Magnetic Vortex Dynamics Driven by DC Spin-Polarized Current

CNF Project # III-80
Principal Investigators: Robert A. Buhrman, Daniel C. Ralph

Abstract:
We fabricated nanopillar spin-valves with a thick spin-polarizing layer. In the presence of a spin-polarized current, we observe microwave dynamics, which correspond to precession of a magnetic vortex core in the thick magnetic layer, coupled to oscillations of the thinner layer. Dynamics are observed for in-plane and out-of-plane applied fields. The oscillation frequency varies weakly with the applied field strength and current amplitude. The oscillations have quality factors of up to 3400 and high power densities.

Summary:
In the presence of a magnetic field and a spin-polarized current, a magnetic moment obeys a modified version of the Landau-Lifshitz-Gilbert (LLG) equation with an additional term describing the torque exerted by the spin current [1,2]. The spin transfer torque (STT) effect provides a new handle for manipulating magnetic particles at the nanoscale and could have possible applications for current-switched non-volatile memory and as DC-driven microwave sources. Experiments have demonstrated that STT can be used to induce current-controlled hysteretic switching [3], as well as persistent microwave dynamics [4] in magnetic trilayers, and can drive domain wall motion [5].

An important issue, both theoretically and for technological applications, is understanding how to increase the coherence of STT-driven microwave oscillations. Previous experiments focused on uniform precession modes [4]. In our experiment, we use STT to drive oscillations of a non-uniform magnetic structure, a magnetic vortex formed in a nanopillar spin valve.

The samples were fabricated by depositing (Ta (5nm)/Cu (2 nm)/CuO (20 nm)) x 2/Ta (20 nm)/Py (60 nm)/Cu (40 nm)/Py (5 nm)/Cu (20 nm)/Pt (30 nm) on a thermally-oxidized silicon wafer, using DC-magnetron sputtering. Electron-beam lithography was used to define ~160 nm x 75 nm ellipses. Then, ion milling was used to etch to the bottom of the thick Py layer, defining a pillar-shaped structure. Contact is made by bonding Au ribbon to lithographically-patterned Cu leads. The sample is DC-current-biased to generate STT on the magnetic layers. The resulting oscillations of the magnetizations of the Py layers produce a time-varying voltage via the giant magneto-resistance (GMR) effect. Simulations indicate that these oscillations are consistent with the precession of a magnetic vortex in the thick Py layer (gyrotropic vortex mode). Such vortex oscillations have previously been observed in experiments on single Py dots where a magnetic field was used to excite them [6]. We find that the frequency of the gyrotropic mode increases with increasing perpendicular-to-plane applied magnetic fields and decreases with increasing in-plane fields applied along the major axis of the ellipse, consistent with a tightening and, respectively, distortion of the magnetic vortex. Pinning introduces anomalies in the general trend. We observed constructive and destructive interference of the gyrotropic mode with other modes, likely resulting from coupling between the two magnetic layers. Additionally, we have determined that the gyrotropic mode is highly coherent, with measured quality factors of up to 3400 at room temperature.

References:
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• We study magnetization dynamics in nanopillar spin valves that contain a magnetic vortex (Figure 1).

• Spin-torque drives vortex precession in the thick Py layer, which couples to oscillations in the thin Py layer (Figure 2 (vertical axis is power in units of Johnson noise at 300 K)).

• Oscillations have high quality factors of up to 3,400 (Figure 3).

• We observe frequency modulation driven by an oscillating applied magnetic field (Figure 3).

Figure 1

Figure 2

Figure 3