
Interlayer coupling across an FeSi spacer studied with nuclear resonant scattering of synchrotron radiation

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Overview

I Motivation: - Fe/FeSi/Fe: The System
- Fe/FeSi/Fe: Interlayer Coupling

II Nuclear Resonant Scattering of Synchrotron Radiation

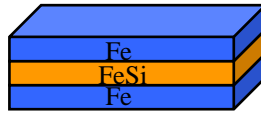
III Analysis of the measured spectra

IV Interpretation

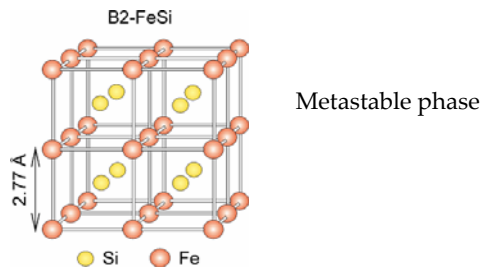


Fe/FeSi/Fe : The System

- Epitaxially grown trilayer on a substrate



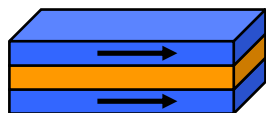
- Under well controlled conditions, CsCl FeSi spacer can be formed



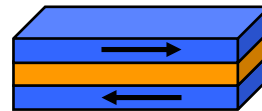
Interlayer Coupling

Coupling between the magnetization vectors of two adjacent **ferromagnetic** materials (Fe), separated by a **non-magnetic** spacer layer (FeSi).

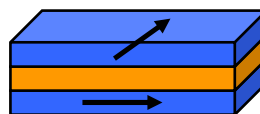
- BILINEAIR: \vec{M}_1 and \vec{M}_2 parallel



- \vec{M}_1 and \vec{M}_2 antiparallel



- BIQUADRATIC: \vec{M}_1 and \vec{M}_2 perpendicular

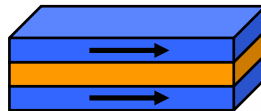


Interlayer Coupling in Fe/FeSi/Fe

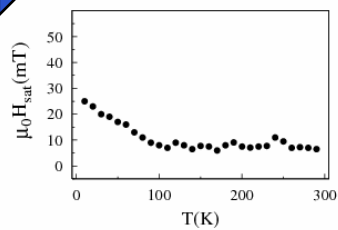
Fe/Fe_{0.57}Si_{0.43}/Fe directly on MgO

- bilinear coupling found

Fe (2.0 nm)
Fe_{0.57}Si_{0.34} (3.4 nm)
Fe (4.0 nm)



- continuous temperature dependence

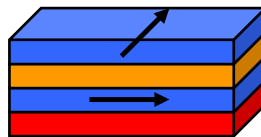


Properties of Interlayer Coupling in Fe/FeSi/Fe

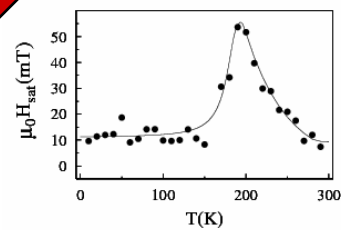
Fe/Fe_{0.57}Si_{0.43}/Fe on a thick Au-buffer

- strong biquadratic coupling found

Fe (2.0 nm)
FeSi (3.4 nm)
Fe (4.0 nm)
Au (150 nm)



- unconventional temperature dependence

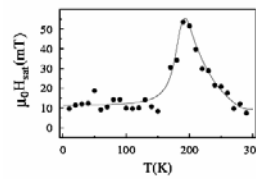
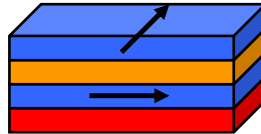


Properties of Interlayer Coupling in Fe/FeSi/Fe

Fe/Fe_{0.57}Si_{0.43}/Fe on a thick Au-buffer

- strong biquadratic coupling found

Fe (2.0 nm)
FeSi (3.4 nm)
Fe (4.0 nm)
Au (150 nm)



- unconventional temperature dependence

How can we understand this complex coupling behavior?



Microscopic study of magnetic properties of the silicide spacer



Overview

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- Interlayer coupling in Fe/FeSi/Fe-trilayers

II: Nuclear Resonant Scattering of Synchrotron Radiation

III: Analysis of the measured spectra

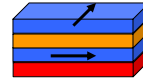
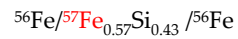
IV: Interpretation



Nuclear Resonant Scattering of Synchrotron Radiation



Is an isotope selective technique



no foreign impurity atoms must be introduced in the spacer layer

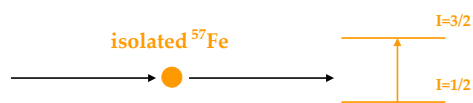


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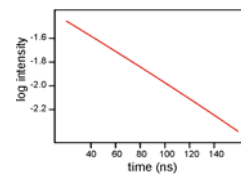
Nuclear Resonant Scattering of Synchrotron Radiation



Is a hyperfine interaction technique



exponential decay



due to lifetime of excited state

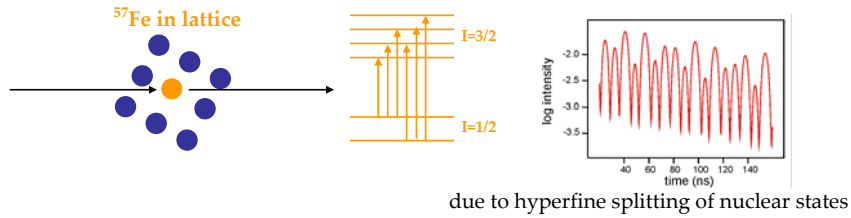


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Nuclear Resonant Scattering of Synchrotron Radiation



Is a hyperfine interaction technique



due to hyperfine splitting of nuclear states

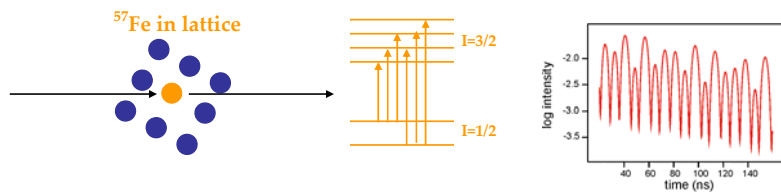


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Nuclear Resonant Scattering of Synchrotron Radiation



Is a hyperfine interaction technique



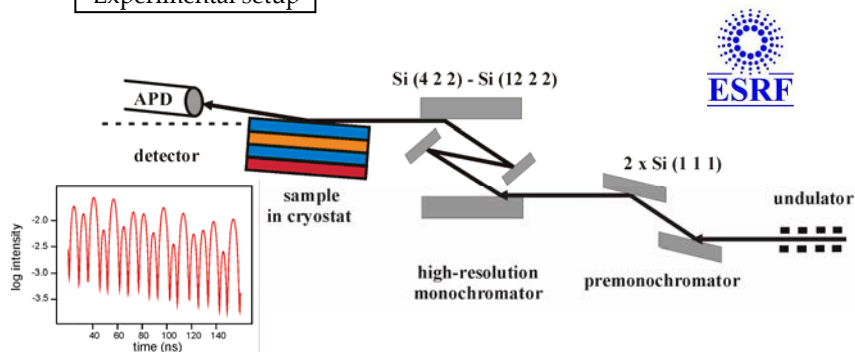
By analyzing the spectra, the direction and the magnitude of the magnetic hyperfine fields (magnetization) in the system can be deduced



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Nuclear Resonant Scattering of Synchrotron Radiation

Experimental setup

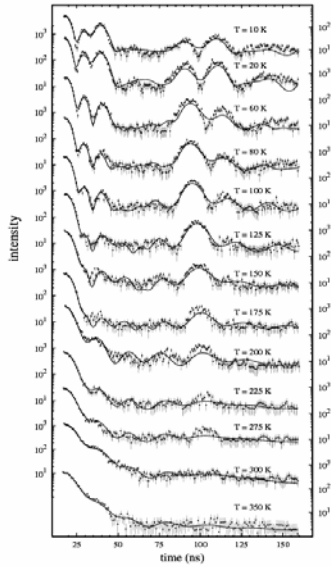


- sample placed in grazing incidence
- sample in cryomagnet: cooling down to 2 K, external fields up to 6 T

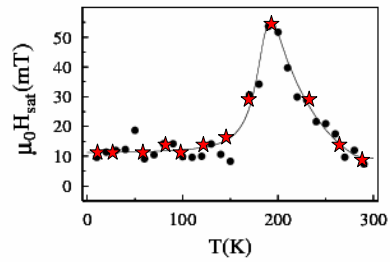
Overview

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- Interlayer coupling in Fe/FeSi/Fe-trilayers
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- III: Analysis of the measured spectra
- IV: Interpretation

Overview of the measured spectra



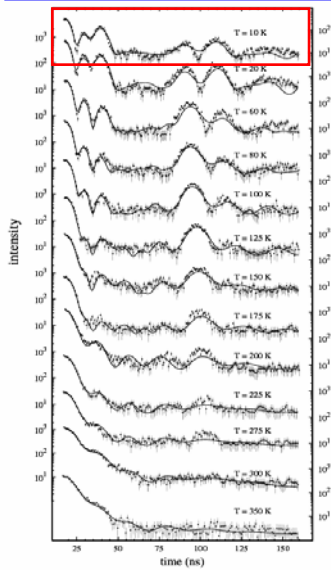
- Time spectra measured at 13 different temperatures, between 10 K and 350 K



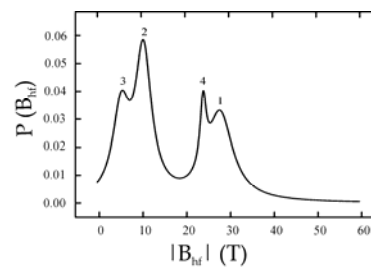
- Time spectra show a magnetic signal
- The magnetic signal undergoes a damping with increasing T



Analysis of the spectrum at 10 K



FeSi spacer composed of 4 magnetic sites

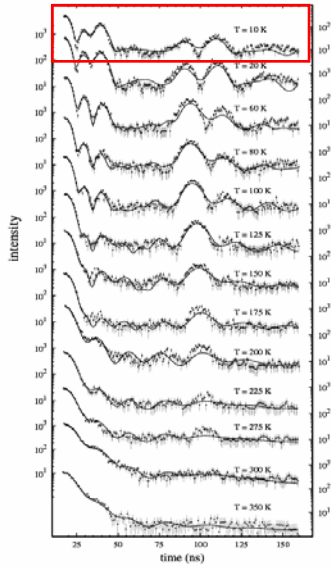


	site 1	site 2	site 3	site 4
B _{fit} (T)	-28.1(2)	-10.6(1)	-5.4(3)	-24.2(1)
width (T)	6.8(3)	4.6(5)	4.5(3)	2.6(9)
weight	0.34(2)	0.37(4)	0.23(3)	0.06(2)
iso (mm/s)	--	0.4(2)	0.9(2)	0.1(1)

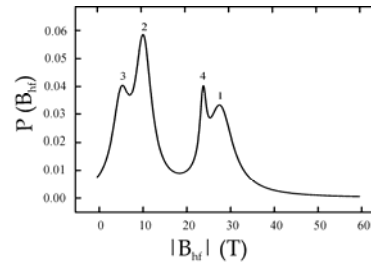
M. Walterfang *et al*, PRB 73, 214423 (2006)



Analysis of the spectrum at 10 K



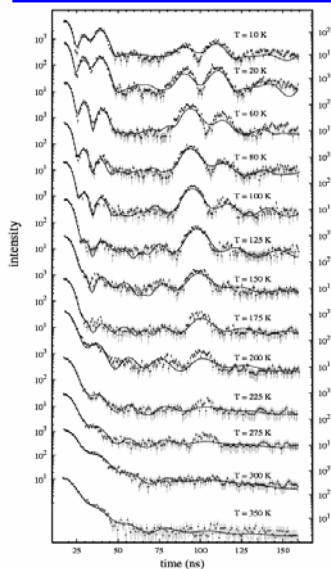
FeSi spacer composed of 4 magnetic sites



Static magnetic ordering at low temperatures



Analysis of the spectrum at high T



How to explain the damping of the magnetic signal:

- Distribution model
- Fluctuation model



M.Blume and J.A. Tjon,
Phys. Rev. 165

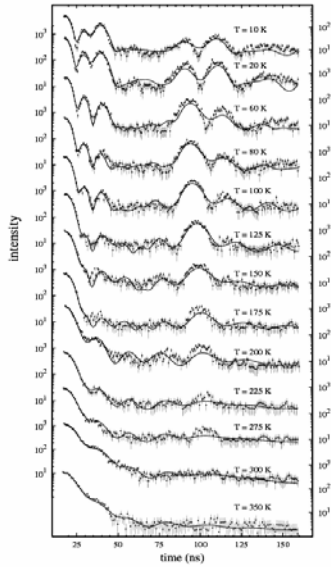
B_{hf} fluctuates between two opposite in-plane directions (easy axes of the sample)

For each site:

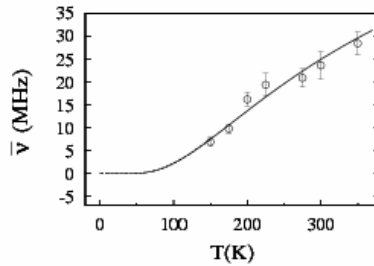
- weight, width and iso fixed (10 K values)
- B_{hf} decreases with increasing T
- fluctuation frequency free



Analysis of the spectrum at high T



weighted fluctuation frequency increases with increasing temperature



thermal activation process ($E_a=31(3)$ meV)



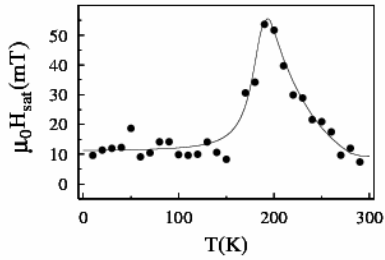
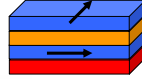
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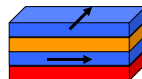
Interpretation

Macroscopic properties
of the interlayer coupling

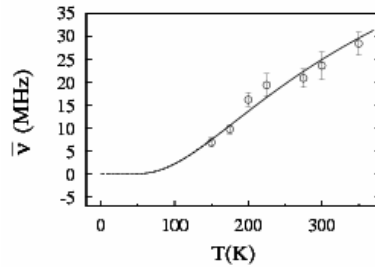
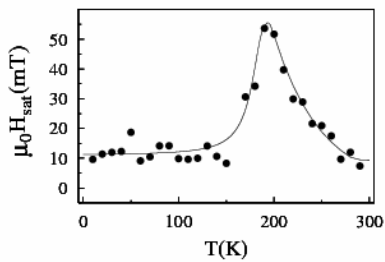


Interpretation

Macroscopic properties
of the interlayer coupling



Microscopic properties
of the spacer

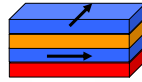


Low temperatures: static magnetic ordering in the FeSi
High temperatures: superparamagnetic Fe moments mediate the coupling

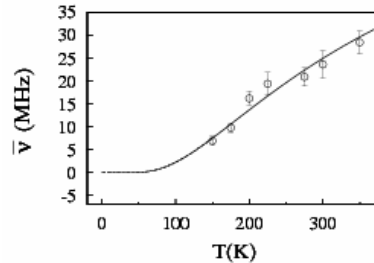
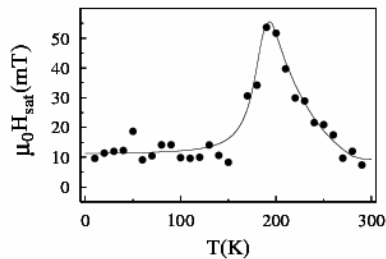


Interpretation

Macroscopic properties
of the interlayer coupling



Microscopic properties
of the spacer



Low temperatures: static magnetic ordering in the FeSi
High temperatures: superparamagnetic Fe moments mediate the coupling

The biquadratic coupling can be associated with fluctuating magnetic Fe moments in the FeSi spacer



Conclusions

- In order to understand the complex coupling behavior in an Fe/FeSi/Fe trilayer, we selectively probed the magnetic state in the FeSi spacer
- Experimental technique used to this purpose: Nuclear Resonant Scattering of Synchrotron Radiation
- We provide strong evidence that the biquadratic coupling in the trilayer can be associated with fluctuating magnetic moments in the FeSi spacer











