X-Ray Imaging of Magnetic Normal Modes Driven by Spin Transfer Torque in Magnetic Nanopillar Devices

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Abstract:
We have fabricated permalloy/copper/cobalt magnetic nanopillars with a 100 × 200 nm² elliptical cross section on top of a suspended silicon nitride membrane, designed for performing x-ray transmission microscopy of magnetic dynamics. We are now studying these devices to image the magnetic normal modes that can be excited by the spin transfer torque from a microwave-frequency current passing through the pillar.

Summary of Research:
A spin-polarized current passing through a ferromagnet can exert a torque on the ferromagnet strong enough to either reverse its magnetization or excite steady-state high-frequency (1-20 GHz) magnetization precession, depending on the device structure and applied magnetic field [1]. This spin-torque effect is under intensive study both because of its fundamental importance and because of its potential applications in magnetic random access memory (MRAM) and high speed signal processing. One of the critical outstanding issues in this field is the nature of the magnetization dynamics excited by the spin torque. Direct imaging [2,3] of the spatial and temporal dependence of the magnetic dynamic modes with high resolution x-ray transmission microscopy can offer a unique understanding of this effect and would be a major advance in this field. X-ray transmission microscopy can selectively image a ferromagnetic element via x-ray magnetic circular dichroism (XMCD), by which the transmission of x-ray photons through a ferromagnetic material depends on the polarization of the photons and the magnetization direction of the ferromagnetic element.

We start with a silicon (Si) substrate coated with 150 nm low stress (film tension < 200 MPa) silicon nitride films on both sides, which will be made into a suspended membrane to allow for x-ray transmission microscopy (Figure 1). We deposit the metallic multilayers of the structure (in nm): { Ta 3 / CuN 20 } 2 / Ta 3 / Py 15 / Cu 4 / Co 5 / Cu 2 / Pt 20 (where Py is the magnetic alloy permalloy, Ni₈₁Fe₁₉) in a sputtering system. E-beam lithography and ion milling are then used to define pillars with elliptical cross section of 100 × 200 nm² (Figure 2).

Figure 1: Device schematic: nanopillar device on top of a suspended silicon nitride membrane.
Multiple steps of photolithography and ion milling are used to make the contact leads. Silicon nitride is deposited by plasma enhanced chemical vapor deposition (PECVD) to provide electrical isolation between top and bottom leads. To form the suspended nitride membrane, the Si substrate is etched anisotropically in heated potassium hydroxide (KOH) solution, using photolithographically-patterned silicon nitride on the back side of the substrate as the etch mask.

The XMCD experiment is carried out at the soft full-field x-ray transmission microscope (XM-1) at the Advanced Light Source of Lawrence Berkeley National Laboratory. The XM-1 microscope has a spatial resolution of 15 nm and temporal resolution of 70 ps. The x-ray is incident at 30° from the normal direction of the device plane (Figure 1), and its energy is tuned to the characteristic Co $L_3$ resonance absorption edge. These experiment conditions allow detection of the in-plane component of the magnetization of the 5 nm thin Co layer in the nanopillar. A magnetic field is applied in the device plane along the short axis of the ellipse. Figure 3 is the x-ray transmission image taken for an applied magnetic field $H = 0$. We have located the nanopillar in the x-ray microscope. The XMCD contrast associated with the magnetization of the Co free layer is low in such a thin and small sample.

We are working to optimize the sample and experiment condition to improve the signal.

The next step of the experiment is to excite magnetic dynamics with a microwave current bias, and image the magnetic normal modes. We will apply a continuous rf-current at the resonance frequency of a particular normal mode of interest. The rf-frequency will be phased-locked to the x-ray pulses, and the relative phase of the x-ray pulse will be stepped through its oscillation period. The magnetization of the Co layer will be resonantly excited by the spin transfer torque from the rf current to undergo persistent precession [4]. We hope to be able to map out the spatial configuration and the time evolution of the excited normal mode and its phase relationship with the rf-drive, and compare the results to theoretical models. These experiments are currently underway.

References: