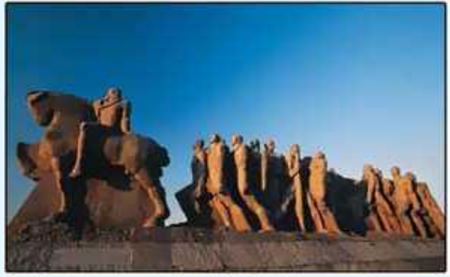
Hyperfine Interactions Laboratory



Temperature dependence of the magnetic hyperfine field at ^{111}Cd in ZnO doped with Co.

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Introduction

Semiconductor oxides doped with 3*d* ions are good candidates to produce Diluted magnetic semiconductor (DMS) material for spintronics

Thomas Dietl , *et al. Science 287, 1019 (2000) – calculated that ZnO doped with 5% of Mn would present T_C above room temperature.*

Yuji Matsumoto, *et al. Science 291, 854 (2001) – measured magnetization in TiO2 doped with 7% Co. Results showed T_C > 400 K and saturated magnetization = 0.32 μ_B*

ZnO, In_2O_3, TiO_2, SnO_2, SnO, etc. are wide band-gap semiconductor oxides, which have been reported to show ferromagnetic ordering when doped with transition metal elements

Introduction

Almost all papers which have reported the occurrence of ferromagnetism in ZnO doped with different transition elements observed it by magnetization measurements.

Several papers have, however, reported that samples of ZnO doped with transition metal elements do not show magnetism.

Magnetic ordering observed:

• Only in nano-structured thin films,
• not in bulk samples,
• only in small fraction of samples (2% to 3%)
• It is likely due to defects (oxygen vacancies).

Magnetic ordering not observed:

• magnetism could come from impurities in samples,
• defects in samples are difficult ot control.

Introduction

Latest explanation about this controversy is that:

Bad samples show magnetism

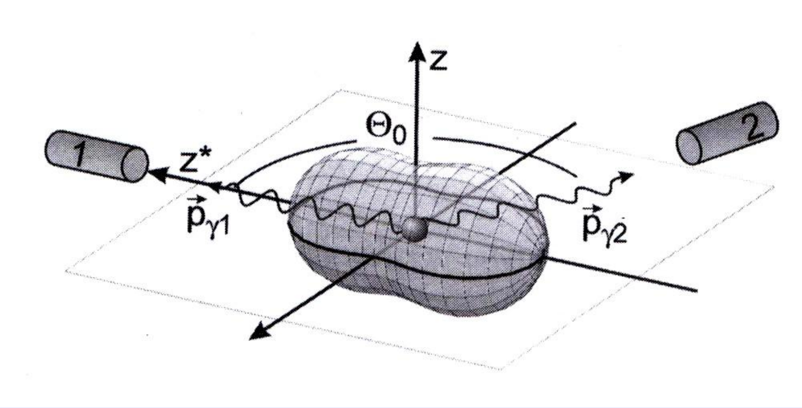
Good samples don't show magnetism

An investigation of doped ZnO samples using a very sensitive local technique would help to understand the occurrence of magnetism in these materials.

In this work perturbed angular correlation (PAC) technique was used to investigate the electric quadrupole interactions during preparation of ZnO samples doped with Co as well as to study the temperature dependence of the magnetic hyperfine field (B_{hf}) in one of them.

PAC method

PAC measures the time dependence of the γ-ray emission pattern. This evolution in time is caused by hyperfine interactions



The angular distribution of the emission pattern is given by the correlation function

$$W(\theta,t) = 1 + A_{22}G_{22}(t)P_2(\cos\theta)$$

Hyperfine interactions cause a precession of the emission pattern described by the perturbation factor

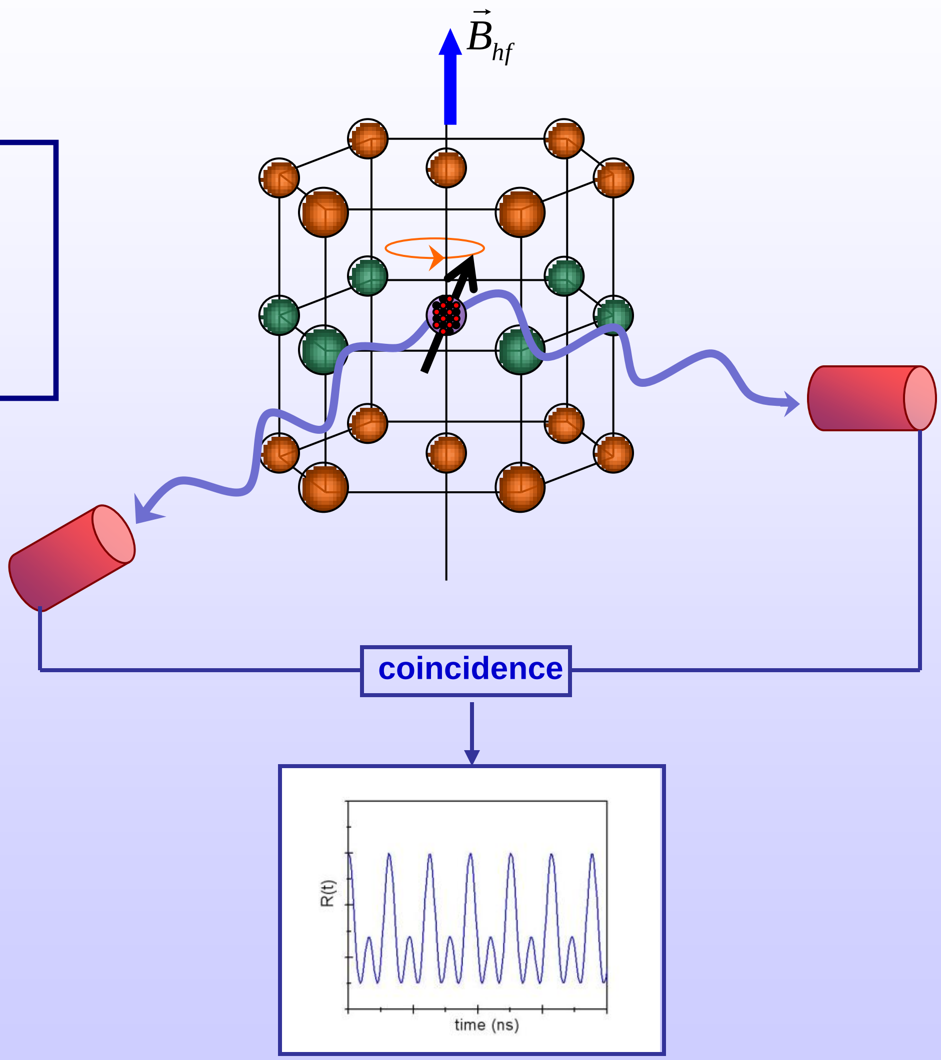
PAC method

Magnetic interaction:

$$\omega_L = -g\frac{\mu_N}{\hbar}B_{hf}$$

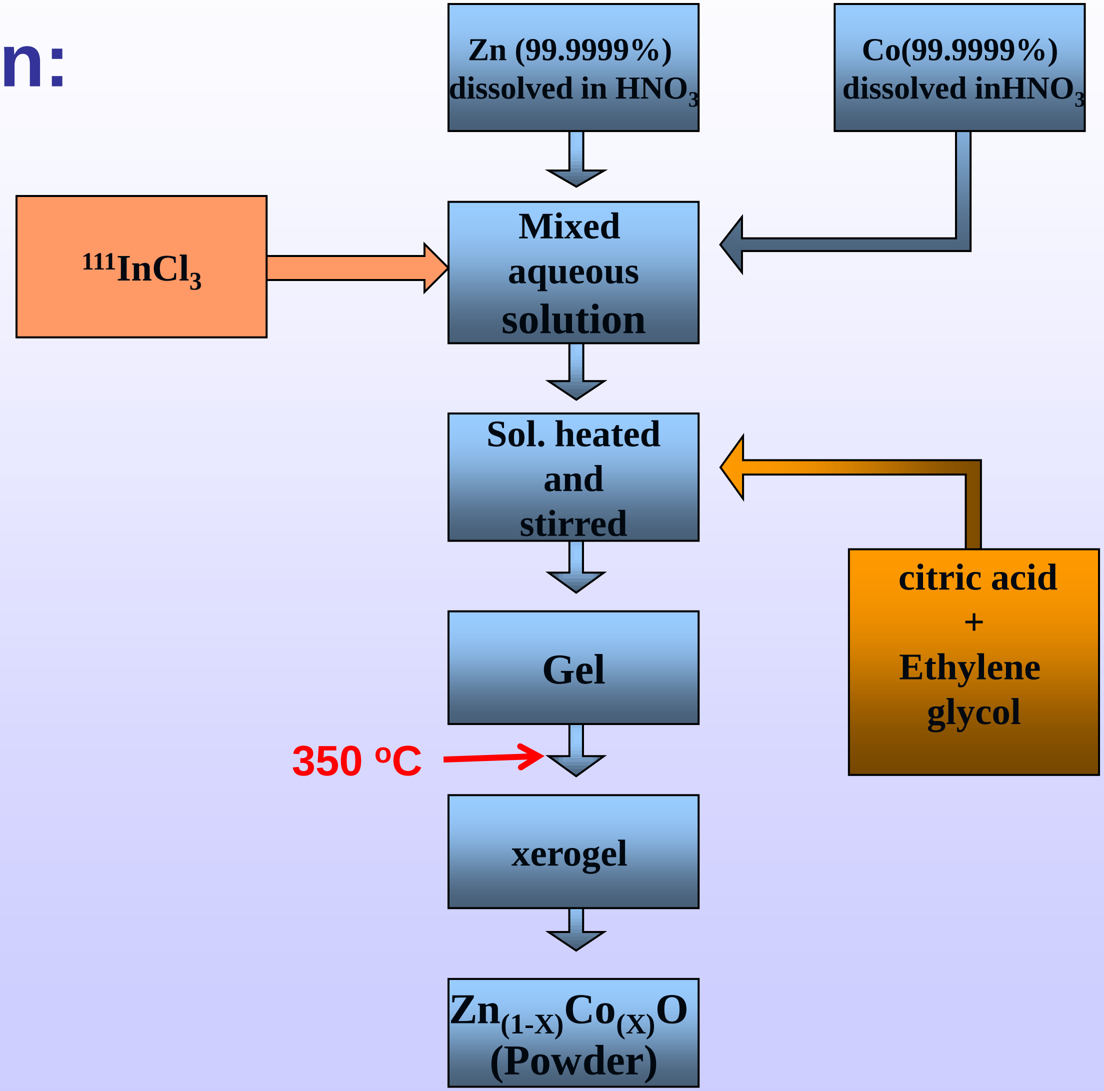
Electric quadrupole interaction:

$$\omega_Q = \frac{eQV_{zz}}{4I(2I-1)\hbar}$$



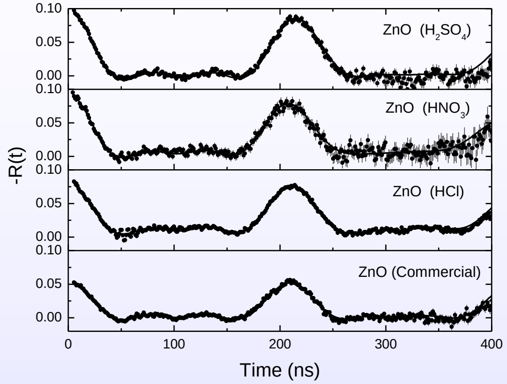
Experimental

Sample preparation:



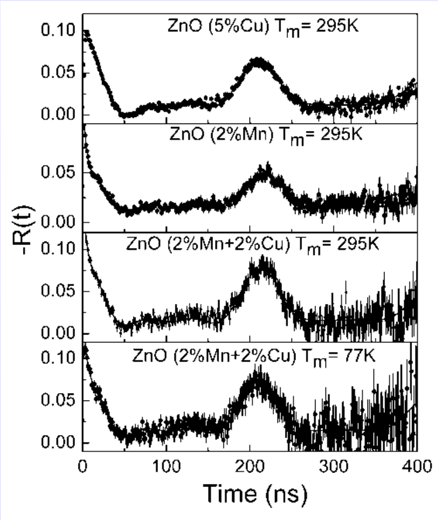
Results

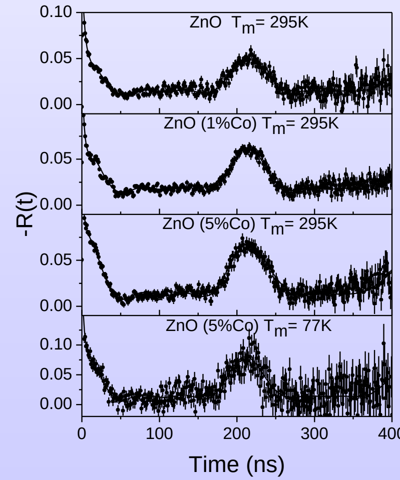
Twelve samples of pure ZnO: $< \nu_Q > = 31.9(3)$ MHz

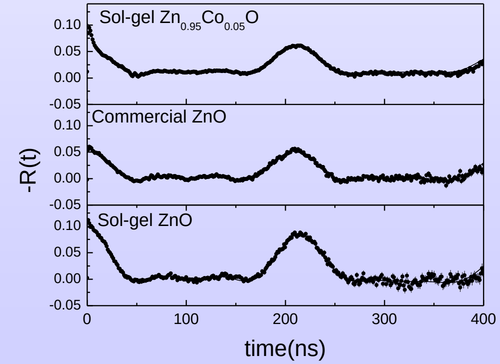


several samples of ZnO doped with different concentrations of Co, Mn, Cu:

$\nu_Q \sim 32(4)$ MHz

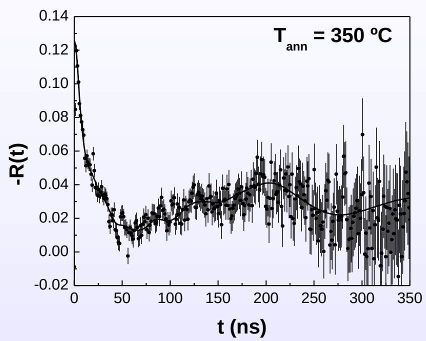




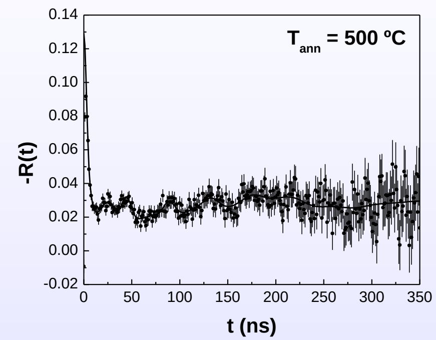


Results

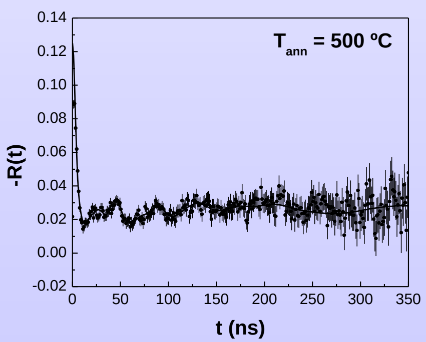
ZnO doped with 10% of Co



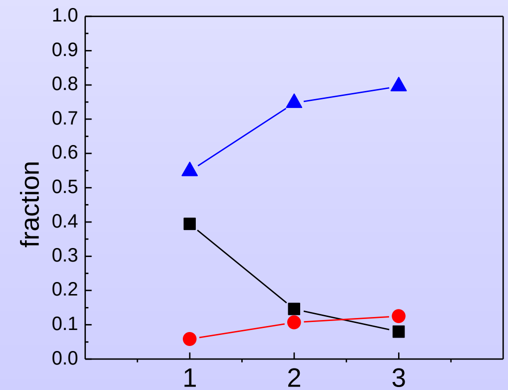
1 - Xerogel: after first annealing at 350 ºC



2 - annealing at 500 ºC in flowing N_2



- ■ ν_{Q1} = 31 MHz, η_1 = 0.3, δ_1 = 9%, f_1 = 8%
- ● ν_{Q2} = 150 MHz, η_1 = 0.2, δ_1 = 7%, f_1 = 12.5%
- ▲ ν_{Q3} = 190 MHz, η_1 = 0, δ_1 = 58%, f_1 = 79.6%

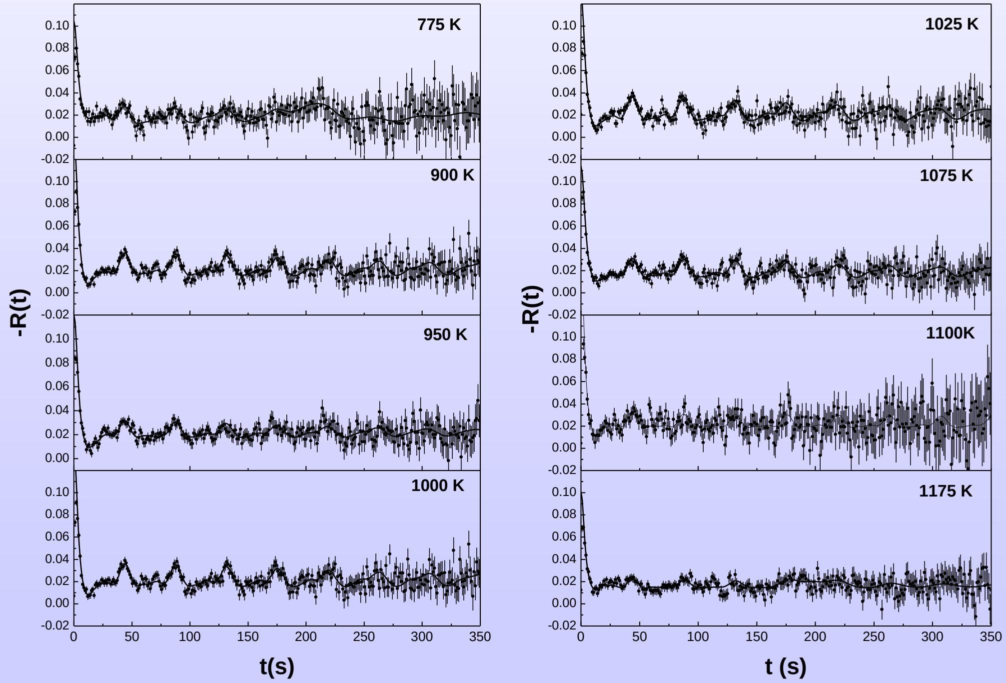


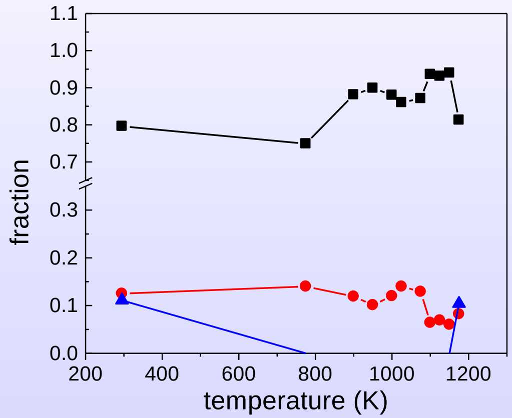
3 - pellet: annealing at 500 ºC in N_2

Results

Sample sealed in a quartz ampoule at 2 x 10^{-2} mbar

Sample measured at different temperatures from ~500 ºC to ~900 ºC

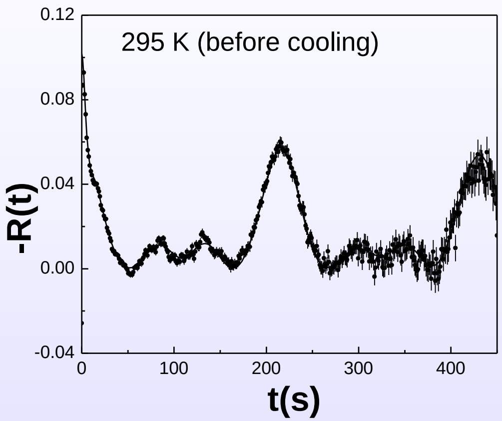


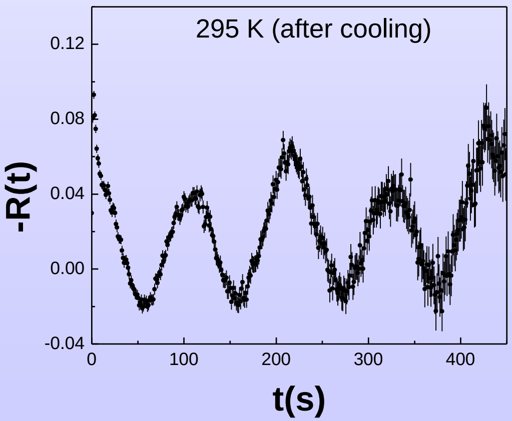


A. W. Carbonari

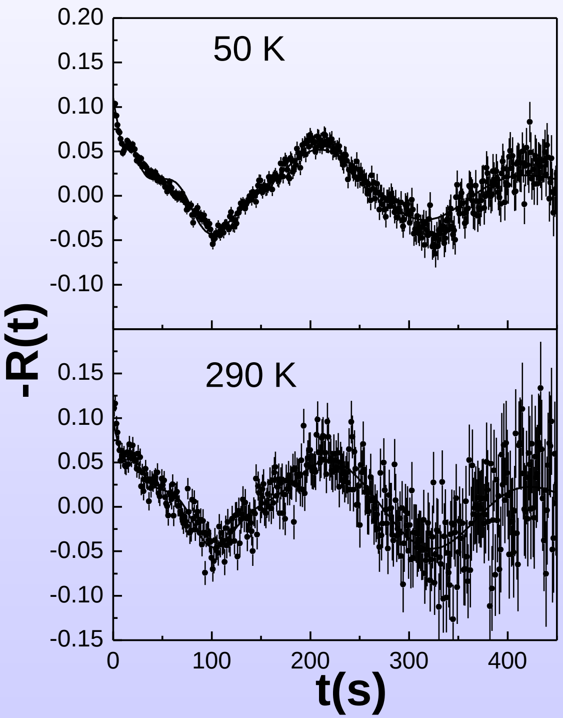
Results

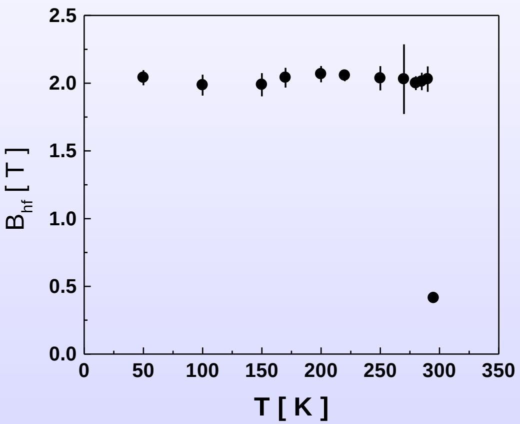
quartz ampoule was broken: sample measured at room temperature





Sample measured from 50 K to 295 K

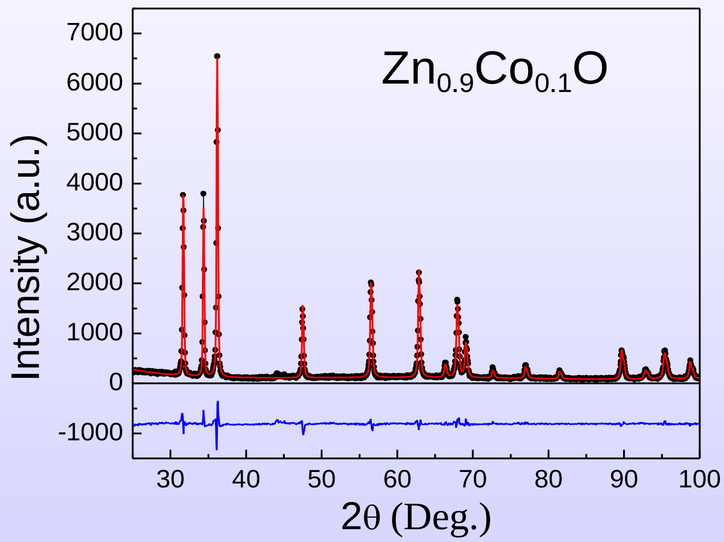


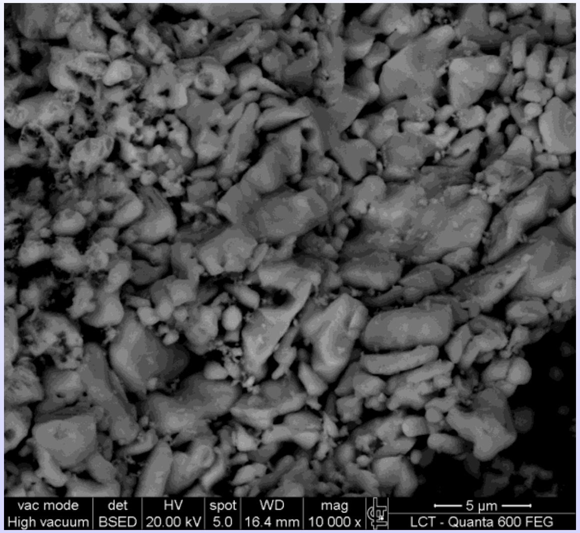


- B_{hf} ~ 2T
- First order transition
- Unusual magnetic behavior

Results

Sample quality checked be X-ray diffractomertry, SEM and EDS



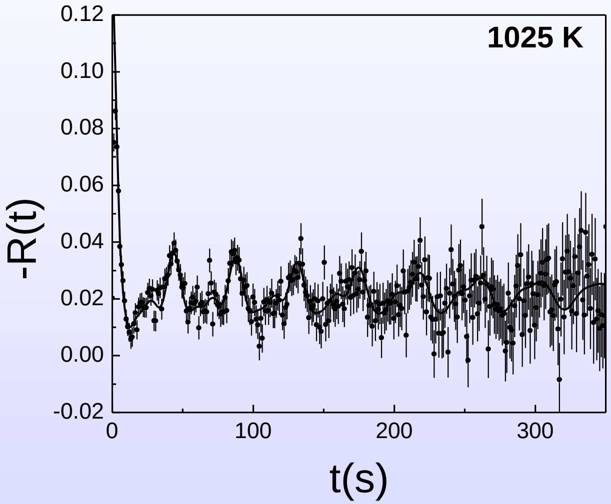


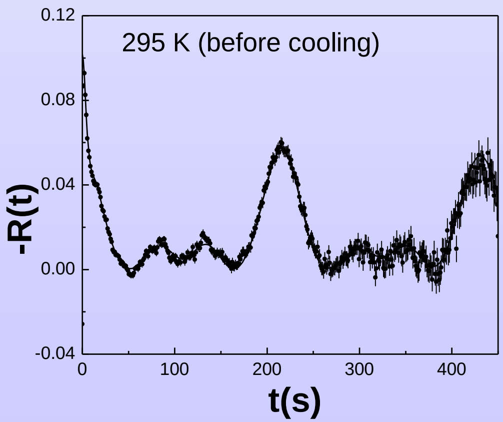
Good bulk sample showing magnetism!

Conclusion

Key to understand the occurrence of magnetism:

Explanation of the probe environment corresponding to ν_Q = 151 MHz





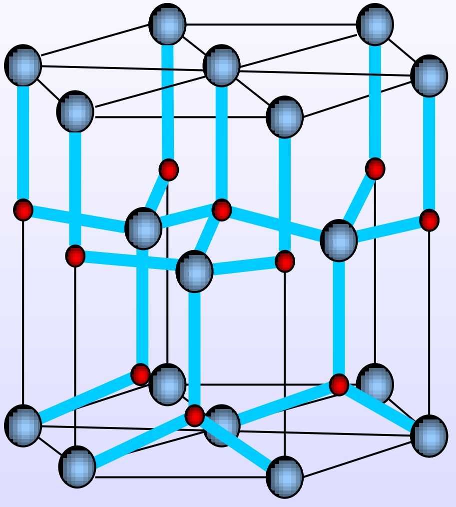
In_2O_3 ? ν_{Q1} = 155 MHz η = 0 (29%)
ν_{Q2} = 119 MHz η = 0.71 (71%)
[S. Habenicht *et al.* Z. Phyz. B101(1996)187]

Co_2O_3 ? ν_Q = 146 MHz η = 0.15
[Z. Inglot *et al.* J. Phys.:condens. Matt. 3(1991)2137]
T_N = 40 K

CoO ? ν_Q = 0
T_N = 298 K B_{hf} (4K) = 17.7 T
[H. H. Rinneberg, D. A.Shyrley, Phys. Rev. 13(1976)2138]

In – V_{OX} ? ν_Q = 185 MHz η = 0.1 in ZnO + Zn
[S. Deubler et al., Nucl. Instrum. Meth. B63(1992)223]

In near interstitial Zn ?
ν_Q = 170 MHz η = 0.12 in ZnO + Zn
[R. Wang et al., J. Solid State Chem. 122(1996)166]


Zn
O