Grain Size Reduction by Doping Cr Underlayer with Ru for Longitudinal Magnetic Recording Media

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A Cr underlayer was doped with 10 at. % Ru to enlarge the Cr lattice and promote the Co(11.0) formation of the CoCrPtTaB magnetic layer by in-plane tensile stress at a recording layer/underlayer interface. The texture, grain size and magnetic characteristics of CoCrPtTaB/Cr(Ru) were examined as well. The CrRu(002) underlayer exhibit markedly enhanced Co(11.0) orientation, increasing coercivity and preferential alignment of the c-axis. The grain size and grain size distribution of the recording layer decreased as the CoCrPtTaB magnetic layer grew epitaxially on the CrRu underlayer. The grain size of the recording layer was reduced from 11.2 nm with a pure Cr underlayer to 5.4 nm with a CrRu underlayer. The latter is the smallest grain size yet reported for CoCr-based alloy recording media.

Index Terms—**Chromium alloys, cobalt alloys, epitaxial growth, magnetic recording.**

I. Introduction

CO-BASED longitudinal magnetic recording media presently dominate the magnetic recording market. High signal-to-noise ratio (SNR), low media noise at the transition length and narrow signal pulse width (PW_{50}) must be achieved to increase further magnetic recording density. Approaches for reaching these objectives are based on scaling down such physical parameters as grain size, width of the grain size distribution and crystallographic orientation. The appropriate underlayer enables these parameters to be reduced, since the grain size of the underlayer and the lattice mismatch at the recording layer/underlayer interface affect these physical parameters if the epitaxial growth proceeds at the recording layer/underlayer interface [1]–[3]. In a typical Cr-based underlayer, Mo [3]–[5], Ti[3], [6], W [3], [7], Mn [1] and V [3], [8] are soluble, improving the lattice match between the recording layer and the underlayer. However, adding these elements does not significantly reduce the grain size. The Cr underlayer was doped with Zr [1], [2], [4], Nb [2] and B atoms [9] to reduce the magnetic grain size, because these elements are insoluble in Cr lattices, and thus segregate in the grain boundaries, preventing further grain growth. Although doping with these elements reduces the magnetic grain size, the Co(11.0) orientation was poor and the coercivity was low [1]. The expanded Cr lattice has been found to induce in-plane tensile stress in the FePt/CrRu plane and promote the formation of the FePt(001) texture [10]. Thus, in this work, the Cr lattice was doped with 10 at.% Ru to adjust the lattice constant of the Cr(002) underlayer and lattice matching at the recording layer/underlayer interface. Incorporating Ru into Cr expands the body-centered cubic Cr lattice and helps to realize the Cr(002) orientation [10]. Additionally, the CrRu(002)[110] lattice is slightly larger than the Co(11.0)[00.2] lattice and an in-plane tensile stress is present along the crystallographic direction CrRu(002)[110]//Co(11.0)[00.2] [1]–[3], [11]. Therefore, the Co(11.0) plane is expected to be able to develop on a CrRu(002) underlayer, reducing the grain size and the width of its distribution.

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II. Experiment

The CoCrPtTaB/Cr(Ru) bilayer films were deposited on glass substrates by dc magnetron sputtering in a ultrahigh vacuum sputtering chamber. The base pressure was under 3×10^{-9} Torr before sputtering. The substrate temperature was maintained at 275° during sputtering. The thickness of the CoCrPtTaB recording layer was kept at 50 nm, but the thickness of the Cr(Ru) underlayer was varied from 15 to 60 nm. The film thickness was measured using an atomic force microscope (AFM). The crystallographic orientation and lattice constant of the films were determined by X-ray diffraction (XRD) using Cu-K_α radiation. After the Cr underlayer was doped with Ru, the composition of the CrRu underlayer was found to be about $Cr_{90}Ru_{10}$. The magnetic properties were measured at room temperature using a vibrating sample magnetometer (VSM) with a maximum applied field of 1.2 T.

III. Results and Discussion

Fig. 1 displays the XRD patterns of CoCrPtTaB/Cr(Ru) bilayer films with a 60-nm thick Cr(Ru) underlayer. In Fig. 1, the intensity of the Cr(002) peak is similar to that of the CrRu(002) peak. However, the intensity of the Co(11.0) peak was much higher when a CrRu underlayer was presented, suggesting that doping the Cr underlayer with Ru improve the Co(11.0) orientation and the preferential alignment of the c-axis in the plane. A narrow crystallographic distribution of Co(11.0) orientation was obtained with a CrRu underlayer. Therefore, the incorporation of Ru into the Cr underlayer can promote the formation

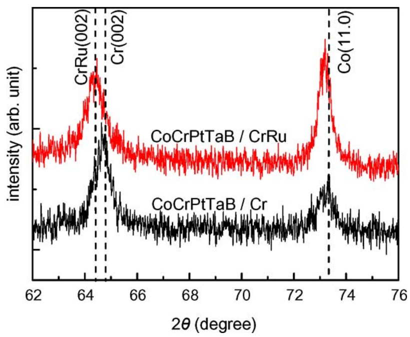

Fig. 1. X-ray diffraction patterns of CoCrPtTaB/Cr(Ru) bilayer films with 60 nm thick Cr(Ru) underlayer.

of the Co(002) orientation more efficiently. Doping with Ru moves the Cr(002) and the Co(11.0) peaks to lower angles. The Cr(002) peak shifts from 64.74° to 64.36° and the Co(11.0) peak shifts from 73.30° to 73.16°. Hence, the d-spacing of the Cr(002) plane, $d_{Cr(002)}$, increases from 0.1438–0.1446 nm, and $d_{Co(11.0)}$ increases from 0.1289–0.1292 nm, revealing that some Ru atoms replaced Cr atoms in the Cr lattice sites, expanding the lattice as a substitutional solid solution. In the case of a CoCrPtTaB/Cr bilayer structure, the lattice constant of pure Cr(002)[110] is approximately 0.4067 nm, which is close to the value 0.406 nm for Co(11.0)[00.2] [11]. However, in the CoCrPtTaB/CrRu structure, the lattice constant of CrRu(002)[110] is around 0.409 nm. Therefore, when the CoCrPtTaB film is staked on the CrRu(002) plane, the Co(11.0)[00.2] axis will be elongated by in-plane tensile stress, causing Co(11.0) to form easily on the CrRu(002) plane [10].

Fig. 2(a) and (b) plot the peak intensities of the Cr(002), CrRu(002) and CoCrPtTaB(11.0) planes, and the coercivity of the CoCrPtTaB/Cr(Ru) bilayer films versus underlayer thickness, respectively. In Fig. 2(a), the intensities of the Cr(002) or the CrRu(002) peaks increases with the thickness of the underlayer, indicating that thickening the underlayer promotes the formation of the Cr(002) and CrRu(002) orientations. In addition, the Co(11.0) intensity obtained with the CrRu underlayer increases with the CrRu(002) intensity and always exceeds that obtained using Cr films. However, the Co(11.0) intensity of CoCrPtTaB/Cr bilayer films does not increase with the Cr thickness above 30 nm, suggesting that the microstructure of CoCrPtTaB magnetic layer does not change significantly with the thickness of the Cr underlayer, perhaps because the lattice constant of pure Cr(002)[110] is close to that of Co(11.0)[00.2], so a smaller stress is formed at the CoCrPtTaB/Cr interface with thicker Cr underlayers. However, the tensile stress is larger at the CoCrPtTaB/CrRu interface, expanding Co(11.0)[00.2] axis. Therefore, a higher CrRu(002) intensity corresponds to better Co(11.0) planes [2], [3]. The thickness of the Cr(Ru) underlayer affects the coercivity, as shown in Fig. 2(b). The coercivity increases from 5–30 nm because the Co(11.0) orientation is improved [1]–[4]. When the thickness of the underlayer exceeds 30 nm, the doping of the Cr underlayer with Ru increases the coercivity, by improving the preferential alignment of c-axis in the plane [3]. The coercivity of the CoCrPtTaB/Cr bilayer film does not change much with the pure Cr thickness over 30 nm.

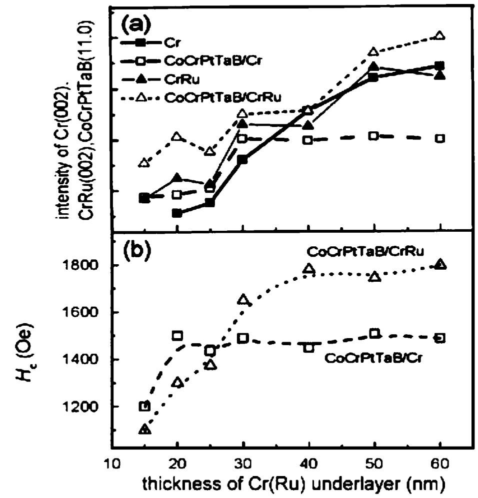

Fig. 2. (a) Peak intensities of the Cr(002), CrRu(002), and CoCrPtTaB(11.0) planes, and (b) Coercivity of CoCrPtTaB/Cr(Ru) bilayer films as a function of underlayer thickness.

It is associated with a small Co(11.0) crystallographic enhancement. The coercivity of CoCrPtTaB/CrRu bilayer films does not increase, even at a higher Co(11.0) intensity with the thickness of CrRu over 40 nm, perhaps because the presence of the ultra-fine grains in the magnetic layer [4] below the superparamagnetic limit [12].

The AES (Auger electron spectroscopy) depth profile and the cross section TEM+EDS (energy dispersive X-ray diffractometry) were investigated to determine the effects of diffusion and the distribution of Ru in the CoCrPtTaB/CrRu bilayer film. The results demonstrate grain-by-grain growth in the CoCrPtTaB/CrRu bilayer film. Epitaxial growth occurred at the CoCrPtTaB/CrRu interface, and extended into the CoCrPtTaB magnetic layer. The Ru atoms diffused from the CrRu underlayer into the CoCrPtTaB recording layer. The Ru content at the grain boundaries in the CoCrPtTaB magnetic layer exceeded that in the CoCrPtTaB magnetic grains, indicating that Ru atoms prefer to segregate at the CoCrPtTaB grain boundaries. It also impedes further grain growth [1]–[4], [9].

Fig. 3 presents a plane-view TEM bright-field image of single Cr(Ru) underlayer and CoCrPtTaB/Cr(Ru) bilayer films. Both the recording layer and the underlayer are 50 nm thick. The plane-view TEM images reveal that the mean grain size in the pure Cr underlayer was around 16.2 nm, and it was reduced to 8.8 nm when 10 at. % Ru was incorporated as a dopant. When the CoCrPtTaB film was deposited on a CrRu underlayer, the mean grain size was reduced from 11.2 nm for the CoCrPtTaB/Cr film to 5.4 nm for the CoCrPtTaB/Cr(Ru) film. Comparing with the current longitudinal media the grains are quite small and the small grains in the underlayer limit the growth of grains in the magnetic layer. The segregation of Ru at the CoCrPtTaB grain boundary may also reduce the grain size in the magnetic layer.

This study also examined the grain size distribution. Fig. 4 shows the grain size distribution of the CoCrPtTaB/Cr(Ru) bilayer films, in which each of the magnetic layer and underlayer was 50 nm. In Fig. 4(a), when CoCrPtTaB was deposited on pure

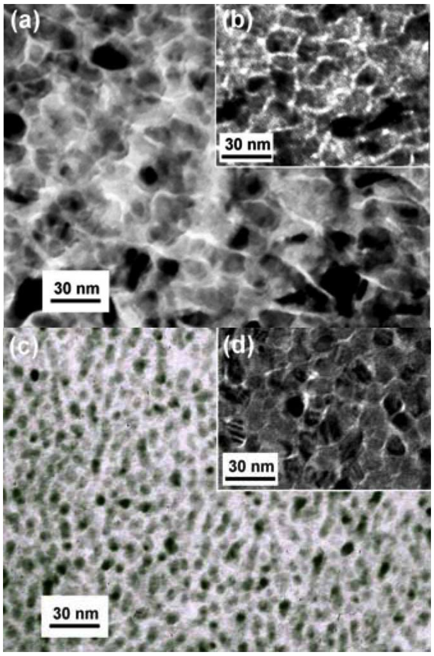

Fig. 3. Plane view TEM bright field images of (a) CoCrPtTaB/Cr bilayer films, (b) single Cr underlayer, (c) CoCrPtTaB/CrRu bilayer films, and (d) single CrRu underlayer.

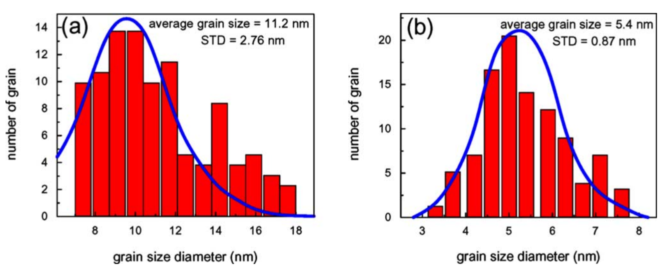

Fig. 4. Grain size distribution of (a) CoCrPtTaB/Cr and (b) CoCrPtTaB/CrRu bilayer films, where the thickness of magnetic layer and underlayer was 50 nm.

Cr underlayer, the distribution was wide and non-normal. However, when the CoCrPtTaB magnetic layer was grown on the Ru-doped Cr underlayer, the grain size distribution was narrow and normal. The standard deviation (STD) σ of the distribution declined from 2.764 nm with a pure Cr underlayer to 0.8729 nm with a CrRu underlayer. Accordingly, low media noise, small transition length and narrow PW_{50} can be obtained for longitudinal magnetic recording.

IV. Conclusion

Ru-doped Cr film was utilized as the underlayer to improve the Co(11.0) texture and the coercivity, while reducing the grain size for longitudinal magnetic recording. When the CoCr-base recording layer is stacked on the CrRu(002) plane, the larger lattice of CrRu expands the Co(11.0)[00.2] lattice, enhancing the Co(11.0) texture and the preferential alignment of the c-axis in the plane. Doping the Cr underlayer with Ru substantially reduced the grain size of the CrRu underlayer. The small grain size of the CrRu underlayer limits the growth of grains in the recording layer. The segregation of Ru at the grain boundary is also important in preventing further grain growth in the recording layer. Therefore, the grain size of 5.4 nm is ultra-small in the CoCr-base recording layer.

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