

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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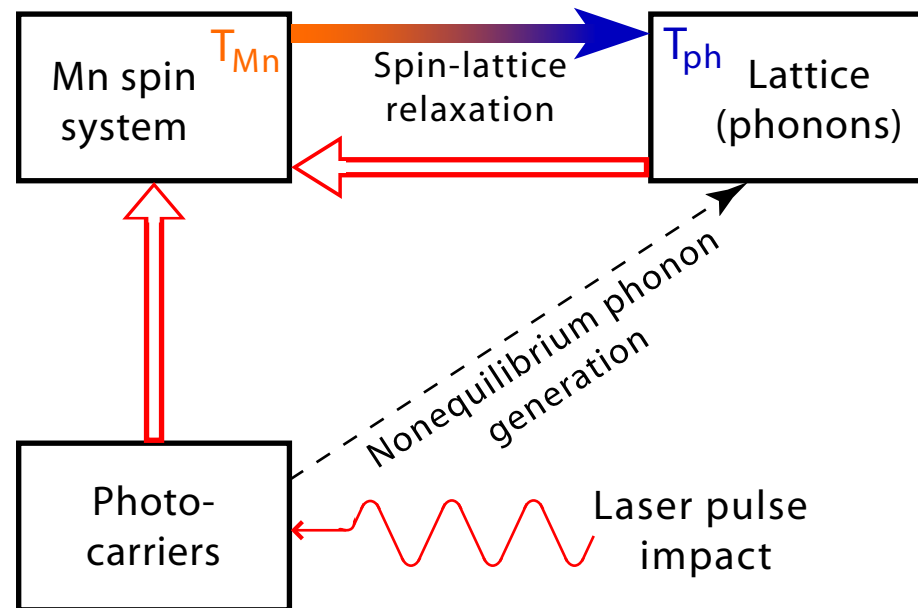
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Introduction

- 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
 $T_{Mn} \longrightarrow T_{ph}$
 - 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:

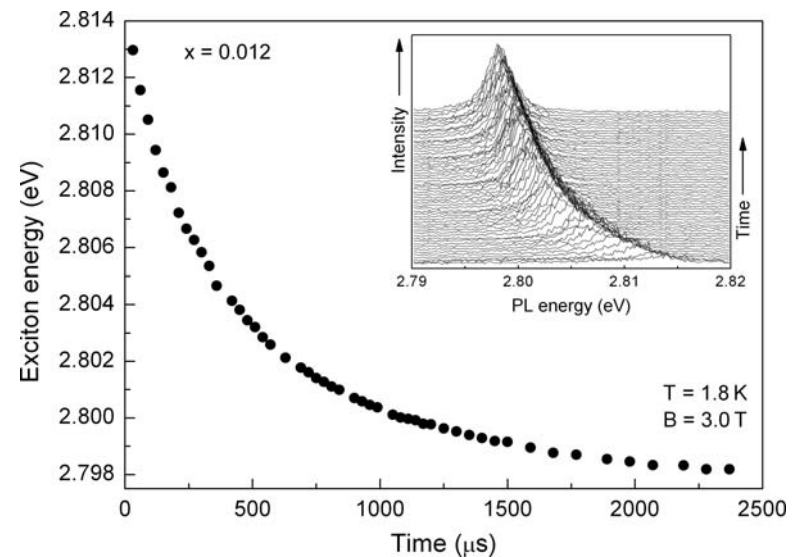
- Time-resolved PL

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

- Time-integrated PL

Giant Zeeman shift:

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



- Influences on spin-lattice relaxation

- Lattice temperature

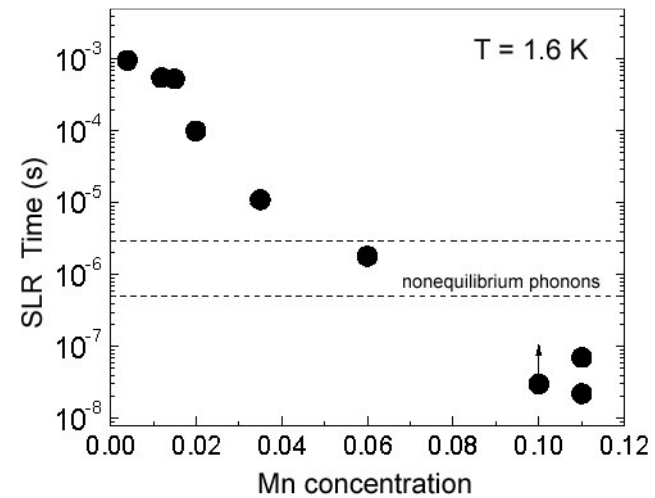
- Concentration of free carriers

- ↳ Modulation doped samples

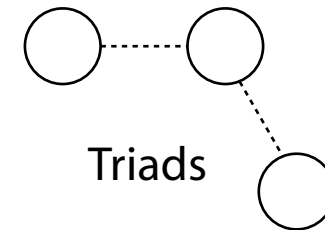
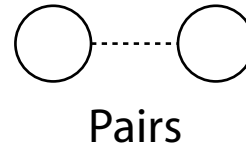
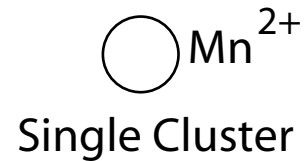
- ↳ Laser excitation density

- External magnetic field

- **Mn ion concentration**



- Mn ion cluster formation

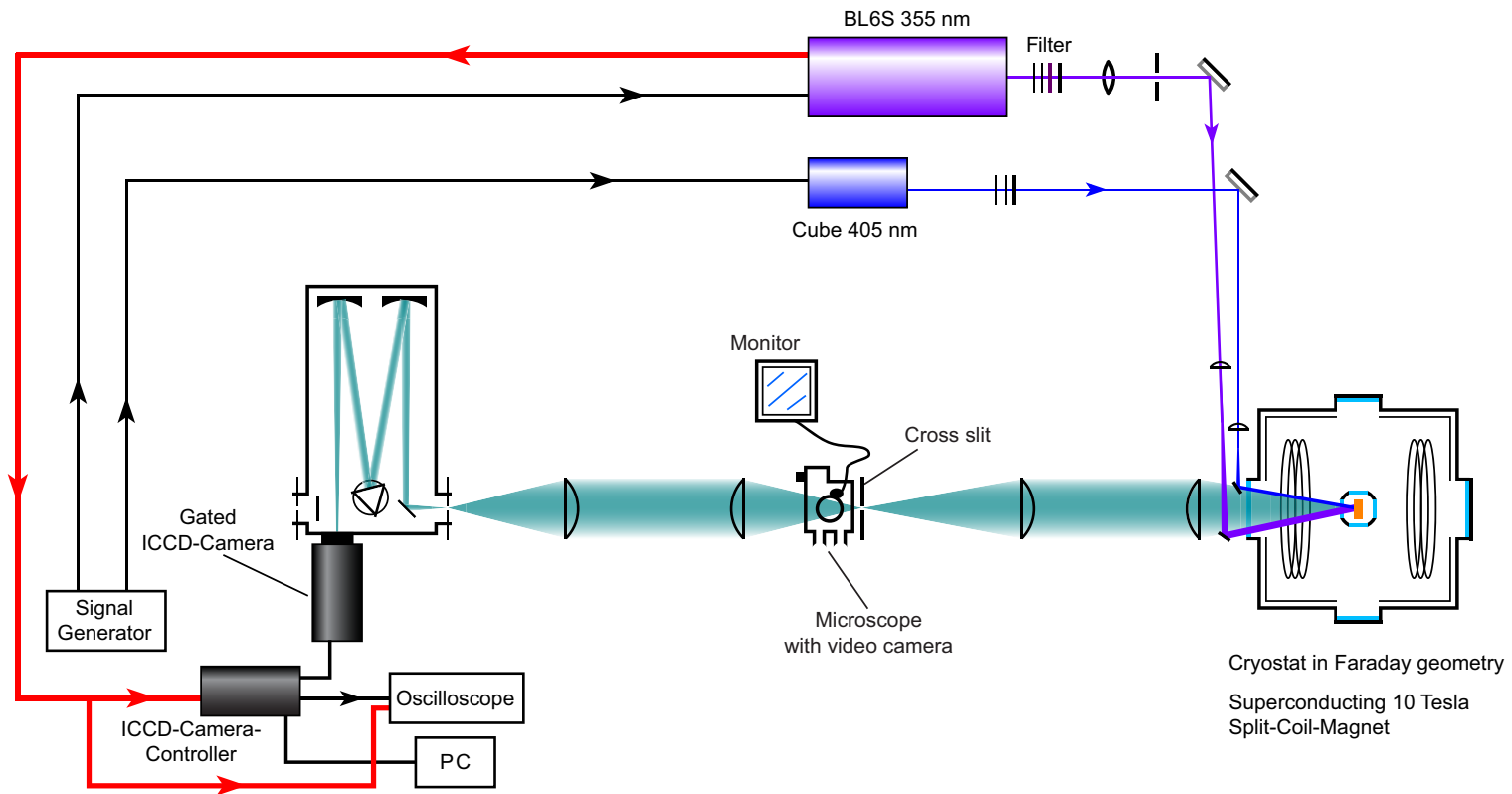


- Spin-spin interactions in Mn clusters:
Dzyaloshinsky-Moriya and magneto-dipole coupling
- High Mn concentration \Rightarrow High probability of Mn ion clustering
- Mn clusters act as fast relaxing centers
- Aspects should be clarified:

Characteristics of Mn clusters in ZnMnSe QW

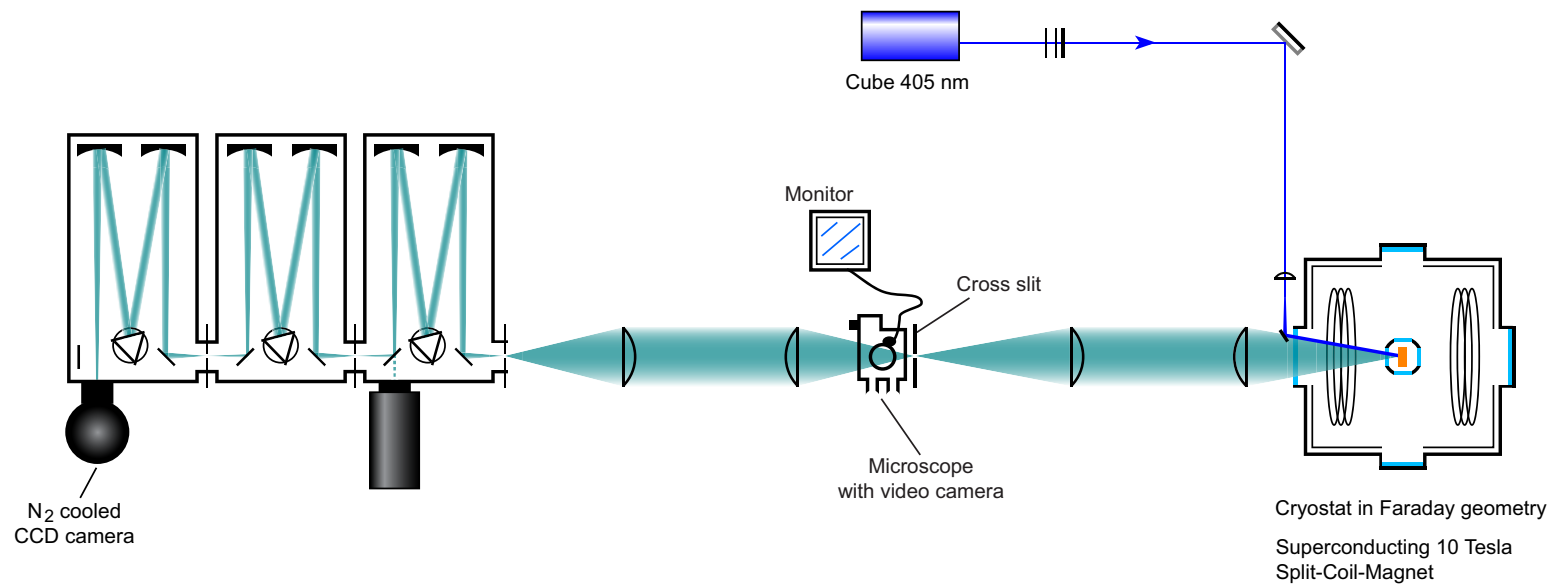
Influence on spin-lattice dynamics
(Reason for additional accelerated SLR)

Experimental Details



Experimental Details

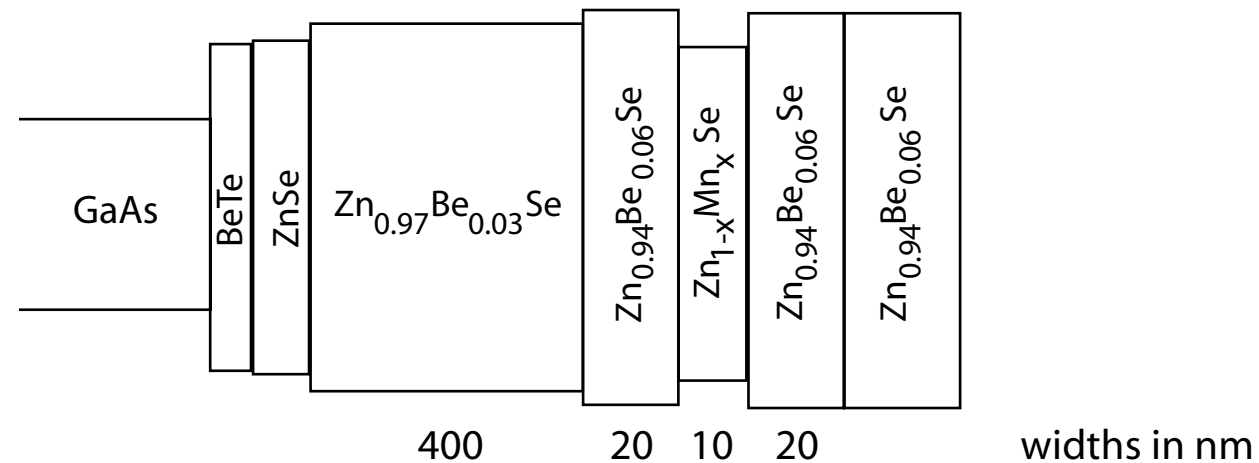
Time-integrated PL-Setup



Samples

$\text{Zn}_{1-x}\text{Mn}_x\text{Se} / \text{Zn}_{0.94}\text{Be}_{0.06}\text{Se}$ quantum well heterostructures

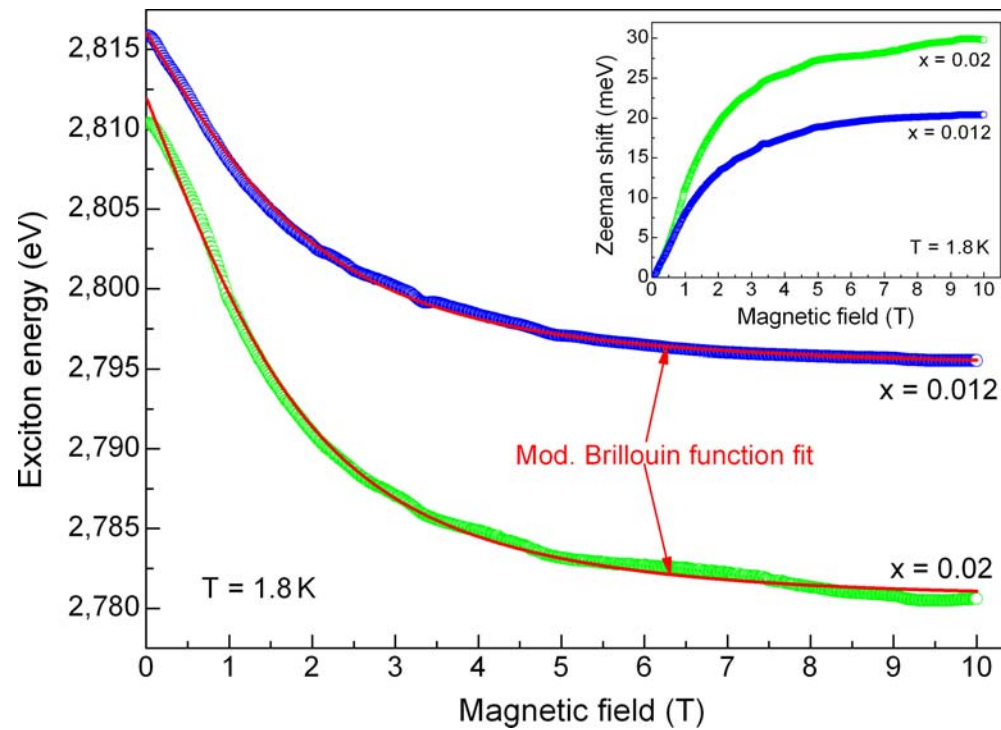
- Grown by molecular beam epitaxy
- Mn concentration: $x = 0.012$ and $x = 0.02$
- Nominally undoped



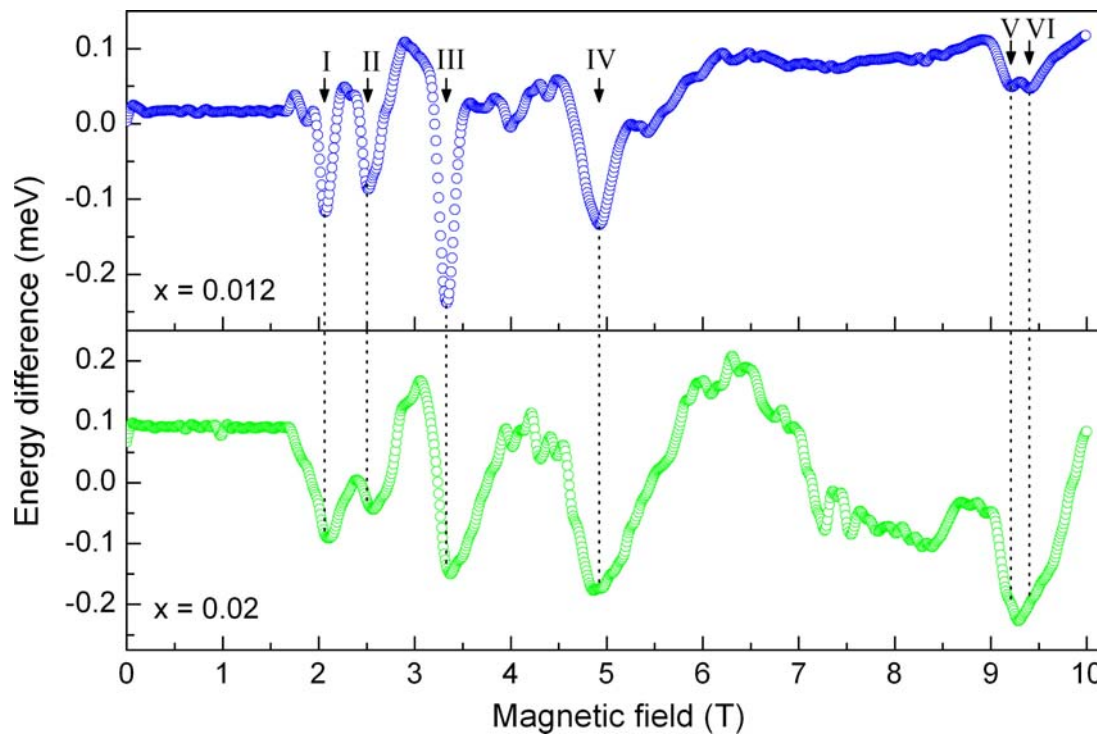
Results

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

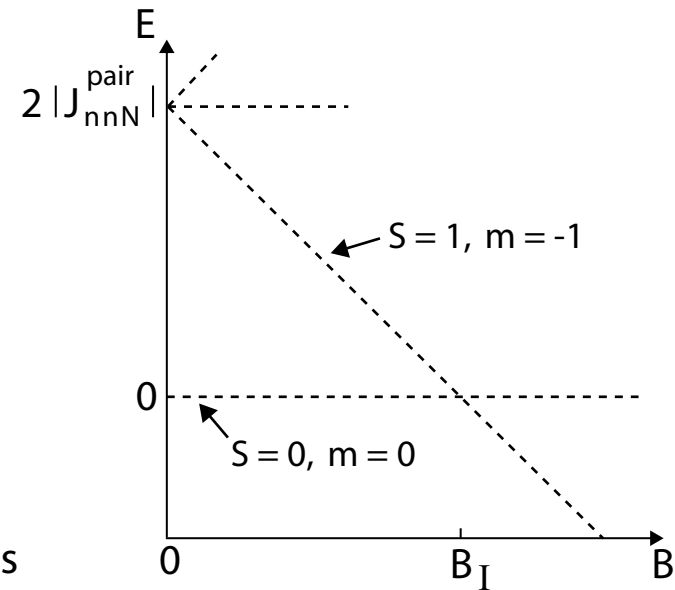
Selection rules $\Delta S = \pm 1$ and $\Delta m = 0, \pm 1$

Emission of resonant phonons causes cooling of Mn spin system

- Responsible cluster types:

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

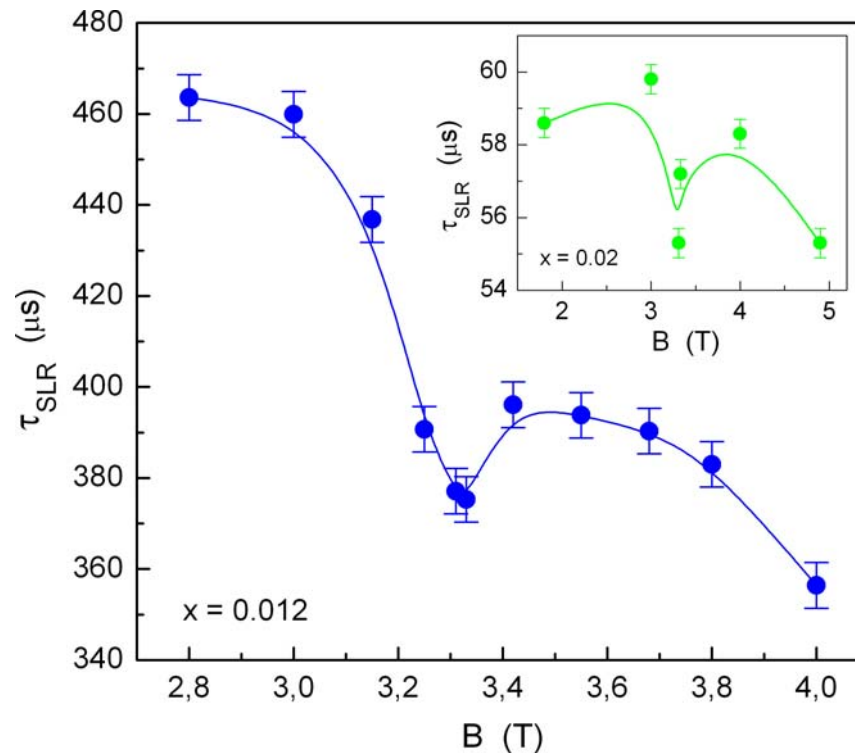
- Dependence on Mn concentration due to changed anisotropic exchange interaction and efficient SLR



Results

Time-resolved measurement

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

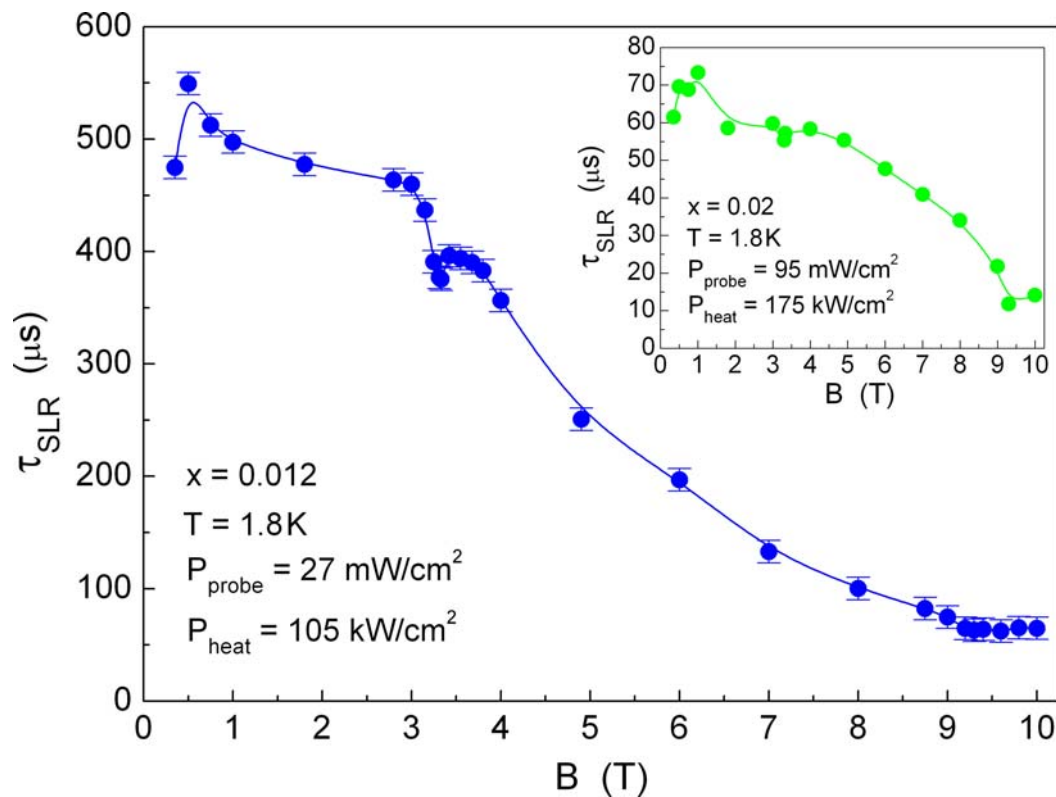


Resonant phonon emission supports SLR carried out by Orbach processes

Acceleration $\approx 15\%$

Spinlevel crossing affects static and dynamic magnetization of DMS

- Magnetic field dependence of SLR-Time



τ_{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