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Economical Manufacture of Seamless High-Purity Niobium

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Goal/Approach

The technical objective of this project was to develop an efficient, cost-effective means of fabricating seamless ultrahigh-purity niobium superconducting radio frequency (SRF) cavities suitable for particle accelerator applications. The focus of the work was on optimizing chemical vapor deposition (CVD) niobium processing to deposit structural high-purity (RRR300 or better) niobium.

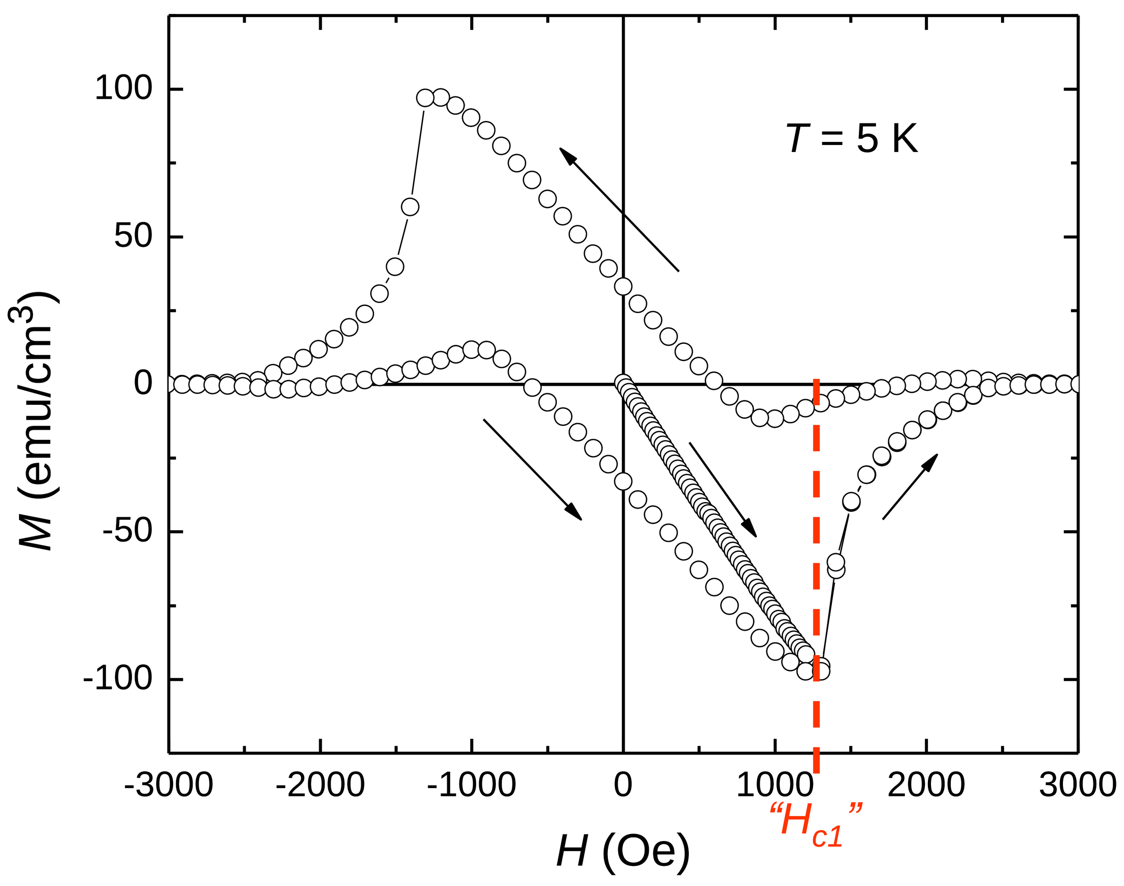

Figure 1: Gradient Performance Potential
Complete magnetization loop at 5 K for tested sample, showing H_{c1} (field of first significant flux penetration) at ~1300 Oe and H_{c2} at high field to be ~2750 Oe

CVD Condition #	RRR*
1	**100**
2	**150**
3	**160**
4	**282** †**
5	**233** †**
6	**226** ‡**
6	**213** ‡**
Control (>RRR200 Nb)	**238****

* No heat treatment prior to RRR measurements
** RRR measured in 1-T magnetic field
† CVD using >RRR200 grade Nb control material
‡ CVD using as-received commercial-grade Nb scrap

Table 1: RRR measurements performed by ORNL

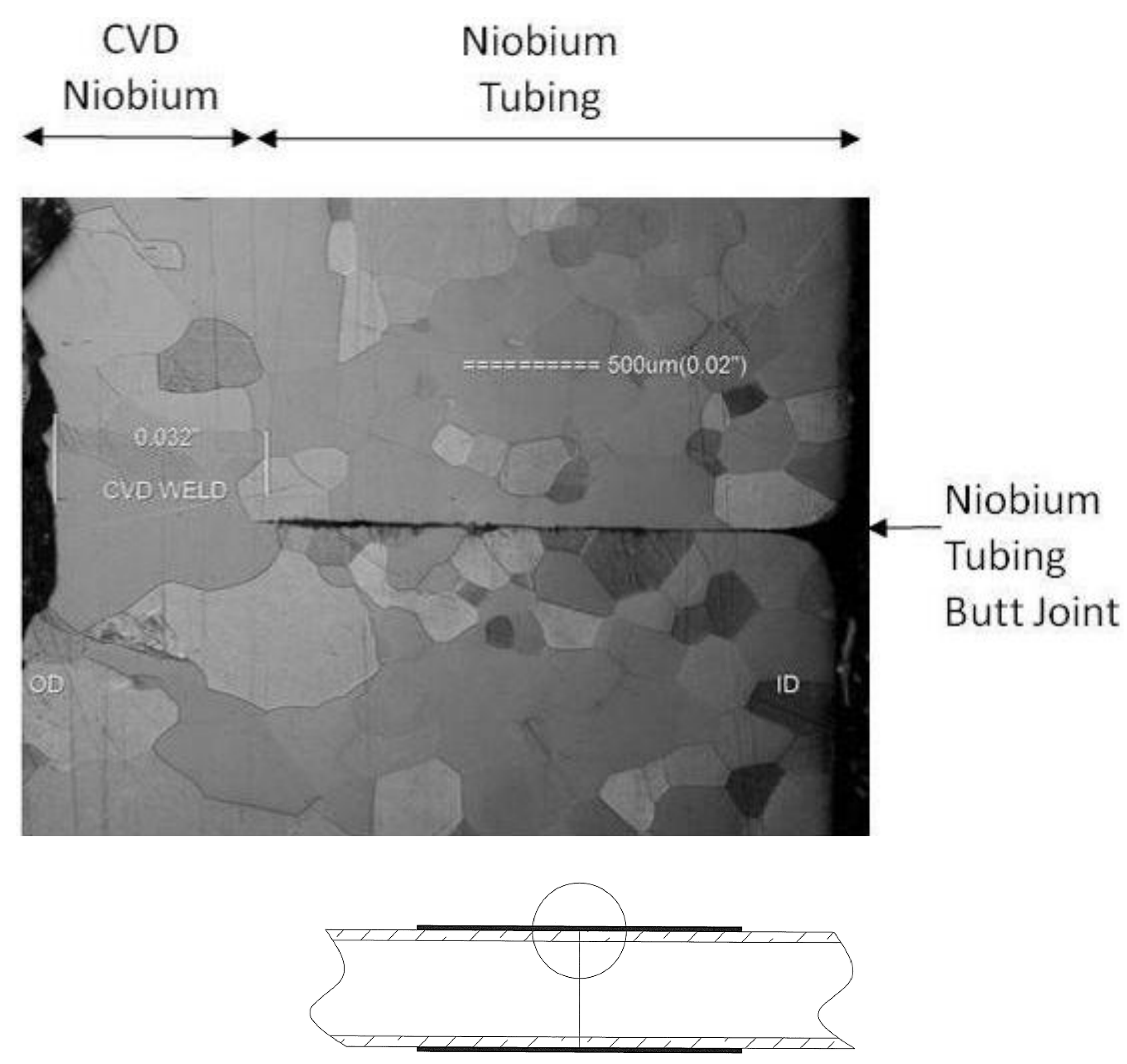

Figure 2: CVD Joining
Micrograph and schematic of CVD-welded tensile test specimen (butted Nb tubes with CVD Nb weld , ~0.030" thick). Measured ultimate tensile strength was 39.327 ksi, vs. reported strength of pure annealed niobium = 43.5 ksi

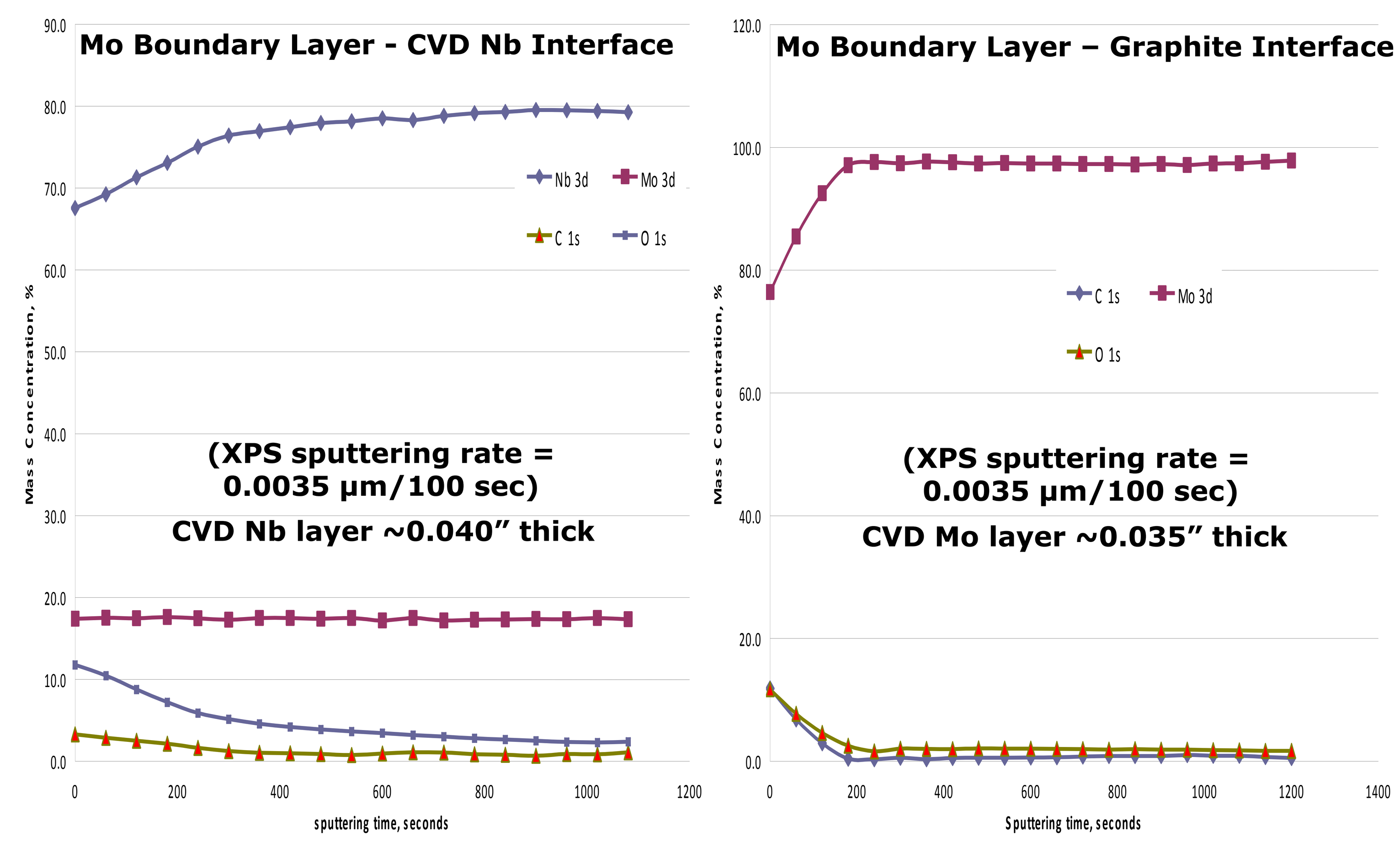

Figure 3: Boundary layer Optimization
XPS analysis of Mo/CVD Nb interface (left) and Mo/graphite interface (right) showing mass concentration (%) vs. sputtering time (sec)

The XPS results in Figure 3 verify that a significant percentage of the impurities present in the CVD niobium test specimens following mandrel removal were confined to the surface of the material to a depth of less than ~0.035 µm.

Performance Testing at ORNL: A SQUID magnetometer was used to determine the magnetization of the CVD niobium samples at 5 K, yielding the overall magnetic hysteresis (energy loss per cycle) and critical fields (Figure 1). The low field of first flux penetration, related to the lower critical field H_{c1}, indicates the CVD niobium material's potential high gradient performance capabilities if the material were to be used in a superconducting accelerator cavity application. Table 1 shows the RRR results for materials produced from the matrix of deposition conditions used to advance the CVD niobium process technology.

CVD Welding: The CVD niobium joining process does not induce the unwanted recrystallization that occurs during electron beam welding. The inherently large grains of the as-deposited CVD niobium weld material can be seen at left in this cross-sectional optical micrograph of a simple untested butt-joint specimen (Figure 2). Unaffected and significantly smaller grains of the niobium tubes fabricated by powder metallurgy are apparent at the right of the image.

Demonstration Component: Seamless CVD Niobium Cell

(Produced in previous DOE-funded research)

As-Deposited CVD Niobium (with graphite mandrel)

CVD Niobium Cell Structure (mandrel removed, OD polished)

>RRR200 CVD Nb Potential Applications:

- Fabrication
- Joining
- Modification
- Repair

Summary

The niobium material optimization conducted in this project, combined with the demonstration of near-net-shape cell prototype fabrication performed in earlier work, continue to support further development of this innovative approach to the fabrication, joining, modification, and repair of SRF accelerator components.

CVD niobium was deposited under various conditions to maximize purity using a relatively low-cost, moderate-purity niobium starting material, and resistance and magnetic properties were characterized. Impressive RRR values up to 282 were measured in testing at ORNL.

The initial feasibility of using the CVD process to join prefabricated niobium components, as a means to reduce or eliminate expensive electron beam welding, was demonstrated, and preliminary development of a low-cost mandrel for cavity fabrication in a production environment was performed.