Perpendicular Magnetic Anisotropy in Co/Pd Multilayered Films Prepared by Electroplating

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Co/Pd, Co/Pt and Co/Au multilayered films, generally prepared by dry methods such as sputtering, vacuum evaporation, and MBE method, are known to exhibit perpendicular magnetic anisotropy. We prepared Co/Pd multilayered film by electroplating from aqueous solution and first time observed that the easy axis of magnetization of the obtained film was in a direction perpendicular to the film plane.

Magnetic thin films which are preferably magnetized in a direction perpendicular to the film plane are said to have a "perpendicular" magnetic anisotropy. Co based multilayered films (Co/Pd, Co/Pt, Co/Au) exhibit large perpendicular magnetic anisotropy and are currently of great interest in relation to high-density magneto-optical storage and perpendicular recording.[1-8] These films are generally prepared by sputter or evaporation techniques. The electrochemical deposition of these films seems to be technologically interesting since the electrodeposition is a fast and cost effective deposition process useful to cover large areas and applicable to mass production[9]. Although there are some papers on the giant magnetoresistance of electrodeposited mutilayers, there are few papers on the magnetic anisotropy of an electrodeposited one.[10] Jyoko et al. prepared Co/Pt multilayered films by electrodeposition, which tend to exhibit "in-plane" anisotropy.[10]

In the present paper, we report Co/Pd multilayered film which is preferably magnetized in a direction perpendicular to the film plane. The Co/Pd multilayered films were prepared on a 1cm x 1 cm polycrystalline copper substrate using the dual bath method. The copper surface had a mirror-like finish by electro-polishing. As Co is easy to oxydize, electroplating was carried out in a nitrogen glove box. The Co plating bath contained 0.1 M $CoSO_4 \cdot 7H_2O$, 0.73 M H_3BO_3 and 0.29 M NaCl. The Pd plating bath is a commercially available one (Palladex, EEJA Co.). In order to avoid the substitution reaction between Pd and Co during the Pd plating, the Pd plating was carried out at the lowest temperature possible of 40°C. The Co plating was carried out at 25°C. The film thickness was controlled by changing the applied current density and electroplating time. A multilayered structure was confirmed by TEM and film thickness of one layer by Co and Pd analysis using ICP. The magnetic properties of multilayered Co/Pd films were measured at room temperature with a vibrating sample magnetometer (VSM) at applied fields up to 10 kOe.

From the cross-sectional TEM image, it is found that a Co and Pd film was accumulated mutually and the Co/Pd multilayered film preparation is possible when the thickness of Co and Pd film is greater than several nanometers (Figure 1). In Figure 1, the white layer is Co and the black layer is Pd. In the case when the film thickness of one layer is less than 1 nm, a multilayered structure could not be confirmed, as it exceeds the resolving power of the TEM. However, the thickness of one layer assumed from the electricity consumed for film deposition is nearly equal to that calculated from the deposited weight measured by ICP. Therefore, the multilayered structure also seems to be constructed even when the one-layer thickness is less than 1 nm. We can not deny that the films have the structure jumbled like a granular materials.

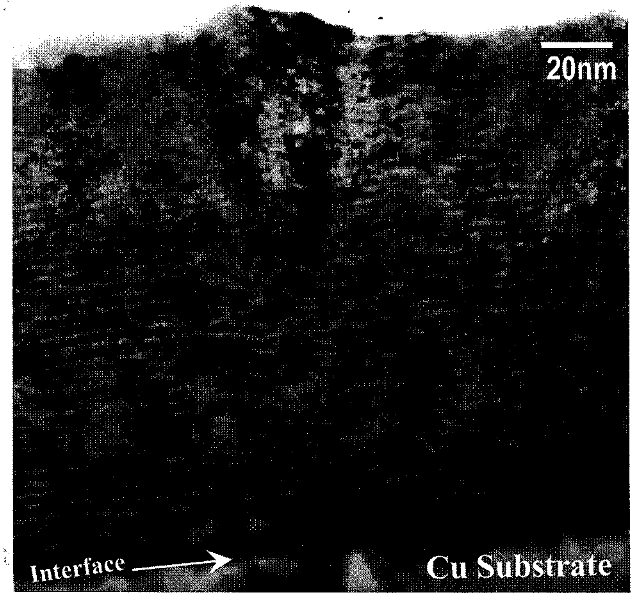
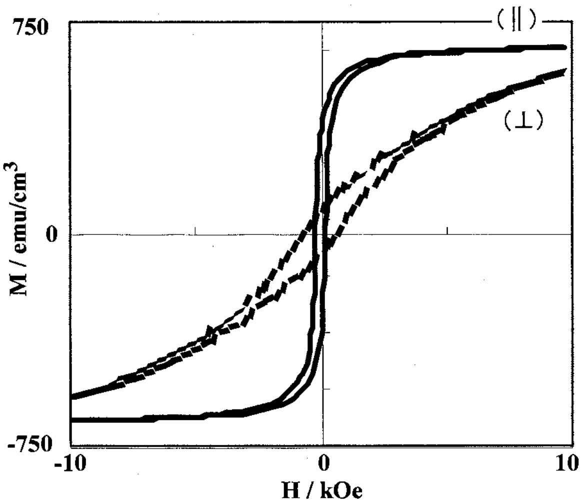


Figure 1. Cross-sectional TEM image of $[Co(1\ nm)/Pd(1\ nm)]_{40}$ electrodeposited multilayered film. Current density of Co and Pd plating was 1.25 and 12.5 mA/cm^2 , respectively. TEM sample was prepared by ion milling method.

Changing the monolayer thickness of Co and Pd by controlling the plating time, current density, and the number of multilayers, various types of electrodeposited films were prepared and their magnetic properties were measured. Figure 2 shows an example of magnetic hysteresis loops for forty layers of electrodeposited Co/Pd multilayered films. Setting the Pd monolayer thickness as 1 nm, the Co monolayer thickness was changed. When the Co monolayer thickness is greater than 0.6 nm, the easy magnetization axis is in plane as seen in the upper hysteresis loop in Figure 2. However, the easy axis of magnetization of the multilayered film shifted from in plane to perpendicular to the film as seen in the lower hysteresis loop in Figure 2 when the Co monolayer thickness is less than 0.4 nm, i.e., perpendicular magnetic componet is stabilized. The remanent magnetic ratio, which is the ratio of the remanent magnetization perpendicular to the film plane to that of in the plane of the film, and the coercive force were plotted versus Co layer thickness as shown in Figure 3. A remanent magnetic ratio$>$1 is characteristic of a perpendicular easy axis of magnetization.[11] By decreasing the Co layer thickness, the remanent magnetic ratio became large and exceeded 1 for about a 0.4 nm Co layer thickness, which indicates that the easy axis of magnetization of the multilayered film changed from a direction parallel to the film



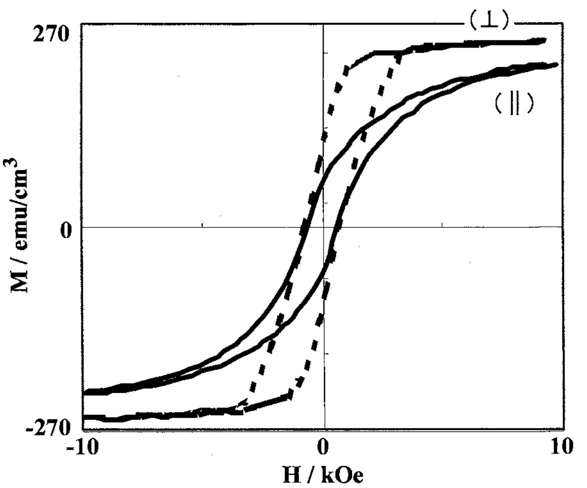


Figure 2. Magnetic hysteresis loops of [Co(1.0 nm)/Pd(1.0 nm)]$_{40}$ multilayered film (upper) and [Co(0.4 nm)/Pd(1.0 nm)]$_{40}$ multilayered film (lower) measured with applied magnetic field perpendicular to the film surface (dashed curve) and in the plane of the film (solid curve).
Current density of Co and Pd plating is 1.0 and 10.0 mA/cm^2, respectively.

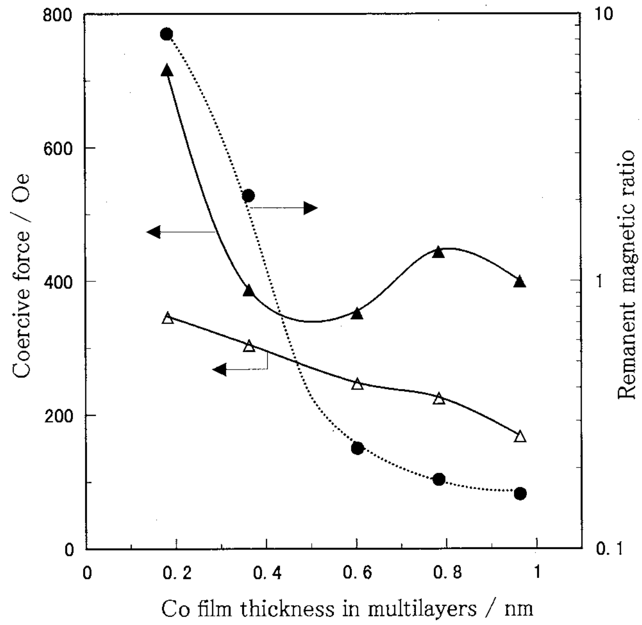


Figure 3. Relationship between magnetic properties of [Co(X nm)/Pd(1.0 nm)]$_{40}$ electrodeposited multilayered film and Co film thickness.
Dashed curve is the remanent magnetic ratio (Mr(⊥)/Mr(‖)) (●), and solid curves are coercive force perpendicular to the film surface (▲) and in the plane of the film (△).
Current density of Co and Pd plating is 1.0 and 10.0 mA/cm^2 , respectively.

plane to perpendicular to the film plane at this Co film thickness. It is reported that the rf sputtered Co/Pd and Co/Pt thin-film layered structures have perpendicular magnetic anisotropy, when the Co layer thickness is less than 0.8 nm in the Co/Pd and 1.4 nm in the Co/Pt multilayers.[2] We think our value of 0.4 nm is in good agreement with the literature value, because the film structure prepared by electrodeposition and that by rf sputtering may be not necessarily the same and our value of 0.4 nm is a calculated one based on the ICP analysis. The coercive force increased with decreasing Co layer thickness as shown in Figure 3. These values are comparable to those of the Co/Pd multilayered films prepared by rf sputtering.[11] For example, the coercive force for the film with a Co layer thickness of 0.47 nm, bilayer periodicity of 1.53 nm and the total film thickness of 0.31 μm is 550 Oe.[11] On the other hand, the coercive forces of our films are presently between 180 and 720 Oe depending on the Co layer thickness. Based on all these results and discussion, we think that the preparation of the Co/Pd multilayered films with a perpendicular magnetic anisotropy using the electroplating technique is possible.

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