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Contactless terahertz probes of correlations and dynamics in low-dimensional electron-hole gases

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Confinement of carriers in nanostructures entails strong modifications of their physical properties, offering a well-defined laboratory for investigating the complex many-body interactions between charge, lattice and spin degrees of freedom [1]. In particular, electron-hole (*e*-*h*) gases photoexcited into low-dimensional semiconductors are characterized by new optical transitions and strongly enhanced Coulomb interactions. Terahertz radiation offers a unique tool to measure low-energy excitations and transport properties in nanostructures without the need for an electrical contact. Along this path, we have recently developed a new, sensitive scheme to probe time-varying Coulomb correlations in confined carrier plasmas.

Here, we discuss experiments that utilize this pulsed terahertz source to probe the dynamical interplay of bound and unbound *e*-*h* pairs on a picosecond timescale [2]. A new low-energy oscillator is observed directly after resonant creation of heavy-hole excitons in GaAs quantum wells. This peak arises from transitions between the hydrogen-like exciton bound states, most notably the 1s-2p level transition. The terahertz field probes excitons in a large range of in-plane momenta K in contrast to the usual restriction of interband probes close to K ~ 0. Owing to the strongly correlated motion of electrons and holes, charge-neutral excitons are electrically insulating up to a frequency that matches the separation between their lowest internal states. Above-bandgap excitation at elevated temperatures however induces unbound *e*-*h* pairs which represent a conducting ionized gas with a Drude-like response.

The distinct responses of these extreme phases enable us to follow in time a metal-insulator transition that occurs upon formation of excitons out of a gas of unbound *e*-*h* pairs, as well as its reverse process of ionization. These are dynamical transitions which occur on different timescales. Ionization of excitons can occur within only a few picoseconds, and depends on the phonon occupation. Exciton formation is a more complex process with several timescales involved: the first is the surprising, quasi-instantaneous appearance of an excitonic peak in an otherwise conducting state after excitation of unbound pairs. On a much longer timescale of several 100 ps, this complex mixture evolves into an insulating exciton gas. Our results demonstrate the suitability of terahertz pulses as a contactless measure of correlations and dynamics, motivating their use for studies of fundamental processes in novel nanoscale materials.

[1] D. S. Chemla and J. Shah, Nature **411**, 549 (2001) and references therein.
[2] R. A. Kaindl, *et al* Nature **423**, 734 (2003).

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