Use of bias sputtering to enhance decoupling in oxide composite perpendicular recording media

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The effects of substrate bias on two types of oxide composite perpendicular recording media $CoCrPt-SiO_2$ and FePt–MgO were investigated. The use of substrate bias greatly modified the thin film microstructure and resulted in the enhanced grain decoupling in the films. The growth characteristics due to preferential resputtering were interpreted to arise mainly from weak surface bonding to the growing films for nontextured growth, combined with strong cohesion for the textured growth. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2748326]

Oxide composite perpendicular media has been shown to produce fine grains that are decoupled by oxide at the grain boundaries, leading to low noise performance in disk drive media.[1,2] However, too large an increase in oxide content to decouple the grains can result in spherically shaped metal alloy phase particles embedded in the oxide phase rather than segregating completely to boundaries of columnar grains.[3,4] The resulting microstructure does not have desirable well-isolated columns but rather an interconnected or isolated network of magnetic volumes.

In Co-alloy thin film media, Ru/Ru-oxide interlayer combination,[5] oxide seed layer with low surface energy,[6] and high gas pressure sputtering[7] have been suggested as methods to attain better intergranular exchange decoupling in the magnetic layer. However, it is not easy to obtain desirable microstructure for various types of oxide composite perpendicular recording media, where the magnetic grains need to be well separated by nonmagnetic oxide phase grain boundaries.

In this study, we examine the effect of substrate bias during sputter deposition of two types of oxide composite perpendicular media: A ($CoCrPt-SiO_2$) and B (FePt–MgO). Bias sputtering was utilized to modify the film microstructure. The use of bias sputtering led to a well-separated media microstructure and an increased columnar growth due to the enhanced oxide mobility incorporated with the preferential resputtering.

$Co_{71}Cr_9Pt_{20}-SiO_2$ thin films were deposited on Si substrate/Ru underlayer (20 nm), while $Fe_{47}Pt_{53}-MgO$ composite films were prepared with Si substrate/Ta (16 nm)/MgO underlayer (12 nm). A CoCr alloy target with bonded Pt and SiO_2 chips (for the $CoCrPt-SiO_2$) or a MgO target with bonded Fe and Pt chips (for the FePt–MgO) were used for magnetic film preparation. Films were prepared by rf diode sputtering in a Leybold-Heraeus Z-400 system with no oxygen added to the argon gas and no intentional substrate heating. The films were all provided under similar sputtering conditions. The base pressure was about 5×10^{-7} Torr and the Ar sputtering pressure was fixed at 10 mTorr. Deposition was performed at about a 2.3 W/cm^2 sputtering power density. Substrate bias was utilized to change morphology during magnetic film growth. The bias voltage varied from zero to −200 V. Care was taken to ensure that no significant temperature increase occurred during deposition, even when the bias was applied. The film compositions were determined by energy dispersive x-ray fluorescence and inductively coupled plasma analysis. Film textures and microstructures were characterized by an x-ray diffractometer (Philips X'pert Pro with x-ray lens) using Cu $K\alpha$ radiation and by a JEOL JEM-2010 transmission electron microscope (TEM) operating at 200 kV for conventional analysis and a TECNAI F20 for high resolution studies.

In Figs. 1(a) and 1(b), plan-view TEM images of media A and B are shown. The figures indicate a dramatic change in grain morphology as substrate bias was applied. Oxide grain

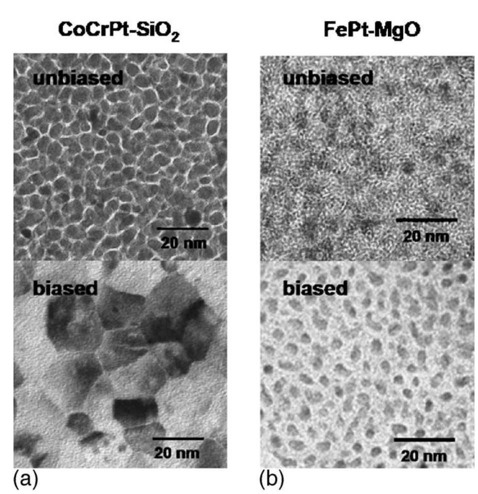

FIG. 1. Plan-view TEM images of the two different oxide composite perpendicular media with/without substrate bias: (a) $CoCrPt-SiO_2$ and (b) FePt–MgO films. The films were all fabricated at room temperature.

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boundaries are shown as white contrast between contiguous grains. When substrate bias was not applied during deposition, medium A ($CoCrPt-SiO_2$) with a Ru underlayer has a microstructure of apparent Co grains of diameter of 5–8 nm, separated with SiO_2 at the grain boundaries. On the other hand, in medium B (FePt–MgO), the length scale for the precipitation of oxide is much smaller (1–2 nm), and well-defined grains with boundaries are not in evidence; rather an interconnected network is seen, which is likely to produce a large switching volume.

As substrate bias was applied, in medium A, a similar trend as previously reported in $CoCrPt-SiO_2$ longitudinal media was observed.[8] Biasing had an effect of reducing the total amount of oxide in the growing films and promoting the growth of larger apparent grains. In contrast, in medium B, there was no clear preferential oxide removal during bias sputtering. Rather, there seems to be a slight increase in MgO content with substrate bias. For the two types of media, the preferential sputtering appears to be quite different; however, the enhanced grain separation in the biased films seems to be similar.

In Figs. 2(a) and 2(b), striking contrast in the FePt+MgO film morphology is shown from the cross-sectional TEM examination. For unbiased FePt+MgO films [see Fig. 2(a)], spherically shaped FePt particles are observed and the oxide acts as a matrix in which FePt particles are embedded in the through thickness direction. The spherical shape of a particle equilibrated in the matrix can be thought in terms of the surface energy of the particle since spherical shapes minimize surface per unit volume.

Compared with Fig. 2(a), the biased FePt+MgO film is highly columnar in its growth morphology [Fig. 2(b)]. It is seen that several grains come from the underlayer template grain, indicating crystallographic registry between these grains. The atomic registry across the MgO/FePt–MgO boundary is evident in the high-resolution TEM (HRTEM) image [see Fig. 2(c)]. The grain-to-grain growth through the MgO/FePt–MgO interface can be seen. The lattice mismatch between FePt (200) and MgO (200) is known to be about 9.4%.

Moreover, the use of bias sputtering not only enhanced the columnar growth but also greatly promoted the epitaxial growth of the films [again see Fig. 2(c)]. Typical bias-sputtered FePt–MgO films have two characteristic x-ray peaks: MgO (200) at 42.2° and FePt (200) at 45.6° in θ-2θ scan. No other peaks were found at 2θ=20–60°, indicating the strong epitaxial growth. A similar trend was observed for the bias-sputtered $CoCrPt-SiO_2$. The FePt–MgO (200) was epitaxially grown onto the underlayer MgO (200), whereas the CoCrPt (00.2) texture was obtained onto the underlayer Ru (00.2).

In Fig. 3, the resputtered fraction (in percentage) was computed. The resputtered fraction (RF) is given by RF=[D(unbiased)×V(unbiased)−D(biased)×V(biased)]/[D(unbiased)×V(unbiased)], where D is the deposition rate of medium and V is the volume fraction of each species (metal or oxide) in the medium. With a substrate bias of −150 V, only 10% of the MgO appears to be resputtered. However, the FePt and CoCrPt remained about half for the same bias voltage. Of particular note is the SiO_2 content that showed a sharp increase in the resputtered fraction up to about 90% as bias voltage was applied.

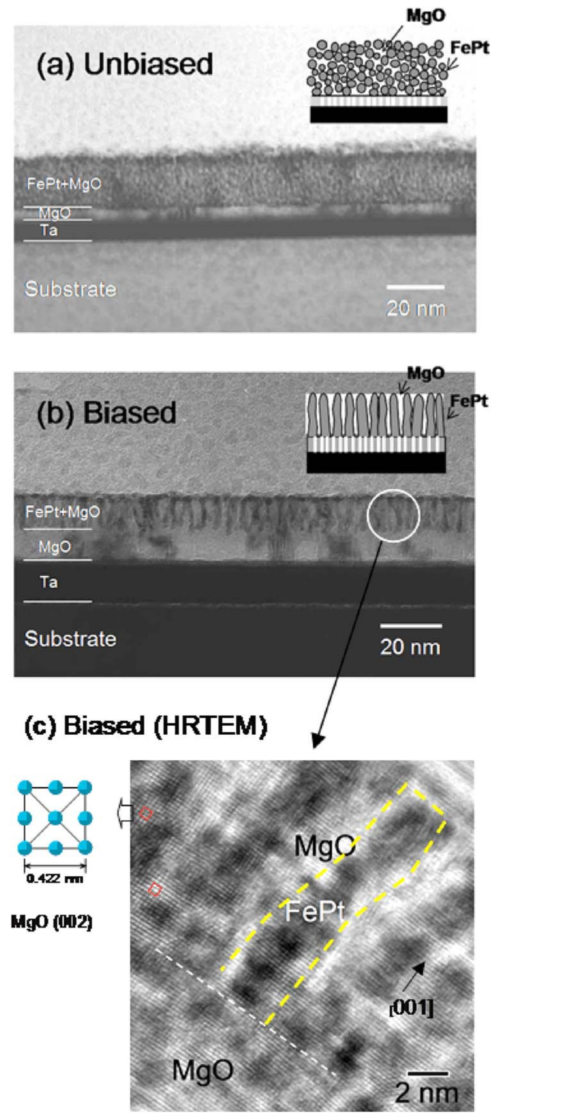

FIG. 2. Cross-sectional TEM images of medium B (FePt–MgO) sputtered (a) with substrate bias and (b) with no bias. (c) HRTEM image of the stack shown in (b). As substrate bias was applied, the columnar growth was highly promoted. In (c), the white contrast indicates the oxide phase (MgO), which can be confirmed by the lattice image.

This variation according to the metal and oxide species can shed some light on the resputtering process. We conjecture that bias sputtering will favor one particular growth texture which gives rise to a better orientational relationship with the underlayer over all others and consequently promote columnar growth. This suggests, of course, that the metal and

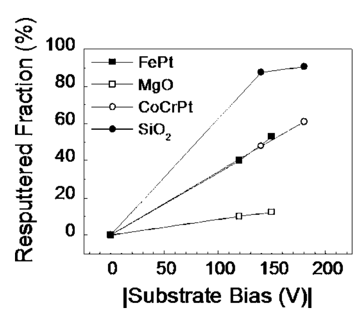

FIG. 3. Resputtered fraction (RF) in% as a function of bias voltage. The RF widely varied according to the species. The RFs are listed from high to low $RF(SiO_2) > RF(CoCrPt) \approx RF(FePt) > RF(MgO)$.

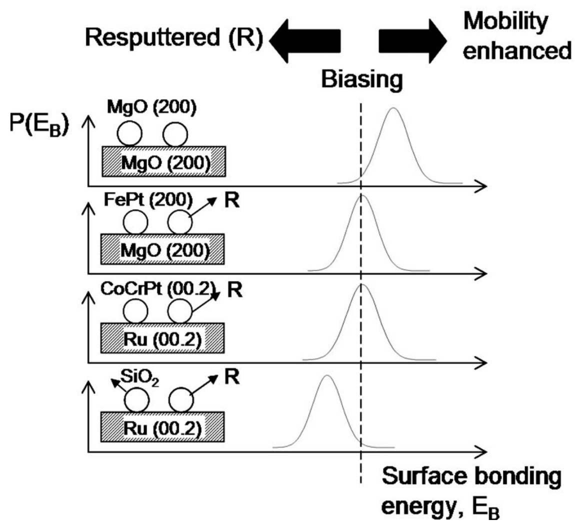

FIG. 4. Schematic representations of preferential removal substrate bias made. Substrate bias preferentially removes weakly bonded species, which can be interpreted in terms of surface bonding energy for different film orientations.

oxide species prefer to bond to materials that are similar to themselves, i.e., MgO (200) on MgO (200), which will produce strongly bonded surface species at each layer of the deposition.

The reported interface adhesion energies for metal species on MgO and for MgO on MgO are less than 1–2 and 30–100 eV, respectively,[9,10] which also supports the concept that a difference in surface bonding energy between species in the magnetic layer and the underlayer is the chief mechanism of the observed preferential resputtering. In the case of SiO_2 on Ru (00.2), the adhesion energy may be quite small, presumably less than 1 eV since biasing removed larger amount of the SiO_2 in the growing films than the others.

Further investigation was pursued to ascertain that this is not simply due to different sputtering yields for the species. Typical sputtering yields for SiO_2, MgO, Co, and Fe at low incident particle energy region (50–60 eV) were reported as 0.022, 0.008, 0.048, and 0.064, respectively,[11,12] indicating that oxides generally have lower sputter yields than metal targets. Thus, this difference in sputtering yield does not account for the variation in preferential resputtering. The resputtered rate of SiO_2 observed in the present work doubled that of the Co or Fe.

Accordingly, the following model for the selective resputtering is presented in Fig. 4. The figure schematically shows how substrate bias can preferentially remove weakly bonded species by thinking in terms of the distribution of surface bonding energy for different film orientations. A bonding energy distribution with a bell shape such as Gaussian distribution was assumed. Bias voltage was used to estimate the average kinetic energy of incoming Ar^+ which strikes the substrate. Although a more relevant parameter would be the sheath voltage—the plasma potential minus the bias potential—we carried out an order of magnitude estimate of energy of bias sputtering, which was several eV.[13]

For the atoms which remain on the surface, we speculate that there is likely some enhancement in their mobility. Substrate bias led grains to be well separated with clear boundaries for the two media, suggesting that biasing is generally effective in driving the segregation. This is ascribed to an increase in Ar^+ ion bombardment of the substrate during bias sputtering, which helps to increase mobility of the oxide molecules on the growing surface such that they reach grain boundaries. Which factor dominates, removal of poorly bonded species or increase in the mobility of the species that remain on the surface, is thought to depend on the adhesion energy between species in the magnetic layer and the underlayer.

A reduction in grain boundary areas in FePt–MgO can be easily achieved by utilizing targets of different starting compositions (less oxide), which is likely to influence grain sizes as well. Further work is in progress to optimize the magnetic properties of the CoCrPt–SiO_2 and the proper ordered phase ($L1_0$) of the FePt–MgO films. The magnetic properties were previously shown to be a strong function of biasing in CoCrPt films.[8]

In summary, the observations in this work are all related to the elimination of the weakly bonded (or faulted) regions from the growing films driven by ion bombardment during bias sputtering. Particularly important are the weak bonding of molecules to the nontextured growth and their strong bonding to the textured growth. Such features of bias sputtering can be greatly useful to attain desirable oxide composite media properties (good orientation and well-separated grains) when designing high density recording media with low media noise.

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