with respect to the open surface of the grating and in this way determines the starting direction of the oscillations.

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QWN4 5:30 pm

Driving a harmonic quantum oscillator with few-cycle THz pulses

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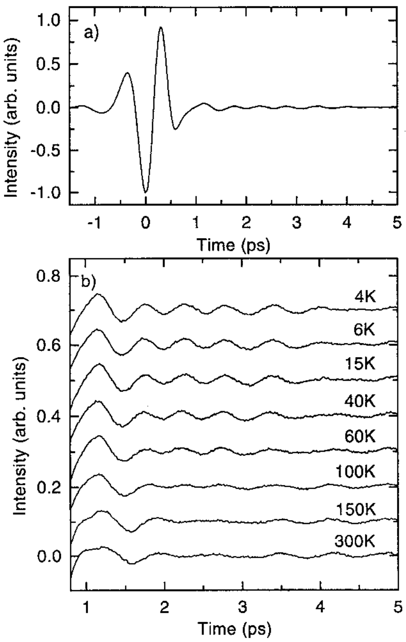
Quantum engineering of III-V semiconductors allows the realization of band structures with parabolic shape. Due to their equally spaced subbands, these quantum structures are ideal systems to study the dielectric response of charge carriers to an ultrafast electric field change. In our time-resolved studies we investigate the response of the electronic charge carrier system in a GaAs/AlGaAs parabolic quantum well (PQW) to an exciting few-cycle THz pulse.

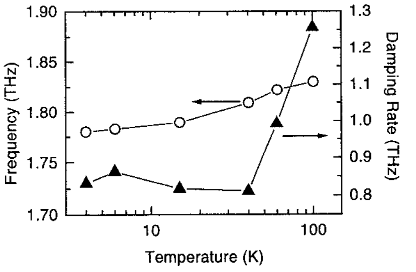
The parabolic quantum well structure consists of a 200-nm-wide GaAs PQW embedded in $Al_{0.3}Ga_{0.7}As$.[1] The carrier concentration in the modulation doped PQW is $n_e = 2.7 \times 10^{11}$ cm^{-2}. A 16-μm period metal grating on top of the sample is used to couple the THz radiation to the intersubband transitions. For our experiments, we use a femtosecond Ti:sapphire laser to generate few-cycle THz radiation by excitation of coherent plasma oscillations in n-doped GaAs.[2] This THz beam is transmitted through the PQW sample mounted in a helium flow cryostat. Time resolution is achieved by mixing the transmitted THz signal with a second THz beam and detecting the superposition with a 4 K bolometer.

Figure 1a shows the time-resolved THz pulse after transmission through the sample. The first part of the signal ($t < 1.5$ *ps*) shows mainly the exciting THz pulse, which has a center frequency of about 1.5 THz. At longer time delays, the dielectric response of the electrons in the PQW becomes visible. According to Kohn's theorem the electrons in the parabolically confined potential interact with light only at the bare harmonic oscillator frequency $\omega_0 = \sqrt{8\Delta/(L^2 m^*)}$, where Δ is the energetic depth of the potential and L the well width.[3] The observed oscillations agree with the calculated intersubband transition frequency of about 1.8 THz and show the free induction decay of the polarization of the collective electron intersubband mode. The transients in Fig. 1b are magnifications of these oscillations recorded at different temperatures.

Figure 2 shows the temperature dependence of the oscillation frequency and the damping rate. From the excellent stability of the oscillation frequency we deduce that Kohn's theorem is valid in our structure. The damping rate shows a strong increase above 40 K, which is unexpected for a equally spaced subband system. We interpret this dephasing of the polarization by the onset of optical phonon scattering from higher subbands into the lowest subband.



QWN4 Fig. 1. (a) Time-resolved THz pulse after transmission through the parabolic quantum well. (b) Magnification of the free induction decay recorded at different temperatures.



QWN4 Fig. 2. Temperature dependence of the oscillation frequency and the dephasing rate of the intersubband transition.

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QWN5 5:45 pm

Coherent THz-plasmons in AlGaAs/GaAs heterostructures

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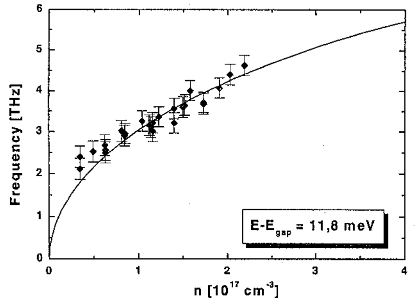
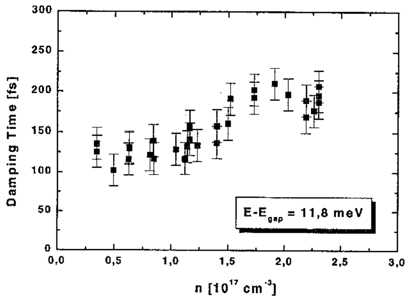
Coherent plasma oscillations in polar semiconductors like GaAs can be generated by ultrafast screening of a space charge field by exciting cold electrons and holes with femtosecond laser pulses.[1–4] Because of their high mobility, the electrons can undergo coherent oscillations following the periodically reversing electric field in the space charge region. For low excitation densities, the plasma frequency is well below the optical phonon frequency, therefore, the coupling between plasmons and optical phonons is very weak. In this range of "pure" plasmons, the frequencies obey the well known relation $\omega_P{}^2 = n \cdot e^2/m^* \cdot \varepsilon \cdot \varepsilon_0$. Increasing the carrier density leads to a stronger coupling of plasmons to optical phonons when the plasma frequency ω_P approaches the phonon frequencies ω_{LO} and ω_{TO}.[5] This coupling appears in the carrier density dependence of both the frequency and the damping time of the plasmon phonon-coupled modes.

We report on femtosecond time-resolved experiments that allow the generation and detection of coherent plasma oscillations tunable in the frequency range of 1-5 THz. The samples are GaAs/AlGaAs modulation doped single heterostructures with a i-GaAs capping layer, a 38-nm heavily n-doped $Al_{0.36}Ga_{0.64}As$ layer ($n = 1.2 \times 10^{18}$ cm^{-3}), and a 19-nm i-$Al_{0.36}Ga_{0.64}As$ spacer above the i-GaAs substrate. A two-dimensional (2D)-channel with an electron surface density of $n_s = 4.8 \times 10^{11}$ cm^{-2} at $T = 77$ K is located between the intrinsic GaAs and AlGaAs layers. Below the 2D-channel a depletion field of 3-5 kV/cm extends from about 180 nm to several micrometers. In the pump-probe experiments we measure the transient change in reflectivity using a combined fast-scan and lock-in technique. For the first time, several coherent oscillations (up to five full periods) are clearly visible, so that the damping behavior of the coherent plasmons can be quantitatively analyzed. Oscillations are observable up to carrier excess energies of 100 meV.

We interpret the observed oscillations as due to changes in the electric field caused by coherent 3D-plasma oscillations of the photoexcited carriers in the i-GaAs layer below the 2D-channel. The changes in reflectivity are due to the DC Franz Keldysh effect. The photon energy of the laser pulses ($\tau < 90$ fs) is tuned around the bandgap of GaAs. Ensemble Monte Carlo simulations show that the photoexcited carrier density is limited by absorption saturation due to the finite joint density of states ($\sim 10^{17}$ cm^{-3}). We can exclude quantum beats from confined electrons in the 2D-channel as the origin of the changes in sample reflectivity, since only one characteristic frequency is observed. Figure 1 shows the measured plasmon



QWN5 Fig. 1. Plasmon frequencies as a function of carrier density. The maximum of the laser spectrum was 11.8 meV above the bandgap. The solid line is the lower branch of the plasmon-phonon coupled modes.



QWN5 Fig. 2. Plasmon damping times as a function of the carrier density. The maximum of the laser spectrum was 11.8 meV above the bandgap.

frequencies as a function of the excited electron density. The experimental data lie exactly on the lower branch of the plasmon phonon-coupled mode. The analysis of the damping behavior leads to a surprising result: The damping time is expected to decrease at higher electron-hole densities due to electron-hole momentum scattering. We observe, however, an increase of the damping time at frequencies $\nu > 3$ THz (Fig. 2). This behavior can be understood as a consequence of the transition from "pure" plasmons to coupled plasmon-phonon modes.

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