Investigation of Epitaxial Niobium Thin Films Grown on Different Surfaces Suitable for SRF Cavities

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Research Objectives

The currently proven superconducting radio frequency (SRF) technology used in linear accelerators is based on bulk niobium cavities. Since this has a high cost and these cavities are approaching the maximum field gradients that they can withstand, development of a suitable, reliable, cost effective alternative to bulk niobium SRF cavities is needed. Attempts have been made to replace bulk niobium cavities with niobium coated copper cavities since the thermal conductivity of a suitable base material such as copper is better than bulk niobium. Coating niobium on SRF cavities is a promising but also challenging path, since there are several difficulties associated with various thin film deposition techniques. Additionally, multilayered structures have been proposed as a way of shielding niobium from higher fields.

Experimental Methods

Films were prepared using DC magnetron sputtering

Film structure was determined using reflection high energy electron diffraction (RHEED) and X-ray diffraction (XRD)

Surface Morphology was examined using atomic force microscopy (AFM)

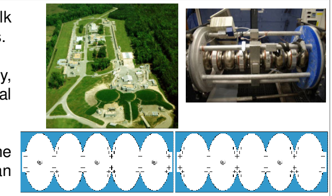
Superconducting properties were determined using residual resistance ratio (RRR) values as well as SQUID magnetometry

SRF Cavities

SRF cavities, constructed from bulk niobium, are used in linear accelerators.

In order to improve thermal efficiency, cavities made from a suitable material like copper can be coated with niobium.

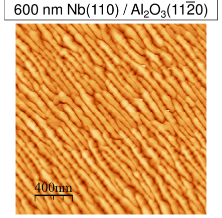
Current cavities are operating near the critical field that bulk niobium can withstand.



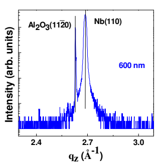
Images: jlab.org

Niobium on Ceramic and Metallic Templates

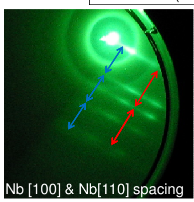
600 nm Nb(110) / $Al_2O_3(11\bar{2}0)$



RRR = 96 RMS = 4.68 nm

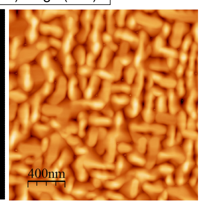


600 nm Nb(110) / MgO(100)



Nb [100] & Nb[110] spacing

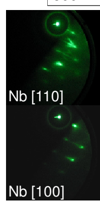
RRR = 46.5

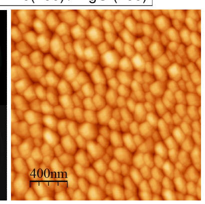


RMS = 6.51 nm

The superposition of RHEED streaks with a √2 ratio is indicative of coexisting Nb(110) domains at right angles.

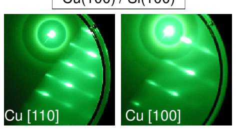
500 nm Nb(100) / MgO (100)



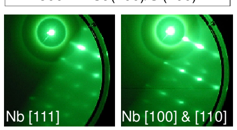


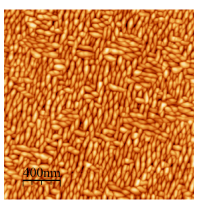
RRR = 165.5 RMS = 4.06 nm

Cu(100) / Si(100)



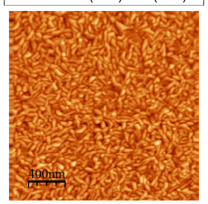
500 nm Nb(110) / 500 nm Cu(100)/Si(100)



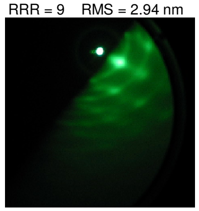


RRR = 25 RMS = 3.58 nm

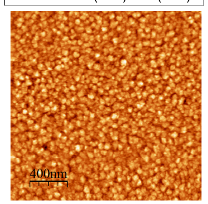
500 nm Nb / 1 nm MgO / 15 nm Cu (100) / Si (100)

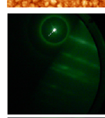


RRR = 9 RMS = 2.94 nm



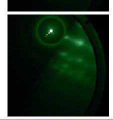
30 nm Nb / 20 nm Au / 250 nm Cu (100) / Si (100)





20 nm Au

Identical patterns along Si[100] and Si [110]

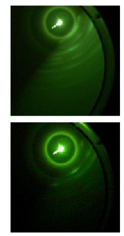


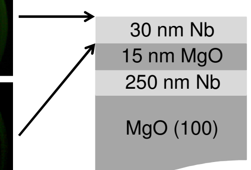
30 nm Au

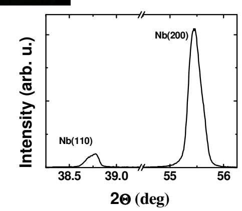
Identical patterns along Si[100] and Si [110]

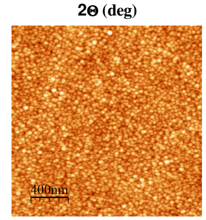
Superconducting-Insulating-Superconducting (SIS) Structure

SIS structure may provide a route to shield Nb from higher magnetic fields, thus allowing for an increase in accelerating gradient, and delaying vortex formation [1].







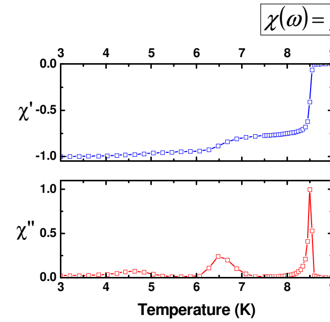


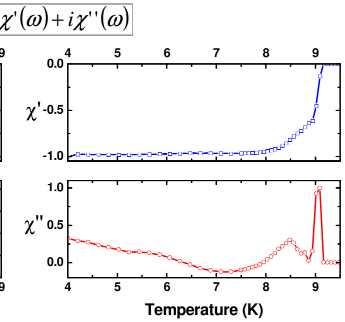
RMS: 2.65 nm

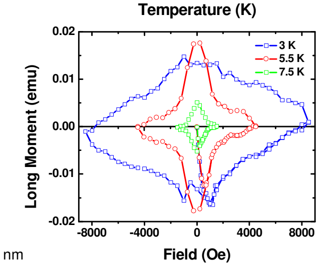
Nb / MgO / Nb / MgO (100)

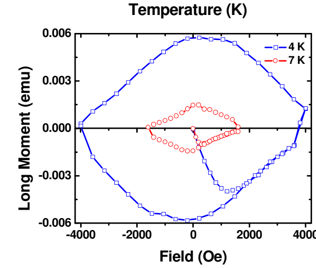
Nb (100) / MgO (100)

$$\chi(\omega) = \chi'(\omega) + i\chi''(\omega)$$









Conclusions

We have shown that the number of grain boundaries has a large effect on the transport properties in Nb thin films. In order to obtain Nb coated Cu cavities with optimal performance, the use of seed layers may help overcome the multiple growth domains caused by the poor lattice mismatch between Nb and Cu.

We have fabricated and characterized an initial SIS structure consisting of Nb and MgO. While the structural and magnetic information is still being analyzed, this is a preliminary step towards fabricated future SIS devices with other materials that can help increase accelerating gradients and thus decrease the size of linear accelerators.

Future Research Plans

We will continue searching for an appropriate combination of materials in seed layers that will minimize the grain boundary density found in Nb thin films grown on Cu templates. These seed layers will help optimize transport properties in the critical surface of cavities while allowing for a more desirable substrate.

The surface material in the SIS structure will be replaced with a higher critical field superconductor such as NbN, Nb_3Sn, or MgB_2 such that the Nb can be shielded from higher magnetic fields. Ultimately, the seed layer and SIS approach will be combined to improve SRF cavity performance compared to current operations.

References

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

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