Interdisciplinary group at UCSD laser-generated x-rays to watch atoms move

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INTERDISCIPLINARY GROUP AT UCSD USES LASER GENERATED X-RAYS TO WATCH ATOMS MOVE

Atoms move about and bond with each other at a speed that's generally out of our grasp: one trillion times faster than the blink of an eye.

But now a group of chemists, physicists and engineers at the University of California, San Diego, has devised a laser-based method for probing into the high-speed world of atoms to directly observe what happens when they move.

Using ultra-fast pulses of light from a very powerful laser to produce x-rays from a simple copper wire, the Wilson Group at UCSD's Department of Chemistry and Biochemistry observed atomic motions inside crystals of gallium arsenide, a synthetic compound used as a semiconducting material. The experiment is described in the March 25 issue of Nature.

Kent Wilson, co-author of the paper and director of the laboratory where the experiment was conducted, says the achievement is a promising first step in a development that could produce details of atomic motions in a variety of materials and natural processes.

"What makes this technology promising is that in a relatively short time you may be able to watch in detail how molecules assemble and disassemble during chemical reactions," said Andrea Cavalleri, a paper co-author. "We should be able to time-resolve the motions of single atoms and take pictures of the motions in these elementary chemical reactions."

To achieve the result, the group directed bursts of high-power, high-repetition, laser light, whose duration was 25 millionths of a billionth of a second long (25 femtoseconds), into a gallium arsenide crystal. The bursts heated a thin layer on the surface so rapidly that the atoms didn't have time to move. Like a microscopic sonar gun, the subsequent expansion of this hot, high-pressure layer sent a very fast sound pulse traveling deep into the crystal.

At the same time, the laser was directed onto a copper wire, which produced extremely short duration x-ray pulses. These pulses, arriving at chosen times after the atoms of the crystal started to move, diffracted from the moving atoms, generating a "movie" of the moving sound pulse. This movie shows what the atoms in the crystal are doing with subatomic position accuracy and trillionths of a second time resolution.

"Most of the science behind this is in the x-rays," said co-author Ting Guo, "which are so short in wavelength that they match the interatomic distances in the material. If you tried to monitor the same thing with visible light you couldn't see anything because the light waves are just too big."

"Every freshman chemistry book can tell you that A plus B goes to C, but no one's really directly watched the dynamics of that change happen," said Christopher Barty, co-author and Director of Ultrafast Science at UCSD's Institute for Nonlinear Science. "With our ultrafast x-rays you get direct knowledge about the positions of the atoms during the interaction and you get direct access to the motion."

One of the main reasons the group believes the achievement will have broad appeal is because it was completed with equipment on the scale of a university laboratory, rather than the factory-sized scale of a synchrotron facility. "The equipment takes up less space than a two-car garage and can be built by a few good graduate students," said co-author Craig Siders.

"This has potential across many fields," said Wilson. "In physics this applies to the behavior of solid-state materials, which are at the basis of modern electronics. In chemistry and biochemistry it applies to how atoms move in biologically important processes. And in materials science, it allows us to look inside new kinds of materials to help us design and understand their properties." Besides Wilson and Barty, UCSD authors on the paper include postdoctoral researchers Ting Guo, Craig Siders and Andrea Cavalleri of the Department of Chemistry and Biochemistry and research scientist Jeff Squier of the Electrical and Computer Engineering Department at the Jacobs School of Engineering. Two of the principle experimentalists, Christoph Rose-Petruck and Ralph Jimenez, as well as Ferenc Raksi and Barry Walker, were at UCSD during the time of the experiments but are now at other institutions.

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