BP-04

IN-SITU OBSERVATION OF DEVELOPMENT OF INTERNAL STRESS AT THE INITIAL STAGE OF FILM GROWTH

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I. INTRODUCTION

It is important to clarify origins and mechanism of an internal stress induced in a film during the film formation, because the development of the internal stress is strongly related to the properties of films which are used for magnetic storage media and spintronic devices. Facing targets sputtering (FTS) system can form various functional ferromagnetic thin films owing to its unique configuration of substrate and targets. Ru/FeCo(B) thin films prepared by the FTS system shows large uniaxial magnetic anisotropy along the facing targets direction in the film plane.[1] Structural analysis using in-plane X-ray diffraction measurements clarified that the in-plane anisotropy was caused by an anisotropic residual stress formed during deposition process. However, the origin of the anisotropic residual stress has not been understood yet. We developed an in-situ stress observation system of an anisotropic internal stress at the initial stage of film growth by detecting displacement of cantilever substrate during the film deposition process to clarify initiation and accumulation of the internal stress σ.

II. EXPERIMENTAL

Fig. 1 shows in-situ stress observation system installed in the FTS system. Two rectangular thin glass substrates with a size of 45 mm x 5 mm x 30 µm were set at the film deposition region as cantilevers to detect internal stress σ along the cross-targets (facing) and the orthogonal direction to the cross-targets direction, respectivel. Internal stress σ formed along facing and orthogonal directions is evaluated using Storney's law [2,3] from the displacement of the cantilevers measured by laser displacement sensors.

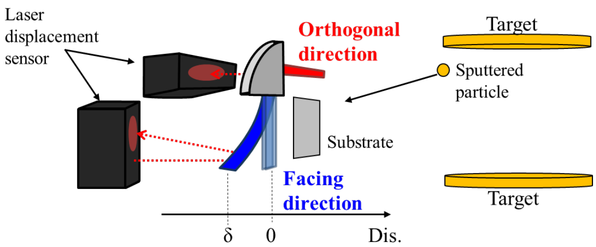

Fig.1 In-situ stress observation system installed in FTS

III. RESULTS AND DISCUSSION

It is well known that low and high Ar gas pressure cause compressive and tensile internal stress, respectively, to the films prepared by sputter-deposition method. However, the σ of all the films prepared at various Ar gas pressure shows tensile stress at the initial stage of the film growth. The tensile stress at the early stage of the film growth is caused by the formation of island structure and their agglomeration on the substrate. The critical thickness of the film t_p where the stress changes from tensile to compressive is around 1.5 to 8 nm depending on the surface energies of the film materials and that of the substrate.

Figure 2 (a), (b) and (c) show changes of a product of stress σ and nominal film thickness t as a function of t for Ti, Ru and FeCo, respectively. Ti, Ru and FeCo were deposited with Ar gas pressure of 0.04 Pa. Deposition rates for Ti, Ru, and FeCo were 0.066, 0.083 and 0.11 nm/s, respectively. It is recognized that the σ formed along facing and orthogonal directions are different. Positive and negative slope of $\sigma \cdot t$ - t curves indicate that tensile and compressive stress developed more dominantly than the other. $\sigma \cdot t$ - t curves for Ti (a) and Ru (b) can be divided into two zones: tensile stress growth (Zone-1), and compressive stress growth (Zone-2). The critical thickness between Zone-1 and Zone-2 is defined as t_{P1}. In Zone-1 ($t < t_{P1}$), the film growth mode is considered to be island growth, and the tensile stress would be caused by the surface tension or van der Waals's force [4] among the islands. In Zone-2 ($t > t_{P1}$), the compressive stress would be caused by the

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peening effect [5] that is observed in continuous layers prepared at relatively low sputtering gas condition. Thus, t_{P1} is considered to be the critical thickness that growth mode changed from island to layer-by-layer growth. t_{P1} of Ru was thicker than that of Ti as shown in Fig. 2 (a) and (b). This result is consistent with that the surface energy of Ru is larger than Ti.

A $\sigma \cdot t$ - t curve for a ferromagnetic FeCo film, shown in Fig. 2(c), was slightly different from those of Ti and Ru. The curve showed two peaks at t = 3.3 nm and 7.8 nm, and a dip was observed at t = 4.2 nm.

In-situ measurement of a resistivity ρ of the film is appropriate method to detect continuity of the film during the deposition. Fig.3 shows the change of $\sigma \cdot t$ and $\rho \cdot t$. as a function of nominal thickness of the FeCo film at the early stage of the film growth. Plane-view TEM images are also indicated for t of 3, 4.5 and 10 nm, respectively. The dip appeared at t of 4.2 nm corresponds to the phase transition from amorphous to crystalline stage, since the drastic change of the ρ and the lattice image in the TEM view are clearly observed at the thickness. In-situ observation system of the internal stress developed in this study is a powerful tool to detect the change of the phase transition and crystallization and as well as macroscopic deformation of the film structure.

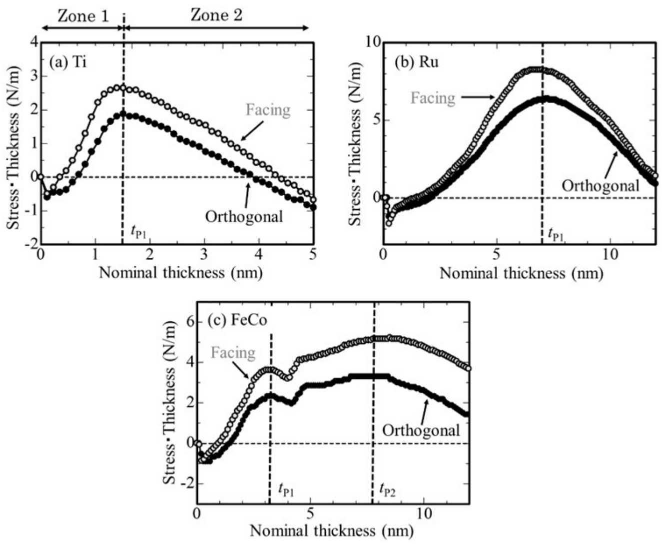

Fig.2 $\sigma \cdot t$ - t curves for (a) Ti (b) Ru and (c) FeCo films.

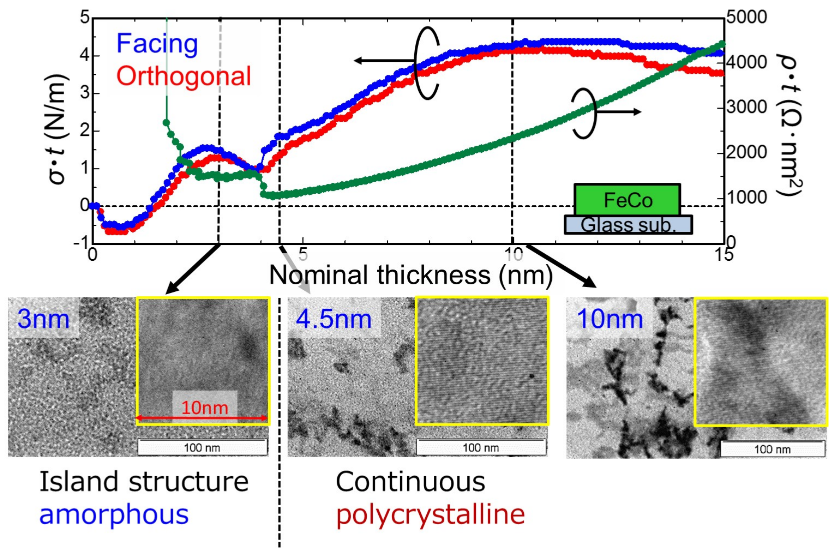

Fig.3 . change of $\sigma \cdot t$ and $\rho \cdot t$. as a function of nominal thickness t of the FeCo film. Plane-view TEM images for t of 3, 4.5 and 10 nm

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