Thickness dependence of superconducting properties in MgB2 thin films

Douglas B. Beringer
Department of Physics
The College of William and Mary

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Collaborators & Acknowledgements

Sample Preparations

Teng Tan and Dr. Xiaoxing Xi — Temple University

Lukaszew Research Group
The College of William and Mary

Cesar Clavero — Department of Applied Science
R. A. Lukaszew — Departments of Physics and Applied Science

SRF Institute at JLab

Dr. C. E Reece, Anne-Marie Valente-Feliciano, Josh Spradlin

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Overview

- Introduction
- MgB_2 thin films
- Morphological and structural characterization of MgB_2 thin films
- DC SQUID measurements of H_{c1}
- Conclusions

Our philosophy and approach

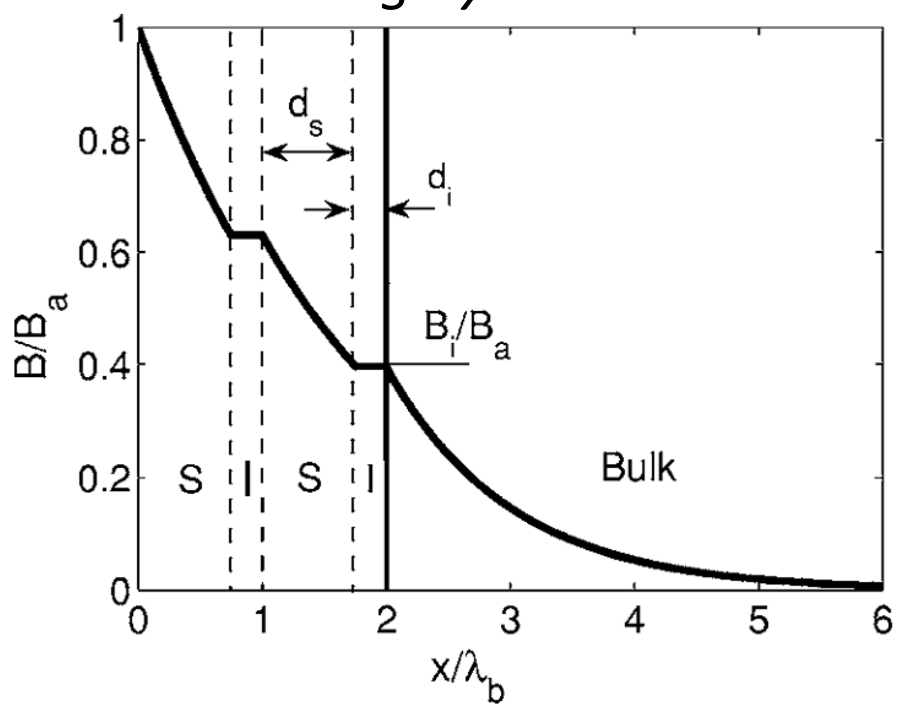
- We believe that in order to fully understand and confront the challenges inherent to the successful realization of next generation thin film SRF cavities, a fundamental understanding of thin film growth, structure, morphology and superconducting properties is imperative.
- Our group aims to correlate structure, morphology and superconducting properties in candidate thin film materials in order to inform the design of proposed SRF surfaces.
- Previous work with collaborators includes: Epitaxial thin Nb thin films*^; Multilayer structures; NbN thin films— Will Roach.

***C. Clavero *et al.*, Cryst. Growth Des. 12, 2588 (2012).**

^W. M. Roach *et al.,* Phys. Rev. ST Accel. Beams 15, 062002 (2012)

Motivation for SRF thin films

Shielding by SIS structures



A. Gurevich, *Appl. Phys. Lett.* **88**, 012511 (2006).

Hc1 enhancement for thin films

$$B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\xi} \qquad d < \lambda_L$$

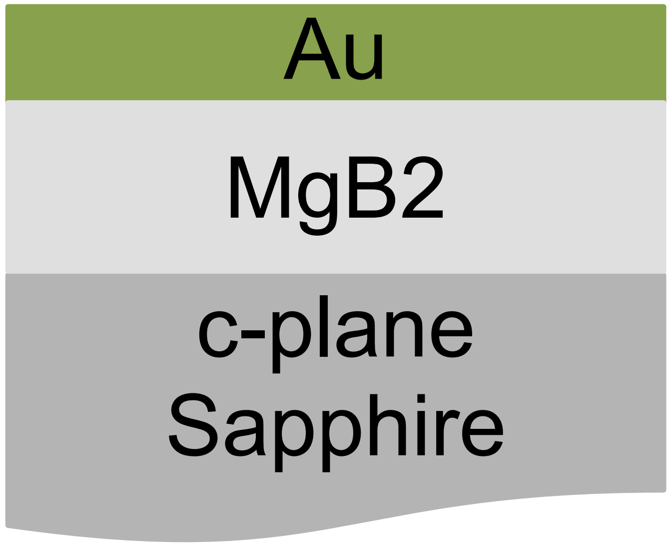
A. Gurevich, *Appl. Phys. Lett.* **88**, 012511 (2006).

- Seeking new material solutions which will enhance SRF performance
- Superconducting/ Insulating/Superconducting (SIS) multilayer structures.
- Hc1 enhancement in thin films. (high Hc1 to prevent early vortex penetration)

A thickness series (40-100 nm) of MgB_2 thin films were prepared on c-plane sapphire.* Each film was capped with a protective Au coating (~ 10nm).

*MgB2 samples generously provided courtesy of Teng Tan and Dr. Xiaoxing Xi of Temple University

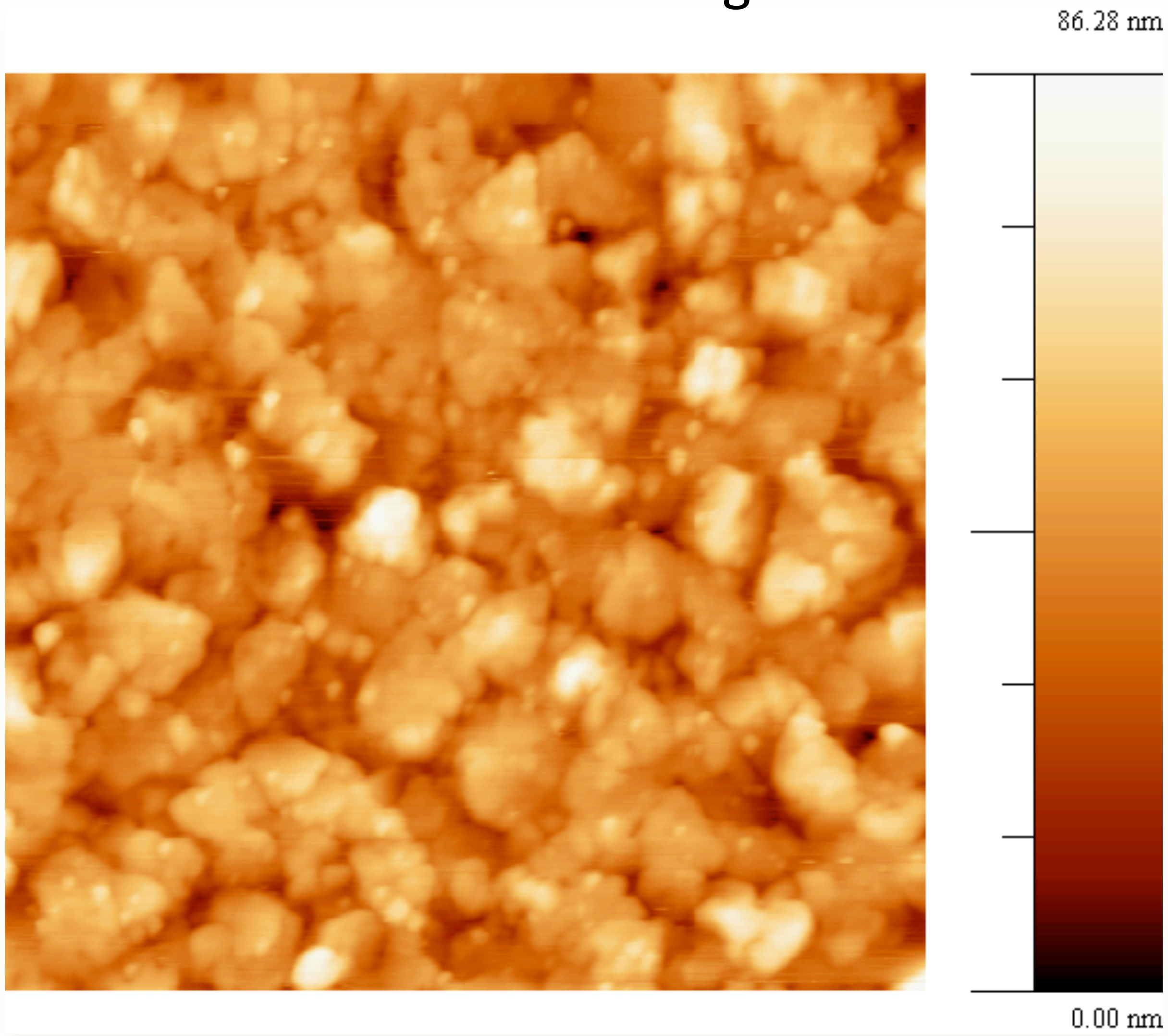
- 40 nm
- 60 nm
- 80 nm
- 100 nm



Schematic Diagram of MgB2 samples

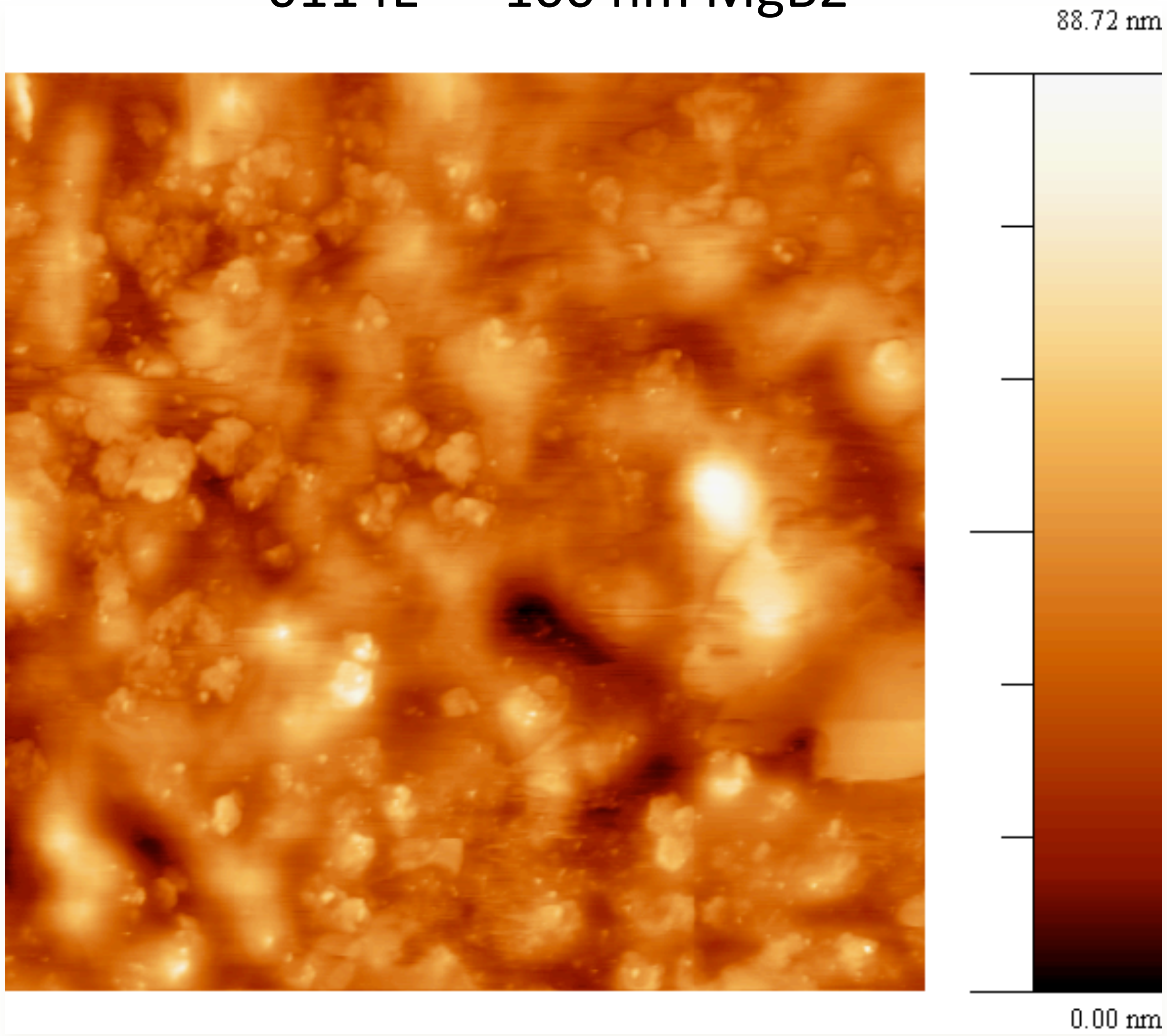
Surface Morphology — AFM

2x2 micron scan
0114B — 40 nm MgB2



RMS Roughness= 10.8 nm
Average height= 41 nm
Max height = 86 nm

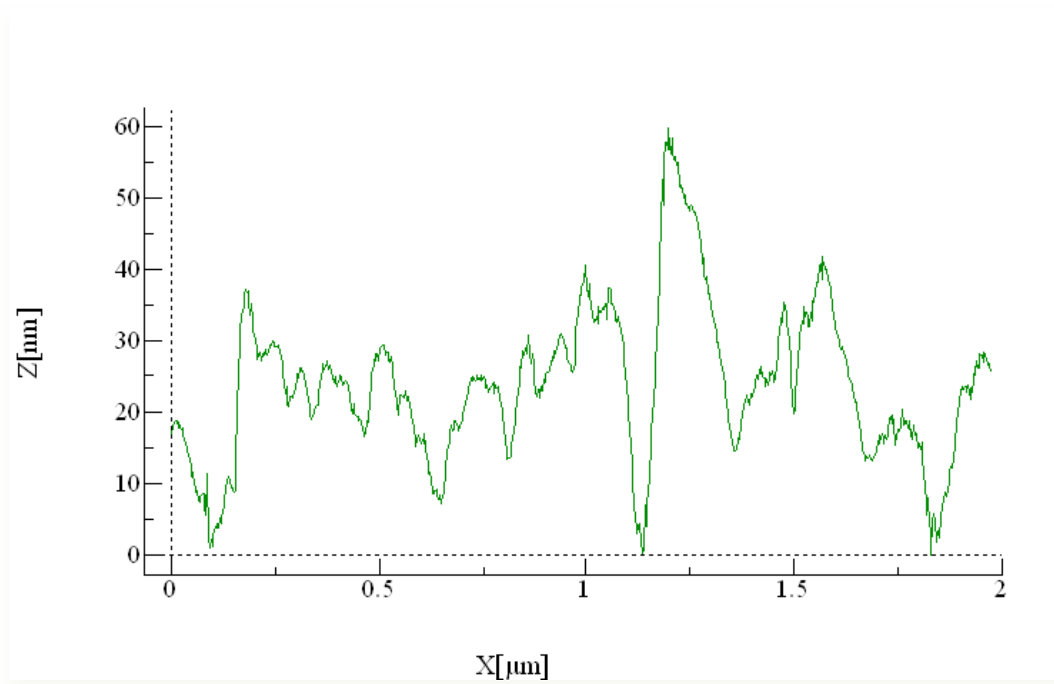
5x5 micron scan
0114E — 100 nm MgB2



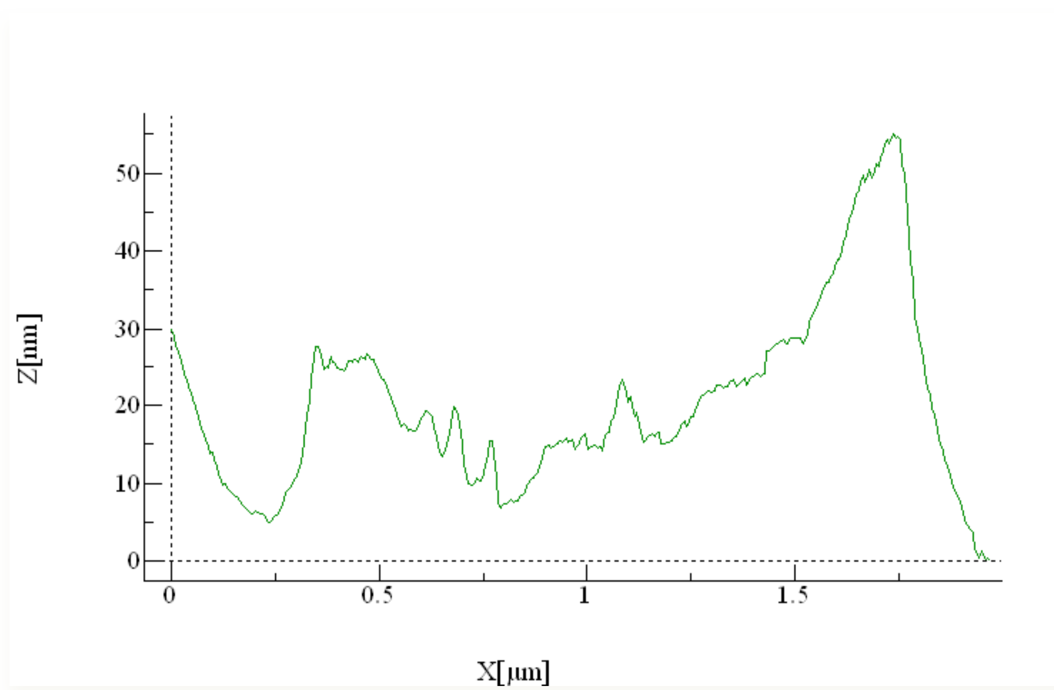
RMS Roughness= 10.6 nm
Average height= 34 nm
Max height = 88 nm

2 micron line scan profiles

0114B — 40 nm MgB2



0114E — 100 nm MgB2

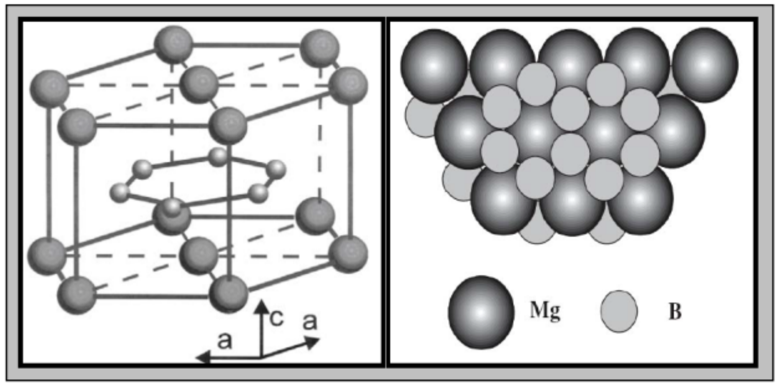


Important Observations

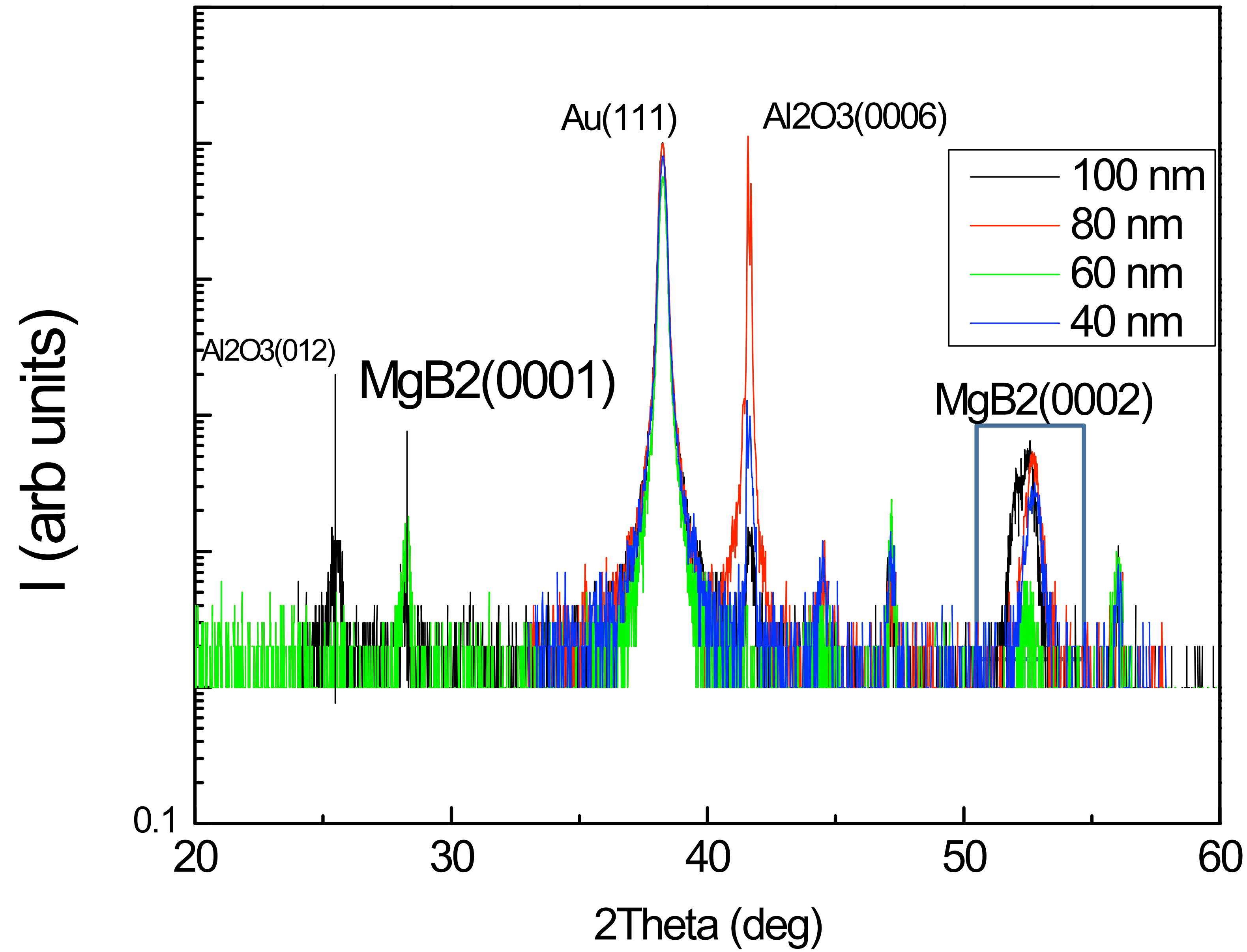
- The samples in this series are characterized by a rough morphology (~10 nm RMS roughness).
- In particular, the thinest film (~40 nm) appears, comparatively, to have exceptionally course features relative to nominal film thickness.
- Film roughness interfered with attempts to reconfirm MgB2 and Au thicknesses via XRR.

Structural Characterization— X-ray diffraction

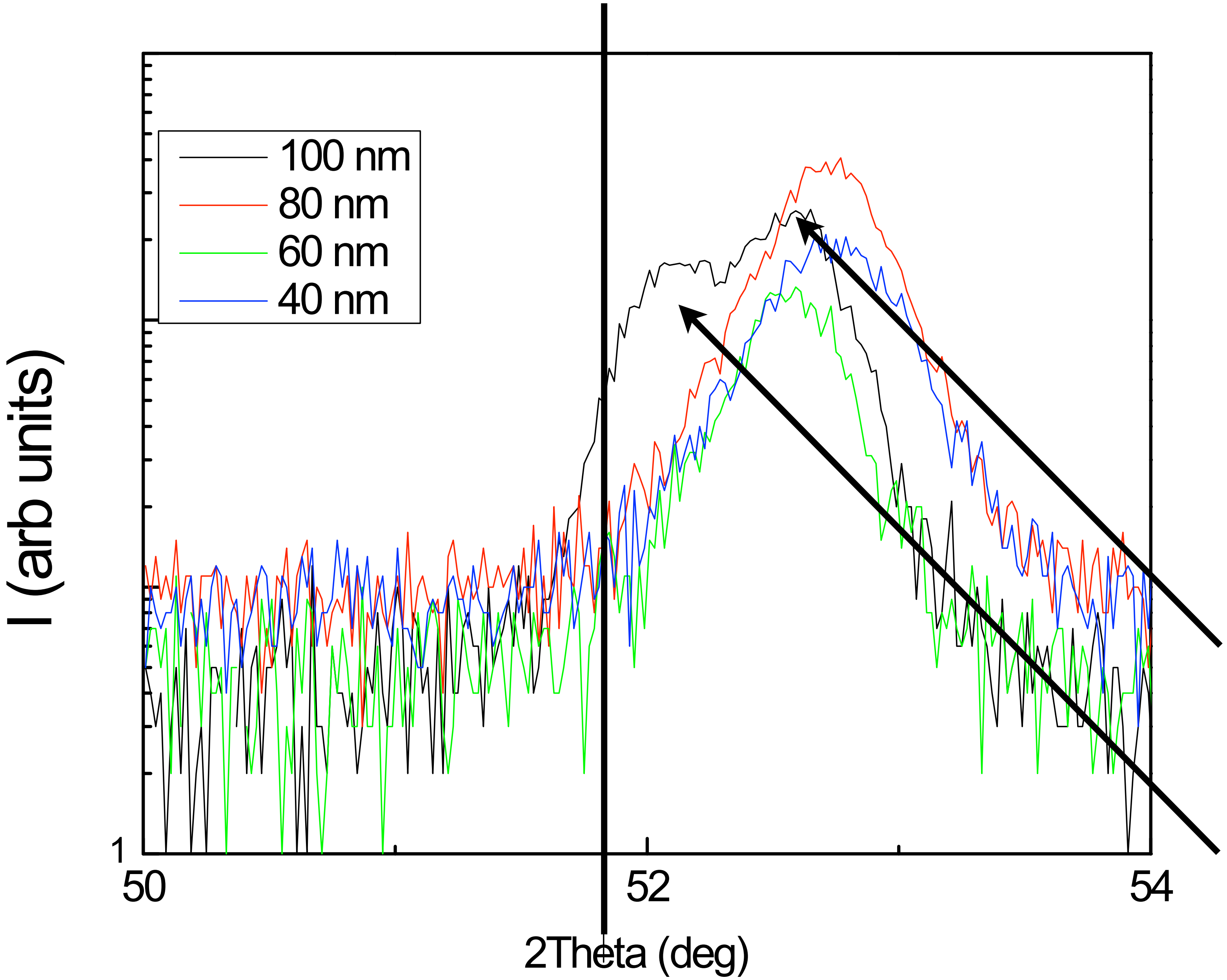
X-ray diffraction was used to determine lattice parameters, the mosaic structure, and also to give an estimate of grain size for the MgB2 films.



Symmetric scan

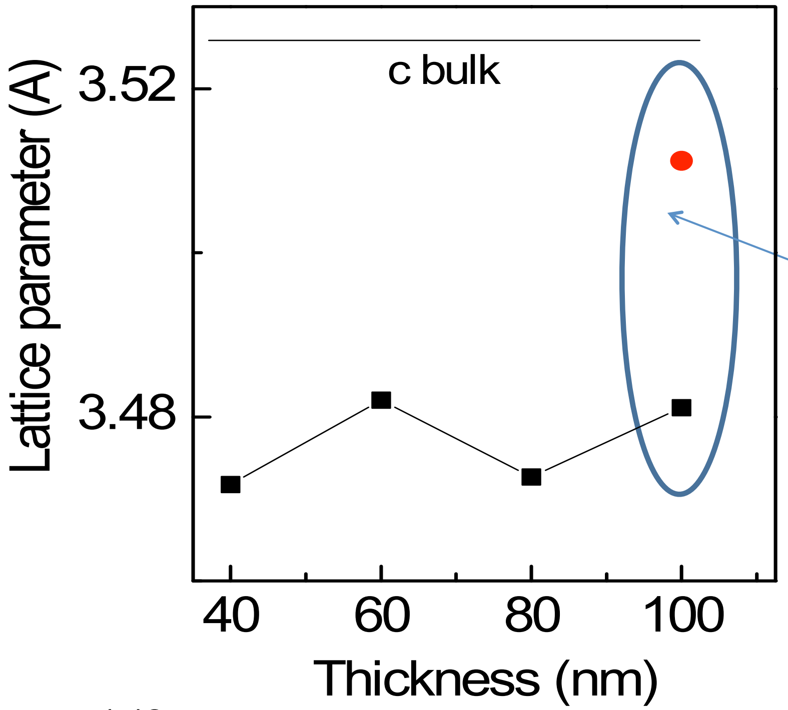


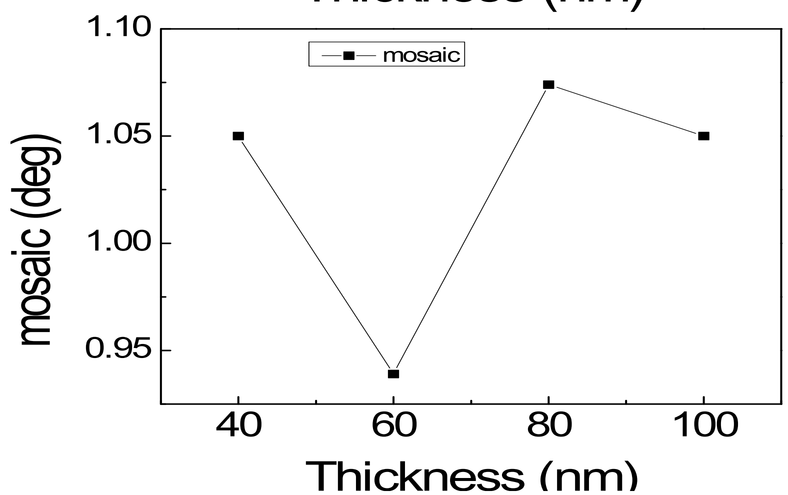
Symmetric Scan—MgB2(0002)

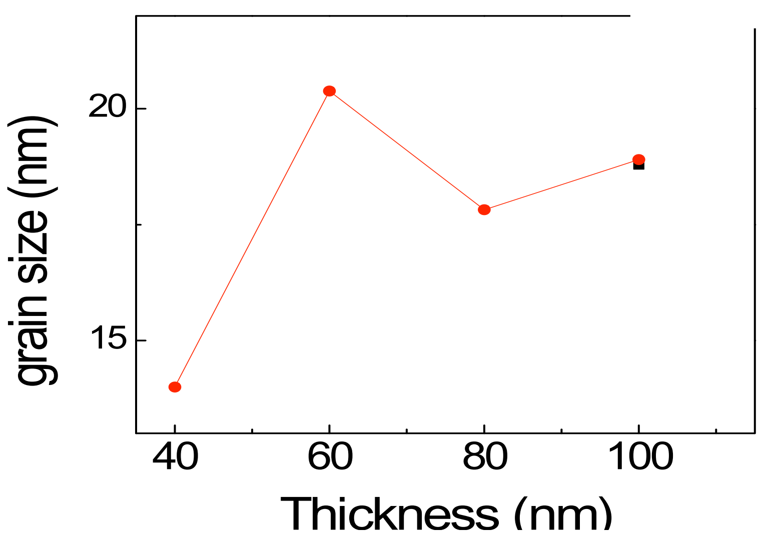


- Black line indicates expected bulk peak position
- Note the presence of a double peak in the 100 nm film (mixed phase)
- strained film contribution
- bulk like contribution (relaxed)

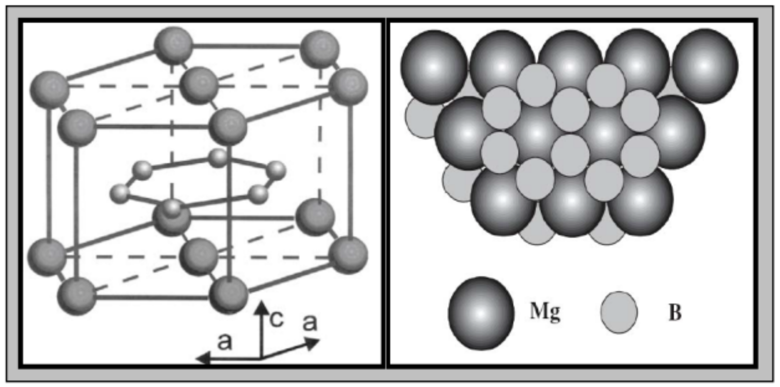
X-ray diffraction







Symmetric scans

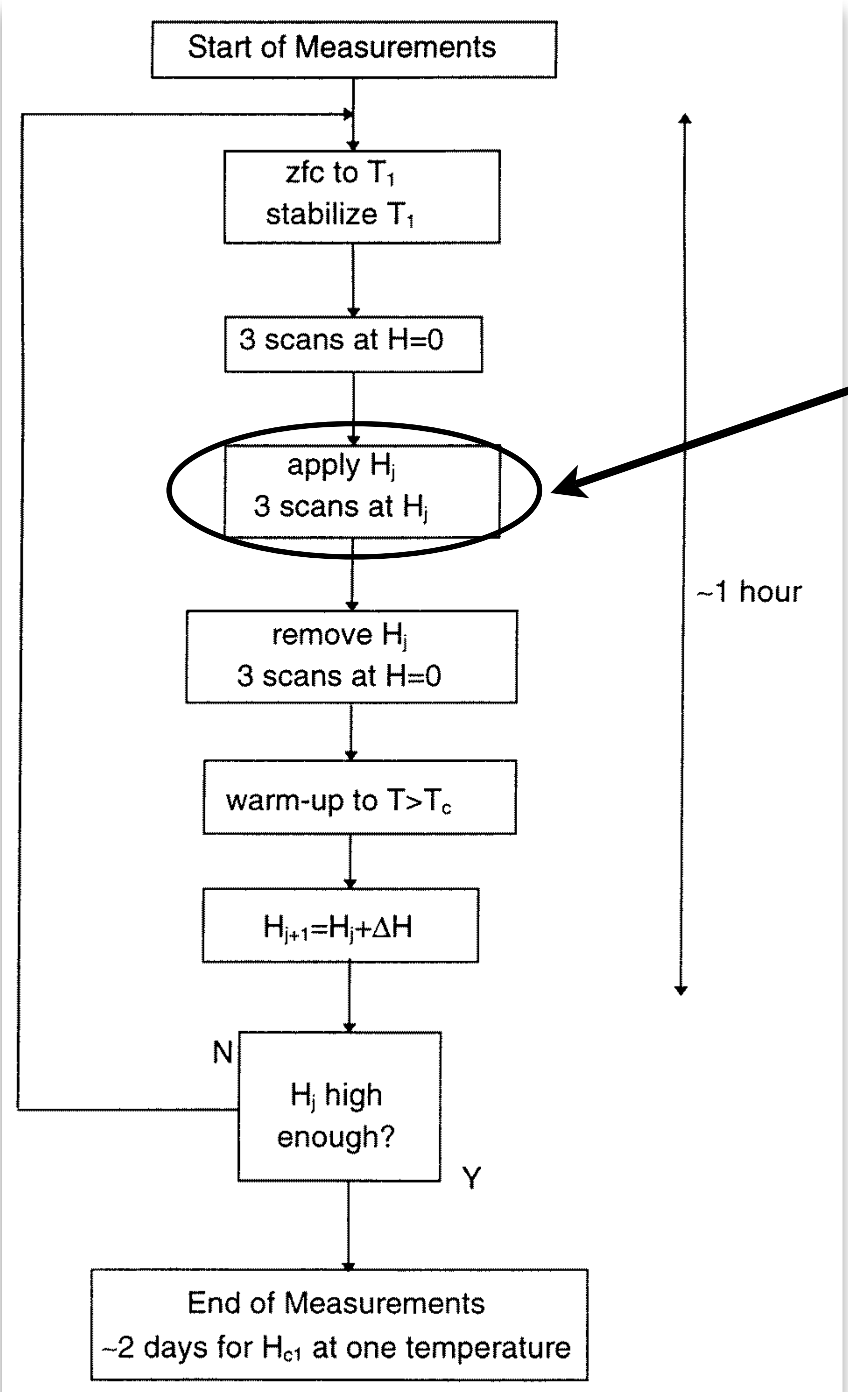


- Two phases were found in the thickest sample.
- No obvious thickness trends in either the mosaic structure or MgB2 estimated grain size.
- We note that the 60 nm film has a larger grain size and better long range order.

DC Superconducting Measurements

- Quantum Design SQUID MPMS
- DC measurements conducted to determine Critical Temperature, Hc1 and Hc2 for each MgB2 thin film
- Methods used to determine Hc1 outlined in [C. Bohmer, G. Brandstatter and H. W. Weber, *Supercond Sci Technol* **10**, A1-A10 (1997)].
- This method is reliable for determining Hc1 in the case where pinning occurs (i.e. when the magnetization curve is irreversable).
- Alignment is critical in these measurements.

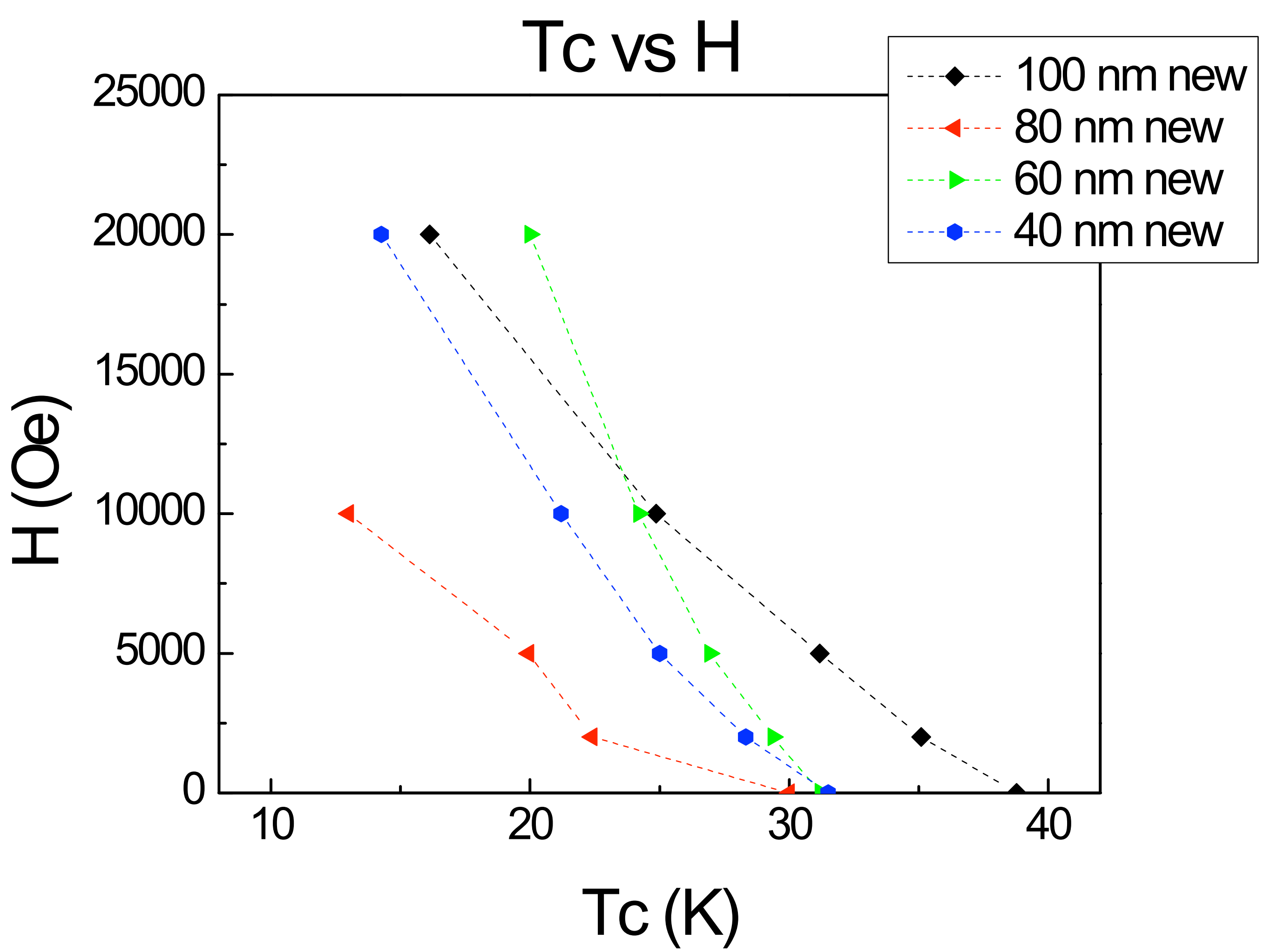
Finding the Trapped Field

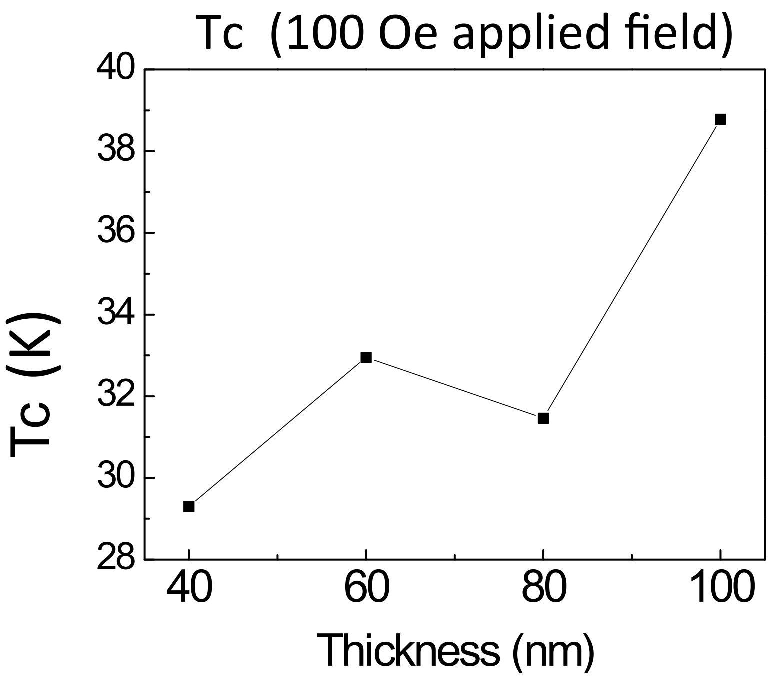


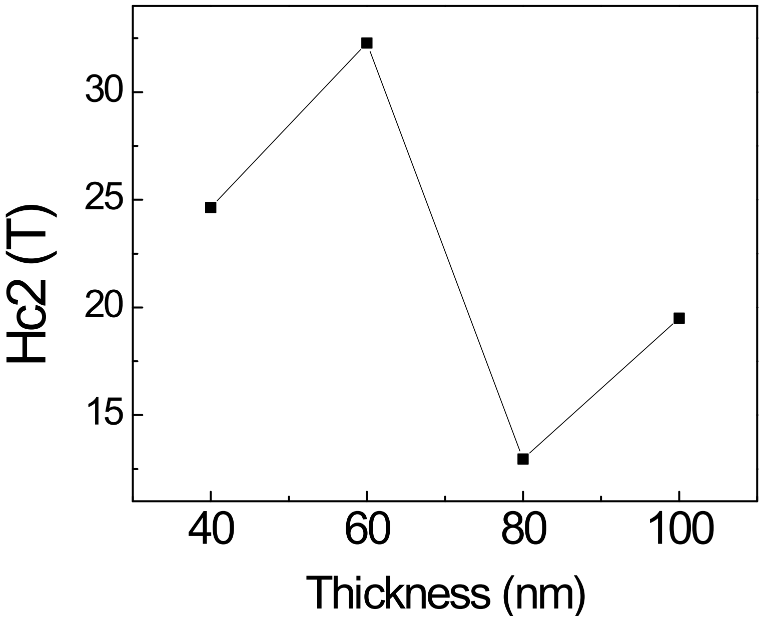
- Hc1 is often defined as the value of H where the M vs. H data starts to deviate from the Meissner slope (votex entry). This method typically provides an overestimate, because it assumes there will be no contributions from pinning.
- This procedure provides a method for accurately finding the point at which field penetrates by subtracting out background contributions from trapped magnetization that appear after application and removal a field H >= Hc1

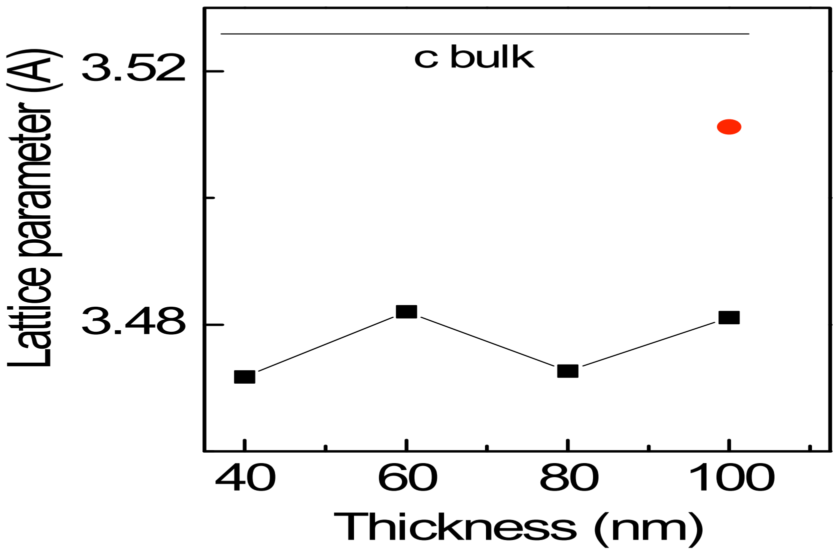
- [C. Bohmer, G. Brandstatter and H. W. Weber, *Supercond Sci Technol* **10**, A1-A10 (1997)].

Estimates of Hc2



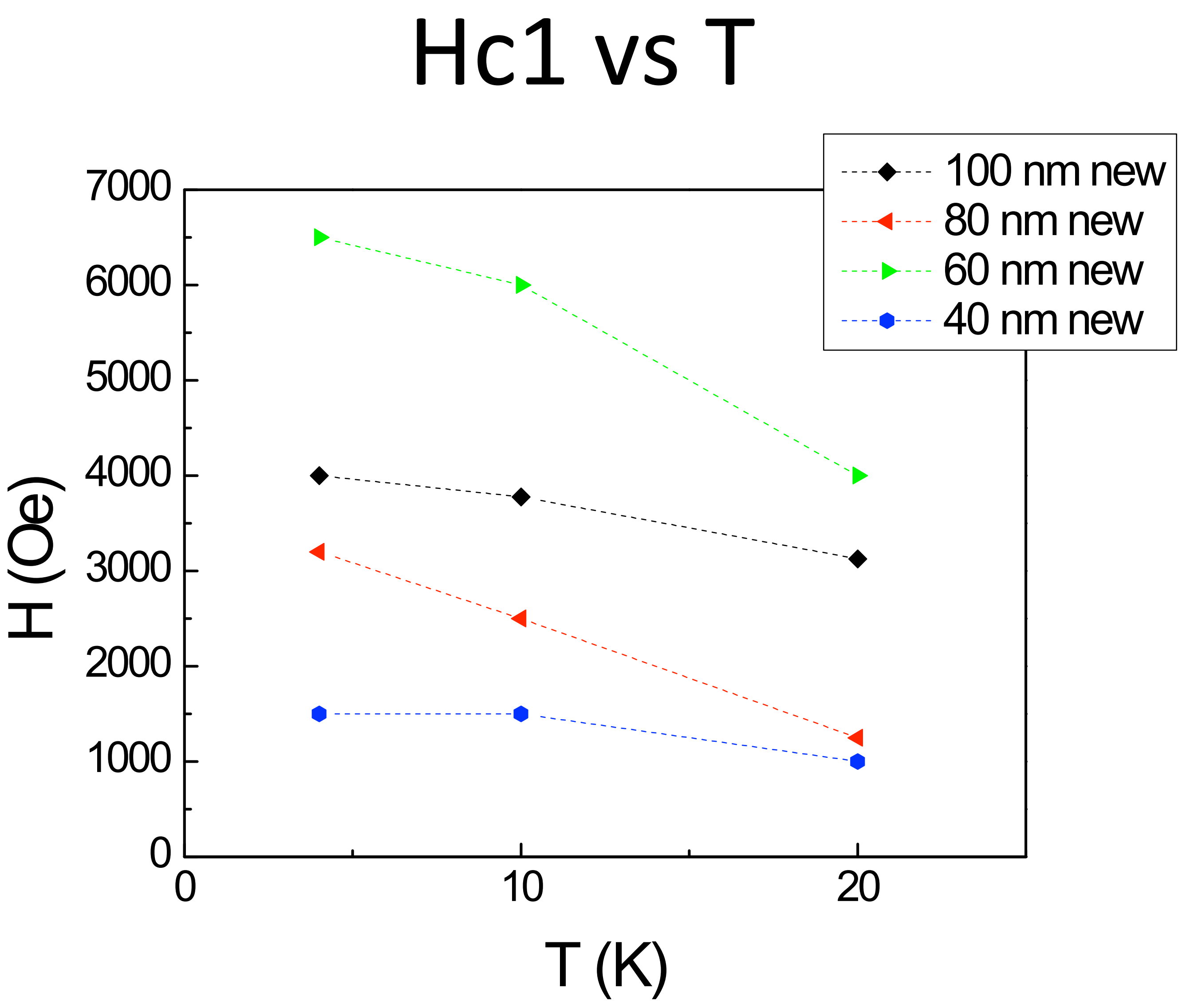


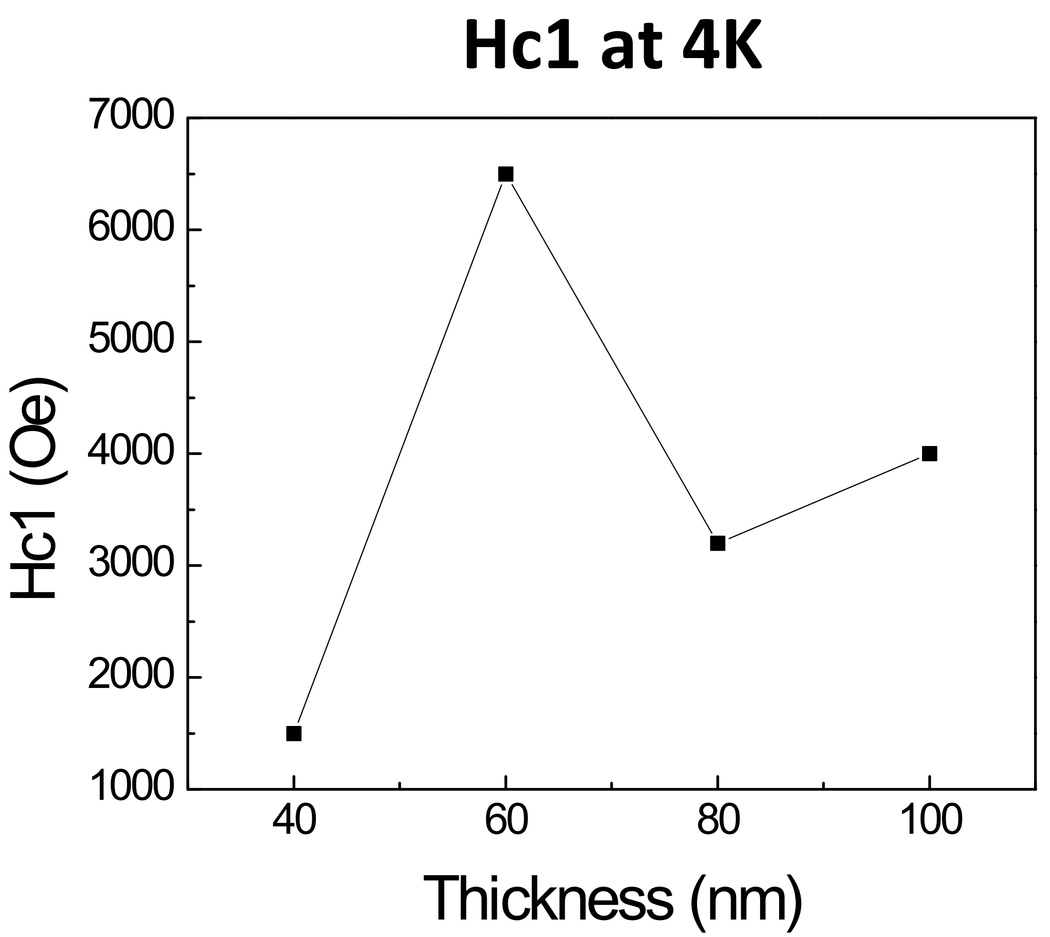


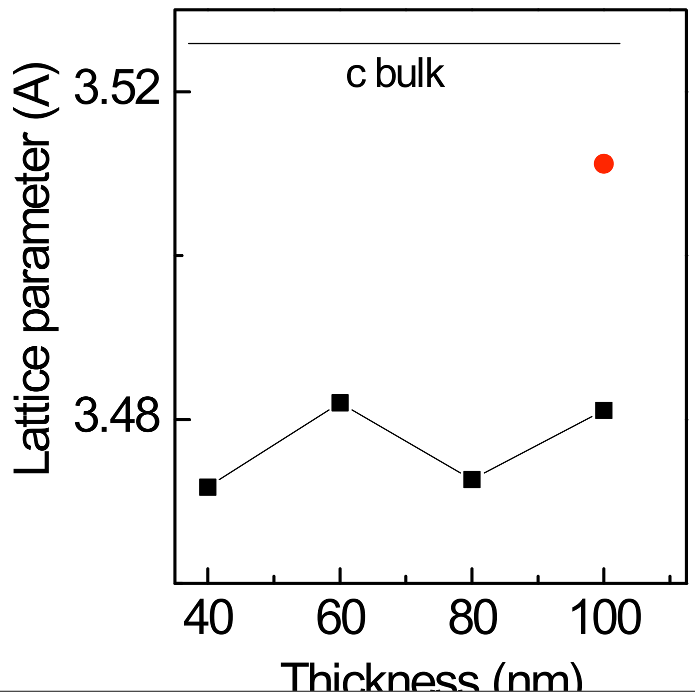


MgB2 demonstrates a very large Hc2 (i.e a much larger field than magnetometer is capable of producing), thus estimates were made using BCS fits.

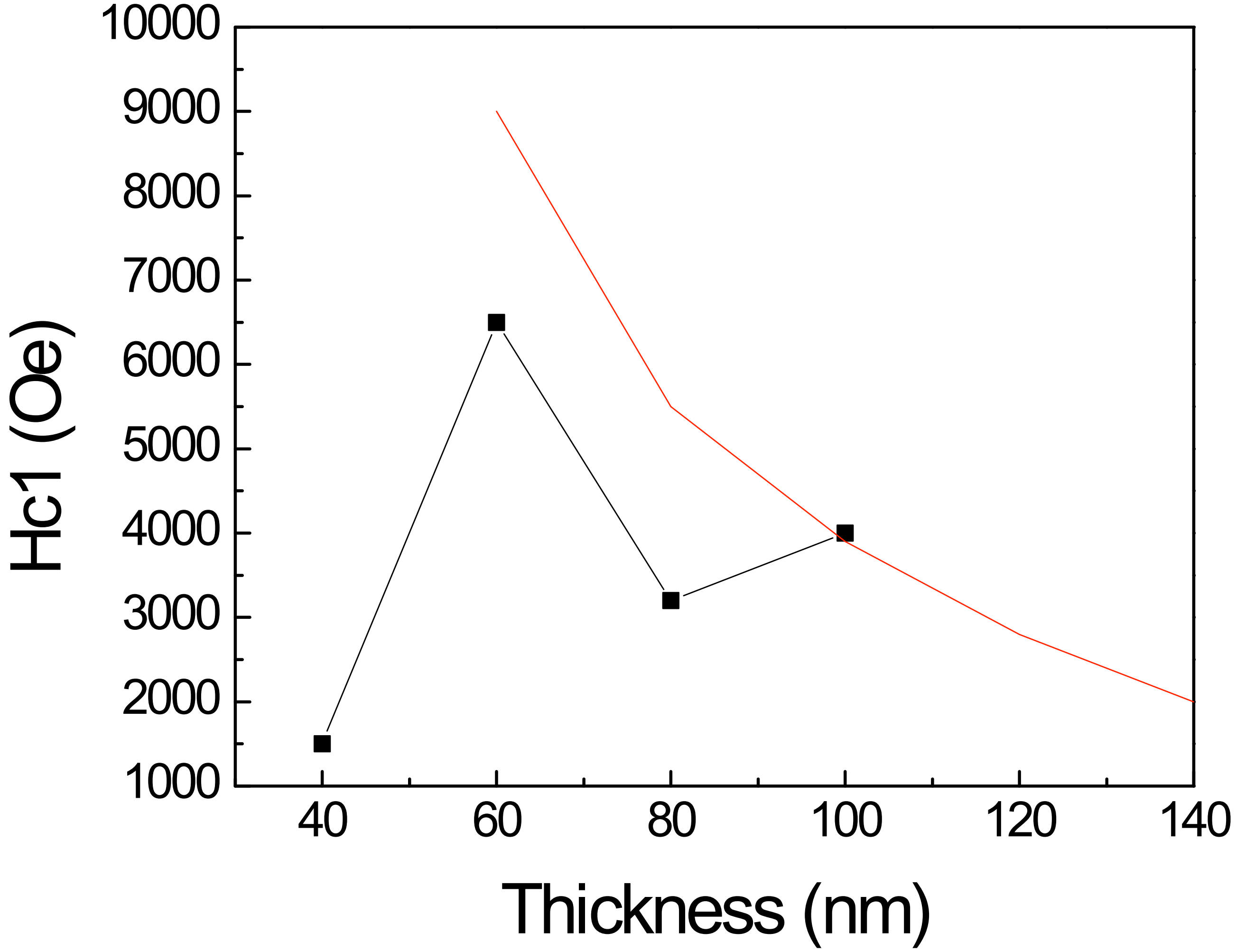
Superconducting Properties — Hc1







Hc1 Enhancement



- We can see an enhancement in the Hc1
- These enhancements correlate well with the structural characterization
- the relatively low Hc1 value for the 40 nm film may be further impacted by the coarse surface morphology

Hc1 enhancement for thin films

$$B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\xi} \qquad d < \lambda_L$$

A. Gurevich, *Appl. Phys. Lett.* **88**, 012511 (2006).

Theoretical enhancement (red line) is based on these assumptions:
coherence length = 5 nm
penetration depth = 140 nm

Conclusions

- A correlation between morphology, structure and superconducting properties was found for MgB2 thin films with different thicknesses.
- We observed an enhancement of Hc1 for MgB2 films.
- Future work includes further detailed studies examining the morphology of these films (PSD and Wavelet analysis).