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Influence of multilayer modulation on structural and magnetic features in the Pt/Sm–Co system

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ABSTRACT

In this work, we study the influence of Pt underlayer in Pt/Sm–Co/Pt trilayers and in Pt/Sm–Co multilayers. In both cases, Pt underlayer seems to impose better crystallinity to Sm–Co layer and certainly promotes the evolution of the hard-magnetic $SmCo_5$ phase. Particularly, in the case of multilayer form, where multiple interlayers of Pt each one serving as a dedicated underlayer for the deposition of a specific Sm–Co layer, enhanced crystallinity is observed. Moreover, post-deposition annealing facilitates these features at relatively lower temperatures (~400 °C) than those met in thin-film cases. This behavior is also followed by enhancement of saturation magnetization, while higher temperature post-deposition thermal treatment seems to deteriorate structural and magnetic features. If annealing temperature gets over 550 °C macroscopic magnetic features depress, probably due to domination of annealing-activated processes such as Sm oxidation and formation of non-magnetic phases since Pt diffuses throughout the whole magnetic layer.

1. Introduction

The development of large coercivity and remanence as well as high anisotropy phases comprises highly relevant objectives in diverse technological fields, such as ultra-high-density recording and microelectromechanical devices. Sm–Co phases are among the favorite magnetic materials for high-temperature applications, where strong and localized magnetic fields are needed since they exhibit high Curie temperatures (~800 °C) and huge magneto-crystalline anisotropy [1–3]. More specifically, nanoscale research areas like the reduction of the critical grain size for magnetic recording to withstand the superparamagnetic limit and the quest of enhanced energy products via exchange coupling are perfectly matching with the well-defined geometry of Sm–Co bilayers, trilayers, multilayers [4], and more recently nanoparticles [5].

A major challenge resides in the fact that the preparation of Sm–Co hard-magnetic thin films by physical vapor deposition methods is usually a complicate problem, since the films prepared at room temperature are usually amorphous and do not present the desired magnetic properties. To achieve hard-magnetic properties the films must be prepared at high temperatures and/or to be annealed after deposition. The temperatures at which these thermal treatments are carried out are usually high (>600°C) and eventually not compatible with the typical Si-based technology (upper limit ~450 °C) [6,7].

The magnetic properties and crystal phases of the Sm–Co-based films are strongly determined by the film composition, which can be controlled by adjusting the deposition parameters. For thin films, in addition to the key parameters that control microstructure: composition and temperature, the buffer and the substrate materials play an important role. The intention of a buffer layer is to prevent interdiffusion, to induce the intended texture and to optimize the microstructure [8]. Since the maximum obtainable coercivity is strongly dependent on the grain microstructure and domain sizes, a sound understanding of the smallest magnetic entity becomes a prerequisite.

Eventually, the ultimate goal is the isolation of $SmCo_5$, with the highest uniaxial magnetocrystalline anisotropy together with crystallographic growth control for this phase, such that the grains grow in a manner that only one *c*-axis orientation exists throughout the sample.

In the present work, we will examine the influence of multilayer modulation on the hardening process of Pt/Sm–Co/Pt//Si and examine the role of Pt interlayers as intermediate buffers facilitating the crystallization process of the hard-magnetic layer. Actually, the choice of Pt as a buffer material, a smooth film underlayer, ensures minimum roughness and isolation from substrate diffusion into Sm–Co layer.

2. Experimental

Three samples were developed by the e-beam evaporation method under identical UHV conditions using Pt and $SmCo_5$

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targets. The base pressure was 5×10^{-9} Torr and the substrate temperature was ~60 °C. Two Inficon XTC deposition monitors were used to control the deposition rates at 0.1 nm/s. In all cases a 5 nm Pt layer was developed on a naturally oxidized Si(1 1 1) wafer to promote texturing, and a film sequence was always ending with a 5 nm Pt capping layer to provide protection from corrosion and oxidation. Samples A and B are Pt/Sm–Co/Pt trilayers having a Sm–Co thickness of 8 and 1.6 nm, respectively. The third sample (Sample C) is a Pt/Sm–Co multilayer of 20 repetitions with a multilayer period of 2.8 nm comprising of 1.6 nm of Sm–Co and 1.2 nm of Pt.

The microstructure of the films was examined by X-ray diffraction (XRD) with CuK_a radiation, conventional (TEM) and high-resolution (HRTEM) transmission electron microscopy. The composition of the Sm–Co target used for evaporation was estimated to be close to $SmCo_5$ (±10%) by an energy-dispersive X-ray analysis (EDS) detector fitted in a scanning electron microscope.

Since thickness of Sm–Co layers is considerably small in all films fabricated, an analogous EDS estimation was performed during HRTEM observations and the composition of magnetic films was evaluated to be $SmCo_5$ (±20%). To examine the influence of thermal treatment on microstructure and magnetic features, all samples were subjected to post-deposition annealing at ambient conditions at the temperature range 400–700 °C for 30 min.

Magnetic hysteresis loops (in and out of film plane) were recorded at room temperature under maximum magnetic field of 1 T by a vibrating sample magnetometer (1.2H/CF/HT Oxford Instruments VSM).

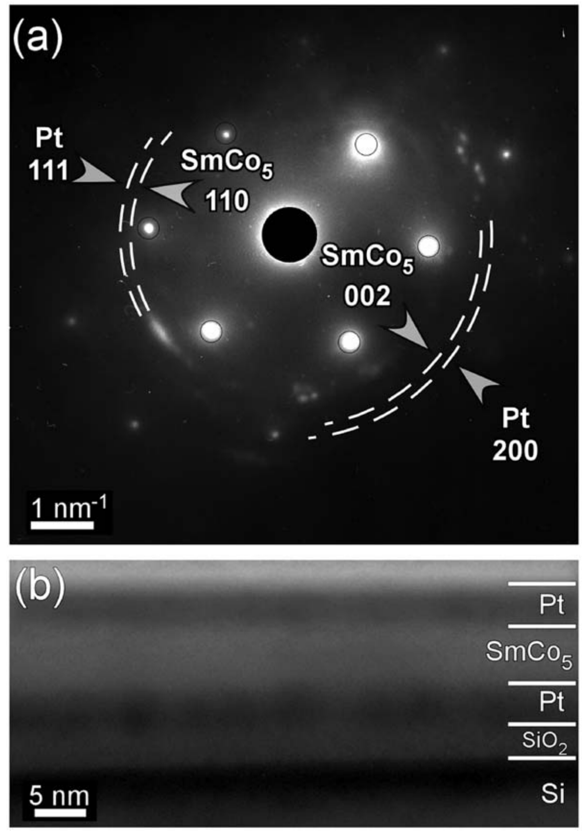

Fig. 1. Selected area electron diffraction pattern (a) and corresponding cross-section view (b) of Sample A: a Pt/Sm–Co/Pt trilayer with 8 nm of Sm–Co.

3. Results and discussion

Most of the relevant literatures on Sm–Co thin films are focused on the use of Cr underlayer as an optimum choice to promote the hard-magnetic behavior of Sm–Co films [9–11]. On the contrary, only a few publications examine alternate materials such as Cu and Pt [12–14].

Pt as a buffer material has already been used in our previous studies on series of Ni- and Co-based magnetic multilayers because of its high quality in thin-film form, (1 1 1) texturing, nanocrystalline character and minimum roughness [15–17]. In the case of Sm–Co thin films, it has already been demonstrated that Pt underlayer leads to crystallization of Sm–Co layer at some extent near the interface, while the upmost part of the magnetic layer remains amorphous [12].

Consequently, by choosing appropriately small thickness of Sm–Co layers (1.6 nm) modulated by Pt interlayers (1.2 nm) one may completely crystallize the magnetic layer even without performing post-deposition thermal treatments or use of elevated temperatures during deposition to promote hard-magnetic behavior as observed in textured $SmCo_5$ layers contrary to amorphous ones [6,8,10,18–21].

Initially, the X-ray diffraction patterns for both trilayer samples (not shown here) corresponding mostly to Pt (because of its high atomic number, atomic scattering factor and volume fraction together with the ultrathin character of both trilayers) could not safely conclude the Sm–Co presence. On the contrary, by TEM imaging, two distinct phases may be identified as Pt and $SmCo_5$, as depicted in the selected area electron diffraction (SAED) pattern (Fig. 1a) for Sample A (the trilayer with the relatively thick Sm–Co layer—8 nm). The corresponding cross-section view of this sample depicted in Fig. 1b illustrates that the three-layer structure exists in the whole area of the sample and layers are uniform and relatively sharp. The Sm–Co layer (being considerably small at

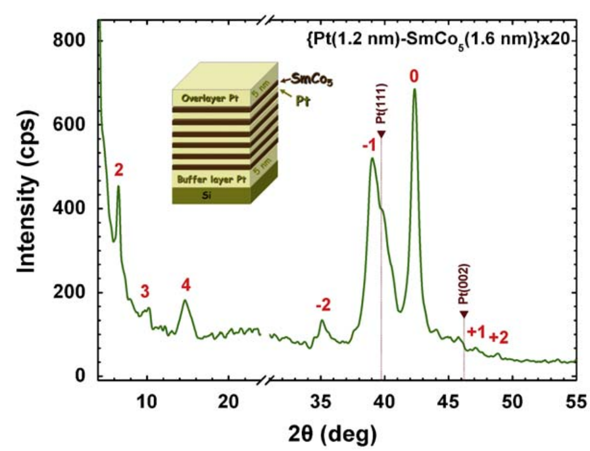

Fig. 2. X-ray diffraction pattern of Sample C revealing excellent multilayer sequence.

8 nm), seems quite uniform and not separated in two parts like in the case of much thicker (25 nm) Sm–Co magnetic layers where two distinct layers are formed (a bottom crystalline and a top amorphous one) due to the insufficient dissolution of Pt within the magnetic layer [12].

From the X-ray diffraction pattern of the multilayered sample (Sample C) shown in Fig. 2, multiple evident peaks may be identified and attributed mainly to multilayer modulation and Pt. Since potential $SmCo_5$ peaks are too superimposed by the Pt and multilayer peaks, no safe conclusion about the presence of $SmCo_5$ and its crystallization may be drawn solely by the XRD pattern. On the other hand, the existence of multiple reflections at small angle