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Interfacial Co nanolayers for enhancing interlayer exchange coupling in antiferromagnetic interlayer exchange coupling media

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Significant enhancement of the interlayer coupling strength has been achieved by depositing Co nanolayers on both sides of the Ru layer in a conventional CoCrPt/Ru/CoCrPt antiferromagnetic interlayer exchange coupling structure. The interlayer coupling increases nearly linearly from 0.13 to 0.8 erg/cm^2 and then levels off with an increase in Co thickness. Substrate bias was found to be very harmful to the exchange coupling. The texture, structure and the growth of the grains and the crystal lattices were also studied with an x-ray diffractometer and a transmission electron microscope. [DOI: 10.1063/1.1452262]

I. INTRODUCTION

Multilayer thin film media with antiferromagnetic interlayer exchange coupling (AFC) has been proposed to enhance thermal magnetic stability.[1–3] It has been reported that, for a given thickness ratio between the top and bottom magnetic layers in a double-magnetic-layer medium, the thermal stability enhancement can be maximized by optimizing the interlayer exchange coupling strength. A conventional CoCrPt/Ru/CoCrPt structure exhibits relatively weak interlayer exchange coupling strength in contrast to relatively strong coupling strength in a Co/Ru/Co structure. In this article, we present experimental work that demonstrates significant enhancement of the interlayer coupling strength by depositing Co nanolayers at the Ru layer/magnetic layer interfaces. The results of microstructural studies are also reported.

II. EXPERIMENT

The AFC thin films were rf sputtered onto Cr/NiAl underlayers on glass substrates at room temperature. Cr/NiAl underlayers were used to control the $(10\bar{1}0)$ growth texture and grain size of magnetic layers. The Ar bleed pressure during sputtering was set to 10 mTorr and the rf power to 100 W. The sandwich structure of magnetic layers is CoCrPt (18 nm)/Co (x nm)/Ru (y nm)/Co (x nm)/CoCrPt (8 nm) with $x=0.0-1.4$ nm and y optimized at 0.9 nm. Substrate bias was also applied for a comparison during the sputtering of CoCrPt layers. The full and minor $B-H$ loops were measured with a DMS vibrating sample magnetometer (VSM) to determine the exchange coupling strength. The microstructures were investigated with an x-ray diffractometer (XRD) and conventional and high-resolution transmission electron microscopes (TEMs). Both plan-view and cross-sectional samples for TEM observations in this study have structure of CoCrPt (18 nm)/Co (1 nm)/Ru (0.9 nm)/Co (1 nm)/CoCrPt (8 nm)/underlayers/substrate.

III. RESULTS AND DISCUSSION

In the AFC structure, the ruthenium layer plays a critical role in interlayer exchange coupling. It was found the exchange coupling strength is very sensitive to the thickness of the Ru layer. For our sputtering setup, the Ru thickness was optimized at 0.9 nm and fixed for all the experiments on various Co thicknesses. Figures 1(a) and 1(b) show, respectively, a measured $B-H$ loop of CoCrPt (18 nm)/Co (1 nm)/Ru (0.9 nm)/Co (1 nm)/CoCrPt (8 nm) and the dependence of the interlayer coupling strength on the Co nanolayer thickness, which was chosen to be the same on both sides of the Ru layer. The minor loop in Fig. 1(a) was taken to determine the exchange coupling field which is defined as the shift of its center from the vertical axis. It is clear from Fig. 1(b) that the initial increase in the Co nanolayer thickness yields a nearly linear increase of the coupling strength. As the Co layer thickness increases from 0 to 1 nm, the interlayer coupling increases from 0.13 to 0.8 erg/cm^2. The coupling strength levels off after the Co layer thickness exceeds 1 nm. The results indicate that the interlayer exchange coupling strength can be varied easily in the linear range shown in Fig. 1 to optimize a medium's thermal stability.

Substrate bias was also applied during sputtering of the CoCrPt layers in order to get higher coercivity. Figure 2 shows the measured exchange coupling field (H_{ex}) and single layer coercivity (H_c) as a function of the substrate bias. Here H_{ex} and H_c are referred to as the half width and the shift of the center from the vertical axis of the minor loop, respectively. It should be noted that H_{ex} dropped rapidly as bias was applied while H_c increased a little bit at

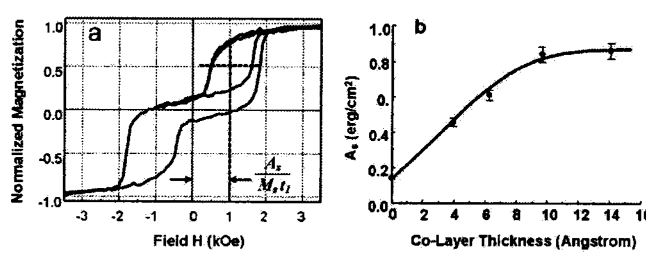

FIG. 1. (a) Full and minor $B-H$ loops of CoCrPt (18 nm)/Co (1 nm)/Ru (0.9 nm)/Co (1 nm)/CoCrPt (8 nm) and (b) the dependence of the interlayer coupling strength on the Co nanolayer thickness.

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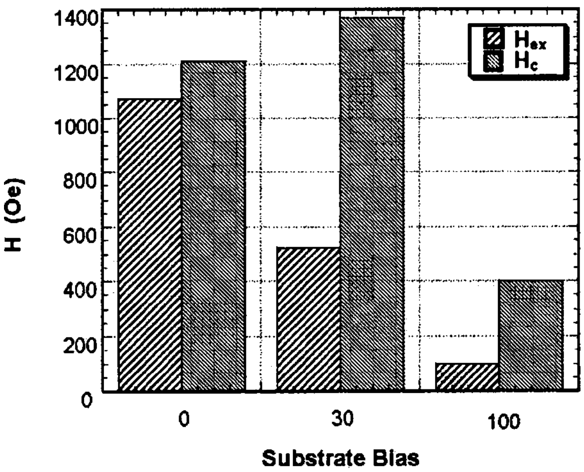

FIG. 2. Dependence of H_{ex} and H_c on the substrate bias.

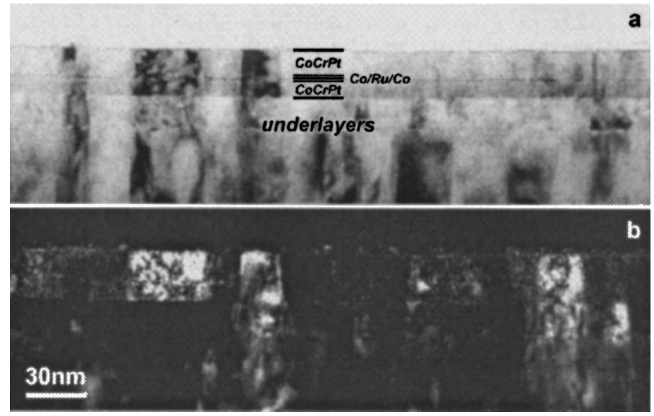

FIG. 4. Cross-sectional (a) bright and (b) dark field images of the AFC thin film.

small bias and then decreased at higher bias. It is not surprising that bias impairs H_{ex} when we realize that exchange coupling is an interfacial effect and is very sensitive to the interfacial perfectness which can be destroyed by the resputtering effect of substrate bias.

The microstructures of the thin films were investigated by x-ray diffraction and transmission electron microscopy. XRD shows that the thinner the intermediate layers (Co and Ru) the better the $(10\bar{1}0)$ texture. It is difficult to ascertain from XRD spectra how good the texture is since the (0002) peak of CoCrPt overlaps the (110) peak of the underlayers (Cr/NiAl). Plan-view electron diffraction of only the CoCrPt layer was utilized to determine this. It is known that different textures of the same material correspond to different three-dimensional (3D) structures in reciprocal space. By taking electron diffraction patterns at different specimen tilting angles, the reciprocal structure can be revealed and hence the texture can be determined.[4–6] Here we give a simple approach by which to identify growth texture. Figure 3 shows the reciprocal structure of a $(10\bar{1}0)$ textured CoCrPt thin film, for simplicity, within the $10\bar{1}1$ reciprocal sphere, i.e., only $10\bar{1}0$, 0002, and $10\bar{1}1$ reflections are included. The electron diffraction patterns taken at tilting angles of 0°, 30°, and 55°, respectively, are also given in Fig. 3. The three diffraction patterns fit well with the intersections of a plane (to be exact, an Ewald sphere) and with the reciprocal structure at the corresponding angles. The fit indicates that the CoCrPt layer possesses $(10\bar{1}0)$ texture. However, the texture is not perfect since some extra weak rings can also be seen in addition to those derived from the reciprocal structure, which implies some random component coexists with $(10\bar{1}0)$ texture. For example, the 0° pattern also contains weak $10\bar{1}0$ and $10\bar{1}1$ rings which do not exist in the 0° plane of the reciprocal structure. It is not surprising that there is a random component of grain orientation in the CoCrPt layers since Co/Ru/Co nanolayers were introduced into the system for interlayer exchange coupling.

Cross-sectional TEM observation shows that continuous sharp flat Co/Ru/Co nanolayers were sandwiched between

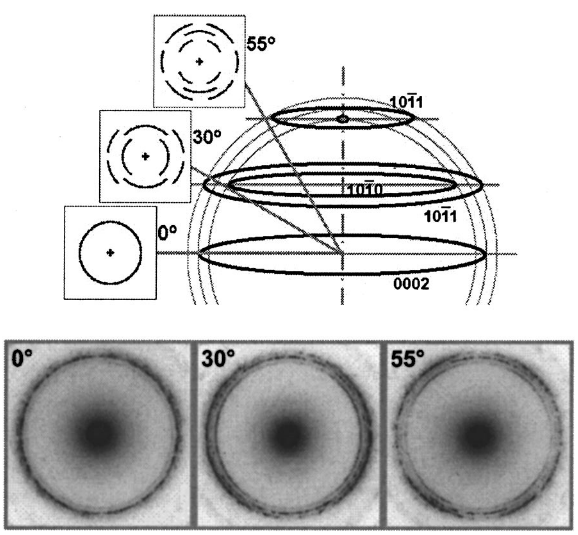

FIG. 3. Electron diffraction patterns at different tilting angles and schematic of the reciprocal structure of a CoCrPt thin film with $(10\bar{1}0)$ texture.

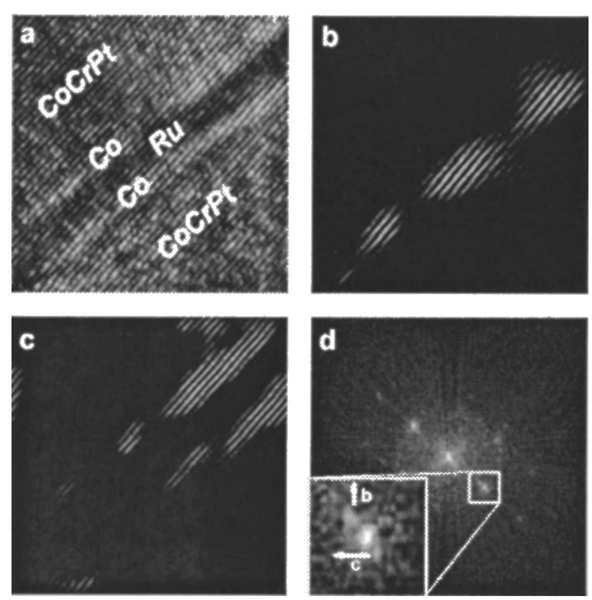

FIG. 5. FFT and IFFT images of the high resolution lattice at the interfaces.

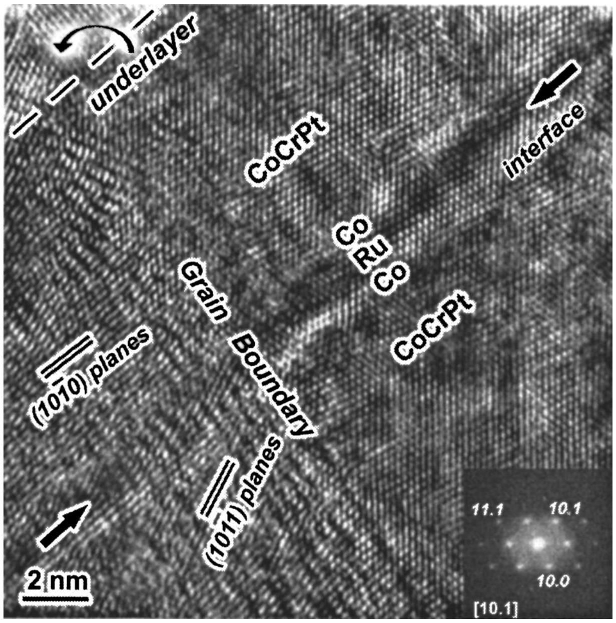

FIG. 6. High resolution image of the AFC thin film.

two CoCrPt layers. Both the bright and dark field images in Fig. 4 show some CoCrPt grains growing through Co/Ru/Co layers. Bright–dark–bright contrast can be seen in the interfacial area of the bright field image, which corresponds to the Co/Ru/Co nanolayers. The Ru atoms are heavier and have a higher scattering factor, so the Ru layer appears as the darker line in the bright field image. A similar reason explains why the Co layer appears as a bright line. The contrast has also been confirmed by the fast Fourier transform (FFT) [Fig. 5(d)] and inverse FFT (IFFT) [Figs. 5(b) and 5(c)] of the one-dimensional high resolution lattice image of the interfacial area [Fig. 5(a)]. The FFT image of (0002) fringes shows split spots with the inside satellite corresponding to the region with the greater *d* spacing and the outside one to the region with the smaller *d* spacing. The IFFT images of inside and outside satellites match the dark and bright lines, respectively. Therefore, the dark contrast corresponds to greater (0002) spacing which is Ru ($c=0.428$ nm in the bulk) and the bright contrast the smaller (0002) spacing of Co ($c=0.406$ nm in the bulk). Figure 6 is a high resolution transmission electron microscopic (HRTEM) image of the AFC thin film viewed along the $[10\bar{1}\bar{1}]$ direction, in which the crystalline lattices grow through Co/Ru/Co interfaces and the grain boundary was inherited after the interfaces; the latter is also shown in the bright and dark field images. Although the HRTEM observations also showed some interfaces with defects, generally the Co/Ru/Co nanolayers did not significantly impede coherent growth of the CoCrPt grains.

IV. SUMMARY AND REMARKS

An experimental study of adding Co nanolayers on both sides of Ru layers in double magnetic layer AFC media was reported. The addition of Co nanolayers yields an over six-fold enhancement of the antiferromagnetic exchange coupling strength between the top and bottom magnetic layers. More important, for Co nanolayer thickness of less than 1 nm, the interlayer coupling strength is linearly proportional to the Co nanolayer thickness, thereby providing a mechanism for optimizing the coupling strength. The microstructures of the thin films were also characterized. The $(10\bar{1}0)$ texture of AFC thin films remains for Co thicknesses up to $\sim$1 nm, although the texture tends to get worse with an increase in Co thickness. Correspondingly, some grains of CoCrPt and their crystal lattices have been found to grow through the Co/Ru/Co layers.

Since only small size film samples were made in this study, no recording characterization was performed. We speculate that the addition of the Co nanolayer at Ru interfaces could yield an increase of ferromagnetic exchange coupling among neighboring grains laterally within the film plane, thereby resulting in a possible increase of transition noise if the Co nanolayer is not sufficiently thin. If this is the case, schemes that prevent the increase of lateral intergranular exchange coupling due to the addition of the Co nanolayer at Ru interfaces need to be developed.

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