VIEW FROM... FRONTIERS IN OPTICS 2009/LASER SCIENCE XXV

X-ray race

The development of new light sources and focusing techniques suggests that ultrafast X-ray microscopy is poised to impact numerous fields of science.

David Pile

Thanks to the advent of compact table-top X-ray lasers, free-electron lasers and next-generation synchrotrons, X-ray imaging is now becoming a powerful tool for unveiling structures and dynamics at spatial and temporal scales previously inaccessible. This was the clear message from two conferences that took place in San Jose, USA, on 11–15 October 2009.

The two meetings — Frontiers in Optics 2009, organized by the Optical Society of America, and Laser Science XXV, organized by the American Physical Society — brought together more than 1,500 attendees from a broad range of disciplines. There were more than 40 company exhibits and 1,000 presentations, with topics including giga-pixel cameras, exawatt lasers and the diet of the prehistoric bear, revealed through laser archaeology.

However, it was arguably the exploitation of X-rays for microscopy and the imaging of chemicals, molecules and atoms that generated the most interest throughout the event. Janos Kirz from the Advanced Light Source at the Lawrence Berkeley National Laboratory, California, kicked off discussions on this topic with a packed plenary session on X-ray microscopy. In particular, he emphasized the emergence of coherent X-ray sources and the new forms of lensless X-ray microscopy that they enable.

"Diffraction microscopy, ptychography and Fourier transform holography have been developed using synchrotron radiation sources, and are making progress. The free-electron lasers such as those in Hamburg (FLASH) and Stanford (LCLS[1]) make it possible to extend some of these techniques to ultrafast imaging, with the promise of imaging before sample radiation damage occurs and — in the case of the LCLS — reaching near-atomic resolution," Kirz told *Nature Photonics*. "In the short term, we at the Advanced Light Source are planning to build COSMIC — a beamline for coherence-based imaging techniques. Beyond that, we intend to develop a high-repetition-rate array of soft X-ray free-electron lasers for studying dynamics."

The race is now on to develop hardware and techniques that can focus the light from these new sources, and thus realize their potential. Gene Ice, from the Oak Ridge National Laboratory in Tennessee, gave a talk on nanoscale X-ray focusing with reflective optics. "Approaches based on traditional ideas such as glancing angle mirror focusing and zone plates have been revived by modern fabrication methods," said Ice.

DAVID PILE

Researchers at the meeting showing off recent results (left: Volker Sorger; right: Rupert Oulton).

New methods such as those involving compound refractive focusing, diffractive imaging and the use of achromatic focusing optics are also being investigated. Ice commented that imaging with precision below 10 nm has now been achieved, and there does not seem to be any fundamental limit preventing subnanometre X-ray science.

The short duration of intense X-ray pulses also offers exciting potential for both single-molecule imaging and structural science. Martin Neilsen, from the Niels Bohr Institute at the University of Copenhagen, spoke about the structural tracking of chemical reactions in solution using time-resolved X-ray scattering. His particular interest is the understanding of structural dynamics at the atomic level and how it translates to functionality in nanomaterials.

"Although optical spectroscopy at softer energies can reveal significant detail about the material and chemical kinetics, structural information can only be obtained by comparing the optical response with pre-calculated spectra of hypothetical intermediate structures," Neilsen explained. "In contrast, using ultrashort pulses of higher-energy X-rays allows key features of the transient molecular structures to be inferred directly from the scattering patterns. This opens the field of ultrafast structural science to the full power of almost 100 years of experience in X-ray structural determination."

Munira Khalil from the University of Washington presented a talk on ultrafast photochemical dynamics in solution. "Recent results from femtosecond X-ray beamlines at the Swiss Light Source and the Advanced Light Source have shown how absorption spectroscopy can be used to measure changes in the local electron density around a particular atom, following a photo-induced ultrafast charge-transfer event," said Khalil.

The increasing capability of LCLS — the world's first hard-X-ray free-electron laser — and the numerous related presentations, were further cause for excitement. According to Steve Johnson from the Swiss Light Source, "the LCLS, along with the already-running FLASH free-electron laser, will offer considerable new opportunities for using X-ray diffraction and spectroscopy to study the ultrafast dynamics of materials on time scales relevant for structural dynamics." To demonstrate that dynamic X-ray microscopy is not only a tool of the future but also has applications in the present, Johnson showed a 3D video of the unit cell dynamics in a crystal of tellurium reconstructed from femtosecond diffraction measurements.

Further developments in ultrafast X-ray microscopy will undoubtedly be revealed at the Frontiers in Optics 2010 and Laser Science XXVI events in Rochester next year, from 24–28 October 2010. ❐

David Pile is at Nature Photonics*, Chiyoda Building, 2-37 Ichigayatamachi, Shinjuku-ku, Tokyo 162-0843, Japan.*
e-mail: d.pile@natureasia.com

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