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# Ultrafast strong THz-field effects in semiconductors

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## Extended Abstract

Present-day high-power terahertz (THz) sources can output field strengths comparable to those created by atomic-scale potentials of solids. Such sources can dynamically create ultrafast charge-carrier acceleration and ballistic electron transport in a semiconductor. Controlling these processes could eventually yield both high-speed electronics and novel light sources, adjustable from THz up to extreme ultraviolet spectral range.

Microscopically, a strong THz field nonresonantly excites polarization between valence and conduction bands, which eventually excites also charge carriers. For strong enough electric fields, this process becomes macroscopic even though a THz photon energy is typically much smaller than semiconductor's bandgap. At the same time, a THz bias simultaneously accelerates electrons and holes as well as polarization to high-momentum states within the bands. The resulting charge currents are strongly coupled with the interband polarization, and their interplay leads to the emission of a high-harmonic (HH) frequency comb [1].

We outline a quantum-mechanical theory based on the semiconductor Bloch equations[2] to systematically describe nonperturbative interplay between intra- and inter-band excitations. We will illustrate its predictive capabilities by extensive theory–experiment comparisons [3]. Surprisingly, the HH spectrum of GaSe can exhibit resonances at *even* multiples of the driving frequency, besides the expected odd ones. We demonstrate that the even harmonics stem from a nonperturbative electronic quantum interference which can only occur in crystal directions where the inversion symmetry is broken. Simultaneously, we find evidence of dynamical Bloch oscillations in the carrier–polarization dynamics during the excitation. Time-resolved studies reveal a fascinating unipolar emission characteristics of HH intensity in GaSe where emission dominantly occurs at positive field crests of the driving waveform. We explain this unipolar emission with the same quantum interference that also creates the even harmonic orders, and demonstrate that it is robust against changes in THz frequency and field strength [4].

Light and particle emission from particle collisions carries detailed information about atomic species involved. This concept can be transferred to semiconductors by combining optical and THz excitations. The optical pulse creates electron–hole coherences, while the constituent electrons and holes are subsequently accelerated and collided by a strong THz field, which results in the emission of high-order sidebands. We discuss how the sideband radiation reveals structural details of the colliding quasiparticles and provides insights into e.g. dephasing times and mechanisms or the exciton binding energy [5], which introduces the concept of a quasiparticle collider.

## References

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