Terahertz subcycle quantum control:
From high-harmonics generation to vacuum fluctuations

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Terahertz (THz) spectroscopy has opened up exciting new chapters in ultrafast condensed matter physics. Phase-locked, single-cycle THz waveforms are uniquely suited to control the quantum motion of electrons and spins, while the resulting field dynamics can be traced on subcycle time scales. Here, we dive into some of the recent developments in THz solid-state strong-field nonlinear spectroscopy.

We discuss how lightwave acceleration of charges by atomically strong multi-THz pulses leads to dynamical Bloch oscillations and all-coherent charge transport throughout the entire Brillouin zone of a conventional semiconductor. Moreover, we show that Dirac fermions of topological surface states of Bi_2Te_3 support inertia-free, ballistic subcycle currents with coherent electron transport across distances that largely exceed typical gate widths of transistors, moving lightwave-electronic devices into practical reach. This subcycle temporal resolution is furthermore extended by subwavelength control of electromagnetic fields in custom-cut metallic microresonator structures. Here, light-matter interaction can be tailored on length scales far below the far-field diffraction limit. With this powerful concept, we implement minimally dissipative, ballistic spin switching in antiferromagnets and observe carrier-wave Rabi flopping of electronic excitations as well as high-order nonlinearities, by two-dimensional spectroscopy. Ultimately, in THz cavity quantum electrodynamics, light-matter coupled structures explore a novel limit where the vacuum Rabi frequency – the rate of spontaneous emission and reabsorption of photons – far exceeds the carrier frequency of light itself.