnetic samples. MFM tips are generally prepared by coating non-magnetic sharp tips with magnetic materials [1]. As the areal density of hard-disk-drive (HDD) medium is approaching 1 Tb/in\textsuperscript{2}, where the bit length is becoming narrower than 30 nm, MFM resolution around 10 nm is necessary. Furthermore, in the observation of materials with high Ku like permanent magnets and recording media, high switching field (H\textsubscript{sw}) property is required so that the tip magnetization does not change during the observation process. Recently, we have shown that high H\textsubscript{sw} can be realized by coating Co\textsubscript{50}Pt\textsubscript{50} alloy films on Si base-tips at temperatures around 300 \degree C [2, 3]. A high H\textsubscript{sw} of 1.5 kOe is observed for a tip coated with 20 nm-thick CoPt film which is due to high Ku property of L\textsubscript{11} ordered phase of the film.

To further increase the H\textsubscript{sw} while keeping high resolution property, Fe/CoPt films are deposited on Si base tips with varying the CoPt film thickness up to 200 nm. Top coating of Fe film is introduced to enhance the detection sensitivity of MFM tip which depends on the saturation magnetization. The effects of coating thickness of CoPt film on the resolution and the switching field are investigated.

2. Experimental procedure
MFM tips were prepared by coating base-Si tips of 4 nm radius with films by employing a radio-frequency magnetron sputtering system. Ru, Co\textsubscript{50}Pt\textsubscript{50}, and Fe targets of 3 in diameter were used. Co\textsubscript{50}Pt\textsubscript{50} (x nm), and Fe (10 nm) films were sequentially deposited on Si tips. The thickness of Co\textsubscript{50}Pt\textsubscript{50} layer, x, is varied in a range between 10 and 200 nm. The film growth temperature is fixed at 300 \degree C,
where $L_{11}$-CoPt phase with high-$K_u$ can be prepared. MFM tips were magnetized along the tip axis by applying a magnetic field of 10 kOe so that the tip top possessed the south magnetic pole.

MFM observation was carried out at room temperature under pressures lower than 0.1 Pa by using a scanning probe microscope. A perpendicular medium recorded at linear densities from 500 to 2000 kFCI and an HDD perpendicular medium with an areal density of 163 Gb/in$^2$ were employed for estimation of spatial resolution and $H_{sw}$, respectively. In order to estimate $H_{sw}$, MFM observation was repeated for an MFM tip by applying a magnetic field opposite to the initial magnetization. Magnetic field application was carried out by using an electromagnet after removing the tip from the MFM system, and then the tip was put again in the system for MFM observation. This procedure was repeated by increasing the magnetic field in a stepwise of 0.05 kOe until the MFM image contrast reversed. $H_{sw}$ was estimated from the magnetic field where the MFM image contrast reversed.

3. Results and discussion

MFM observations were carried out for the perpendicular medium to estimate the resolution. Three informations, MFM image, line intensity profile, and power spectrum were used for the estimation. Figures 1(a-1)–(a-3) show the MFM images observed by using an Fe(10 nm)/CoPt(50 nm)/Ru(5 nm) coated tip. As the linear density is increased, the sharpness of image is degraded. Figures 1(b-1)–(b-3) are the signal profiles measured along the dotted lines in figures 1(a-1)–(a-3). Figures 1(c-1)–(c-3) are the power spectra obtained by fast Fourier transformation of the MFM image data. The tip resolution is determined as a half the bit length of recorded linear density until which the bits can be discerned in the MFM image information. They are observable up to the linear density of 1200 kFCI (bit length: 21.2 nm) but not observable at 1300 kFCI (bit length: 19.5 nm). The resolution is thus estimated to be between $21.2/2 = 10.6$ nm (1200 kFCI) and $19.5/2 = 9.75$ nm (1300 kFCI), i.e. $10.2 \pm 0.4$ nm.

![Figure 1](image1.png)

Figure 1. (a-1)–(a-3) MFM images of a perpendicular medium recorded at (a-1) 500, (a-2) 1200, and (a-3) 1300 kFCI observed by using an Fe(10 nm)/CoPt(50 nm)/Ru(5 nm) coated tip. (b-1)–(b-3) Signal profiles along the dotted lines in (a-1)–(a-3), respectively. (c-1)–(c-3) Power spectra for the magnetic bit images of (a-1)–(a-3), respectively.

![Figure 2](image2.png)

Figure 2. MFM images of a same area of HDD perpendicular medium observed by using an Fe(10 nm)/CoPt(50 nm)/Ru(5 nm) coated tip (a) before and (b, c) after applying magnetic fields of (b) 0.65 and (c) 0.70 kOe.
MFM observations were carried out by using an HDD medium (163 Gb/in²) sample to measure the $H_{sw}$ values. Figure 2 shows the MFM images of a same area HDD medium observed by using an Fe(10 nm)/CoPt(50 nm)/Ru(5 nm) coated tip before and after applying magnetic fields. When a field of 0.65 kOe was applied to the tip, the contrast of MFM image was similar to the initial magnetization state as shown in figure 2(b). When a field of 0.70 kOe was applied, the contrast reversed as shown in figure 2(c). Thus, the $H_{sw}$ of Fe(10 nm)/CoPt(50 nm)/Ru(5 nm) coated tip is determined to be between 0.65 and 0.70 kOe, i.e. $0.675 \pm 0.025$ kOe. Figure 3 shows the dependences of resolution and $H_{sw}$ as a function of CoPt layer thickness. The resolution deteriorates from 9.4 to 12.1 nm with increasing the thickness of CoPt, which is related to the tip radius increase. With increasing the thickness, $H_{sw}$ increases from 0.675 to 2.025 kOe. The experimental result indicates that it is possible to increase the magnetic switching field while keeping good spatial resolutions around 10 nm by employing an Fe/CoPt film structure for MFM tip preparation. Figure 4 is an example of MFM image for an epitaxial $L1_0$-FePt (5 nm) film formed on MgO(001) substrate observed by using a tip coated with Fe/CoPt(100 nm)/Ru film.

4. Conclusion

MFM tips are prepared by coating Si tips with Fe and CoPt alloy films at 300 °C. The influences of coating CoPt layer thickness on the spatial resolution and the switching field are investigated. With increasing the thickness, the spatial resolution worsens from 9.4 to 12.1 nm, while the switching field increases from 0.725 to 2.025 kOe. An Fe/CoPt film coated tip is applied to the observation of high $K_u$ $L1_0$-FePt film is clearly visualized.

References

[1] den Boef A. J. 1990 Appl. Phys. Lett. 56 2045
[2] Ishihara S, Ohtake M and Futamoto M 2013 J. Magn. Soc. Jpn. 37 255
[3] Nagatsu R, Ohtake M, Futamoto M, Kirino F and Inaba N 2016 AIP Advances 6 056503