

Coherent Intersubband Excitations on a Picosecond Time Scale

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Outline

- **Coherent intersubband excitations**
- **Electromagnetically induced transparency and absorption in a ladder system**
- **Quantum coherence beating on a picosecond time scale in a V-system**
- **Density matrix model for a 3-level system**



Intersubband Excitation and Relaxation

Excitation intensity low ($\mu E/h \times \tau_2 < 1$):

- Incoherent regime
- Description by rate equations
- Occupation dynamics $\rho_{ii}(t)$

Excitation intensity high ($\mu E/h \times \tau_2 > 1$):

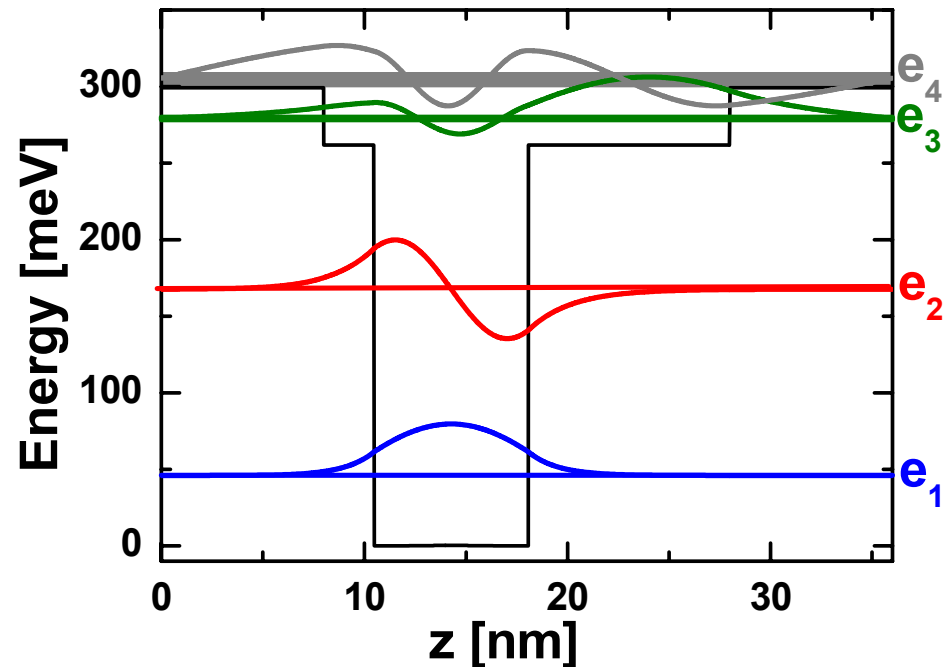
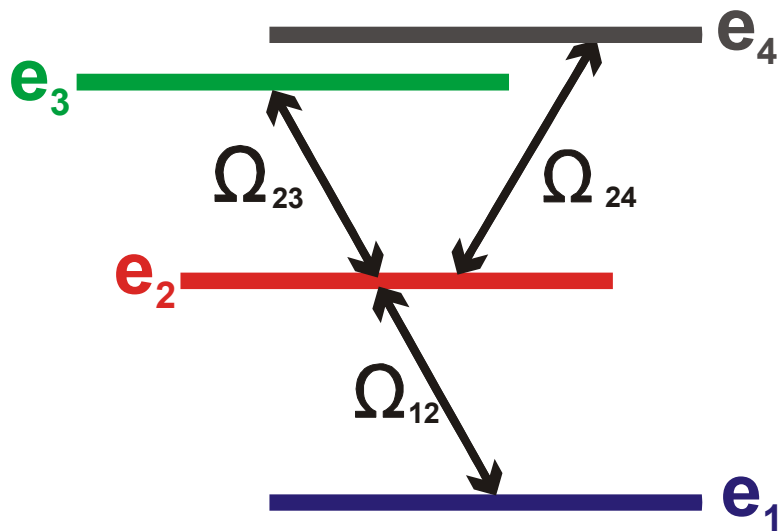
- Quantum coherence regime
- Description by the density matrix formalism

$$\dot{\rho}_{ij}(t) = -i / \hbar [H(t), \rho(t)]_{ij}$$

- Coherences $\rho_{ij}(t)$ play an important role

Electromagnetically Induced Transparency and Absorption

Ladder system



60 periods of

8nm $\text{Al}_{0.40}\text{Ga}_{0.60}\text{As}$

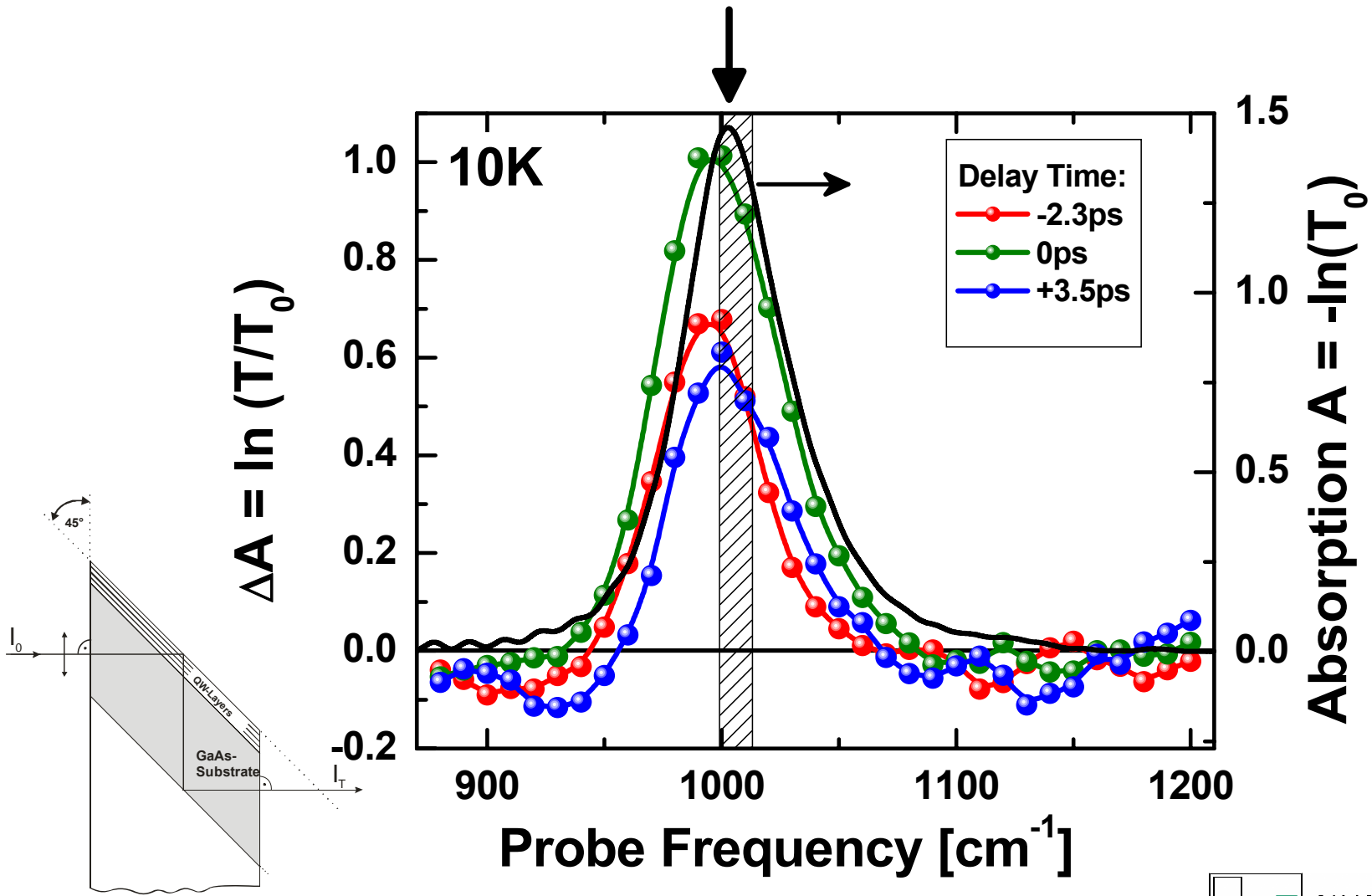
2.5nm $\text{Al}_{0.35}\text{Ga}_{0.65}\text{As}$

7.5nm n-GaAs ($3 \cdot 10^{17} \text{ cm}^{-3}$)

9.9nm $\text{Al}_{0.35}\text{Ga}_{0.65}\text{As}$

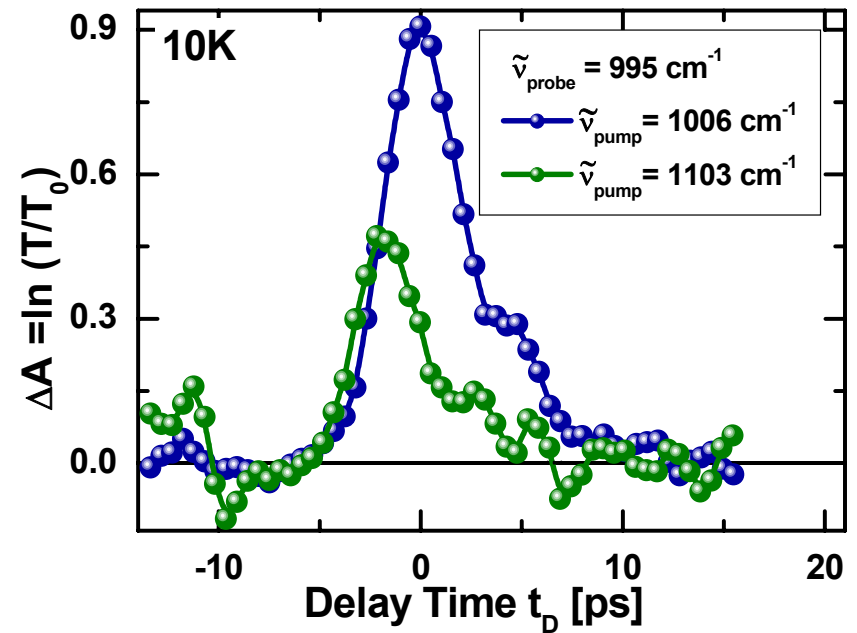
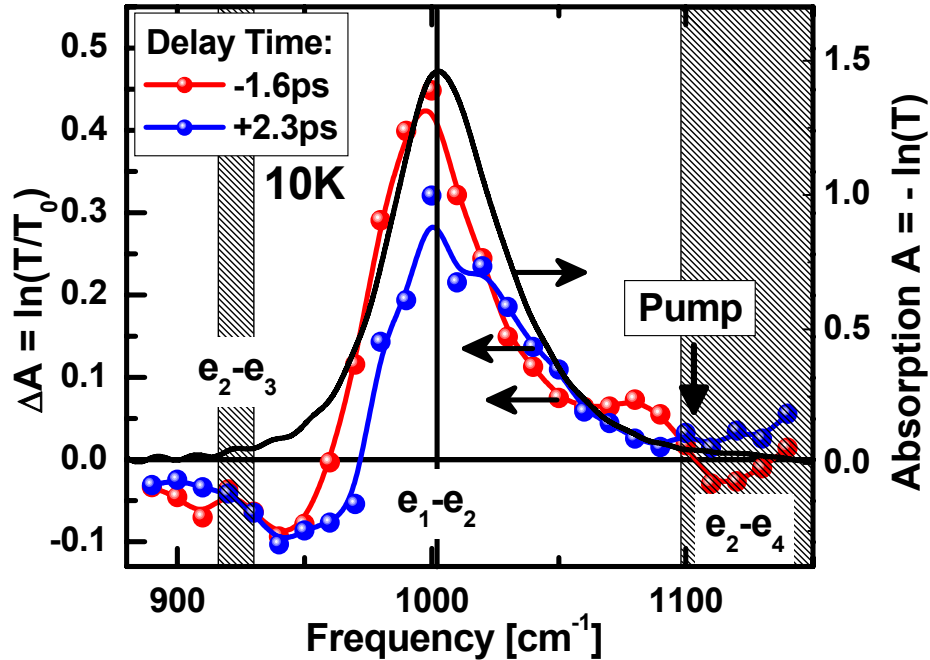


Absorption Spectrum / Absorption Change after Resonant Excitation



Electromagnetically Induced Transparency and Absorption

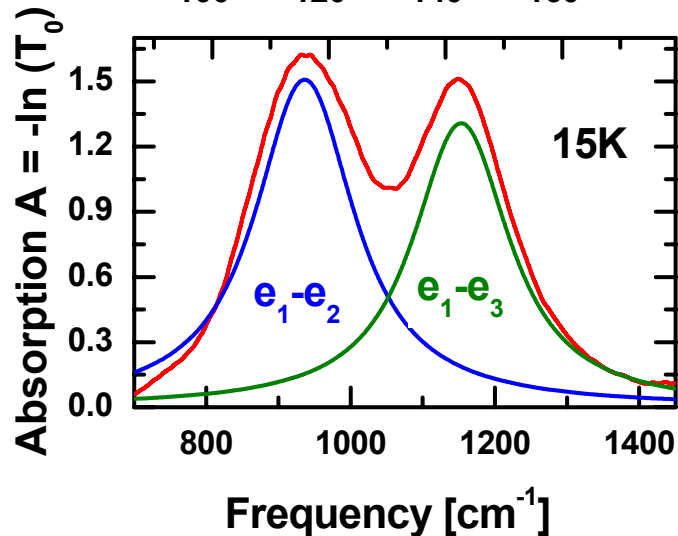
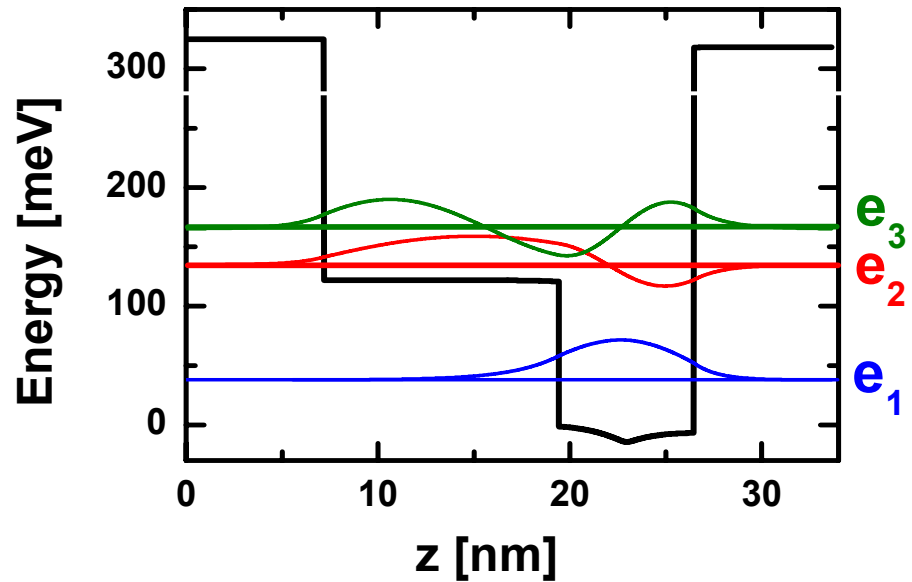
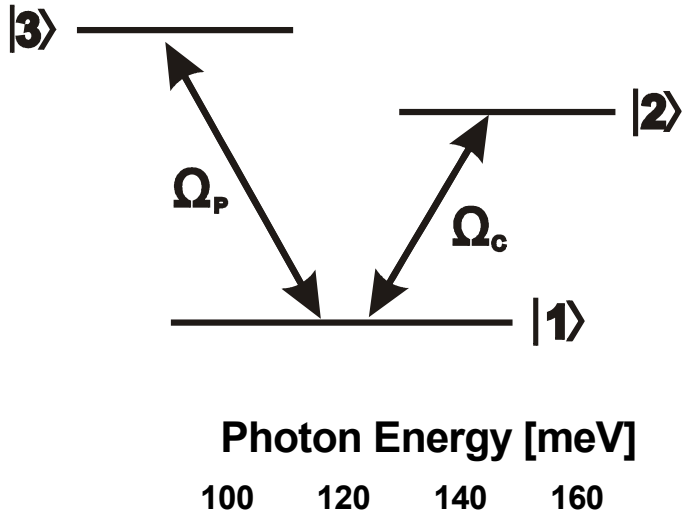
Rabi frequency of excitation pulse $\Omega_{24} \sim 6\text{meV}$



Transmission increase is 7 times larger than estimated from population numbers \Rightarrow electromagnetically induced transparency

Quantum Oscillations on a ps-Time-Scale

V-type level system:



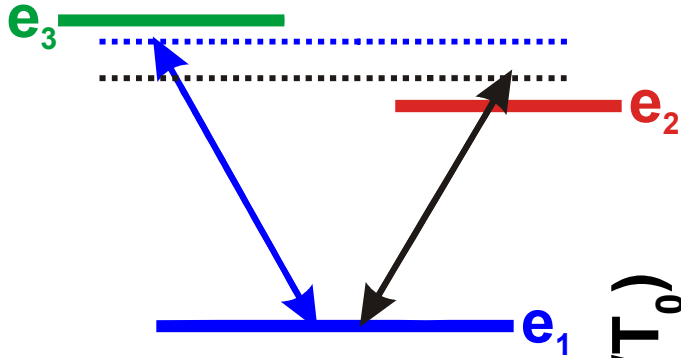
100 periods:

12.2 nm $\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}$

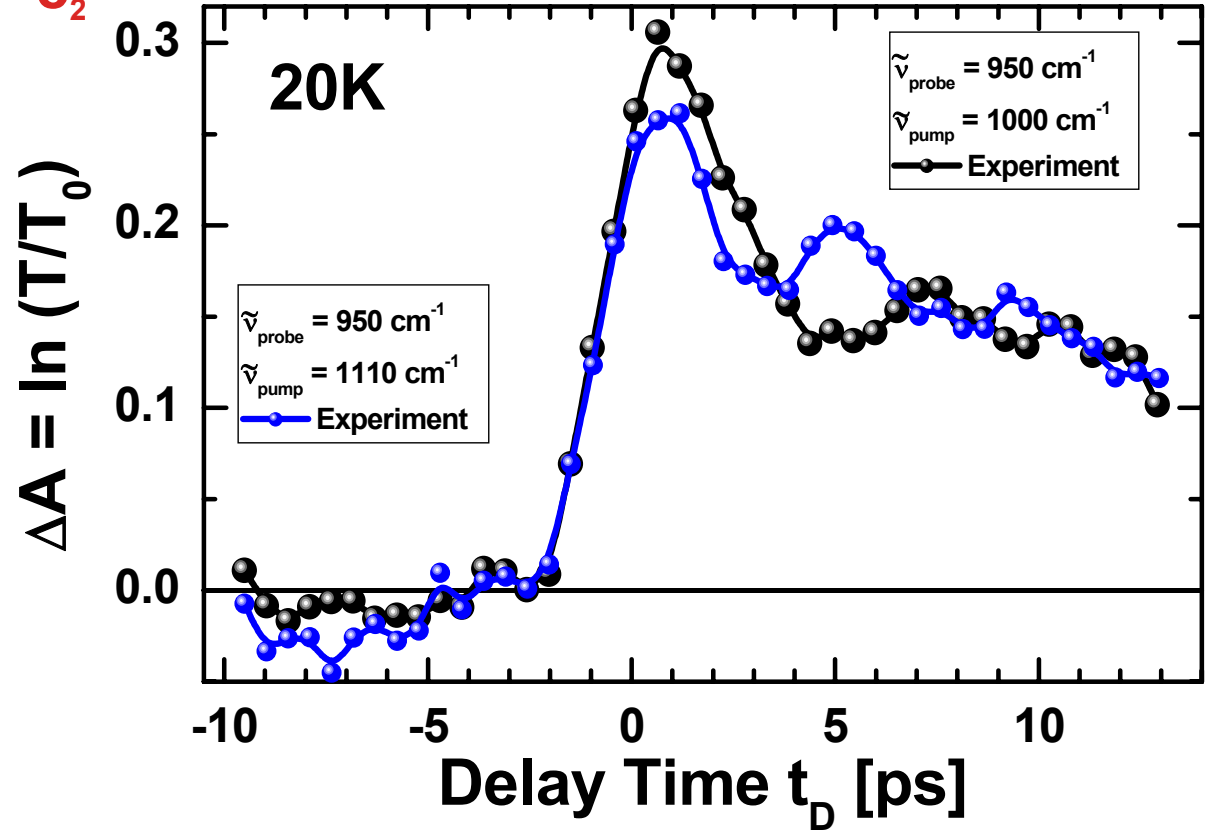
7.0 nm n-GaAs (δ -doped 10^{12} cm^{-2})

7.2 nm $\text{Al}_{0.43}\text{Ga}_{0.57}\text{As}$

Excitation at Frequencies between the Two Transitions



Estimated Rabi frequencies:
3...5 meV



The Model

$$\dot{\rho}_{nm}(t) = \left(-\frac{1}{\tau_{nm}} - i\omega_{nm} \right) \rho_{nm}(t) + i\Omega_{nm}(t) [\rho_{mm}(t) - \rho_{nn}(t)] \\ + i[\Omega_{nl}(t)\rho_{lm}(t) - \rho_{nl}(t)\Omega_{lm}(t)]$$

$$\dot{\rho}_{nn}(t) = i[\Omega_{nl}(t)\rho_{ln}(t) - \rho_{nl}(t)\Omega_{ln}(t)] + \sum_{E_m > E_n} \frac{\rho_{mm}(t)}{T_{nm}} - \sum_{E_m < E_n} \frac{\rho_{nn}(t)}{T_{mn}}$$

and

the field equations for optical pulse propagation



Simulation of Populations and Coherences

Parameters:

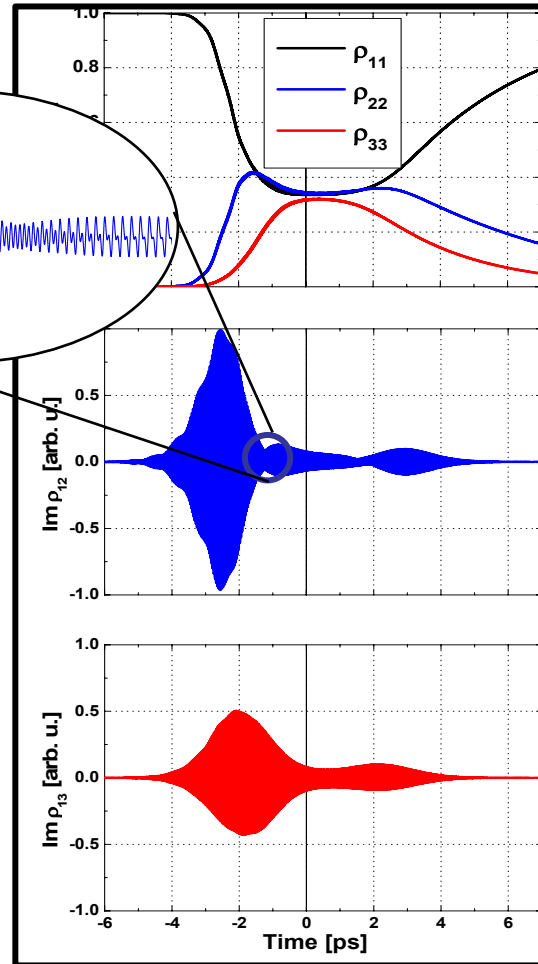
$$\tau_{\text{dephasing}} = 300\text{fs}$$

$$T_{\text{depopulation}} = 4\text{ ps}$$

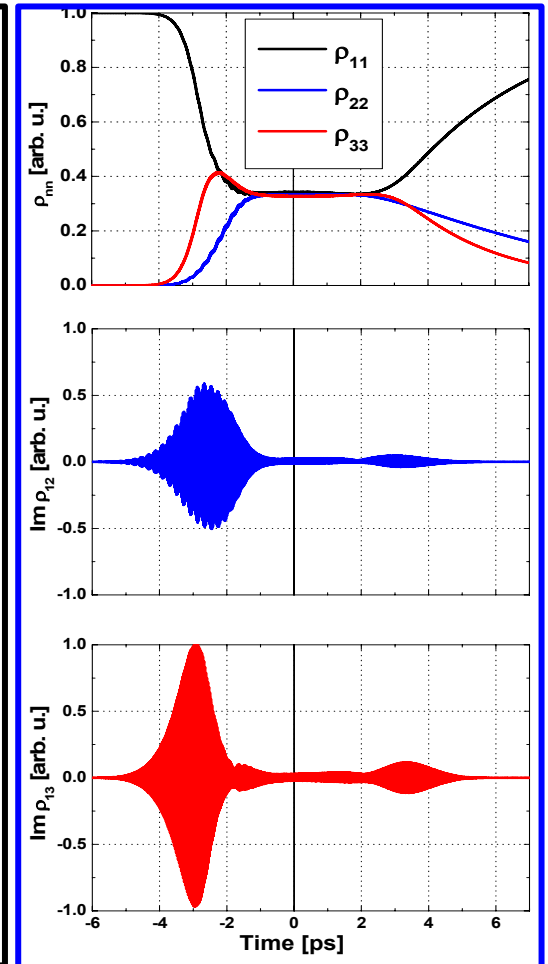
Pulse duration 2ps

Probe frequency 950 cm^{-1}

Rabi-frequencies:

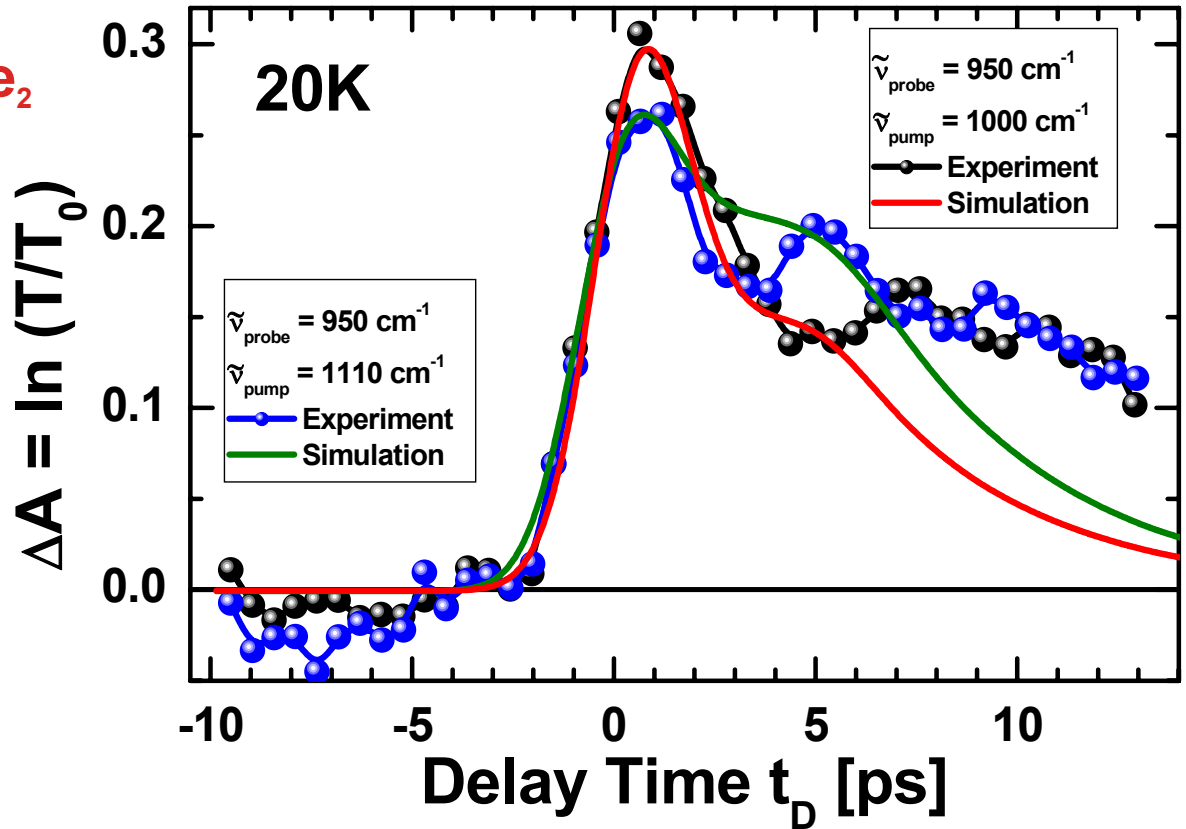
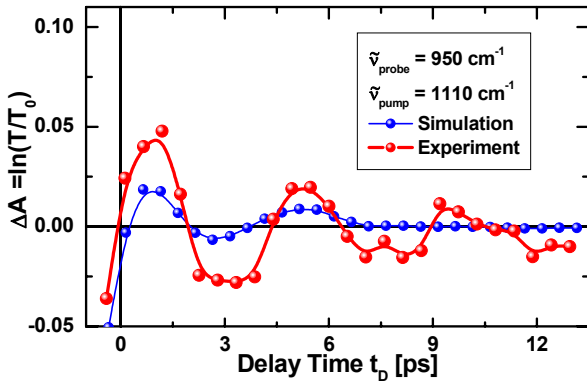
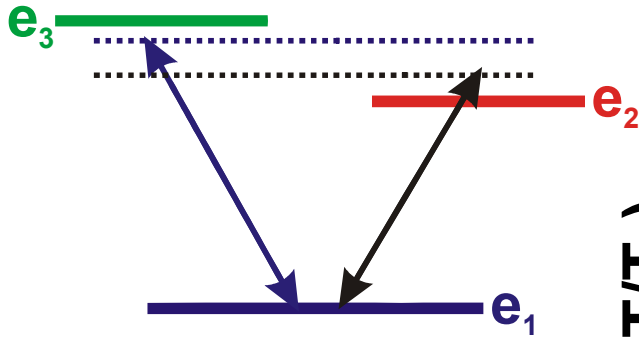


Excitation: $\tilde{\nu}_{\text{exc}} = 1000\text{cm}^{-1}$
 $\Omega_{31} = \Omega_{21} = 20\text{ meV}$



Excitation: $\tilde{\nu}_{\text{exc}} = 1110\text{cm}^{-1}$
 $\Omega_{31} = \Omega_{21} = 40\text{ meV}$

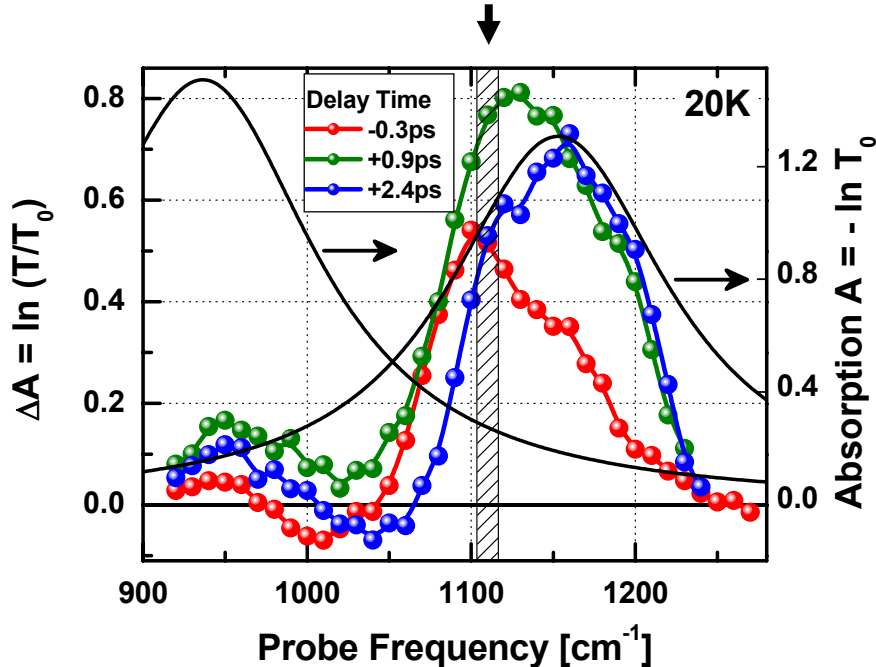
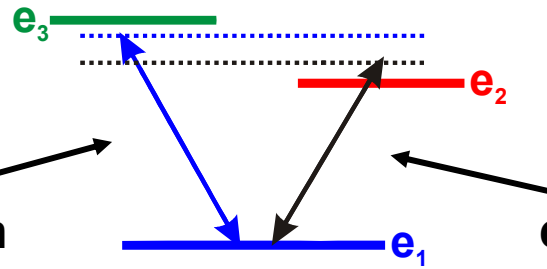
Experimental Results and Simulation



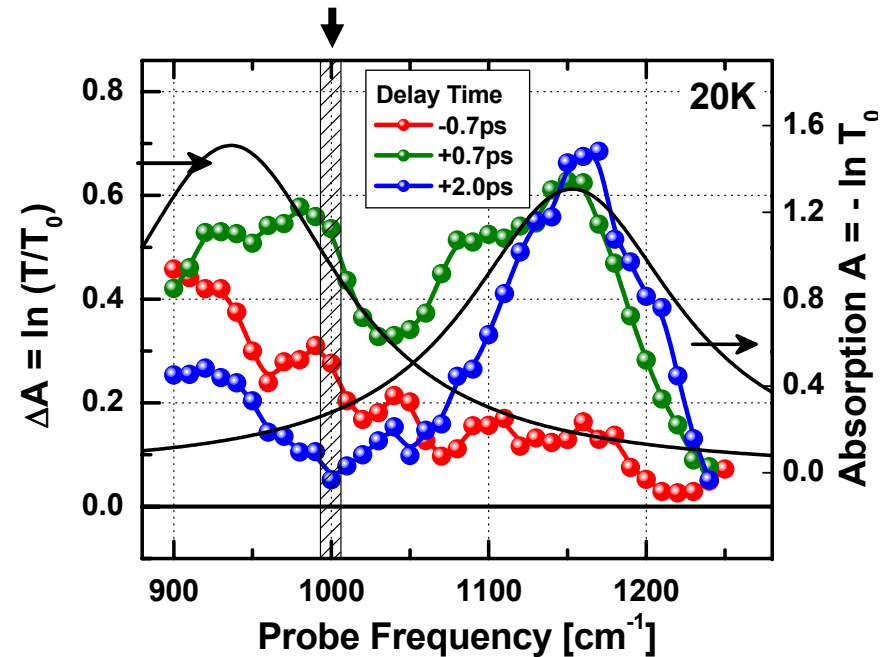
↪ Oscillations due to beating of coherences



Transient Spectra due to Coherent Excitation



Transmission increase at the excited transition e_1 - e_3



Transmission increase at the not excited transition e_1 - e_2

Summary

- **Coherent intersubband excitations are observed on a ps time scale**
- **Electromagnetically induced transparency and absorption are found in a ladder system**
- **Time resolved experiments in a V-system show beating of quantum coherences on a ps time scale**
- **The beating period is in agreement with simulations of the corresponding 3-level system**

