Energy resolved nuclear resonant scattering of synchrotron radiation applied to an Fe$_3$Al-foil

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Overview

• Motivation

  Comparative study of three Mössbauer techniques

  Why Fe₃Al?

• Experimental details

  Sample preparation

  Mössbauer spectroscopy

  Time Resolved NRS

  Energy Resolved NRS

• Discussion

• Conclusion
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  Energy Resolved NRS

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Motivation

Techniques

Mössbauer spectroscopy (1966)

Time resolved nuclear resonant scattering of synchrotron radiation (1985)


Materials

Materials with an increasing degree of complexity and reduced dimensions
Motivation

Techniques

Mössbauer spectroscopy (1966)

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Materials

Materials with an increasing degree of complexity and reduced dimensions

Comparative study of the three techniques by extracting the magnetic structure of an Fe$_3$Al foil from a MS spectrum, a time resolved NRS and an energy resolved NRS spectrum
Fe$_3$Al has a cubic DO$_3$ structure with two possible Fe environments:

- Fe(bcc): 2.492 \( \mu \text{B/atom} \), \( B_{hf} = 31 \) T
- Fe(fcc): 1.939 \( \mu \text{B/atom} \), \( B_{hf} = 24 \) T

The Fe(fcc) atoms could exhibit \textit{metamagnetism} under high pressure (32 GPa)

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3 micron thick $^{57}$Fe$_3$Al-foil

melting of $^{57}$Fe and Al
grinding to a foil of 10 micron
cold rolling to a foil of 3 micron (± 1 micron!)

disordered alloy
Sample preparation

3 micron thick $^{57}\text{Fe}_3\text{Al}$-foil

melting of $^{57}\text{Fe}$ and Al
grinding to a foil of 10 micron
cold rolling to a foil of 3 micron (± 1 micron!)

annealing for 4 h at 773 K
annealing for 32 h at 723 K

B. Fultz et al., PRL 80 (1998) 3304
Mössbauer spectroscopy

Mössbauer source

conversion electrons

$^{57}$Co in a Rh matrix source

$^{57}$Fe$_3$Al foil

$B_{\text{ext}} = 0 \text{ T}$

Intensity

a)

Velocity (mm/s)
* Four magnetic sites, Gaussian distribution included for each hyperfine field
  * Site 1 and 3: ordered DO₃ stoichiometric Fe₃Al
  * Site 2 and 4: residual disorder, ...
* Isomer shift of all sites relative to Mössbauer reference
  * Linear dependende of I onto H: I = AH+B

**Measured spectrum = incoherent addition of sextets of peaks**
Time Resolved NRS

synchrotron source

log (intensity)

Time (ns)
Time Resolved NRS

Synchrotron source

APS XOR-3-ID

14.413 keV

15 μm (v) x 10 μm (h)

$^{57}$Fe$_3$Al foil

$B_{\text{ext}} = 2.50$ T

Graph showing intensity vs. time (ns)
Time resolved NRS

Measured spectrum = interference pattern

* Four magnetic sites, Gaussian distribution included for each hyperfine field
  * Site 1 and 3: ordered DO$_3$ stoichiometric Fe$_3$Al
  * Site 2 and 4: residual disorder, …
* Isomer shift of three sites relative to one reference site
  * Linear dependende of I onto H: I = AH+B
Energy Resolved NRS

SS on Mössbauer drive

Energy Resolved NRS

SS on Mössbauer drive

synchrotron source

APS XOR-3-ID
14.413 keV
15 μm (v) x 10 μm (h)

57Fe3Al foil
$B_{ext} = 2.50$ T

SS310 foil (0.93 μm thick)
95% 57Fe enriched
velocity drive in sinusoidal mode
$v_{max} = 16.7$ mm s$^{-1}$
Energy Resolved NRS

Measured spectrum = **coherent addition** of quartets of peaks

* Four magnetic sites, Gaussian distribution included for each hyperfine field
  * Site 1 and 3: ordered DO$_3$ stoichiometric Fe$_3$Al
    * Site 2 and 4: residual disorder, ...
  * Isomer shift of all sites relative to the SS reference
    * Linear dependence of $I$ onto $H$: $I = AH+B$
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Comparison of the spectra

* The three spectra can be analyzed with nearly the same model

* Small discrepancies between the hyperfine field distributions can be assigned to different parts of the sample that are probed with the different techniques
Limitations of the techniques

Mössbauer spectroscopy: limited to samples containing enough nuclear resonant material
Limitations of the techniques

Time resolved NRS: complex systems acquire additional Mössbauer measurements
Limitations of the techniques

Energy resolved NRS: only simple Fe-structures were investigated up till now.

Analysis??
* The spectrum is a coherent addition of the different subspectra
* Due to the coherence effect, the original positions of the resonance lines are affected
* No direct extraction of the different hyperfine fields from the spectrum is possible
For samples with a less complex hyperfine field distribution, a direct extraction of the different magnetic components from the spectrum should be possible.
Analysis of the energy resolved spectrum

Applying the external field perpendicular to the synchrotron plane, results in an even easier to interpret energy resolved spectrum.
Analysis of the energy resolved spectrum

What happens to the spectrum if a phase transition occurs?
The phase transition can be followed in energy domain, but not in time domain!
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Conclusion

* We measured a Mössbauer spectrum, a time and an energy resolved NRS spectrum onto the same Fe₃Al-foil.

* Comparison of the hyperfine field distributions indicates that the three spectra can be analyzed with nearly the same model.

* Both the time and energy resolved NRS technique lend themselves to the study of samples with reduced sizes.

* In most cases, the analysis of the energy resolved spectrum is more straightforward than the time resolved spectrum and allows one for an on-line analysis.