Abstract:
We have fabricated FeMn/Cu/CoFe magnetic nanopillars with 150 nm circular cross section on top of a suspended SiN membrane, designed for performing x-ray transmission microscopy of magnetic dynamics. We are now studying these devices to image the spin torque effects due to electrical currents passing through the antiferromagnetic FeMn and ferromagnetic CoFe layers.

Summary of Research:
A spin-polarized current passing through a ferromagnetic layer exerts a torque on the ferromagnet (F). This spin-transfer torque can either reverse its magnetization or excite steady-state magnetization precession [1]. The 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. In spintronics devices, antiferromagnetic (AF) metals are another important type of material, and are widely used to pin the direction of an adjacent ferromagnetic layer via the exchange interaction at the F/AF interface, the so-called exchange bias effect. Recent theoretical studies [2] predict that spin torque effects should occur not only in ferromagnetic multilayer systems but also in AF/F structures. However, due to the absence of a resistance signal for the rotation of the magnetic moment (or the antiferromagnetic director) in AF/F multilayers, experimental results to date have given only indirect and conflicting evidence about the possibility of spin torque effects involving antiferromagnets. For example, recent experiments [3,4] have attempted to identify the effects of spin torques on an AF by measuring changes in the exchange bias effect, but the results so far are not conclusive. X-ray microscopy can directly image the micromagnetic configurations of ferromagnets 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. This technique may therefore be capable of providing direct images of ferromagnetic dynamics due to spin torques in AF/F multilayers.

We start our sample fabrication with a Si substrate coated with 150 nm low stress (film tension < 200 MPa) silicon nitride films on both sides, one side of 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 4 / FeMn 9 / Cu 6 / CoFe 6 or 10 / 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 circular 150 nm-diameter cross sections.

Multiple steps of photolithography and ion milling are used to make the contact leads, and 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, in the final step of processing the Si substrate is etched anisotropically in heated KOH solution.
The XMCD experiment is carried out at the full-field soft x-ray transmission microscope (XM-1) at the Advanced Light Source of Lawrence Berkeley National Laboratory, in collaboration with Peter Fischer. The XM-1 microscope has a spatial resolution of 15 nm and temporal resolution of 70 ps. To detect the in-plane component of the magnetization of the CoFe layer in the nanopillar, the sample is placed so that the x-ray is incident at 30° from the normal direction of the device plane (Figure 2a), and its energy is tuned to the characteristic Co L3 resonance absorption edge. X-ray transmission images are taken for magnetic fields $H = \pm 500$ Oe applied in the device plane. The magnetic contrast (Figure 3) is computed by taking the ratio of the transmission images at opposite magnetic fields where the magnetization of CoFe also points to opposite directions.

According to theoretical predictions, current passing perpendicularly through the layers should apply a spin torque on the upper CoFe layer. The associated dynamical phase diagram as a function of current and applied magnetic field contains well-defined regions where the moment of the ferromagnetic layer switches by 90° to an out-of-plane orientation and others where a DC current produces steady-state precession. This suggests that we measure the average out-of-plane component of the CoFe magnetization as a function of current and magnetic field applied in the sample plane. To do this, the sample is placed so that the x-ray beam is incident at normal angle to the device plane (Figure 2b). If the magnetization rotates out of plane while applying current, it will have a non-zero component projected along the x-ray beam direction, which should produce a change in magnetic contrast. This will provide unambiguous evidence of current-induced spin torques generated by the current from an antiferromagnet. This work is currently underway.

References: