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# Perpendicular magnetic anisotropy of CoPt/AlN multilayer

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CoPt/AlN multilayer films have been prepared by a two-facing-target magnetron sputtering apparatus at room temperature. The thickness of AlN layer was fixed to 20nm, and the thickness of CoPt layer was varied from 1 to 8 nm. It is found that all as-deposited film show in-plane magnetic anisotropy. After vacuum annealing at 400 °C for 3h, CoPt/AlN films with CoPt thickness below 4nm show perpendicular magnetic anisotropy. Among these annealed films, the one with CoPt thickness of 2nm exhibits clearly uniaxial magnetic anisotropy. Cross-section TEM observation has proved that the CoPt layers have {111} preferred orientation, while the AlN layers have (001) preferred orientation. We believe that for the CoPt/AlN multilayer film to show perpendicular magnetic anisotropy, it is important that the CoPt layers are coherent with the neighboring AlN layers.
Key words: perpendicular magnetic anisotropy, inverse magnetostriction, TEM

## 1. INTRODUCTION

In order to increase the areal density of recording media to the order of 100 Gbit/in$^2$, the size of recording bit must be smaller than 10 nm[1]. However, such a small dimension of magnetically decoupled ferromagnetic particles would make the media thermally unstable. In order to overcome this problem, it is necessary to use a ferromagnetic phase with a large perpendicular magnetic anisotropy. Therefore, perpendicular magnetic anisotropy make use of magnetocrystalline anisotropy and interface magnetic anisotropy was studied[2-4].

CoPt/AlN multilayer films have been grown by a sputter-deposition method in order to study the CoPt order transition in such layered-structure. However, it is interesting to find that CoPt/AlN multilayer films deposited at room temperature show strong preferred orientation with CoPt(111) // AlN(001). And the magnetic properties of this structure changed significantly after annealing. Before the annealing, the easy axis of magnetization of this structure is in the film plane. However, the easy axis takes the normal direction after the annealing, indicating perpendicular magnetic anisotropy was developed[5-6].

In the past, the effect of magnetic layer thickness on the magnetic properties has not been reported. Additionally, it is important to find out the most suitable thickness of both AlN and CoPt. In this paper, We examine how magnetic properties are affected by CoPt layer thickness, and explain the mechanism which induces perpendicular magnetic anisotropy.

## 2. EXPERIMENTAL

CoPt/AlN multilayer films were prepared on fused quartz glass at room temperature by two-facing-target DC magnetron sputtering. The base pressure of chamber was less than $10^{-4}$ Pa. The chamber pressure was 0.2 Pa during sputtering. The gas was a mixture of Ar and $N_2$. The ratio of Ar to $N_2$ was 7:3, which was controlled by mass flow controller. The sputtering apparatus has two sets of targets in the same chamber. One set of the targets consists of Co and Pt disks to produce the Co-Pt layer. And the other one set consists of two Al disks to produce AlN layers by reactive sputtering with $N_2$ gas. A discharge current of 80 mA and a voltage of 900 V yield a coating rate of 0.085nm/sec for CoPt,and a discharge current of 200 mA and a voltage of 400 V yield a coating rate of 0.098nm/sec for AlN. Substrate holder was placed on the center of a vacuum chamber, and the rotation of a holder was controlled by a preset computer program (hyper terminal) to produce different layer thickness which is a parameter of this experiment. The thickness of AlN layers was kept at 20nm. The rotation was repeated five times. Finally, AlN layer (20 nm) was deposited as a capping layer. After deposition, the samples were annealed in a vacuum. Annealing temperature and duration are 400 °C and 3 hours, respectively. Then the sample was cooled in the vacuum to room temperature. The structure of the films was examined by the X-ray diffraction (XRD) and transmission electron microscope (TEM) observation. The magnetic properties of the films were examined by a vibrating sample magnetometer (VSM).

## 3. RESULT AND DISCUSSION

### I. *Structure of the film*

Fig. 1 shows X-ray diffraction profiles of CoPt/AlN multilayer films with different CoPt layer thickness. Fig. 1 (a) shows the results of as-deposited film, and Fig. 1 (b) shows those of annealed film. All CoPt/AlN multilayer show that AlN layers have (001) preferred orientation and CoPt layer have (111) preferred orientation. CoPt layer is fcc structure and AlN layer is hcp structure. In addition, the intensity of AlN (001) and CoPt (111) peaks becomes stronger with

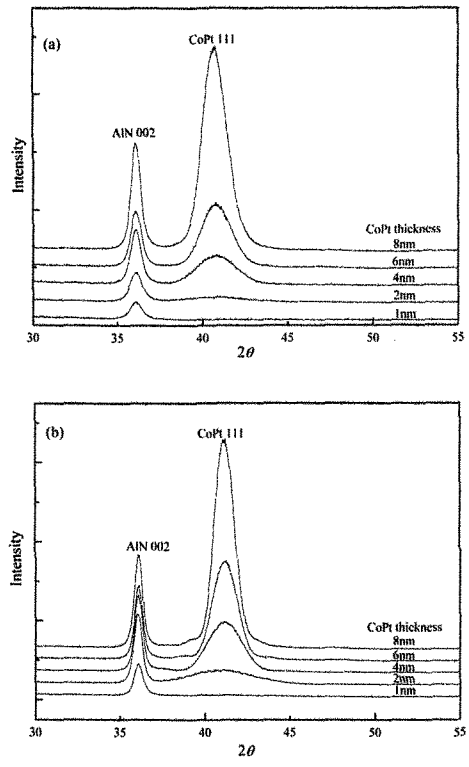


Fig.1. X-ray diffraction profiles of CoPt/AlN films with different CoPt layer thickness; es, (a) as-deposited and (b) annealed at 400℃ for 3 hours

increasing thickness of CoPt. On the other hand, the peak positions of AlN (001) and CoPt (111) reflections do not depend on CoPt thickness. Furthermore, the peak position of AlN $(001)_{hcp}$ reflection was not affected by annealing. However, the CoPt (111) reflection shifts toward higher angle after annealing. This fact indicates that gas atoms incorporated into multilayer film during deposition have been released from the film, which caused the CoPt lattice to shrink. It is considered that the shrinkage of CoPt lattice is mainly in the perpendicular direction, because the shrinkage in the in-plane directions was hindered by interface restriction. Therefore, a tensile stress was introduced into the CoPt layers. As a result, perpendicular magnetic anisotropy was caused by inverse magnetostriction.

Fig. 2 shows bight filed images from Cross-section transmission electron microscope observation. Fig. 2 (a), (b) and (c) correspond CoPt thickness of 1 nm, 2 nm and 8 nm respectively. When thickness of CoPt is 1 nm, interfaces between CoPt and AlN layers are rough. However, when the thickness of CoPt is 2 nm and the 8 nm, interfaces are flat. From this result and the result of X-ray diffraction, it is seen that the AlN layer surface becomes slightly rough at the thickness of 20 nm. The growth of subsequent CoPt layer may regain the flatness of the growing surface. For this purpose, the minimum thickness of CoPt layer required to 2nm. Also the preferred orientation of both AlN and CoPt layers are enhanced by alternate growth.

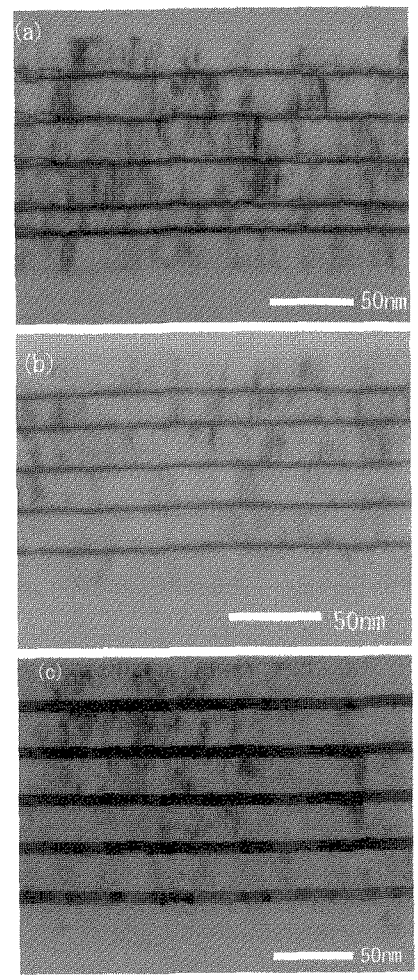


Fig.2. Cross-section TEM bright field image from annealed CoPt/AlN multilayer; thickness of CoPt layer is (a) 1 nm, (b) 2nm, (c) 8nm.

II .*Magnetic properties*

All as-deposited CoPt/AlN multilayer films exhibit in-plane easy magnetization axises. Fig. 3 shows M-H loops of annealed CoPt/AlN multilayer films with CoPt layer thickness varied between 1 nm and 8 nm. Axis of easy magnetization takes vertical direction as thickness of CoPt layer becomes thin. It is argued that the reason of this perpendicular anisotropy is the elastic stress brought into the CoPt layers by interface restriction. For this reason, too thick CoPt layers spoil perpendicular magnetic anisotropy, because relaxation occurred. However, the CoPt/AlN film with a CoPt layer thickness of 1 nm shows poor perpendicular anisotropy as shown in Fig. 3 (a). This is originated from the relative rough interfaces between AlN and CoPt layers as described above, because the rough interfaces result in poor preferred orientation of both AlN and CoPt layers and poor coherent at AlN-CoPt interfaces.

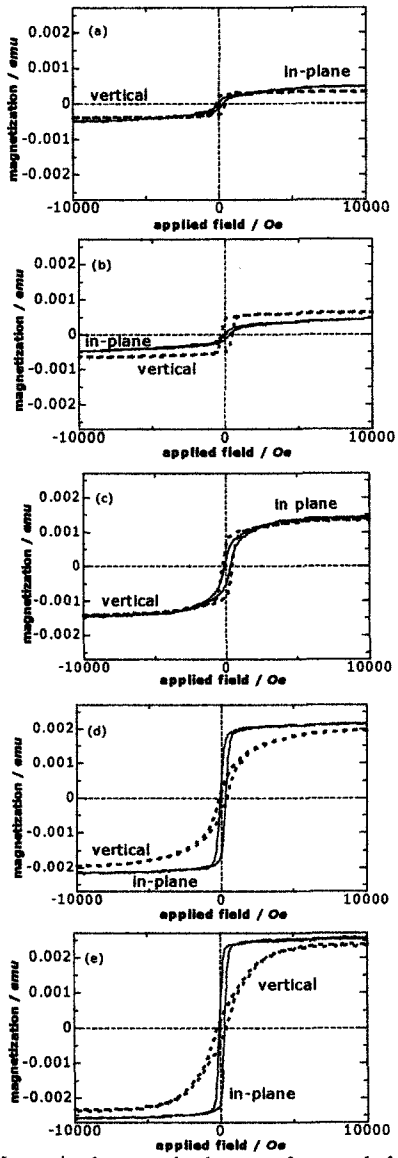


Fig.3. Magnetic hysteresis loops of annealed CoPt/AlN multilayer films; thickness of CoPt layer is (a) 1 nm, (b) 2 nm, (c) 4 nm, (d) 6 nm and (e) 8 nm.

## 4. CONCLUSION

We investigated the perpendicular magnetic anisotropy in annealed CoPt/AlN multilayer films and found the followings. The surface of AlN layer become rough at a thickness of 20 nm. While the subsequent CoPt layer can restore a flat surface provided the thickness of CoPt layer is 2 nm and above. The CoPt/AlN multilayer films grown in this manner are highly orientated. The preferred orientation of CoPt layer is (111) and that of AlN layer is (001). The CoPt/AlN multilayer films with suitable CoPt layer thickness exhibit, strong perpendicular magnetic anisotropy which is caused by tensile stress in the CoPt layers.

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