Observation of quasi-ballistic THz-oscillations in GaAs potential wells detected via two color fs-pump & probe spectroscopy

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High-field electron transport in GaAs is usually dominated and limited by (extremely efficient) intervalley scattering processes: Accelerated electrons that gain kinetic energies above threshold energy for phonon assisted side valley transfer, undergo a strong deceleration on a fs-timescale[1,2]. Mobility in the sidevalleys is limited by high effective masses and high scattering rates. But what happens if electrons (besides high electric fields) just can not gain enough energy? In this contribution we will theoretically and experimentally show that electrons in suitably designed confining potentials will perform several classical, quasi-ballistic THz-oscillations.

The confining potentials are predominantly space charge potentials consisting of either (V-shaped) p^+-i-δn-i-p^+ (see Fig. 1) or (parabola-shaped) p^+-n-p^+ AlGaAs heterostructures (see Fig. 3). In both cases the density of ionized donors controls the well depth and, therefore, the maximum kinetic energy of the electrons. 80-fs laser pulses (wavelength adapted to the GaAs bandgap) generate an electron hole plasma on the left side of the potential. While the holes experience no driving field, the electrons are accelerated by the combined space–charge- and grading pseudo- field. The (stationary) holes and moving electrons build up a dynamic dipole which screens the internal electric field in between. This field screening is monitored via modified Franz-Keldysh absorption with a second, 20 fs laser pulse (wavelength adapted to the AlGaAs bandgap).

For theoretical our investigations we use a realistic ensemble Monte-Carlo simulation which takes into account all relevant scattering mechanisms, all dependences on temperature and Al-content and the dynamics of the carrier generation. The field screening originating from the electron and hole ensemble is directly calculated using the results of the simulations.

As long as the available kinetic energy is above threshold for intervalley scattering, no oscillations are expected from theory nor are they detected in experiment. If the

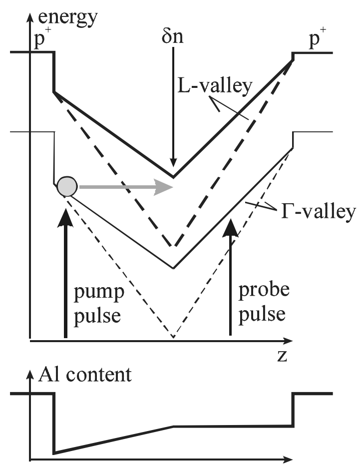

Fig. 1: Schematic bandstructure of a confining potential that allows intervalley scattering (dashed line) and one where intervalley scattering is energetically prohibited (solid line). The Al-grading (bottom) allows for spatial selective carrier generation with fs-laser pulses.

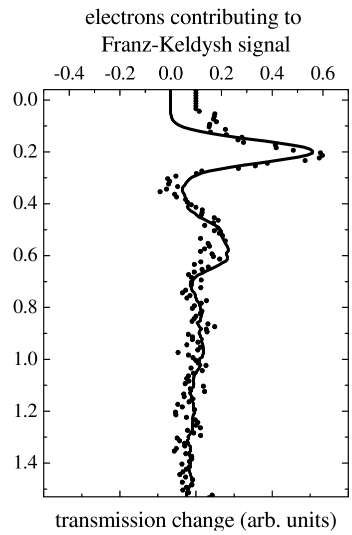

Fig. 2: Measured transmission changes (dots) together with the calculated number of electrons that contribute to the field screening (solid line).

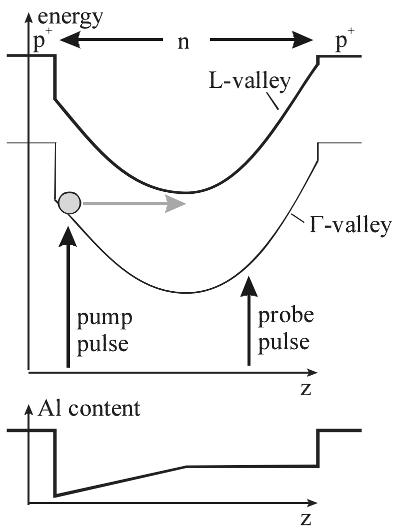

Fig. 3: Schematic bandstructure of a parabolic well. The potential is realized by homogeneous (depleted) n-doping in the whole well. Again an Al-grading is incorporated for carrier generation reasons.

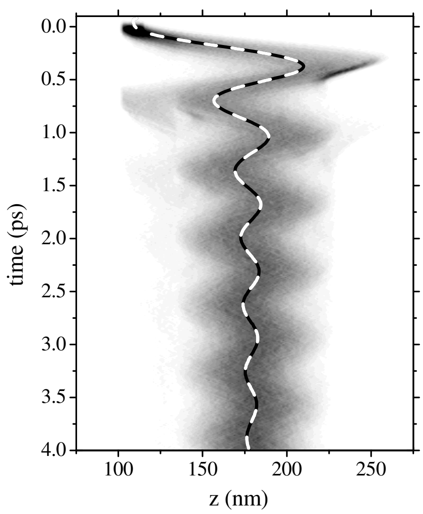

Fig. 4: Calculated electron distribution in the parabolic potential well on the left.

n-doping is chosen in a way that the well depth is just below threshold, the result changes dramatically: According to the simulations, the electrons perform several classical, quasi ballistic, THz- real-space oscillations. Although the electric field is in the range of 50 kV/cm, the electron ensemble moves as a coherent package and reaches drift velocities as high as $5 \cdot 10^7$ cm/s. The duration of the oscillations are limited by the quite fast energy dissipation due to polar optical phonon emission. This process strongly favors small momentum transfer ($1/q$-dependence of the Fröhlich matrix element) and therefore hardly affects the coherence of the oscillating electron ensemble.

These coherent electron oscillations have, in fact, been detected in our fs pump & probe experiments. Fig. 2 shows the measured transmission changes of a V-shaped potential well (p^+-i-δn-p^+ heterostructure) together with the calculated number of electrons contributing to the Franz Keldysh absorption. Here the anharmonicity of the potential still leads to some incoherence. Improved coherence is expected and detected for parabolic (p^+-n-p^+) potentials (see Fig.s 3-5), as the (classical) oscillation frequency becomes independent on the energy. Different parabolic potentials have been examined and the detected frequencies in the transmission changes are in good agreement with the calculations (Fig. 5).

In summary, using suitable confining potentials we have detected a drastic change in the transport properties of electrons in GaAs. In potentials where intervalley scattering is prohibited, electrons perform several THz- real-space oscillations instead of exhibiting a "classical" pure-relaxation trajectory. Different potentials (with and without intervalley scattering) have been investigated and the measurements are in good agreement with the theory.

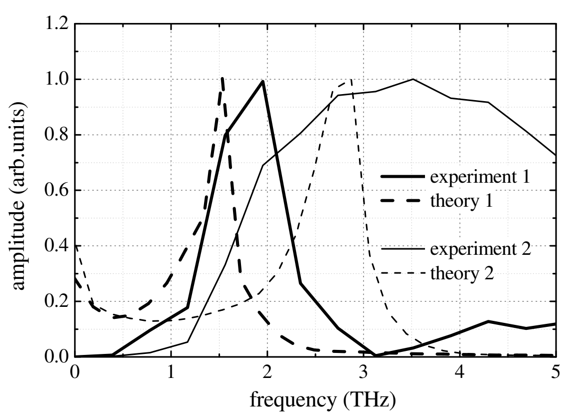

Fig. 5: Frequencies of the transmission changes of two different parabolic wells together with the frequencies extracted from the simulations.

[1] A. Leitenstorfer et al., Physica B 272, 348 (1999)
[2] A. Schwanhäußer et al., Physica B 314, 273 (2002)