INVITED

Strong-field THz spectroscopy of low-dimensional semiconductor systems

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Many low-energy excitations in solids fall into the meV or THz range. Whereas linear spectroscopy is a valuable tool to obtain information on the linear response of these excitations, recent progress in THz sources also enables one to access their nonlinear and time-resolved behavior. To this end we use a free-electron laser to study intraexcitonic transitions in quantum wells and carrier dynamics in graphene.

Excitons possess a hydrogen-like internal excitation spectrum with a characteristic energy scale in the THz range. We pump the 1s-2p intraexcitonic transition in GaAs and InGaAs multiquantum wells with a THz free-electron laser and probe the induced changes in the absorption spectrum via interband absorption using a near-infrared femtosecond laser. We observe a splitting of the 1s exciton line, which can be explained by the Autler-Townes or AC Stark effect [1]. The behavior is, however, much more complex than for an ideal two-level system. Since for electric fields in the 10 kV/cm range the Rabi energy is of the same order of magnitude as the 1s-2p transition energy, we are in fact clearly beyond the validity of the rotating wave approximation. At the highest fields, when also the ponderomotive energy ($e^2F^2/4m\omega^2$) approaches the exciton binding energy, signatures of exciton field ionization are observed.

In graphene with its vanishing bandgap, interband excitations extend down to very low frequencies, where they compete with the free-carrier (intraband) absorption in lightly doped graphene (E_F ~13 meV). We have performed THz pump-probe experiments on multilayer graphene over a wide range of photon energies (10-250 meV) to investigate the carrier dynamics. Interestingly we observe a crossover from induced transmission (bleaching) for $\hbar\omega > 2E_F$ to induced absorption for $\hbar\omega < 2E_F$. At these photon energies interband transitions are initially blocked, but become possible after intraband free-carrier absorption and heating [2]. In a magnetic field the bands split up into non-equidistant Landau levels, which can be pumped and probed selectively. Using left- and right-circularly polarized light reveals some surprising behavior related to the importance of Auger scattering.

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