Spin-Transfer-Driven Ferromagnetic Resonance of a Single Nanomagnet

CNF Project # 598-96

Principal Investigators: Daniel C. Ralph, Robert A. Buhrman

Abstract:
We have developed a new form of ferromagnetic resonance (FMR) spectroscopy which uses the spin transfer torque from an RF current to probe the normal modes of individual nanoscale magnets. We measure the magnetic dynamics of samples smaller in volume by more than a factor of 50 compared with other techniques. Studies of the resonance frequencies, amplitudes, line-widths, and line shapes as a function of microwave power, DC current, and magnetic field provide detailed new information about the exchange, damping, and spin-transfer torques that govern the dynamics in magnetic nanostructures.

Summary:
Spin-polarized current passing perpendicularly through magnetic multilayers can exert torques on the magnetic moments through direct transfer of spin angular momentum at magnetic interfaces. This spin-transfer phenomenon allows small magnetic samples to be manipulated far more efficiently than is possible through the traditional methods involving applied magnetic fields. Here we show that it is possible to use spin transfer to drive FMR in a single nanoscale magnet. We can detect the resulting magnetic dynamics by measuring a DC mixing voltage generated by the precessing nanomagnet [1].

We study magnetic multilayers patterned into nanoscale pillars. We fabricate these nanopillars by first sputtering a multilayer of 120 nm Cu / 20 nm Py (permalloy) / 12 nm Cu / 5.5 nm Py$_{0.65}$Cu$_{0.35}$ / 2 nm Cu / 30 nm Au and then evaporating 50 nm of carbon on top. Electron beam lithography is used to define an elliptically-shaped etch mask of dimensions 90 x 30 nm that is used for ion milling the pillar structure. PECVD-grown SiO$_2$ is then deposited to insulate the pillars before electrical contact to the top is made using photolithography.

The PyCu layer has a smaller magnetic moment than the Py layer, so if we apply an appropriate magnetic field perpendicular to the layers, the PyCu layer saturates out of plane while the Py layer will rotate only slightly. Applying an RF current through the pillar then induces an RF torque to the PyCu moment, exciting precession at the normal mode frequencies. The modes that we observe shift in frequency linearly with field above the saturation field of the PyCu layer, in parallel to the shift that would occur for spatially-uniform precession, but offset to higher frequencies. The offsets are likely due to the exchange field from the non-uniform character of the modes. As expected from modeling, the line shape of the lowest-order mode’s FMR signal is Lorentzian with a linewidth proportional to the dissipation. This allows an efficient measurement of the damping in a single nanomagnet. Applying DC current in addition to the RF drive, we observe a linear decrease in the effective damping, in agreement with predictions.

Previous experiments have shown that large DC currents passing through such devices can excite steady-state dynamical modes, and the resulting magnetoresistance oscillations cause the pillar to emit microwave power, making these devices candidates for field- and current-tunable microwave sources. As a function of DC current, the frequencies of the peaks in the emitted power spectrum often jump in discontinuous steps, and it has previously been a topic of much debate as to why. From the FMR measurements, we are able to identify these jumps in the DC-driven spectra as transitions between different normal modes of a magnetic layer.

This new FMR technique should have immediate utility in academia and industry for efficient probing and optimization of magnetic material parameters on the nanoscale. It should also be possible to scale the technique to much smaller magnetic volumes, approaching the molecular limit.

References:
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Principal Investigators: Daniel C. Ralph, Robert A. Buhrman
Users: Jack Sankey, Patrick Braganca, Ilya Krivorotov, Andrei Garcia, Kiran Thadani

Affiliation: Physics Department, Applied & Engineering Physics Department, Cornell University
Primary Funding: NSF/NSEC, DARPA, ARO
Contact: ralph@ccmr.cornell.edu, rab8@cornell.edu, jcs65@cornell.edu, pmb32@cornell.edu, ink3@cornell.edu, ag254@stanford.edu, kvt2@cornell.edu

- We have developed a new form of ferromagnetic resonance (FMR) spectroscopy using spin transfer torques.
- We are able to characterize in detail the magnetic normal modes in single nanoscale devices.

Figure 1, above: Geometry of the nanopillar device.

Figure 2, right: (a) FMR peak for the fundamental mode of a 30 x 90 nm² sample. (b) Damping parameter as a function of DC current. (c) FMR scans showing many normal modes. (d) Magnetic-field dependence of these modes.