Ultrafast photoinduced above-bandgap transparency in GaAs due to the Dynamic Franz-Keldysh effect

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Abstract: We report the dynamic Franz-Keldysh effect in bulk GaAs. Ultrafast changes in transmission spectra near the band edge, including the first observation of photoinduced transparency as large as 40%, are observed.

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Intense ac fields can coherently and strongly modify the optical properties of semiconductors. One such example is the dynamic Franz-Keldysh effect (DFKE), in which the absorption coefficient becomes finite for photon energies below the band gap and shows spectral modulations for energies above the band gap [1]. Intense long-wavelength laser fields are ideal for this purpose since they can minimize the interband absorption and sample damage while maximizing the ponderomotive potential (quiver energy) [2,3]. Here we report an unambiguous observation of both these features in GaAs at room temperature pumped by an intense mid-infrared (MIR) laser field. The induced above-bandgap transparency, which exists only during the pulse width of the pump field, represents a new type of coherent phenomenon, different from electromagnetically-induced transparency or self-induced transparency.

Our MIR source was an optical parametric amplifier pumped by a chirped pulse amplifier (CPA) (Model CPA-2010, Clark-MXR, Inc.). The system produced tunable, intense radiation from 522 nm to 20 μm using different mixing crystals. We measured the transmission near the band edge of GaAs samples (bulk and film) using broadband white light as a probe. The white light was produced by continuum generation in a sapphire plate, using a fraction of the CPA beam (775 nm). The broadband probe was temporally overlapped with the MIR pump by changing the time delay of the MIR pump relative to the probe.

Shown in Fig. 1 are near-band-edge transmission spectra for a bulk GaAs sample taken for driving fields of different wavelengths. We observe a dramatic decrease in transmission below the band edge (1.4 eV), similar to what was observed in [3]. Note that the effect *increases* with increasing wavelength *despite the fact that the laser intensity drops more than 10 times from 4.7 μm to 9 μm*, demonstrating the importance of the ponderomotive potential, which increases quadratically with wavelength but only linearly with intensity. This unusual aspect of DFKE distinguishes itself from ordinary nonlinear optical processes. In Fig. 2, the transmission spectra for the GaAs film sample (2 μm thick), under identical conditions, show *oscillations above the band gap* along with a decrease below the band gap. The observed photoinduced transparency of up to 40%, just above the band gap, is predicted by theory and is interpreted as being a manifestation of the DFKE [1]. This, to our knowledge, is the first observation of such a large photoinduced transparency in solids. These modifications in the band structure occur only in the presence of the intense MIR pump, demonstrating the virtual nature of the effect, i.e., no MIR excitation of carriers across the band gap and/or lattice-heating effects are involved. We will present detailed power-dependence and pump-wavelength data together with detailed comparison with existing theories.

In addition to the scientific interest, our results may find applications in the field of ultrafast all-optical switching and modulation. As electronics and photonics approach THz frequencies from both sides, nonlinear opto-electronic effects such as DFKE will become increasingly important.

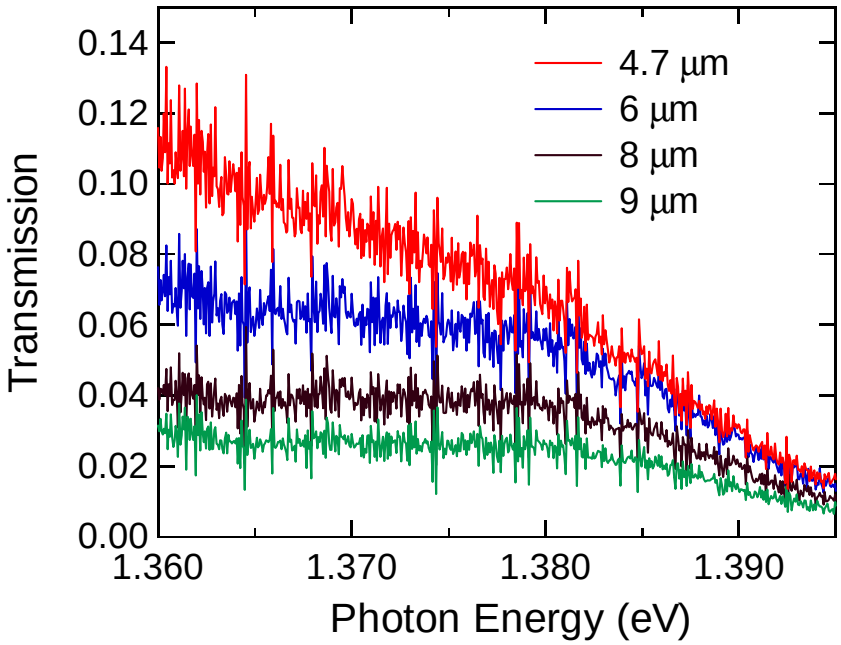

Fig. 1. Near-band-edge transmission spectra for GaAs bulk sample under MIR excitation at four different wavelengths. Note that the intensity of the MIR pump decreases with increasing wavelength while the induced sub-bandgap absorption *increases* with increasing wavelength, indicating the importance of the ponderomotive potential.

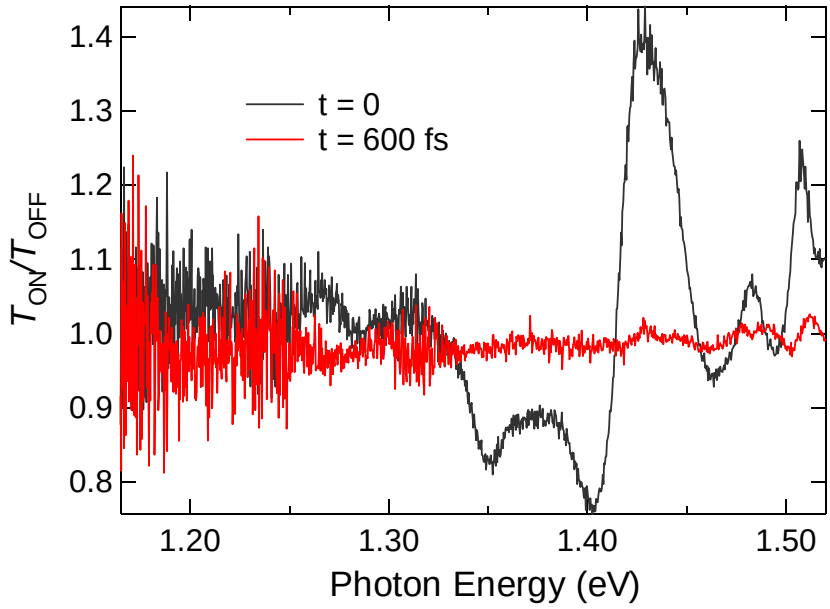

Fig. 2. Near-band-edge transmission spectra for GaAs film sample (2 μm thick). Significant induced spectral modulation occurs during the temporal overlap between the pump and probe. Note the photoinduced *transparency* around 1.43 eV.

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