Thickness dependence of superconducting properties in MgB2 thin films

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Collaborators & Acknowledgements

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Overview

• Introduction
• MgB2 thin films
• Morphological and structural characterization of MgB2 thin films
• DC SQUID measurements of Hc1
• 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.


Motivation for SRF thin films

- 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)

\[ B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\xi} \quad d < \lambda_L \]

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).

*MgB$_2$ 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 MgB$_2$ 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 thinnest 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

![Graph showing diffraction peaks for MgB2(0001), MgB2(0002), Au(111), and Al2O3(0006) with different film thicknesses.]
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
• This method is reliable for determining Hc1 in the case where pinning occurs (i.e. when the magnetization curve is irreversible).
• 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

MgB₂ demonstrates a very large $H_{c2}$ (i.e. a much larger field than a magnetometer is capable of producing), thus estimates were made using BCS fits.
Superconducting Properties — $H_{c1}$

$H_{c1}$ vs $T$

$H_{c1}$ at 4K

Lattice parameter

$c_{bulk}$

$3.52$

$3.48$
Hc1 Enhancement

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

- 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

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).