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Preface to Special Topic: Intense terahertz sources for time-resolved studies of matter

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Terahertz (THz) radiation lies in a unique band between the radio and optical frequencies. This band in the electromagnetic spectrum has been known as the "THz gap," which is difficult to operate due to the challenges of generation, detection, and manipulation of radiation at THz frequencies. One of the main research directions is in the development of reliable and efficient THz sources. Tremendous progress has been made in the last two decades in this area, with new sources such as quantum cascade lasers, photoconductive emitters, backward wave oscillators, and optical rectification of femtosecond laser pulses. These sources have led to broad applications in information technology, materials science, chemical sensing and identification, biological and medical imaging, and homeland security, where the THz wave is mainly used as a probe.

Beyond the generation of weak THz radiation to probe materials, it has been a long-standing goal to utilize THz radiation to control materials. The emergence of intense THz sources has opened opportunities for selective excitation of low-energy collective modes in correlated materials and control of materials through field manipulation of electronic, atomic, and spin degrees of freedom. For example, a narrowband THz wave can directly excite low-energy modes in complex materials, including phonons, polarons, magnons, plasmons, spin resonances, charge orders, and superconducting gaps, while a broadband THz wave can apply an electric field in a few hundreds of femtoseconds without contacts, suitable for manipulating field-driven phenomena at ultrafast speed.

To investigate the optimized scheme for time-resolved studies of matter, particularly in tandem with accelerator-based x-ray sources, we invited leading scientists from around the world to a THz workshop on July 30–31, 2012, at Argonne National Laboratory to discuss cutting-edge THz sources and their applications (http://www.aps.anl.gov/Accelerator_Systems_Division/THz_workshop/). The workshop started with the presentation of new science enabled by the intense THz fields and was followed by discussion of two mainstream technologies utilized to generate intense THz waves.

Accelerator-based THz sources rely on coherent radiation of electrons that may be produced via: (1) transition radiation generated by passing the electron bunch through a metal foil, (2) synchrotron radiation from a bending magnet or undulator, (3) Čerenkov radiation produced by the electron bunch transiting a hollow dielectric pipe, (4) diffraction radiation where the electron bunch passes near to a metal or dielectric, and (5) Smith-Purcell radiation produced by the electron bunch passing over a diffraction grating. All these options require either an ultra-short electron bunch or an electron bunch whose longitudinal density is modulated at the THz frequency. Various methods for obtaining such bunches were briefly discussed during the workshop. These techniques have gained popularity with the development of a variety of accelerators dedicated for photon science and usually offer higher THz peak fields that are naturally synchronized with accelerator-generated radiation such as x-ray pulses.

Ultrafast-laser-based THz sources rely on converting optical photons to THz frequency through nonlinear interaction of ultrafast laser pulses with gaseous or solid materials. Three recently developed techniques were discussed: (1) THz generation through two-color laser-induced plasma in air; (2) optical rectification in $LiNbO_3$ crystal via pulse-front-tilt technique; and (3) differential frequency generation from phase-locked mid-IR radiation. These techniques specialize in generating ultrabroadband, high-peak field, and tunable THz waves, respectively, which have been widely used in nonlinear THz spectroscopy and for the study of field-driven nonequilibrium physics. Compared to accelerator-based techniques, the laser-based THz sources stand out thanks to their high conversion efficiency, compactness, and convenience without radiation hazard.

In this special issue, we present six papers that concentrate on the accelerator-based THz sources in the context of widely reported ultrafast-laser-based THz sources. We hope this special issue will fill the gap and report technical details on the design, implementation, and characterization of accelerator-based THz sources.

All of the papers were peer reviewed according to the journal's standards for Articles, as described in the General Editorial Policies, available online at http://rsi.aip.org/rsi/policy.jsp. The co-organizers would like to thank all of the contributors and attendees to the THz workshop at Argonne. Special thanks are paid to Albert Macrander and Lynn Purdy, as well as the entire staff at *Review of Scientific Instruments* for their assistance in putting this Special Topic together.

