Advanced Nonlinear THz Spectroscopies at the TeraFERMI Beamline

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Abstract: TeraFERMI is a THz beamline delivering high fields for nonlinear spectroscopy. We review existing set-ups and introduce new single-shot diagnostics enabling pulse-resolved studies.

TeraFERMI is the dedicated THz beamline of the FERMI Free-Electron-Laser facility [1], delivering broadband ultrashort pulses with peak electric fields exceeding 5 MV/cm and magnetic fields in the Tesla range. These extreme field strengths enable access to nonlinear THz spectroscopy and a wide variety of strong-field pump–probe experiments. The beamline supports multiple experimental configurations, including fluence-dependent THz spectroscopy [2,3], THz-pump/THz-probe, and THz-pump/IR-probe [4] schemes. More recently, its capabilities have been expanded to include THz-pump/SHG-probe and THz-pump/supercontinuum-probe methodologies, further broadening the range of accessible light–matter interaction regimes.

Current developments at TeraFERMI focus on the implementation of single-shot spectroscopy techniques. This diagnostic approach retrieves THz electric-field waveforms on a single-pulse basis by exploiting polarization diversity in electro-optic crystals [5]. An earlier prototype of this instrument was successfully tested at TeraFERMI [6]; it is now being deployed as a permanent installation, enabling real-time monitoring and analysis of THz waveforms. Single-shot detection is especially advantageous for investigating nonlinear processes such as THz harmonics generation, where FEL-based THz sources exhibit significant shot-to-shot variations in pulse energy and spectral content. Conventional averaging can obscure essential non-perturbative features, whereas single-shot measurements provide a statistical ensemble from which scaling laws, fluctuation-driven behavior, and strong-field responses can be extracted more efficiently.These advances position TeraFERMI as a versatile platform for exploring emergent regimes of ultrafast, non-perturbative THz light–matter interactions in quantum materials.

Fig.1 | Overview of the TeraFERMI laboratory

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