Study on perpendicular magnetic anisotropic CoPt/AlN layered structure

---An exploitation for new perpendicular magnetic tunneling junctions

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Introduction

Recently, magnetic random access memory (MRAM) using magnetic tunneling junction (MTJ), has attracted growing interest due to the attractive properties of nonvolatility, radiation hardness, nondestructive readout, low voltage, and unlimited read and write endurance. So far, most of the reported MTJ devices have used in-plane magnetization film as electrodes, such as CoFe, Fe, CoFeB. However, when patterning these materials into a few tens of nanometers to develop gigabit MRAM, the well-known superparamagnetic effect and the limited aspect ratio will be main issues. Perpendicular magnetic tunneling junction (pMTJ) shows great advantage in solving the above problems. No limitation in aspect ratio and comparatively high anisotropy energy, make pMTJ promising to achieve high areal density for MRAM.

However, up to now, only a few papers report the study of pMTJ. The formation of antiparallel magnetization alignment in pMTJ still remains as a challenging issue. Magnetostatic coupling, Néel coupling and interlayer exchange coupling in pMTJ always result in simultaneous reversal of the ferromagnetic electrode layers. Although solutions have been proposed by inserting additional ferromagnetic coupling or antiferromagnetic coupling layer to harden or pin one electrode as reference layer, the lack of suitable material to pin ferromagnetic layer in perpendicular direction is one of the main difficulty.

In our present work, CoPt/AlN layered structure is proposed to realize pMTJ. Formation of perpendicular magnetic anitparallel alignment and tunneling process through AlN insulator layer are investigated.

Experimental

CoPt/AlN multilayers were deposited by dc magnetron sputtering at ambient temperature with a background pressure below 5x10⁻⁵ Pa. Two pairs of facing targets were mounted in the sputtering apparatus, a pair of Co targets partially covered with Pt plates, and a pair of Al targets. A gas mixture of argon and nitrogen was used as sputtering gas. The volume ratio of Ar/N₂ was 7:3, and the total pressure was 0.2 Pa. Above conditions provided constant growth rates of 0.1 nm/s at Co-Pt side of and 0.089 nm/s at AlN side.

Results and Discussion

Fig.1 shows the effects of annealing temperature $T_a$ on the magnetic anisotropy in Sub/AlN(20 nm)/[CoPt(2 nm)/AlN(2 nm)]₅/CoPt(5 nm) layered films. As increase $T_a$ from 300 °C to 400 °C, a gradual transformation of magnetic anisotropy from in-plane to perpendicular was found (Fig.1(a) to Fig.1(c)).

When $T_a$ is 500 °C, besides the development of PMA, steps appear on the hysteresis loop (Fig.1(d)). The results indicate that the surface CoPt layer shows a larger coercivity than the CoPt interlayers (CoPt layers inside the multilayered film). The steps indicate the formation of antiparallel magnetic alignment between
the CoPt surface layer and the CoPt interlayers. Continuing to increase $T_a$ to 600 °C, the step width is enlarged, as seen in Fig.1(e). Perpendicular loops with $T_a = 520 \degree$C to 580 °C are shown in Fig.1(f). A gradual variation of the step width can be seen. It further indicates that the antiparallel configuration is strongly dependent on the annealing temperature.

![Fig.2 Out-of-plane (Fig.A) and in-plane (Fig.B) XRD profiles of AlN20nm/(CoPt2nm/AlN2nm)5/CoPt5nm with different $T_a$: a) As-deposited; b) 300 °C; c) 400 °C; d) 500 °C; e) 600 °C.](image)

In Fig.(A), the inset figure shows that the peak in the range of 39 ° to 44 ° is the superposition of two peaks: one is from the periodic structure of [CoPt(2 nm)/AlN(2 nm)]5 (marked red) and the other is from the CoPt surface layer (marked blue).

In Fig.(B), the inset figures show variation of CoPt 2-20 interplanar distance with annealing temperature.

Fig.2(A) shows out-of-plane XRD profiles. The films show preferred growth orientation along CoPt [111] direction. The shift towards higher angle of CoPt 111 with increasing $T_a$ can be seen. It indicates the interplanar distance of CoPt 111 planes oriented parallel to the film surface continuously decreases with increasing $T_a$.

Fig.2(B) shows the in-plane XRD profiles. It is noted that the peak position of CoPt 2-20 first shifts towards higher angle with increasing $T_a$ from 300 °C to 500 °C, and then shifts back to lower angle with increasing $T_a$ from 500 °C to 600 °C. As shown in the inset figure, the CoPt 2-20 interplanar distance firstly decreases and then increases. A tensile stress is believed to be introduced according to the XRD results. The tensile stress plays a key role in determining the magnetic anisotropy of the CoPt layers.

![Fig.3 TEM images of CoPt/AlN multilayers with Ta equal to 500 °C.](image)

The structure of the annealed film is shown in Fig.3. A smooth surface (interfaces) can be clearly seen. Growth orientation of CoPt 111 along the substrate Si 002 is further confirmed by the inset electron diffraction pattern.

**Conclusions**

Perpendicular magnetic antiparallel alignment has been realized in CoPt/AlN layered structure. The CoPt surface layer and interlayers show different coercivities after annealing at 500 °C and above. This coercivity difference results in the antiparallel alignment in the perpendicular direction.

Our work not only discovers a new material configuration that is very promising as pMTJ, but also develops a new method to realize the antiparallel alignment in the perpendicular direction.

**Future work**

Our future work will focus on the spin-dependent tunneling process. It includes two steps:

1) To study the tunneling process through AlN layer. A comparatively low resistance was observed through the AlN layer. Some pin-holes in AlN layers were suggested to decrease the observed resistance. Therefore, we will try several methods to increase the tunnel resistance;

2) To pattern the film into micron or submicron size and study the tunneling magnetoresistance.

**Publication**