Understanding laser-accelerated electron radiation through terahertz emissions

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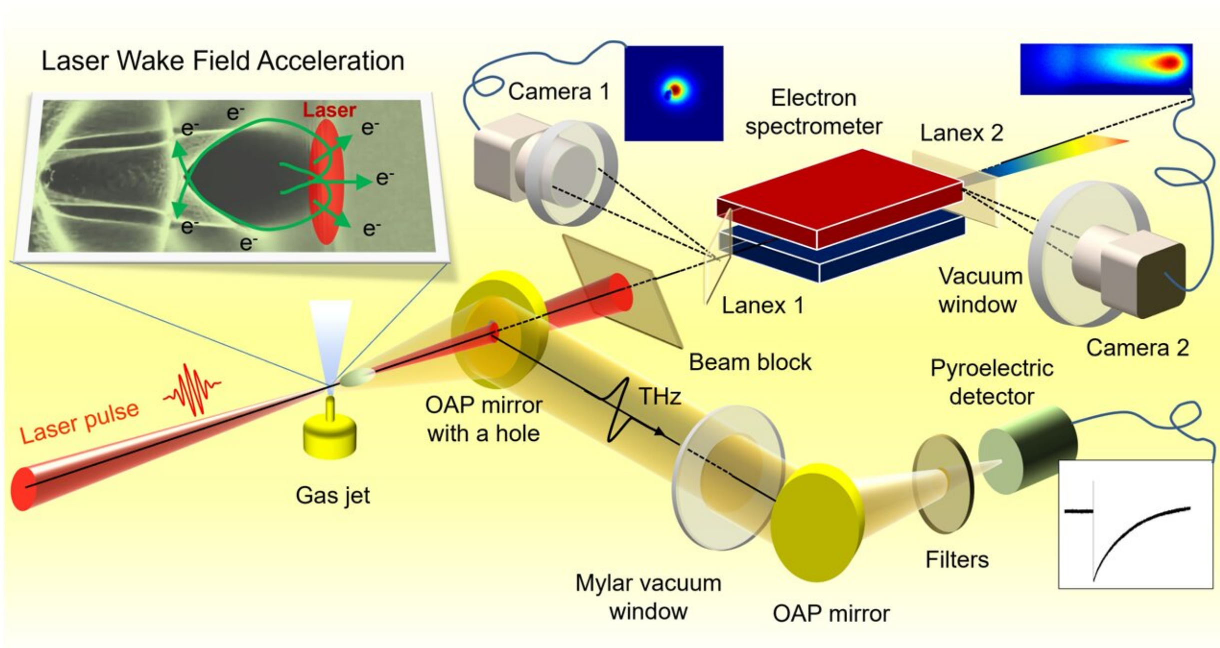

The accelerating electrons radiate coherent THz emissions continuously along the laser propagation direction, resulting in broadband multi-mJ THz radiation in the far field. Credit: Taegyu Pak, Mohammad Rezaei-Pandari, Sang Beom Kim, Geonwoo Lee, Dae Hee Wi, Calin Ioan Hojbota, Mohammad Mirzaie, Hyeongmun Kim, Jae Hee Sung, Seong Ku Lee, Chul Kang and Ki-Yong Kim

The terahertz (THz) gap, a frequency band lying between the microwave and infrared regions of the electromagnetic spectrum where conventional technologies are inefficient in generating and detecting the radiation, is being rapidly closed by development of new THz sources and detectors. Laser-based THz sources are of great interest due to their capability to produce coherent, single-cycle-to-multicycle, broadband (or narrowband) radiation.

Such sources can also provide natural synchronization with the driving laser, allowing ultrafast time-resolved spectroscopy and imaging. Recently, high-power femtosecond lasers have been used to produce strong THz radiation, as well as to explore novel THz-driven phenomena such as molecular alignment, harmonic generation, and electron acceleration.

In a new paper published in *Light: Science & Applications*, a team of scientists led by Professor Ki-Yong Kim from the University of Maryland, College Park, also affiliated with Gwangju Institute of Science and Technology and the Institute for Basic Science, Korea, have developed a new model for high-power terahertz emissions from laser pulses.

Among many laser-based sources, laser-plasma-based ones are well suited for high-power THz generation. Plasmas are already ionized and thus can sustain high electromagnetic fields, with little or no concern about material damage when high-power laser pulses are focused into a small volume for energy-scalable THz generation. Since the pioneering work by Hamster et al, coherent THz generation from laser-produced gaseous and solid-density plasmas has been extensively investigated.

In gases, single- or two-color laser-produced plasmas can generate coherent broadband THz radiation by ultrafast laser-driven currents. In two-color laser mixing, the laser-to-THz conversion efficiency increased up to the percent level by using mid-infrared laser drivers. High-energy THz radiation was also observed from laser-irradiated, high-density plasma targets based on liquids and solids. Recently, tens of mJ of THz energy was observed from a metal foil irradiated by high-energy (~60 J) picosecond laser pulses. Unlike gas targets, high-density ones, however, often pose target debris and target reloading issues, which makes them unfavorable for use in continuous or high-repetition-rate (>kHz) operation.

Laser-wakefield acceleration (LWFA), a gaseous plasma-based compact electron accelerator scheme, is another source of broadband electromagnetic radiation. A relativistic electron bunch produced in LWFA can emit THz radiation when it exits the plasma-vacuum boundary by coherent transition radiation (CTR). This occurs when the bunch length size becomes compared to or less than the wavelength of the emitted THz radiation, and the THz fields produced by individual electrons coherently add up in the radiation direction.

The research team observed multi-mJ THz emission from 100-TW-laser-driven LWFA with an energy conversion efficiency of 0.15%. The emitted THz radiation is radially polarized and broadband, possibly extending beyond 10 THz. The correlation between the electron beam properties (energy and charge) and THz output energy shows that high-energy (>150 MeV) electrons do not necessarily yield high-power terahertz radiation. Instead, low-energy but high-charge electrons can produce much stronger terahertz radiation.

To explain this interesting result together with multi-mJ THz generation, the research team have proposed a coherent radiation model, in which the electrons accelerated by the laser ponderomotive force and subsequent plasma wakefields radiates broadband emission continuously along the laser propagation direction, ultimately resulting in phase-matched conical THz radiation in the far field. This model, however, needs to be verified or examined by more follow-up experiments and analytic/numerical studies in order to have a full understanding of THz generation in LWFA, as well as to optimize the source for future high-power THz applications.

More information: Taegyu Pak et al, Multi-millijoule terahertz emission from laser-wakefield-accelerated electrons, *Light: Science & Applications* (2023). DOI: 10.1038/s41377-022-01068-0

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