Coherence of Microwave-Frequency Nanomagnetic Dynamics Driven by a DC Spin-Polarized Current

Abstract:
The transfer of spin angular momentum from a DC spin-polarized current passing through a nanoscale magnetic multilayer can drive spontaneous coherent magnetic oscillations. By measuring linewidths of spectra from the associated resistance oscillations, we demonstrate that the coherence is limited by thermal deflections of the magnetization about its equilibrium trajectory below 100 K, and by thermally-activated transitions between dynamical modes at higher temperature. The coherence time can be longer than predicted by macrospin simulations, suggesting that spatially non-uniform magnetic modes are relevant.

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 phenomenon allows small magnetic domains to be manipulated far more efficiently than is possible through the traditional methods involving applied magnetic fields. Furthermore, DC currents passing through multilayers can spontaneously excite new types of highly coherent precessional excitations not attainable with fields alone, enabling applications such as nanoscale microwave oscillators with frequencies that are tunable by current and/or magnetic field. The feasibility of such applications depends on achieving precession with a long coherence time, which is the subject of our investigation.

Experiments have shown that DC current passing through such devices can excite steady-state dynamical modes [1,2], which produce peaks when the microwave power density versus frequency is measured with a spectrum analyzer. The narrowest linewidth (FWHM) of the peaks (related to the inverse coherence time) varies between samples, ranging from 550 MHz in room-temperature Co layers [1] down to 6 MHz in Py layers at 40 K [2]. By observing the dependence of the FWHM on temperature T and on the angle of the applied magnetic field relative to the magnetic easy axis, we are able to probe which mechanisms limit the linewidth [3]. Over the range of T studied (25-290 K, depending on the sample), the FWHM is found to increase by as much as a factor of 5. We argue that two mechanisms are important: (a) fluctuations of the moment about its equilibrium trajectory dominate below ~ 100 K and (b) thermally-activated transitions between different modes produce additional broadening at higher T. The low-T linewidths that we measure can be substantially narrower than predicted by simple models which assume that the magnet responds as a single macrospin, from which we conclude that spatially non-uniform modes are relevant and surprisingly effective in increasing the coherence time.

Further evidence for both non-uniform modes and mechanism (b) is observed in devices where, for certain ranges of current and field, two similar modes appear in the spectrum. When both modes are visible, their linewidths increase dramatically, which is likely due to high-frequency mode switching.

Linewidths are also observed to be a strong function of the angle of the applied magnetic field relative to the easy axis of the nanomagnet. This effect is currently under investigation.

References:
Motivation: Understand the coherence time for magnetic dynamical modes driven by a DC current.

The linewidths increase with temperature $T$, dominated by magnetic deflections at low $T$ and thermally-activated mode switching at high $T$.

Switching between modes increases linewidths when two modes are present.

Figure 1, opposite: (a) Geometry of nanopillar. (b) $T$-dependence of linewidths in two devices.

Figure 2, below: Current dependence of (a) frequency and (b) linewidths for two modes in third device.