Spin coherence of electrons and holes in ZnSe-based quantum wells

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SAMPLES: A. Waag and W. Faschinger,
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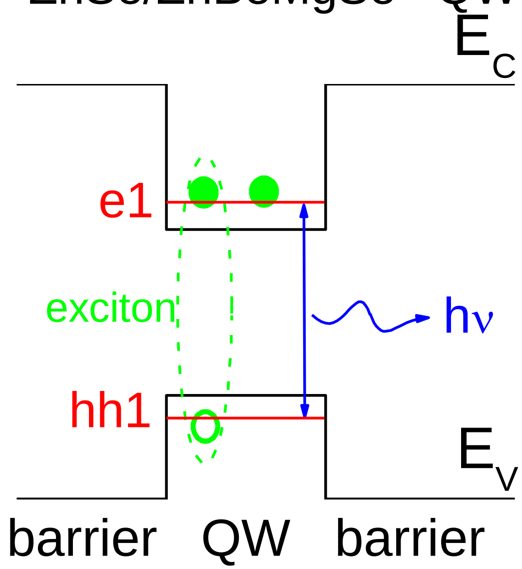
MARIE CURIE ACTIONS

RESEARCH EXECUTIVE AGENCY

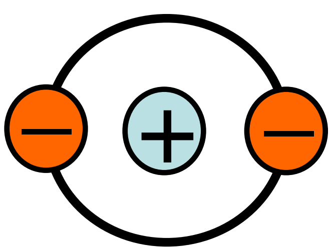
Outline

- Long-lived spin beats in n-type and p-type doped QWs by pump&probe Kerr rotation
- Mechanisms of carrier spin dephasing
- Anisotropy of electron and hole g-factors measured with vector magnet

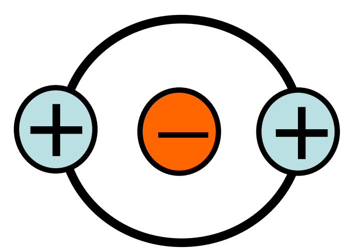
ZnSe/ZnBeMgSe QW



Low-dense carrier gas, charged excitons (trions)



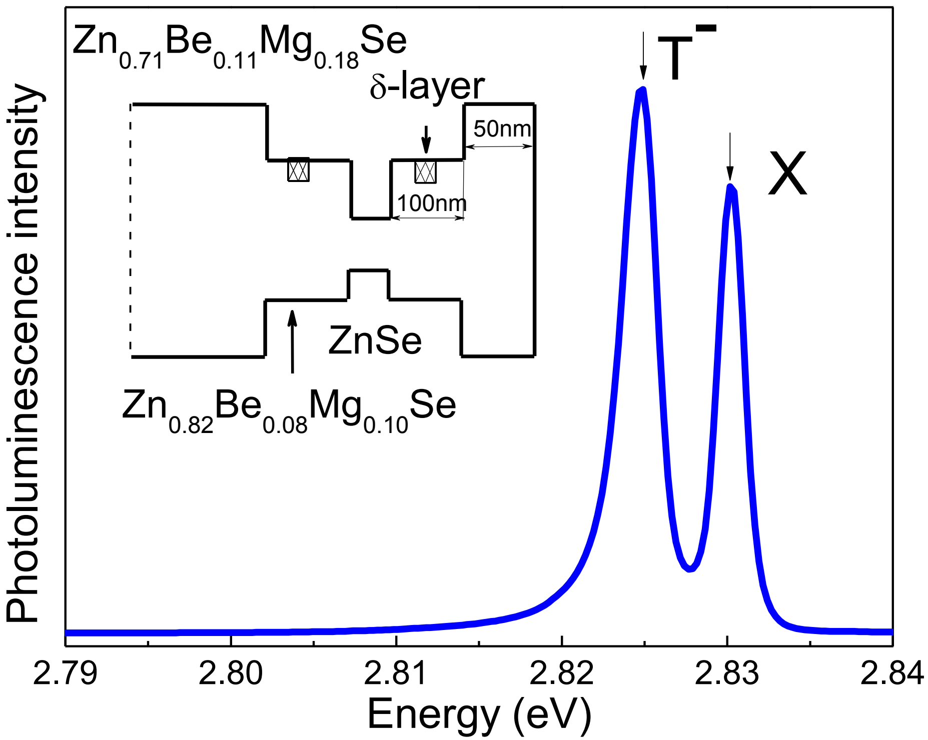
Negatively charged trion, T^-



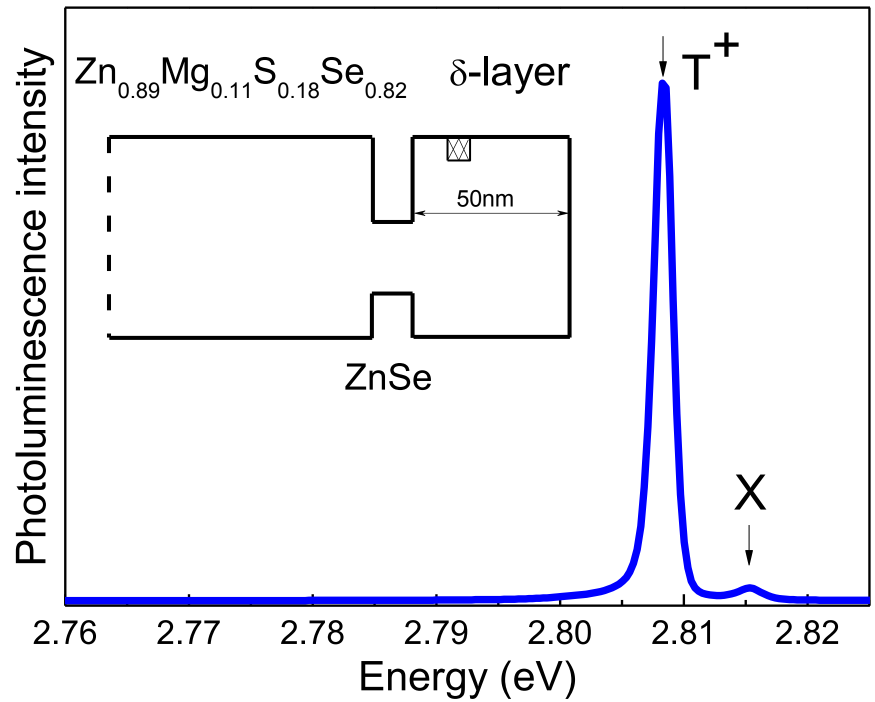
Positively charged trion, T^+

ZnSe QWs with strong Coulomb interaction

n-type, 67 Å ZnSe/ZnBeMgSe QW
$n_e = 3 \times 10^{10}$ cm^{-2}



p-type, 80 Å ZnSe/ZnMgSSe QW
$n_h = 1 \times 10^{10}$ cm^{-2}



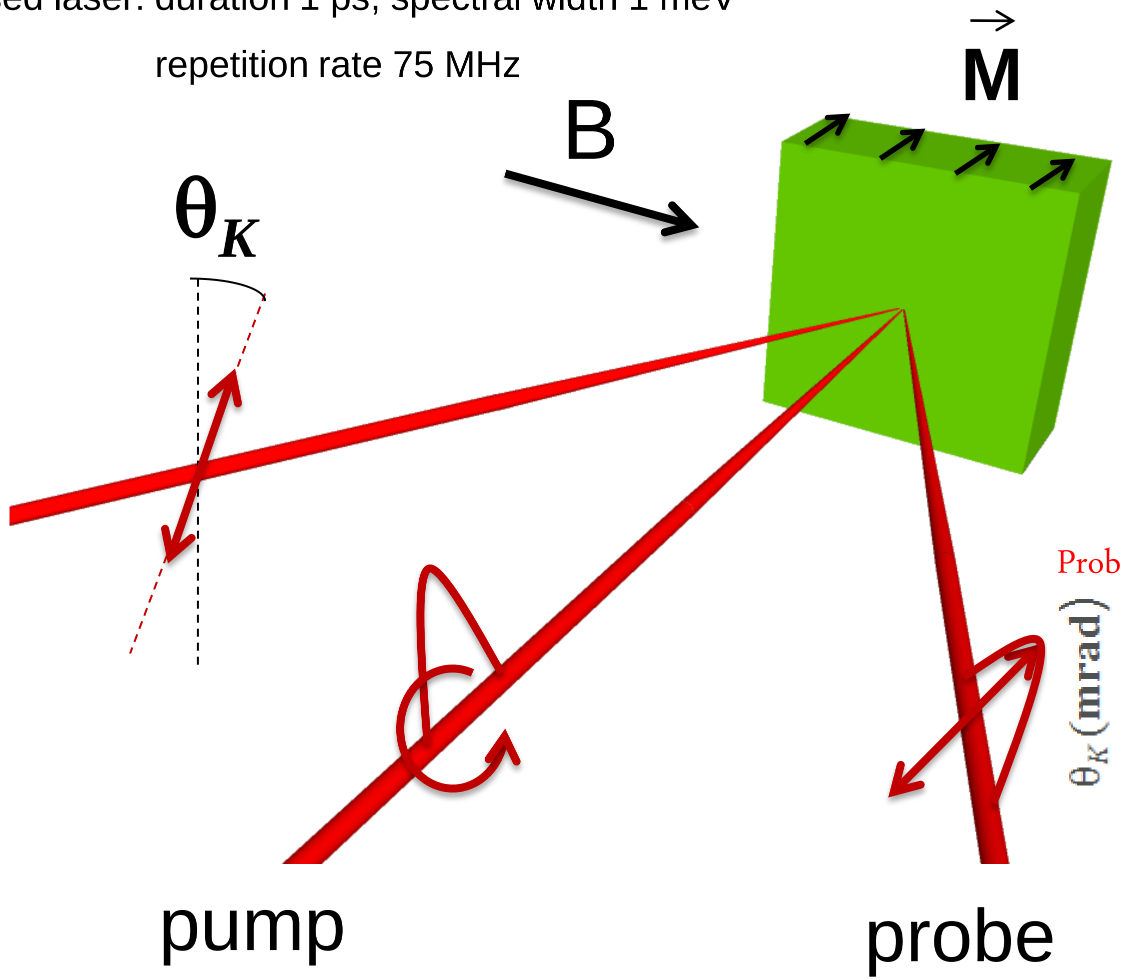
Carrier concentration is tuned by above-barrier illumination.

p-type can be converted to n-type

Detection of spin dynamics: Pump - Probe Kerr rotation

Pulsed laser: duration 1 ps, spectral width 1 meV

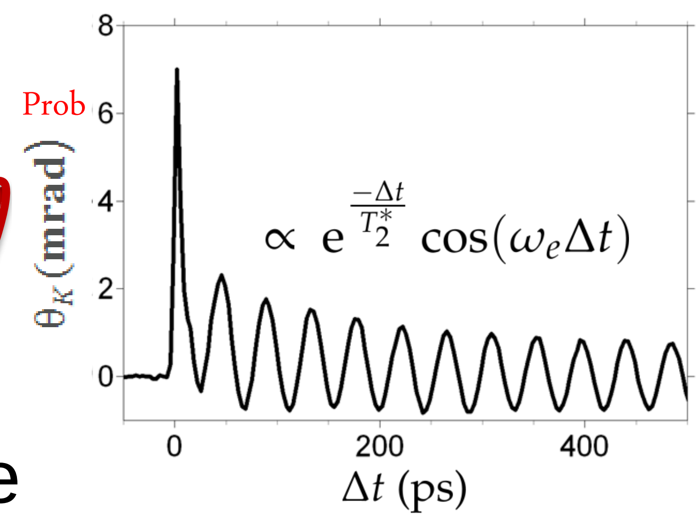
repetition rate 75 MHz



Kerr rotation

- Magnetization rotates plane of polarization

Signal $\propto \vec{M} \cdot \vec{k}_{\text{probe}}$



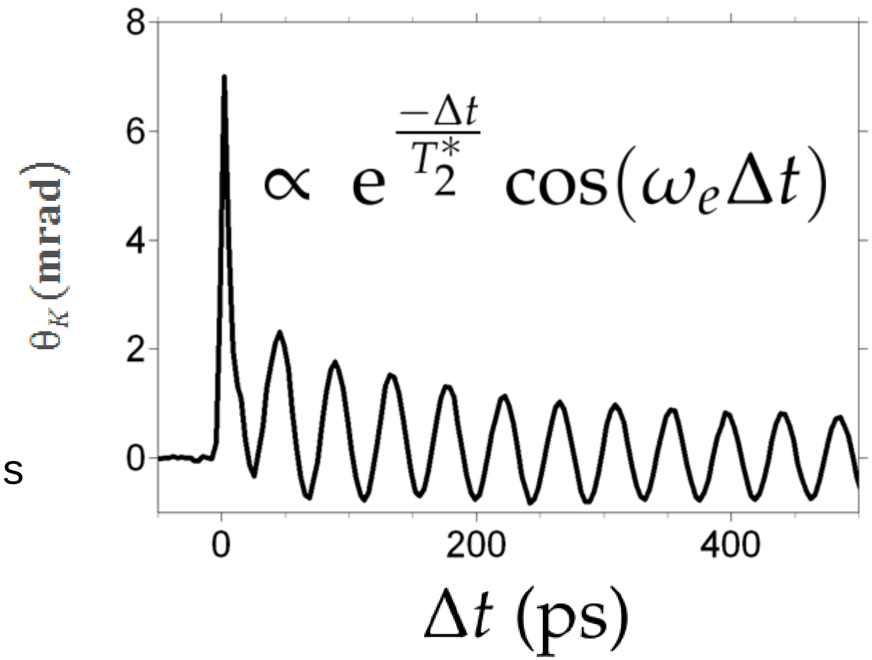
Spin coherence of carrier ensemble

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_{inh}(\Delta g)}$$

Spin dephasing

Decoherence of individual electron

Inhomogeneous dephasing



Larmor spin precession in magnetic field

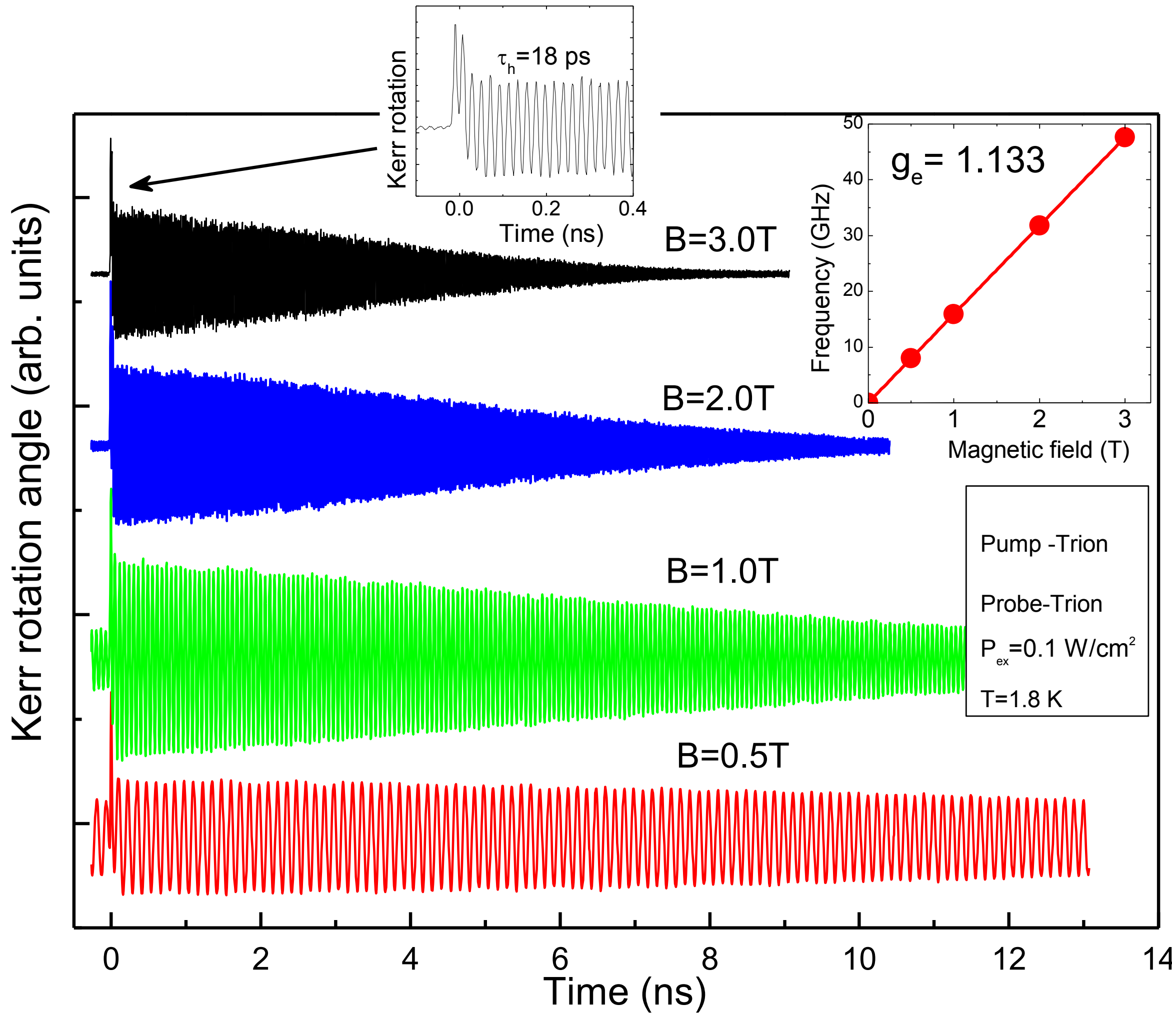
$$\omega_L = \frac{\mu_B\, g\, B}{\hbar}$$

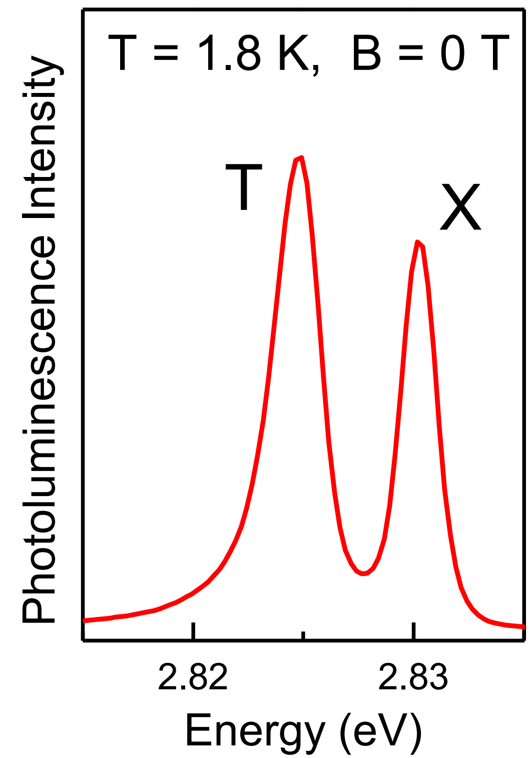
$$\frac{1}{T_{inh}(\Delta g)} = \frac{\Delta g \mu_b B}{\sqrt{2}\hbar}$$

Electron spin coherence in ZnSe QWs

n-doped 67 Å ZnSe/ZnBeMgSe

$n_e = 3\times10^{10}$ cm^{-2}





Electron spin dephasing longer than 30 ns.

Resonant Spin Amplification (RSA) technique

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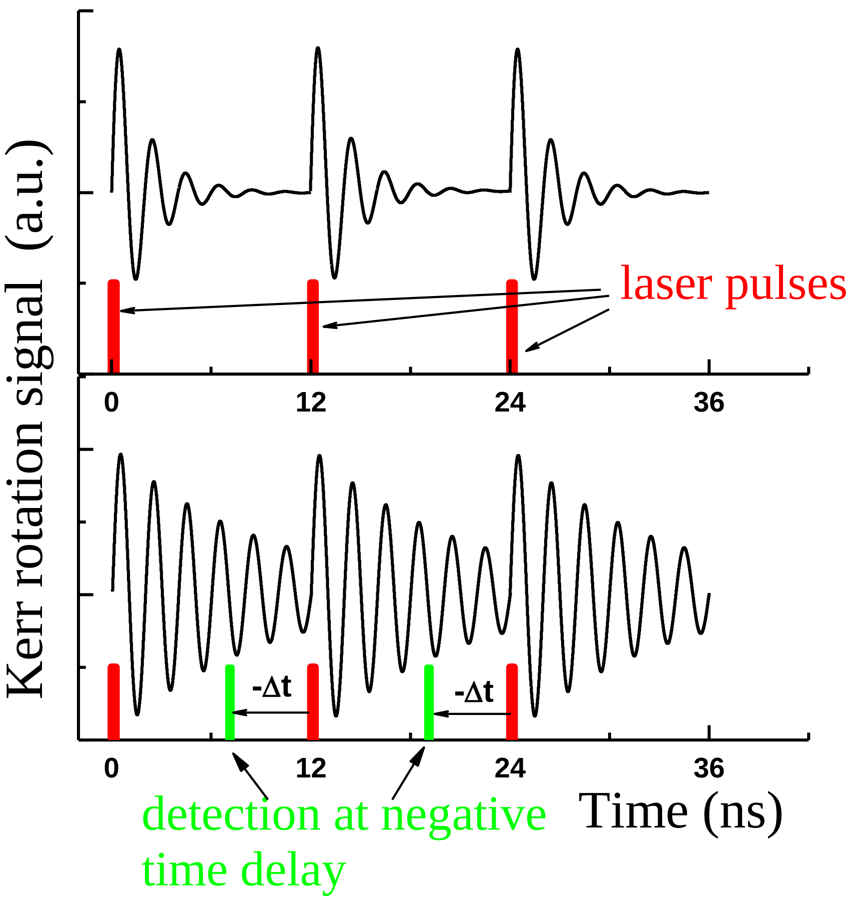
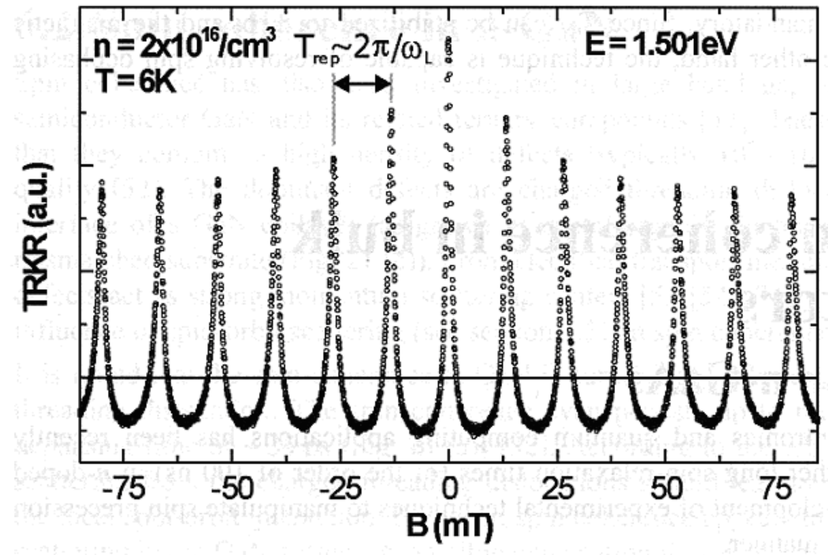




150 ns, n-doped GaAs

Kikkawa, Awschalom PRL 80, 4313 (1998)

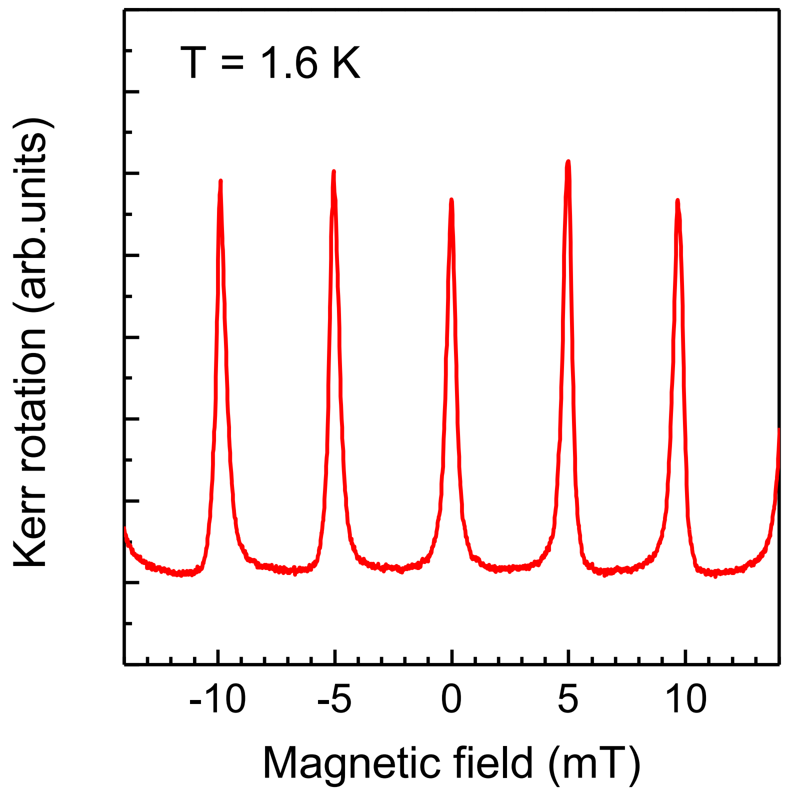
10 ns, GaAs QW, Dzhioev PRB 66 (2002).

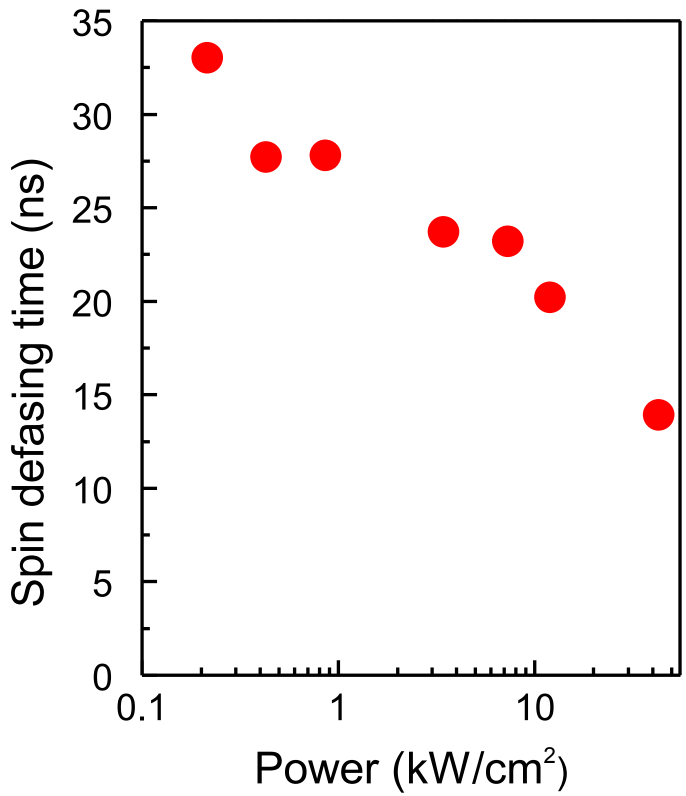
300 ns, GaAs bulk, Dzhioev PRB 66 (2002).

Electron spin coherence in ZnSe QWs

Resonant spin amplification

67 Å n-doped ZnSe/ZnBeMgSe QW
$n_e = 3\times10^{10}$ cm^{-2}





Electron localization favours

long spin dephasing time of 30 ns

4 ns ZnCdSe/ZnSe QW, Kikkawa, Science 1997

6 ns type-II ZnSe/BeTe QW, Mino, APL 2008

Spin coherence time vs bath temperature

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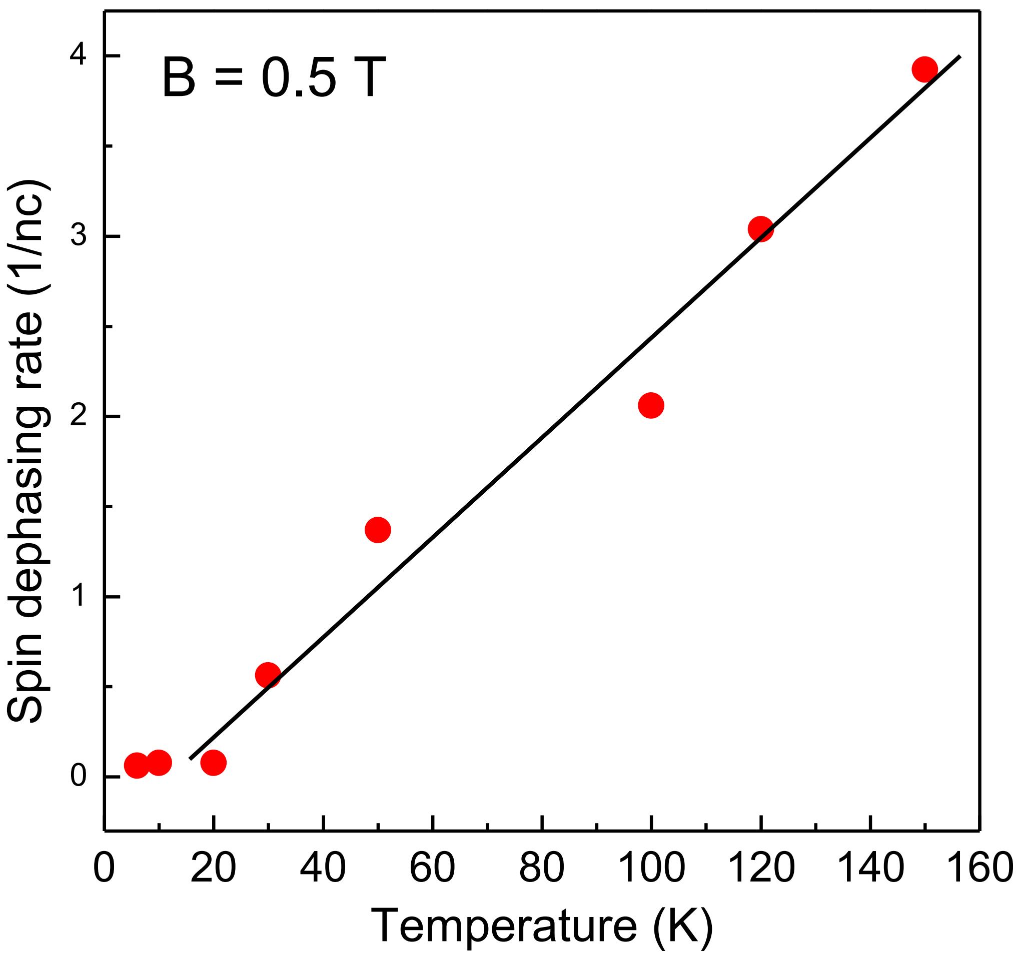
67 Å n-doped ZnSe/ZnBeMgSe QW

$n_e = 3\times10^{10}$ cm^{-2}



Dyakonov-Perel relaxation of electrons in QWs for T > 15 K.

$$\frac{1}{\tau_S} \propto T \times \tau_p(T)$$

At T < 15 K fluctuations of nuclear field contribute to spin relaxation of localized electrons.

Hole spin dephasing

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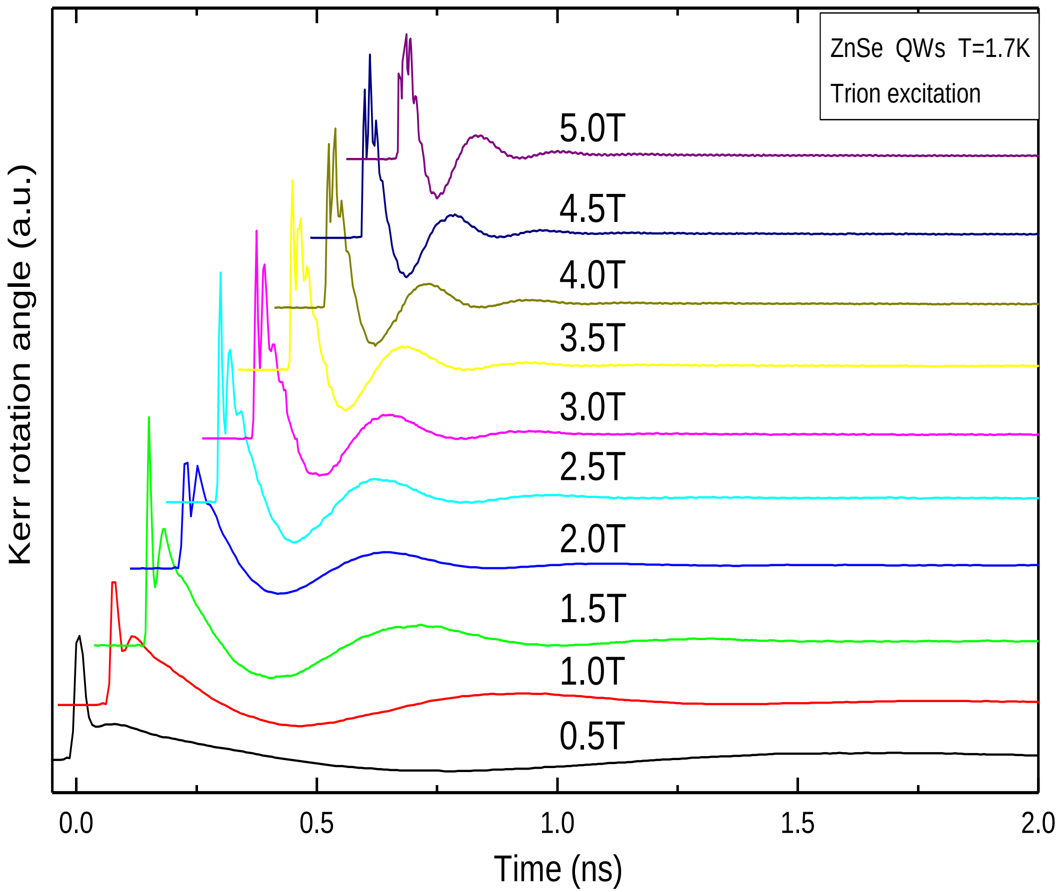
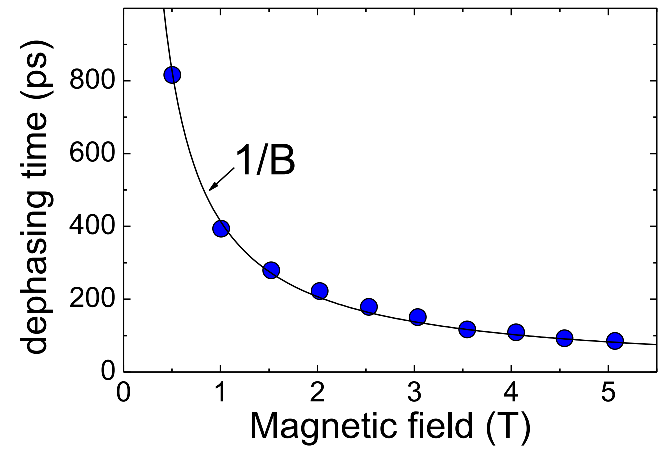
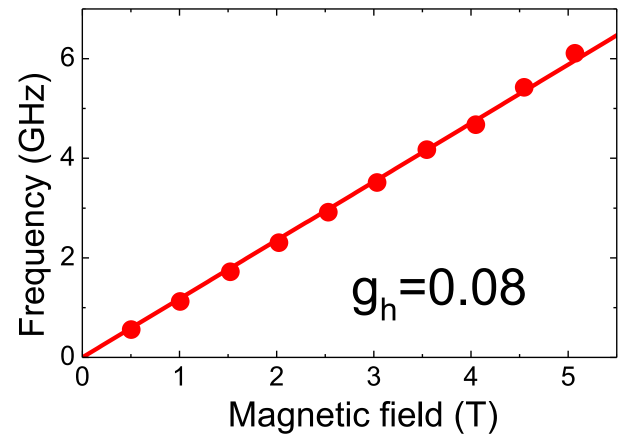
p-type, 80 Å ZnSe/ZnMgSSe QW

$n_h = 1 \times 10^{10}\ cm^{-2}$





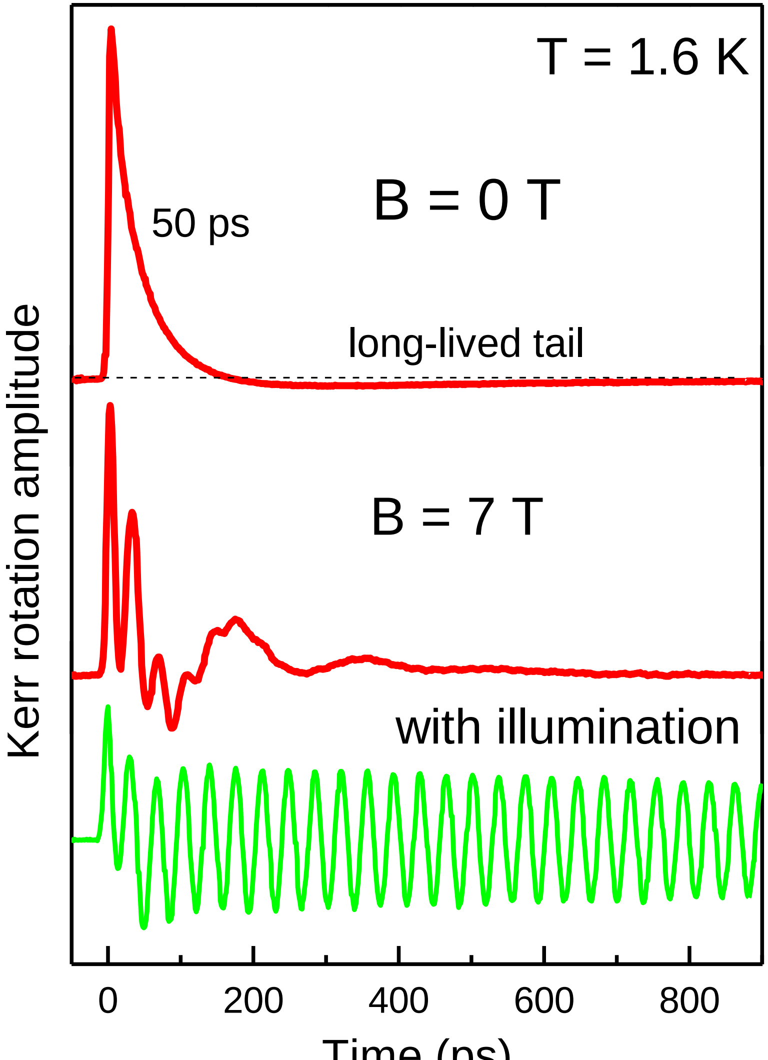


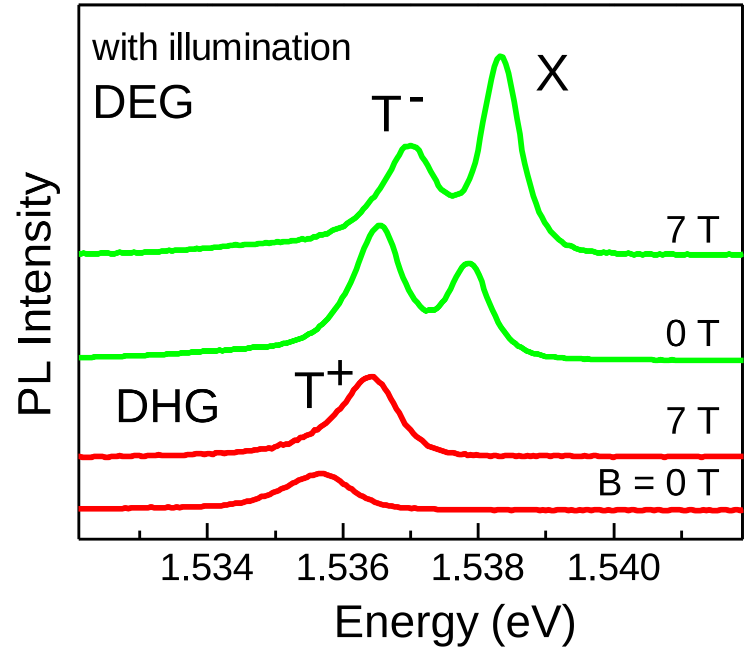
Hole spin dephasing longer 800 ps

Spin coherence of holes and electrons

p-doped GaAs/AlGaAs quantum well

$n_h = 1.5 \times 10^{11}\ cm^{-2}$





Carrier concentration is tuned

by above-barrier illumination.

p-type can be converted to n-type

Syperek, PRL 99, 187401 (2007)

Transformation from p-type to n-type

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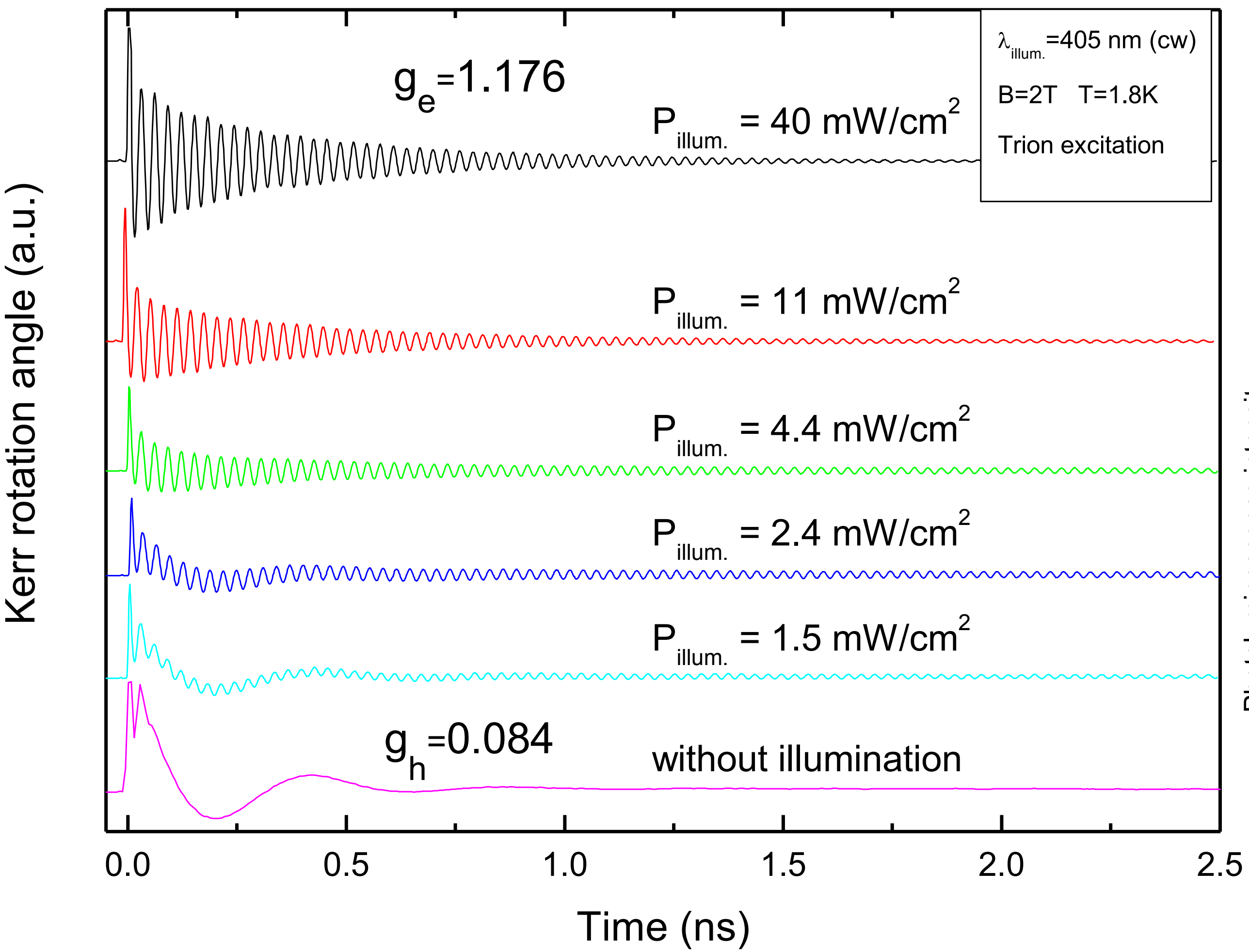
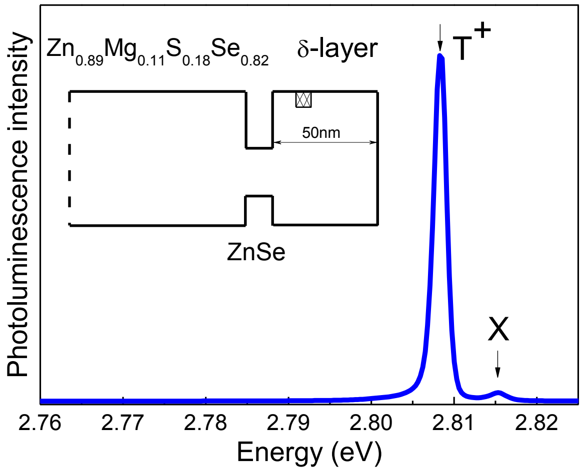
p-type, 80 Å ZnSe/ZnMgSSe QW
n_h = 1 x 10 ^{10} cm^{-2}

Above-barrier illumination
with a photon energy 3.06 eV





Anisotropy of hole g-factor

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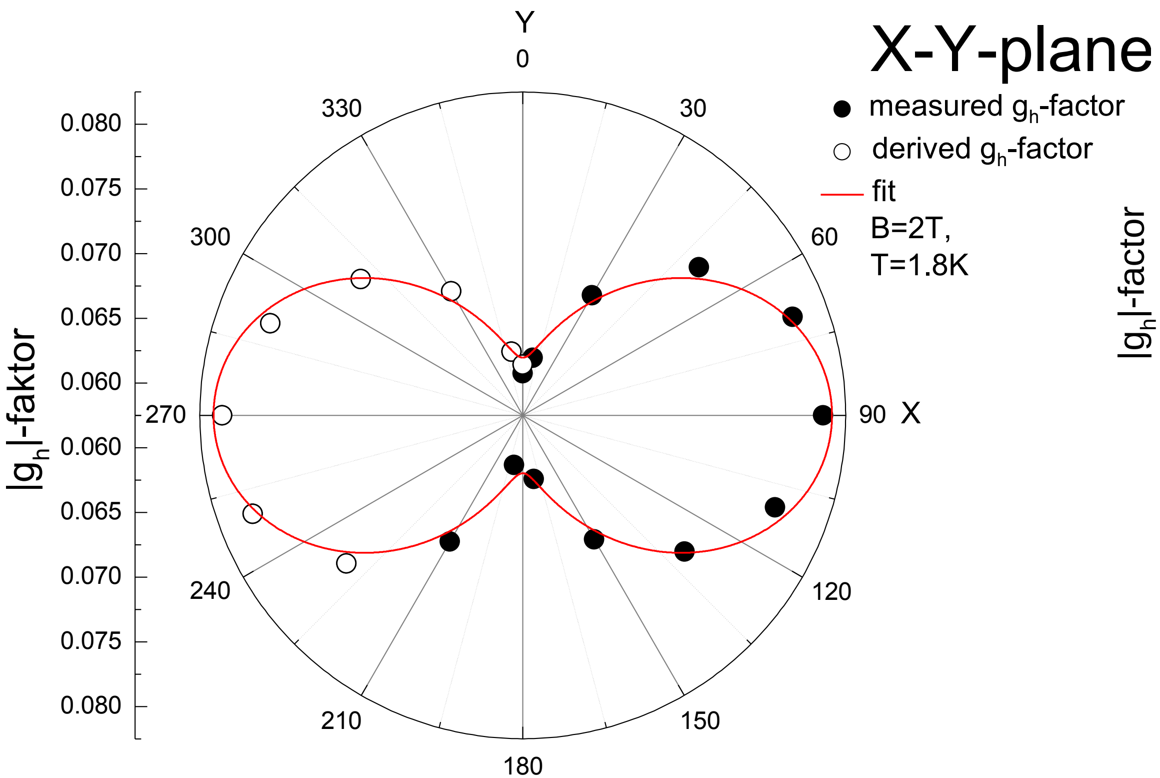
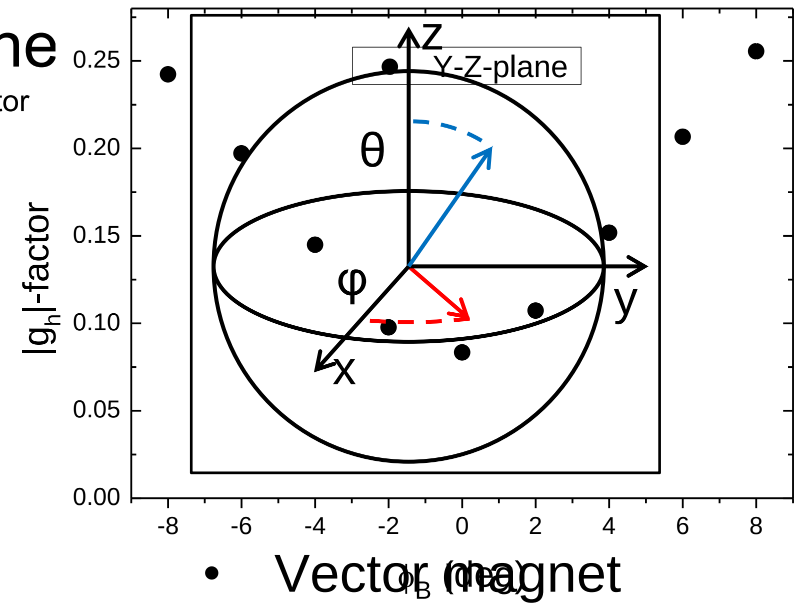
80 Å ZnSe/ZnMgSSe QW, p-type

$n_h = 1 \times 10^{10}$ cm^{-2}



$$|g| = \sqrt{(g_x \cos \varphi)^2 + (g_y \sin \varphi)^2}$$



- Vector magnet allows full 360° field rotation of 3 T
- 1.5-300 K variable temperature

hole g-factor:

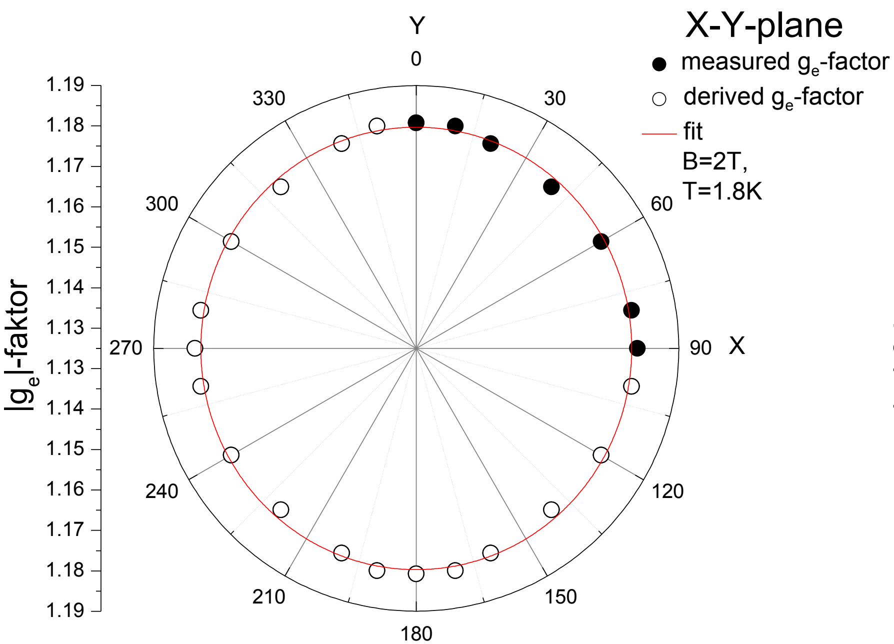
$|g_x| = 0.081$

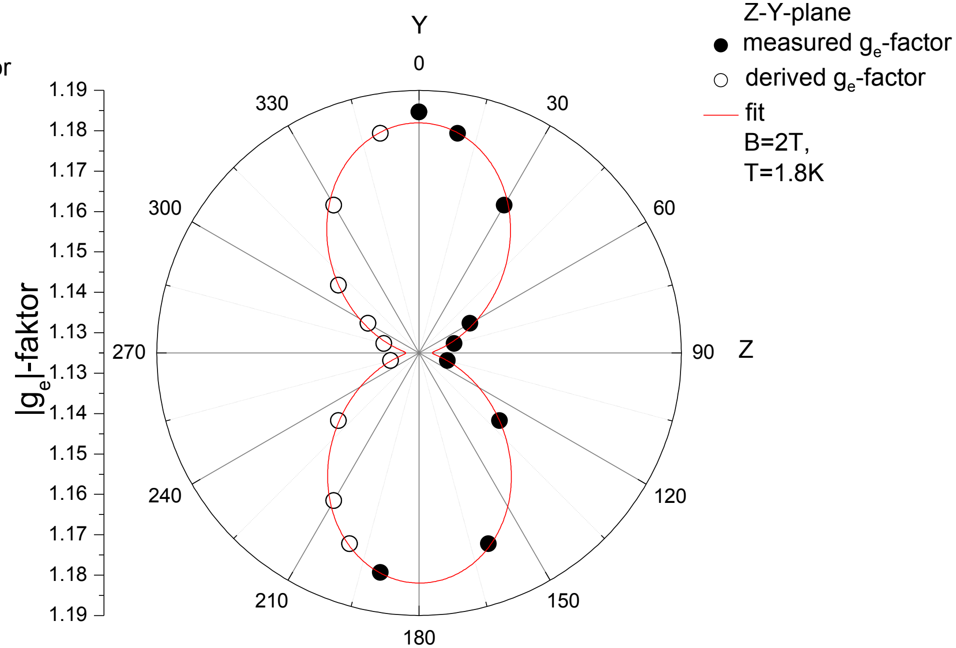
$|g_y| = 0.061$

$|g_z| \approx 1.805$

Anisotropy of electron g-factor

80 Å ZnSe/ZnMgSSe QW, p-type
$n_h = 1 \times 10^{10}\ cm^{-2}$





electron g-factor:

$$|g_x| = 1.179$$
$$|g_y| = 1.180$$
$$|g_z| = 1.129$$

Resonant spin amplification in n-InGaAs QWs

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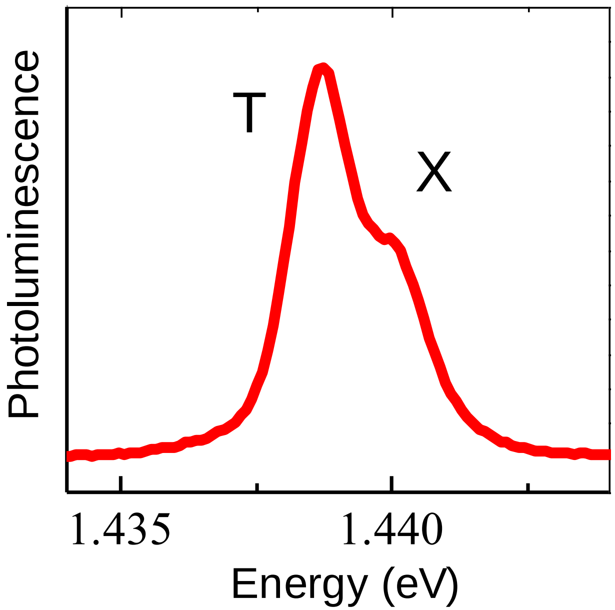
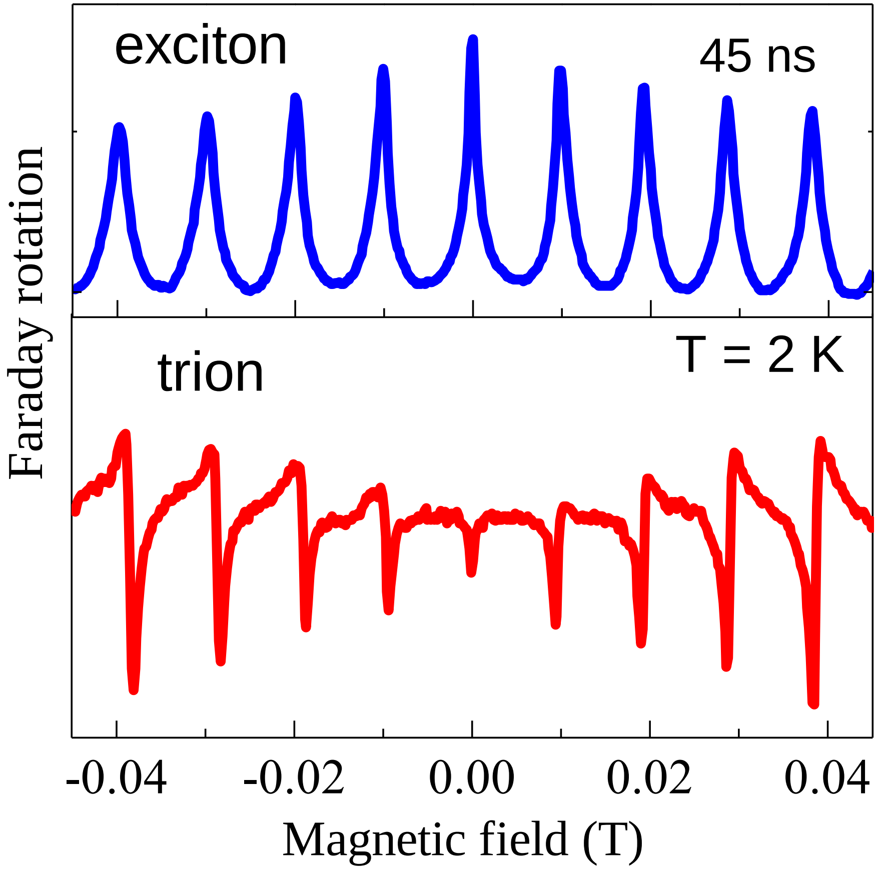
8 nm InGaAs/GaAs QW

$n_e = 10^{10}$ cm^{-2}





Electron spin dephasing time 45 ns.

Unusual shape of RSA spectrum measured at trion.

Yugova, PRL 102, 167402 (2009)

Spin relaxation of electrons
Hanle effect vs Kerr beats

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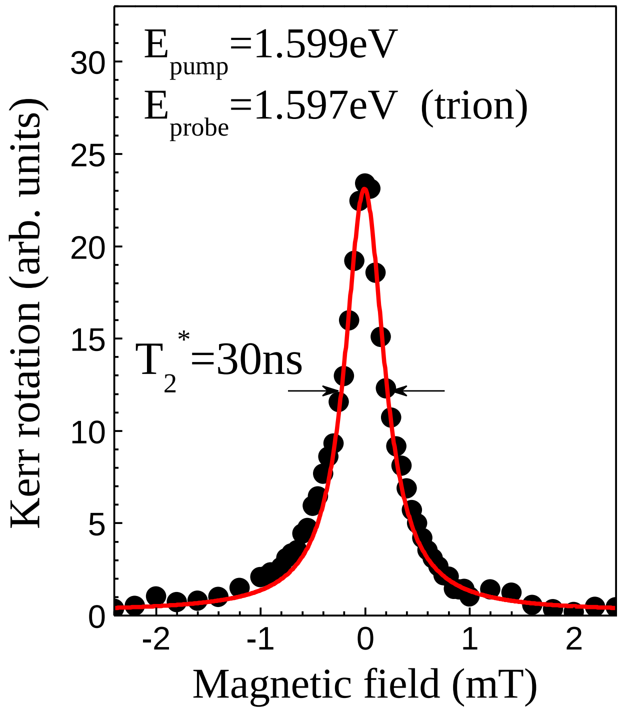
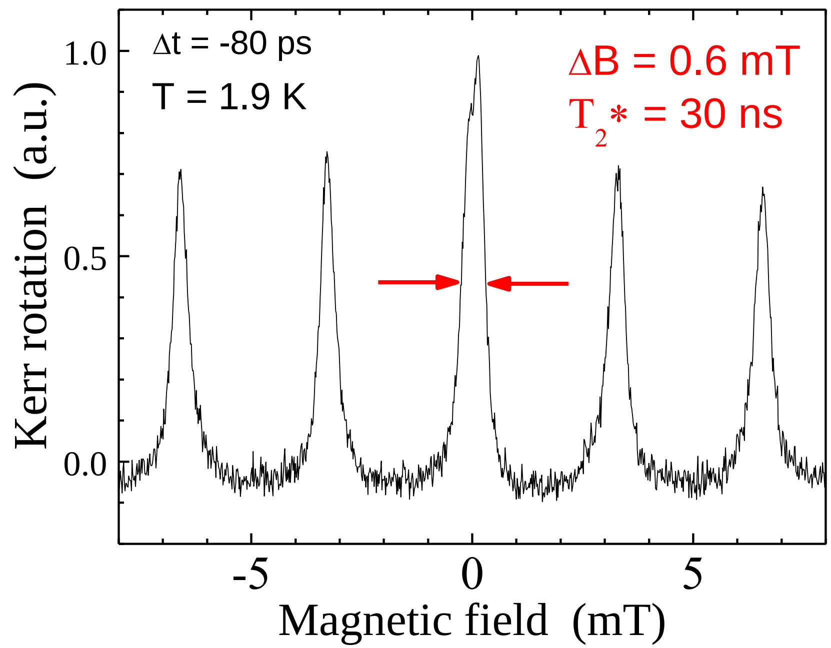
200 Å CdTe/CdMgTe MQW $n_e = 5\times10^9$ cm^{-2}

cw excitation



Hoffmann, PRB 74, 073407 (2006)

ps-pulsed excitation



Zhukov, phys.stat.sol.(b) 243, 878 (2006)

The same spin dephasing times are measured under pulsed and continuous wave excitation.

SUMMARY

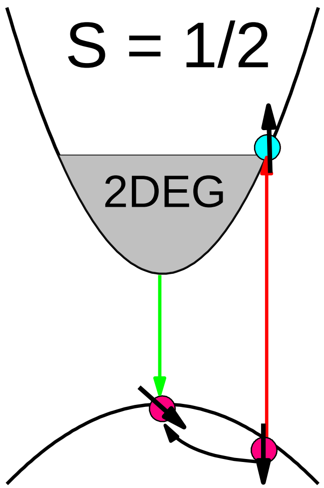
Electron spin dephasing	GaAs/AlGaAs	10 ns
	CdTe/CdMgTe	30 ns
	ZnSe/ZnBeMgSe	30 ns
	InGaAs/GaAs	55 ns

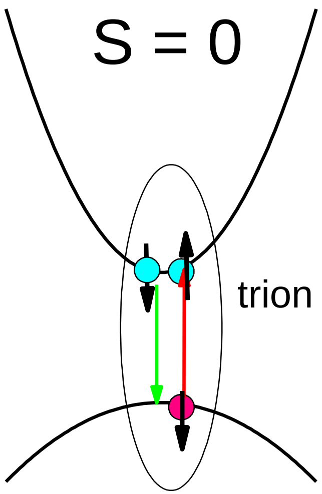
Is the electron-nuclei interaction the only limiting mechanism for localized electrons at low temperatures?

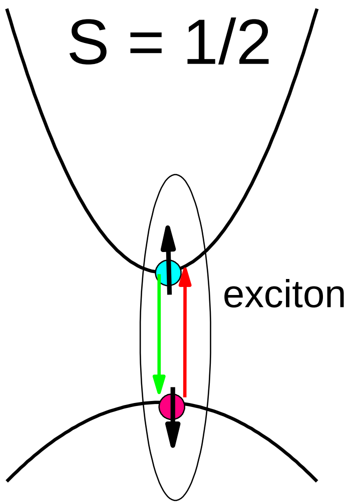
Hole spin dephasing	GaAs/AlGaAs	> 650 ps , p-doped.
	CdTe/CdMgTe	> 450 ps, p-doped.
	ZnSe/ZnBeMgSe	> 800 ps, p-doped.
	InGaAs/GaAs	> 2 ns , n-doped.

Generation of spin coherence

High density 2DEG	Low density 2DEG	undoped



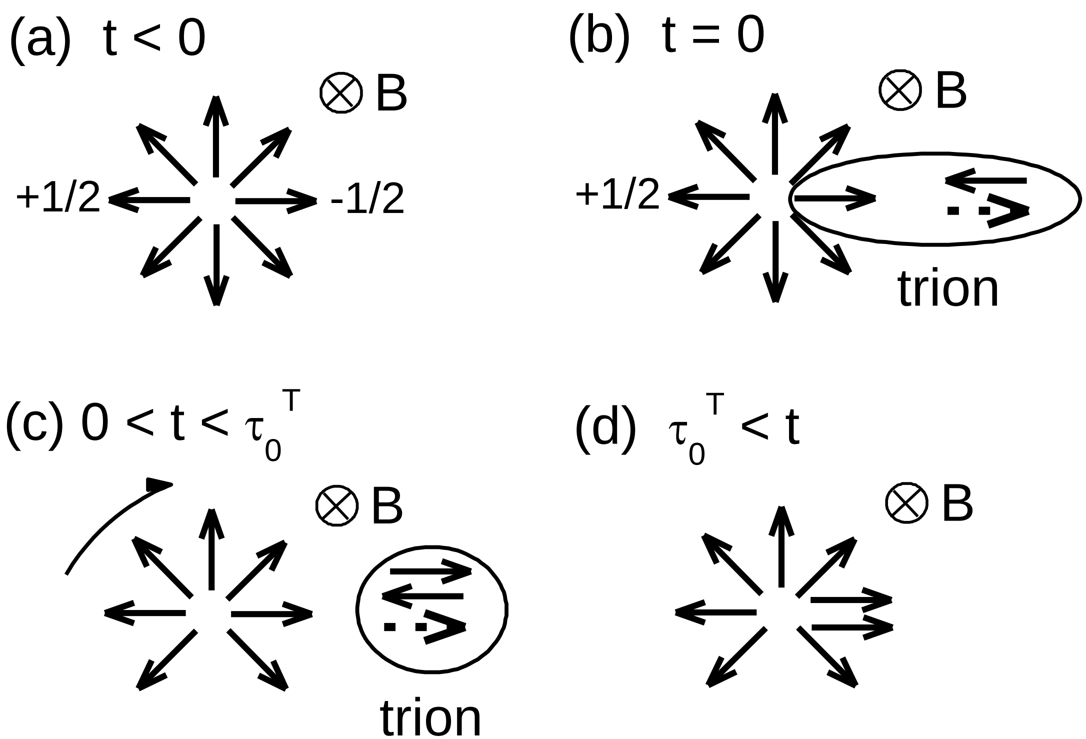




Long-lived spin beats of 2DEG	No beats	Beats of electron in exciton, < 30-100 ps

Problem: How the spin coherence is excited in low density 2DEG?

Mechanism of generation spin coherence in magnetic fields



External magnetic field provides electron spin precession,

but not the trion spin (zero in-plain heavy-hole g-factor)

Zhukov, PRB 76, 205310 (2007)