Two-color pump-probe spectroscopy of electron dynamics in doped superlattices

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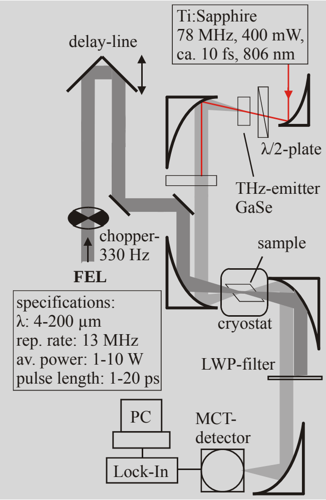
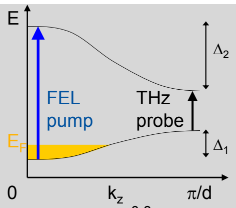
Introduction and Method

- Semiconductor superlattices have been much less investigated with respect to their dynamics as compared to other hetero-structures like quantum wells
- Single-color pump-probe measurements on doped superlattices revealed an **interminiband relaxation within 1-2 ps** [1]
- Compagnone et al. [2] calculated the inter- and intraminiband relaxation times in a Monte-Carlo simulation in InGaAs/InAlAs (4 ps and 1-2 ps, resp.)

→**here**:
first time resolved two-color pump-probe experiment to investigate the **electron dynamics** in doped superlattices (SL) with different miniband widths



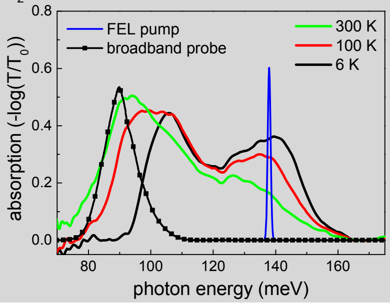
- Two-color pump-probe setup
- **Pump beam**: free-electron laser at the Forschungszentrum Dresden-Rossendorf pumps at the mini-Brillouin zone center (pulse length 1-2 ps)
- **Probe beam**: synchronized broadband THz pulses generated by optical rectification in a GaSe crystal probe transitions at the mini-Brillouin zone edge



- Linear absorption spectra of the superlattice samples (shown for the sample with a miniband width of Δ_1 = 10 meV) depend strongly on the temperature

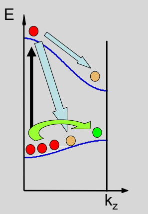
Sample-parameters:
GaAs/$Al_xGa_{1-x}As$ SL, 300 periods, waveguide geometry, miniband width Δ_2 > 41 meV

	No. 1	No. 2	No. 3
well width (nm)	8.5	7.7	6.8
barrier width (nm)	3.1	2.1	1.1
Al-content x	0.3	0.33	0.4
miniband width Δ_1 (meV)	10	22	45
sheet density (2D) (10^{10} cm^{-2})	5	6	4



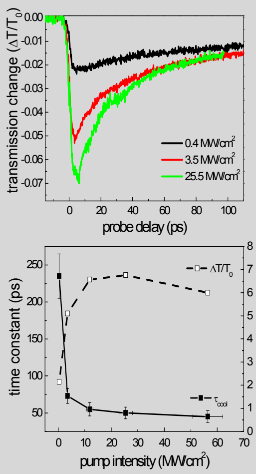
Results

@ 6 K

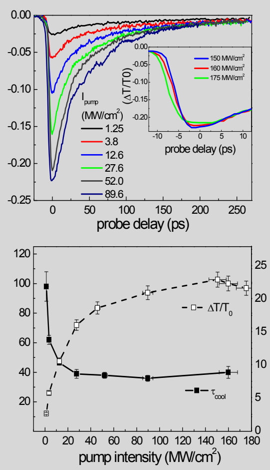


Negative transmission change (induced absorption) due to **heating** of the electrons **in the lower miniband.** The decay reflects subsequent **cooling**.

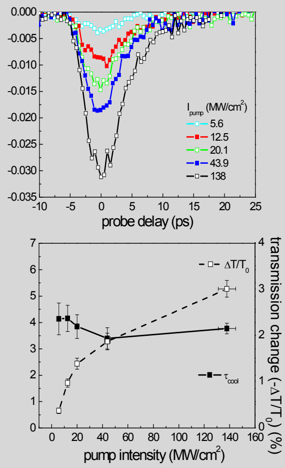
miniband width Δ_1 = 10 meV < ħω$_{LO}$ (36meV)



miniband width Δ_1 = 22 meV < ħω$_{LO}$



miniband width Δ_1 = 45 meV > ħω$_{LO}$



- **Decay times depend strongly on pump intensity** as observed in quantum wells [3]:
  40 and 50 ps, resp. , for intensities > 20 MW/cm²
  long decay times (100 and 250 ps, resp.) for small intensities
- Smaller decay times (40 ps) for Δ_1 = 22 meV because transitions closer to ħω$_{LO}$ are more likely [3]
- Equal electron temperature in lower miniband after approx. 100 and 200 ps, resp., except for lowest pump intensity

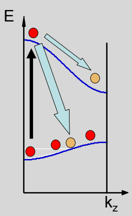
→ e$^-$-e$^-$ and e$^-$-impurity scattering heat up the electrons in the lower miniband.
Electrons in the tail of the Fermi-Dirac distribution (above ħω$_{LO}$) relax by optical-phonon emission.
→ This threshold is not reached at lower intensities.

- **Fast decay** times of 3-4 ps

→ Decay mainly through efficient LO-phonon scattering for all pump intensities

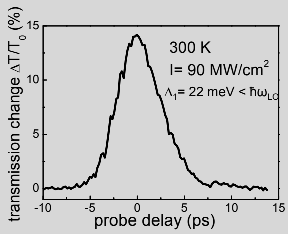
- Again induced absorption, **no gain**

@ 300 K



Positive transmission change

- At 300 K heating effect is less pronounced



- **Fast intraminiband relaxation in the upper miniband for all SLs** within a few ps due to:
  - Filling of the empty places in the zone center
  - Pauli-blocking in the upper miniband

Conclusion

- Measured intraminiband relaxation times agree well with theory.
- At 6 K *induced absorption:*
  for miniband width < ħω$_{LO}$
  → Intraminiband relaxation in the lower miniband depends strongly on intensity with decay times of 40-250 ps!
  for miniband width > ħω$_{LO}$
  → Faster decay within 3-4 ps due to efficient LO-phonon scattering.
  → No gain measured even for high intensities!
- At 300 K *induced transmission:*
  Decay time within upper miniband of a few ps

References:
[1] D. Stehr et al., Appl. Phys. Lett. **88**, 151108 (2006)
[2] F. Compagnone, A. DiCarlo, and P. Lugli, Appl. Phys. Lett. **80**, 920 (2002)
[3] M. Dür, S. M. Goodnick, and P. Lugli, Phys. Rev. B **54**, 17794 (1996)

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