SOFT MAGNETISM OF Fe-Cu THIN FILMS WITH NON-EQUILIBRIUM PHASE
DEPOSITED BY ION BEAM SPUTTERING

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Abstract--- The requirements of the soft magnetic thin films are to have large saturation magnetization $4\pi M_s$, small coercivity H_c , enough high permeability, finite electrical resistivity, etc. The pure iron thin films with the Cu content X_{Cu} of 0 at.% did not show any clear peaks. The peaks became clearer gradually as X_{Cu} increased. The structure of the Fe-Cu thin films was amorphous-like, bcc and fcc phases for X_{Cu} in ranges of 0-10, 10-40 and more than 40 at.%, respectively. On the other hand, $4\pi M_s$ decreased monotonically as X_{Cu} increased. However, $4\pi M_s$ decreased remarkably when X_{Cu} became more than 50 at.%.

The coercivity H_c of the film thickness of $0.4\ \mu m$ showed the lowest value of 0.3 Oe at X_{Cu} of 32.8 at.% where $4\pi M_s$ was 11.4 KGauss. The films exhibited the excellent thermal stability and corrosive resistance.

INTRODUCTION

The high-quality thin films of Fe-Cu system seemed to be useful for soft magnetic layers in the thin film head and the perpendicular magnetic recording media. Iron and copper scarcely have any solid solutions by melting[1]. Sputtering is one of the techniques useful for quenching the vapor phase and, in addition, for depositing magnetic layers in preparation of thin film heads. Especially, the Ion Beam Sputtering (IBS) is the promising one since the growing film on the substrate is in the very low gas pressure during film deposition.

The requirements of the soft magnetic thin films are large saturation magnetization $4\pi M_s$, small coercivity H_c , enough high permeability, finite electrical resistivity, etc. For the X-ray diffraction diagrams of the Fe-Cu thin films deposited by the IBS, the pure iron thin films with the Cu content X_{Cu} of 0 at.% did not show any clear peaks. The peaks became clearer gradually as X_{Cu} increased. The structure of the Fe-Cu thin films was amorphous-like, bcc and fcc phases for X_{Cu} in ranges of 0-10, 10-40 and more than 40 at.%, respectively. On

the other hand, $4\pi M_s$ decreased monotonically as X_{Cu} increased. However, $4\pi M_s$ decreased remarkably when X_{Cu} became more than 50 at.%. The S/N ratio in moessbauer effect spectra decreased with increase of X_{Cu} . The positional change of 6 absorption lines could not found out for X_{Cu} at least in the range of 0 to 15.3 at.%. The internal magnetic field doesn't change with the difference in composition in the region of bcc-dominant phase, though the dispersion of the internal magnetic field becomes larger with increase of X_{Cu} . The correlation between the magnetic properties and the film structure implied that the bcc phase and the fcc one are predominant in the lower and higher ranges of X_{Cu} , respectively, based on the simple dilution law. On the contrary, H_c depended strongly and remarkably on X_{Cu} . H_c of the films with thickness of $0.4\ \mu m$ showed the lowest value of 0.3 Oe at X_{Cu} 32.8 at.%, where $4\pi M_s$ was 11.4 KGauss. The Fe-Cu thin films exhibited the excellent thermal stability and corrosive resistance, though they were in non-equilibrium[2].

EXPERIMENT

Figure 1 shows the Dual Ion Beam Sputtering (DIBS) apparatus[3] which was used for this study. This apparatus has two ion sources. The lower one is for sputtering the target (named sputtering ion source) and the upper one is for bombarding the film surface on the substrate (named bombarding ion source). The cover glasses and glass slides were used as a substrate. The bombarding ion source was used for discussing the effect of bombarding the film surface by the high-energy ions from the bombarding ion source.

The target used for preparing the Fe-Cu thin films is shown in Fig.2. The composition of the Fe-Cu thin films was controlled by changing the ratio of the iron area to the copper one of the target. The acceleration voltage of sputtering argon ions (V_{mg}) was 500 V and that of bombarding argon ions (V_{sg}) was in the range of 80 to 155 V.

The composition of the thin films was analyzed by the Electron Probe

Fig.1 Dual Ion beam Sputtering Apparatus

Microanalysis. The structure of the Fe-Cu thin films were examined by the X-ray diffractometry---Cu-K α . Magnetic properties, such as saturation magnetization and coercivity, were evaluated by using the Vibrating Sample

Fig.2 Fe-Cu compound target

Magnetometer (VSM). Moessbauer spectra were obtained by using ^{57}Co radiation source under the uniform acceleration mode.

RESULTS AND DISCUSSION

Figures 3 and 4 show the dependence of the X-ray diffraction patterns of the Fe-Cu films deposited by the IBS on the Cu content X_{Cu} . According to these X-ray diffraction patterns, the pure iron thin films with Cu content X_{Cu} of 0 at.%, did not show any clear peaks. The peaks became clear gradually as X_{Cu} increased. The crystal structure of the Fe-Cu thin films was amorphous-like, bcc and fcc phases for X_{Cu} in ranges of 0-10, 10-40 and more than 40 at.%, respectively. The dependence of the saturation magnetization $4\pi M_s$ on the Cu content X_{Cu} is shown in Fig.5. $4\pi M_s$ decreased along the simple dilution law monotonically as X_{Cu} increased up to about 50 at.%. Furthermore, $4\pi M_s$ decreased remarkably when X_{Cu} became more than 50 at.%. It is found out that comparing the Cu content dependence of the crystal structure and the saturation magnetization, the bcc phase is dominant in the region subject to the simple dilution law, while the fcc phase is dominant in the region where $4\pi M_s$ is smaller than the value estimated due to that.

Fig.3 Dependence of X-ray diffraction diagrams on Cu content (Part 1)

In Fig.6, the dependence of coercivity H_c on the Cu content X_{Cu} is shown. H_c decreased as X_{Cu} increased. At X_{Cu} of 32.8 at.%, the minimum value, H_c of 0.3 Oe, was obtained. $4\pi M_s$ of this thin film was 11.4 KG. H_c began to increase when X_{Cu} increased furthermore. Consequently, it can be thought that H_c becomes smallest at X_{Cu} of about 33 at.%.

In Fig.7, it is shown that how Moessbauer spectra changed along the change of the composition of the Fe-Cu thin films. The S/N ratio in Moessbauer effect deteriorated since the number of

Fig.4 Dependence of X-ray diffraction diagrams on Cu content (Part 2)

iron atoms reduced against the increase of Cu content. However, the shift of 6 absorption lines cannot be found at least in the region of X_{Cu} of 0 to 15.3 at.%. Accordingly, it cannot be thought that the value of the internal magnetic field changed due to the difference of the composition of the thin films in the bcc-phase dominant region. However, it is presumed that the distribution of the internal magnetic field spread since the spectrum width became broader compared to the case of pure iron.

Figure 8 shows the Cu content X_{Cu}

Fig.5 Dependence of saturation magnetization $4\pi M_s$ on Cu content

Fig.6 Dependence of coercivity H_c on Cu content

dependence of coercivity H_c of the thin films deposited by the RF Sputtering (RFS) and the IBS. H_c of the thin films prepared by the RFS was much larger than that by the IBS. In the case of the RFS, H_c was about 10 Oe even at a minimum value. This seems to be due to the reason that in the case of the IBS, the thin films hardly included impurities and hardly damaged since they can be deposited on plasma-free substrates at considerably

Fig.7 Dependence of Moessbauer spectra on Cu content

lower argon gas pressure compared to the RFS.

Figures 9 and 10 show Moessbauer spectra of the thin films prepared by the RFS and the Facing Target Sputtering (FTS)[4], respectively. In every sputtering method, 6 absorption lines, which are characteristic of ferromagnetic substances, can be observed in the bcc-phase dominant region less than 40 at.%Cu. First, concerning the position of absorption lines, there is no difference between deposition methods. So, it can be recognized that there is scarcely

Fig.8 Dependence of coercivity H_c on Cu content

difference on the internal magnetic field between them. However, concerning the intensity ratios, it is obvious that there is difference. As for IBS, the 2nd and 5th absorption lines are very intensive, while these two absorption lines are weak in the RFS and FTS. This indicates that the magnetization of the thin films by the IBS is in the in-plane direction, while that by the RFS and the FTS is in the perpendicular one to the film surface. Furthermore, in the fcc-dominant, higher- X_{Cu} region, the spectra include one absorption line, which shows paramagnetism.

This corresponds to that 4LMs showed the lower value than that estimated due to the simple dilution law in the region over 50 at.%Cu in Fig.5. In addition, this coincides with the report that the magnetic moment per one iron atom is constant in the bcc-phase region, but this moment would decrease remarkably with the

Fig.9 Dependence of Moessbauer spectra of RF sputtered films on Cu content

increase of the Cu content in the fcc-phase region[5].

In order to test the chemical stability, specimen films were put in saturated water vapor or dipped in water at room temperature. After being kept in both conditions for more than 1 month, the films deposited with the suitable-energy ion bombardment ($V_{sg} = 100$ V) did not rust and did not exhibit any change in their magnetic properties. Therefore, the DIBS system is very useful for preparing the Fe-Cu thin films with soft magnetic properties and good chemical stability.

Fig.10 Dependence of Moessbauer spectra of Facing-Target sputtered films on Cu content

CONCLUSION

The Fe-Cu thin films deposited by the DIBS system have very useful properties for soft magnetic layers in magnetic recording devices. First, the structure of the Fe-Cu thin films was amorphous-like, bcc and fcc phases for X_{Cu} in the ranges of 0 to 10, 10 to 40 and more than 40 at.%, respectively. Second, in the bcc-

phase region $4\pi M_s$ decreased along the simple dilution law and H_c decreased monotonically. Third, in the fcc-phase region $4\pi M_s$ decreased remarkably more than the value estimated due to the above-mentioned law and H_c began to increase. Fourth, the excellent, soft magnetic Fe-Cu thin films were obtained at 32.8 at.%Cu, where $4\pi M_s$ was 11.4 KGauss and H_c was 0.3 Oe. Finally, the films deposited with the ion bombardment exhibited good chemical stability, which did not rust and did not exhibit any change in magnetic properties, even after being kept in saturated water vapor for more than 1 month. Consequently, the Fe-Cu thin films deposited by the DIBS system is very useful for soft magnetic layers in magnetic recording devices.

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