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Compact X-ray Laser

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Editorial Note

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EDITORIAL NOTE

Light sources referred to as free-electron lasers can produce intense X-ray radiation for a good range of applications. The method usually needs huge particle accelerators, but an experiment shows the way to overcome this limitation. The arrival of latest tools for investigating our world has always led to discoveries. Light sources called Free-Electron Lasers (FELs) are samples of such tools. FELs can produce radiation during a broad array of wavelengths, including the extreme-ultraviolet and X-ray ranges, and may generate ultrashort pulses, at femtosecond (10^{-15} s) or maybe attosecond (10^{-18} s) timescales. At these spatial and temporal scales, there's little difference between biology, chemistry and physics, and FELs have revolutionized all three disciplines. FELs have enabled interest be frozen in situ and observed at the microscopic level, allowing scientists to resolve the motion of atoms or electrons, control chemical reactions and follow the dynamics of chemical bonds or energy-transfer processes. FELs generate radiation from a high-energy beam traversing an undulator, an extended array of magnets of alternating polarity.

Energy is efficiently transferred from the beam to the laser light if the beam features a high-enough current and is sufficiently monochromatic that is, if the electrons have similar energies, follow similar trajectories and emit light with similar properties. When such a high-brightness beam interacts with the electromagnetic field of the sunshine generated inside the undulator, the beam transfers a part of its kinetic energy to the laser light. As a result, the light is amplified by several orders of magnitude while propagating through the undulator. FELs therefore require high-energy and high-brightness electron beams to get intense laser light at short wavelengths, like extreme-ultraviolet or X-ray wavelengths.

Electron beams are normally accelerated by injecting the electrons into an extended sequence of hollow metal structures called resonant cavities, where the particles progressively gain energy by ‘surfing’ an electromagnetic radiation. The ultimate energy depends on the amplitude of the wave (that is, the strength of the accelerating field) and therefore the length of the accelerator. Present technology limits the sector strength in accelerating cavities to a couple of tens of megavolts per metre. Therefore, an accelerator several hundred metres to a couple of kilometres long is required to succeed in the beam energy of several Giga Electron Volts (GeV) needed by an X-ray FEL. High-energy electron beams therefore tend to be available only at large accelerator facilities, limiting the amount of scientists who can access FELs or advanced investigation tools needing high-energy electrons.

This restriction is one among the motivations behind the look for other ways of manufacturing strong accelerating fields to scale back the footprint and costs related to accelerators. One promising idea involves exciting an electromagnetic radiation during plasma an ionized gas-using the high power density of optical lasers. Accelerating fields that are thousands of times stronger than those in conventional accelerating cavities are often generated during plasma. With such fields, the electron-beam energy required by an X-ray FEL might be reached during a few tens of centimeters rather than a couple of kilometres.

Plasma waves are often excited by a laser pulse or the beam itself. Indeed, it's possible to shape the beam current in such how that one a part of the beam excites the wave, which then accelerates a second a part of an equivalent beam. Both approaches were explored previously, and massive field strengths, almost like those predicted, were demonstrate. But one among the missing ingredients to drive FELs successfully using these beams concerned the beam quality. Specifically, the energy difference between the electrons was overlarge and therefore the emitted radiation behaved as if generated by randomly distributed electrons, instead of by electrons bunched into regions about the dimensions of the radiation wavelength, that the sunshine amplification is several orders of magnitude larger. Various teams are concentrating on finding the conditions for stable and reliable acceleration of a beam that's sufficiently monochromatic for FEL amplification.