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# Acceleration of the spin-lattice relaxation in (Zn,Mn)Se/(Zn,Be)Se quantum wells by cross-relaxation of Mn cluster spin-levels

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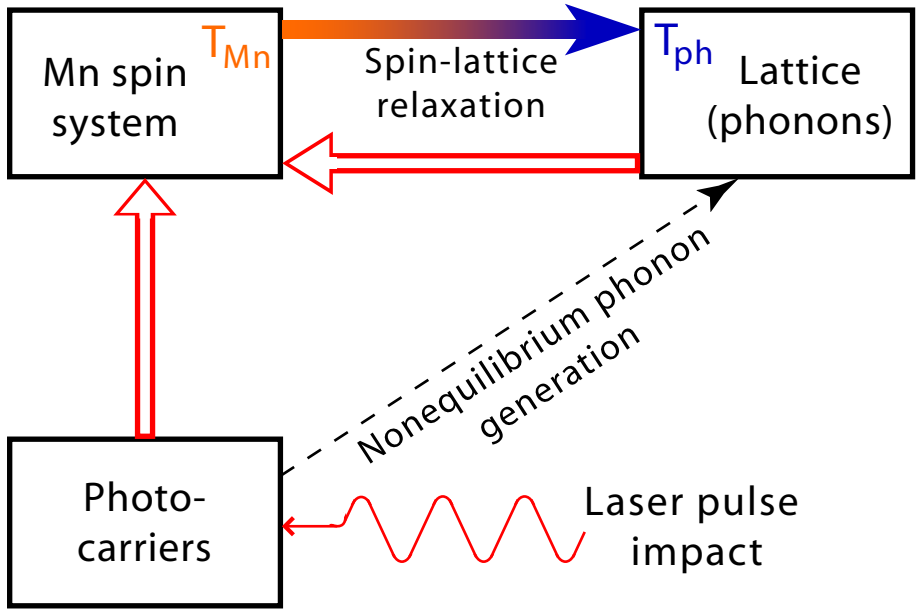
# Introduction

- Diluted magnetic semiconductors (e. g. ZnMnSe)
  - → Tunability of lattice parameter and energy gap
  - → Magnetic effects (e. g. giant Zeeman effect)
  - → Promising materials for spintronic devices
- Spin system of magnetic ions
  - → Heating of spin system by photogenerated carriers

- Systems responsible for spin dynamics in Mn-based DMS



- What does spin-lattice relaxation mean ?

→ Mn spin system goes into equilibrium state with lattice

$T_{Mn} \rightarrow T_{ph}$

→ Spin and energy transfer via

spin-spin interactions between Mn ions and
spin-phonon interactions

→ Waller-Mechanism:

Lattice vibrations change Mn ion distance

Local magnetic fields induce spin level transitions

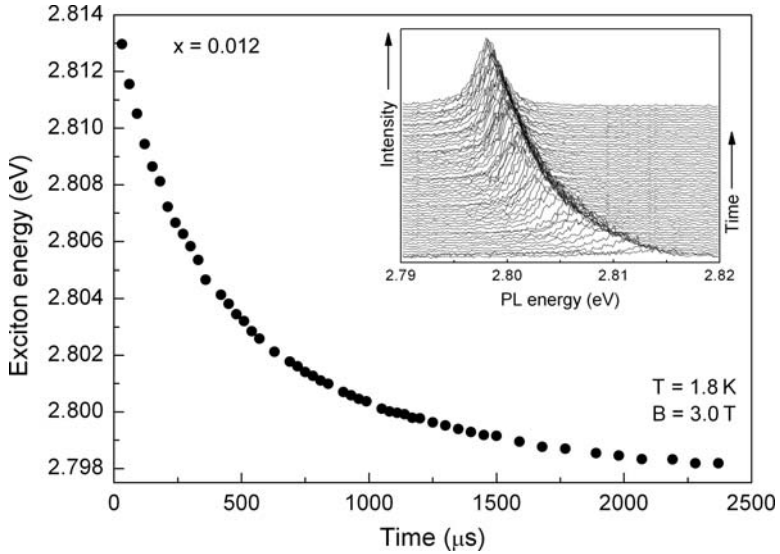
- How can we get information about SL interaction ?

→ Photoluminescence of electron-hole recombination in QW

Direct and indirect approach:

→ Time-resolved PL

$E(t) \sim \exp(-t/\tau_{SLR})$




→ Time-integrated PL

Giant Zeeman shift:

$E(B) = E(0) + \text{const.} \cdot B_{5/2}(B/T_{Mn})$

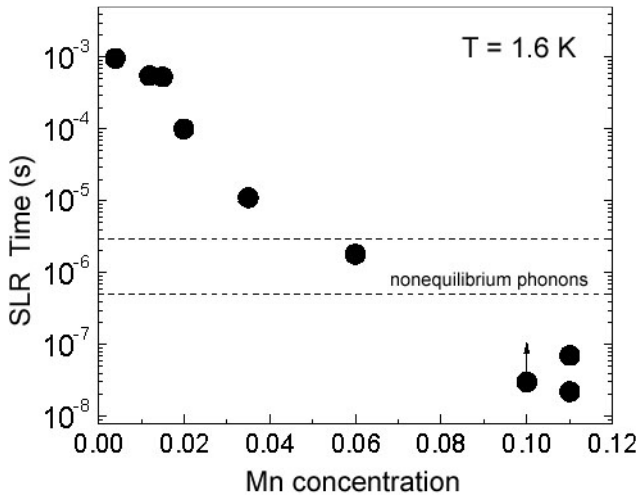
- Influences on spin-lattice relaxation

  → Lattice temperature

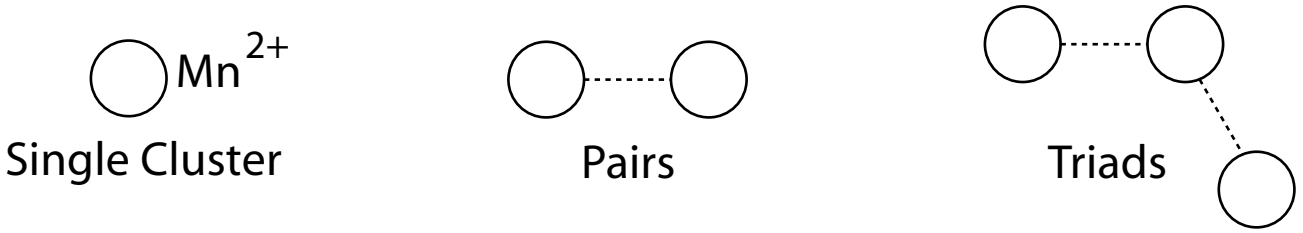
  → Concentration of free carriers
    - Modulation doped samples
    - Laser excitation density

  → External magnetic field

  → **Mn ion concentration**



- Mn ion cluster formation




→ Spin-spin interactions in Mn clusters:
Dzyaloshinsky-Moriya and magneto-dipole coupling

→ High Mn concentration ⟹ High probability of Mn ion clustering

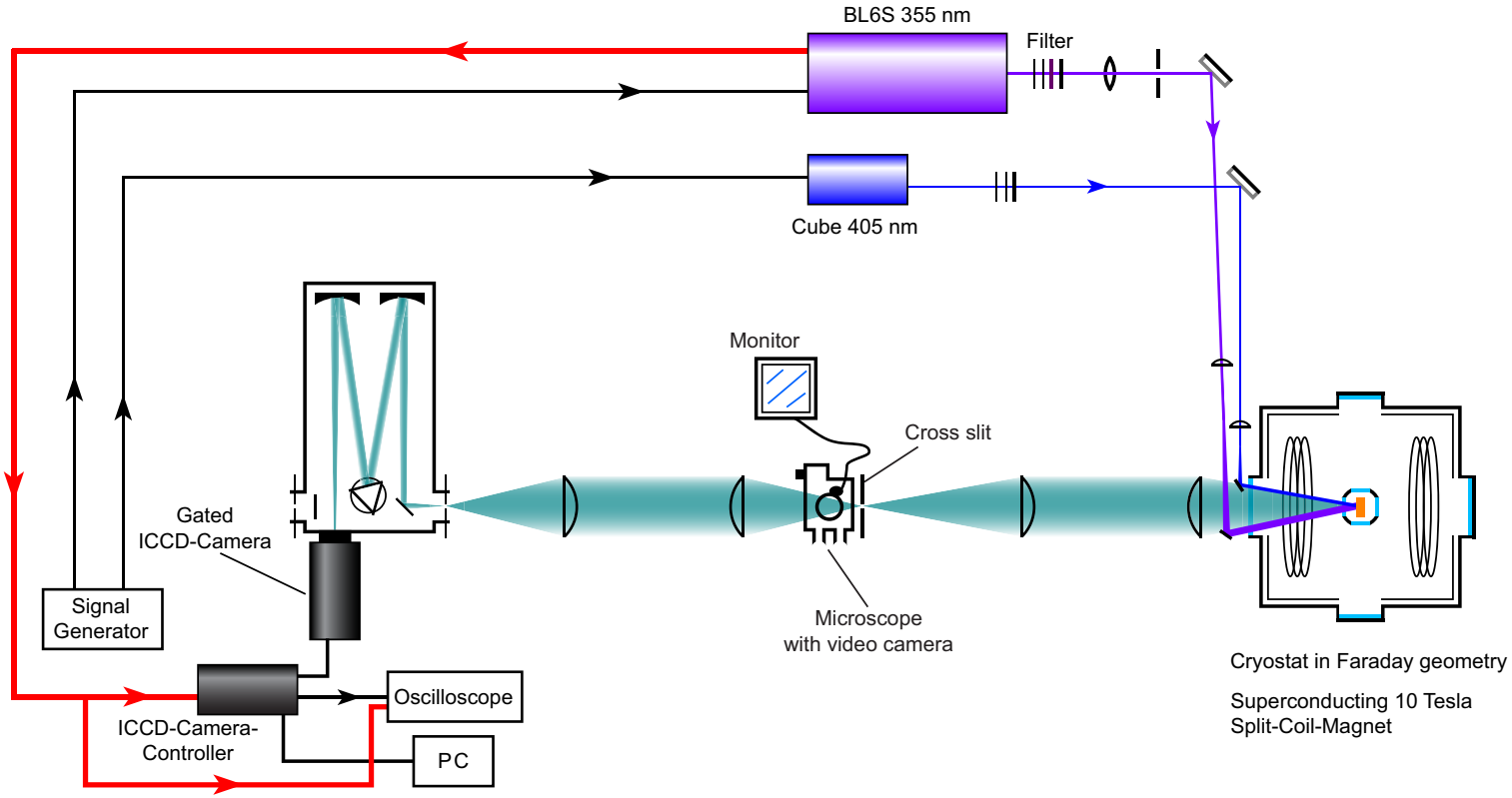
→ Mn clusters act as fast relaxing centers

→ Aspects should be clarified:

Characteristics of Mn clusters in ZnMnSe QW

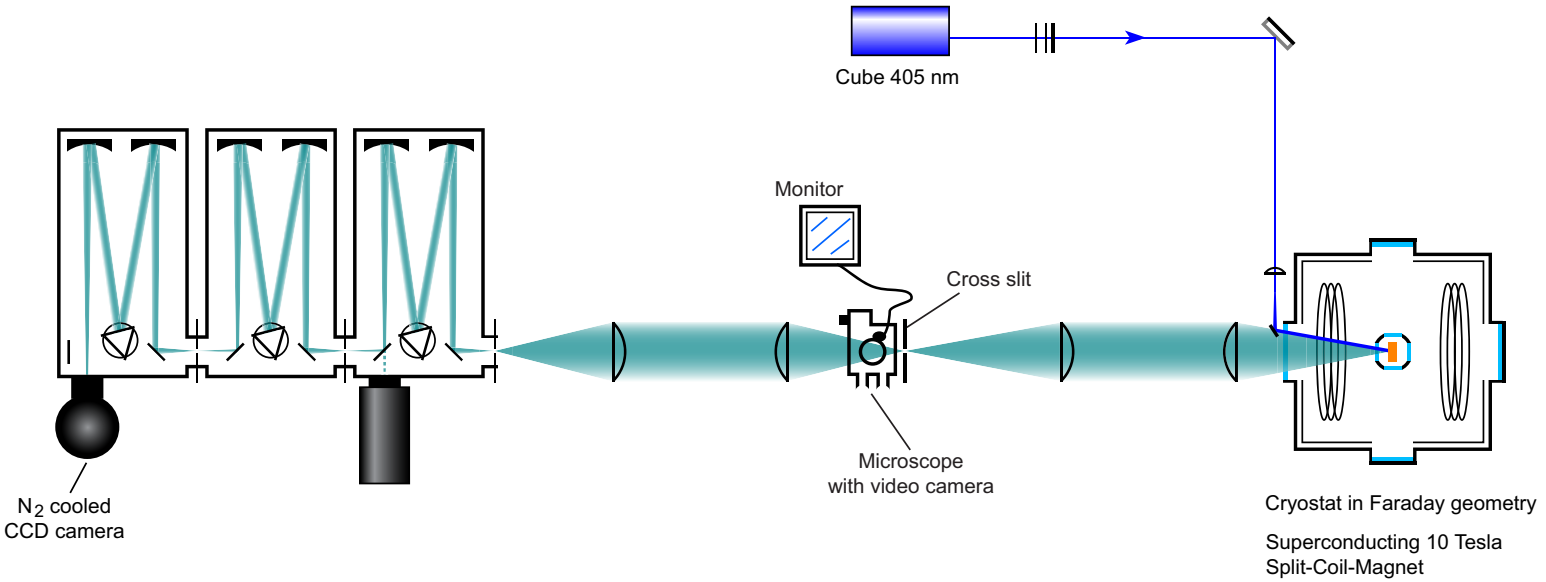
Influence on spin-lattice dynamics
(Reason for additional accelerated SLR)

# Experimental Details



# Experimental Details

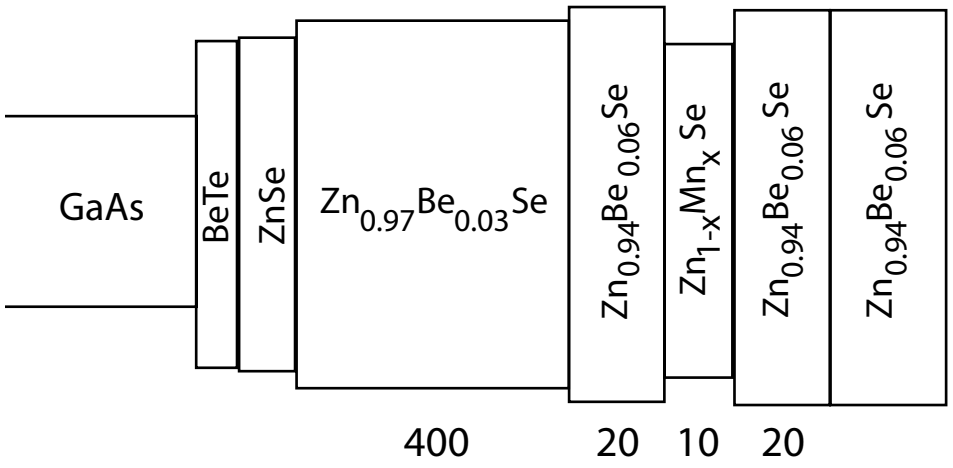
## Time-integrated PL-Setup



# Samples

$Zn_{1-x}Mn_xSe$ / $Zn_{0.94}Be_{0.06}Se$ quantum well heterostructures

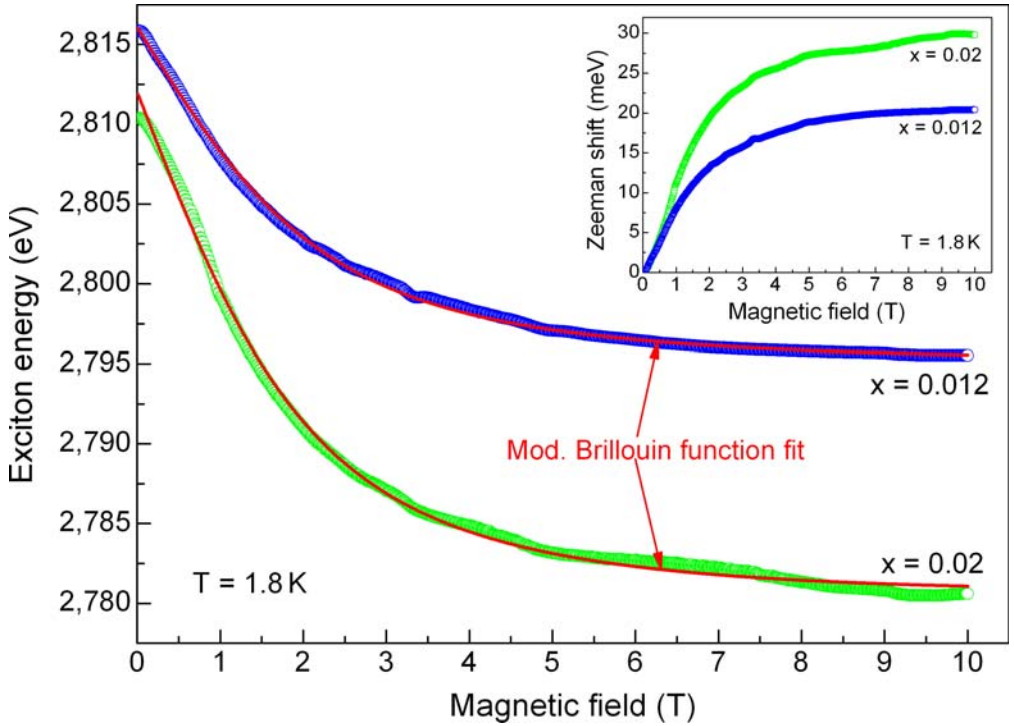
- Grown by molecular beam epitaxy
- Mn concentration: x = 0.012 and x = 0.02
- Nominally undoped



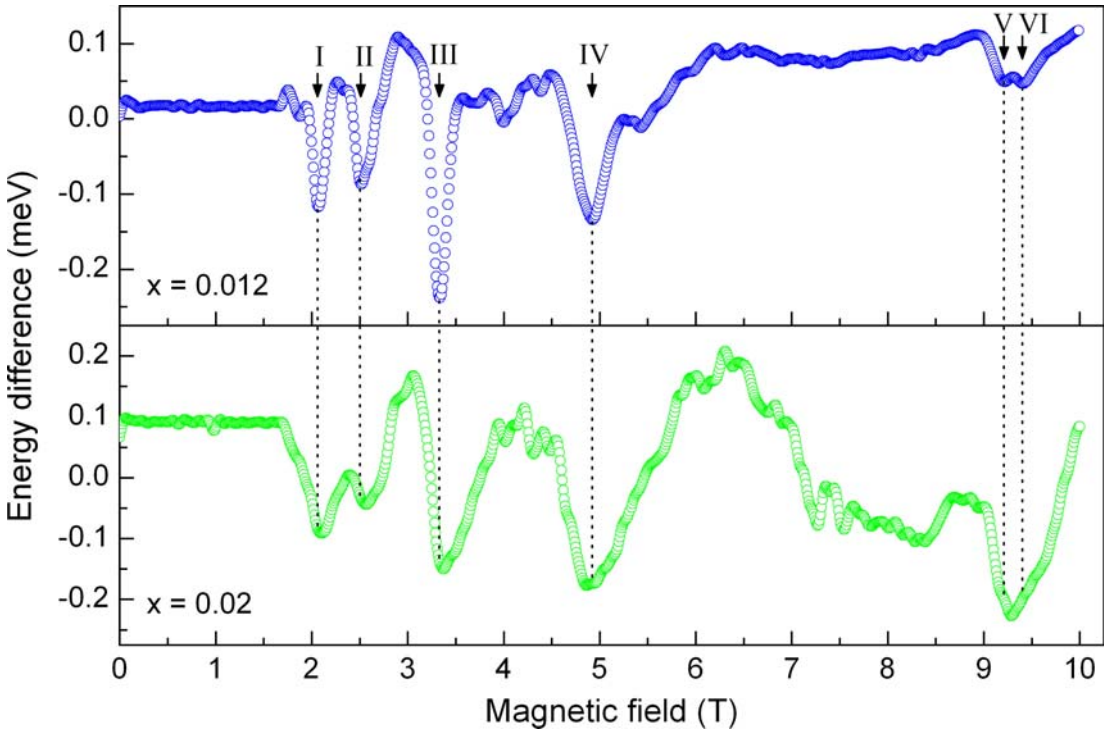
# Results

## Time-integrated measurement

- Excitonic giant Zeeman shift



- Cooling of Mn spin system at specific B-Fields




| | |
|---|---|
| I | 2.07 T |
| II | 2.50 T |
| III | 3.33 T |
| IV | 4.92 T |
| V | 9.21 T |
| VI | 9.40 T |

differ approx. 7% from calculated values

→ Energy sinks correspond to a more efficient SLR

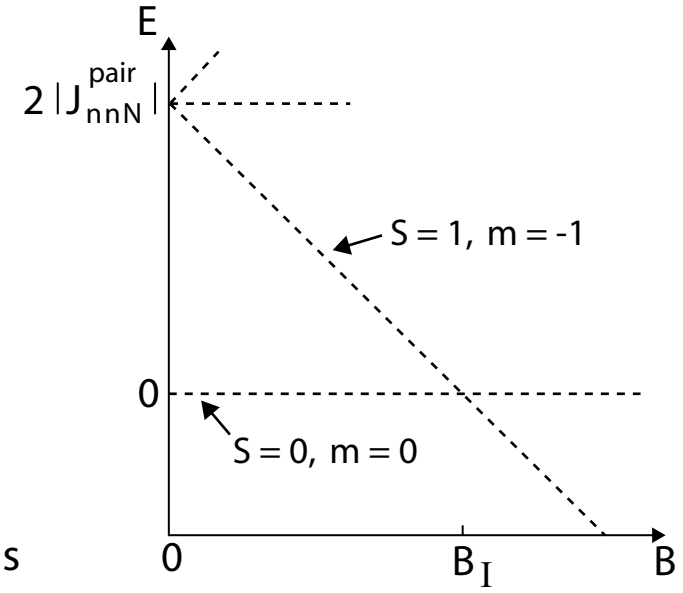
- Reason for cooling effect of Mn system

→ Crossing of spin sublevels of Mn clusters

Direct spin-phonon transitions

Selection rules $\Delta S = \pm 1$ and $\Delta m = 0, \pm 1$

Emission of resonant phonons
causes cooling of Mn spin system




→ Responsible cluster types:

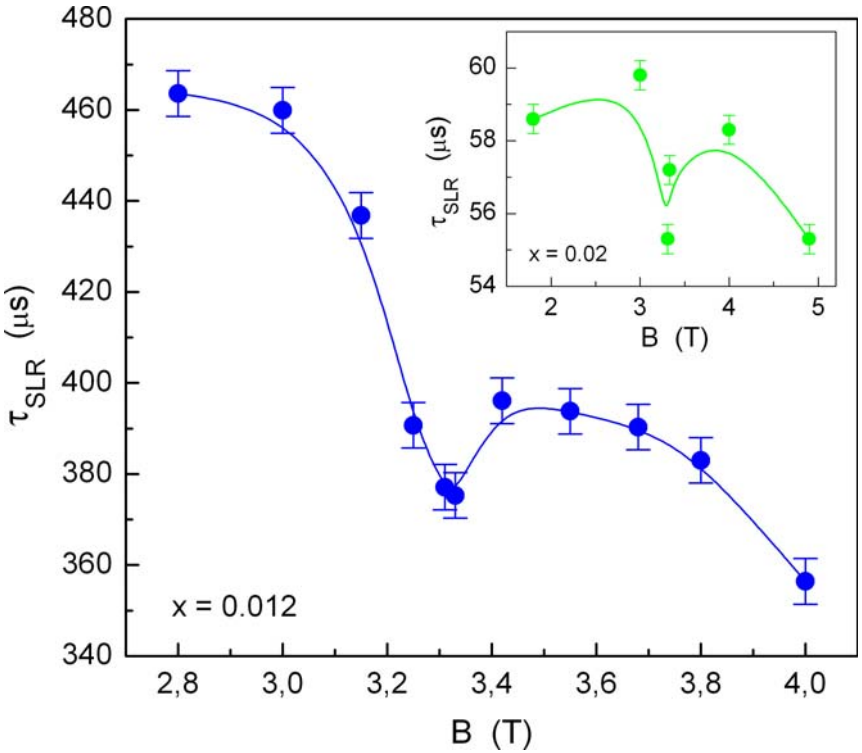
Pairs, open and closed Triads
with next nearest neighbor Mn ions

→ Dependence on Mn concentration due to
changed anisotropic exchange interaction and efficient SLR

# Results

Time-resolved measurement

- Acceleration of spin-lattice relaxation $\tau_{SLR}(B)$

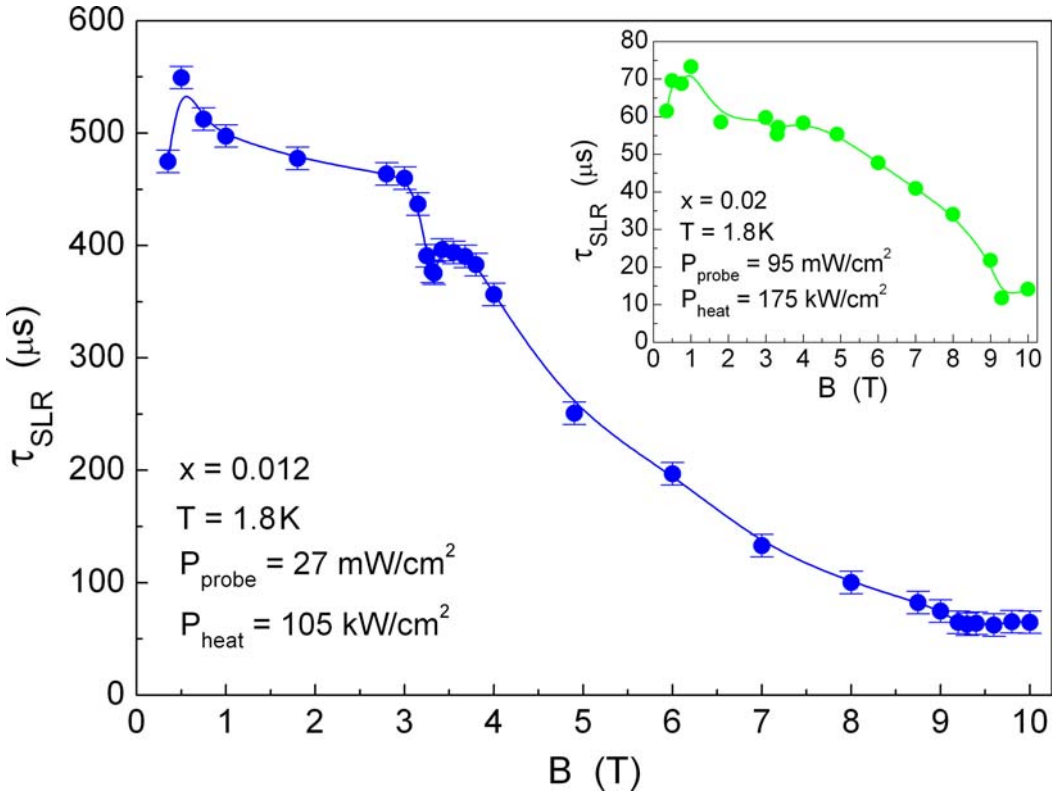



Resonant phonon emission supports SLR carried out by Orbach processes

Acceleration ≈ 15 %

Spinlevel crossing affects static and dynamic magnetization of DMS

- Magnetic field dependence of SLR-Time




$\tau_{SLR}$ decreases one order of magnitude

⇑

Proposals:

Stronger exchange coupling

More efficient Orbach processes

Inter-Cluster-Relaxation

# Conclusion

- Excited magnetic ion spins relax into thermal equilibrium state via spin-spin and spin-phonon interactions
- SLR is mainly affected by Mn ion concentration and strength of external magnetic field
- Crossing of Mn cluster spin levels results in more efficient SLR, direct phonon emissions support Orbach processes
- Pair- and triple-clusters with next nearest neighbor Mn ions influence the static and dynamic magnetization of DMS