Ultra-intense THz source
and extreme THz nonlinearities in condensed matter

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Few-cycle light pulses in the terahertz (THz) spectral domain have evolved into an invaluable probe of low-energy excitations in condensed matter [1]. Novel challenges such as nonlinear THz optics, coherent control, or high-harmonics generation call for enhanced electric field amplitudes. We introduce a new hybrid laser source combining the stability and versatility of a multi-branch Er:fiber seed laser with the high power levels attainable with a Ti:sapphire amplifier. The system provides phase-locked transients tunable from 1 THz to beyond 100 THz with energies of up to 19 μJ and peak fields of 108 MV/cm [2]. These values exceed current records by several orders of magnitude. Amplitude and phase information is gained via electro-optic sampling with 8-fs pulses from a numerically optimized nonlinear bulk fiber integrated in the Er:system [3] [see Fig. 1(a)].

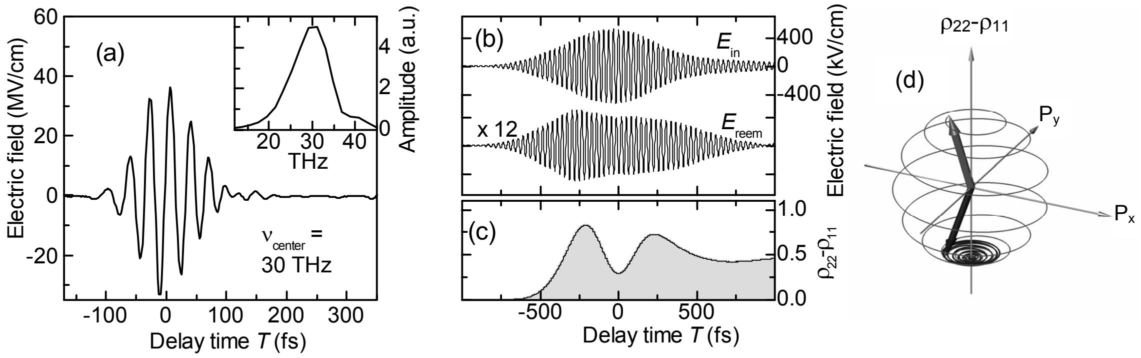

Fig. 1 (a) Electro-optically detected typical high-field THz transient generated by the novel hybrid Er:fiber/Ti:sapphire laser system. Insert: Amplitude spectrum. (b) THz transient resonantly driving the atom-like internal 1s-2p transition of paraexcitons in Cu_2O (upper curve). The reemitted field (lower curve) exhibits a non-monotonous envelope characteristic of up to two internal Rabi cycles. (c) A microscopic theory confirms an oscillatory change of the population inversion of the 1s-2p two-level system. (d) Schematic of the Bloch sphere of the 1s-2p intra-excitonic two-level system.

We will summarize latest advances in THz optoelectronics and exploit this technology for two studies of THz nonlinearities going beyond the perturbative regime:

(i) Intense multi-terahertz fields of the order of MV/cm are used to coherently promote optically dark and dense 1s para excitons in the semiconductor Cu_2O into the 2p state [Fig. 1(b)]. The nonlinear field response of the intra-excitonic degrees of freedom is directly monitored in the time domain via ultrabroadband electro-optic sampling. Up to two internal Rabi cycles are identified in accord with a microscopic many-body theory [Fig. 1(c), (d)][4,5]. The results point out a promising route for preparing ultracold exciton gases which may be relevant for potential solid state Bose-Einstein condensation.

(ii) In a second example, we employ a semiconductor microcavity to switch on ultrastrong vacuum Rabi splitting on a femtosecond scale without an external driving field [6]. Intersubband cavity polaritons in a quantum well waveguide structure are photogenerated by 12-fs near-infrared pulses. Multi-THz transients trace a novel nonlinear optical phenomenon: the conversion of bare photons into cavity polaritons. Our structure represents the first sub-cycle switching device of strong and ultrastrong light-matter coupling and paves the way towards unprecedented quantum optical phenomena, such as the release of Casimir-type vacuum radiation [7].

References

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