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Perpendicular magnetic anisotropy of Co-Ti-N films

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In recent years, the magnetic nano-granular film is considered promising to be applied as next generation magnetic recording media. In this work, we have investigated the magnetic property and microstructure of Co-Ti-N nano-granular films using VSM, XRD and TEM. The precursor films have been deposited on fused quartz substrates at room temperature by DC reactive sputtering with N_2 as reactant gas.
The as-deposited films are amorphous-like state by XRD results, and the formation of (FCC) Co and TiN crystallites have been confirmed by electron diffraction when the films were thermally annealed at temperatures above 600°C.
It have been confirmed by VSM measurement that the films annealed at appropriate temperatures have perpendicular magnetic anisotropy, which is due to the unique microstructure of the films. TEM observation of the films reveals that such films are featured with columnar structure with the nano-sized fibers which are perpendicular direction to the substrate surface. The fibers are composed of Co and TiN crystallites, and Co nano-fibers are separated by TiN.
Therefore we have concluded that Co crystallites are magnetically coupled more closely in a perpendicular direction than in a in-plane direction and thus perpendicular anisotropy is developed.

Key words: perpendicular anisotropy, shape anisotropy, columnar structure, granular film

1. INTRODUCTION

Magnetic films for perpendicular magnetic recording media has been studied extensively in recent years. Generally, perpendicular magnetic anisotropy of thin film is obtained through utilizing the magnetocrystalline anisotropy of magnetic materials, such as employing magnetic materials with $L1_0$ magnetic particles dispersed in nonmagnetic matrices(e.g. CoPt/Ag, CoPt/C, CoPt/SiO_2, CoPt/Al_2O_3)[1-5]. However in such a case, control of preferred orientation or even epitaxial growth of the film is necessary. This increases the complexity of the film growth process. For the arising problem mentioned above, instead of a method utilizing $L1_0$, we suggest a simple method to obtain films with perpendicular magnetic anisotropy, which utilizes the columnar structure of a magnetic - nonmagnetic granular film. The role of non-magnetic is to decouple magnetic interaction in an in-plane direction.

Our recent investigations demonstrated that magnetic - nonmagnetic granular films of (FCC) CoPt-TiN reveal perpendicular magnetic anisotropy due to shape anisotropy of columnar structure. This columnar structure of the films is formed by shadowing effect during sputtering at comparatively high working pressure[6,7]. The relative proportion of Co, Pt and Ti was 3:1:1 at that experiment. Namely, the relative proportion of magnetic and nonmagnetic was 4:1.

It is thought that this content of Ti as nonmagnetic matter is not enough to decouple magnetic interaction of FCC-CoPt in an in-plane direction.

In order to enhance perpendicular magnetic anisotropy of FCC-Co based magnetic-nonmagnetic granular films, we have decided optimal content of Ti as nonmagnetic matter to decouple magnetic interaction in an in-plane direction and optimal film thickness to exert its magnetic performance. VSM measurement, ICP-OES analysis and TEM observation have been conducted and the results have clarified the relation between Ti content of the films and perpendicular magnetic anisotropy.

2. EXEPERIMENTAL

Co-Ti-N films were deposited onto fused quartz substrates by non-magnetron DC reactive sputtering with pure Ar as sputtering gas and N_2 as reactant gas. The sputter-target consists of a pure Co disc at the back, Ti sheets and a donut-shape Ti disc at the front. The control of Ti composition was done with changing the number of Ti sheets.

The composition of the film could were controlled by changing the number and size of Ti sheets at the front. The vacuum chamber was evacuated under 2.0×10^{-5} Pa before depositions. Then Co-Ti-N films were prepared in Ar + N_2 atmosphere, where partial pressure of N_2 gas was set to 2.4×10^{-3} Pa, and total pressure of Ar + N_2 gas was set to 7.5×10^{-2} Pa. The working (sputtering) gas pressure was about 10 Pa. All the depositions were conducted at the room temperature. The cathode voltage and discharge current were 2.5kV and 12mA respectively. After deposition without breaking vacuum, thermal annealing of the films were conducted in a same chamber at 800°C for 180 min.

The composition of the films was analyzed by inductively coupled plasma optical emission spectroscopy(ICP-OES). The magnetic properties, including in-plane and perpendicular saturation magnetization(4πMs), coercivity(Hc) and squareness ratio(Rs=Mr/Ms) were measured by vibrating sample magnetometer(VSM). X-ray diffractometer(XRD) was used to evaluate the crystal state. And the nano-structure of the films was characterized by transmission electron microscopy(TEM).

3. RESULTS AND DISCUSSION

3.1 magnetic properties measured by VSM

The dependence of in-plane and perpendicular magnetic properties on Ti content has been studied. Fig. 1 shows transition of M-H loop of Co-TiN film annealed at 800°C in a vacuum for 180min after deposition with increasing Ti content. In fig.2-a, the values of Hc are sorted out in order to make a clear understanding of the dependence of magnetic properties on Ti content. As increasing Ti content, the values of Hc of the films rise up, and the values are larger in a perpendicular direction than in an in-plane direction until relative atomic ratio of Ti and Co becomes 2.3:1. Further increasing Ti content over the ratio of 3:1, the values of Hc in a perpendicular direction are almost same with the values in an in-plane direction. The values of Rs are also sorted out in fig.2-b. The values of Rs of the films rise up as well, and the values are larger in a perpendicular direction than in an in-plane direction until relative atomic ratio of Ti and Co becomes 3:1. Further increasing Ti content, the values of Rs in a perpendicular are almost same with the values of in an in-plane direction. By the way, we regard the differences of the value of Hc and Rs between in-plane direction and perpendicular direction as an empirical indicator of magnetic anisotropy, and the difference of the value between in-plane and perpendicular becomes maximum at the ratio of 3:1. From this viewpoint, the films in this system have the best perpendicular magnetic anisotropy at the atomic ratio of Ti:Co=3:1

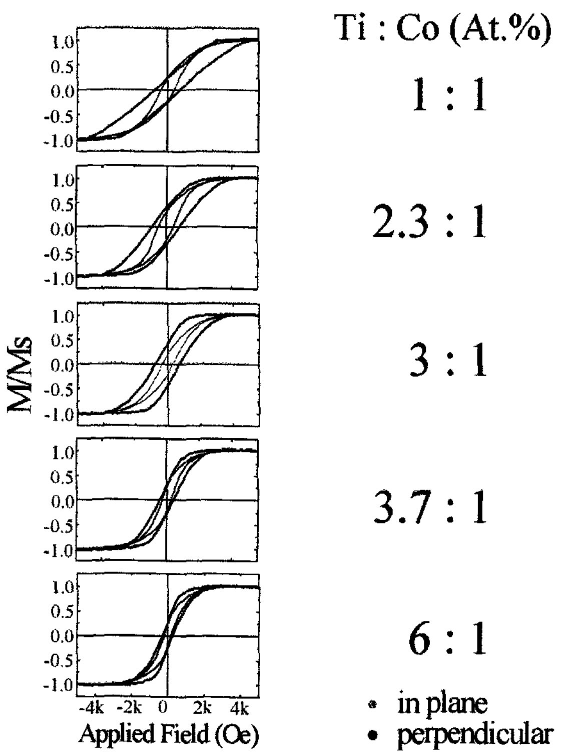

Fig. 1. Transition of M-H loop of Co-TiN film with increasing Ti content.

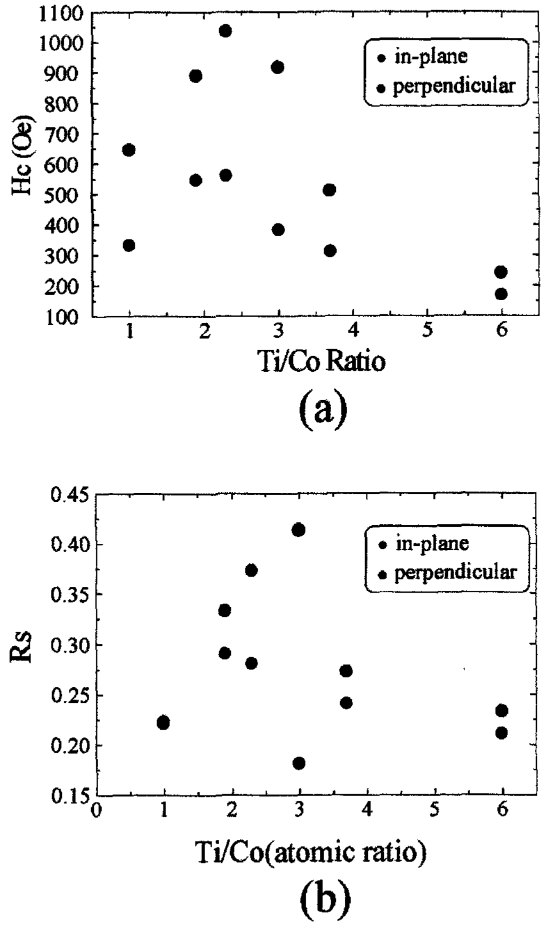

Fig. 2. Dependence of magnetic property on Ti content. **a.** Relation between Ti content and Hc, **b.** Relation between Ti content and Rs.

The dependence of magnetic properties in terms of a film thickness has also been investigated. Fig.3 shows dependence of magnetic properties on film thickness. Film thickness was controlled by deposition time, which is about 2nm/min.

Fig.3-a indicates that both direction(in-plane and perpendicular) of Hc become large with deposition time until 80min. We can see that the film deposited for 80min has a peak value of Hc. Deposition time being longer than 80min, the values of Hc become lower gradually. Tendency of in-plane and perpendicular Hc resembles each other.

The relation between deposition time and Rs appears in fig.3-b. The value of Rs in a perpendicular direction increases with deposition time and have its peak at deposition time 70min and then Rs value decreases by degrees. On the other hand, Rs value in an in-plane direction decreases modestly. As well as the case of fig.2, we have estimated the differences of the values between in-plane direction and perpendicular direction as an empirical degree of magnetic anisotropy. Accordingly, the film which was deposited for 70min has best perpendicular anisotropy in this system.

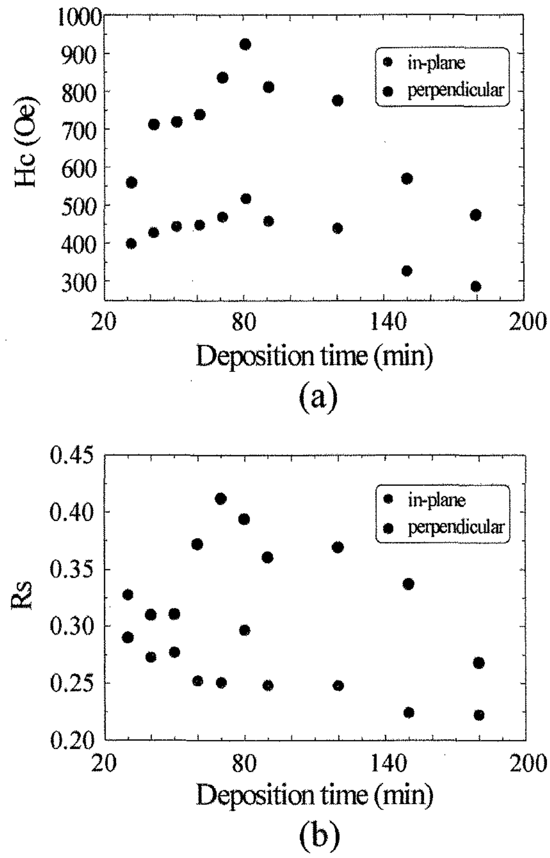

Fig. 3. Dependence of magnetic property on film deposition time(film thickness). **a.** Relation between deposition time and Hc, **b.** Relation between deposition time and Rs.

3.2 Nano-structure by TEM image

To clarify magnetic performance of the films stated above in terms of nano-structure, we carried out XRD analysis and TEM observation.

Crystal structure of films couldn't be evaluated by XRD, for the reason of its smallness of particles which constitute the film.

Cross-sectional HREM image of Co-based magnetic–nonmagnetic granular film appears in fig.4. In the first place, we can interpret perpendicular anisotropy of the film derives from fibrous Co particles(high contrast parts) which induce shape anisotropy as shown in fig.4.

By the optimization of Ti content(Ti:Co=3:1) in the film, in-plane interaction of Co fibers reduces. With excess of Ti content, magnetic interaction is decoupled not only in an in-plane direction, but in a perpendicular direction.

With increasing film thickness, aspect ratio which decides shape anisotropy of Co fibers also increases and then perpendicular anisotropy is enhanced until about 140nm in film thickness. As film thickness becomes over 140nm, Co fibers can't extend in perpendicular direction any more so that aspect ratio of the fibers can't become high.

Thus magnetic performance of films in this experiment has been correlated with film nano-structure.

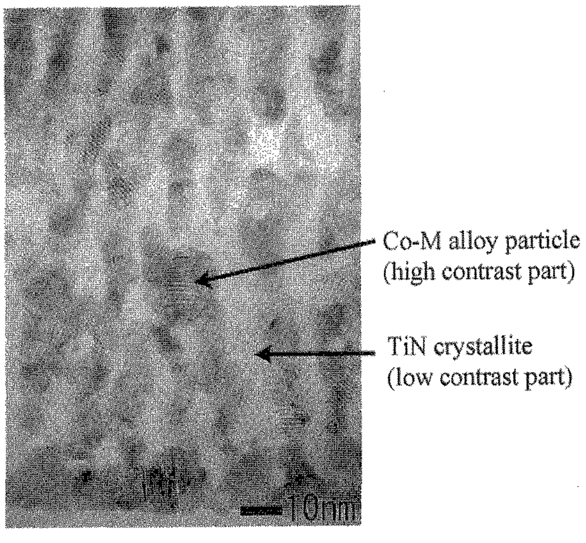

Fig. 4. Cross-sectional HREM image of Co-based magnetic-nonmagnetic granular film

4. CONCLUSIONS

Successfully, Co-TiN granular films which indicate stronger magnetic anisotropy in perpendicular direction than in an in-plane direction have been prepared. It has been figured out that the optimum atomic ratio of Ti and Co is 3:1 and optimal film thickness for this system is about 140nm. The films with such composition and thickness show the best perpendicular magnetic anisotropy.

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