Thermally strong perpendicular magnetic anisotropy features of CoFeB/MgO frames *via* diffusion control

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1. Introduction

Magnetic tunnel junctions (MTJs) with Ta/CoFeB/MgO frames possessing perpendicular magnetic anisotropy (PMA) are attracting significant interest for realizing the next generation non-volatile memory[1-2] and the spin-orbit torque switching devices.[3] Among all the PMA materials, such as rare-earth-transition metal films, [Co/(Pt, Pd)] and [Fe/(Pt, Pd)] multilayers,[4] and their $L1_0$ ordered alloy films,[5] Ta/CoFeB/MgO frame combines the advantages over the MTJs with in-plane magnetic anisotropy including giant tunneling magnetoresistance (TMR) ratio via Δ_1 symmetry, fast switching with low current density based on low damping constant,[1-2,6] and the simple structure to manufacture. However, the PMA features are easily deteriorated at annealing temperature over 300 °C caused by Ta diffusion.[7] In this study, diffusion barrier (DB) was inserted at the Ta/CoFeB interface to prevent Ta diffusion to maintain the PMA properties.

2. Experimental Details

Ta (5)/DB (*d*)/CoFeB (1.4)/MgO (2) with Ta capping layers (the numbers in parentheses represent the nominal thickness of each layer in nanometers, *d* represents the thickness of DB.) were prepared by utilizing a DC/RF-magnetron sputtering system on oxidized Si substrates at room temperature and annealed at various temperature for an hour under 3 T magnetic field in high vacuum. After the samples with different DB thicknesses were tested within a nominal thickness range from 0 nm to 1 nm with annealing temperature up to 400 °C, the optimized sample with 0.4 nm thickness was selected for subsequent evaluation in this work. Two series of samples were prepared for in-depth study of PMA properties as follows: subs./Ta (5)/CoFeB (t)/MgO (2)/Cap (3) (Series A) and subs./Ta (5)/DB (0.4)/CoFeB (*t*)/MgO (2)/Cap (3), where the numbers in parentheses represent the nominal thickness of each layer in nanometers and the thickness of CoFeB layer (*t*) varied from 1 nm to 2.4 nm.

Vibrating sample magnetometer (VSM) was used to measure the magnetic hysteresis loops of each sample and X-ray diffractometer (XRD) was carried out to confirm the structure crystalline of the DB layer. The effect of the DB was evaluated by the cross-sectional high-resolution scanning transmission electron microscope (HR-STEM) and energy-dispersive X-ray spectroscopy (EDX).

3. Results and Discussion

Clear PMA properties of Ta/DB/CoFeB/MgO frames containing various DB thicknesses were maintained even after annealing temperature over 400 °C, compared with those the frames without the DB insertion layer. However, as the DB thickness increases, the magnetic dead layer also seems to be increased. The EDX observation suggests some evidences of highly suppressed Ta diffusion due to DB layer and vigorous B diffuse-out at the CoFeB/MgO interface after the high temperature annealing.

Ordinary Ta/CoFeB/MgO frames (Series A) revealed PMA with the largest anisotropy field (H_k) about 9 kOe after the 250 °C annealing and dramatically deteriorated with the small H_k value as the annealing temperature increases. On the other hand, with the 0.4 nm thick DB insertion (Series B), the largest H_k value of 12 kOe was observed after 350 °C annealing and PMA behaviors were still observed up to annealing temperature 425 °C.

4. Conclusion

In summary, we present thermally stable behaviors of Ta/CoFeB/MgO frame with 0.4 nm thick DB layer insertion. The PMA properties were maintained after post thermal annealing of more than 425 ^{o}C. It may be due to highly suppressed Ta diffusion by the DB layer insertion. High temperature annealing may lead to the enhancement of the H_k by providing a vigorous B diffuse-out at the CoFeB/MgO interface. Basic Ta/CoFeB/MgO frame revealed an effective anisotropic energy (K_{eff}) of around 4.6 Merg/cc, while a modified Ta/DB/CoFeB/MgO provided a significantly higher K_{eff} value of 9.6 Merg/cc after proper temperature post annealing.

5. References

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