Dynamic nuclear polarization in InGaAs/GaAs and GaAs/AlGaAs quantum dots under non-resonant ultra-low power optical excitation

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Light-polarization-independent nuclear spin alignment in a quantum dot

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- Photoluminescence spectroscopy of dark and bright exciton states in neutral quantum dots

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❖ GaAs quantum dots: Modification of the low-power DNP due to electron-hole exchange interaction

Quantum dot samples and experimental conditions

- GaAs/AlGaAs interfacial dots formed by a monolayer fluctuations of GaAs quantum well in $Al_{0.3}Ga_{0.7}As$ barriers.
- Self-assembled InGaAs/GaAs dots.
- T=4.2 K.
- Magnetic field B_z up to 8 T applied normal to the sample surface.

Bright and dark states

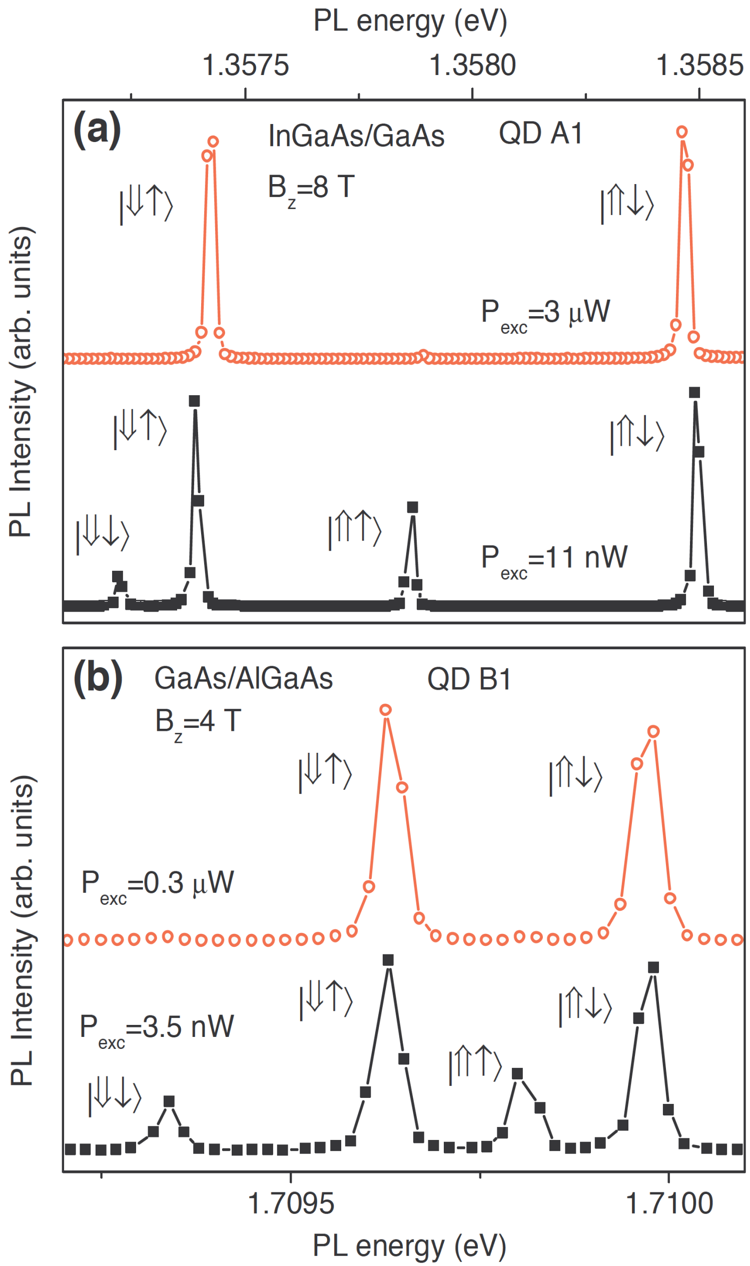
- Electrons $\uparrow(\downarrow)$ and heavy holes $\Uparrow(\Downarrow)$

- “dark” excitons $|\Uparrow\uparrow\rangle$, $|\Downarrow\downarrow\rangle$,

spin projection +2, -2;

- “bright” excitons $|\Uparrow\downarrow\rangle$, $|\Downarrow\uparrow\rangle$,

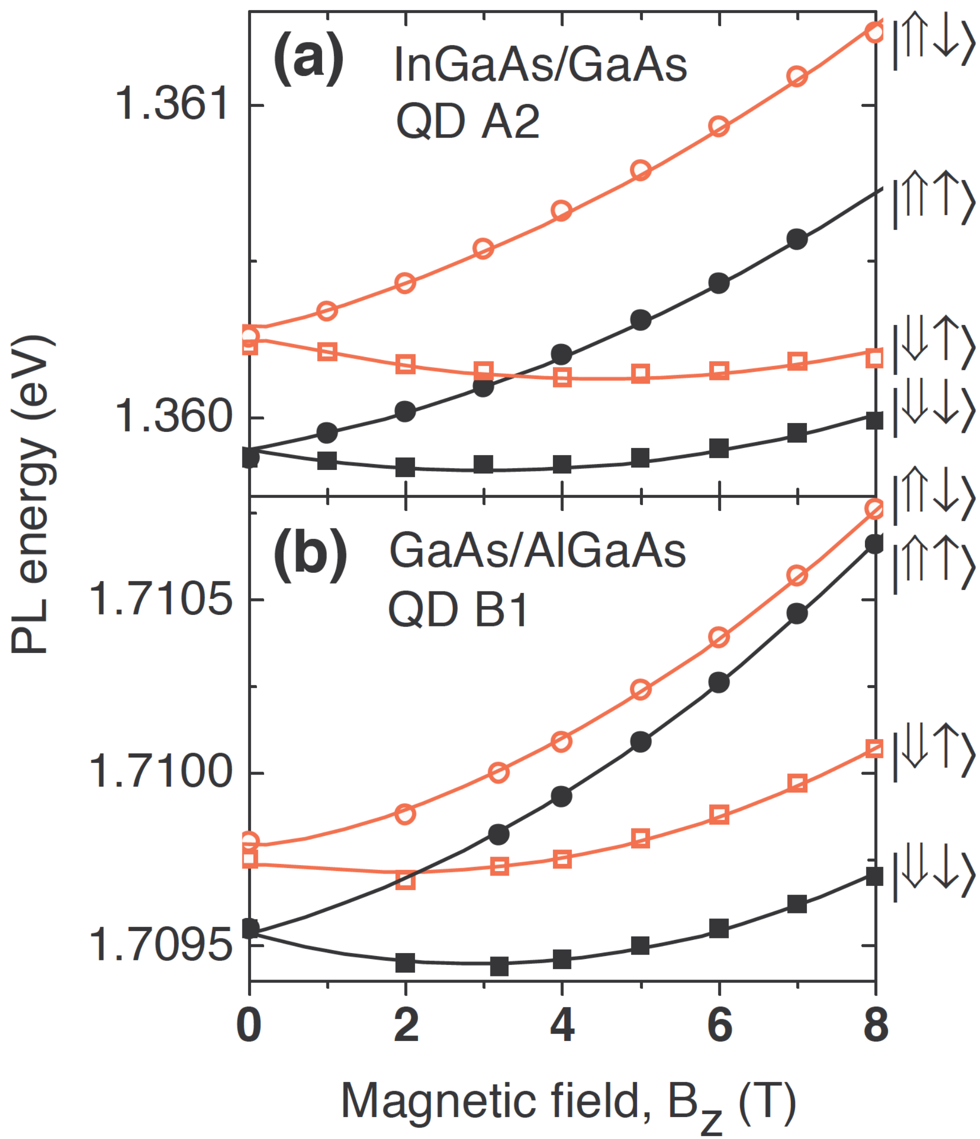
spin projection +1, -1.



Photoluminescence (PL) spectra measured in external magnetic field B_z=8 T (a) and B_z=4 T (b).

At ultra-low excitation powers all four (bright and dark) excitons are observed in PL.

At high powers PL of dark states is saturated and only bright states are observed.



Magnetic field dependence of exciton PL Energies in InGaAs QD (a) and GaAs QD (b).

Lines show fitting allowing electron and hole g-factor to be determined (??).

$$E_b = E_0 + \kappa B_z^2 + \frac{\delta_0}{2} \pm \frac{1}{2}\sqrt{\delta_b^2 + \mu_B^2 (g_h - g_e)^2 B_z^2},$$

$$E_d = E_0 + \kappa B_z^2 - \frac{\delta_0}{2} \pm \frac{1}{2}\sqrt{\delta_d^2 + \mu_B^2 (g_h + g_e)^2 B_z^2}$$

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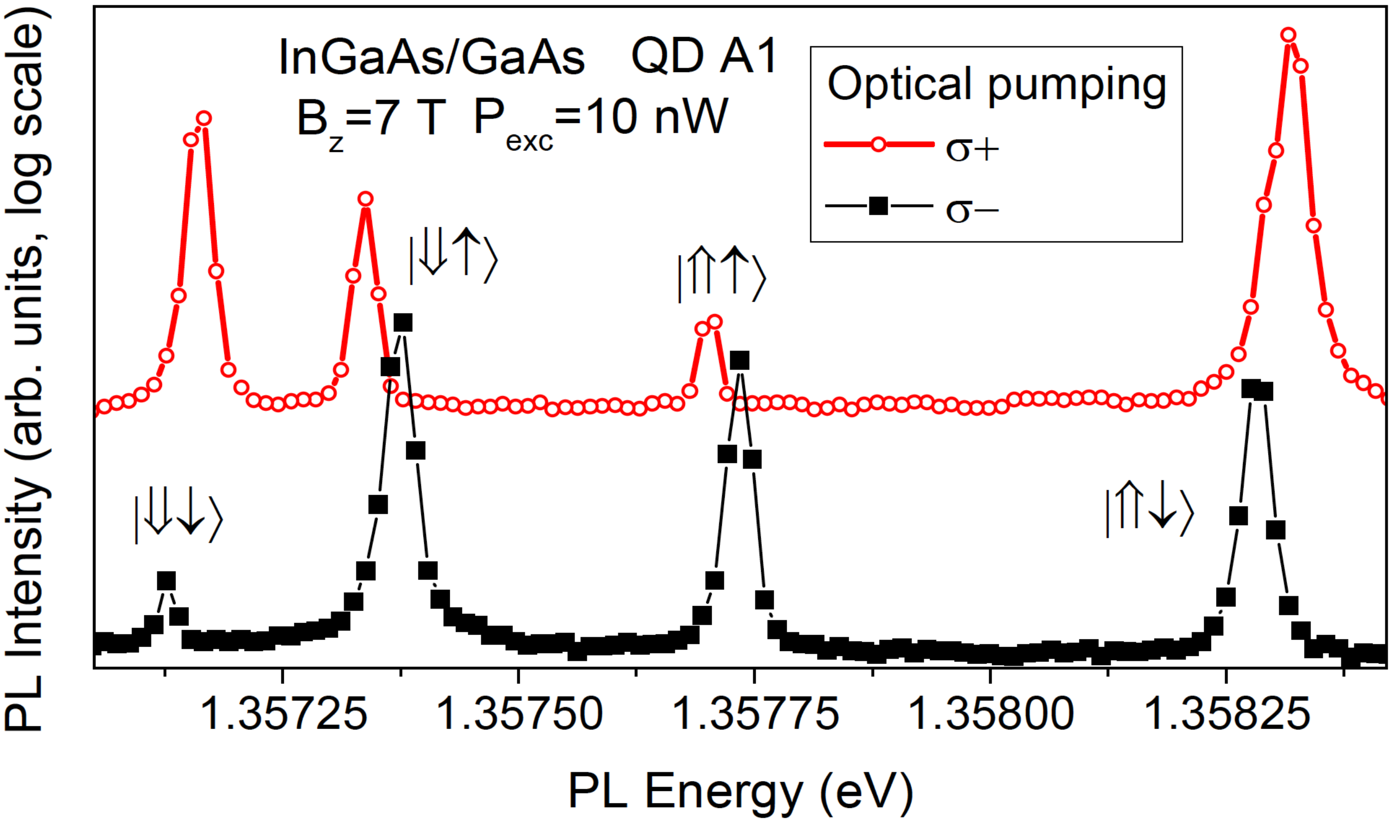
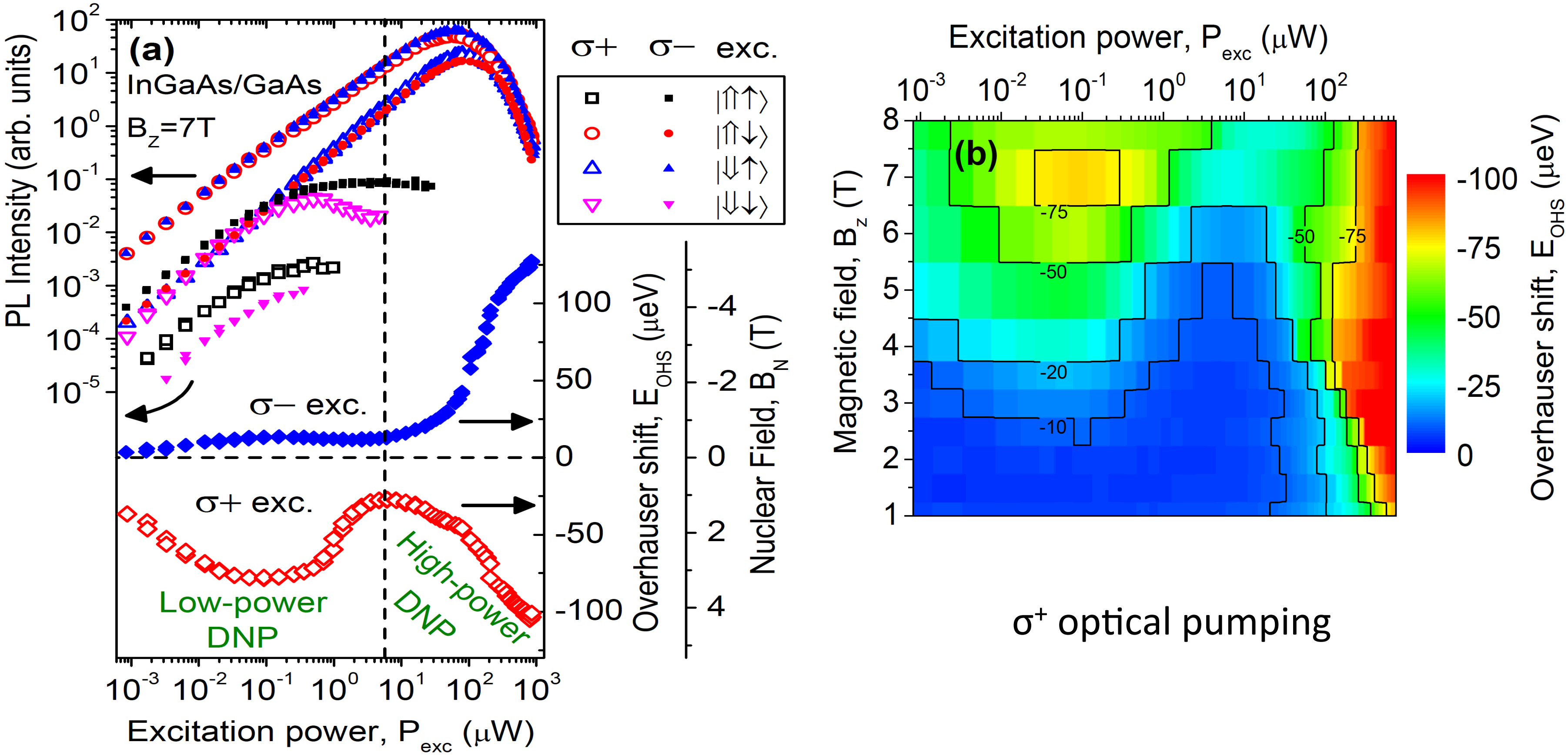
Detection of nuclear spin polarization using PL in a QD



Nuclear spin polarization shifts excitons with electron spin ↑(↓) to lower (higher) energies.

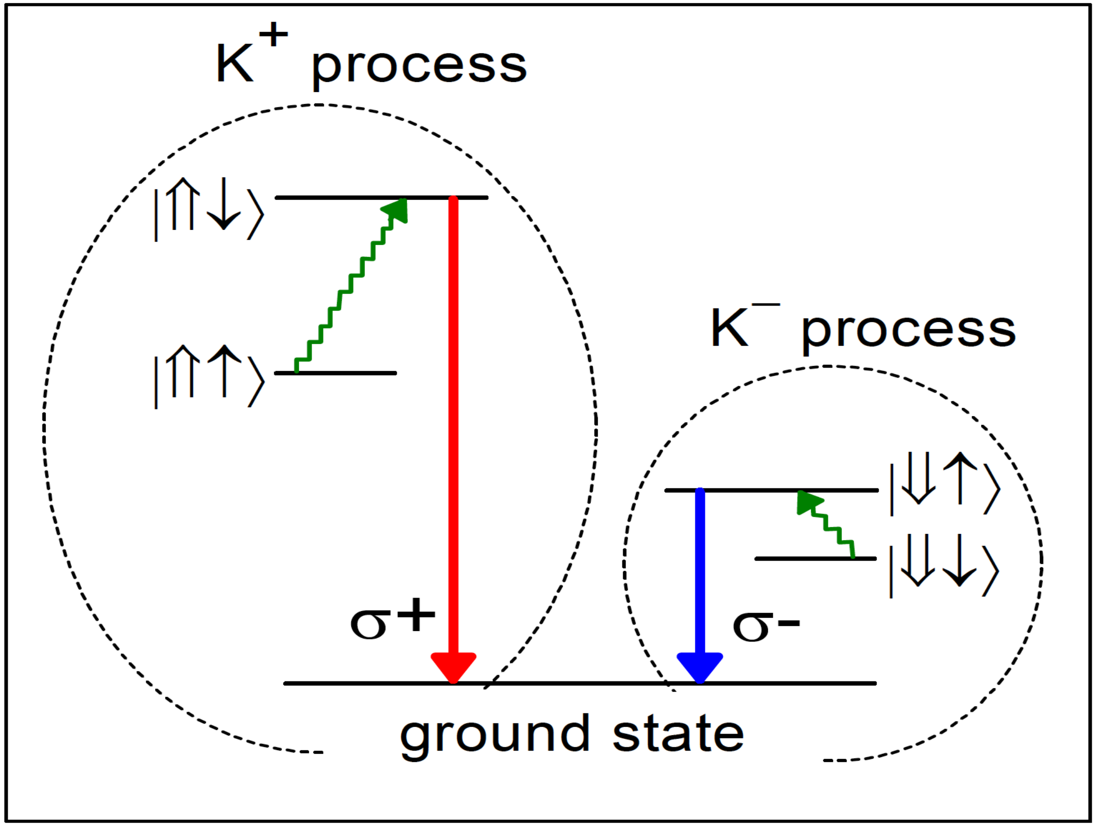
$$E_{OHS} = -(\Delta E_{|\Uparrow\downarrow\rangle,|\Downarrow\uparrow\rangle} - \Delta E^{B_N=0}_{|\Uparrow\downarrow\rangle,|\Downarrow\uparrow\rangle})$$

DNP in InGaAs quantum dots

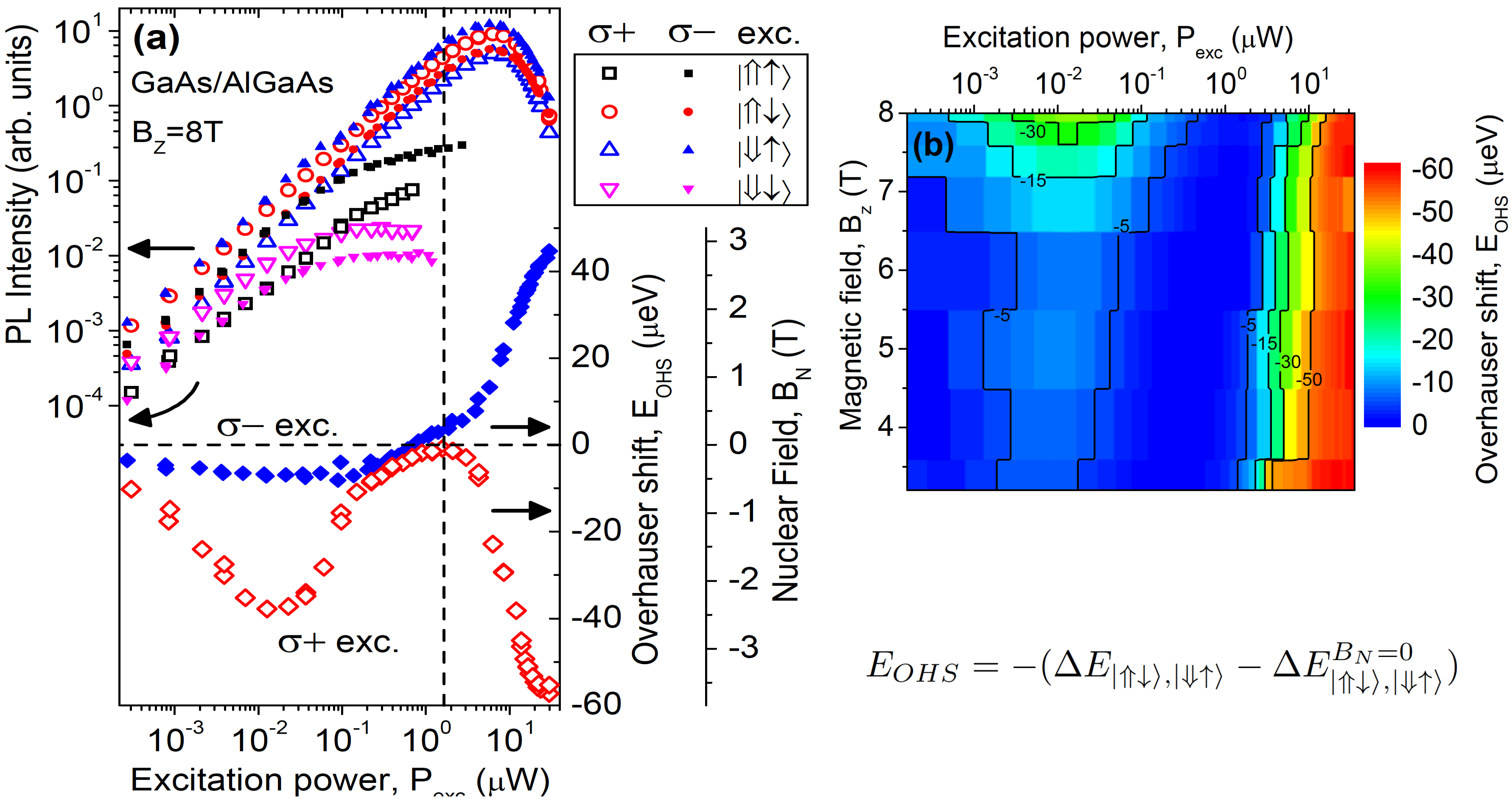


σ+ optical pumping

Energy level diagram of a neutral exciton in an InGaAs/GaAs QD at high magnetic field B_z



GaAs quantum dots: Modification of the low-power DNP due to electron-hole exchange intraction



$$E_{OHS} = -(\Delta E_{|\Uparrow\downarrow\rangle,|\Downarrow\uparrow\rangle} - \Delta E^{B_N=0}_{|\Uparrow\downarrow\rangle,|\Downarrow\uparrow\rangle})$$

Conclusions

- Nuclear spin pumping via second-order recombination of dark neutral excitons previously observed in InP/GaInP dots has a general nature and is found in InGaAs/GaAs and GaAs/AlGaAs dots.

- In InGaAs dots low-power optical pumping is found to lead to large Overhauser shifts up to 80 μeV.

- In GaAs dots low-power DNP is found to be less efficient than in InGaAs dots. It is attributed to the dark-bright exciton mixing stemming from the low-symmetry electron-hole exchange interaction.

- Varying the magnitude of the dark-bright mixing in different individual GaAs/AlGaAs dots leads to variations in the magnitude of the Overhauser shift including the change of its sign.