Deposition of hard magnetic SmCo₅ thin films by magnetron sputtering

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Abstract. We report the study of the microstructural and magnetic properties of SmCo₅ thin films. Textured SmCo₅ films having one or more of the following magnetic properties – high coercivity (1.5 kOe), remanence ratio (0.85), and maximum energy product (15 MGOe) – were prepared by magnetron sputtering on heated Si substrates.

1. Introduction

Permanent magnetic films play an important role in the realisation of Magnetic Micro Electromechanical System devices [1-2]. One of the major requirements of such applications is the need to deposit permanent magnetic films with high coercivity and large energy products on silicon substrates. Among the rare earth group of permanent magnetic films SmCo films offer excellent intrinsic and extrinsic magnetic properties [3-6].

SmCo based materials have been investigated for many years for applications at room temperature and at high temperature permanent magnets. It is known that a particular nanostructure is required to obtain the hard magnetic properties in these materials. Important aspects of this structure involve the size and the shape of crystalline grains, their crystal orientation, and their inter-grain coupling. In this work we study initially homogeneous sputtered, stoichiometric SmCo₅ films with thicknesses from 0.5 to 1.5 microns.

2. Experimental

SmCo films were prepared by magnetron sputtering with a base pressure of 1×10⁻⁷ Torr. The sputtering gas was Ar and the pressure varied from 15 to 30 mTorr. Our sputtering techniques have one special feature, namely, we use sputter pressure high enough to achieve thermalization of the sputtered atoms and control the Sm/Co ratio and consequently the stoichiometry of films by changing the sputtering pressure.

The target was a 50-mm- diameter disk magnet with a composition of Sm₁₉Co₸₂ (MQ). Samples were prepared by varying the deposition pressure pₐr with a target power density of 61 mW/mm² and a target substrate-distance from 5 to 9 cm giving a deposition rate 10 –15 Å/sec. The film thickness ranged from 0.5 to 1.5 µm as measured by profilometry. There is no evidence that film thickness has a significant effect on the physical properties over this range.

The deposition of SmCo films with a substrate temperature Tₛ lower than 250 °C results in X-ray amorphous samples. The hard magnetic properties progressively increased as the substrate temperature
increased up to 450 °C. In order to obtain samples with hard magnetic properties the films deposited at 450 °C on Si substrates.

A 30 nm buffer layer Cr and 80 nm cap layer were used to avoid the oxidation of the rare-earth metal Sm. The buffer layers are deposited at 450 °C substrate temperature to relieve the strain induced by lattice mismatch and to improved the adhesion properties of SmCo thick films.

Structural characterization of the samples was performed by X-ray (CuKα) diffractometry (XRD). The chemical composition of the sputtered films were analysed by EDAX method. The magnetic properties of the films measured at room temperature using a vibrating sample magnetometer with a maximum applied field of 2 Tesla, and at 300 K using a Quantum Design MPMSR2 superconducting quantum interference device (SQUID) magnetometer, with a maximum applied field of 5 Tesla.

3. Results and discussion

Shown in Fig. 1 are XRD results of a stoichiometric SmCo₅ film with thickness 0.5 microns and with Cr buffer and cap layer. The Cr has a [110] peak of the bcc structure indicating that the Cr is highly textured. This high texture was interpreted based on the lattice matching between SmCo₅ and Cr [110].

![Figure 1: X-ray diffraction pattern of a SmCo₅ film sputtered at 24 mTorr pressure on a heated Si (100) substrate (Tsubstrate = 450 °C)](image)

![Figure 2: In plane magnetization measurement of SmCo₅ film sputtered at 24 mTorr pressure on a heated Si (100) substrate (Tsubstrate = 450 °C)](image)

We control the composition of the films by changing the sputtering pressure [7]. For stoichiometric SmCo₅, (Sm 16.7%) the lattice parameter c/a ≈ 0.80. In Fig.1 at high deposition pressure (24 mTorr) and at 450 °C substrate temperature, the film crystallizes as SmCo₅ with c/a ≈ 0.81, and the texture is predominant to (110) growth mode. It is a nearly single phase CaCu₅ with the crystallite c-axis aligned onto the film plane.

All samples show a smooth hysteresis (Fig. 2) typical for a single phase, hard magnetic material, and in the case of a measurement in the film plane, an almost square-shaped loop with high coercive field Hc and remanence Mr. It should be noted that the remanent magnetization for zero applied field is 85% of magnetization at an applied field of 5 Tesla. Intrinsic coercivity of 15.5 kOe and Mr = 8.5 kG, have been achieved and in the film plain static energy product up to 15 MGOe have been observed. The high energy product values were measured for an applied field parallel to the plane. The magnetic properties were measured directly after the films were removed from the sputtering system without any subsequent heat treatments. It has been possible to make films that exhibited the easy axis of magnetization aligned onto the film plane fairly thick, without having adherence problems.

Figure 3 shows a SEM photograph of a directly crystallized SmCo₅ film. Elongated grains with diameters about 100 nm, and the long axis about 400 nm are observed. The long axis of that grains, lies parallel to the surface of films and that leads to an in plane texture [8].
The ferromagnetic Sm-Co grains, that form upon deposition have their own stray field, as the Curie temperature of Sm-Co compounds (≈ 800°C) is above the deposition temperature of 450°C [8]. The magnetic energy term dominates other energy terms such as surface energy, which could lead to a different texture.

4. Conclusions
A series of SmCo$_5$ films prepared, by varying the deposition pressure with constant power and substrate temperature with 17% Sm content. The in plane texture is preferable. In that case the magnetic properties are: $H_{c} = 15.5$ kOe, $B_r = 8.5$ kG, and the $(BH)_{max} = 15$ MGOe at room temperature. These properties with high technical interest, are promising for MEMs applications.

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6. References
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