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Discovering new physics in magnetic thin films using coherent EUV from high harmonic generation

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The understanding of nanoscale magnetism has become much more critical with recent advances in magnetic data storage applications, as bits on a hard disk are already packed at scales of about 20nm. However, a microscopic model of how spins, electrons, photons and phonons interact does not yet exist. This understanding is fundamentally constrained in large part by our limited ability to observe magnetism on all relevant time and length scales. Until recently, measuring magnetization dynamics used either ultrafast visible-wavelength lasers, or X-rays from synchrotrons and free electron lasers. Our recent work has shown that the fastest dynamics in magnetic materials can be captured using extreme ultraviolet (XUV) harmonics – with elemental resolution and at multiple atomic sites simultaneously. We first probed with elemental sensitivity how fast the magnetic state can be destroyed in an Fe-Ni alloy. After exciting an Fe-Ni alloy with a fs laser, the spin sublattices randomize on sub-ps timescales. Surprisingly, even in a strongly coupled ferromagnetic alloy, the demagnetization of Ni lags that of Fe by 10 fs [1]. Moreover, we were able to tune this time lag by diluting the alloy with Cu to further reduce the exchange energy. After a time lag characteristic of the exchange energy, the Ni sublattice demagnetizes at the same rate as Fe. This reveals both how the exchange interaction can mediate ultrafast magnetic dynamics in alloys, and how the intrinsic demagnetization process is site-specific such that spins on one sublattice can interact more strongly with the optical field than spins on the other sublattice. In our latest work, we uncovered evidence of giant spin-currents in magnetic multilayers that are generated in the course of the laser-driven ultrafast demagnetization process [2]. By exciting a magnetic multilayer (Fe/Ru/Ni) with a laser pulse, and separately, yet simultaneously, probing the magnetization response of the Ni and Fe layers when the two layers are aligned with an applied magnetic field, we found that optically induced demagnetization of the top Ni layer causes the buried Fe layer to undergo a transient enhancement of the magnetization, of up to 20 percent. This is due to an intense, majority spin-current that enters the Fe layer.

[1] S. Mathias, et al., PNAS 109, (2012).
[2] D. Rudolf, et al., Nat. Comm. 3, (2012).