# Modification of single ion anisotropy in epitaxial $Mn_5Ge_3$/Ge(111) films by carbon doping

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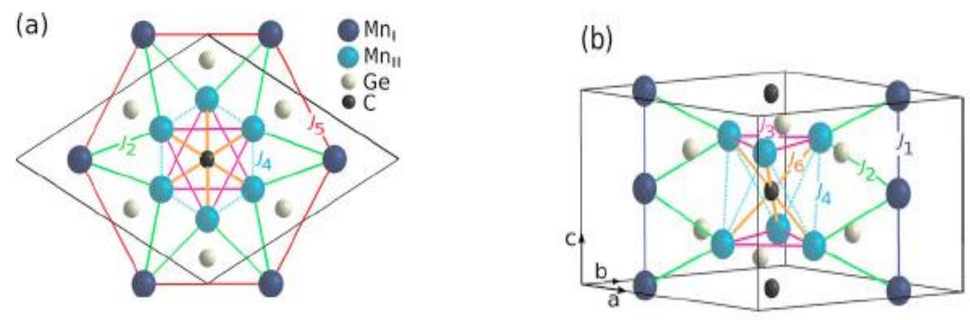
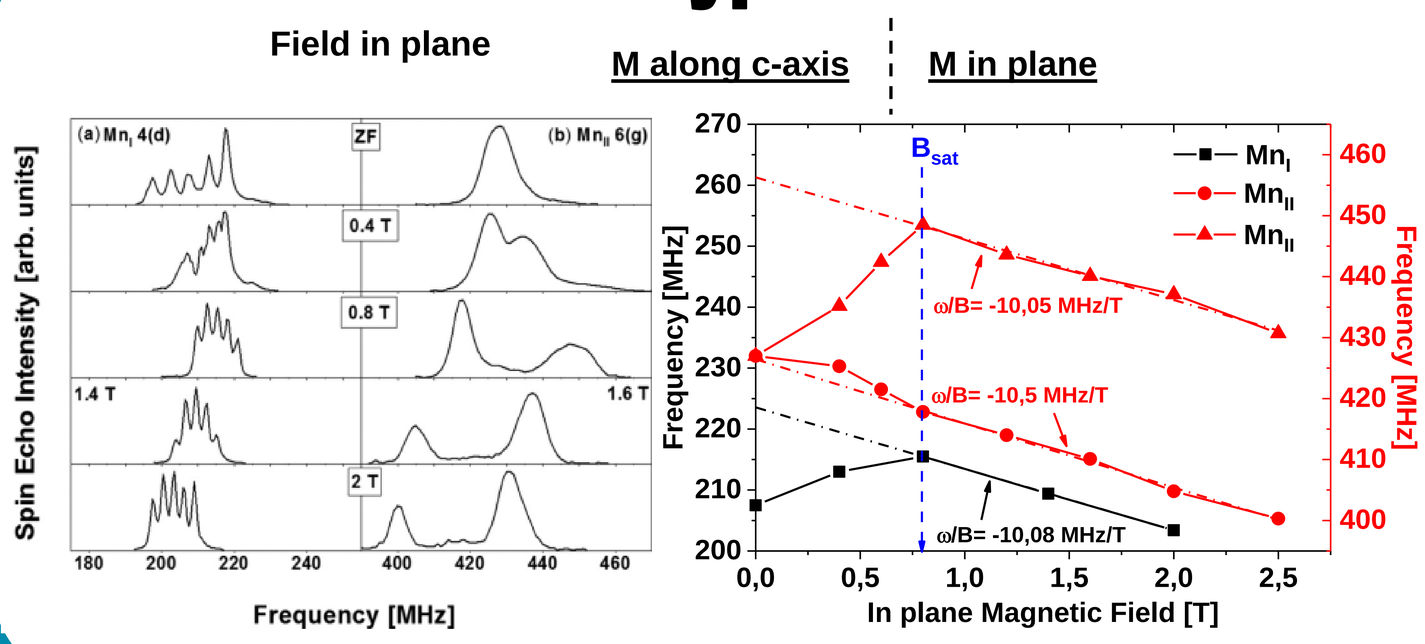
## Introduction

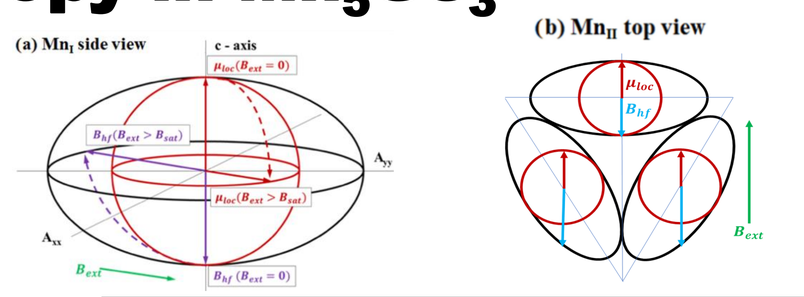
$Mn_5Ge_3$ is a very interesting compound with potential for application in spintronic devices. Numerous advantages of this compound, like high spin polarization (42%), easy fabrication, high Curie temperature ($T_C$ = 296 K), which can be further increased up to 445 K by addition of small amount of carbon, as well as full compatibility with Si and Ge based technology, make it one of the best candidates to incorporate into conventional Si-based electronic devices. To investigate the anisotropic properties of $Mn_5Ge_3$ epitaxial thin films, we performed a thorough study using $^{55}$Mn NMR (Nuclear Magnetic Resonance) technique. This technique belongs to the advanced characterization methods and can yield a unique magnetic and structural information on the nanoscale.




*Crystal structure of $Mn_5Ge_3C_x$ phase with interstitial carbon at x=1 (full occupancy of carbon): a) projection on xy – plane and b) side view [ref 1].*

## Hyperfine Field anisotropy in $Mn_5Ge_3$




$$\vec{\omega} = \gamma \vec{B}_{hf} = \gamma(\vec{B}_{Fcon} + \vec{B}_{orb})$$

$\vec{B}_{Fcon}$ – Fermi contact term
$\vec{B}_{orb}$ – orbital term

**Hyperfine Field anisotropy**

**Mn$_I$ sites:**

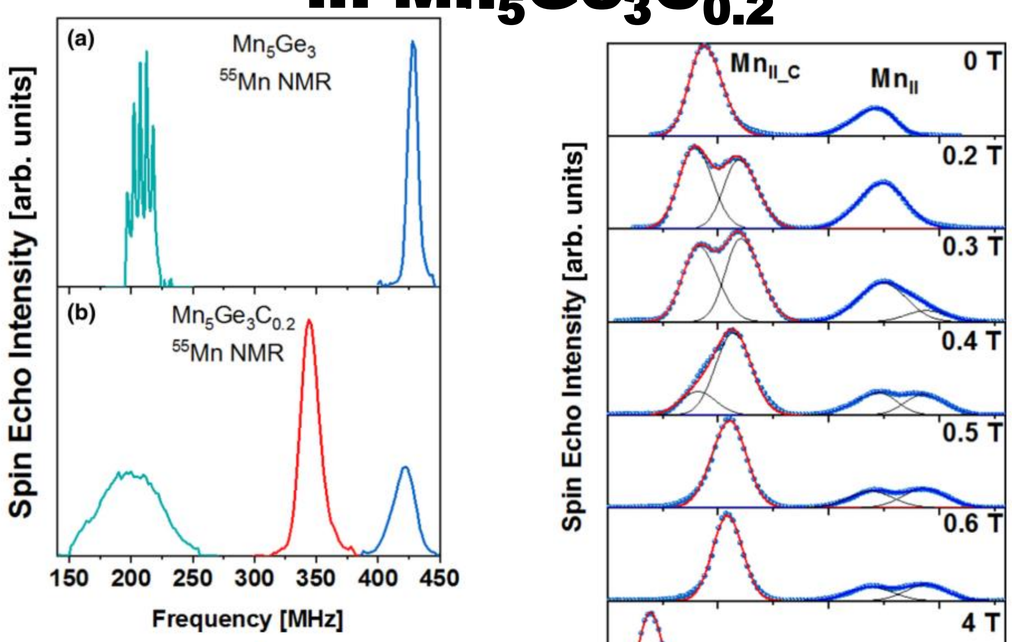
$$\Delta B = B_{\parallel} - B_{\perp} = 1.52\ T$$

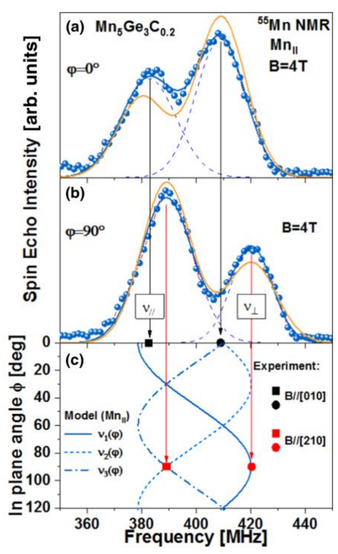
**Mn$_{II}$ sites:**

$$\Delta B = B_{\parallel} - B_{\perp} = up\ to\ 4.08\ T$$

**modulated in plane**

## Hyperfine Field anisotropy in $Mn_5Ge_3C_{0.2}$




**Hyperfine Field anisotropy**

**Mn$_I$ sites:**

$$\Delta B = B_{\parallel} - B_{\perp} = 1.42\ T$$

**Original Mn$_{II}$ sites:**

$$\Delta B = B_{\parallel} - B_{\perp} = up\ to\ 3.96\ T$$

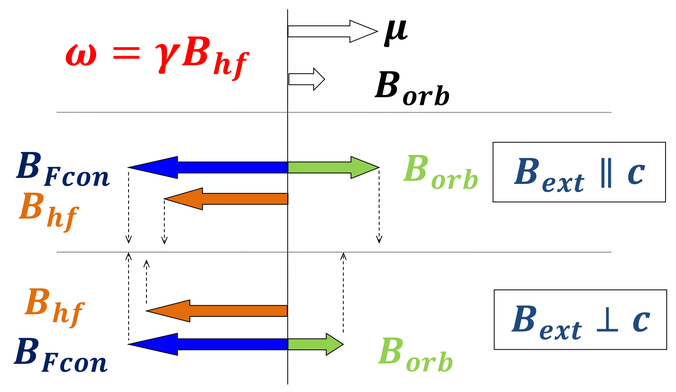
**modulated in plane**

**Mn$_{II_C}$ sites:**

$$\Delta B = B_{\parallel} - B_{\perp} = 1.56\ T$$

**in plane modulation lifted**

## Single Ion Anisotropy




$$B_{hf} = B_{Fcon} + B_{orb} = -A_{Fcon}\,\mu^{s}_{loc} + A_{orb}\,\mu^{L}_{loc}$$

$$B_{iso} = B_{Fcon}$$
$$B_{ani} = B_{orb} = 2\mu_L\langle r^{-3}\rangle$$

$(\mu_L)_{\parallel} > (\mu_L)_{\perp}$ on both, Mn$_I$ and Mn$_{II}$ sites

## Conclusions

- We provide the first experimental evidence of a strong anisotropy of $^{55}$Mn Hyperfine Fields in $Mn_5Ge_3$ and determine its origin.
- The main component of the Hyperfine Field is the isotropic Fermi contact term but on top of it there exists a significant anisotropic orbital contribution , originating from the anisotropic orbital moment.
- We propose that the magnetocrystalline anisotropy observed in this system has a single ion origin and can be linked to the observed anisotropic orbital moment of Mn.
- Interstitial carbon significantly lowers the anisotropy of the orbital contribution on Mn$_{II}$ sites from 4.08 T down to 1.56 T, explaining the drop of the bulk uniaxial magnetocrystalline anisotropy upon carbon doping.