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Microstructure study of the Co-added FePt thin films with high energy density

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Recently, $L1_0$ FePt was received considerable attention due to its remarkable characteristics, such as very high anisotropy (7×10^7 erg/cm^3), high Curie temperature (~450°C), and excellent chemical stability. Many attempts have been made to improve the energy density of the FePt thin films, ribbons, or particles for the permanent magnetic applications. In our previous investigations, it was found that the energy product of the FePt thin films can be significantly improved by controlling the average grain size and the proportion of order and disorder phase through the third element addition of of Nb and Co [1-3]. The addition of cobalt was found to increase the ordering transformation temperature and results in a structural inhomogeneity [3]. In this study, $Fe_{49-x}Co_xPt_{51}$ (x=0.0, 0.7, 1.3, 2.2) thin films deposited onto heated Corning 1737 glass substrates by magnetron sputtering were studied. Microstructures and compositional distribution of the Co-contained FePt thin films with improved energy density were investigated using transmission electron microscope and energy dispersed spectroscope (EDS), respectively. The results reveal that the average grain size of the films deposited at 500°C did not significantly change with the increasing of Co. However, the composition distribution of Co is different. In the x = 1.3 films, the average grain size is about 50 nm. Concentration of cobalt in those grains larger than 40 nm is quiet low (<0.3 at%); in contrast, in those small grains with ~10 nm in diameter, cobalt concentration is significantly higher (~2 at%). In the x=2.2 film, grain size is slightly larger (about 55 nm), the composition of Co becomes uniform. In the structural analysis of X-ray diffractometry, the volume fraction of ordered phase in those $Fe_{49-x}Co_xPt_{51}$ (x=0.0, 0.7, 1.3, 2.2) samples, are 97%, 98%, 79%, and 93%, respectively. A structural inhomogeneity was clearly found in the x=1.3 film, which corresponded to the EDS results. The solution of Co in FePt phase increases the ordering transformation temperature, that is, the FePt grains in the films with higher Co concentration have lower extent of chemical ordering. The moment of these small low-ordered grains will be aligned by the neighboring highly ordered grains with low Co concentrations. This strong exchange coupling explains the obtained high energy density in the x=1.3 sample.

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Dependence of magnetic properties of $SmCo_5$ film with perpendicular magnetic anisotropy on magnetic layer thickness

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$SmCo_5$ alloy is awell-known material as a permanent magnet with the high uniaxial magneto-crystalline anisotropy larger than 10^8 erg/cm^3. Therefore the $SmCo_5$ film has many potential applications such as magnetic recording medium, MEMS, and so on. Authors have focused on controlling the crystal orientation so far, and prepared successfully the SmCo film with the perpendicular magnetic anisotropy by using the Cu underlayer with 200 nm [1]. In addition, it was revealed that the Ru (5 nm)/Cu (5 nm)/Ru (5 nm) tri-layer was comparable to the Cu underlayer [2]. However the thickness of $SmCo_5$ layer was thinner than 20 nm for the aim of applying to the perpendicular recoding medium. For the use of magneto-electronics devices, thick $SmCo_5$ films and multilayered films were prepared and studied their magnetic properties in this study.

The films were prepared without exposure to air by a system composed of facing targets sputtering and DC magnetron sputtering. The SmCo target was a composite type with Sm plates of 10×10 mm^2 on a Co disk and the number of Sm plates was adjusted to obtain 17 at.% in the film which is almost the same value in the stoichiometric $SmCo_5$ alloy. Ru and Cu layers were prepared without the substrate heating (below 40 °C) and $SmCo_5$ layers were prepared at 350 °C. The $SmCo_5$ layers with the range of 10 nm to 5 um were prepared onto Ru (5 nm)/Cu (5 nm)/Ru (5 nm) films. The multilayered films were based on the structure of $SmCo_5$ (100 nm)/Ru (5 nm)/Cu (5 nm)/Ru (5 nm) and the total thicknesses of the $SmCo_5$ layers was varied from 100 nm to 1 um.

In the XRD diagrams of $SmCo_5$/Ru/Cu/Ru films, the diffraction lines from Cu (111) plane and $SmCo_5$ (00*l*) planes were observed when the thickness of $SmCo_5$ layer was thinner than 100 nm. For the film with the thickness thicker than 500 nm, not only $SmCo_5$ (00*l*) planes but also other planes from $SmCo_5$ alloy phase were observed. When the thickness was less than 100 nm, the magnetic properties showed excellent perpendicular magnetic anisotropy. The squareness ratio in the perpendicular and the in-plane direction were about 0.8 and less than 0.3, respectively. The perpendicular coercivity exhibited a maximum value of about 16 kOe at the $SmCo_5$ layer thickness of 40 nm. In contrast, when the thickness was thicker than 500 nm, the shapes of the hysteresis loops in both directions were similar and the squareness ratios were about 0.5.

The SEM cross section image of the [$SmCo_5$/Ru/Cu/Ru]10 multilayered film showed that the multilayered structure was formed clearly. The diffraction lines from $SmCo_5$ (00*l*) planes were observed in the XRD diagram of the $[SmCo_5/Ru/Cu/Ru]_6$ film while other planes from $SmCo_5$ alloy phase were also observed in that of the $[SmCo_5/Ru/Cu/Ru]_{10}$ film. The coercivity in the perpendicular direction of the $[SmCo_5/Ru/Cu/Ru]_{10}$ film was about 9 kOe and the squareness ratio in the perpendicular and the in-plane direction were about 0.75 an 0.47, respectively. It was found that the multilayered structure is necessary to prepare the thick $SmCo_5$ film with perpendicular anisotropy.

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