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Magnetism of Cobalt Base Artificial Lattice Films

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ABSTRACT

The Co/Pd and Co/Pd artificial lattice films have attracted much interest by their special magnetization properties. We discussed the effect of the Pt, Pd layer thickness on the magnetic anisotropy, and we showed the effect of the hydrogen ion implantation on the magnetic properties of multi-layered films. The Co/Pt and Co/Pd multi-layered films were formed on Si(111) substrates with molecular beam epitaxy. We did structure analysis, magnetic domain analysis and magnetic properties evaluation with XRD, MFM and VSM, respectively. Among the series of films of 0.4nm Co layer, XRD showed that the film of 1.0nm Pt layer had a highest periodicity and that they had (111) plane orientation completely. The magnetic domain size reduced with the increase of the thickness of Pt layer. We found out that the coercivity decreased linearly as a function of the length of magnetic domain wall in the unit area. The result of VSM showed that the multi-layered films of Pt thickness of less than 2.8nm had perpendicular magnetic anisotropy. The perpendicular anisotropy energy changed by the nonmagnetic layer thickness and had a maximum value for 0.4nm Co 0.4nm/ nonmagnetic metal 1.0nm multi-layered film. After hydrogen implantation into the films, XRD showed that the lattice spacing was swelled with hydrogen dose. Also, MFM observed that the magnetic domain size reduced with the increase of the hydrogen dose. The easy axis of magnetization changed from perpendicular to parallel in the plane with the increase of the hydrogen dose. After evacuation of hydrogen at 473K, perpendicular anisotropy was partially recovered. This phenomenon suggested that the origin of magnetic anisotropy was mainly the lattice mismatch and distortion in the layer interface. But Co/Pd film was not recovered by this thermal treatment. This means that Pd made stable hydride and did not evacuate hydrogen at this temperature.

INTRODUCTION

Pd and Pt of large spin-orbit interaction show large paramagnetic susceptibility and large magnetic polarization. Accordingly, when Pd and Pt atom adjoin with ferromagnetic Co atom, the magnetic moment is caused and large magnetic anisotropy and magnetostriction are generated. Recently, the magneto-optical memory, using short wavelength blue LASER for the high-density data recording, has attracted much interest. Co/Pd, Co/Pt multi-layered films have a promise of recording device and many research about these films have been done [1]-[4]. These films have very large Kerr rotation angle for short wavelength light, and show perpendicular magnetic anisotropy [5]. For the Co layer thickness of below 1.0nm, Co/Pd and Co/Pd multi-layered films show strong perpendicular magnetic anisotropy [6]. And Co base artificial lattice films show very large Kerr rotation angle in the light of 350nm wavelength [7]. To research the structure and the misfit of interface lattice is very important for understanding the origin of perpendicular magnetic anisotropy, because the magnetostriction effect contributes largely on the magnetic properties of the Co base artificial lattice films. The hydrogen, that is the smallest element, is easily introduced to metal and versatile to modify the interface structure of multi-layered films. In this paper, the hydrogen ion implantation was used to modify the magnetic properties and structure of the Co base multi-layered films. The artificial lattice multi-layered films of Co/Pt and Co/Pd were prepared on the Si single crystal substrate by using molecular beam epitaxy (MBE). Co base multi-layered films showed well perpendicular magnetic anisotropy. The effects of the hydrogen implantation on the magnetic properties of the multi-layered films were discussed.

EXPERIMENTAL DETAILS

By using MBE (ULVAC PHI, B8000S), the artificial lattice films of Pt/Co and Pd/Co were prepared. The pressure in the chamber during the formation of films was held below the 1.0×10^{-7} Pa. The Si single crystal (111) was used as the substrate, and substrate temperature was 473K. The layer thickness of Co, Pd and Pt was changed as the experiment variable. The hydrogen ion was irradiated to the films with the ion gun with the acceleration voltage of 3kV, and with the flux of 1.5×10^{13} ions/cm^{2}s. The sample of hydrogen irradiated was annealed at 473K in vacuum, and the structure and properties change were evaluated.

The structure of film was examined by X-ray diffraction (RIGAKU, RU-60) with the source of CuKα_1 (λ = 0.1541nm). The magnetic properties were measured by the vibrating sample magnetometer (VSM, RIKEN, BHV-50H). The magnetic domain was observed by the scanning probe microscope (SII, SPA300) in the magnetic force microscope mode (MFM).

RESULTS

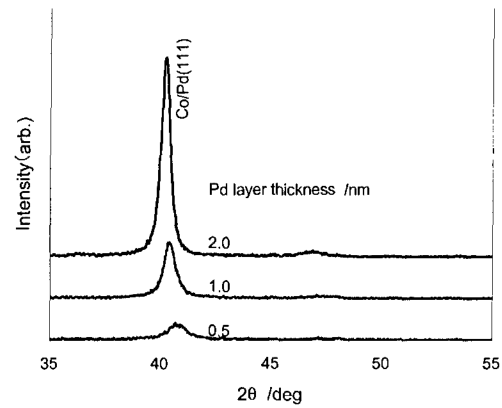

Figure 1. X-ray diffraction profiles of Co/Pd multi-layered films
Co layer thickness is 0.4nm

The X-ray diffraction profiles of Co/Pd multi-layered films are shown in Figure 1. As same as in the case of Co/Pt multi-layered films [8], the X-ray diffraction peak of Co/Pd (111) was shifted to lower angle, because the lattice constant of Pd (0.389nm) is larger than fcc-Co (0.355nm), and the half-width of this X-ray peak decreased with the increase of Pd layer thickness. The X-ray diffraction profiles of lower angle showed that the diffraction peak reduced remarkably and layer structure became indistinct for Pd layer thickness of below 0.7nm. Contrastively, AFM observation confirmed that the interface roughness of multi-layered films increases with the layer thickness of Pd of over 1.0nm. However, it is interesting that hardly the size of crystal grain changed, even if the layer thickness of Pd increased.

The magnetization curves of (Co0.4nm/Pd1.0nm) 15 layers film is shown in Figure 2. This profile is a typical perpendicular magnetic anisotropy.

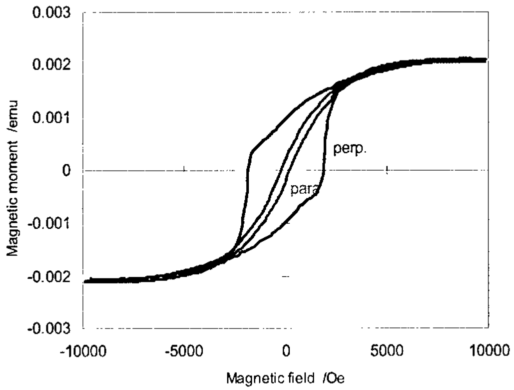

Figure 2. Magnetization curves of Co/Pd multi-layered film (Co0.4nm/Pd1.0nm) × 15 layers

The magnetic properties was affected largely by the thickness of Co layer and showed the maximum perpendicular magnetic anisotropy with about 0.4nm Co. The magnetic properties also depended on the thickness of Pt and Pd, and showed the largest perpendicular magnetic anisotropy with thickness of about 1.0nm.

As Co layer thickness changed, the magnetic domain changed largely. Figure 3 shows the MFM images of multi-layered films with Co layer thickness. As very thin Co layer, magnetic domain has island form of very large size, but the domain size decreases with the increase of the thickness of Co layer, and then, the magnetic domain becomes typical maze pattern of in-plane magnetization anisotropy.

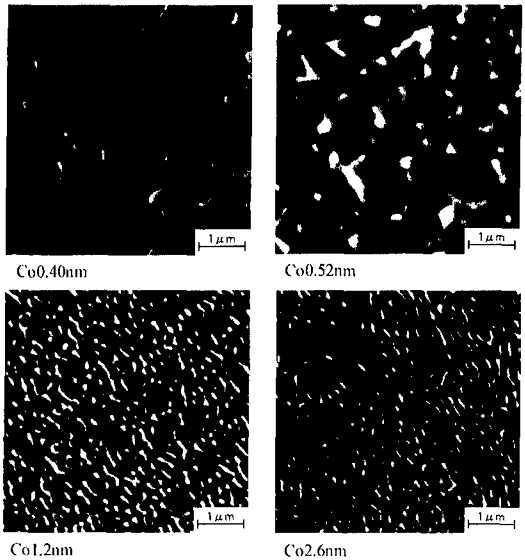

Figure 3. MFM images of Co/Pt films with the thickness of Co layer
Pt thickness is 1.0nm

The X ray profiles of Co0.4nm/Pd1.0nm multi-layered film, shown in Figure 4, illustrate that peak angle reduced and lattice spacing swelled with the hydrogen injection. As the increase of hydrogen injection quantity, the half-width of the peak increased and the shoulder of Pd hydride appeared.

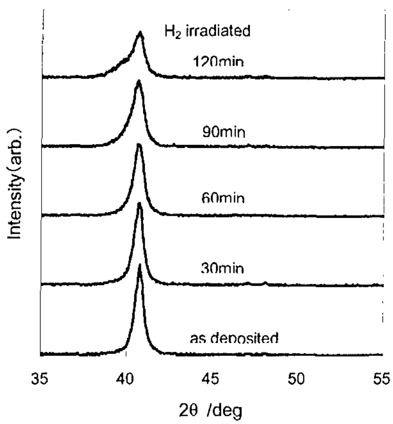

Figure 4. X-ray profiles of Co/Pd multi-layered film
(Co0.4nm/Pd1.0nm) ×15 layers

As the increase of hydrogen injection quantity, the perpendicular magnetization anisotropy energy decreased and the film became to prefer the in-plane magnetization. By vacuum annealing, the magnetic properties of Co/Pt films partially recovered to the perpendicular anisotropy, but Co/Pd films hardy recovered by the annealing.

The origins of magnetic anisotropy of Co-noble metal multi-layered films are mainly the distortion of lattice. The magnetic anisotropy caused by distortion is naturally expected to be altered by hydrogen implantation. It is possible to inject the hydrogen to the films over its solubility limit with hydrogen ion implantation. The acceleration voltage was chosen with the 'TRIM' code calculation as the peak density of hydrogen was to locate in the middle of film thickness. It is expected that the hydrogen injected diffuses easily in room temperature and migrates in a stable site. This site is estimated ordinarily to be the interface where the distortion is accumulated. It is conceivable that the magneto-elastic anisotropy decreases with the decrease of distortion of lattice, and the film changes to prefer in-plane magnetic anisotropy.

The data of MFM detects only the vertical component of the magnetic force between the probe and the film, so cannot show the magnetization direction. Figure 5 shows the comparison between MFM image and the result of Boundary Element Method calculation (BEM). The MFM profile and calculation result showed good agreement and the magnetization direction is able to estimate with MFM and BEM.

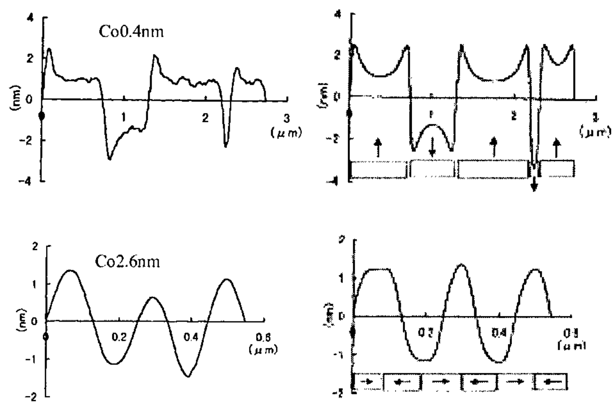

Figure 5. MFM profiles and BEM calculations
Left side: MFM, Right side: BEM

The process of magnetization can be considered as the migration of the magnetic wall. Accordingly, with the increase of domain wall length, magnetic domain size reduces, and the coercivity reduces. The magnetic domain walls were extracted from MFM image by the image processing. As shown in Figure 6, there was linear relation between the magnetic wall length and the magnetic coercivity. The coercivity decreased with the increase of the magnetic domain wall length. It is very interesting that the linear relation is consisting with the films of many couples of Co layer thickness and non-magnetic layer thickness.

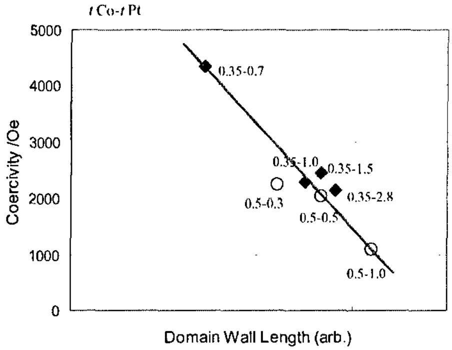

Figure 6. Coercivity and domain wall length

The thermal stability of the injected hydrogen in Co/Pd film showed the possibility of modifying the magnetic properties by hydrogen implantation. The hydrogen implantation is considered to be a new technique for the application of magnetic properties design.

CONCLUSIONS

Pt/Co, Pd/Co multi-layered films of perpendicular magnetization anisotropy were prepared with MBE. The effects of the hydrogen implantation on the structure and the magnetic properties of films were examined. The atomic mixture of interface and the change of interface distortion reduced the perpendicular magnetization anisotropy energy. The annealing after hydrogen implantation evacuated the hydrogen and increased the perpendicular anisotropy energy for Co/Pt films. For Co/Pd films, the annealing did not evacuate the hydrogen because of its thermal stability. This suggests the possibility of the magnetic properties design by hydrogen implantation.

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