X-ray vision

The century-old field of X-ray physics is being rejuvenated by new forms of ultrabright sources based on laser technology, promising a revolution in imaging capabilities.

This month *Nature Photonics* presents a special Focus Issue dedicated to the latest advances in X-ray optics, a field that has a long and rich history.

"I have seen my death," exclaimed Anna Röntgen in mid-November, 1895. She had just seen the first ever human X-ray image — a picture of her own hand revealing the bones beneath the flesh. While experimenting on vacuum tube equipment earlier that month, her husband Wilhelm had observed a fluorescent glow from a barium platinocyanide board, which he attributed to a mysterious new type of radiation. He called the discovery 'X-rays', in keeping with the language of mathematics, where 'X' denotes an unknown. Röntgen published the discovery within a matter of weeks[1] and was awarded the Nobel Prize for Physics in 1901. The blossoming research that followed ultimately led to the development of medical radiology and the ability to investigate matter at atomic scales.

So what's new? Well, based on presentations at the recent X-Ray Microscopy 2010 in Chicago, USA, the answer is a lot. The conference was a key gathering for disseminating the latest advances in state-of-the-art high-resolution X-ray imaging techniques. The meeting also covered new X-ray sources, tools for manipulating X-rays and the applications of X-rays in a broad range of fields, including biology, chemistry and materials science.

At the meeting, Janoz Kirz, one of the pioneers of modern X-ray optics, explained that there is much excitement and anticipation regarding the start of experimental programmes that use next-generation X-ray free-electron lasers (FELs). One of the most exciting recent developments is the successful operation of the first next-generation FEL laser — the Linac Coherent Light Source (LCLS) at the Stanford Linear Accelerator Center in the USA — which provides output wavelengths as small as 1 Å. The machine achieves this by accelerating electrons to 99.9999999% of the speed of light and then 'wiggling' them back and forth with astonishing precision through 100 m of alternating magnets. Impressively, the beam position deviates by only about a micrometre over the 100 m path length.

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On page 802 we have an interview with Paul Emma from the LCLS, who gives the inside word on what was involved in making this facility a reality and what we can expect in the future. In a Review on page 814, Brian McNeil and Neil Thompson explain the basics of how an FEL generates intense coherent X-rays and summarize the next-generation facilities around the world that are hot on the heels of the LCLS. Although it may take some time, it is clear that these new X-ray sources will play a significant role in the emergence of new science from the field.

Nearly 20% of the talks at the meeting were on trace-element analysis techniques that use nanoprobes and X-ray fluorescence. New software and hardware (particularly detectors) have sped up data acquisition and analysis rates, resulting in higher resolution and better sensitivity.

"David Paterson's talk was the one that stood out. What is exciting here is the ability to map quantitatively the distribution of trace metals in biomedical samples," Kirz told *Nature Photonics*. "This subject is important in diagnosis and therapy, having to do with toxicology, metal-containing drugs and metal-containing labels. There are of course many other applications to do with environmental samples, botany, archaeology and even intergalactic dust. I see this as a real growth area."

Alan Michette, another prominent figure in the field of X-ray optics who attended the conference, believes coherent diffractive imaging to be one of the most promising techniques. Coherent diffractive imaging has the potential to achieve synchrotron-level resolution in a laboratory setting, using either high-harmonic generation, laser wakefield or various types of plasma sources. This is in stark contrast with the immobile nature of synchrotrons, in which most high-resolution work has been done so far. X-ray imaging schemes generally utilize soft X-rays or high-spatial-resolution hard X-rays, with or without lenses, in a modality that is either coherent or incoherent, diffractive or non-diffractive, and either two- or three-dimensional. This variety of imaging methods, together with the wide range of applications being proposed and tested, is quite staggering.

This Focus Issue also includes two Reviews dedicated to X-ray imaging. Keith Nugent and Henry Chapman summarize lensless coherent imaging on page 833, and Anne Sakdinawat and David Attwood give their view on nanoscale X-ray imaging with a focus on techniques using lens elements on page 840. Lenses at X-ray wavelengths are quite different to what we are used to in the visible spectrum.

Bright and compact sources are bringing high-resolution X-ray imaging applications to conventional laboratory settings. On page 822 of this issue, Tenio Popmintchev and colleagues review the generation of X-rays from compact tabletop systems using nonlinear optics. According to Michette, small sources expand the applications of X-rays into several new areas, including environmental science, health sciences and cultural heritage. In many cases it is more practical to take the source to the object rather than the object to the source — synchrotrons will always have their place, but lack portability.

There is still a lot of work to be done, and some of the most promising avenues are only just opening. Maya Kiskinova pointed out that researchers are pushing forwards with three-dimensional elemental and chemical analysis, *in situ* experiments with functional specimen environments that allow the nanoscale control of parameters such as temperature, pressure and electromagnetic fields, and improving the time resolution and monitoring of ultrafast processes in nanostructures.

References

1. Stanton, A. *Nature* **53**, 274–276 (1896).