Temperature dependence of the hyperfine fields of ^{111}In in sapphire (Al_2O_3) single crystals

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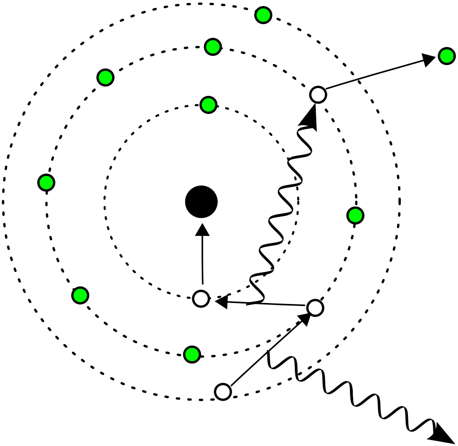
Introduction

- Basing on previous measurements of undoped Al_2O_3

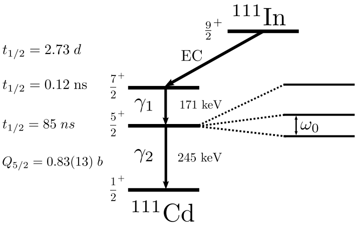
  Penner and Vianden, Hyperfine Interactions 158(1), 389 (2004)
- Temperature dependent measurements of the electric field gradient (EFG) in doped Al_2O_3
- Experimental technique: time-differential perturbed angular correlation (TDPAC)
- Investigation of the "electron capture after effect"
- Possible application: electron mobility studies in semiconductors and insulators

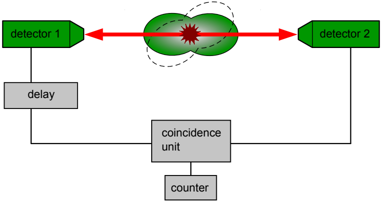
Electron capture decay of ^{111}In

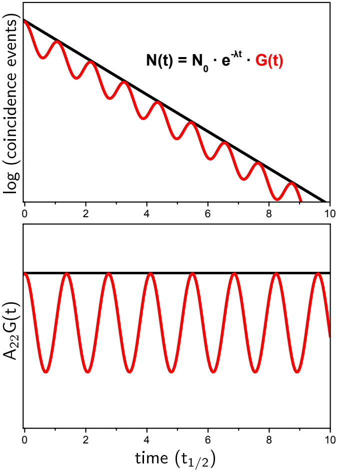


- $(p) + e^{-} \longrightarrow (n) + \nu_e$
- Half life of the (highly) ionized state depending in the electronic surrounding
  - vacuum: $t_{1/2}$ large
  - metallic: $t_{1/2} \approx 10^{-12}$ s
  - insulating: $t_{1/2} \approx 10^{-9}$ s, influenced by electron mobility and density

Experimental technique: TDPAC





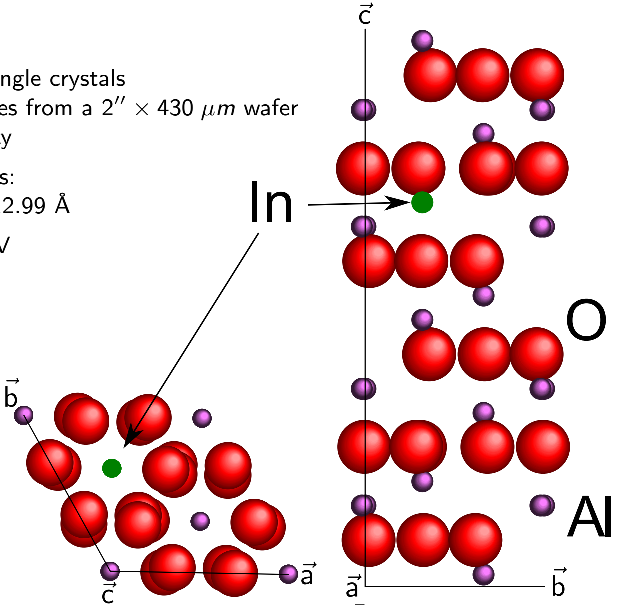


Hyperfine interaction of the EFG with the nuclear quadrupole moment Q

$\Rightarrow$ Quadrupole interaction frequency $\nu_Q = \frac{eQV_{zz}}{h}$

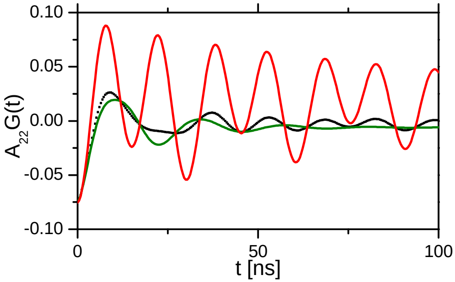
Al_2O_3

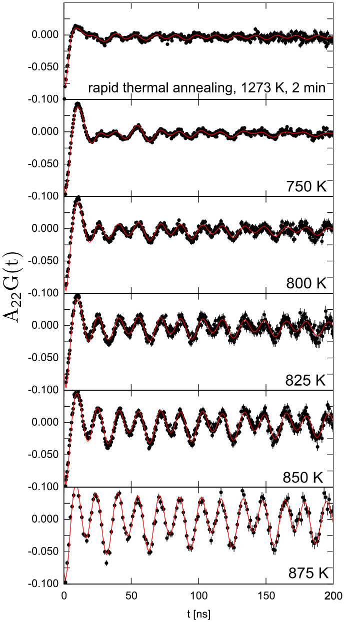
- Material:
  (0001) oriented single crystals
  (5×5) mm^2 pieces from a $2'' \times 430$ μm wafer
  $\approx$ 99.9999% purity
- Lattice parameters:
  $\mathrm{a} = 4.75$ Å, $\mathrm{c} = 12.99$ Å
- Bandgap $=$ 9.9 eV



^{111}In in undoped Al_2O_3

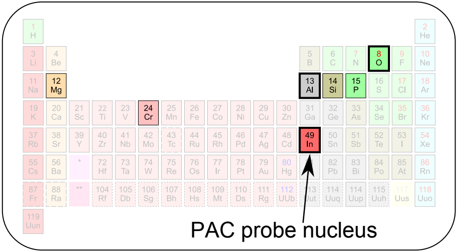
- Ion implantation of ^{111}In at BONIS (BONn Isotope Separator)
- Rapid thermal annealing ($T_a = 1273$ K, 2 min, N_2-flow)



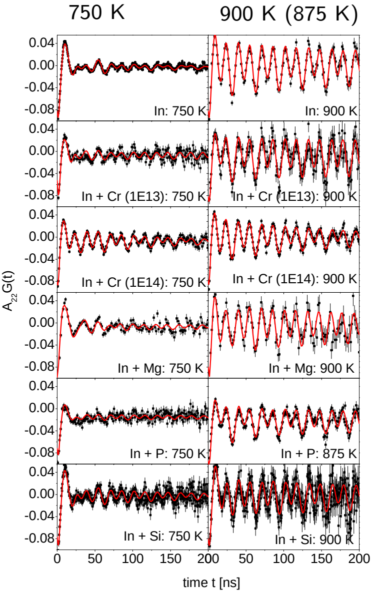


Temperature dependence of the EFG in doped Al_2O_3

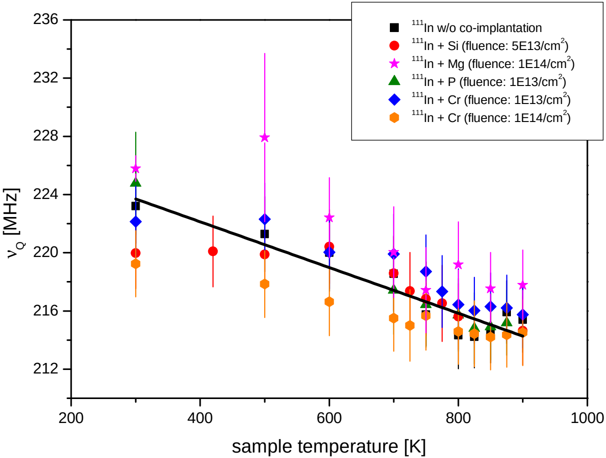
- Co-implantation with overlapping implantation profile



	Energy (keV)	Fluence (atoms/cm^2)	Effective charge subst. Al
^{111}In / ^{111}Cd	160	10^{12}	ionized
Cr	80	$10^{13}/10^{14}$	isoelectronic
Mg	40	10^{14}	acceptor
P	60	10^{13}	double donor
Si	50	$5 \cdot 10^{13}$	donor

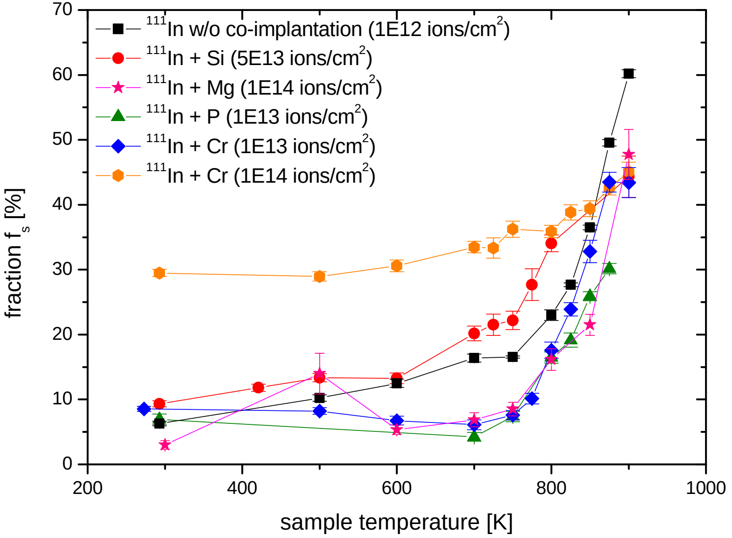


Temperature dependence of ν_Q



$$\nu_Q(\mathrm{T}) = 228(2)\ \mathrm{MHz} - 1.6(3)\cdot 10^{-2}\ \mathrm{MHz/K}\cdot \mathrm{T}$$

Temperature dependance of the static interaction f_S



Summary

- Characterization of the EFG in relation to the sample temperature in an insulator (Al_2O_3)
- Changes of this relation following doping of Cr, Mg, P and Si
  - Minor temperature dependence of ν_Q
  - Doping of Cr has a large impact at higher Cr fluences (fluence dependent effect)
- Relaxation of the atomic shell of ^{111}Cd after electron capture gives us information about the electron mobility and the conductivity of the insulator