Title: MnSi Epitaxial Thin Films: Structure and Magnetic Properties

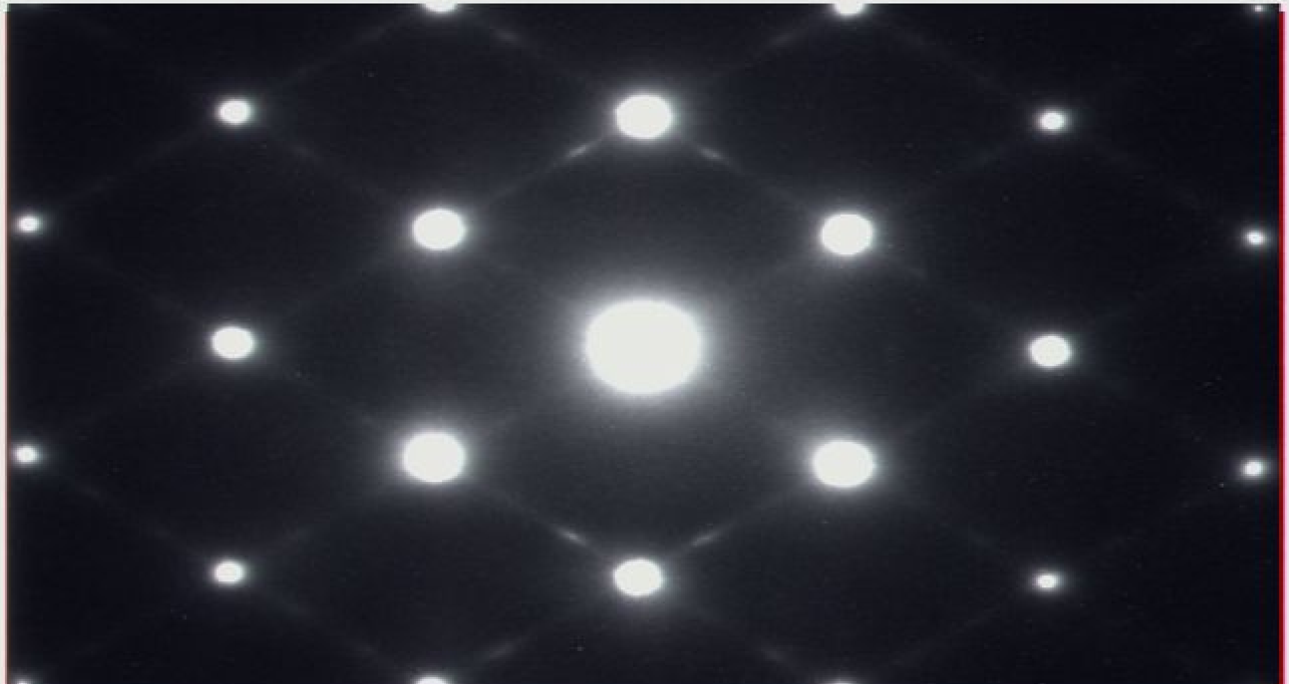
Date: Jul 20, 2011 02:40 PM

URL: http://pirsa.org/11070073

Abstract: Epitaxial MnSi grown on Si (111) offers new opportunities in the development of spin-dependent transport in helical magnets. Helical magnets are a class of noncollinear structures that have shown promise as a material for spin-dependent electron transport studies.The helical magnets are of particular interest in spintronics because in these magnets the electron spins spiral about a particular crystallographic direction, this property can allow for control over electron spin. Many interesting magnetic properties can be studied with the combination of thin-film heterostructures and helical magnets. Through use of x-ray diffraction, SQUID magnetometry and transmission electron microscopy, we have observed the structural and magnetic properties of crystalline MnSi thin-films to determine the effects of strain on the magnetic properties. As a result, we have found that epitaxially induced tensile strain results in an increase in the unit-cell volume, and that the atypical strain relaxation behaviour is correlated with a magnetic response.The talk will give a brief outline of the theory/techniques used, and the results gathered.

Cathryn Parsons

Acadia University



MnSi Epitaxial Thin Films

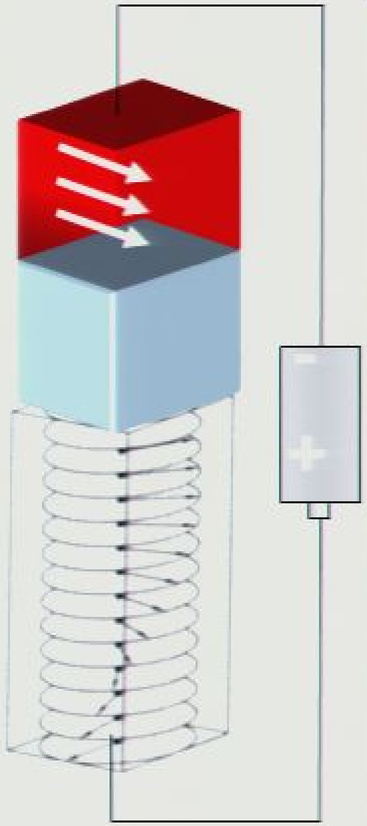
Structure and Magnetic properties

Overview

- Spintronics
  - What is it?
  - Use of helical magnets (MnSi) in spintronics.
- MnSi
  - Annealing Process
- Transmission Electron Microscopy (TEM)
  - Sample Preparation
  - What we did, what we were looking for, and what we found.
- Structural Observations
  - Chirality
  - Tensile Strain
- Magnetic Properties
  - Correlations with structural findings
- Conclusions

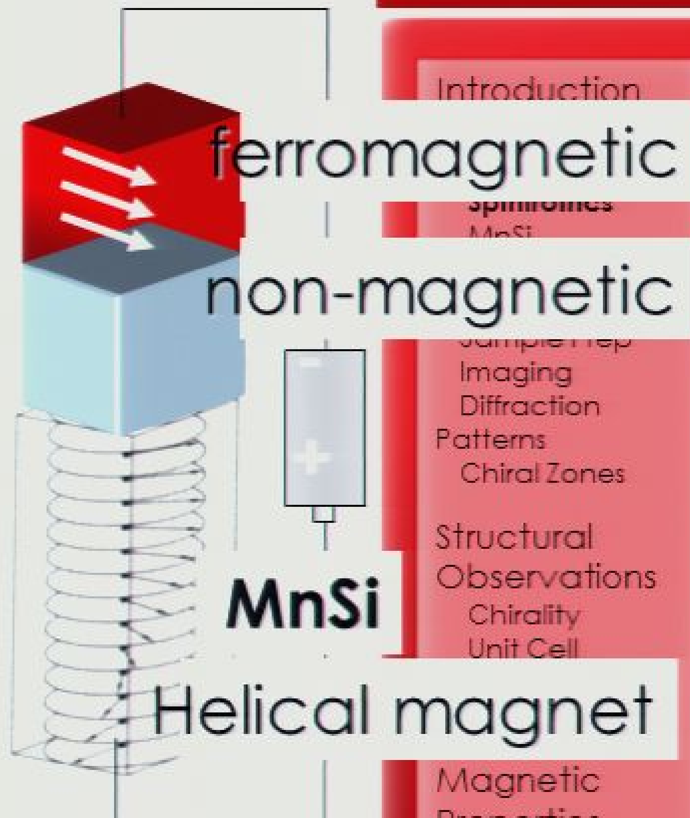
Spintronics

- Manipulation of electron spin, with semiconductor and magnetic applications.
  - Opportunity for faster and lighter devices.
- Spintronics is used in the production of computer storage
  - Magnetoresistive Random Access Memory (MRAM).
- Spin Torque Transfer (STT) is the main method through which MRAM is achieved.
  - Helical magnets such as MnSi can be used to achieve STT.



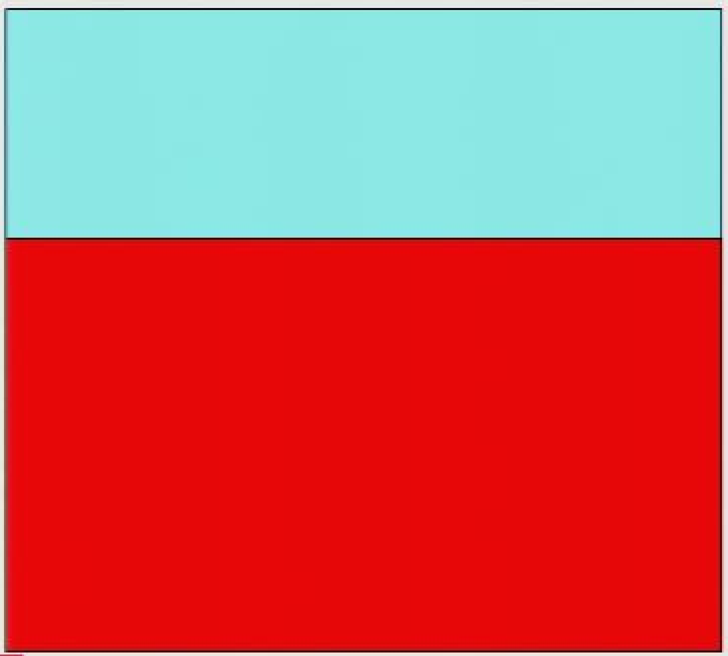
Spintronics

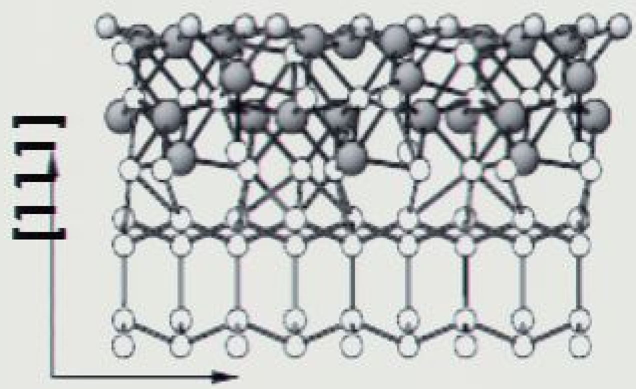
- Manipulation of electron spin, with semiconductor and magnetic applications.
  - Opportunity for faster and lighter devices.
- Spintronics is used in the production of computer storage
  - Magnetoresistive Random Access Memory (MRAM).
- Spin Torque Transfer (STT) is the main method through which MRAM is achieved.
  - Helical magnets such as MnSi can be used to achieve STT.



MnSi

- Solid phase Epitaxy (SPE)
  - Sample annealed under Ultra High Vacuum at 400° C until MnSi formation
  - a-Si protective cap is then applied

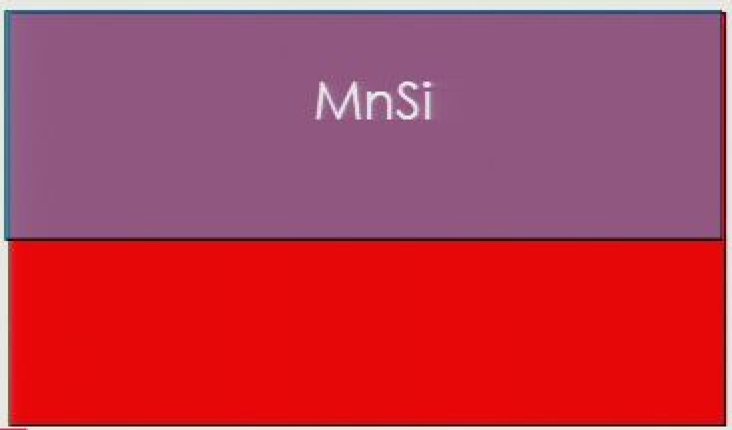


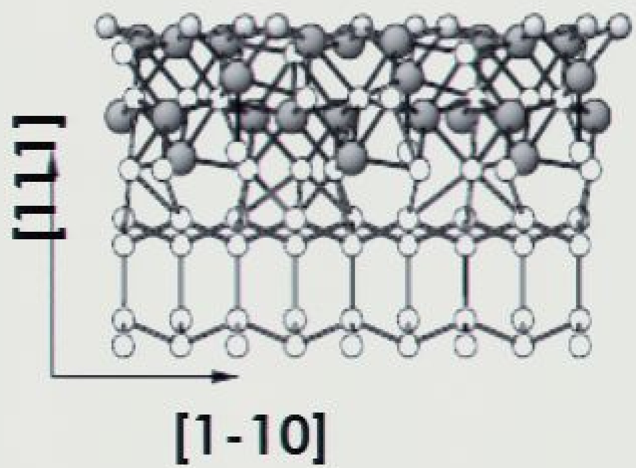


Adapted from Hortamani M. et al, PRB **76**, 235426 2007

MnSi

- Solid phase Epitaxy (SPE)
  - Sample annealed under Ultra High Vacuum at 400° C until MnSi formation
  - a-Si protective cap is then applied

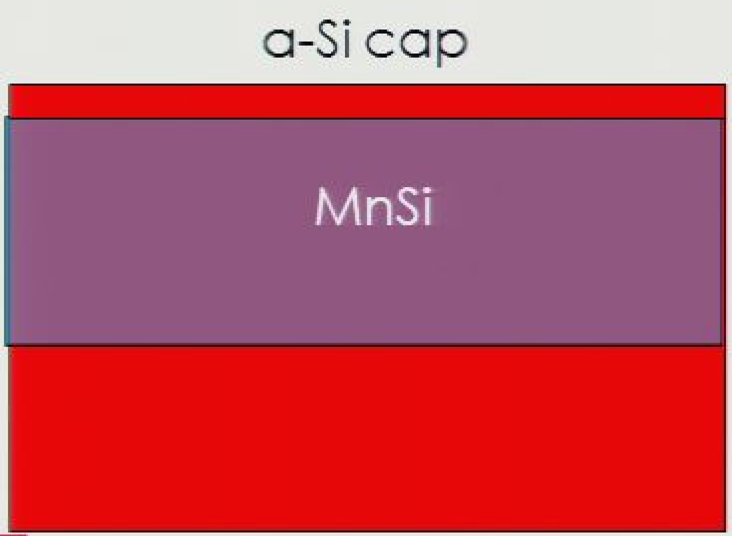


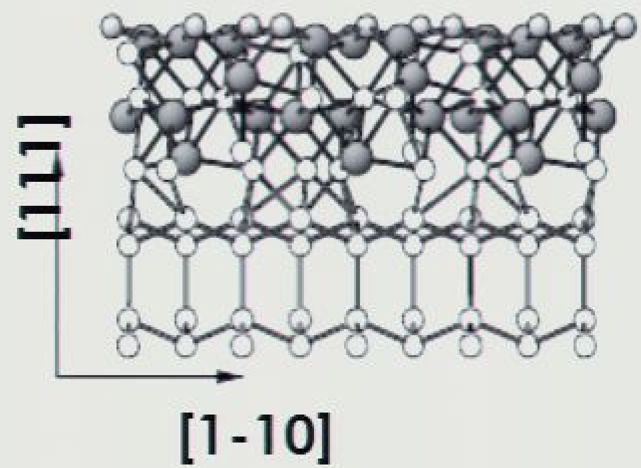


Adapted from Hortamani M. et al, PRB **76**, 235426 2007

MnSi

- Solid phase Epitaxy (SPE)
  - Sample annealed under Ultra High Vacuum at 400° C until MnSi formation
  - a-Si protective cap is then applied

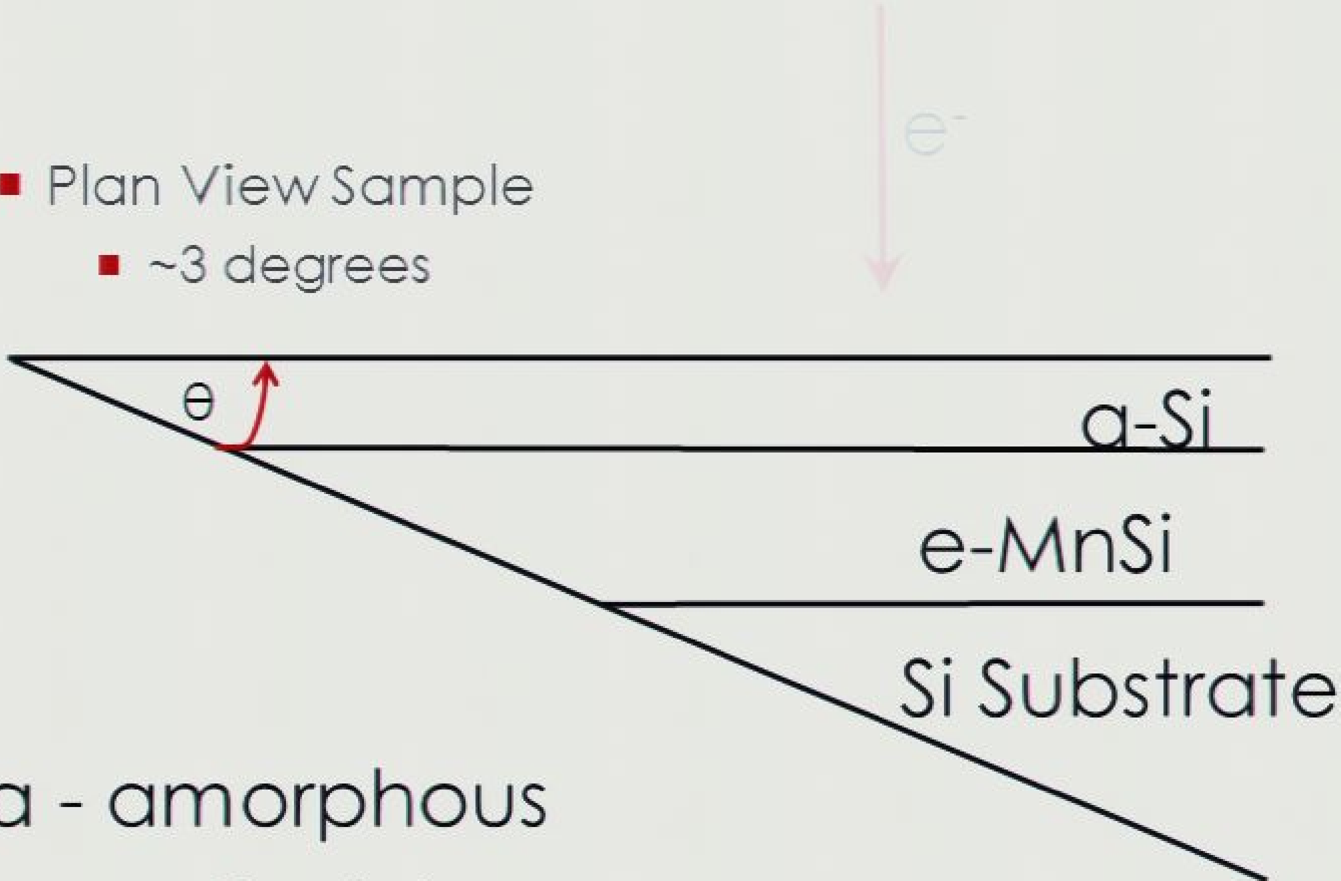




Adapted from Hortamani M. et al, PRB **76**, 235426 2007

Sample Preparation

- Plan View Sample
  - ~3 degrees

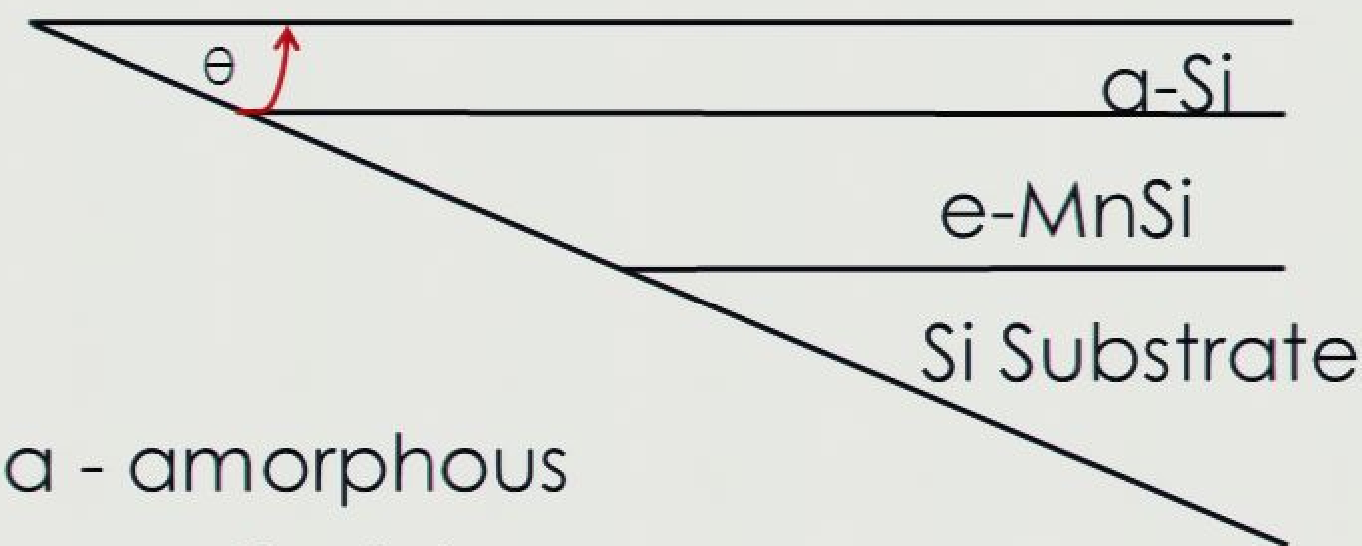


a - amorphous

e - epitaxial

Sample Preparation

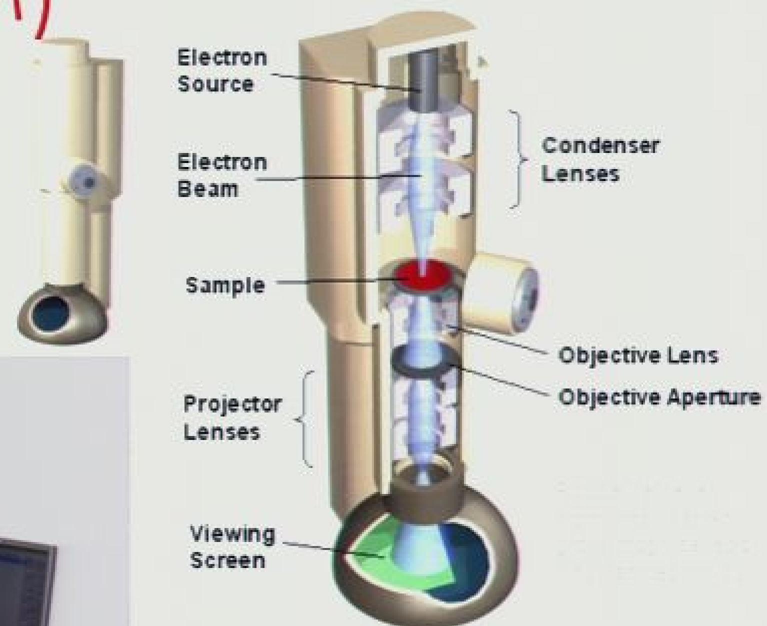
- Plan View Sample
  - ~3 degrees

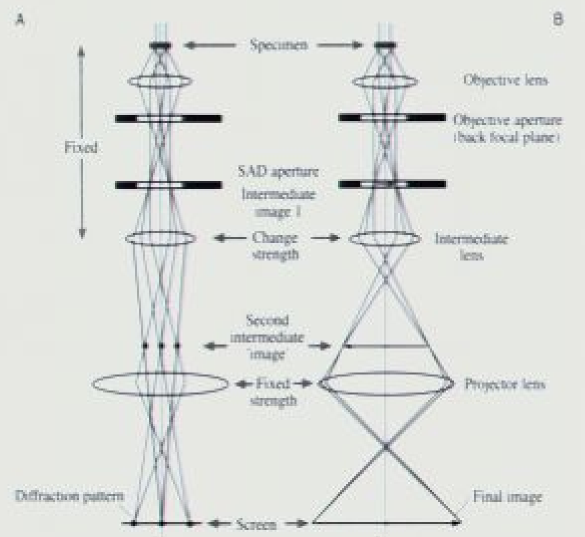


a - amorphous

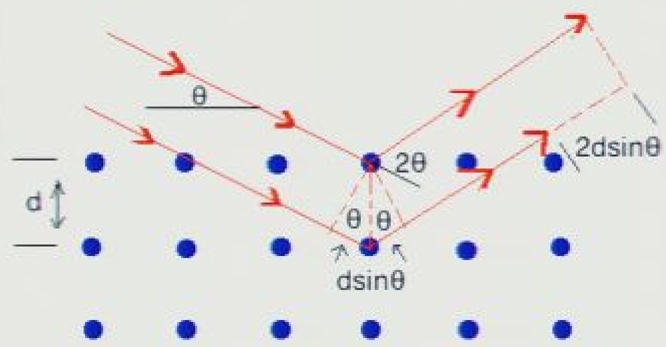
e - epitaxial

Transmission Electron Microscopy (TEM)



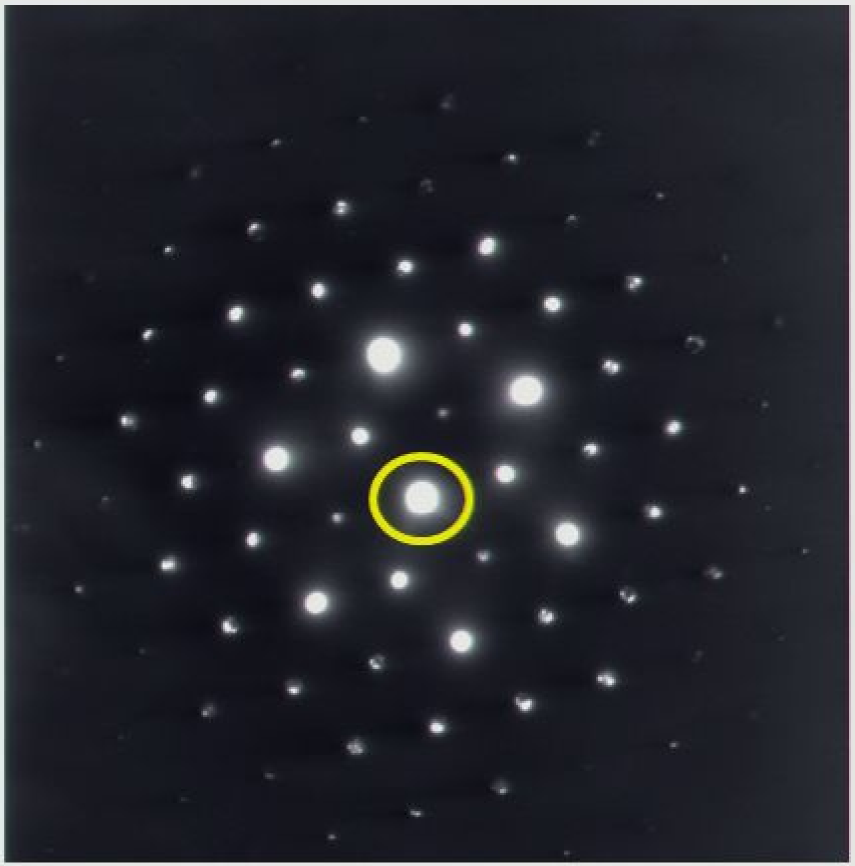


Imaging

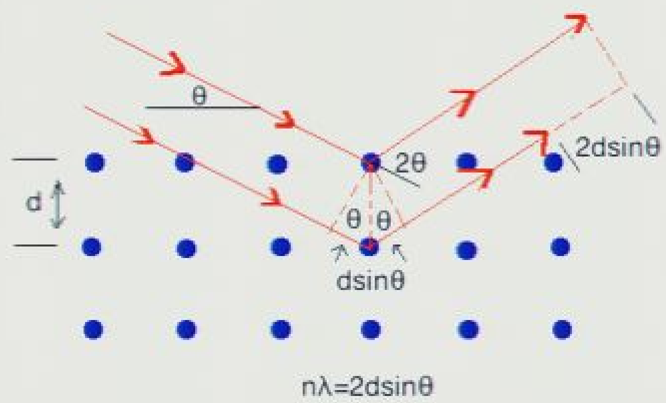


$n\lambda = 2d\sin\theta$

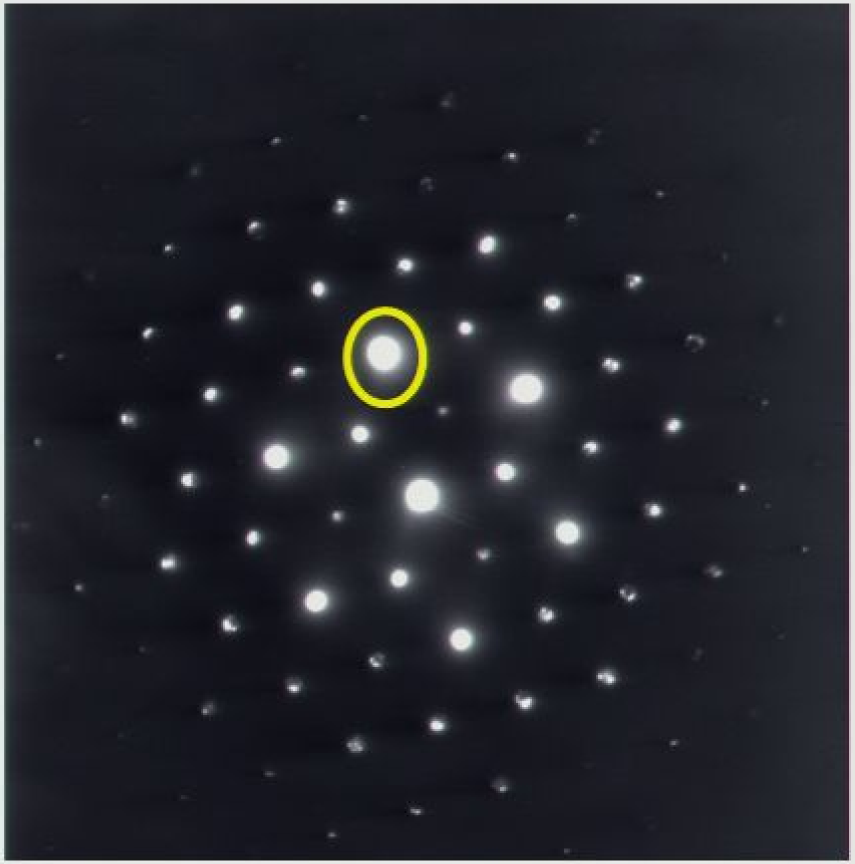
Imaging



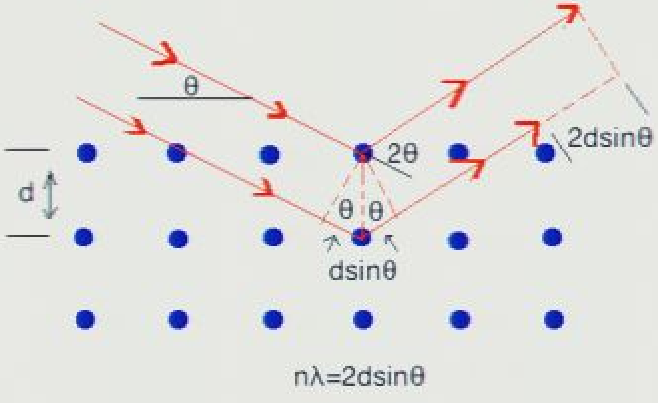
Bright-field image
(use transmitted beam)



Imaging

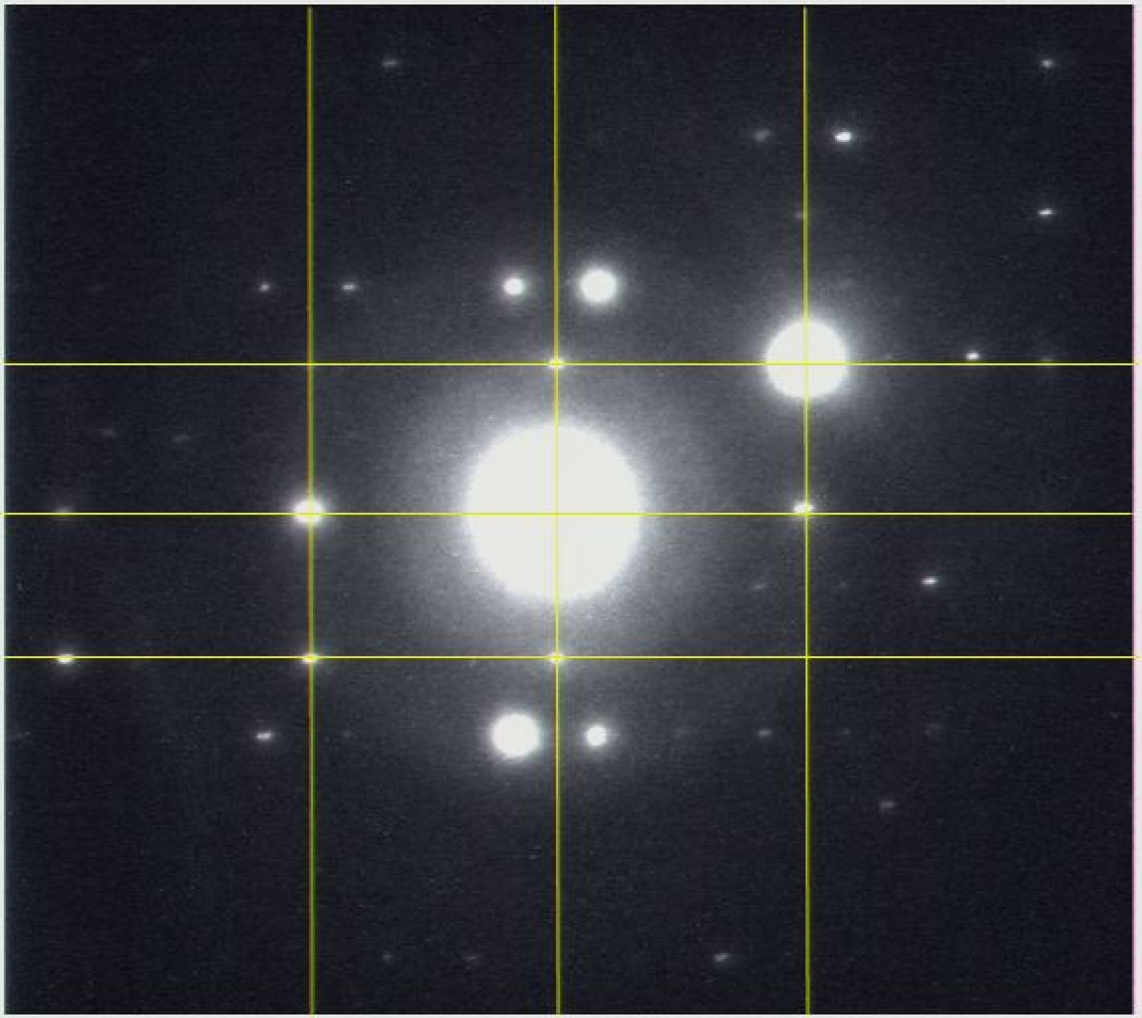


Dark-field image
(use diffracted beam)



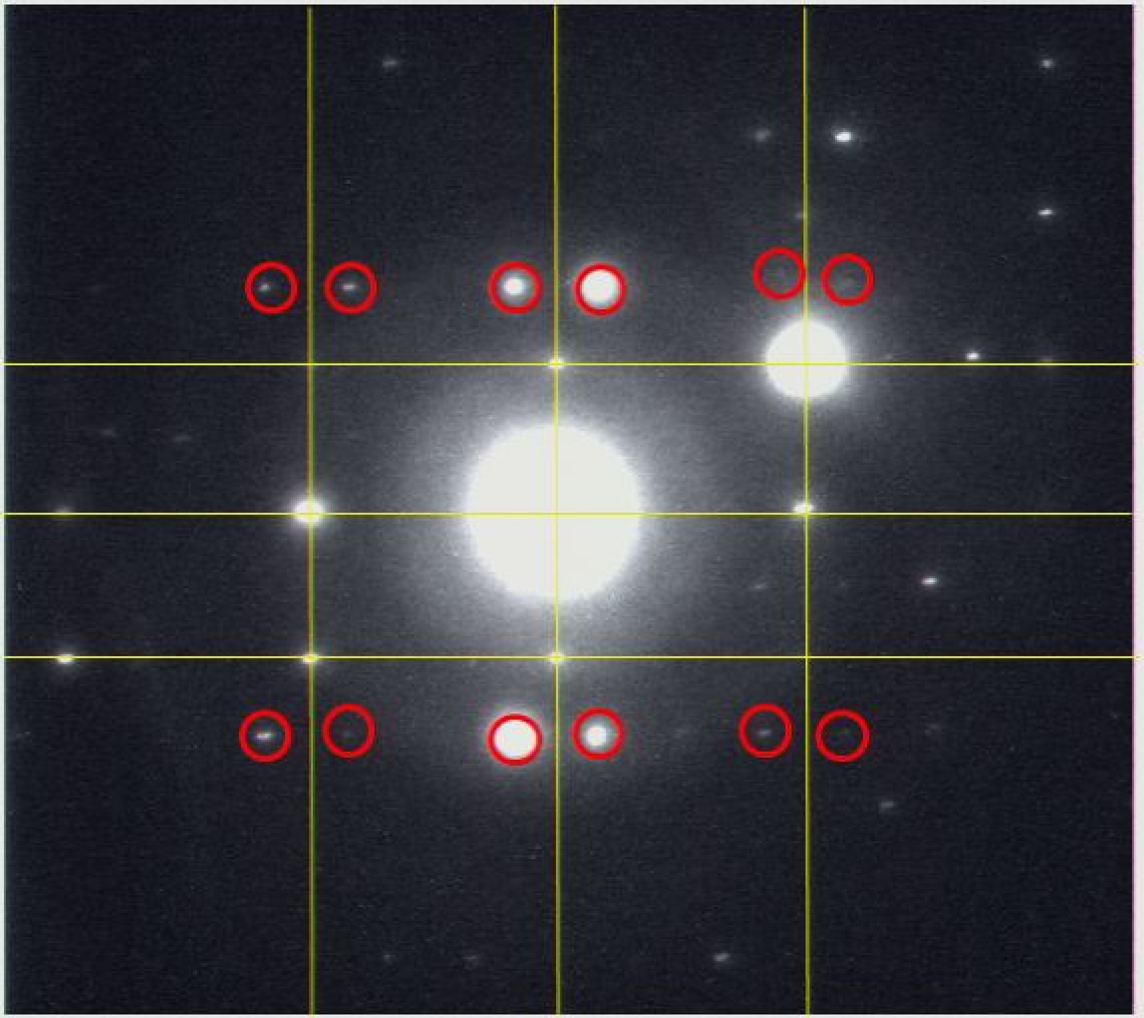
Diffraction patterns

Diffraction patterns



Si (112)

Diffraction patterns

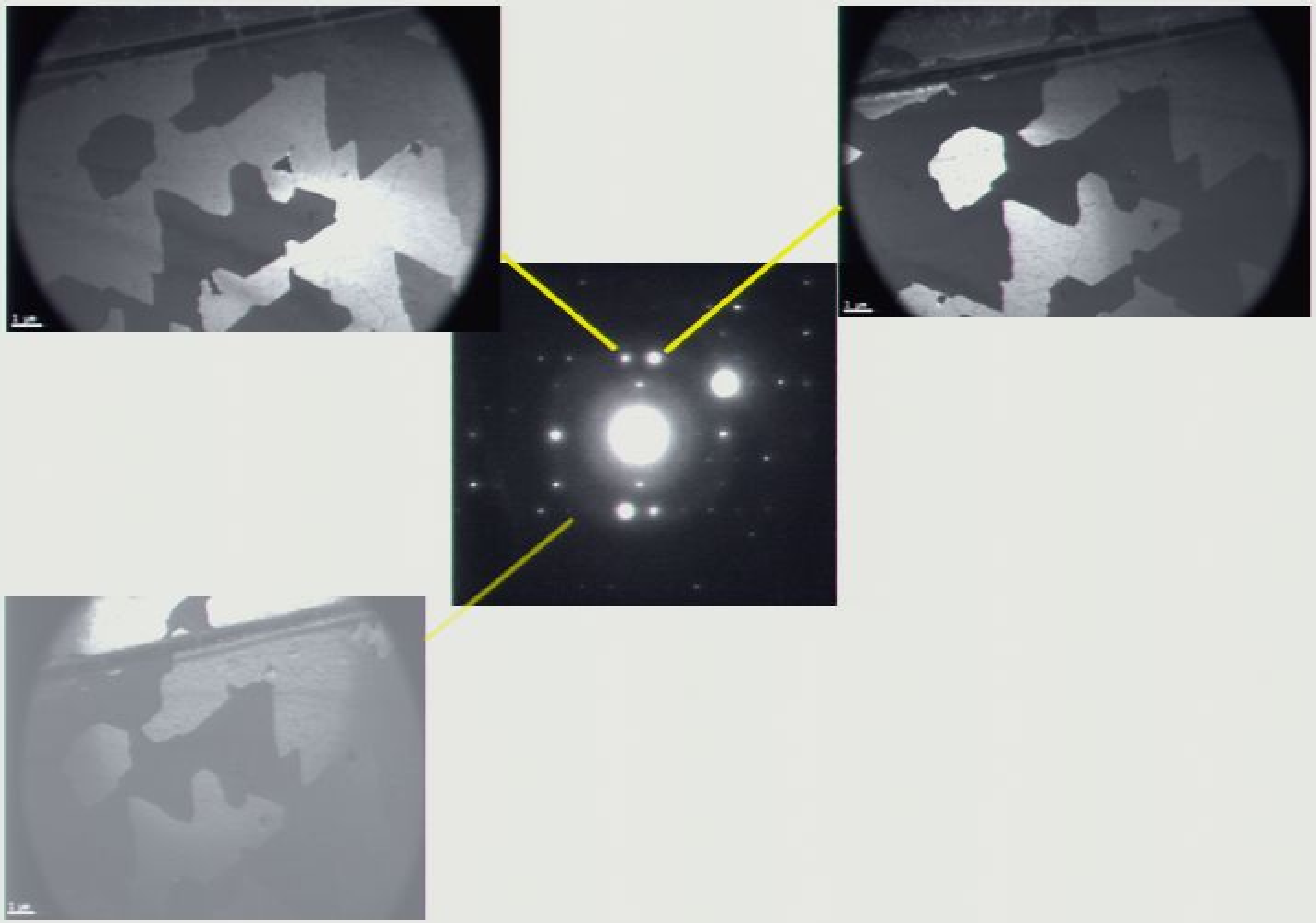


Si (112)

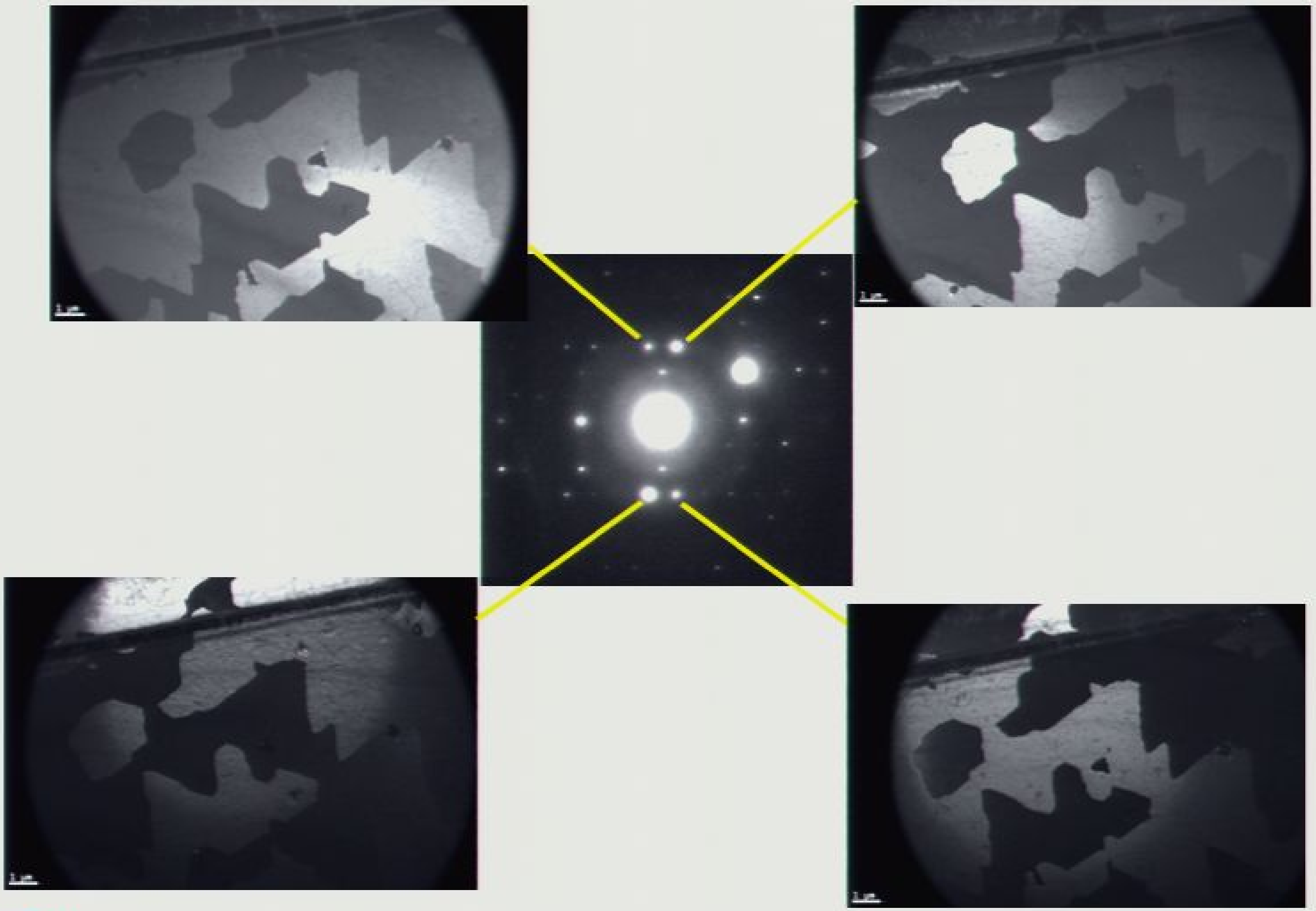
MnSi (221)

Chiral Zones

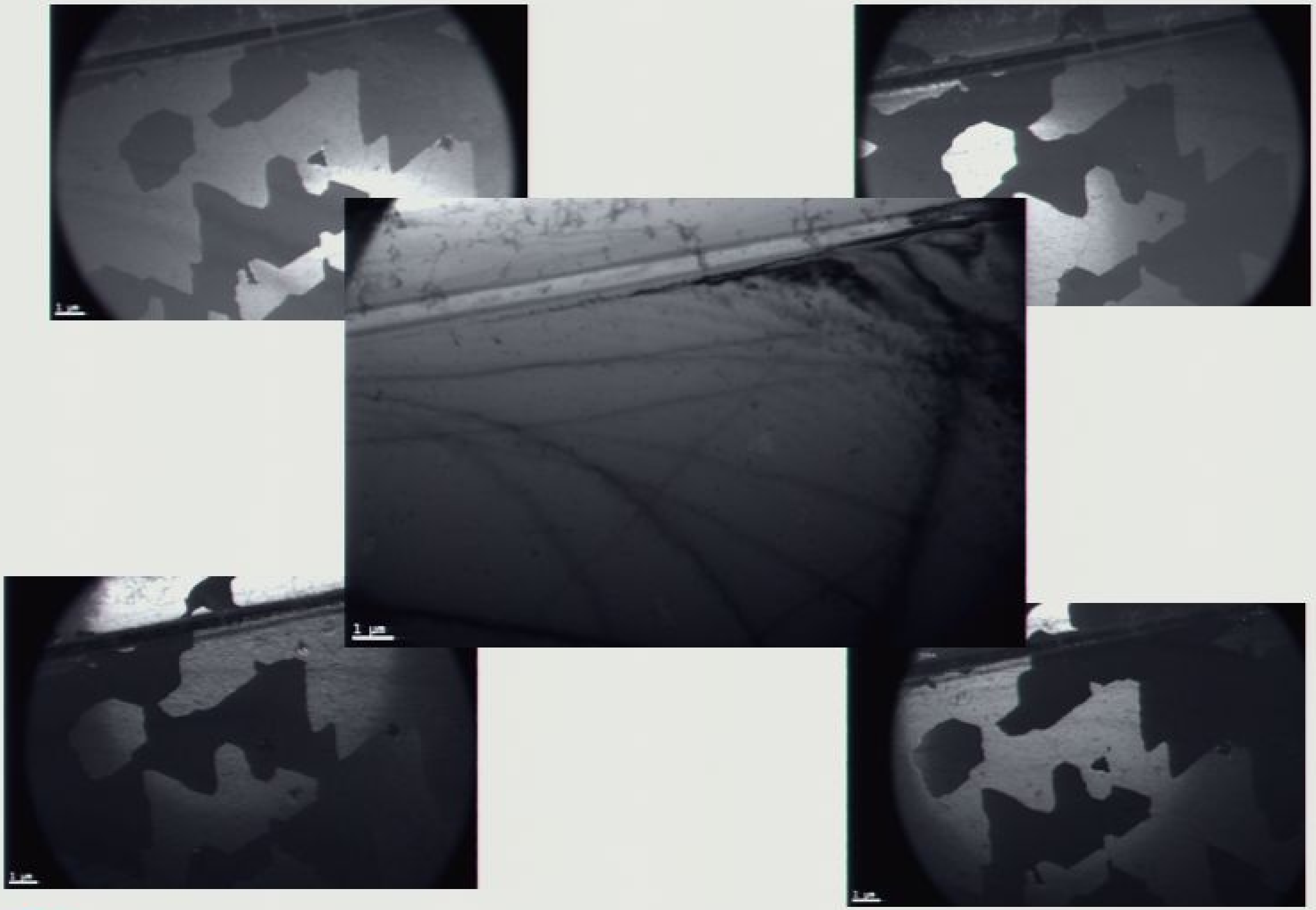
Chiral Zones



Chiral Zones

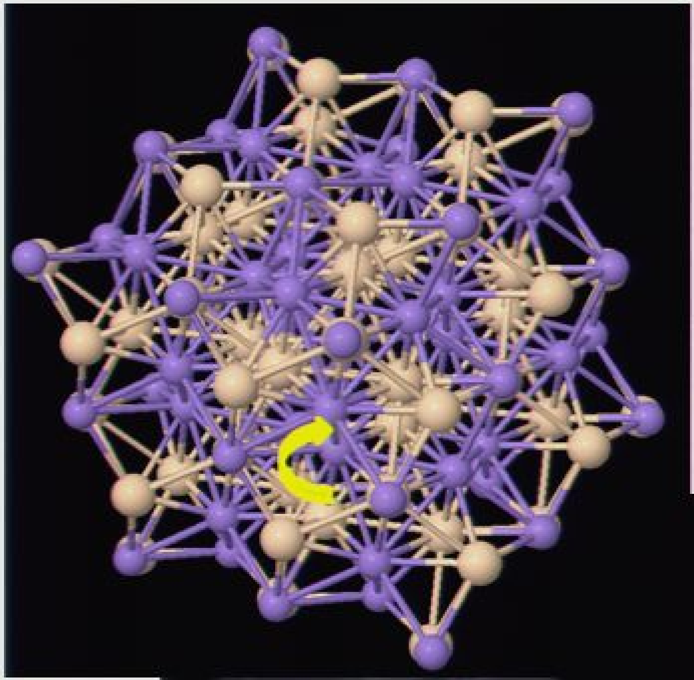


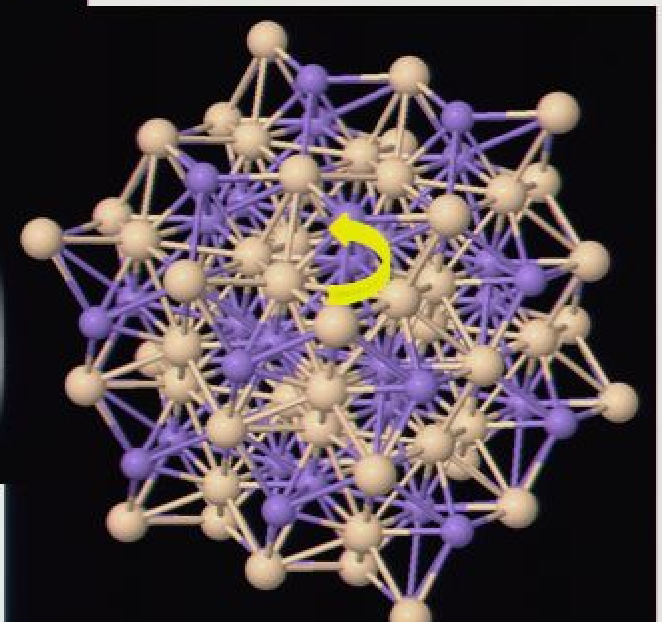
Chiral Zones



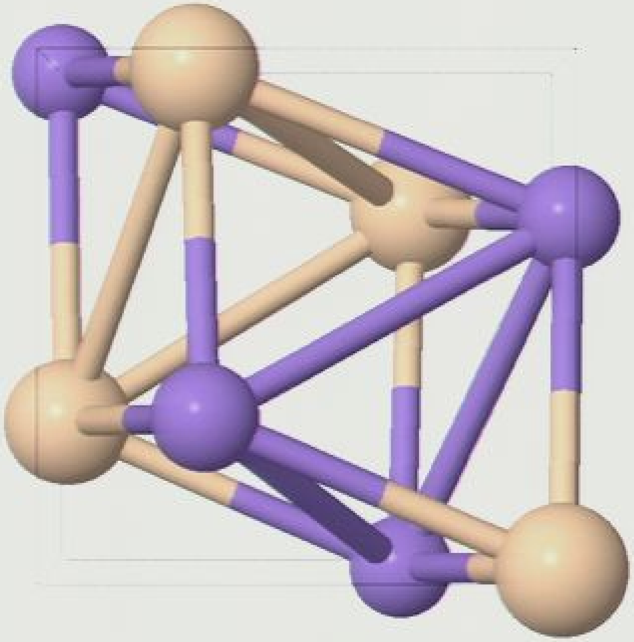
Chirality

- Atomic structure
  - Left and right handed
    - The structural chirality has an affect on the magnetic chirality.
    - R & L chirality leads to a helical magnet.
    - See Grigoriev et. Al. PRB **81** 012408

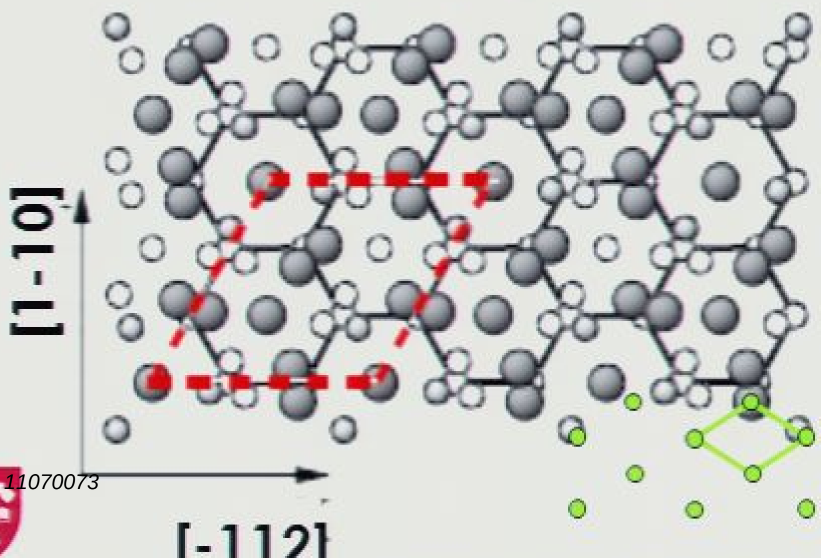




MnSi

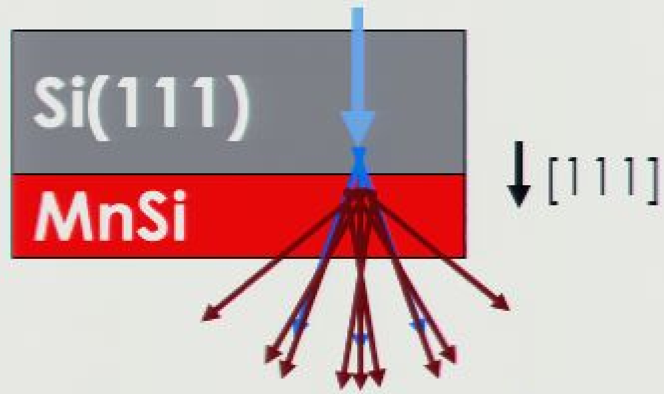


- MnSi-Cubic unit cell with a lattice parameter of 0.4558 nm
- Si-lattice parameter of 0.5430 nm
  - MnSi (111) layer rotated 30° w.r.t the substrate
    - 3.0% lattice mismatch results

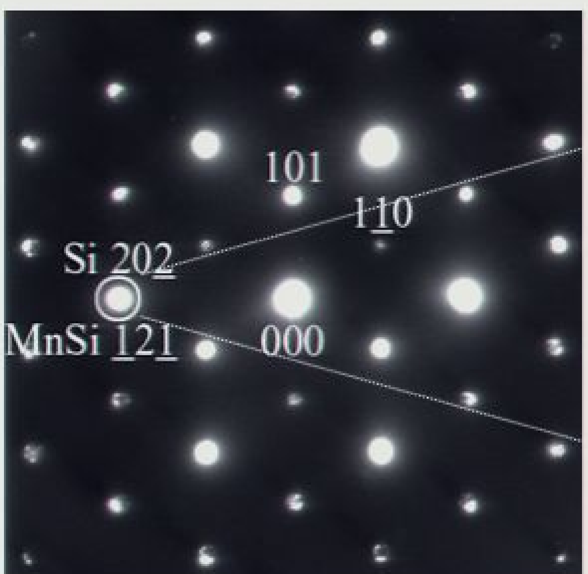


MnSi Strain Measurements

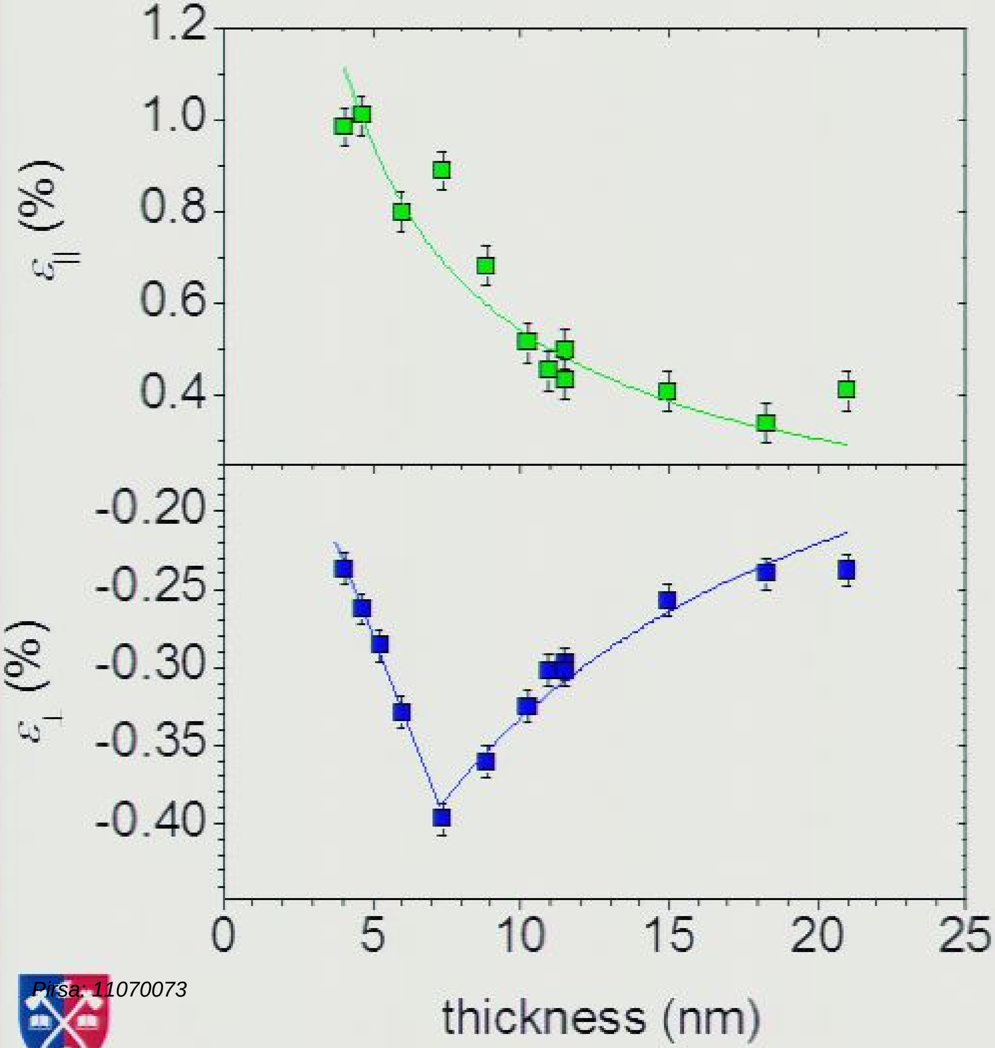
- [111] Zone Axis
  - MnSi [110] Inner ring
  - Si (202) & Mn (121) in 2nd ring
- Strain measured with double diffraction spots and Si (202) spots.



$$\varepsilon_{\|}(\%) = 3.0\% - 100\% \frac{\Delta g}{g_{ref}}$$



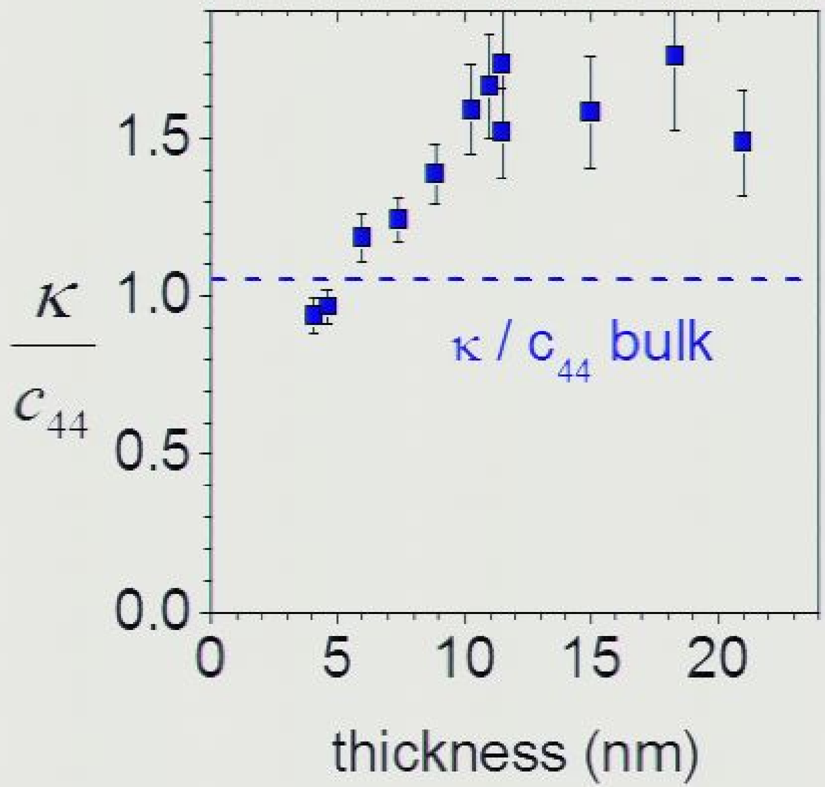
In-plane and Out-of-plane Tensile Strain vs. Thickness



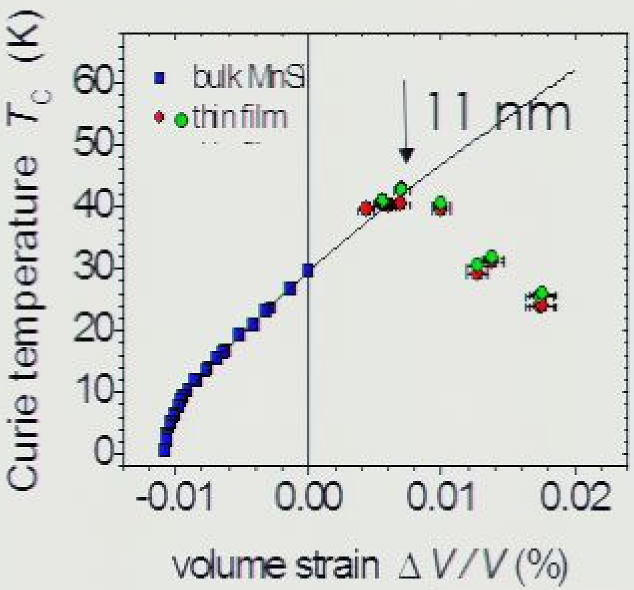
- Top graph- TEM data gathered on in-plane strain.
- Bottom graph- X-ray diffraction data gathered on the out-of-plane strain.
- Strange results < 7 nm (bottom graph).
  - Possible cause may be interstitial defects.

Elastic Constants Vs. Thickness

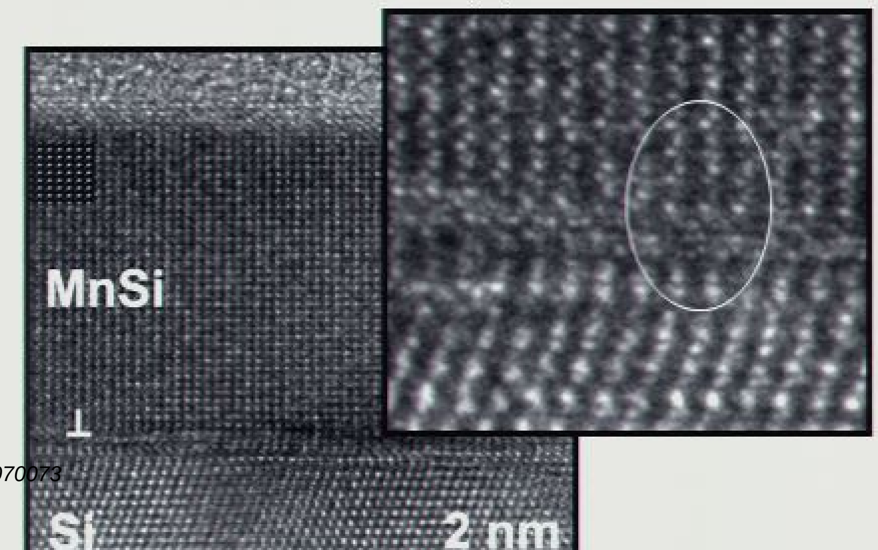
- Ratio is the compressibility (K) to the Shear elastic constant (C_{44})
- The elastic constants are part of the strain tensor used to provide information on the strain in a material
  - (See Hooke's Law, or Kittel)



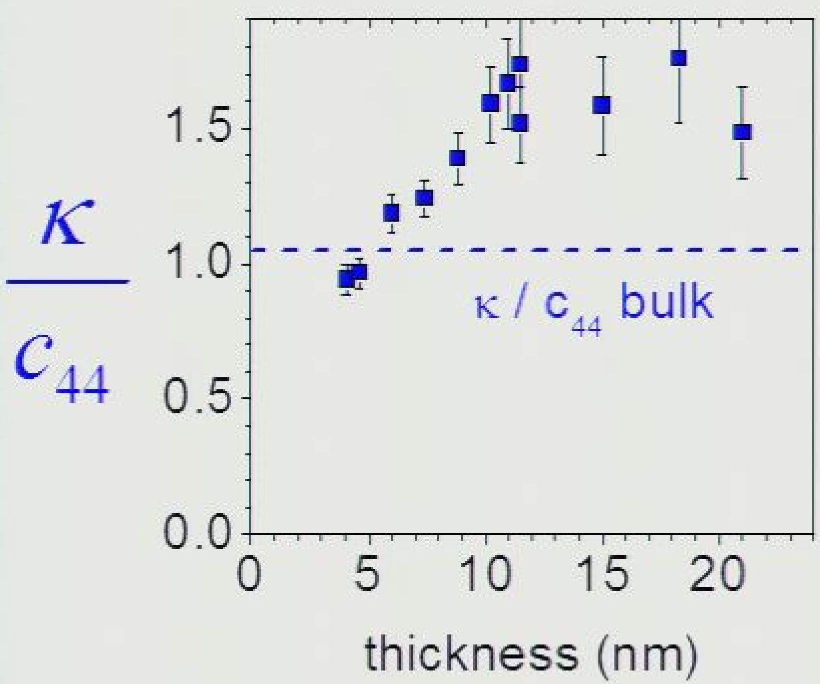
Magnetic effects of Strain



- Measurements made with Superconducting Quantum Interference Device (SQuID)
- Tensile strain (green/red) is compared with measurements of bulk MnSi under compressive pressure (blue).
- Compressive strain decreases the Curie temperature (T_C), tensile strain should increase it.
  - < 10 nm doesn't match the curve.
  - Defects are affecting the data.
  - MnSi compensating by adding extra layers.



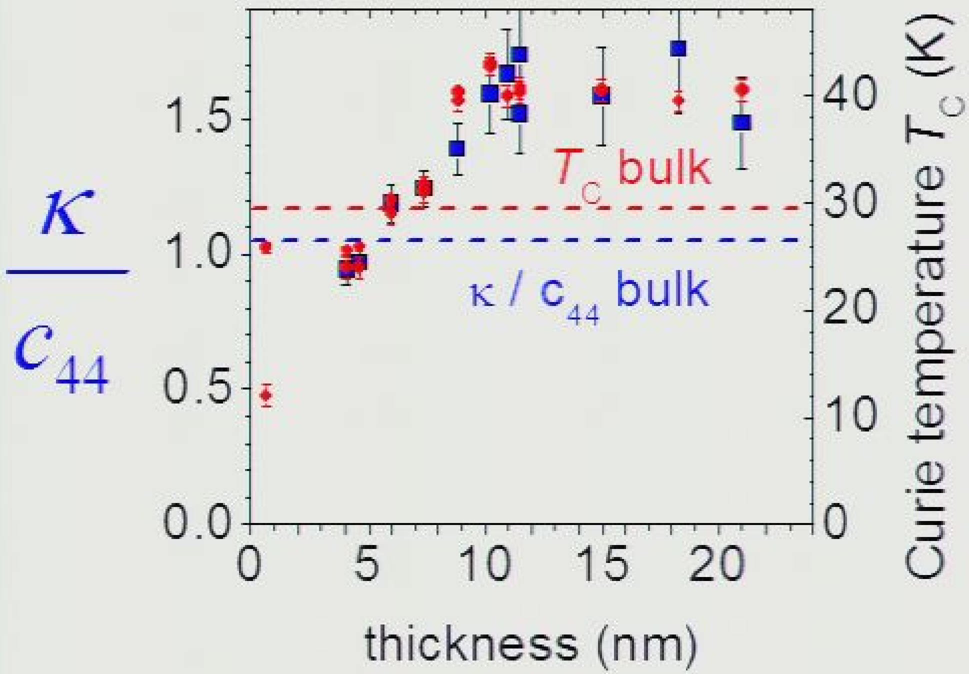
Strain Data/Curie Temperature Correlation



- Strong correlations between elastic constants and T_C.
- Indicates common origin.
  - Possibly from, interstitials.

E. Karhu et al., Phys. Rev. B, **82**, 184417 (2010).

Strain Data/Curie Temperature Correlation



- Strong correlations between elastic constants and T_C.
- Indicates common origin.
  - Possibly from, interstitials.

E. Karhu et al., Phys. Rev. B, **82**, 184417 (2010).

Conclusions

- Strong correlations between the structure and magnetic properties of epitaxial MnSi thin films
- Epitaxially induced strain in MnSi causes a volume expansion in the MnSi
  - > 10 nm, the increase in cell volume is consistent with the increase in T_C.
- Lower film thickness departs from the expected behavior
  - The drop in T_C can not be explained by finite size.
- Interstitial defects could explain both observed changes

Acknowledgments

- Michael Robertson
- Ted Monchesky, Eric Karhu, and Samer Kahwaji
  - Images Courtesy of Dr. Michael Robertson and Dr. Ted Monchesky
- Acadia Physics Department and the Acadia Centre for Microstructural Analysis
- NSERC USRA program
- PI, IQC and the organizers.
- You for Listening ☺

ACADIA UNIVERSITY

DALHOUSIE UNIVERSITY

NSERC CRSNG