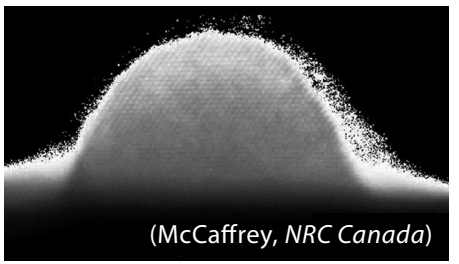
Spin properties of the indirect exciton in indirect band-gap (In,Al)As/AlAs quantum dot ensembles

Jörg Debus, D. Dunker, D. R. Yakovlev, M. Bayer
TU Dortmund University

T. S. Shamirzaev, K. S. Zhuravlev
Institute of Semiconductor Physics, Novosibirsk

Motivation

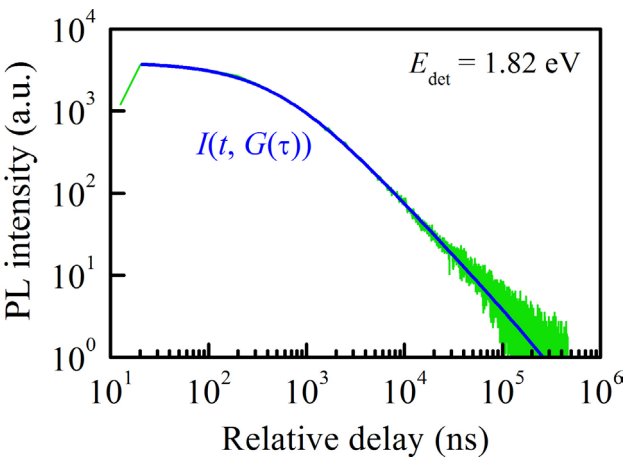
- Implementation of quantum dots in spin electronics or quantum information applications



problem: Short lifetime of exciton complexes limits coherent manipulations

→ **Indirect exciton:**

- Long lifetimes of more than 100 µs
- Optically addressable

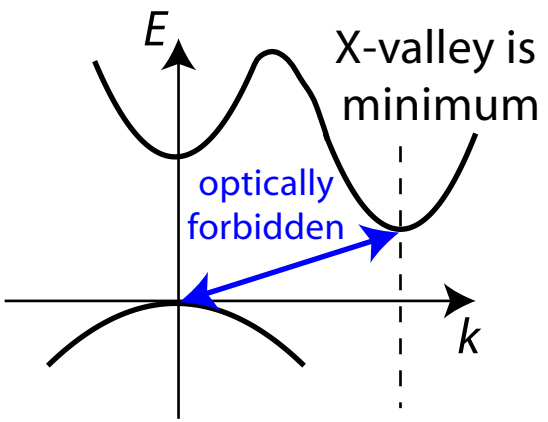


What about its spin dynamics ?

Self-assembled (In,Al)As/AlAs quantum dots

Ensemble of undoped QDs

- Indirect band gap

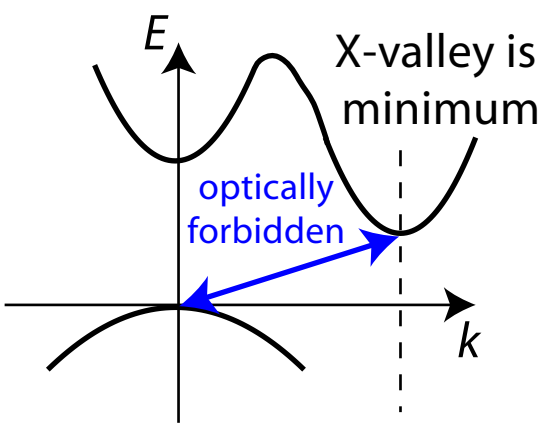


- Type-I band alignment

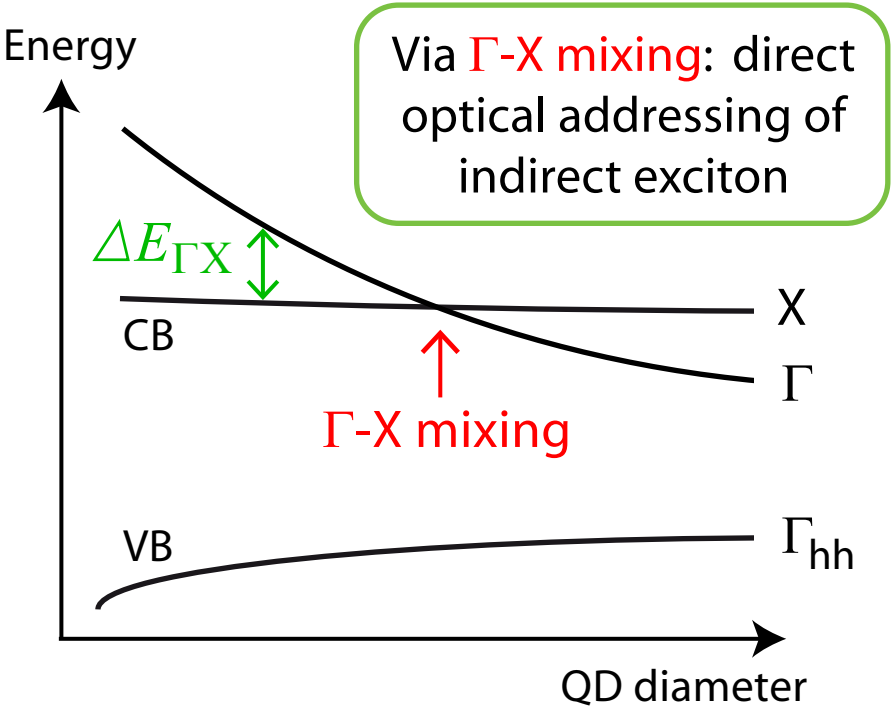
Self-assembled (In,Al)As/AlAs quantum dots

Ensemble of undoped QDs

- Indirect band gap



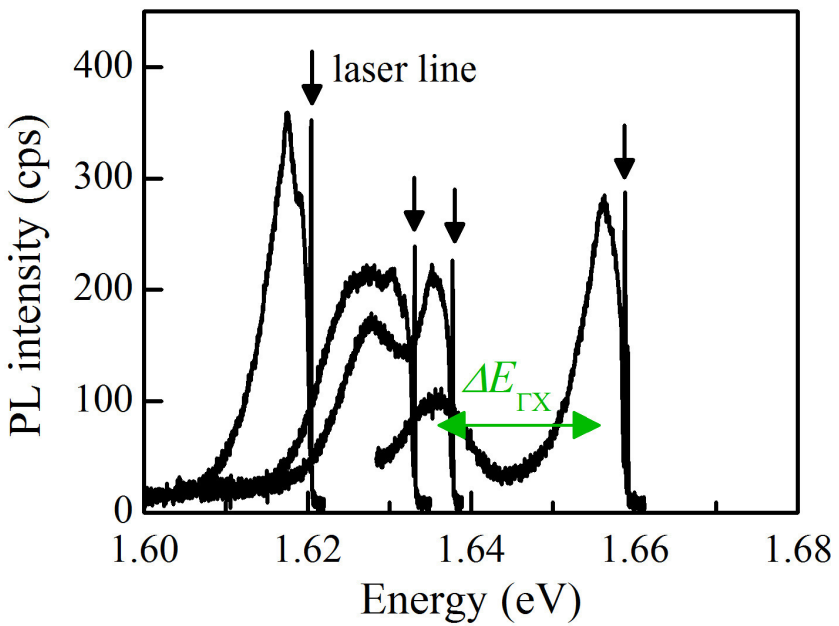
- Type-I band alignment

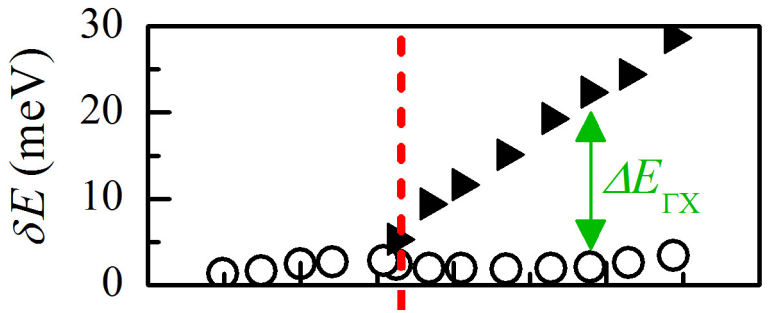


Self-assembled (In,Al)As/AlAs quantum dots

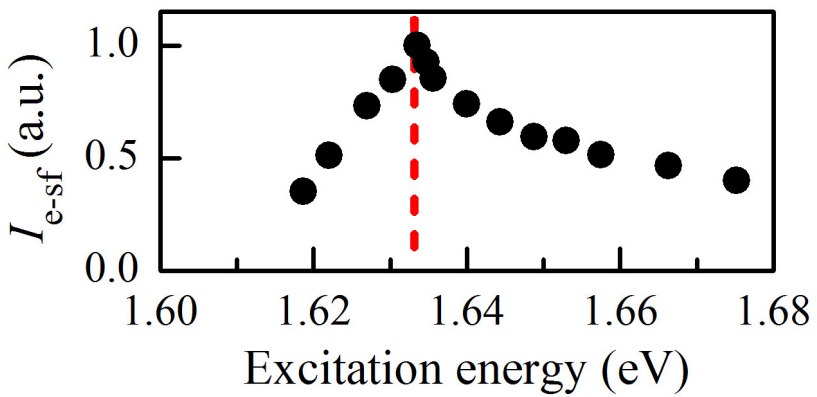
Revelation of Γ-X mixing

- Resonant photoluminescence



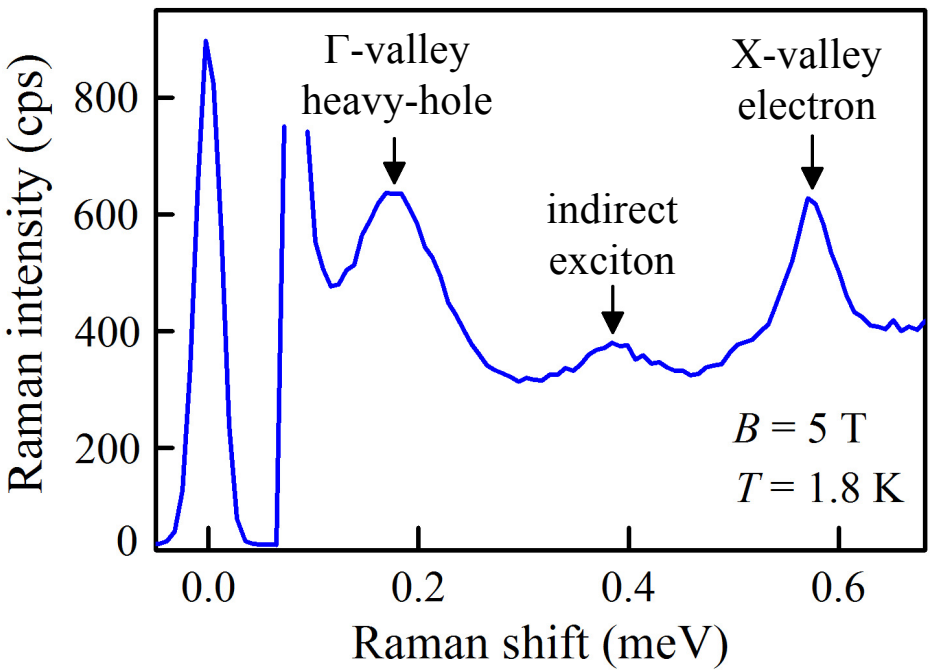


Level crossing determined by electron-spin-flip Raman scattering



Fine structure of indirect exciton

via spin-flip Raman scattering



0.1 meV ~ 1 cm^{-1}

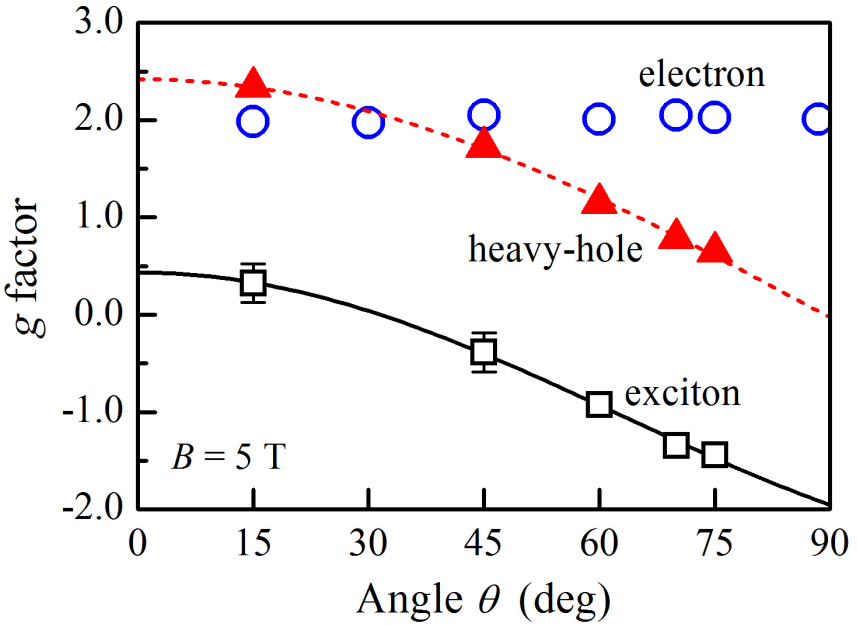
- Resonant excitation of indirect exciton in Γ-X mixing regime
- Evaluation of *g* factor tensor
  - → Angle dependence of SFRS

$$\begin{pmatrix} g_{xx} & 0 & 0 \\ 0 & g_{yy} & 0 \\ 0 & 0 & g_{zz} \end{pmatrix}$$

- Raman shift: $\Delta E = g\,\mu_B\,B$

Fine structure of indirect exciton

via spin-flip Raman scattering



Weak perturbations, high QD symmetry

X-valley electron

$$g_e^{\parallel} = g_e^{\perp} = 2.00 \pm 0.01$$

negligible spin-orbit interaction

$$\Delta g \sim \frac{\Delta_{so}}{E_g^2} \rightarrow 0$$

large band gap at X-point

Γ-valley heavy-hole

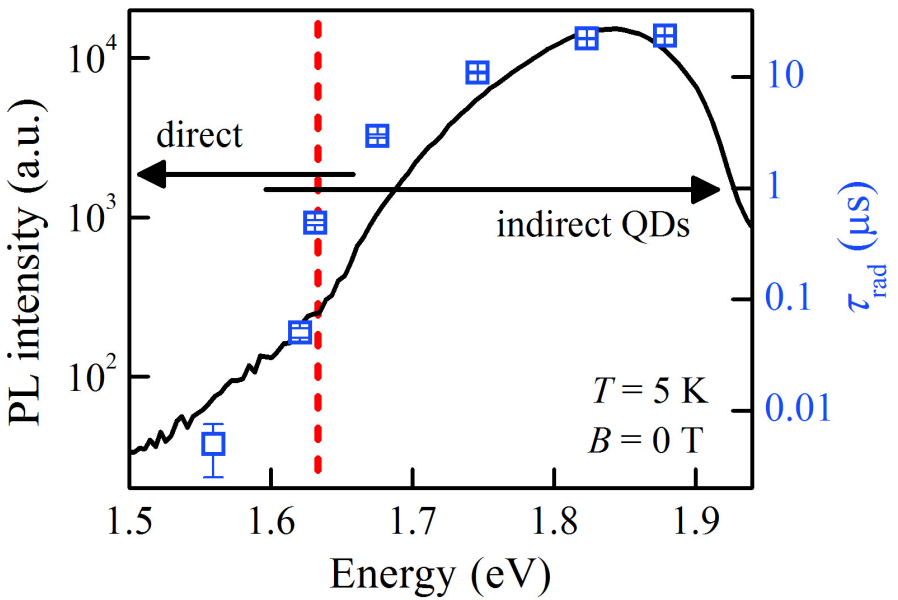
$$g_{hh}^{\parallel} = 2.42 \pm 0.05 \quad , \quad g_{hh}^{\perp} = 0.03 \pm 0.05$$

no light-heavy-hole mixing

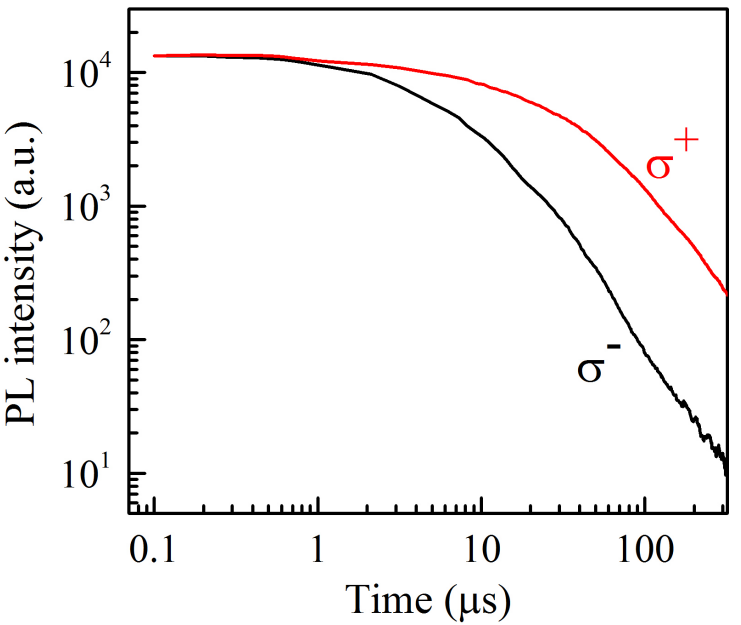
isotropic localization potential

Spin relaxation of indirect exciton

- Time-integrated QD photoluminescence



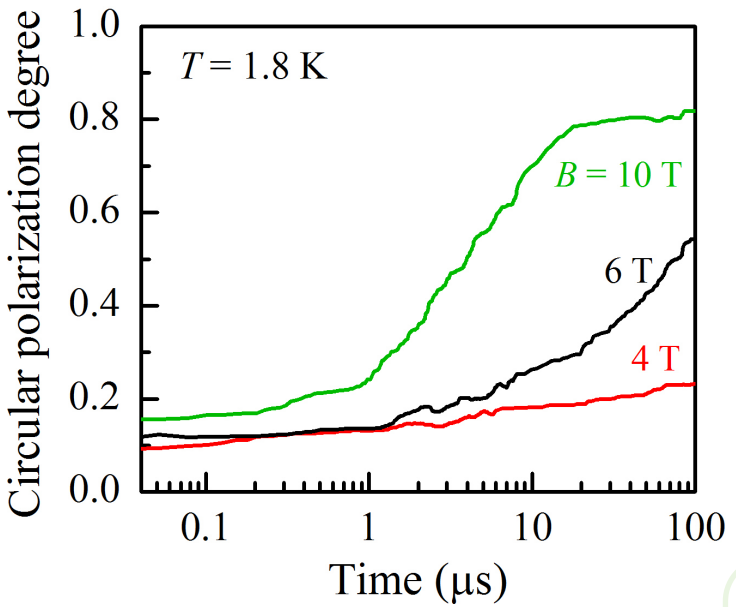
- Decay of circularly polarized PL of indirect band-gap dots



Phys. Rev. B ***84****, 155318 (2011)*

Spin relaxation of indirect exciton

- Non-exponential time evolution of circular polarization degree



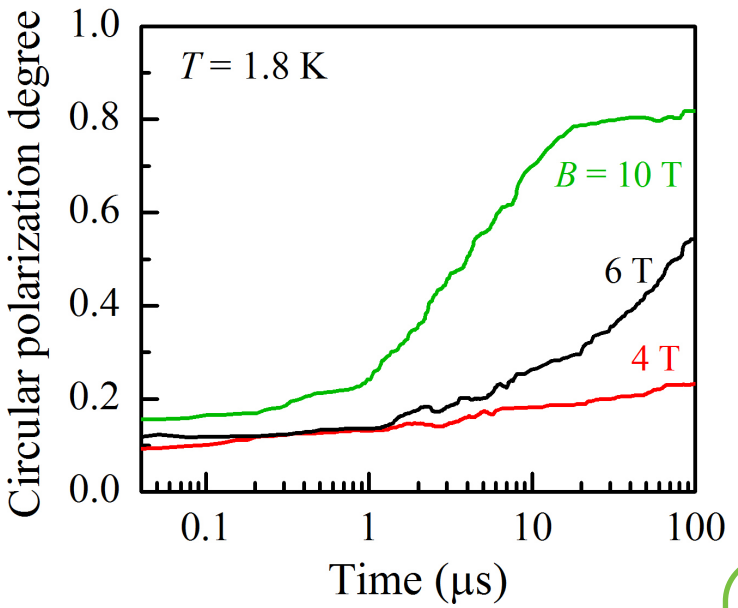
Appl. Phys. Lett. ***101****, 142108 (2012)*

- *B*-field dependence → $\tau_S \sim B^{-5}$
- Temp.- dependence → $\tau_S \sim T^{-1}$

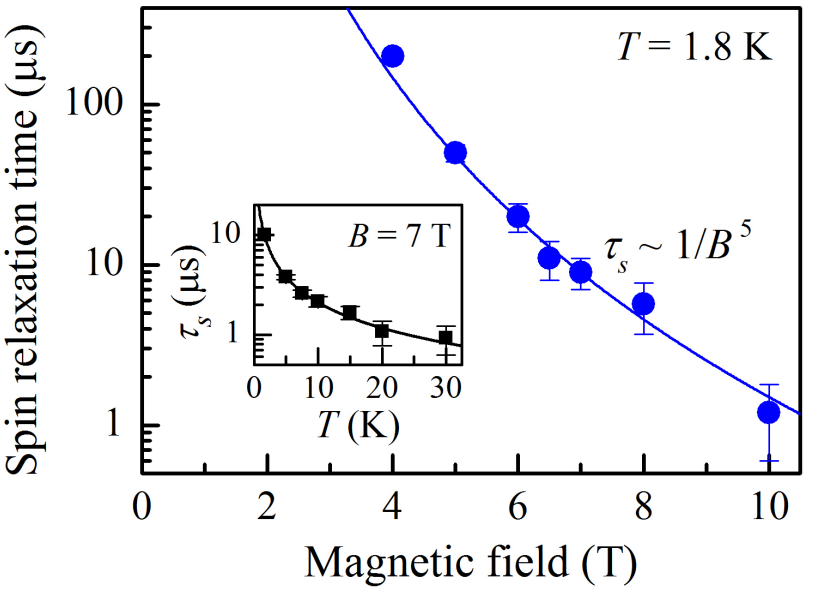
One acoustic phonon-assisted spin relaxation

Spin relaxation of indirect exciton

- Non-exponential time evolution of circular polarization degree



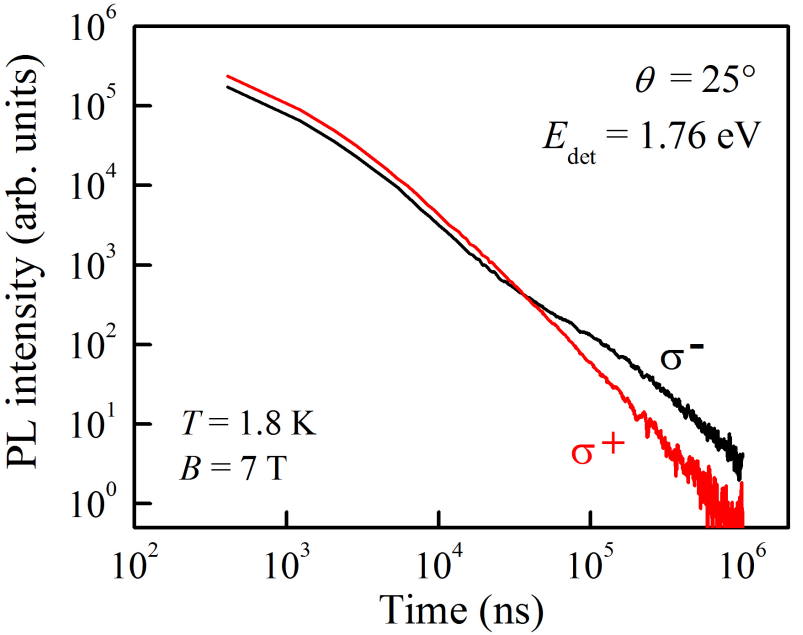
Appl. Phys. Lett. ***101****, 142108 (2012)*



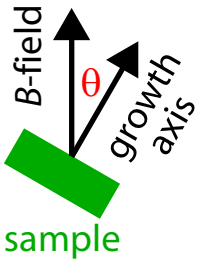
- *B*-field dependence → $\tau_S \sim B^{-5}$
- Temp.- dependence → $\tau_S \sim T^{-1}$

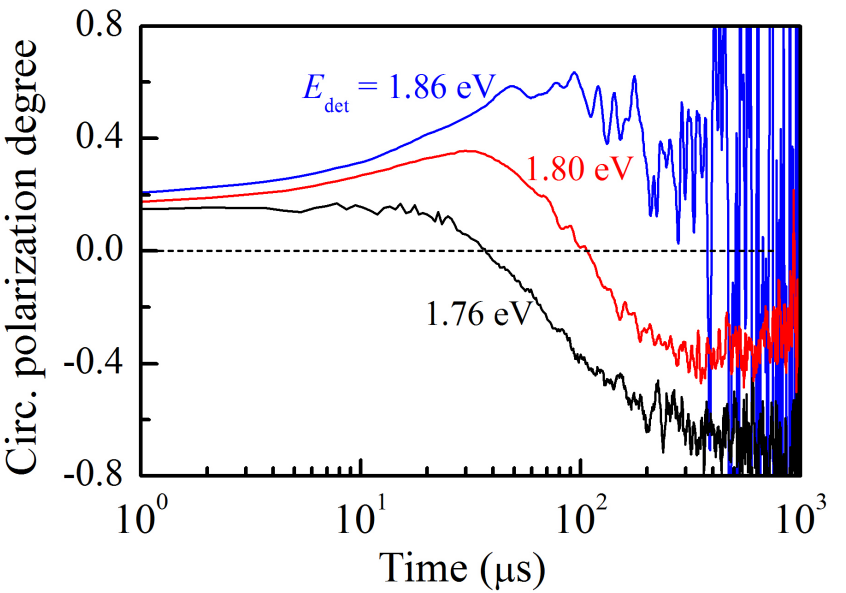
One acoustic phonon-assisted spin relaxation

Angle dependence of spin dynamics



- Crossing of PL decays for oppositely circular polarizations



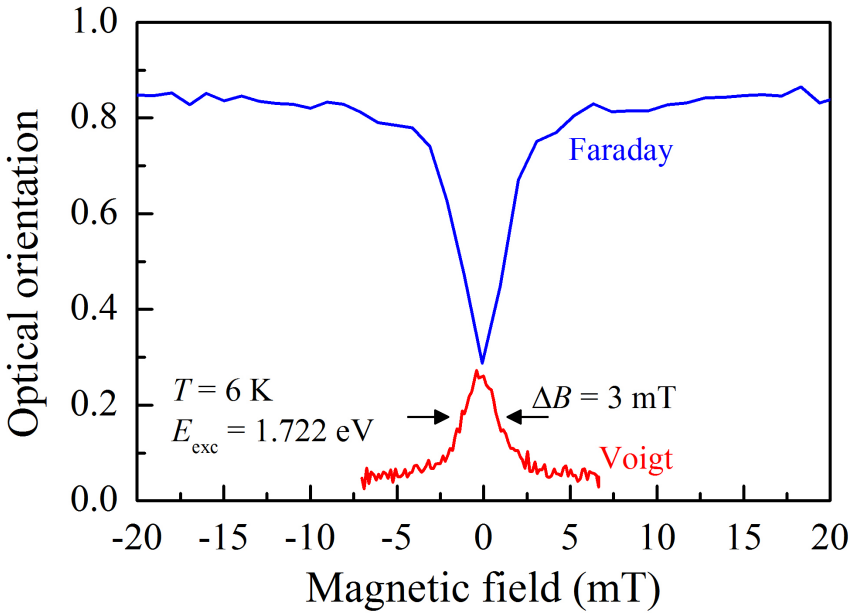


- Dependence on QD size

Assumption:

Mixing between dark and bright excitons having differently long spin dynamics

Optical orientation in low magnetic fields



- Resonant cw-excitation
- Nuclei spin fluctuations are stabilized in longitudinal fields
- Suppression of optically induced spin orientation by transverse magnetic fields
- Hanle curve: Spin lifetime given by ~ 2 ns

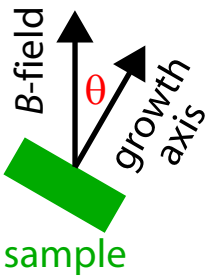
High optical orientation degree indicates long spin relaxation times compared to recombination dynamics

Conclusion

Indirect band-gap (In,Al)As/AlAs QDs

- High QD symmetry, weak carrier perturbations

→ Novel (In,Al)As QD ensembles have promising features, like long exciton recombination and spin-relaxation times



- Mixing between dark and bright excitons with differently long spin dynamics may account for crossing in circular polarization degree

Further studies on:

- Hyperfine interactions and exchange interactions in low magnetic fields