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Fast intraband capture and relaxation of electrons in InAs/GaAs self-assembled quantum dots

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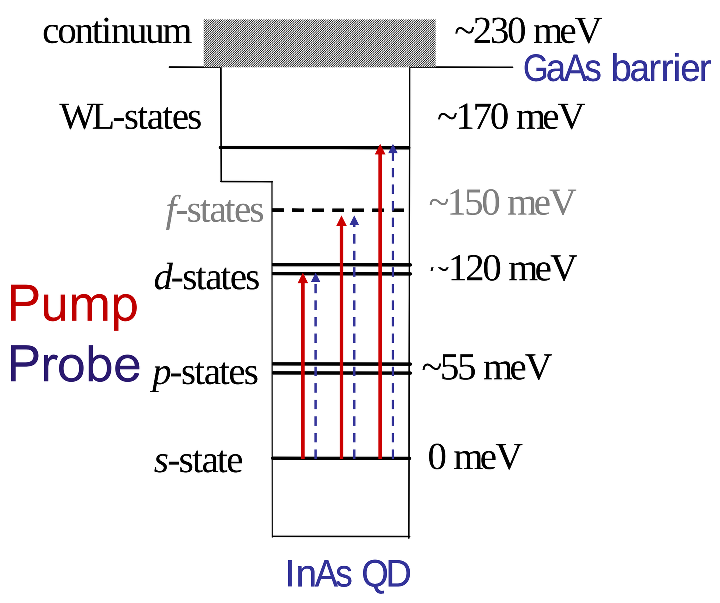
Summary

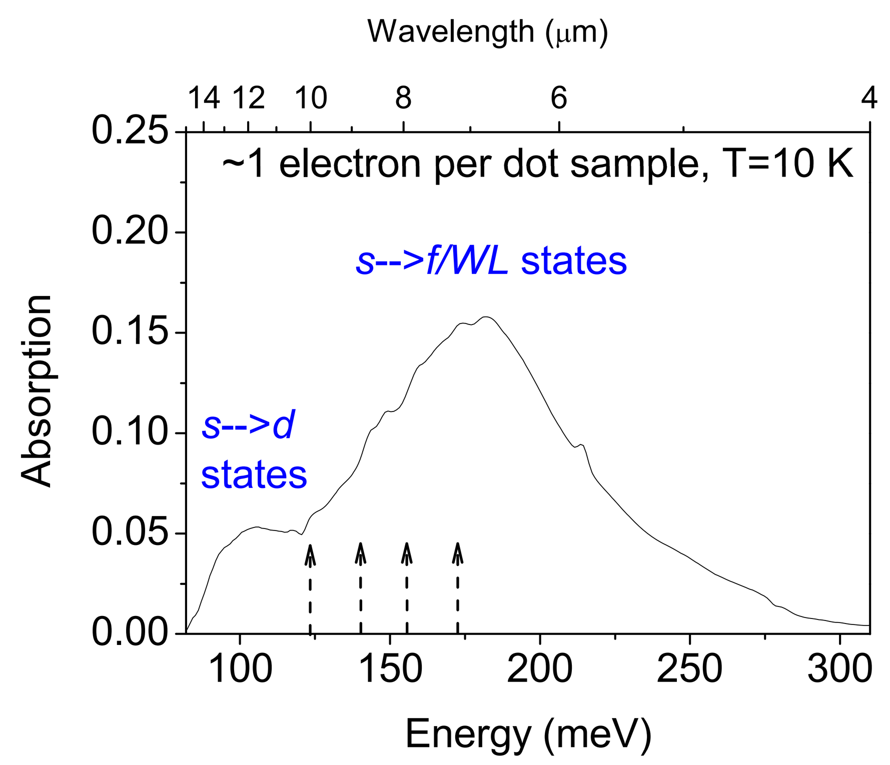
- One and two colour pump-probe study of intraband relaxation processes in n-type InAs/GaAs quantum dots (QDs) for electron transition energies between 100 and 180 meV.
- Relaxation time from high energy QD excited / wetting layer states ~5ps in the presence of holes and ~8ps in the absence of holes.
- Increase of the QD population decreases the capture/relaxation time.
- Fast electron relaxation in QDs occurs via multiphonon emission due to nonadiabatic electron-phonon interaction directly into the QD ground state

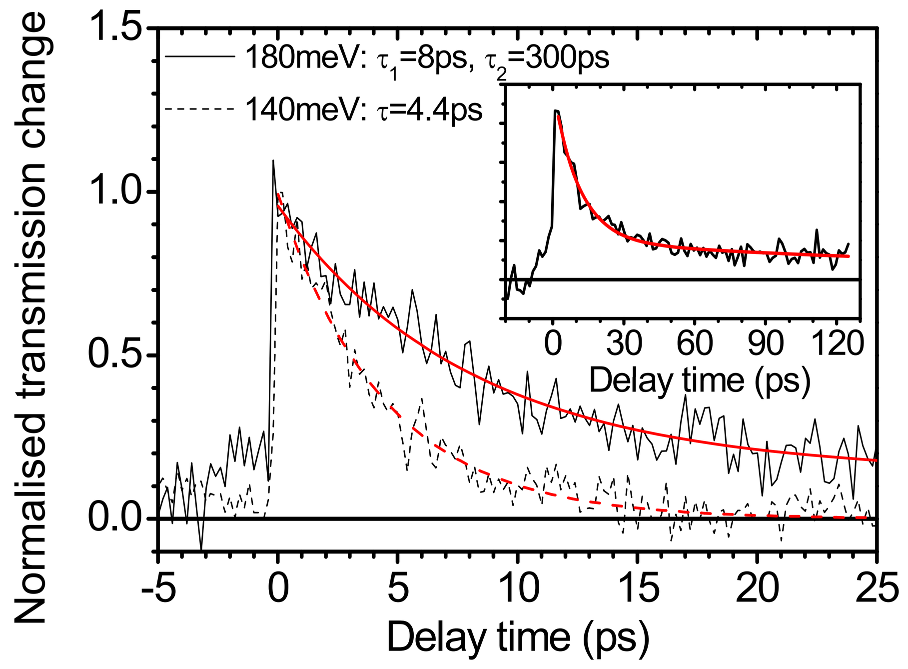
  ⇒ sequential scattering process involving the p-state can be ruled out (because s-p transition τ~50ps) .
- Due to the relatively long high energy excited state lifetime (~10ps), QD infrared photodetectors have the potential for higher efficiencies than quantum well infrared photodetectors.

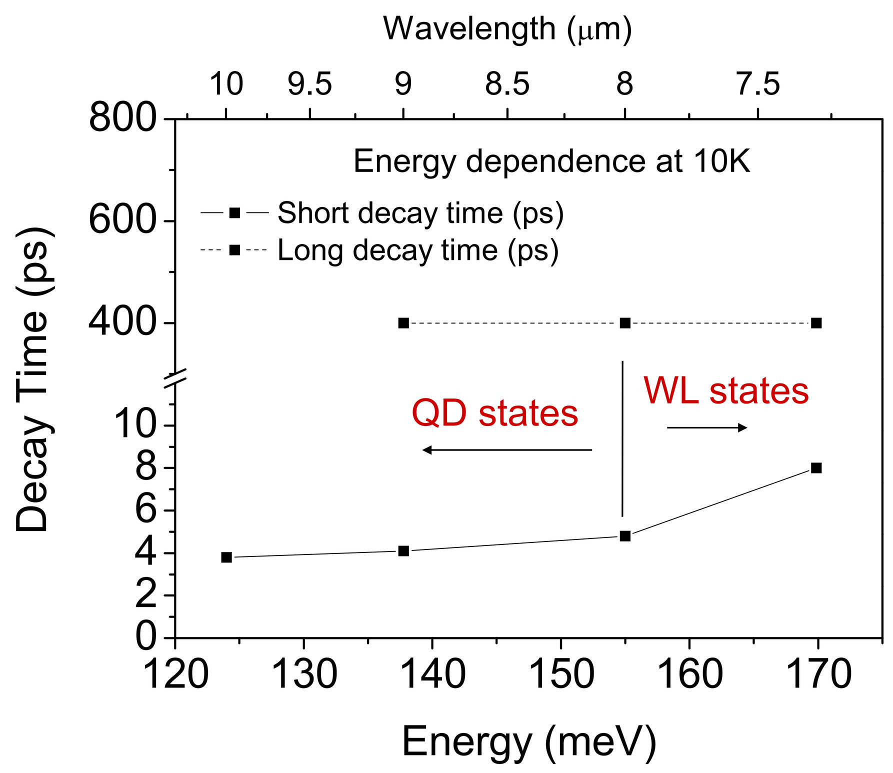
Intraband pump-probe results



- 45° multipass waveguide geometry (~10 passes through the QD layers)
- Using intraband absorption spectroscopy information about the electron energy structure in QDs can be obtained
- One colour pump-probe measurements
- Only electrons are excited (no holes)



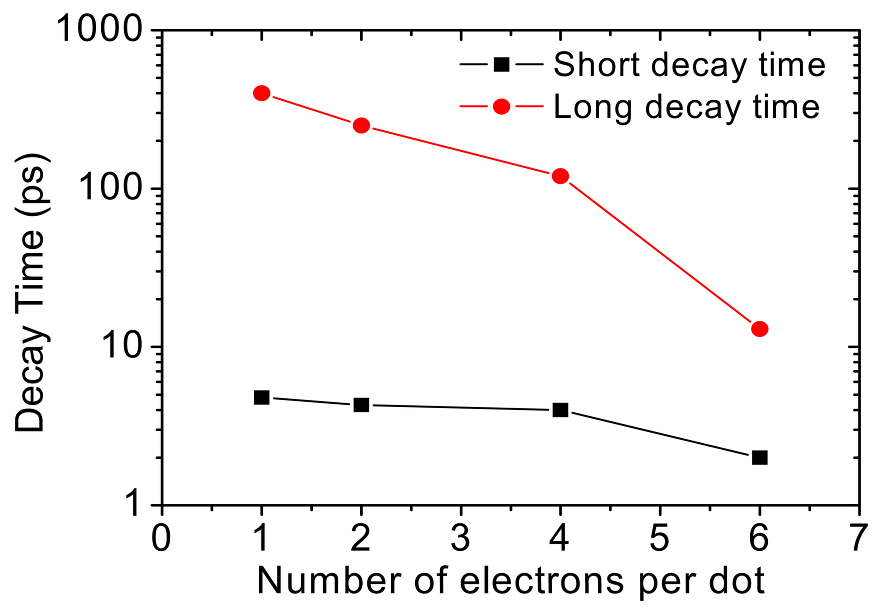




•Relaxation time for electron energy of ~140meV is **~4 ps**, interesting because p-s relaxation time is ~50ps in the same sample [1]

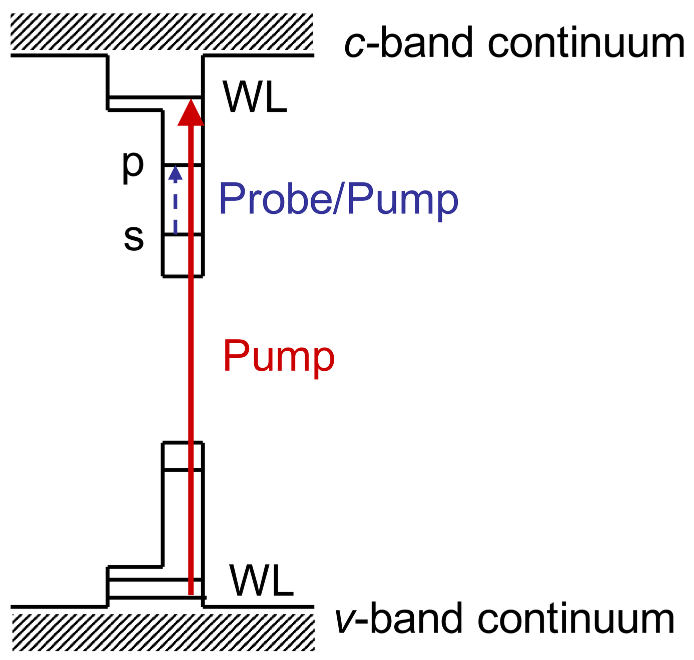
⇒ apparently electrons avoid p-state

•Clear bi-exponential dependence is observed at 180 meV with short decay time of **~8 ps** and long decay time of ~300 ps at 10K

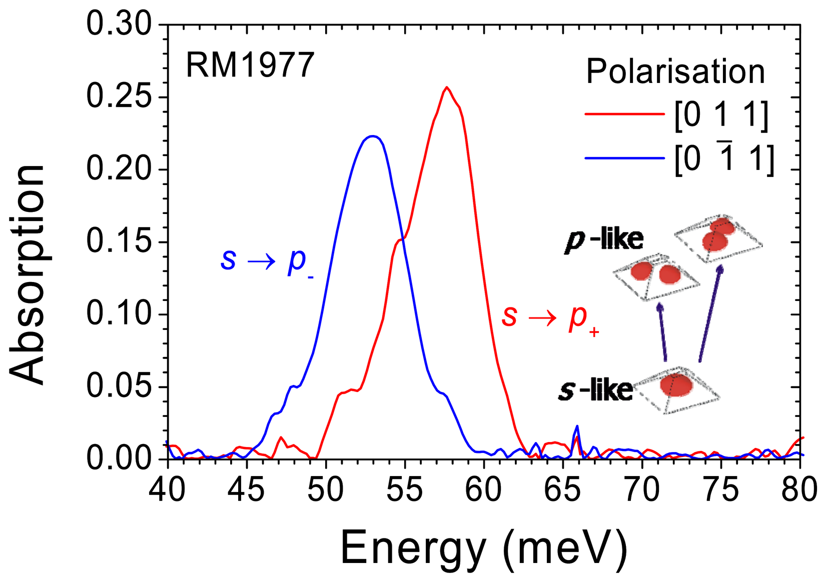


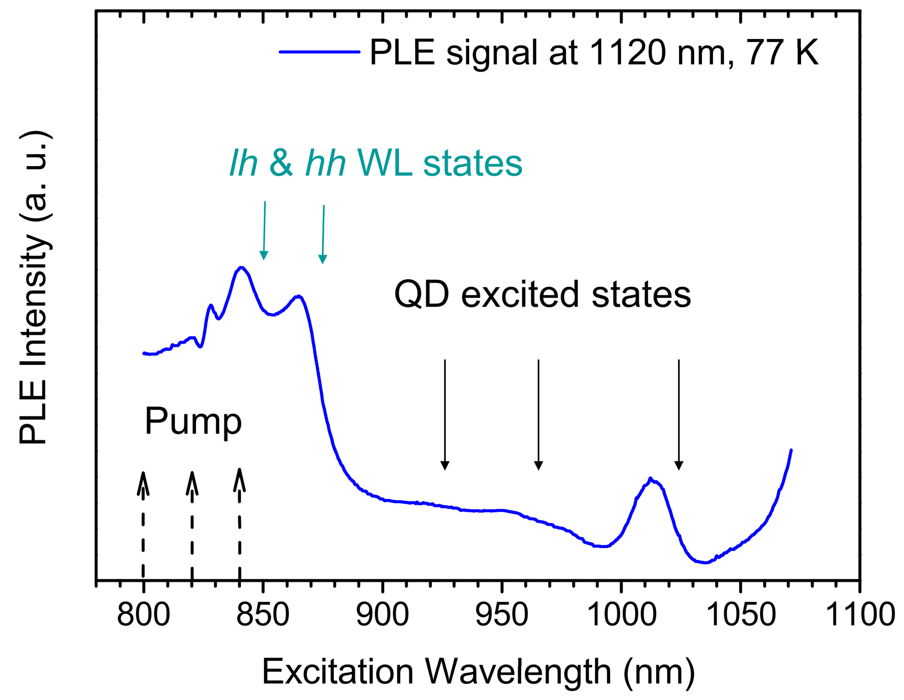
- Increase of the QD population from ~1 to ~6 e/dot decreases the capture/relaxation time from **~4.8 ps to ~2 ps** at 8 μm
- The *long decay time* decreases from **~400 ps to ~13 ps** with increase of number of electrons in QDs from ~1 to ~6

Interband pump – intraband probe results

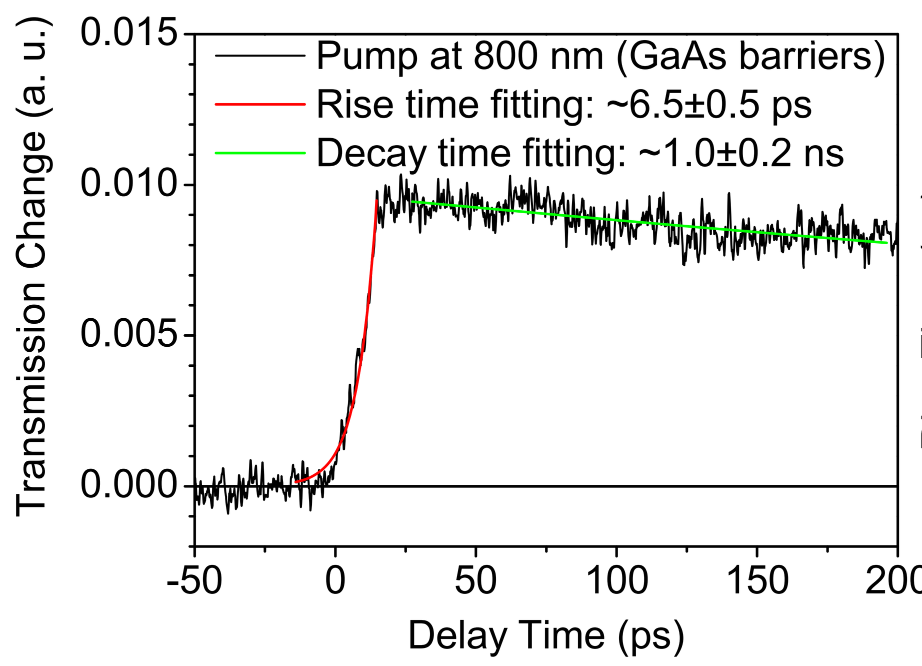


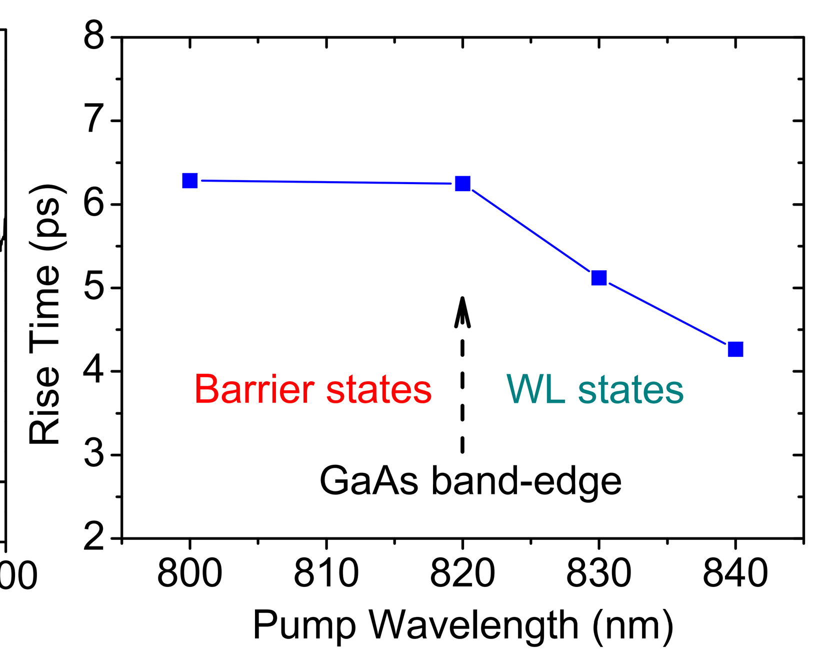
Interband pump – intraband probe measurements using free-electron laser synchronised with femtosecond Ti:Sa laser.





- Selective pump excitation into the barrier or WL states (dashed arrows)
- Intraband probe between s ground and p_+ first excited states at ~21 μm (~ 60 meV)



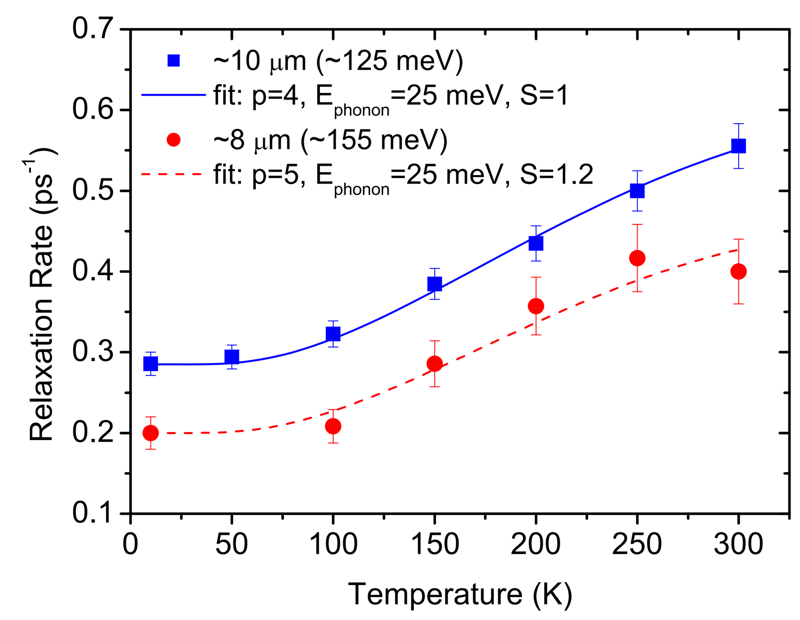


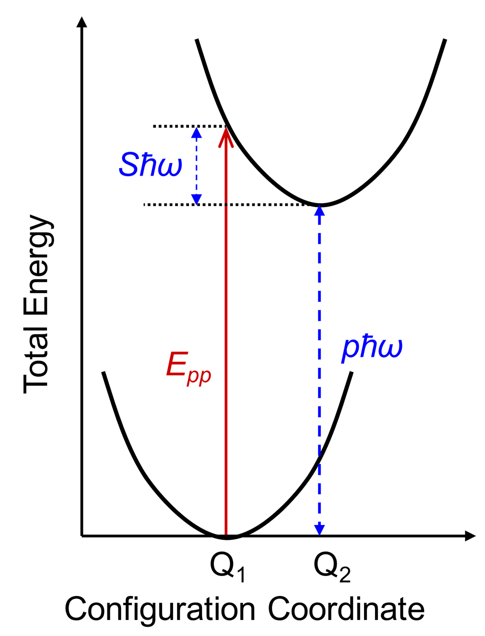
•Low temperature capture time from the barrier states is longer compared to capture time from the wetting layer states, **~6.5 ps** and **~4.5 ps** correspondingly.

•Faster capture time obtained from interband pump – intraband probe measurements (~4.5ps) compared to the one measured using intraband pump-probe technique (~8ps)

• ⇒ **influence of electron-hole scattering**

Temperature dependence





- Fast relaxation time and weak temperature dependence – **nonadiabatic electron-phonon interaction** (observed previously in PbSe colloidal QDs [2]).

From [3], for $(p+4)^2 >> 4S^2 n(n+1)$

$$\Gamma = \Gamma_0 \cdot (1+n)^p \cdot e^{-2 \cdot S \cdot n}$$

where:

$$n = \frac{1}{e^{\frac{\hbar\omega}{kT}} - 1}$$

p – number of emitted phonons,
S – Huang-Rhys factor

References

[1] E.A. Zibik *et al.*, Phys. Rev. B **70**, 161305 (2004)
[2] R.D. Schaller *et al.*, Phys. Rev. Lett. **95**, 196401 (2005)
[3] B.K. Ridley, *Quantum processes in semiconductors* (Claredon,Oxford, 1999)

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