

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

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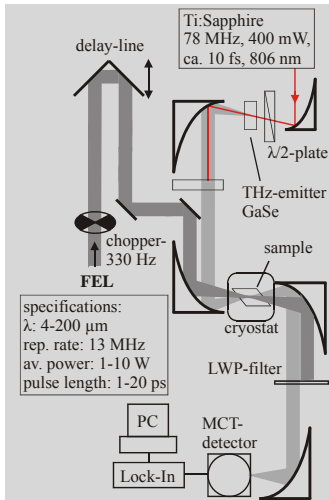
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Introduction and Method

- Semiconductor superlattices have been much less investigated with respect to their dynamics as compared to other heterostructures 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.)

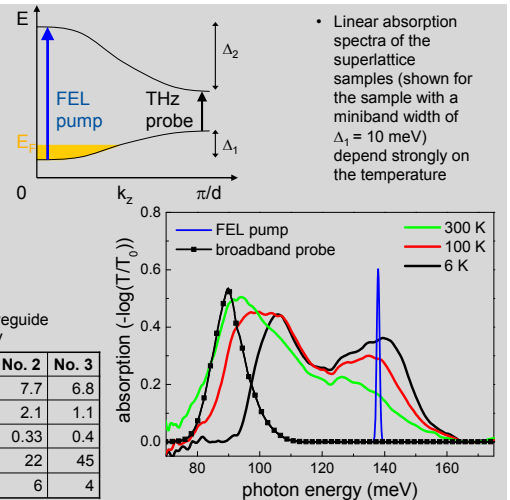
→ here: **first time resolved two-color pump-probe experiment** to investigate the **electron dynamics** in doped superlattices (SL) with different miniband widths



- 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

Sample-parameters:
GaAs/Al_xGa_{1-x}As SL, 300 periods, waveguide geometry, miniband width $\Delta_2 > 41$ meV

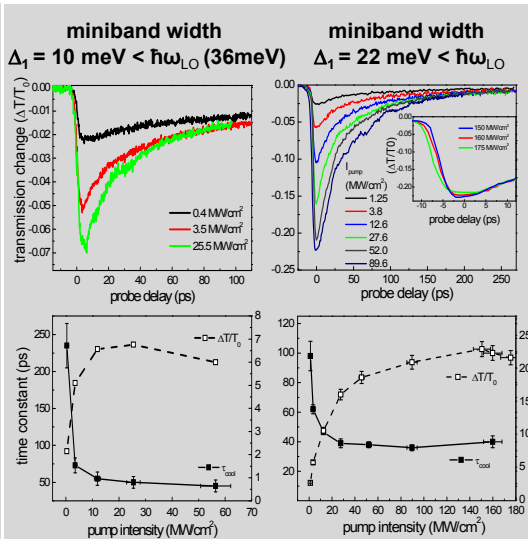
	No. 1	No. 2	No. 3
well width (nm)	8.5	7.7	6.8
barrier width (nm)	3.1	2.1	1.1
Al-content x	0.3	0.33	0.4
miniband width Δ_1 (meV)	10	22	45
sheet density (2D) (10^{10} cm ⁻²)	5	6	4



Results

@ 6 K

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



- 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 $\Delta_1 = 22$ meV because transitions closer to $\hbar\omega_{LO}$ 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 $\hbar\omega_{LO}$) 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
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- Fast intraminiband relaxation in 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 $< \hbar\omega_{LO}$ → Intraminiband relaxation in the lower miniband depends strongly on intensity with decay times of 40-250 ps! for miniband width $> \hbar\omega_{LO}$ → 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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