Characterization of Thin Films for SRF Cavities

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Introduction

Currently the only superconducting material best suited for SRF cavities is bulk niobium, however the critical magnetic field of bulk niobium limits the accelerating gradient of today's particle accelerators. An SIS multilayer with a higher critical magnetic field allows particle accelerators greater acceleration gradients. Copper's high thermal conductivity makes it useful for efficient diffusion of heat away from the superconducting materials which often have critical temperatures near absolute zero. A thin gold layer was used to seed the copper and superconducting niobium together. The superconducting properties and growth patterns of an SIS and copper seed multilayer test film were measured and observed using RHEED, AFM, and SQUID.

Higher Field Gradients with SIS Layers

A Superconducting-Insulator-Superconducting (SIS) tri-layered material will be developed so higher critical fields can be achieved using niobium. Superconducting materials with higher critical temperatures will be used to shield the niobium from the magnetic flux. Layers of non-superconducting materials (insulators) are grown between each superconducting layer in order to de-couple the current vortices which form in Type II superconductors (A. Gurevich).

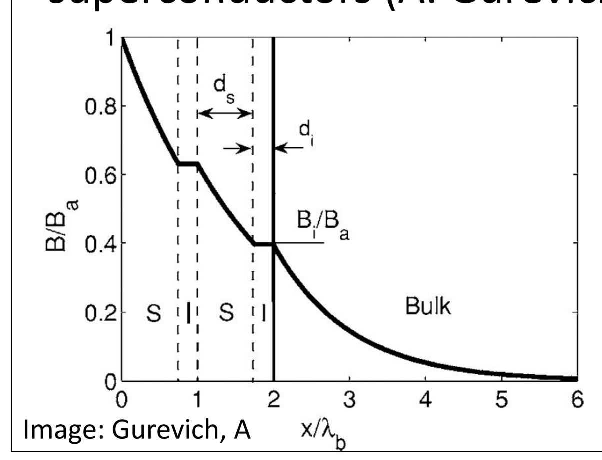
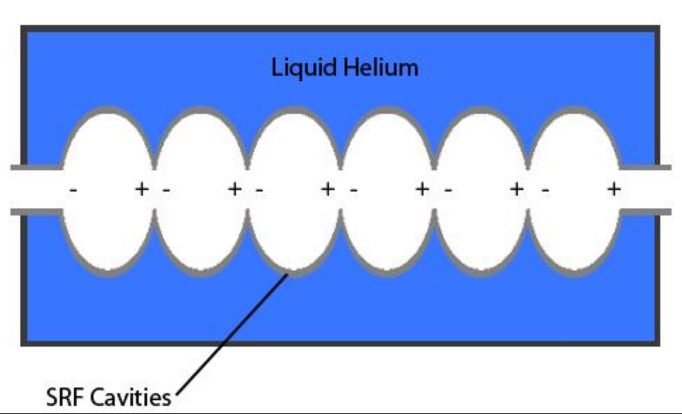


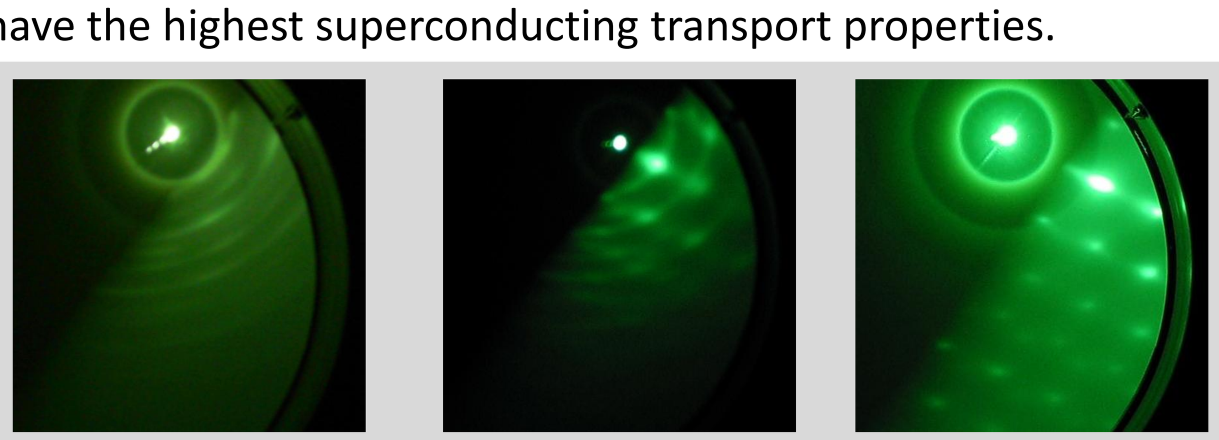
Image: Gurevich, A



RHEED

Reflective High Energy Electron Sputtering (RHEED) is a method used to probe the crystal structure of crystalline materials with smooth surfaces. A coherent electron beam is emitted from an electrode in an ultra-high vacuum. The beam coincides with the surface of the sample at a grazing angle (approximately 1°). Since the wavelength of the electron is close to the lattice spacing of the material, the beam is diffracted by the crystal lattice.

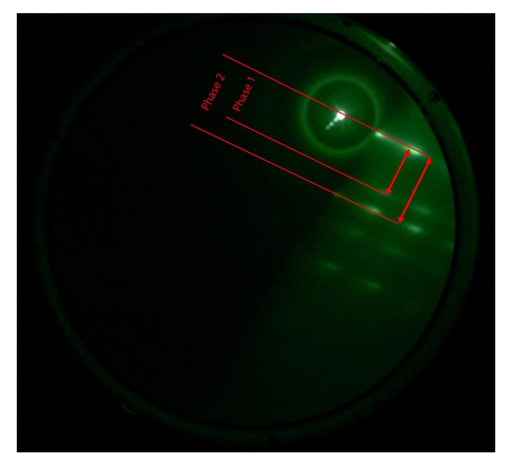
Polycrystalline RHEED pattern (left) shows no distinguishable lines. This structure has the poor superconducting transport properties. Polycrystalline RHEED (center) patterns reveal faint outlines of lines indicating different texture. Single crystal RHEED (right) patterns show highly distinguishable lines and have the highest superconducting transport properties.

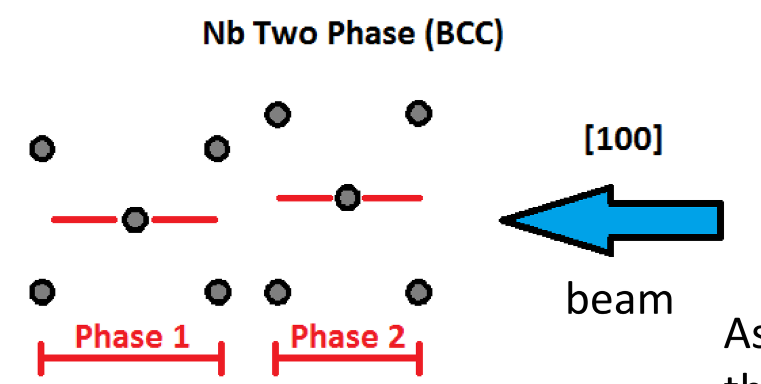


Two Phase Niobium Analysis with RHEED

Two Phase Niobium

- The RHEED image is a superposition of the (220) and (200) diffraction patterns
- Since the crystal lattice is tilted 45 degrees, the RHEED indicates that the electron beam is measuring the crystal structure below one atomic layer
- Two phase niobium growth, like this example, affects superconducting properties.
- Niobium has two modes of growth on MgO (100), which are (110) and (100).
- The distances shown in red were found to be 2.38 Å and 1.66 Å respectively.





600 nm Nb
MgO Substrate (100)

As shown in the AFM image below, the two phase niobium arranges itself in a diagonal herringbone pattern.

Nb/Au/Cu/Si Multilayer

In order to improve the thermal conducting efficiencies of SRF cavities, copper may be used within the multilayer structure. Gold may be used as a seed layer in order to decrease the grain boundary density of niobium in conjunction with copper.

250 nm of copper was grown on a silicon substrate. RHEED revealed that the growth was single crystalline. 20 nm of gold was grown on the copper surface with the VEECO system. RHEED revealed gold (111). This was not intended.

Niobium, Gold, and Copper in Si [110]:

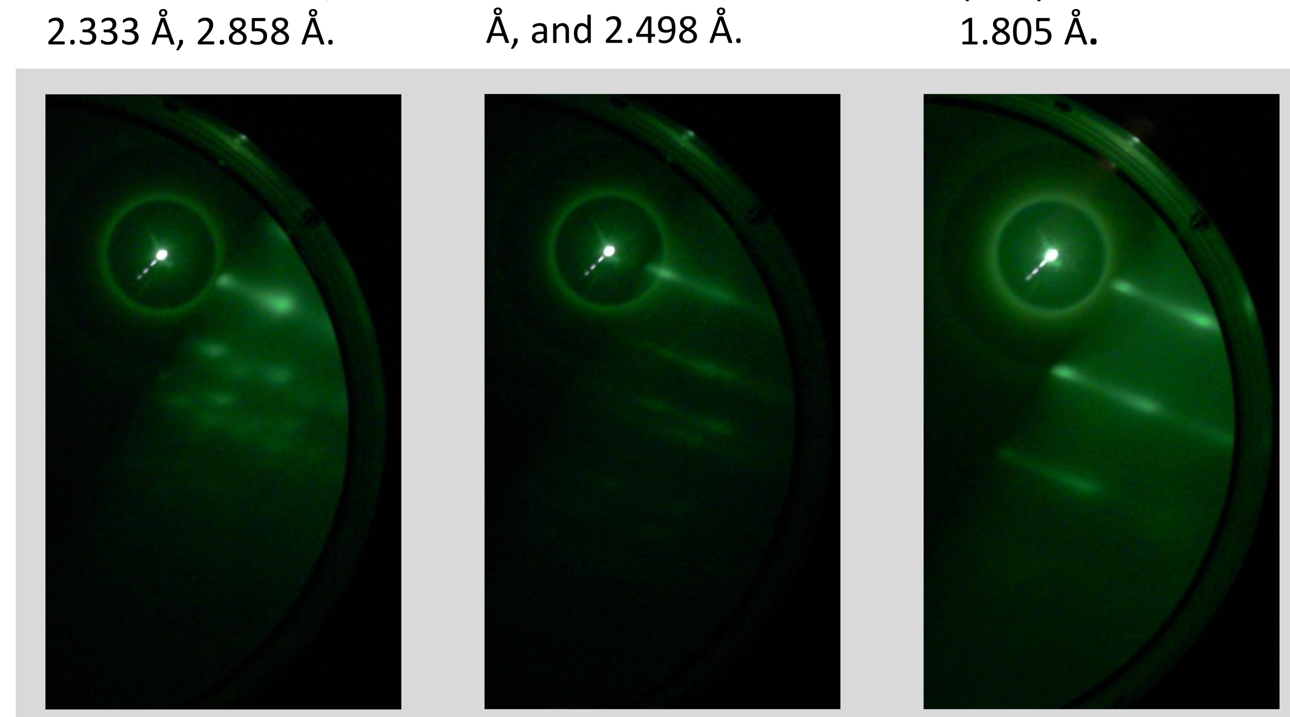
30 nm of niobium was grown on the gold surface. RHEED revealed niobium [110]. Three strong directions were seen in the image.

30 nm Niobium (Fig. 1)
20 nm Gold (Fig. 2)
250 nm Copper (Fig. 3)
Silicon Substrate (100)

30 nm Niobium on gold. These patterns represent (110). Distances 1.65 Å, 2.333 Å, 2.858 Å.

20 nm Gold on copper. These patterns represent (111). Distances 1.442 Å, and 2.498 Å.

250 nm Copper on Silicon. These patterns represent (100). Distance 1.805 Å.



The RHEED images were analyzed using Origin and MatLab. Gaussian curves are used to find the center of the various peaks.

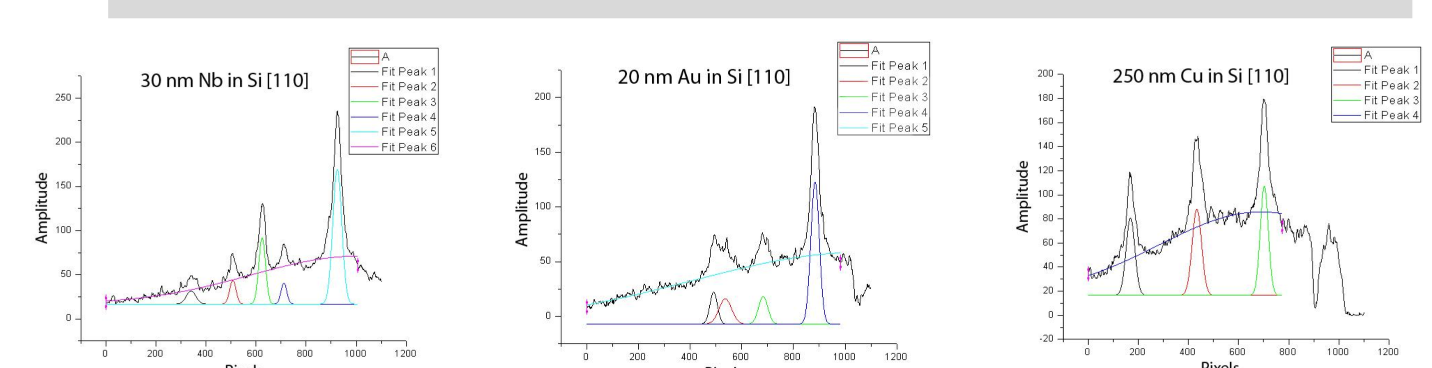
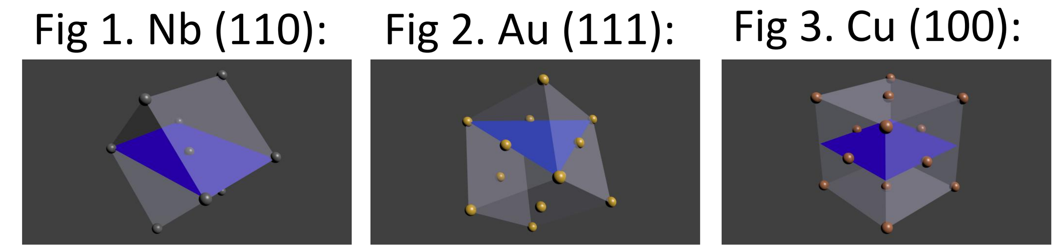
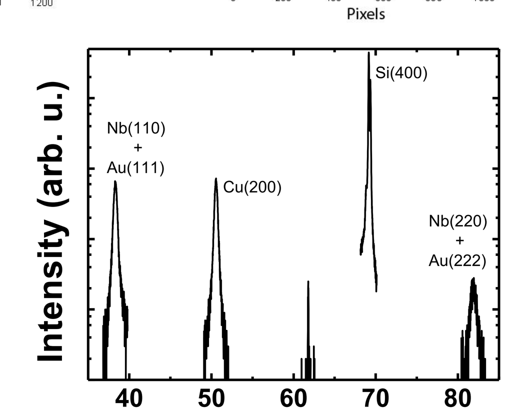


Fig 1. Nb (110): Fig 2. Au (111): Fig 3. Cu (100):



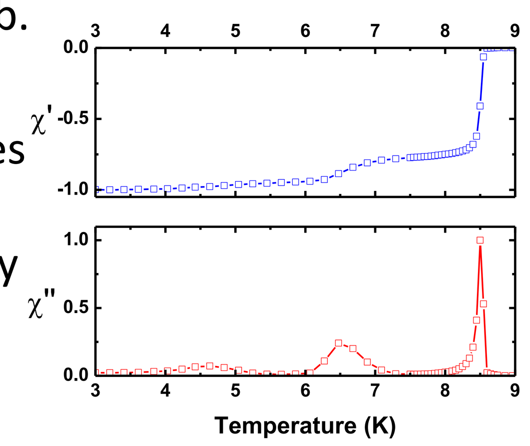
XRD analysis of the multilayer. Nb (110) and gold (111) closely overlap:

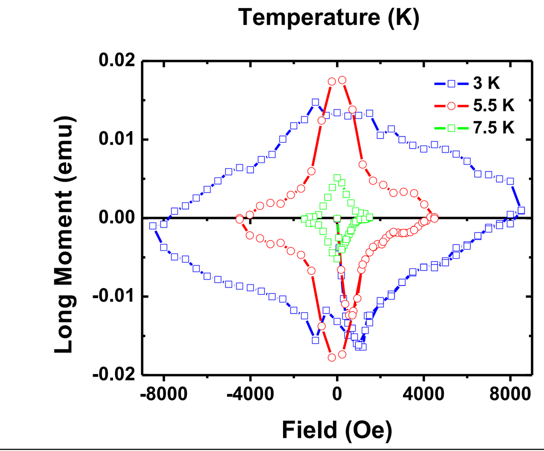


SIS Tri-Layer Analysis with SQUID

- A Nb/MgO/Nb tri-layer was grown in order to test the superconducting transport properties of an SIS tri-layer. No shielding effects should be present since the superconducting material is Nb.
- SQUID measurements reveal the superconducting properties of the Nb/MgO/Nb tri-layer. Strain within the Nb layers may contribute to the rise in magnetic moment at approximately 6.5 K.
- SQUID hysteresis measurements of the Nb/MgO/Nb tri-layer.

30 nm Nb
15 nm MgO
250 nm Nb
MgO Substrate (100)



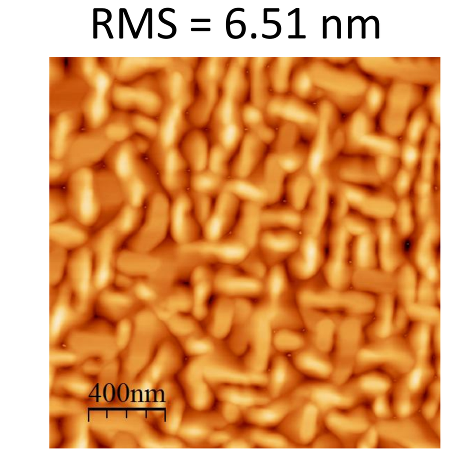


AFM, Surface Roughness, & Scaling Effects

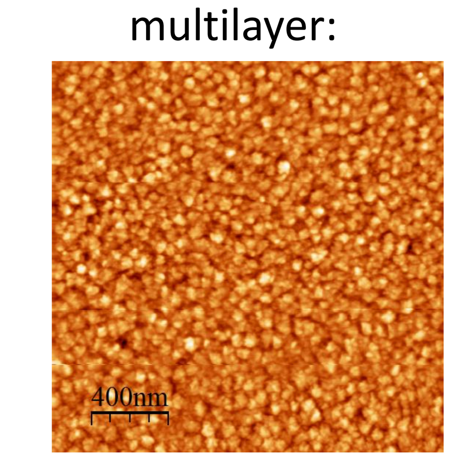
Surface roughness must be accounted for since these features affect the SRF transport properties. Rough surfaces can cause unwanted heating on the inner surface of the SRF cavity. Future studies will investigate the effect of surface roughness on SRF transport properties.

During early stages of crystal growth, individual crystal "islands" form, before melding into larger mounds in later stages.

600 nm Nb/MgO RMS = 6.51 nm



Nb/Au/Cu/Si multilayer:



Conclusion & Future Research

The growth patterns and superconducting properties of SIS multilayer films were measured with RHEED and SQUID. Strain in the S layers affects the superconducting properties. Ambient pressure and temperature were found to be the dominating factor in the epitaxial growth of the MgO and Nb layers. Superconducting materials with higher critical temperatures like NbN, Nb_3Sn, and MgB_2 will be used in future SIS multilayer structures. Future research and testing needs to be done on copper seed layers since the RHEED revealed gold (111) growth, though the XRD was inconclusive.

References & Acknowledgement

1. A. Gurevich, Appl. Phys. Lett. **88**, 012511 (2006).
2. W. Roach, Investigation of Epitaxial Niobium Thin Films Grown on Different Surfaces Suitable for SRF Cavities, Paper Presented at DTRA Conference, July 20, 2011.
3. M.G. Lagally and D.E. Savage. MRS Bulletin, (1993).

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