Microwave oscillations of a nanomagnet driven by spin-polarized current.

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Recommended and a commentary by Barbara Jones, IBM Research Labs., Almaden

The phenomena of current-induced magnetic reversal, and of spin-polarized currents producing a magnetic torque, have been known for some years, since first proposed by J. Slonczewski in 1996. One view of the mechanism is that as the spin-polarized electrons enter the ferromagnet, there is a torque exerted on them to align with the local magnetic environment. This torque in turn creates an opposing torque on the local magnetic environment. If the current density is high enough, the spin torques can overcome local anisotropy and cause a change in the magnetization. Theoretical efforts on this purely quantum mechanical effect have predicted a variety of magnetic phases, including magnetic reversal, canting, precession, and other types of oscillatory behavior not attainable with magnetic fields alone. A long-standing experimental challenge has been to image, or measure, time-dependent states in these very small structures. With the results presented in this publication, direct measurement of microwave frequency dynamics in individual nanomagnets has been obtained, to very interesting and important effect.

The samples used are of a structure common to the field: two magnetic layers, one thick and one thin, separated by a nonmagnetic metallic spacer. The thick "fixed" layer acts as a source of spin-polarized electrons for the thinner "free" layer. These layers are milled to an elliptical cross-section of 130nm x 70nm to form a pillar. Such a thin pillar ensures current flows perpendicularly through the layers, and minimizes any direct Oersted fields from the current. Through the GMR effect (parallel magnetic layers have lower resistance than perpendicular), in a d.c. current, magnetization dynamics will appear as a time-varying voltage, found in these experiments to be typically in the microwave frequency range.

The experimental group uses a novel heterodyne mixer current to measure the dynamics which avoids the previous pitfalls of also applying a high frequency magnetic field. At high current and magnetic field, they find harmonic peaks which grow and shift in frequency as current is increased. When compared to the frequency vs. field behavior of small-angle elliptical precession of a ferromagnet, the fit is excellent, confirming an early prediction of Berger.

At higher currents, additional dynamical regimes appear in dramatic fashion. Dynamical stability diagrams of current vs. applied magnetic field are extracted and show unusual phase boundaries. As commented in the paper, "Explaining the existence of all these modes and the positions of their boundaries will provide a rigorous testing ground for theories of spin transfer driven magnetic dynamics." A single domain simulation by the authors suggests the existence of large angle precession, canted states, and multi-domain instability.

Much theoretical interpretation remains, as well as technological promise. With a large amount of microwave power generated by many of the modes, it is suggested that "nanomagnets driven by spin-polarized currents might therefore serve as nanoscale microwave sources or oscillators, tunable over a wide frequency range." This article is highly recommended.