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Properties of Co-Fe-Al-O Nanogranular Thin Films for Application to Magnetoelastic Devices in the GH frequency range

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I. Introduction

The development of high-frequency devices has become important from the technological point of view because of the increasing volume of information and the variety of communication media, such as mobile telephones and satellite broadcasting devices. Surface acoustic wave devices have conventionally been used for high-frequency devices, because they have the advantage of small size and fine filter characteristics as compared to dielectric filters and duplexers. As consumer adoption of mobile/wireless communications technology continues to expand, it is anticipated that RF frequencies for some systems will extend into higher GHz-band regimes. Co-Fe-Al-O thin films with (Co,Fe) nanograins in an amorphous Al-O matrix were reported to show very good soft magnetic properties even in the GHz range [1]. A high saturation magnetization, anisotropy field and electrical resistivity are essential to the realization of a high ferromagnetic resonance (FMR) frequency [2]. Good magnetic softness of these alloys is mainly due to a nanoscale (Co,Fe) grain size. Common applications of these thin films are inductors and noise absorbers in the GHz range. In these applications, a large magnetostriction is harmful in general and, accordingly, an alloy with a small magnetostriction was sought mainly by adjusting the Fe/Co ratio. On the other hand, an Fe-Co alloy with an equiatomic composition exhibits a very large magnetostriction (of the order of 100 ppm), so this alloy can be of great potential for magnetoelastic device applications in the GHz frequency range. A good magnetic softness and a large magnetostriction are the two key factors to these applications. Soft magnetic and magnetostrictive properties of nanogranular Co-Fe-Al-O thin films are investigated in this work with a particular emphasis being placed on magnetoelastic applications.

II. Experiment

Co-Fe-Al-O nanogranular thin films with a thickness of 0.1 μm were prepared by radio frequency magnetron sputtering in an O_2+Ar atmosphere to a background pressure higher than 7×10^{-7} Torr. The Ar/O_2 ratio was varied to change the oxygen content in the thin films. Co-Fe-Al composite targets composed of a Co-Fe alloy target and Al chips were used. The films were deposited on Si substrates in a static field of 1 kOe to induce uniaxial magnetic anisotropy. The film structure was investigated by high resolution transmission electron microscopy combined with energy dispersive x-ray spectroscopy. Magnetic properties were measured with a vibrating sample magnetometer. The FMR frequency was measured from the frequency dependence of the permeability up to 9 GHz. Magnetostriction was measured by the optical cantilever method under rotating in-plane fields up to 150 Oe. The electrical resistivity was measured using the conventional four-probe method.

III. Results and Discussion

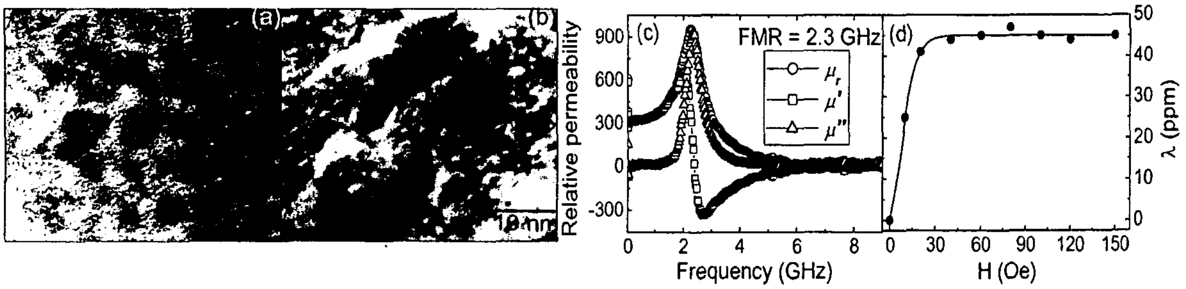

Fig. (a) & (b) HRTEM images of as-deposited Co-Fe-Al-O films prepared at the O_2 flow ratios of 4.7 % (Sample A) and 2.4 % (Sample B), respectively. (c) The frequency dependence of the permeability and (b) λ - H curve for Sample A.

Figs. (a) and (b) show the HRTEM images of as-deposited Co-Fe-Al-O films prepared at two different O_2 flow ratios of 4.7 % (Sample A) and 2.4 % (Sample B), respectively. The compositions of samples A and B are respectively $Co_{61}Fe_{27}Al_{12}O_x$ and $Co_{58}Fe_{35}Al_7O_y$ where x > y. A clear nanogranular structure is seen in Sample A where crystalline (Co,Fe) grains (dark area) with a size of 3~5 nm are surrounded by a rather thick (several nm) amorphous Al-O matrix (gray area). This microstructure is responsible for a very high electrical resistivity of 402 μΩcm. Sample B has a much bigger grain size and, furthermore, (Co,Fe) grains are not completely isolated by the Al-O matrix, resulting in poor soft magnetic properties and a low electrical resistivity (130 μΩcm). The results for the frequency dependence of the permeability and magnetostriction measured at a static field condition are shown in Figs. (c) and (d), respectively. The measured (pseudo) dc permeability is ~315 and this value is in a fair agreement with a calculated value of 356 ($\mu_r = 4\pi M_S / H_K$) based on the rotation magnetization mechanism. This agreement indicates that the magnetization mainly occurs by spin rotation. The measured ferromagnetic resonance frequency is 2.3 GHz and this is in a perfect agreement of a calculated resonance frequency of 2.38 GHz. This agreement is in part due to the high electrical resistivity observed in this film. In addition to good soft magnetic properties in the high frequency range, the thin film also exhibits good magnetostrictive properties, evidenced by a large saturation magnetostriction (~45 ppm) and a very good field sensitivity of magnetostriction. The results for the soft magnetic and magnetostrictive properties clearly indicate that the present thin film can be suitable for magnetoelastic applications in the high frequency range. One possible application under consideration is a surface acoustic wave device for wireless local area network.

IV. References

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