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# XMCD study on Co-Pt films with giant perpendicular magnetic anisotropy

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## Introduction

Co-Pt films deposited on Ru seed layers, with *c*-axis perpendicular to the film plane, showed a giant uniaxial magnetic anisotropy energy (MAE), $K_u$, especially when the film thickness was less than 10 nm [1]. The second order energy term of uniaxial anisotropy, $K_{u2}$, of these films was particularly small, and $K_u$ was almost determined by the first order energy term, $K_{u1}$, ($K_u=K_{u1}+K_{u2}$). Moreover the values of $K_{u1}$ and $K_{u2}$ of Co-Pt films varied significantly with the seed layer materials used [2]. Our results suggested that the values of $K_{u1}$ and $K_{u2}$ were mostly related to the *c/a* ratio and the volume of the hcp Co-Pt lattice, $V_{lattice}$, due to the epitaxial growth of these films on Ru, or other seed layers. $K_{u2}$ decreased as the *c/a* ratio decreased. However, $K_{u1}$ increased significantly as the *c/a* ratio decreased, resulting in an increase in $K_u$. In the present work, we study spin and orbital magnetic moments of Co in Co-Pt films by means of XMCD spectroscopy in order to elucidate the origin of giant MAE.

## Experimental

Co-Pt films were deposited on $SiO_x$/Si substrates by co-sputtering Co and Pt using an UHV DC-magnetron sputtering system. Ru films were used as standard seed layers. No substrate heating was carried out during the deposition process. The value of $K_u$ ($=K_{u1}+K_{u2}$) was obtained by subtracting the shape anisotropy $2\pi M_s^2$ from the value measured by torque magnetometry. The XMCD experiment was carried out at AR-NE1B using an absorption apparatus equipped with a permanent magnet which can generate a maximum field of 1 T. Co $L_{2,3}$MCD spectra were measured for each sample at grazing angles of incidence of 15 and 90 deg.

## Results

Figure 1 shows the $K_u$, crystal axis ratio *c/a*, and lattice volume $V_{lattice}$ for hcp-$Co_{86}Pt_{14}$ perpendicular films deposited on Ru seed layers, as a function of the film thickness, δ. As δ decreases, *c/a* decreases and $V_{lattice}$ increases due to the epitaxial constraint of Co-Pt by Ru. This lattice deformation significantly enhances the magnetic anisotropy $K_u$, and its value reaches $2\times10^7$ erg/cm$^3$ at δ=2 nm, being comparable to that of typical permanent magnets, such as $L1_0$ FePt and $Nd_2Fe_{14}B$. This series of Co-Pt films are investigated by XMCD. The orbital moment of Co is determined by analyzing the XMCD spectra using the sum rules, as shown in Fig.2, where the orbital moment $M_{orb}(\theta=90)$ indicated by the squares is the moment along the *c*-axis (easy axis) and $M_{orb}(\theta=15)$ is nearly perpendicular to the *c*-axis. From Fig.2, the orbital moment difference increases with decreasing thickness. Reminding that the MAE is roughly proportional to the difference of these moments given as MAE$\propto[M_{orb}(\theta=90) - M_{orb}(\theta=15)]$, the XMCD data well explains the thickness dependence of MAE in Fig.1.

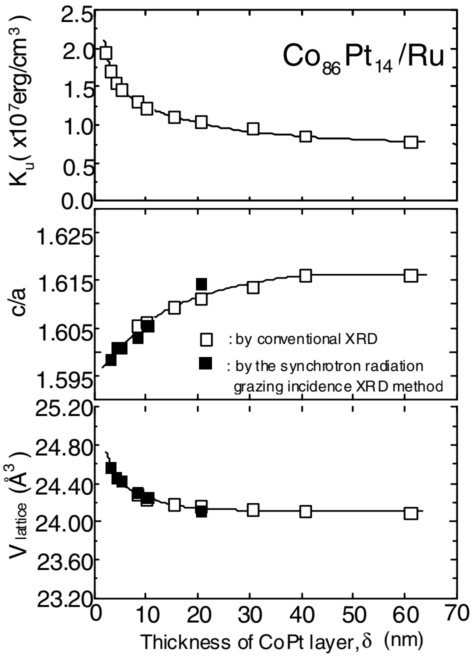


Fig. 1. The values of $K_u$, *c/a*, and $V_{lattice}$ for hcp-$Co_{86}Pt_{14}$ perpendicular films deposited on Ru seed layers, as a function of the film thickness, δ.

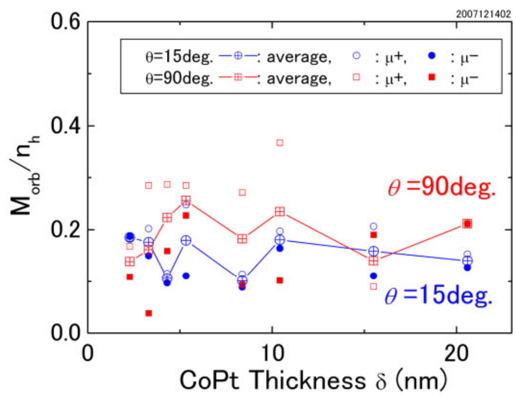


Fig. 2. Magnetic orbital moments as a function of film thickness.

## References

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