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Beamline 7-ID: Using ultrasmall x-rays to probe ultrafast laser-induced processes

X-rays are routinely used to characterize the static structures of complex materials, biomolecules, and surfaces with atomic resolution. However, all structures evolve in time, and the ability to see atoms move with sub-Angstrom spatial resolution and 100-ps time resolution allows researchers to understand the initial response of complex systems to photoexcitation. In the most general terms, researchers can follow the structural response to electron motion induced by impulsive optical excitation. The relaxation to equilibrium contains detailed information about the system. The use of microfocused x-rays (~1–10 μm) in conjunction with ultrafast laser excitation provides several advantages: 1) access to multiple-wavelength excitation because of the extremely efficient use of laser power, 2) the potential to use micron-sized rare samples, and 3) a mitigation of sample damage considerations. Tunable, monochromatic, polarized, microfocused x-rays synchronized with an ultrafast laser (to ~2-ps precision) enable researchers to apply the powerful techniques of time-resolved x-ray absorption spectroscopy (both near-edge, XANES, and extended, EXAFS) and time-resolved x-ray diffraction to study the electronic and structural response to photoexcitation. A variety of research in atomic, molecular, optical (AMO) [1] and condensed matter physics has been the recent mainstay at the X-ray Operations and Research sector 7-ID beamline [2,3], but studies of chemical and biological systems are easily envisioned.

The new Ultrafast Laser Laboratory at sector 7-ID was commissioned in October 2005. It features a regeneratively-amplified Ti:sapphire laser system (2.5-W average power, <50 fs, 1-5 kHz) in a 7.8- x 3.7-m laser laboratory. This provides ample space for "laser-only" experiments, which can be performed during APS maintenance periods (~3 months/year). Such preliminary experiments are essential to commissioning complex apparatus (e.g., three-dimensional ion imaging detectors) prior to use during x-ray beam time.

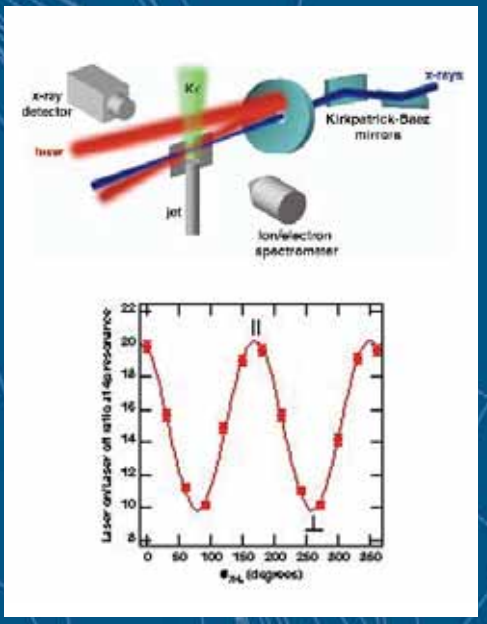

Fig 1. Top: Microfocused x-rays probe atoms in the focus of an intense ultrafast laser. Bottom: Intensity of the 1s → 4p resonance as a function of the angle between the polarization of the laser and x-rays. This intensity is a measure of the 4p orbital hole density and thus a measure of the alignment of the 4p electron shell.

An example of recent research using the time-resolved laser/x-ray facility is shown in Fig 1 [1]. Here, microfocused, polarized x-rays probe the shape of the electron cloud of an atom which has been ionized using the strong electric field present in tightly-focused, intense laser beam (~2 x 10^{14} W/cm^2). The strong electric field of the laser rips out an electron from a krypton atom, leaving the electron cloud aligned with respect to the polarization axis of the laser. A direct experimental proof of this fundamental effect had been lacking so far. Using the time-resolved x-ray microprobe, the alignment was directly observed and the degree of alignment understood by taking into account spin-orbit coupling, a relativistic effect. Understanding the atomic response to strong laser fields is of significant fundamental and technological interest, since it forms the basis for compact, coherent sources of soft x-ray radiation.

[1] L. Young et al., Phys. Rev. Lett. accepted.
[2] S.H. Lee et al., Phys. Rev. Lett. **95**, 246104 (2005).
[3] M. DeCamp et al., Phys. Rev. Lett **91**, 165502 (2003).

CALL FOR PROPOSALS

At the Advanced Photon Source, our door is open to experimenters from all scientific disciplines whose research requires the highest brilliance hard x-ray beams in the Western Hemisphere.
General-user proposals for beam time during Run 2007-1 are due by November 3, 2006.
Information on access to beam time at the APS is at http://www.aps.anl.gov/user/beamtime/get_beam.html or contact Dr. Dennis Mills, DMM@aps.anl.gov, 630/252-5680.

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