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Thickness dependent magnetization dynamics of perpendicular anisotropy Co/Pd multilayer films

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ABSTRACT

We present the measurements of the picosecond magnetization dynamics of Co/Pd multilayer films. The dynamic magnetization properties of sputtered multilayer films were analyzed as a function of Co layer thicknesses and applied bias field. Both the eigenfrequencies of the magnetization precession in the multilayers and the associated Gilbert damping exhibit extreme sensitivity to the magnetic layer thickness on an atomic monolayer scale. The eigenfrequency increases more than threefold when the Co thickness decreases from 7.5 to 2.8 Å, mainly due to the changes in effective saturation magnetization and perpendicular anisotropy constant. A concomitant 2.6-fold increase in the damping of the oscillations is observed and attributed to stronger interface dissipation in thinner Co layers. In addition, we introduce a quasi-1D micromagnetic model in which the multilayer stack is described as a one-dimensional chain of macrospins that represent each Co layer. This model yields excellent agreement with the observed resonance frequencies without any free parameters, while being much simpler and faster than full 3D micromagnetic modeling.

Studies on thin films with alternating ferromagnetic/nonferromagnetic layers are of broad interest since these structures often exhibit strong perpendicular anisotropy [1]. Substantial attention has been paid to Co/Pd and Co/Pt multilayers as a promising candidate for perpendicular magnetic storage and patterned media [2–5]. So far, most Co/Pd and Co/Pt studies are focused on the hysteresis behavior and the associated changes in domain structures, which only involve quasi-static processes [6–14]. Typical recording and reading operations in real devices, however, involve dynamic processes down to sub-nanosecond time scales. Thus, dynamics in the span of one nanosecond need to be addressed in order to optimize the reversal speed of Co/Pd and Co/Pt media [15], and these multi-GHz dynamic properties cannot be observed with quasi-static techniques. In this paper, we present the first systematic study on the picosecond dynamics of Co/Pd multilayer films using time-resolved magneto-optics. Specifically, we investigate the dependence of the small-angle magnetization precession frequencies and damping on the thickness of the Co layer. In addition, we introduce the use of a simplified quasi-1D micromagnetic modeling method that can treat magnetic multilayer systems much faster but with accuracy comparable to that of full 3D modeling. The model is shown to reproduce the observed magnetization dynamics without any free fitting parameters. As a result, this work provides a complete set of static and dynamic magnetic properties necessary for designing perpendicular anisotropy high-speed magnetic devices.

The Co/Pd multilayer samples were deposited by magnetron sputtering using a confocal sputter-up geometry in an ATC 2200 system (AJA International). 15 Å Ta adhesion and 30 Å Pd seed layers were deposited on a (1 0 0) oriented Si wafer with a native Si-oxide surface layer before growing eight repeats of Co(t)/Pd(9 Å) bilayers. In this work, the Co layer thickness varied as t=2.8, 5.0 and 7.5 Å. During growth the samples were rotated at ~3 Hz for better uniformity, and deposition rates were 0.5–2 Å/s. The background pressure was about 2×10^{-8} Torr and sputtering pressure of 3 mTorr argon was used during deposition. Finally, the samples were capped with an 11 Å thick Pd layer to prevent oxidation. X-ray reflectivity and diffraction measurements confirm a well-defined multilayer structure with a (1 1 1) crystalline texture of the Pd buffer layer and Co/Pd multilayers [5]. Quasi-static magnetic properties were measured in a vibrating sample magnetometer (VSM) that can apply in-plane and out-of-plane fields. The measured hysteresis loops of the multilayers are shown in Fig. 1. As expected, the out-of-plane loops have much lower saturation fields than the in-plane loops, clearly confirming a strong perpendicular anisotropy. The in-plane hysteresis loops allow the effective anisotropy field H_k to be determined from the field required to saturate the magnetization and these values

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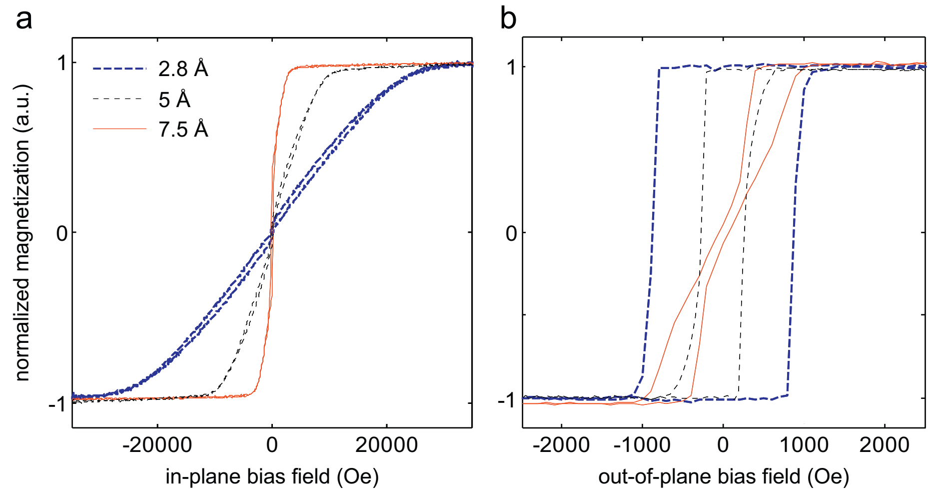

Fig. 1. In-plane (a) and out-of-plane (b) hysteresis loops of Co/Pd multilayers as obtained by VSM.

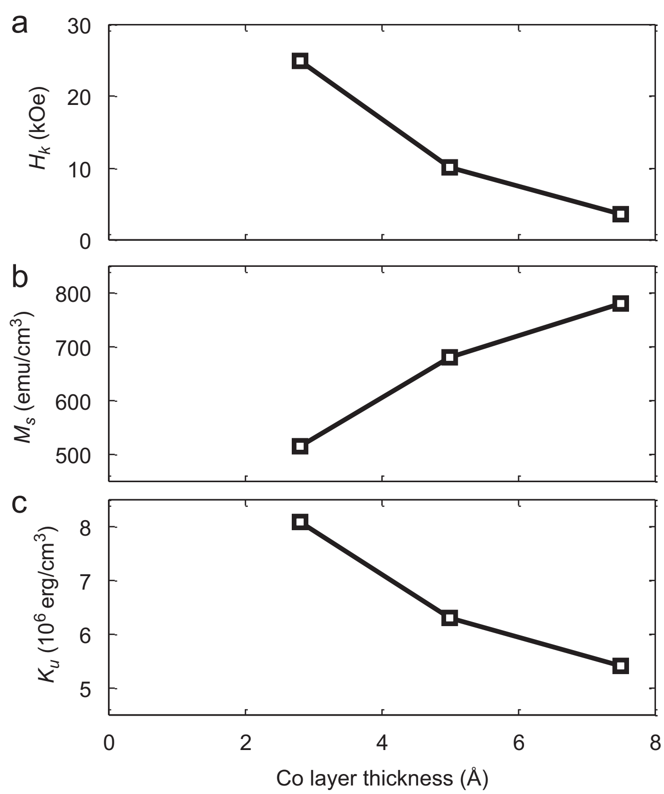

Fig. 2. Magnetic properties of the Co/Pd multilayers as a function of Co layer thickness: (a) anisotropy field, (b) effective saturation magnetization and (c) perpendicular anisotropy constant.

are shown in Fig. 2(a). Fig. 2(b) shows the effective saturation magnetization M_s with the magnetic moment per unit area normalized by the total $[Co/Pd]_{x8}$ thickness; as the Pd thickness remains constant, M_s decreases for thinner Co layers. For this type of perpendicular anisotropy media, the perpendicular anisotropy can be described by

$$K_u = M_s(H_k + 4\pi M_s)/2 \quad (1)$$

where the effective field due to the shape anisotropy is $-4\pi M_s$, and K_u is the perpendicular anisotropy constant due to the intrinsic material properties [16,17]. Based on the data in Fig. 2(a and b), we deduce the K_u values, as shown in Fig. 2(c). These quasi-static measurement data are used as parameters for the micromagnetic Landau–Lifshitz–Gilbert formalism when analyzing our dynamic measurement results.

The dynamic measurements were performed using a time-resolved magneto-optical Kerr effect microscope (TRMOKE). The details of this all-optical, two-color pump-probe setup have been described in previous publications [18,19]. The magnetic sample is excited by a strong femtosecond laser pulse, which perturbs the magnetization instantaneously and causes an internal anisotropy field pulse [20,21]. This results in a change in the equilibrium magnetization orientation and triggers precessional dynamics on the picosecond time scale. A weak probe pulse (fluence ratio between pump and probe >20) is focused on the pumped area to measure the change in magnetization as a function of the delay time between pump and probe. An additional magnetic field with a dominant out-of-plane component $H_{0\perp}$ can be applied to study the field dependence of the dynamics.

Representative measured traces of the polar MOKE signal for the three Co layer thicknesses (for an out-of-plane bias field component of $H_{0\perp}=3000$ Oe) are plotted in Fig. 3(a). The time scan periods were chosen to be long enough to observe a sufficient number of oscillations to deduce the precession frequencies using Fourier transformation. The corresponding Fourier spectra shown in the inset all show a single dominant resonance. The peak frequency of this magnetization precession as a function of Co thickness is shown in Fig. 3(b). It strongly depends on the Co layer thickness, and a changing rate of about -9 GHz/Å can be estimated. This sensitivity provides a convenient tuning mechanism as the eigenfrequencies of magnetic elements can determine their optimal switching speed, which is potentially important for patterned media and MRAM applications. We note that samples with thinner Co layers yield weaker signals (i.e., lower signal-to-noise ratio), which can be seen from both the time traces and from the Fourier spectrum of $t=2.8$ Å sample (inset of Fig. 3(a)). The weaker TRMOKE signals may be caused by the stronger perpendicular anisotropy in thinner Co layers, since it gives stronger out-of-plane confinement to the excited magnetization precession, leaving less change in the out-of-plane component of magnetization (i.e., polar Kerr signal).

By varying the bias field $H_{0\perp}$, we obtain the field dependent frequencies for the multilayers, and the results for different samples are shown in Fig. 4 with the open data points. For a better quantitative understanding of these results, we carried out micromagnetic simulations to model the precession dynamics and to verify the anisotropy constants obtained from the VSM