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Future bright for mini synchrotrons

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Colliding a stream of electrons with laser light near an array of tiny silver structures could be the recipe for a new X-ray source that could revolutionize medical imaging and security scanning.

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Technology (SIMTech) and collaborators from MIT, Technion and the University of Mons have devised a simple and compact method of generating X-rays by colliding free electrons with surface waves on a material illuminated by a laser pulse1.

"Based on our theoretical predictions, our lab-scale experiment will be able to generate an X-ray brightness comparable with that used for medical imaging," Wong said.

"With some tweaks, we are optimistic we can reach synchrotron brightness. We're very excited about that."

Synchrotrons are X-ray sources whose radiation is bright enough to allow detailed study of tiny structures such as proteins or complex crystals. However, they are large installations; typically tens of meters in scale that require entire buildings to house them.

Wong and his team envisage a table-top apparatus for their X-ray generators, which rely on the interaction between a laser at wavelengths between infrared and ultraviolet, and electron energies around five mega-electron volts, a regime achievable by current state-of-the-art electron guns.

The arena for the interaction between the laser and the electrons is an array of microscopic silver structures on a glass slide. The laser is directed at the surface at an angle, creating surface waves called plasmon polaritons. The electrons are then shot parallel to the surface into the surface waves, which interact with the free electrons, causing their trajectories to undulate, which generates X-rays.

The up-conversion to X-ray energies is a result of the properties of plasmon polaritons, hybrid particles formed by coupling electrons and photons. These hybrid particles are strongly confined on the surface, which concentrates the intensity. As the spatial dimension is greatly reduced, the polariton's momentum is greatly increased at a given energy, resulting in the conversion from few-eV plasmon polaritons into keV X-rays, using MeV electron energies.

"It's an electrodynamical process that no one had predicted," Wong said.

The team explored a range of configurations for the metamaterial, with groups of structures ranging in size and spacing from 5 nanometers to 26 nanometers and spaced regularly around 90 nanometers apart.

The results showed it was possible to control the spatial and temporal characteristics of the X-rays by changing parameters such as the geometry of the metasurface, or the shape of the electron wave-packets. The ability to control the beam features is a huge benefit because X-rays are challenging to focus and steer: they tend to pass through most materials without interacting.

As an example, Wong points out that with the right configuration, highly directional X-rays that are in step (coherent) can be generated. "For coherent output, you need to make sure your electron wave-packet is properly shaped," Wong says.

Generating coherent X-rays gives the process a big advantage over conventional medical imaging because it allows phase contrast imaging, a technique that can give higher contrast than the absorption processes that form conventional X-ray scans.

The team developed software to make ab initio calculations using classical electromagnetic theory, and then cross-checked them with a second approach based on quantum electrodynamics. They found excellent agreement between the two approaches, which has given them confidence to take the next step.

Wong and his co-workers now plan to conduct proof of principle experiments with the new X-ray source.

"If we do manage to scale up, the impact will be quite revolutionary. Instead of just having a few synchrotrons to use, you can put a high-brightness X-ray source in every lab and hospital," he says.

More information: Gilles Rosolen et al. Metasurface-based multi-harmonic free-electron light source, *Light: Science & Applications* (2018). [DOI: 10.1038/s41377-018-0065-2](https://dx.doi.org/10.1038/s41377-018-0065-2)

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