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Controlled anisotropy variation in Co thickness graded Co/Pd multilayers

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As the magnetic recording industry looks beyond perpendicular recording [1] multilayered media such as exchange coupled composites have the demonstrated increased storage density potential [2]. Recent theoretical work has shown further enhancements when the anisotropy is varied continuously between soft and hard layers [3]. In practice, experimental realization of graded media is non-trivial, partly due to the difficulty in probing the anisotropy gradient. Co/Pd multilayer films with perpendicular anisotropy are ideal candidates for studying graded anisotropy effects. This is because their perpendicular anisotropy is controllable by growth parameters such as Co layer thickness, sputtering pressure and annealing [4-6]. Here we examine a series of Co/Pd multilayer films where the Co layer thickness was varied to produce different anisotropy profiles. Four samples were grown, each with 30 repeats of a Co(t_{Co})/Pd(1 nm) bilayer. The first 15 bi-layers for each sample are high anisotropy regions with t_{Co} = 0.4 nm. For the subsequent 15 bi-layers, t_{Co} is varied as follows: 1)monolayer – 15 repeats of t_{Co} = 0.4 nm, 2)bilayer – 15 repeats of t_{Co} = 0.8 nm, 3)trilayer – 8 repeats of t_{Co} = 0.6 nm followed by 7 repeats of t_{Co} = 0.8 nm, and 4)graded – 15 repeats where t_{Co} progressively increased by 0.05 nm, from 0.4 nm to 1.2 nm.
To determine the variation in the anisotropy normal to the film plane, polarized neutron reflectometry (PNR) was used to measure the sample's in-plane magnetization aligned by an in-plane field [7]. Figure 1 shows the results of modeling the PNR data for different applied fields as a function of the depth relative to the film surface, z, for the graded sample. The gradual decrease in nuclear scattering length density in moving away from the Pd seed layer (Fig. 1a) is consistent with increased Co content due to thicker Co layers. The in-plane magnetization (Fig. 1b) also increases monotonically with the thicker Co layers (at smaller z), indicating it is easier to tilt their magnetization into the plane. Normalizing the magnetic depth profiles to the maximum magnetization at each field (Fig. 1c) shows the depth profiles do not scale with each other. This proves the magnetization variation is due to a variation in the anisotropy in the sample.
With varying anisotropy established, hard and easy axis major loops, as well as first order reversal curve (FORC) distributions, were measured to probe the magnetization reversal behavior of the film. Easy axis loops and the FORC – switching field distribution (Figs. 2a & 2b) show behavior consistent with Co/Pd films where reversal occurs by nucleation and propagation of domains oriented perpendicular to the film normal [8]. A decrease in the nucleation field is observed for the bilayer, trilayer and graded samples compared to the monolayer, indicating easier domain nucleation in the former materials similar to that observed in the hard layer of an exchange-spring system. Pre-nucleation, the graded sample also shows a reversible decrease in magnetization due to the weaker perpendicular anisotropy in thickest Co layers. The hard axis loops (Fig. 2c) show a decrease in the net anisotropy field with grading due most prominently to exchange coupling between Co layers.
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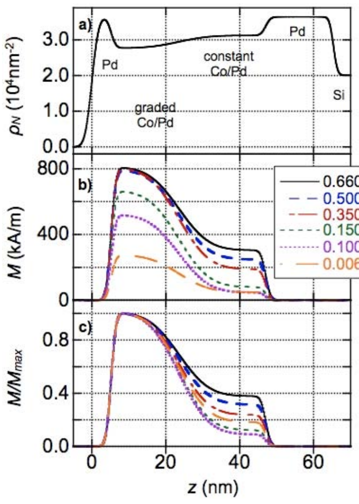

Figure 1 - a) nuclear scattering profile, b) in-plane magnetization depth profiles for different applied in-plane magnetic fields, and c) normalized in-plane magnetization depth profile for the graded sample. The sample surface is defined at z=0 nm, with the Pd seed layer at z ≈ 45 nm.

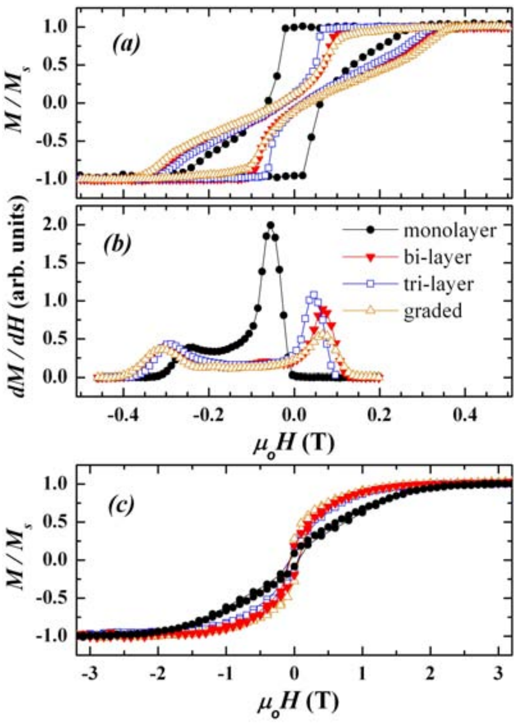

Figure 2 - a) Easy axis major loops, b) FORC – switching field distributions and c) hard axis major hysteresis loops for the samples. a) and b) have same horizontal axes.