SPIN TRANSFER TORQUES IN HIGH ANISOTROPY MAGNETIC NANOSTRUCTURES

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In most magnetic applications the orientations of the magnetic elements within devices are controlled by external magnetic fields. However, it has recently been appreciated that the relative orientations of nano-magnets can be controlled directly by the injection of spin polarized currents known as spin transfer effects [1]. The ability of a spin-polarized current to reverse the magnetization orientation of a nanomagnets should enable a range of magnetic devices such as high performance random-access magnetic memories and spin-oscillators [2].

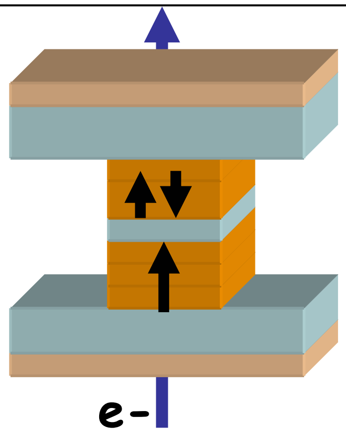

Fig. 1: *Schematic of a simple perpendicular anisotropy spin-torque device.*

In this presentation we highlight recent research on using spin-transfer torques to manipulate nano-elements having strong perpendicular magnetic anisotropy (as shown schematically in Fig. 1 [3-7]. The use of perpendicular anisotropy materials has a number of advantages. The magnetic response is more strongly determined by the intrinsic properties of the materials rather than by the shape of the device. The resulting device performance is less sensitive to lithography variations and is controllable by judicious engineering of materials properties. Other advantages of high anisotropy materials include: higher stability against thermal activation, more efficient coupling of the spin-current to magnetic excitations [3], and higher magnetic resonance frequencies. Finally, the study of spin-transfer reversal of perpendicular anisotropy elements provides insight into the magnetic reversal of patterned media elements.

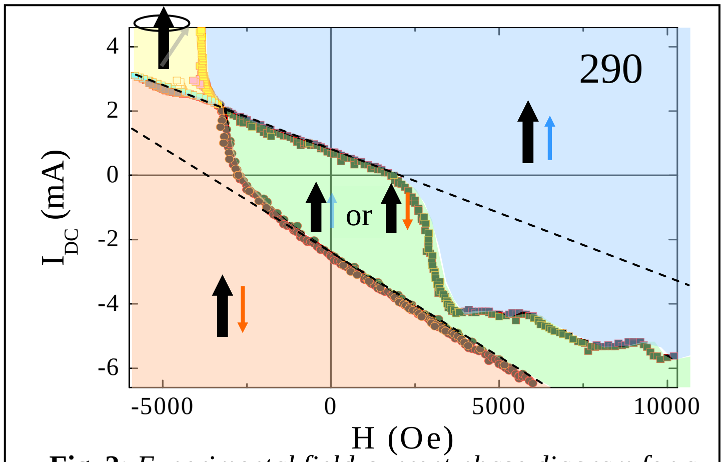

Fig. 2: *Experimental field-current phase diagram for a 50 x 100 nm^2 hexagonal nanopillar at 290 K. The data points indicate changes in the magnetic configurations with current and field*

To take advantage of the perpendicular geometry one needs materials systems with perpendicular anisotropy while maintaining a high spin polarization p and low damping α. One materials set that has proven effective is Co/Ni multilayers [3]. In the structure in Fig. 1 the reference high-coercivity reference layer is a $[Co/Pt]_4/[Co/Ni]_2$ multilayer and the free layer that reverses under the action of either current or field is a [Co/Ni] multilayers. Using such structures we have demonstrated current-induced reversal in perpendicular anisotropy nanopillars and explored the current-field phase diagram shown in Fig. 2 and described in detail in Ref. 3. We find regions of hysteretic switching and regions of reversible behavior. For perpendicular anisotropy devices the switching current is expected to be proportional to the effective field acting on the free layer and therefore should be linear with the applied field. While the linear trends are observed in the data there are several discrepancies between theoretical and experimental results and will be discussed. In addition we have also observed current induced domain-wall formation in the free layer [4] and current-induced telegraph noise between the uniform and domain state of the free layer [6].

The better understand the reversal behavior we studied the angular dependence of the applied field on the device [7]. The switching field in the absence of current is well described by the Stoner-Wohlfarth asteroid for a uniaxial system. With the addition of current we find that spin-torque reversal is most efficient when the applied field is parallel to the anisotropy axis. Surprisingly, for fields applied at an angle to the anisotropy axis the switching fields are current independent for currents lower than a critical value and the critical current increases with increasing field angle.

Finally, several advances are still needed to realize a practical device [2]. One key point is the reduction of the currents required to switch magnetization while maintaining the thermal stability of the free layer. To address this issue we adjusted the perpendicular anisotropy and volume of the free element. We observe that the critical current scales with the height of the anisotropy energy barrier and we achieve critical currents as low as 120 μA in quasi-static room-temperature measurements of a 45-nm diameter device [5]. We have also explored anti-parallel coupled reference layers to limit the dipolar interactions between the free and reference layer and we will present results for coupled reversal of the free and reference layer.

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