Ru+oxide interlayer for perpendicular magnetic recording media

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Ru+oxide composite thin films were studied as potential intermediate layers (interlayers) for perpendicular magnetic recording media for the purpose of grain size reduction. It was found that the orientation spread of the Ru grains increased from 3.7° to 4.6° when the oxide addition was increased to 50 vol %, and the roughness of the thin films stayed constant. The grain size of the Ru layer was reduced as the oxide volume fraction increased. At lower doping levels, the oxide stayed at the Ru grain boundaries. However, when the oxide was higher than 30 vol %, a "salt and pepper"-type microstructure was obtained, where both Ru and oxide grains are small and intermixed. It was found that the magnetic layer did not have a one to one grain growth on the Ru+oxide layer with the ''salt and pepper''-type microstructure. The coercivity (H_c) of the media decreased as the oxide volume fraction increased, while the squareness of the hysteresis loops stayed at unity until more than 30 vol % of oxide was added. Oxide additions to the Ru interlayer seem to be a good process variable to further decrease the grain size for higher areal density magnetic recording. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2830971]

INTRODUCTION

One of the major challenges for future perpendicular magnetic recording media is to obtain smaller grain size in order to improve the signal to noise ratio characteristics and to optimize magnetic transition parameters.[1] Thin films of CoCrPt(O) and CoPt(Cr)+oxide with 7 nm grain size have been obtained by epitaxial grain growth from granular Ru interlayer with similar grain size. In such films, the magnetic grain isolation was achieved by means of either O_2 reactive sputtering and/or oxide additions.[2–8] Ru, as an interlayer material, plays an important role in controlling the crystalline orientation, grain size, and magnetic grain separation. Recently, it was reported that the grain size of magnetic layers was able to be reduced to about 6 nm on various seedlayers or interlayers with reasonable size distribution.[9–11] All of these results indicate that the grain size distribution can be controlled by the microstructure of the nonmagnetic layers underneath the recording layer. In particular, SiO_2 additions to the Ru interlayers seem to be a good path to improve the grain separation to reduce grain size and possibly to reduce overall Ru thickness.[12,13]

In the present study, Ru+oxide interlayers were investigated to further reduce the grain size of the CoPt+oxide magnetic layer. We used various oxide types, volume fractions (vol %), and process pressures. It was found that the microstructure of the Ru+oxide layers varied greatly with the oxide type and vol %. It was also found that the magnetic properties and microstructure of magnetic layer varied significantly with the microstructure of Ru+oxide interlayer. The Ru grain size was greatly reduced to 2–3 nm. However, the smallest CoPt grain observed was about 5.8 nm with optimized magnetic properties.

EXPERIMENT

Granular media with film structure: glass\Ta (3 nm)\Ru (low pressure) (15 nm)\Ru+TiO_2 or WO_3 (10 nm)\CoPt +oxide (11 nm)\carbon overcoat was sputter deposited at room temperate using a Unaxis Circulus-M14 system. The volume fraction of TiO_2 or WO_3 varied from 0 to 50 vol % in the Ru+oxide interlayer. The magnetic layer in each sample was fixed with the same composition and thickness. Ru+oxide interlayer was studied at both low and high pressures. Hysteresis loops were measured by the magneto-optic Kerr effect magnetometer. The crystalline orientation was evaluated from x-ray rocking curve scans of Ru (00.2) peaks taken on a Philips X'pert diffractometer. Microstructures and surface morphology of samples deposited up to Ru+oxide interlayer and samples up to CoPt+oxide magnetic layer were analyzed on the JOEL 2000 transmission electron microscope (TEM) and a commercial Digital Instrument atomic force microscope (AFM).

RESULTS AND DISCUSSION

Composite films of Ru+x vol % TiO_2 or WO_3 (x =0–50) at low and high deposition pressures for the effect on the microstructure and magnetic properties of the subsequent granular CoPt+oxide layer were studied. Figure 1 shows the dependence of the angular dispersion of the Ru (00.2) orientation on TiO_2 or WO_3 vol %. The full width at half maximum (FWHM) of the Ru (00.2) rocking curve increases from 3.7° to 4.2° for the low pressure deposition with either of the oxide as the vol % increases from 0% to 50%.

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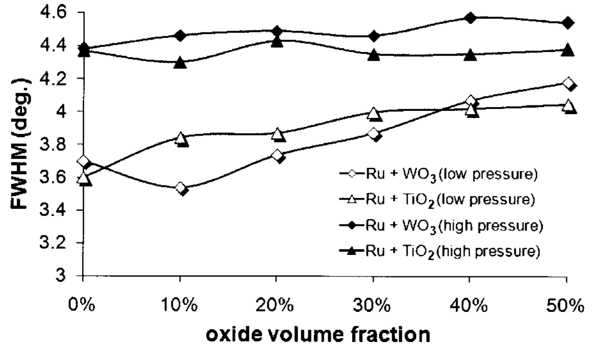

FIG. 1. FWHM of Ru (00.2) rocking curves vs oxide vol % in Ru+oxide interlayers at two different pressures.

On the other hand, the FWHM increases from 4.3° to 4.6° for the high pressure deposition. The actual increase of the FWHM of the Ru+oxide layer should be much more significant than that being manufactured by the combination of the two layers. It is obvious that both oxide and argon pressure have the strong effect on the orientation of the Ru+oxide interlayer. Moreover, pressure seems to be a stronger factor than oxide vol %. Usually higher pressure introduces more collisions between Ru and Ar atoms. As a result, the Ru atoms will have a lower surface mobility when they arrive onto the substrate. Consequently more porous and poorer orientated Ru films will be generated.

Figure 2 shows how coercivity of granular CoPt+oxide films varies with oxide vol % in cases of WO_3 and TiO_2 at two pressure conditions. Figure 3 shows the perpendicular *M-H* loops for media with Ru+40 vol % WO_3 and TiO_2 interlayers at two pressures. Samples with Ru+oxide deposited at higher pressure always exhibit higher H_c than those at lower pressure. The (H_c+H_n) value for higher pressure samples (e.g., 5.4 kOe for 40 vol % WO_3 and 5.8 kOe for 40 vol % TiO_2) is larger than that for the lower pressure samples as well (e.g., 1.3 kOe for 40 vol % WO_3 and 3.4 kOe for 40 vol % TiO_2). These indicate that the magnetic grains are better decoupled on the Ru+oxide films sputtered at higher pressure. In this condition, the coercivity of the films starts from more than 9 kOe at 0 vol %, gradually decreases to 8 kOe for WO_3 at 50 vol % and dramatically decreases to 2 kOe for TiO_2 at 50 vol %. The nucleation field H_n remains around −3 kOe for WO_3, but greatly increases to positive value for TiO_2 with up to 40 vol % oxide addition at

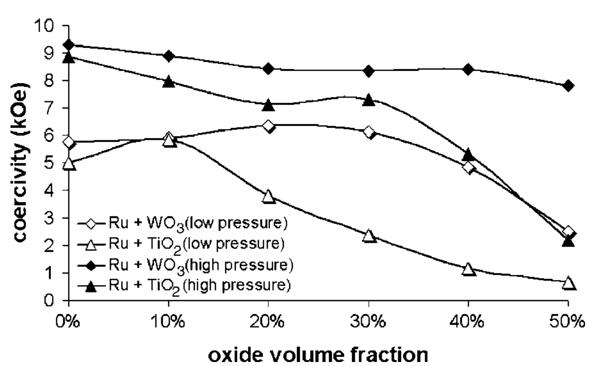

FIG. 2. Coercivity (H_c) of the media vs oxide vol % in Ru+oxide interlayers at two different pressures.

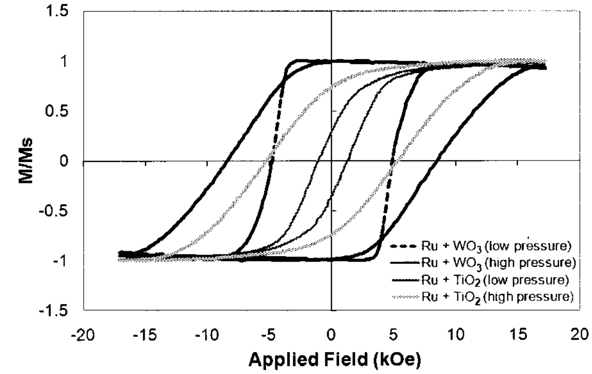

FIG. 3. Hysteresis loops of the media with interlayers Ru+40 vol % WO_3 and TiO_2 at two different pressures.

both high and low pressures. The dramatic decrease of H_c and increase of H_n in the case of TiO_2 are due to orientation degradation of CoPt grains. On the other hand, the orientation of the CoPt grains is not greatly affected by the Ru +WO_3 layer. X-ray diffraction data are very difficult to be obtained due to low intensity of the CoPt peaks and their close position to the Ru peaks. At low pressure, H_c of the CoPt+oxide films increases with oxide additions and then decreases. This increase is most likely due to improved grain separation induced by Ru+oxide films. The later decrease of H_c is due to either grain size reduction or orientation deterioration. Judging from the hysteresis loops in Figure 3, the orientation of CoPt grains on top of Ru+TiO_2 (40 vol %) is getting bad in both low and high pressure cases. On the other hand, the magnetic layers on top of Ru+WO_3 (40 vol %) still maintain a full loop squareness, suggesting a good orientation.

Figures 4(a)–4(c) show the TEM bright field images of CoPt+oxide films on top of low pressure sputtered Ru +WO_3 films with 0, 20, and 40 vol % oxide addition. Figures 4(d)–4(f) show the TEM bright field images of low pressure sputtered Ru+WO_3 films with 0, 20, and 40 vol % oxide addition. Figures 5(a)–5(f) show the same format as Figures 4(a)–4(f), except that the oxide is TiO_2. It can be seen from the figures that the average CoPt grain size is slightly reduced with increasing oxide vol % in the Ru

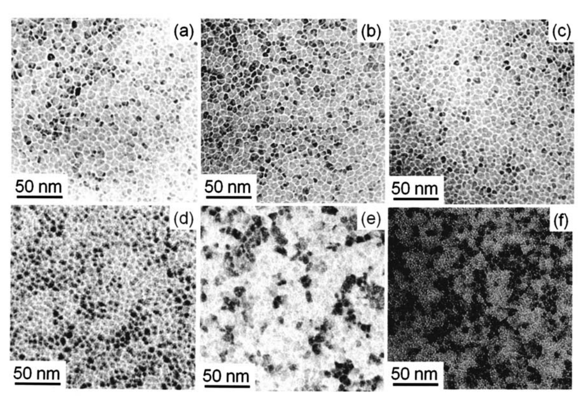

FIG. 4. (Color online) Plan-view TEM images of CoPt+oxide granular media with interlayer Ru+0 vol % (a), 20 vol % (b), 40 vol % (c) WO_3, and images of interlayer Ru+0 vol % (d), 20 vol % (e), 40 vol % (f) WO_3, respectively, sputter deposited at low pressure.

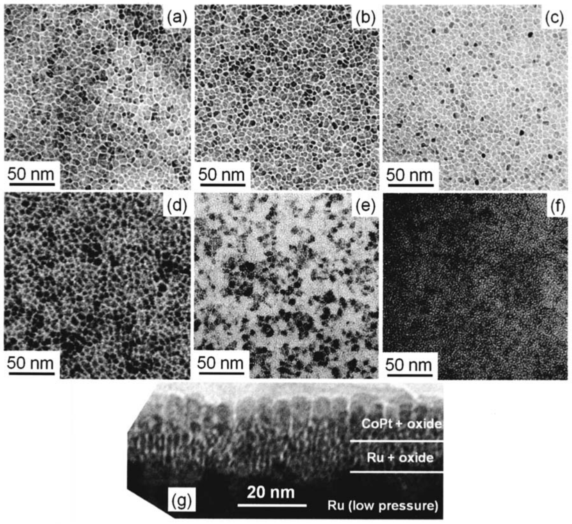

FIG. 5. (Color online) Plan-view TEM images of CoPt+oxide granular media with interlayer Ru+0 vol % (a), 20 vol % (b), 40 vol % (c) TiO_2, images of interlayer Ru+0 vol % (d), 20 vol % (e), 40 vol % (f) TiO_2, respectively, sputter deposited at low pressure and the cross-sectional TEM image of the media with Ru+40 vol % TiO_2 interlayer (g).

+oxide layer. On the other hand, the microstructure of the Ru+oxide layer changes dramatically as the oxide addition increases. In the case of WO_3, a mixture of Ru+WO_3 can be seen in Figure 4(f). This "salt and pepper"-like microstructure has the average grain size of about 2–3 nm. However, the grain size of CoPt+oxide film on top of this film was not much affected. In the case of TiO_2, the salt and pepper microstructure happens with less oxide than WO_3. It can be seen in Figure 5(e) (20 vol %) that fine Ru and oxide grains as small as 2–3 nm coexist. The large grain features in the image are due to the contrast from the underlying Ru (low pressure) layer. In order to understand the growth of the CoPt grain on top of Ru+oxide film with the salt and pepper microstructure, a cross-sectional TEM image was taken on the sample with 40 vol % TiO_2 [Figure 5(g)]. It can be seen that Ru grains have the average columnar width of 2 nm. The TiO_2 is segregated to be Ru grain boundaries. This microstructure is more evident on the thinner part of the sample (left side of the image). It is clear that CoPt ignores the grain size of the Ru and grows on top of multiple grains. The average grain size of CoPt is around 5.8 nm. Based on the results of film orientation, coercivity, and microstructure, it is found that the "salt and pepper" structure greatly reduces the feature size in the Ru+oxide interlayer. As a result, it reduces the average CoPt grain size from 7.2 ± 1.72 nm to as small as 5.8 ± 0.98 nm.

Figure 6 shows AFM roughness (R_a) of Ru+WO_3 films as a function of oxide vol %. As expected, since higher pressure sputtering condition for the interlayer shortens the mean free path and lowers the surface mobility of the atoms, the film surface is rougher than those samples sputtered at lower pressures. On the other hand, increasing vol % from 0% to 50% does not increase the surface roughness of the film as much as the effect of pressure.

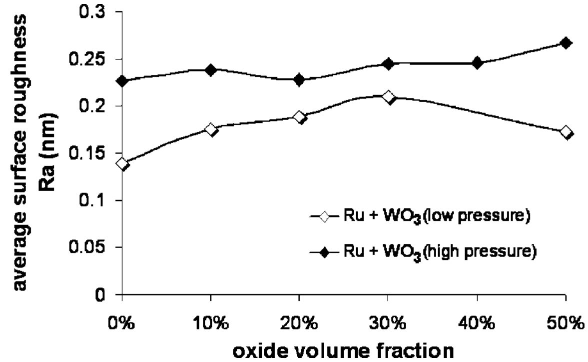

FIG. 6. Average surface roughness (R_a) of Ru+WO_3 interlayers vs oxide vol % at two different pressures.

SUMMARY

The Ru+WO_3 and TiO_2 interlayers reduce the grain size of CoPt+oxide film to 5.8 nm with smaller standard deviation due to the microstructure transition of Ru+oxide interlayer from the granular type to "salt and pepper"–type with much smaller feature size under the present sputter processing conditions. The media with WO_3 in the interlayer have much higher H_c and smaller grain size with up to 40 vol % of the oxide addition, while the media with TiO_2 maintain the competitive H_c up to 20 vol % oxide doping. The CoPt grains on top of Ru+WO_3 have better perpendicular orientation than those on top of Ru+TiO_2. Utilizing the composite interlayer of Ru+WO_3 is a promising method to reduce the grain size of CoPt+oxide films without much deterioration of c-axis orientation.

ACKNOWLEDGMENTS

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