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Perpendicular-MgO-MTJs with fcc(111)-oriented CoPt superlattices

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1. Introduction

An MgO-based magnetic tunnel junction (MgO-MTJ) with perpendicular magnetic anisotropy (p-MgO-MTJ) has attracted attention for a memory cell of high density spin-torque switching type MRAM (so-called Spin-RAM). The number of studies concerning spin-torque switching in nanopillars with perpendicular anisotropy has increased in recent years [1]. Although there is a whole lot of perpendicular materials and structures, a perpendicular layer in a p-MgO-MTJ has been mostly restricted to a super-lattice structure or an $L1_0$-ordered alloy. We have focused on a film with an hcp-c-plane or an fcc(111) oriented chemically ordered alloy such as an $L1_1$- CoPt [2] possessing large perpendicular anisotropy K_u (> 1x10^7 erg/cc) and better grain orientation than that of an $L1_0$-ordered structure.

We have also attempted to synthesize an alloy film artificially using an alternate monatomic layer deposition method. It is expected that such a film exhibits magneto crystalline anisotropy unlike an existing super-lattice with interfacial perpendicular anisotropy, and the chemical ordering of an alloy gives higher thermal stability than existing super-lattices. If this method provides a very thin perpendicular film without deteriorating magnetic properties, it will be a candidate for a free layer of spin-RAM with perpendicular magnetic anisotropy (PMA), because a thin free layer (typically less than 3 nm) enables spin-torque switching.

In this study, we have prepared (111) - oriented CoPt superlattice films by alternation of nearly-monatomic Co and Pt layers, and succeeded to obtain $L1_1$-ordered-CoPt-like properties in samples even for them with less than 1.5 nm in thickness. Then, using the CoPt superlattice as a free layer, we have prepared p-MgO-MTJs with/without CoFeB insertions beneath and onto an MgO barrier.

2. Experiments

Films were deposited using sputtering (Canon-Anelva C-7100) on thermally oxidized Si wafers. A [Co/Pt]*n* (*n*: alternation period) superlattice film was formed by alternate deposition of Co and Pt on a Ru(001) or a Pt(111) buffer. The substrate temperature during the deposition varied from 170 to 300ºC. We used X-ray fluorescence analysis (XRF) for the composition analysis. A p-MgO-MTJ device structure was prepared using e-beam lithography and Ar ion milling process.

3. Results

Figure 1 shows *M-H* loops of a [Co(0.23nm) / Pt(0.17nm)]6 film (2.4 nm in nominal total thickness) deposited on a Pt buffer at 250ºC. The loop of out-of-plane magnetic field shows a sharp transition with good squareness and that of in-plane shows good linearity, suggesting the formation of a high-quality perpendicular magnetized film with narrow dispersion of the grain orientation. Fig. 2 shows Co composition dependence of M_s, H_k and estimated $K_u(= H_k M_s/2 + 2\pi M_s^2)$ for [Co(t_{Co}) / Pt(0.4- t_{Co})]6 samples with various Co thickness (t_{Co}) from 0.16 to 0.23 nm deposited at 250ºC. According to the linear t_{Co} dependence of M_s and H_k, K_u monotonically increased with increasing t_{Co}. We obtained the largest K_u to be 1.1x10^7 erg/cc in [Co(0.23nm) / Pt(0.17nm)]6. Properties of post-annealed samples were also investigated. They did not show any change up to the post-annealing temperature of 350ºC. Post-annealed samples at 430ºC lost their squareness in *M-H* and showed increased H_c in spite of decrease in K_u compared to those of as-deposited. It is suggested that diffusion of atoms in [Co/Pt] deteriorated the chemical ordering resulting decrease of K_u, on the other hand, the grain growth brought some pinning sites for domain wall

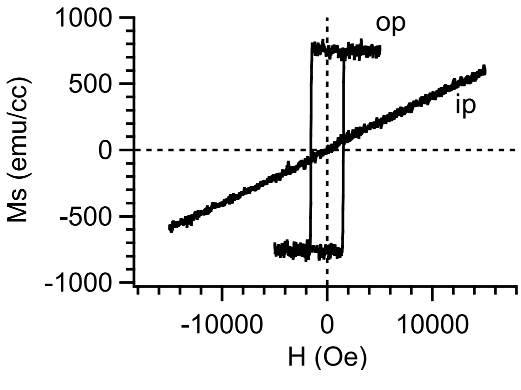

Fig.1 Magnetization loops of out-of-plane (op) and in-plane (ip) for a [Co(0.23nm) / Pt(0.17nm)]6 superlattice film (2.4 nm-thick) deposited at 250ºC.

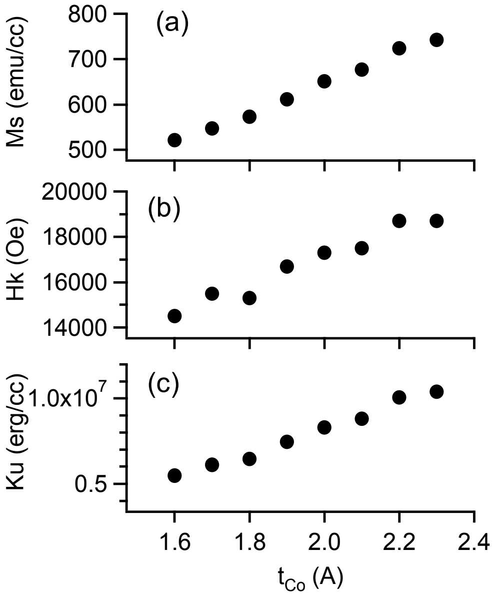

Fig.2 Co thickness (t_{Co}) dependence of (a) M_s, (b)H_k and (c) estimated K_u in [Co(t_{Co}) / Pt(0.4nm- t_{Co})]6 superlattice films deposited at 250℃.

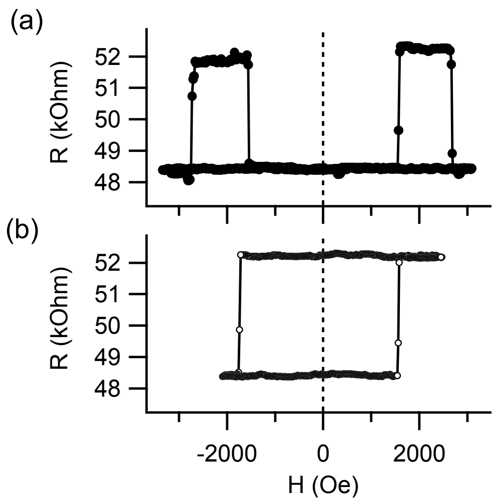

Fig.3 (a) *R-H* full and (b) minor loops of a [Co/Pt](4nm) / MgO(2nm) / [Co/Pt](8nm) MTJ.

motion which can cause increase of H_c. We also obtained PMA in very thin [Co/Pt] supperlattices. Although K_u decreased with decreasing the thickness of a film, *M-H* loops maintained the perfectness, such as shown in Fig. 1, even for a sample with the total thickness of 1.4 nm.

Fig. 3 represents *R-H* full and minor loops of a p-MgO-MTJ with [Co(0.2nm) / Pt(0.2nm)]10 / MgO (2nm) / [Co(0.2nm) / Pt(0.2nm)]20 deposited on a Ru buffer at 250ºC. In this structure, [Co/Pt] layers with more than 4 nm in thickness were employed in order to study nothing but an MR ratio. The size of circle shaped pillar was 160 nm in diameter. The directly deposited the upper [Co(0.2nm) / Pt(0.2nm)]20 layer on the MgO successfully formed to be a perpendicular magnetized film probably due to epitaxial growth onto a (111)- oriented MgO barrier. We obtained a small MR ratio to be 7.8 % in the sample without employing CoFeB layers beneath and onto an MgO barrier. We improved the stacking structure by insertion of CoFeB layers, then an MR ratio more than 30 % has been realized.

4. Summary

We prepared (111)-oriented CoPt superlattice films with high PMA for spin-RAM application. We succeeded to obtain K_u of $1.1x10^7$ erg/cc maintaining good *M-H* characteristics in the sample with 2.4 nm in thickness deposited at 250ºC. We also prepared p-MgO-MTJs with/without CoFeB insertions beneath and onto an MgO barrier. The MR ratio exceeded 30 % for the sample with CoFeB layers.

Acknowledgement

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