Spin transfer switching characteristics in a $[Pd/Co]_m/Cu/[Co/Pd]_n$ pseudo spin-valve nanopillar with perpendicular anisotropy

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We successfully demonstrate spin transfer switching (STS) characteristics in a $[Pd/Co]_m/Cu/[Co/Pd]_n$ pseudo spin-valve nanopillar with 100 nm diameter. We observed lower critical current density and high giant magnetoresistance (GMR) ratio in our devices compared to other fully perpendicularly magnetized pseudo spin-valve structures. The devices showed a current-perpendicular-to-plane GMR of 1.2% and a STS critical current density of $J^{AP\text{-}P} = -2.6 \times 10^7$ A/cm^2 and $J^{P\text{-}AP} = 3.8 \times 10^7$ A/cm^2. The observed low critical current density is thought to be due to higher spin-transfer efficiency arising from smaller spin orbital scattering, longer spin diffusion length of the thinner Pd, and thinner soft-layer-film thickness and coercivity in the nanopillar devices. © *2012 American Institute of Physics*. [doi:10.1063/1.3675150]

Perpendicular anisotropy materials (PMAs) promise the lowering of critical current densities and the improvement of scalability due to their high thermal stabilities in spin-transfer switching (STS) driven applications. The lowering of critical current density is theoretically predicted to be due to the contribution of the dipole field toward the reduction of the switching current.[1] Despite several recent works using PMA materials such as Co/Pt, Co/Ni, FePt, and CoFe/Pd to develop STS devices, the critical current density remains high.[1–8] One of the major issues to overcome toward achieving a reduction in the high current density is to reduce the large anisotropy field of PMAs and the free layer thickness without reducing the thermal stability. In addition, PMA films that incorporate Pt, while providing high perpendicular anisotropy, also have high spin-orbital scattering leading to lower spin transfer efficiency. [Co/Pd] based spin-valves are particularly more attractive in overcoming these limitations as they are expected to exhibit high and tunable perpendicular anisotropy with thinner Pd thicknesses and lower spin orbital scattering leading to better spin transfer efficiency and higher giant magnetoresistance (GMR).[9–12] Furthermore considering the linear dependence between the current-perpendicular-to-plane (CPP)-GMR and the inverse critical current density, taking into account the polarization of the current incident on the soft layer,[13] achieving a high CPP-GMR in [Co/Pd] based spin-valves is beneficial in reducing the STS critical current density.

In this letter, we successfully demonstrate STS characteristics of a $[Pd/Co]_m/Cu/[Co/Pd]_n$ pseudo spin-valve (PSV) nanopillar. The device performance was analyzed in terms of the GMR and the STS critical current density. Current-in-plane (CIP) and CPP devices were fabricated and their GMR performance was explored. Furthermore, the STS characteristics of the CPP PSV devices were measured and the device performance was investigated in terms of the thickness of the soft layer, perpendicular anisotropy and spin-transfer-efficiency parameters relevant to the critical current density.

The PSV with a structure of bottom electrode/[Pd(1)/Co(0.38]$_3$/Pd(0.6)/Co(0.38)/Cu(2.25)/Co(0.38)/[Pd(0.75)/Co(0.29)]$_4$/Ta(2 nm) was deposited using a magnetron sputter system with the base pressure kept below 4×10^{-8} Torr and an Ar working gas pressure of 2 mTorr. A vibrating sample magnetometer was used to measure the intrinsic magnetic properties of the PSV. The measured coercivity of soft, [Pd(1)/Co(0.38)]$_3$/Pd(0.6)/Co(0.38 nm), and hard, Co(0.38)/[Pd(0.75)/Co(0.29)]$_4$, layers were 425 and 650 Oe, respectively. In order to fabricate the CPP devices, the bottom electrode was first patterned onto the deposited films using photolithography followed by Ar ion milling of the films. Sputtered SiO_2 was used to isolate each contact/device region. The device pillar was then defined using electron beam lithography (EBL) utilizing maN 2405 negative resist, which is capable of achieving high aspect ratio features. The EBL resist structure acts as an etch mask for Ar ion milling to define the device pillar. Sputtered SiO_2 was also used to form the insulation layer while the resist posts are still intact, and are subsequently removed using mr-Rem 660 creating an opening for the top contact. The top contact pattern was defined using photolithography, followed by lift-off of thermally evaporated Au contact. The scanning electron microscope (SEM) image of the final device structure is shown in Fig. 1. The GMR and STS measurements were made using micromanipulator probe station and a Keithley 2420 source meter. For GMR measurements, an electromagnet was used to apply a magnetic field of $\pm$ 2.5 kOe perpendicular to the film plane. For STS measurements an additional wave function generator was connected via a T-bias circuit to the current source such that a pulsed current from nanoseconds to seconds could be applied. For the measurement configuration, the positive

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