Role of underlayer for segregated structure formation of CoCrPt-SiO₂ granular thin film

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Abstract. We have investigated the role of the Ru underlayer for the segregated structure formation of CoCrPt-SiO₂ granular thin film to improve the recording performance of CoCrPt-SiO₂ perpendicular magnetic recording media. The coercivity of the granular film decreases with decreasing Ru layer thickness, which comes from the change in the segregated structure. Formation of an oxide grain boundary is needed to obtain higher coercivity. According to a morphology analysis, the Ru layer roughness is closely related to the coercivity. The results indicate that the oxide grain boundary formation of the granular layer is enhanced by the roughness of the Ru underlayer. The shapes of the Ru grains probably serve as a template in CoCrPt grain growth and oxide grain boundary formation. As one of the methods for enhancing the roughness of the Ru underlayer, an island shape growth on the low surface energy materials is applicable. The roughness of the Ru layer was increased using a Pd/MgO/Pd seed layer and high coercivity was successfully obtained even when the Ru layer thickness was 3 nm.

1. Introduction
CoCrPt-SiO₂ granular thin film is well known as a recording layer of perpendicular magnetic recording media [1–3]. To obtain a high signal to noise ratio (SNR), magnetically isolated CoCrPt grains are required. Magnetically isolated grains can be attained by forming an oxide grain boundary surrounding the CoCrPt grains, called a “segregated structure”, of granular film. To control the segregated structure of the recording layer, the role of the underlayer is important as well as the sputtering condition of the CoCrPt-SiO₂ granular film. Ru film is well known as a suitable underlayer for obtaining a c-axis oriented Co-alloy film [1–7] and a segregated structure of granular film. However, a thick Ru layer is usually used for obtaining better performance. To reduce the magnetic spacing between the head and soft-magnetic layers in the medium, the Ru layer thickness should be reduced. However, the coercivity of the granular medium often decreases with decreasing Ru layer thickness [7]. To improve the recording performance of the granular media, we should overcome the trade-off between Ru layer thickness and recording layer properties. We investigated the role of the Ru underlayer in the formation of a segregated structure of CoCrPt-SiO₂ granular film to overcome this trade-off relationship and to improve the performance of CoCrPt-SiO₂ perpendicular recording media.
2. Experimental procedure
A CoCrPt-SiO₂ perpendicular medium was prepared on a glass disk substrate. An amorphous CoTaZr film was deposited as a soft-magnetic underlayer. A Ta seed layer and a Ru underlayer were deposited to control the c-axis orientation of the recording layer. An additional seed layer, Pd/MgO/Pd, were inserted between Ta and Ru layers in experiments for roughness enhancement. The typical sputtering process condition of the Ru layer is a low deposition rate (0.2 nm/sec), which we call process A in this study. We also prepared samples by applying higher deposition rates of 1.0 (process B) and 6.0 nm/sec (process C) to clarify the role of the Ru layer. The CoCrPt-SiO₂ recording layer was deposited by co-sputtering of CoCrPt and SiO₂. A carbon nitride protective layer was then deposited on the surface of the recording layer. All the sputtering processes were carried out without heating.

The surface roughness (Ra) of the Ru layer was measured using an atomic force microscope (AFM). These AFM samples were prepared without recording layer deposition. The roughness we measured is the height difference between grain center and boundary. However, the real grain boundary depth is hard to measure due to the limited penetration depth of AFM cantilever. Therefore, the measured roughness is not real but relative value. The magnetic properties were measured using a Kerr effect magnetometer, vibrating sample magnetometer (VSM), and torque magnetometer. Samples without a soft-magnetic underlayer were prepared for VSM and torque measurements. The perpendicular uniaxial magnetic anisotropy energy was calculated by subtracting the shape anisotropy energy from the measured energy. The microstructures were observed using a high-resolution transmission electron microscope (TEM).

3. Results and discussion

3.1. Ru layer thickness impact on magnetic properties of granular film
Figures 1(a) and 1(b) show TEM plan-view images of Ru and CoCrPt-SiO₂ layers observed for a typical perpendicular medium with a 17-nm-thick Ru layer. The average grain pitches of Ru and CoCrPt were 8.1 and 7.8 nm, respectively, according to grain size analysis. This result indicates that there is one-to-one grain growth between the Ru and CoCrPt-SiO₂ layers. The cross-sectional TEM image, shown in figure 2, supports this relationship between Ru and CoCrPt-SiO₂ layers. Therefore, grain size and orientation of the Ru layer greatly impact those of the CoCrPt-SiO₂ layer [2]. In this case, CoCrPt grains are well isolated by oxide grain boundaries as shown in figure 1(b).

The magnetic properties were measured for samples with various Ru layer thicknesses using a VSM and torque magnetometer. Figure 3 shows the dependence of coercivity (Hc) on the Ru layer thickness. The coercivity decreased with the Ru layer thickness. This effect is the same as results reported elsewhere [7]. Figure 3 also shows the change of loop slope around coercivity, which we call α. The increase of α with reducing Ru layer thickness comes from the increase in inter-granular exchange coupling. Figure 4 shows the uniaxial magnetic anisotropy energy (Ku) and the saturation
magnetization ($M_s$) measured for the same sample. Both $K_u$ and $M_s$ remained almost the same when the Ru layer thickness was decreased. The results indicate that insufficient phase separation is not the cause of the coercivity reduction and that the difference in the segregated structure, which is probably the width of oxide grain boundary, is a possible cause. The width of oxide grain boundary affects inter-granular exchange coupling and coercivity.

3.2. Relationship between Ru layer roughness and magnetic properties
To clarify the mechanism of coercivity reduction observed in the samples with a thin Ru layer, the surface morphologies of the Ru films were observed using AFM. The films were deposited using three process conditions. Figure 5 shows the dependence of the roughness ($R_a$) on the Ru layer thickness. Here, the roughness indicates the surface morphologies of Ru grains. When the thickness was increased, the roughness increased for each of the deposition process conditions. Figure 6 shows the relationship between Ru layer roughness ($R_a$) and coercivity ($H_c$) measured using a Kerr effect magnetometer. The CoCrPt-SiO$_2$ recording layers were deposited using the same process conditions on the various Ru intermediate layers. These results show that coercivity is closely related to the roughness - the higher the roughness, the higher the coercivity. The two Kerr loops depicted in Figure 6 were measured for samples with Ru thicknesses of 5 and 20 nm. When the roughness was increased, the coercivity increased, and the loops became shared in shape. Such changes in the Kerr loop can be explained from reductions in the inter-granular exchange coupling of the recording layer. Therefore, the oxide grain boundary formation of the granular recording layer is apparently enhanced by the roughness of the Ru layer. The shapes of the Ru grains probably serve as a template in CoCrPt grain growth and oxide grain boundary formation. Therefore, we should increase the roughness of the Ru grains as well as creating proper diameters and a good c-axis orientation to improve the properties of the recording layer.
3.3. Oxide seed layer
When an ultra-thin metal layer is formed on an oxide layer that has a low surface energy, island growth is expected [8-9]. This island shaped layer will help enhance the roughness of Ru layer surface and the segregated structure formation of CoCrPt-SiO$_2$ layer. We prepared a stacked structure of Pd (1.5 nm)/MgO (1 nm)/Pd (1.5 nm) and inserted it below the Ru layer. Then, we successfully obtained a Ru layer roughness ($R_u$) of 0.37 nm even when the Ru thickness was only 3 nm. The roughness enhancement by the Pd/MgO/Pd seed layer resulted in high coercivity even when the total thickness of the underlayer was less than 10 nm, as shown in figure 7. The results indicate that the surface roughness of the Ru underlayer contributes to increased coercivity and to an enhanced segregation structure of CoCrPt-SiO$_2$ granular film. The oxide seed layer is one of the promising candidates for overcoming the trade-off between Ru layer thickness and recording layer properties.

4. Conclusion
We have investigated role of the Ru underlayer for the segregated structure formation of CoCrPt-SiO$_2$ granular film. The coercivity of the granular film decreases with decreasing Ru layer thickness, which probably comes from the change in the segregated structure. Formation of an oxide grain boundary is needed to obtain higher coercivity. Judging from the AFM analysis results, the shapes of the Ru grains serve as a template in CoCrPt grain growth and oxide grain boundary formation. As one of the methods for enhancing the Ru layer roughness, introduction of a Pd/MgO/Pd seed layer was investigated. The Ru layer roughness was increased and high coercivity was successfully obtained even when the Ru layer thickness was 3 nm.

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