Magnetic and structural properties of manganese doped (Al,Ga)N studied with Emission Mössbauer Spectroscopy

Proposal to the ISOLDE and
Neutron Time-of-Flight Committee

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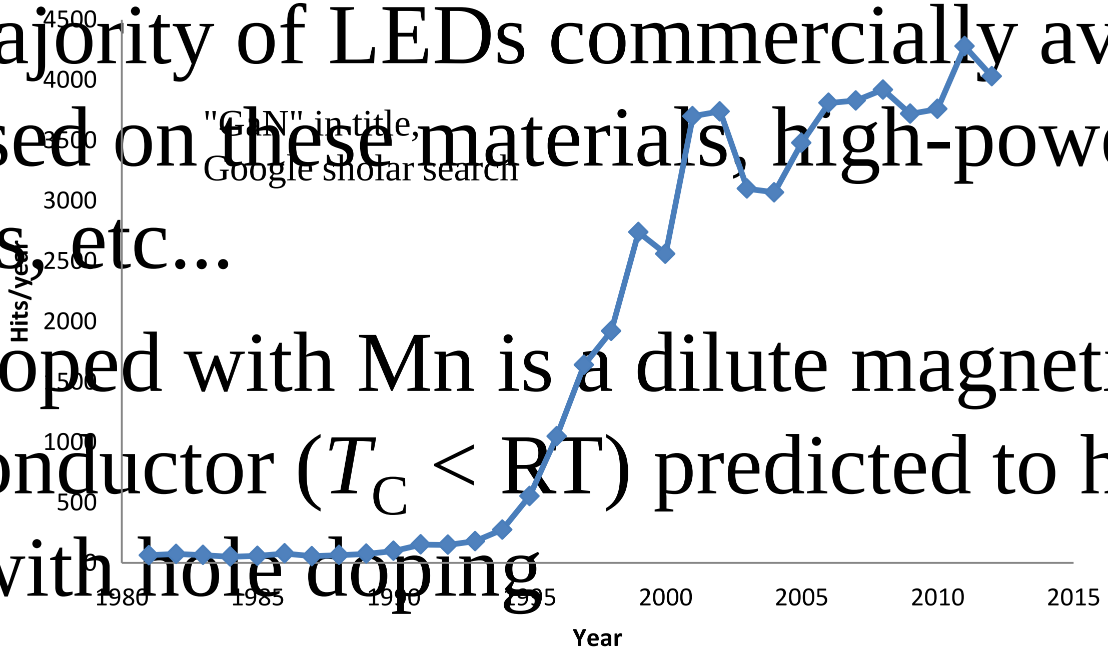
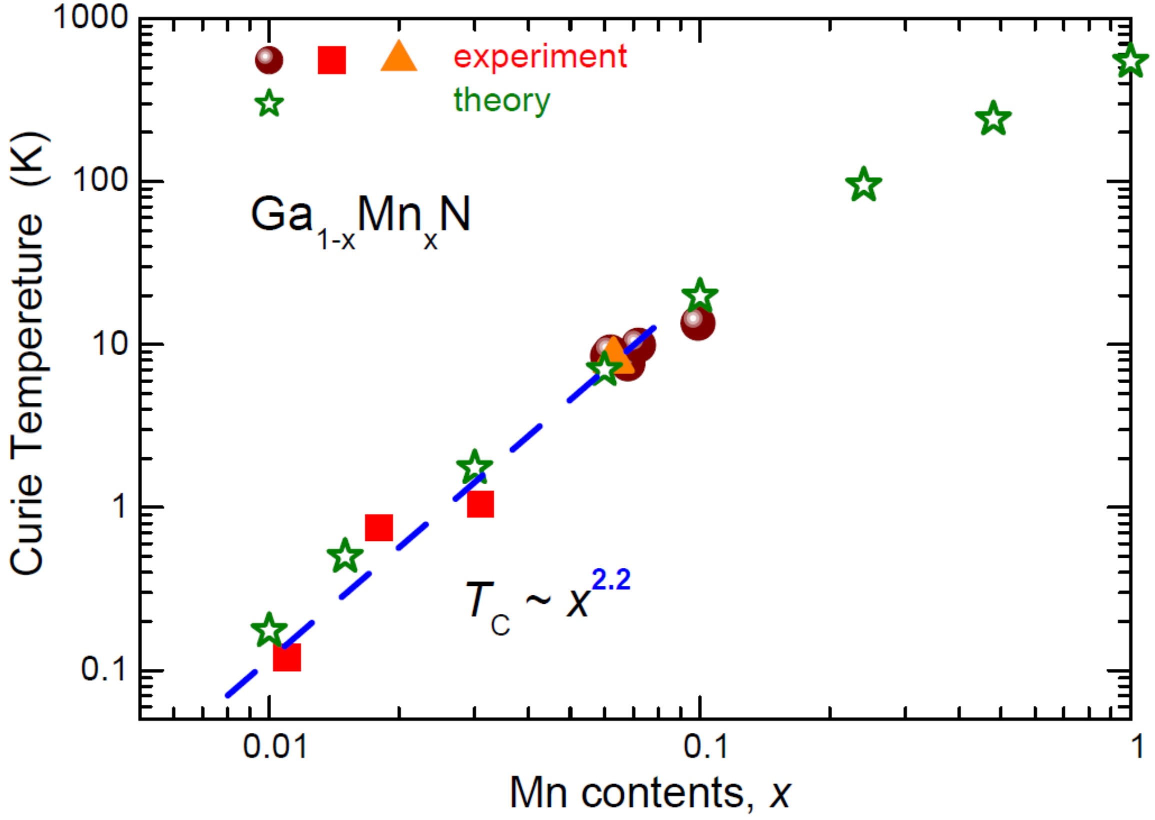
Why study Nitride III-V's

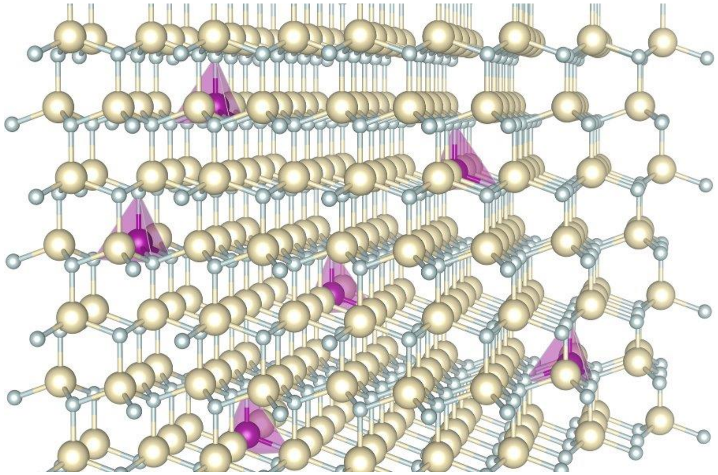
- Importance of (GaN, AlN, InN) system
- The majority of LEDs commercially available are based on these materials, high-power devices, etc...
- GaN doped with Mn is a dilute magnetic semiconductor (T_C < RT) predicted to have T_C > RT with hole doping



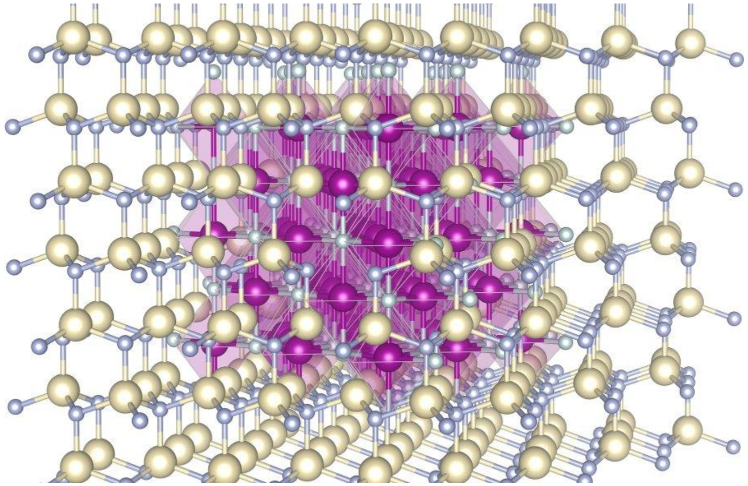
Dilute magnetism in GaN



Dilute magnetism in GaN



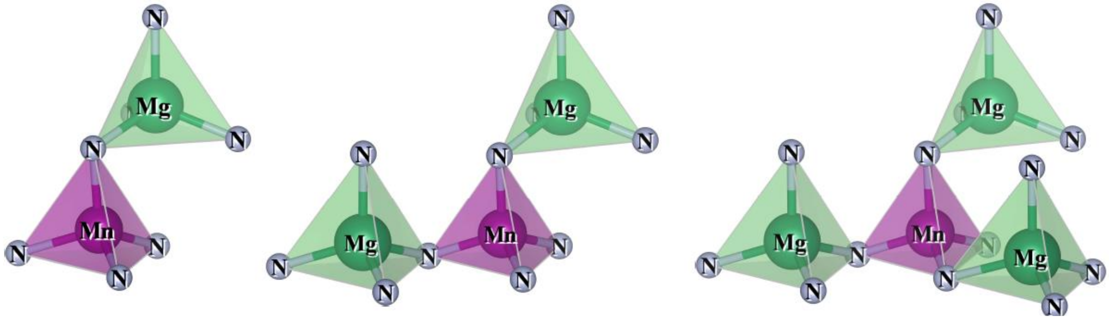
dilute magnetic semiconductors (superexchange interaction provided)



condensed magnetic semiconductors (we can produce ordered arrays of magnetic nanocrystals)

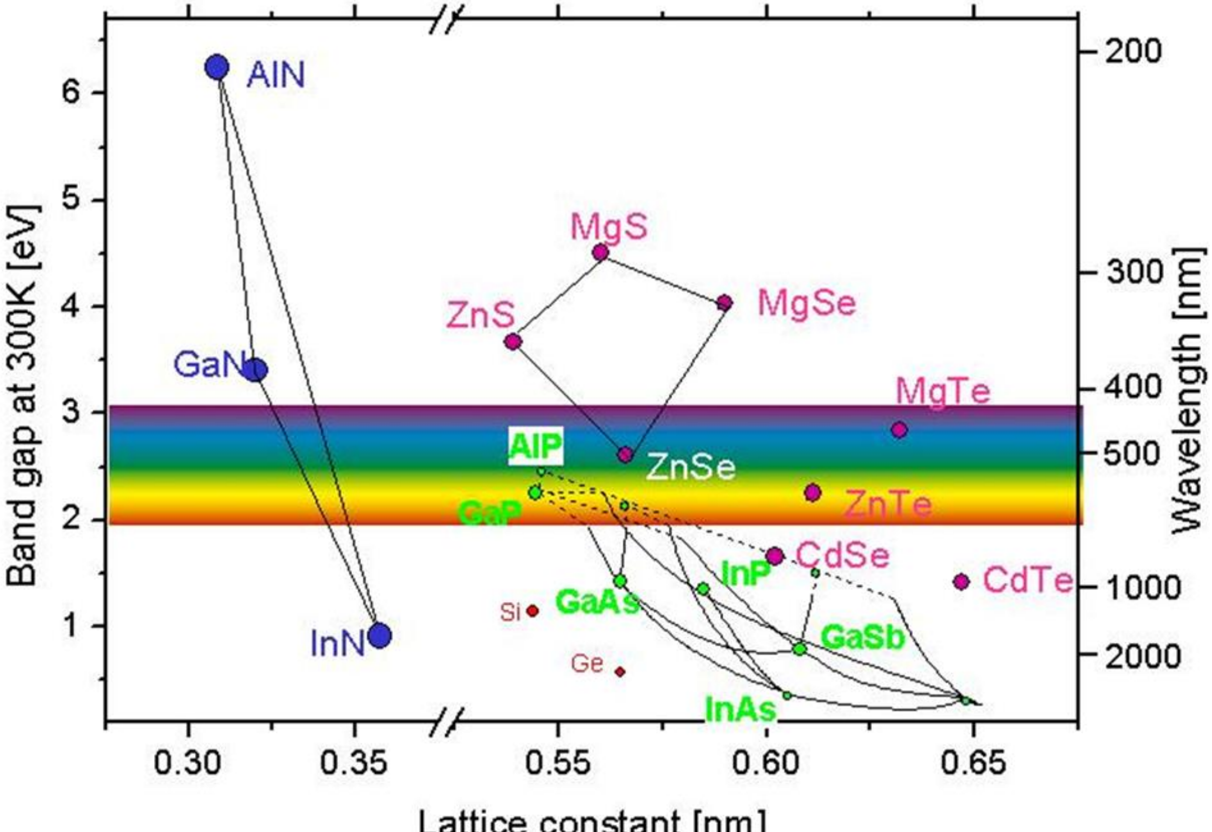
+ Mg/structural defects:

functional Mn/Mg complexes which allow tuning of the spin state and the optical properties of the system



Why study (Al,Ga)N ?

- One can tune the band gap over an exceptionally large range



GaN → AlGaN
(a_0 engineering):

⇒ Tuning of band-gap & magnetism (p-d hybridization)

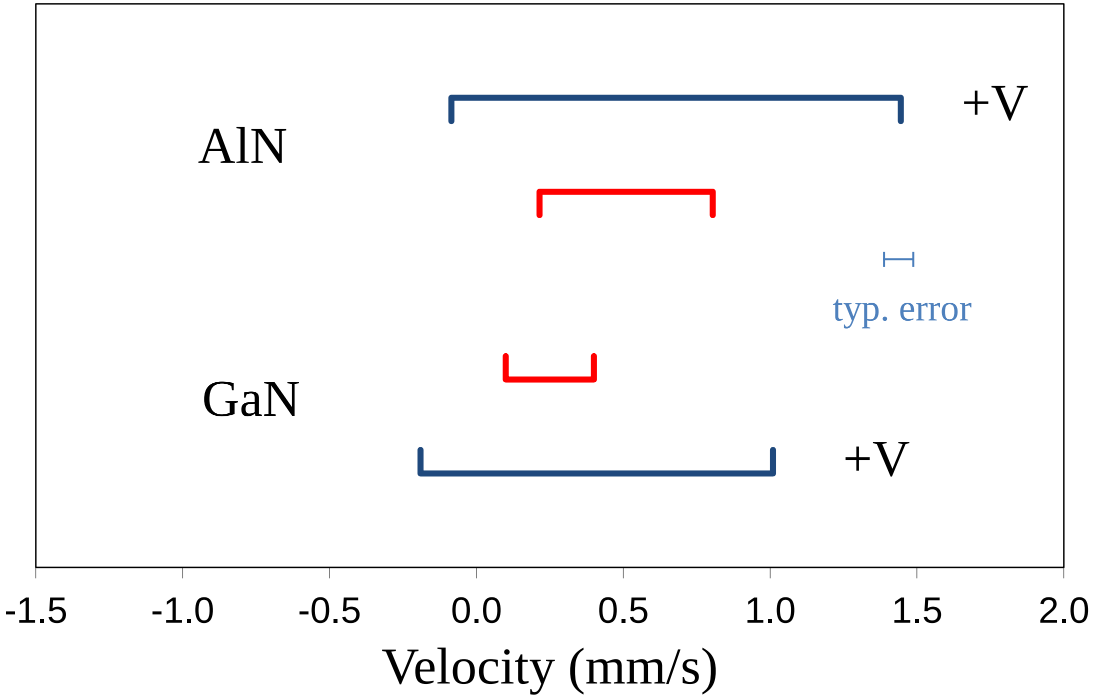
[Navarro APL 101 (2012) 081911]

Why ISOLDE?

- We can apply ^{57}Mn ($T_{½}$=1.5 min.) $\rightarrow$ ^{57M}Fe
- Use *emission* Mössbauer spectroscopy
  - Valence(/spin) state of probe atom (Fe^{n+}, Sn^{n+})
  - Symmetry of lattice site (V_{zz})
    - Differ amorphous/point-defects (angular dependence)
  - *Diffusion of probe atoms (few jumps ~100 ns)*
  - *Binding properties (Debye-Waller factors)*
  - Magnetic interactions (ferro/para)
  - Paramagnetic relaxation (~10^7-10^8 Hz)
  - Can usually detect and distinguish up to 4-5 spectral components (substitutional, interstitial, damage, vacancy-defects,…)

Feasibility of current proposal:

- Already have data on end-members
- Substitutional Fe (Fe_S)
- Fe-V complexes (Fe_C)
- Fe^{3+}



Feasibility: Material

- (Al,Ga)N:Mn made by MOVPE (metalorganic vapour phase epitaxy)
- Characterization:
  - HRTEM, EELS;
  - HRXRD and synchrotron XRD;
  - synchrotron XANES and EXAFS;
  - magneto-photoluminescence;
  - SQUID magnetometry;
  - EPR (electron paramagnetic resonance);
  - magneto-transport.

Experimental plan:

- Temperature series: ^{57}Mn, 2-4 h per series
    - Site populations
    - Annealing of defect
    - Spin lattice relaxation rates
  - ~5 (Al,Ga)N compositions
  - 3.5% Mn doped ~5 (Al,Ga)N compositions
  - Specific (Al,Ga)N and ~5 Mn concentrations
- External B field, angular measurements, isothermal annealing, quenching experiments (HT impl/LT meas) + …
- ^{119}In (2.3 min) → ^{119M}Sn; ^{57}Co (272 d) → ^{57M}Fe measurements

Formal beam request:

Isotope ($T_{½}$)	Minimum Intensity (μCi)	Energy (keV)	Shifts	Target	Ion source
^{57}Mn (1.5 min)	(2-3) × 10^8	≥ 50	9	UC_x	Mn RILIS
^{119}In (2.3 min)	(2-3) ×10^8	≥ 50	2	UC_x	In RILIS
^{57}Co (270 d)	9×10^7	≥ 50	2	ZrO_2 or YtO_2	VADIS or Co RILIS
Total			**13**		

Mössbauer collaboration at ISOLDE/CERN

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CERN: K. Johnston
Berlin: R. Sielemann
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South Africa: D. Naidoo, K. Bharuth-Ram, H. Masenda, M. Ncube
Leuven: G. Langouche, L. Pereira
Reykjavík: T. E. Mølholt, S. Ólafsson, H. P. Gíslason

Funding agencies involved

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[Net1] EC FP7 Marie Curie Networks - Marie Curie Initial Training Network on Nanoscale Semiconductor Spintronics SemiSpinNet [EU FP7 215368];

European Commission funded action

[EC1] REGPOT-2012-2013-1, FP7 CAPACITIES
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[Fonds zur Förderung der wissenschaftlichen Forschung] funded projects

[FWF1] “Magnetic nitrides probed via microwave resonances” [P24471]
[FWF2] “Determination of ferromagnetic phase diagram in nitrides” [P22477]
[FWF3] “Controlling the formation of magnetic nanocrystals in diluted magnetic Semiconductors” [P20065]
[FWF4] “Carrier-induced ferromagnetism in (Ga,Fe)N” [P17169]

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