Study describes a tabletop source of bright, coherent X-rays

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Producing tightly focused beams of high energy X-rays, to examine everything from molecular structures to the integrity of aircraft wings, could become simpler and cheaper according to new research.

Today, in Nature Physics, researchers from Imperial College London, the University of Michigan and Instituto Superior Téchnico Lisbon describe a tabletop instrument that produces synchrotron X-rays, whose energy and quality rivals that produced by some of the largest X-ray facilities in the world.

Scientific and medical advances often depend on the development of better diagnostic and analytical tools, to enable more and more precise investigations at higher and higher resolutions. The development and use of high energy light sources to probe the details of a wide range of materials for research and commercial purposes is a rapidly growing area of science and engineering. However, high power, high quality X-ray sources are typically very large and very expensive. For example, the Diamond Light Source synchrotron facility in Didcot, UK, is 0.5km in circumference and cost £263M to build.

The researchers behind today's study have demonstrated that they can replicate much of what these huge machines do, but on a tabletop. Their micro-scale system uses a tiny jet of helium gas and a high power laser to produce an ultrashort pencil-thin beam of high energy and spatially coherent X-rays.

"This is a very exciting development," said Dr Stefan Kneip, lead author on the study from the Department of Physics at Imperial College London. "We have taken the first steps to making it much easier and cheaper to produce very high energy, high quality X-rays. Extraordinarily, the inherent properties of our relatively simple system generates, in a few millimetres, a high quality X-ray beam that rivals beams produced from synchrotron sources that are hundreds of metres long. Although our technique will not now directly compete with the few large X-ray sources around the world, for some applications it will enable important measurements which have not been possible until now."

The X-rays produced from the new system have an extremely short pulse length. They also originate from a small point in space, about 1 micron across, which results in a narrow X-ray beam that allows researchers to see fine details in their samples. These qualities are not readily available from other X-ray sources and so the researchers' system could increase access to, or create new opportunities in, advanced X-ray imaging. For example, ultra short pulses allow researchers to measure atomic and molecular interactions that occur on the femtosecond timescale. A femtosecond is one quadrillionth of a second.

Dr Zulfikar Najmudin, the leader of the experimental team from the Department of Physics at Imperial College, added: "We think a system like ours could have many uses. For example, it could eventually increase dramatically the resolution of medical imaging systems using high energy X-rays, as well as enable microscopic cracks in aircraft engines to be observed more easily. It could also be developed for specific scientific applications where the ultrashort pulse of these X-rays could be used by researchers to "freeze" motion on unprecedentedly short timescales ."

To create their new X-ray system, the research team carried out an experiment at the Center for Ultrafast Optical Science at the University of Michigan that is conceptually simple, but required state-of-the-art laser facilities. They shone the very high power laser beam, named HERCULES, into a jet of helium gas to create a tiny column of ionised helium plasma. In this plasma, the laser pulse creates an inner bubble of positively charged helium ions surrounded by a sheath of negatively charged electrons.

Due to this charge separation, the plasma bubble has powerful electric fields that both accelerate some of the electrons in the plasma to form an energetic beam and also make the beam 'wiggle'. As the electron beam wiggles it produces a highly collimated co-propagating X-ray beam which was measured in these experiments.

This process is similar to what happens in other synchrotron sources, but on a microscopic scale. The acceleration and X-ray production happens over less than a centimetre with the whole tabletop X-ray source housed in a vacuum chamber that is approximately 1 metre on each side. This miniaturisation leads to a potentially much cheaper source of high quality X-rays. It also results in the unique properties of these short bright flashes of X-rays.

In the new study, the researchers describe, for the first time, the technical characteristics of the beam and present test images that demonstrate its performance.

Dr Najmudin concluded: "Our technique can now be used to produce detailed X-ray images. We are currently developing our equipment and our understanding of the generation mechanisms so that we can increase the repetition rate of this X-ray source. High power lasers are currently quite difficult to use and expensive, which means we're not yet at a stage when we could make a cheap new X-ray system widely available. However, laser technology is advancing rapidly, so we are optimistic that in a few years there will be reliable and easy to use X-ray sources available that exploit our findings".

More information: www.nature.com/nphys/

Provided by Imperial College London

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