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Annealing Effect of Microstructure and Asymmetric Giant Magneto-Impedance in Co-Based Amorphous Ribbon

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I. INTRODUCTION

Recently, an asymmetric GMI profile, showing GMI-valve, has been reported in a weak-field-annealed amorphous ribbon due to the bias field of the magnetic layer on the specimen surface [1]. The shape of the GMI profile depends on the annealing time, the temperature, the applied field, and the atmosphere used during annealing, as well as on the composition of the starting material. In this work we prepare weak-field-annealed amorphous samples as a function of the annealing time for the microstructural modification, and discuss the change in GMI profile in term of microstructure on specimen surface.

II. EXPERIMENTAL

The Co-based amorphous ribbons were annealed at a temperature of 380 °C in an open air where annealing time varied 20 min ~ 8 h. The earth's magnetic field was compensated for by using two-dimensional Helmholtz coils. The annealing field, 2 Oe, was applied in the direction of the sample axis direction by using another Helmholtz coils, and its direction was regarded as positive. X-ray diffraction patterns were measured for the structural change of samples and compositional depth profiles were investigated using Auger electron spectroscopy. The impedance Z was measured by using a HP4192A impedance analyzer with four terminal contacts. The remote control software was used for the external magnetic field and ac measuring current. The cyclic magnetic field was applied by a Helmholtz coil using a step-like changing current. The amplitude of the ac was kept at constant value of 5 mA during the sweep of the applied field even though the impedance of the equivalent circuit changed during the measurement. The GMI profile was obtained by plotting $\Delta Z/Z$ for the cyclic applied field [1].

III. RESULTS AND DISCUSSION

A. Microstructural change

The x-ray diffraction patterns of as-quenched, 1 h and 8 h annealed samples are no significant change in the peak of x-ray diffraction pattern, however, FWHM decreases for the 8 h annealed samples in the other condition. These variation suggest that the volume fraction of amorphous phase in a few μm thick surface layer decreases after 8 h annealing.

The composition-depth profiles of an as-quenched and annealed samples for 20 min, 2 h and 8 h are shown in Fig. 1. For 20 min annealed sample shown in Fig. 1(b), the thickness of the surface oxide layer increases to 500 Å. The oxide layer formed on the annealed sample is heavily enriched in B and Si, balanced by a depletion of these elements in the underlying material. The thickness of the oxide layer enriched in B and Si is about 600 Å in annealed samples for 2 and 8 hours, as shown in Fig. 1(c), (d). The reduction of B and Si content decreases the crystallization temperature of amorphous alloy, probably enough so that crystallization of the depleted layer can occur at the annealing temperature of 380 °C [2]. The transformed layer between the outer oxide and the inner amorphous core may be crystalline single phase, crystalline multi-phase or crystallites in an amorphous matrix. The crystals or crystallites in the transformed layer will have higher magnetic anisotropy than the amorphous core [3], and can be exchange coupled with the amorphous core [4].

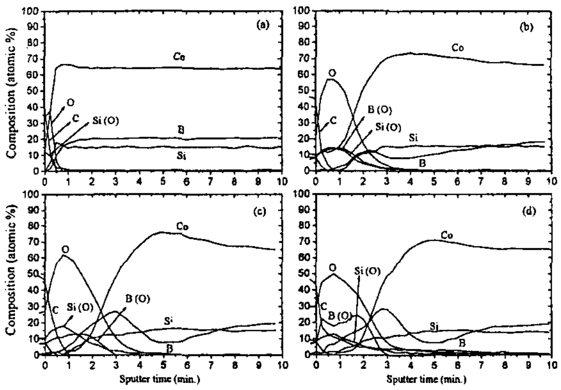

Fig. 1. Auger electron spectroscopy .
(a) as-quenched, (b) 20 min, air, (c) 2 h, air, (d) 8 h, air.

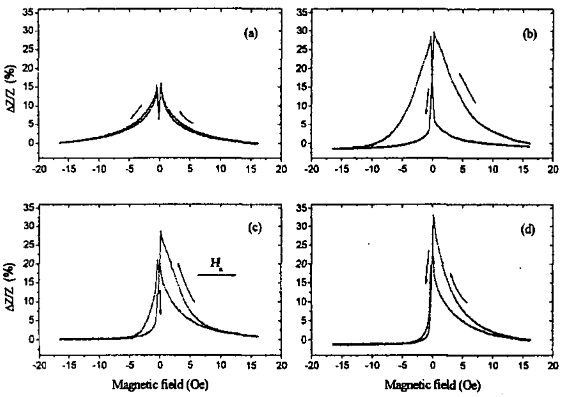

Fig. 2. GMI profiles for various annealing times.
(a) 20 min, air, (b) 1 h, air, (c) 5 h, air, (d) 8 h, air.

B. GMI profile

Fig. 2 presents the GMI profiles at 0.1 MHz measuring frequency during a cycle of magnetization for the samples with various annealing times. GMI profile in Fig. 2(a) shows two typical peaks during a half cycle of magnetization for 20 min annealed sample. At 1 h annealed sample, one of peaks disappears during a half cycle of magnetization, GMI profile exhibits a drastic step-like change, so-called "GMI-valve" near zero field [1]. However, there is hysteresis in the GMI-valve for increasing and decreasing field as shown in Fig. 2(b). As the annealing time increase, the peak in antiparallel field region to annealing field decreases and shows the GMI-valve in parallel field region, as shown in Fig. 2(c)(d). The on-set field of GMI-valve in 8 h annealed sample for increasing and decreasing fields nearly coincides each other. Comparing the results for 2 h and 8 h annealed samples, the variation of GMI profiles is more sensitive to annealing time than the microstructural modification.

In conclusion an surface oxidation layer in the sample annealed in open air is heavily enriched in B and Si, balanced by the depletion of these element in the underlying materials. The reduction of B and Si content decreases the crystallization temperature of the depletion layer, resulting in the formation of crystal or crystallites during annealing in air. The asymmetric GMI profile is due to the exchange coupling between amorphous core and crystalline layer on the sample surface, which have higher magnetic anisotropy than the amorphous core.

IV. REFERENCES

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