# Magnetic reversal phenomena in pseudo-spin-valve films with perpendicular anisotropy

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Perpendicular pseudo-spin-valve films with structure Ti/CoCrPt/Ti/CoCrPt were fabricated by UHV sputtering. The Ti serves both as a seed layer, to promote a perpendicular *c*-axis orientation, and as a spacer between the magnetic layers. The films show characteristic two-step switching with a wide plateau corresponding to antiparallel alignments of the magnetic layers. For a 5 nm Ti/5 nm CoCrPt/5 nm Ti/20 nm CoCrPt, antiparallel alignment exists between 70 and 345 Oe. Minor loops demonstrate switching of the thin layer, in addition to time-dependent magnetization reversal attributed to creep in the magnetization as a result of growth of reversed domains. Magnetic force microscopy and time-dependent magnetization measurements suggest that the domain propagation field is lower than the field necessary for domain nucleation. 
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## I. INTRODUCTION

Pseudo-spin-valve (PSV) films with perpendicular anisotropy have so far received much less attention than PSV films with in-plane anisotropy, even though they show interesting differences in switching behavior because of the magnetostatic interactions between the layers. Furthermore, perpendicular PSVs are expected to show fewer effects of edge roughness when patterned into submicron elements and are therefore of practical interest as possible candidates for magnetic random access memory and for sensing applications such as read-back hard-drive heads. Most perpendicular spin-valve systems reported consist of superlattice structures such as Co/Pt laminates with upwards of 15 individual layers.[1–4] Magnetic reversal mechanisms have been well studied in single-layer films with perpendicular anisotropy[5,6] but there are few reports of reversal in spin-valve structures. In this paper we describe magnetization reversal in a simple spin-valve system of the form Ti/CoCrPt/Ti/CoCrPt with perpendicular anisotropy. The Ti serves both as a seed layer to promote a perpendicular *c*-axis orientation and as a nonmagnetic spacer layer. We discuss a typical sample, where the layer thicknesses were 5 nm Ti/5 nm CoCrPt/5 nm Ti/20 nm CoCrPt.

## II. EXPERIMENTAL PROCEDURES

Samples were prepared by rf magnetron sputtering using 99.999% pure Ar at base pressures better than $1\times10^{-8}$ torr onto prime (100) Si wafers. The two CoCrPt layers ranged between 5 and 20 nm thick and the Ti spacer layer thickness was varied from 1 to 10 nm. The CoCrPt was sputtered from an alloyed target with composition of Co 66 at. % Cr 22 at. % Pt 12 at. % at room temperature with no further heat treatment to avoid Cr segregation to the grain boundaries. The magnetic properties of the samples were measured using a Princeton Measurement Corporation alternating gradient field magnetometer (AGFM) and magnetic force microscopy (MFM) images were taken at different remanent states on a Digital Instruments Dimension 3000 scanning probe microscope using an Asylum Research low-moment magnetic force microscopy tip in standard lift-interleave imaging mode.

## III. RESULTS AND DISCUSSION

Major and minor hysteresis loops of the film were measured with the field applied perpendicular to the sample (Fig. 1). The major hysteresis loop exhibits a characteristic two-step switching, corresponding to the switching of the two magnetic layers, and a tail-like feature (point D) on the approach to saturation.

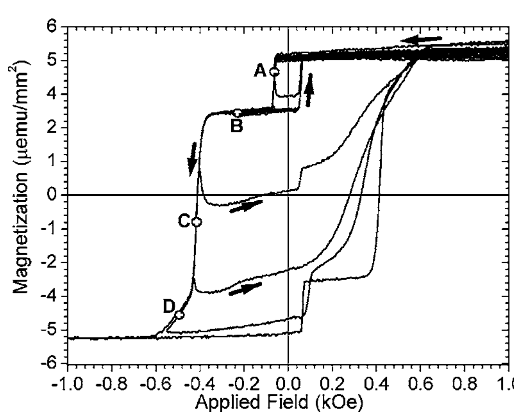


FIG. 1. Major and minor hysteresis loops of a perpendicular PSV sample. Loops starting at the plateau B demonstrate the cycling of the thin (5 nm) CoCrPt layer. Time-dependent switching seen in the minor loops starting at regions A and C is attributed to domain growth.

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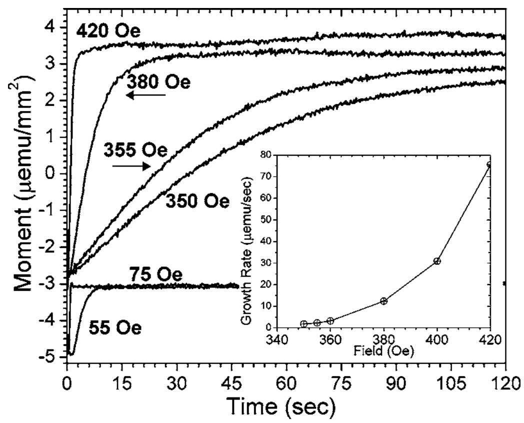


FIG. 2. The rate of change of magnetization at a given reverse field in the range of 55–420 Oe, applied after saturation. When the reverse field is within either of the steps in the major loop, a time-dependent magnetization is observed. The inset shows the reversal rate as a function of applied field.

The low-field step at $H=65$ Oe (point A) corresponds to the switching of the thinner (5 nm) CoCrPt layer. The ratio between the step heights of the low- and high-field steps A and C, 1:4, is in agreement with the nominal thickness ratio of the two layers. The plateau B where the layers are magnetized antiparallel to each other exists over a wide field range of 70–345 Oe. The tail of the loop, D, represents the completion of the reversal of the thicker layer. The tail is more evident for thicker films and may correspond to annihilation of the magnetostatically stabilized small bubble domains remaining in the thick layer after the reversal of the majority of the layer.

Minor loops starting at the first plateau (point B) illustrate the cycling of the thin layer. The minor loop is approximately symmetrical about zero field, suggesting that magnetostatic interactions with the thick layer have a small effect on the reversal of the thin layer. Magnetoresistance measurements show no measurable giant magnetoresistance (GMR) presumably due to large electron scattering in the Ti spacer layer.

Minor loops measured starting from the plateau, B, show no time dependence, but when minor loops are measured starting from either of steps A and C, a slow time-dependent magnetization is found (Fig. 2). The sample was first saturated at a field of −10 kOe, and then the field was quickly reversed to a set value $H_{\mathrm{rev}}$ (between 55 and 420 Oe) where the moment was measured as a function of time at constant applied field. For $H_{\mathrm{rev}}=55$ Oe, within the low-field step, the magnetization decreases until it reaches the plateau value, within about 10 s. For $H_{\mathrm{rev}}=75$ Oe, which is within the plateau, the rate of magnetization reversal $dM/dt=0$. For $H_{\mathrm{rev}}=350-420$ Oe, within the high-field step, the magnetization increases to near the value for the fully reversed film. The time-dependent behavior is also visible qualitatively in the minor loops of Fig. 1.

The asymptotic magnetization values suggest that the "creep" measured for $H_{\mathrm{rev}}$ within the low-field step corresponds to completion of the reversal of the thin layer. In the low-field step reverse domains are nucleated in the thin layer and start to grow. This domain growth continues even when the film is held at a constant $H_{\mathrm{rev}}$ and implies that the field required for domain wall propagation is smaller than the field necessary for domain nucleation. Similarly, the creep seen for $H_{\mathrm{rev}}$ within the high-field step corresponds to growth of reverse domains in the hard layer. A larger $H_{\mathrm{rev}}$ is expected to increase the rate of domain nucleation as well as the rate of domain growth, and $dM/dt$, the magnetization reversal rate, increases with $H_{\mathrm{rev}}$. The inset of Fig. 2 shows the magnetization reversal rate as a function of applied field for the 20 nm thick layer. We notice an exponential dependence on the applied field, analogous to what has previously been reported for single-layer perpendicular films.[5]

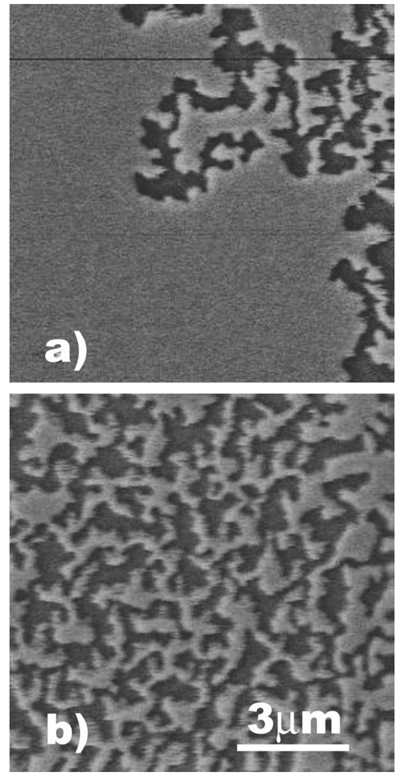


FIG. 3. MFM images taken at remanence with a net zero moment of the sample (equal amount of "up" and "down" domains). For (a) the sample was first saturated, then a reverse field of 355 Oe was applied for 30 s. (b) A short-duration higher field (435 Oe for 200 ms) was applied. Image area is $10\times 10\ \mu\mathrm{m}^2$, phase height is 7°, and light gray regions correspond to reversed domains. Notice the finer domain wall structure present in case (b).

MFM images of domain pattern in the thick CoCrPt layer are shown in Fig. 3. The remanent images correspond to different field histories, both resulting in zero net moment. For Fig. 3(a), after saturating the sample in negative field, a positive field of 355 Oe (i.e., a field just past the start of the high-field step) was applied for 30 s, and the field was removed. The sample shows large (at least several tens of microns across) domains interspersed with regions of mazelike patterns and suggests the nucleation of relatively few domains followed by extensive domain growth during the 30 s hold time. The single domain on the left side of Fig. 3(a) extends beyond the range of the scan field of the instrument. In contrast, Fig. 3(b) shows the domain pattern obtained by applying a short field (435 Oe for 200 ms) to a sample after negative saturation. In this case, small mazelike domains are present throughout the entire sample. These domains have much finer details than seen in Fig. 3(a) and no large domains were observed. This observation suggests that the higher reverse field resulted in more extensive nucleation, but domain growth was suppressed when the reverse field was removed.

The time-dependent measurements at the high-field step show the magnetization asymptotes towards a value which is not fully saturated. This is seen for all values of $H_{\mathrm{rev}}$ within the high-field step and is attributed to small bubble domains that are magnetistatically stabilized by the surrounding regions of the film[7] and therefore require larger fields for annihilation. Thinner films (such as the 5 nm layer) do not exhibit this behavior.

## IV. CONCLUSIONS

Perpendicular pseudo-spin-valve films were grown using rf magnetron sputtering. Hysteresis loops show independent cycling of the thin "free" layer. A slow time-dependent magnetization reversal is attributed to growth of reverse domains which can occur at a lower field than domain nucleation. Magnetic force microscope images show that the domain sizes and distribution can be tailored via the field history of the film.

## ACKNOWLEDGMENTS

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