Visualizing Spin Currents with X-ray Microscopy

Hendrik Ohldag
Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA
Materials Science and Engineering, Stanford University, Stanford CA 94305, USA
Department of Physics, University of California Santa Cruz, Santa Cruz CA 95064, USA

Today's magnetic device technology is based on complex magnetic alloys or multilayers that are patterned at the nanoscale and operate at gigahertz frequencies. To better understand the behavior of such devices one needs an experimental approach that is capable of detecting magnetization with nanometer and picosecond sensitivity. In addition, since devices contain different magnetic elements, a technique is needed that provides element-specific chemical information about not only ferromagnetic but antiferromagnetic materials as well. Finally, instead of manipulating devices with external magnetic fields one now often makes use of so called *spin currents*. Pure spin currents or electrical currents with a net magnetic spin moment are fascinating from a fundamental as well as applied perspective. Their effects on the magnetization of a second magnetic layer in a device have been studied intensively using transport and other macroscopic tools. However, from a fundamental point of view it is also often interesting to directly "see" the currents directly on a microscopic scale.

To answer all these questions soft x-ray microscopy is an excellent tool, because a synchrotron produces tunable and fully polarized X-rays with energies between several tens of electron volts up to tens of kiloelectron volts. The interaction of tunable X-rays with matter is element-specific, allowing us to separately address different elements in a device. The polarization dependence or dichroism of the X-ray interaction provides a path to measure a ferromagnetic moment and its orientation or determine the orientation of the spin axis in an antiferromagnet. The wavelength of X-rays is on the order of nanometers, which enables microscopy with nanometer spatial resolution. And finally, a synchrotron is a pulsed X-ray source, with a pulse length of tens of picoseconds, which enables us to study magnetization dynamics with a time resolution given by the X-ray pulse length in a pump-probe fashion.