Nb_3Sn coating on Cu via CVD

Shreyas Balachandran

1. Department of Mechanical Engineering, FAMU- FSU College of Engineering, Tallahassee, FL.

Collaborators and work presented on behalf of colleagues at Ultramet, Jefferson Lab, and FSU

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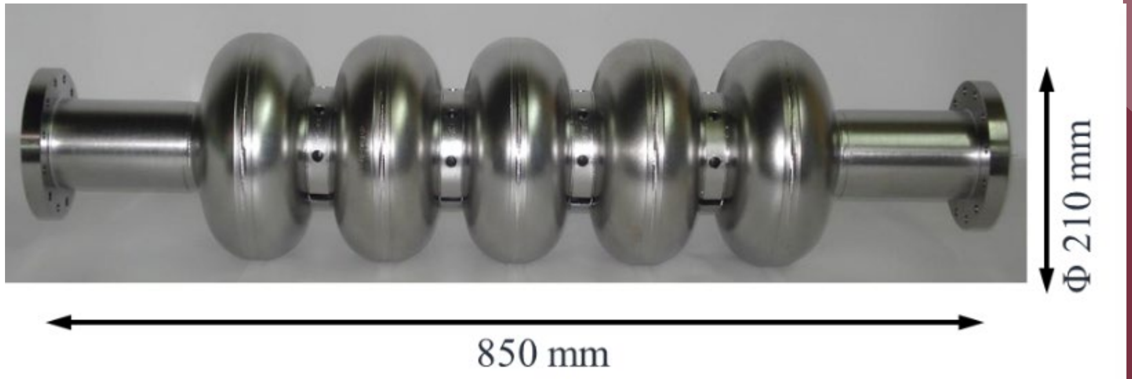
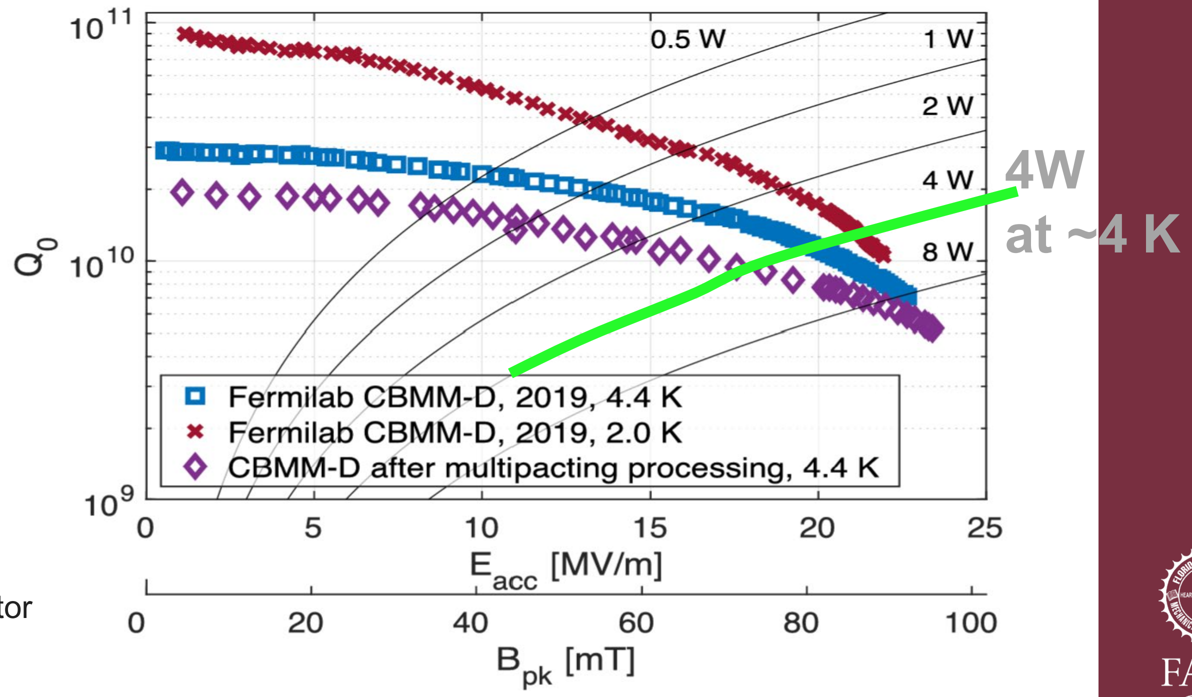
Beyond SRF Nb- Alternative materials: Focus on Nb_3Sn

Property	Nb	Nb_3Sn [a]
T_c [K]	9.2	18
$\mu_0 H_{c1}(0)$ [T]	0.17	0.038
$\mu_0 H_c(0)$ [T]	0.2	0.52
$\mu_0 H_{c2}(0)$ [T]	0.4	30
$\xi_{GL}(0)$ [nm][b]	29	3.3
$\lambda_{eff}(0)$ [nm][c]	41	135

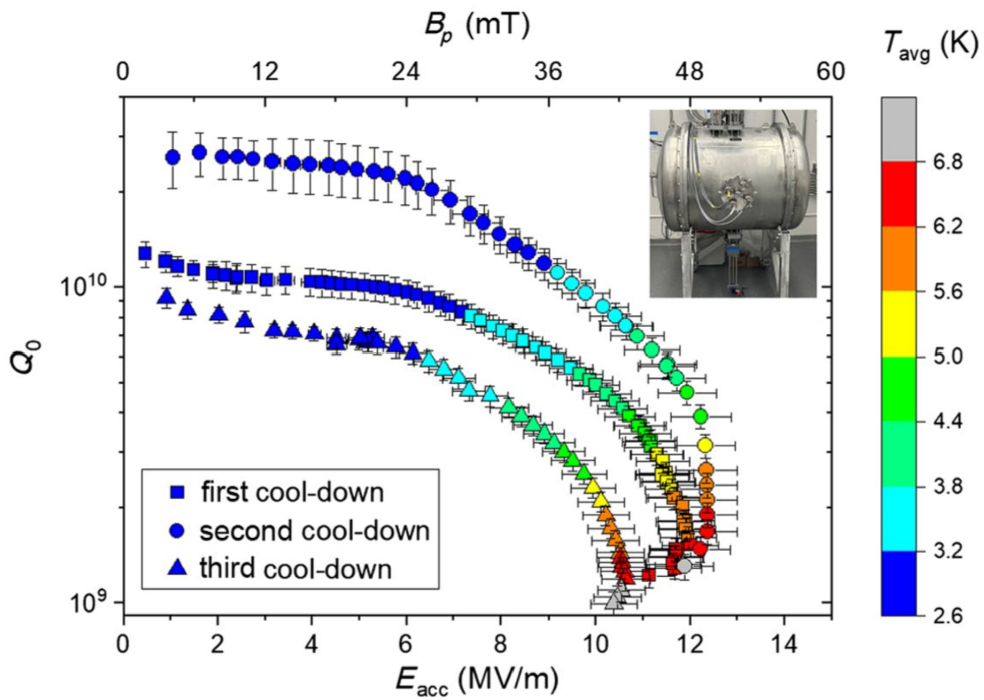
[a] Approaching stoichiometry.
[b] From $\sqrt{\phi_0/(2\pi\mu_0 H_{c2}(0))}$ [8].
[c] From $\sqrt{\phi_0\mu_0 H_{c2}(0)/(4\pi H_c^2)}$ [8].





Posen, S., Lee, J., Seidman, D. N., Romanenko, A., Tennis, B., Melnychuk, O. S., & Sergatskov, D. A. (2021). Advances in Nb_3Sn superconducting radiofrequency cavities towards first practical accelerator applications. *Superconductor Science and Technology*, *34*(2), 025007.

Cryocooled Nb_3Sn on Nb successfully tested in Jefferson Lab- 1MW, 1MeV compact electron accelerator possible.



Development of a prototype superconducting radio-frequency cavity for conduction-cooled accelerators

G. Ciovati,[1,2,*] J. Anderson,[3] S. Balachandran,[1] G. Cheng,[1] B. Coriton,[3,†] E. Daly,[1] P. Dhakal,[1] A. Gurevich,[2] F. Hannon,[1,‡] K. Harding,[1] L. Holland,[3] F. Marhauser,[1,§] K. McLaughlin,[3] D. Packard,[3] T. Powers,[1] U. Pudasaini,[1] J. Rathke,[4] R. Rimmer,[1] T. Schultheiss,[5] H. Vennekate,[1] and D. Vollmer[3]

[1]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
[2]Center for Accelerator Science, Department of Physics, Old Dominion University, Norfolk, Virginia 23529, USA
[3]General Atomics, San Diego, California 92121, USA
[4]TECHSOURCE, Inc., Los Alamos, New Mexico 87544, USA
[5]TJS Technologies LLC, Commack, New York 11725, USA

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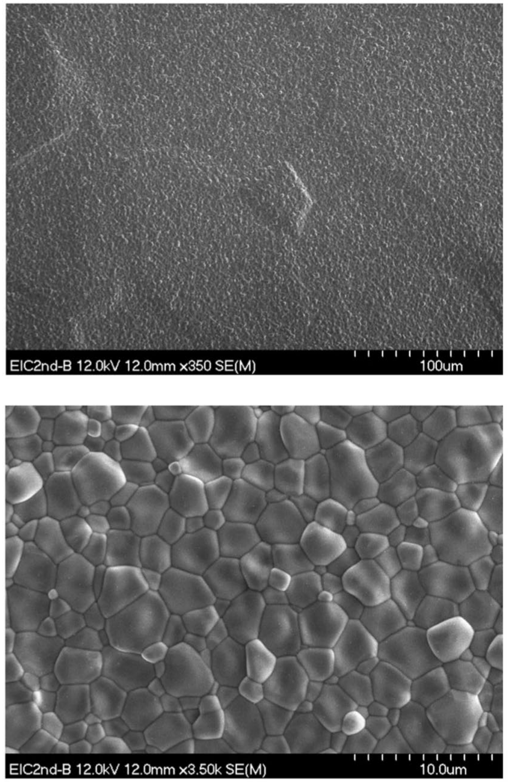
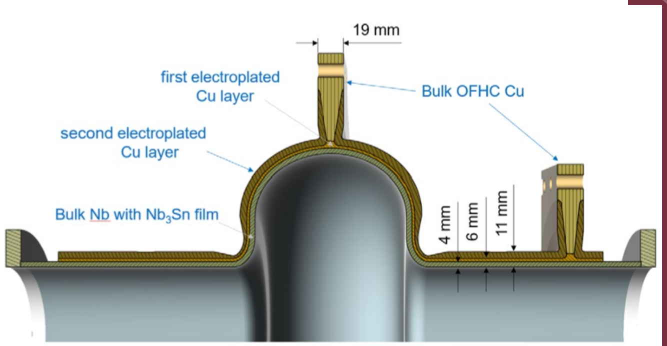
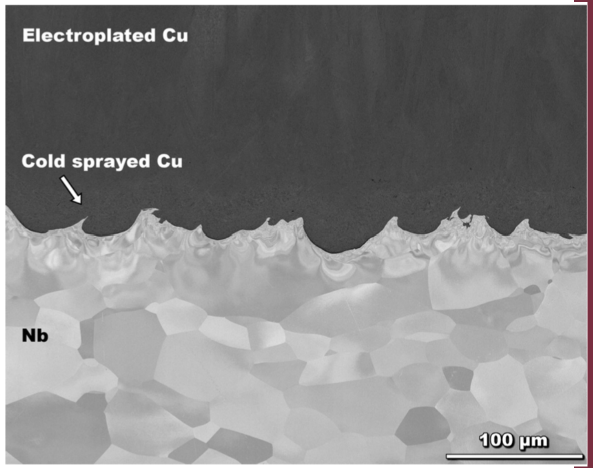


(a)

(b)

FIG. 9. (a) Low (×350) and (b) High magnification (×3.5k) SEM images of the Nb_3Sn film on a Nb witness sample after the second coating.





10 MeV, 1 MW system in the works!

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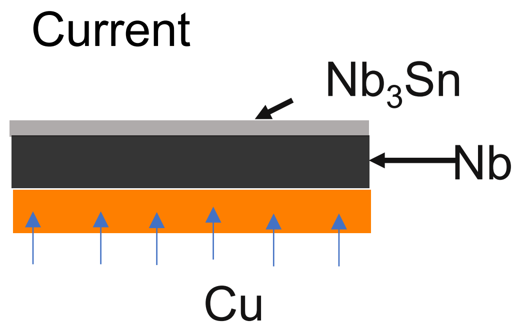
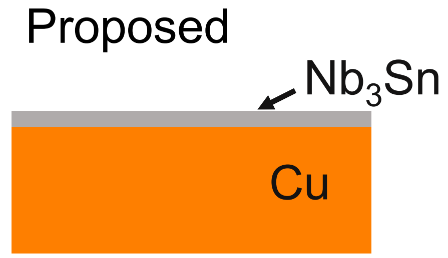
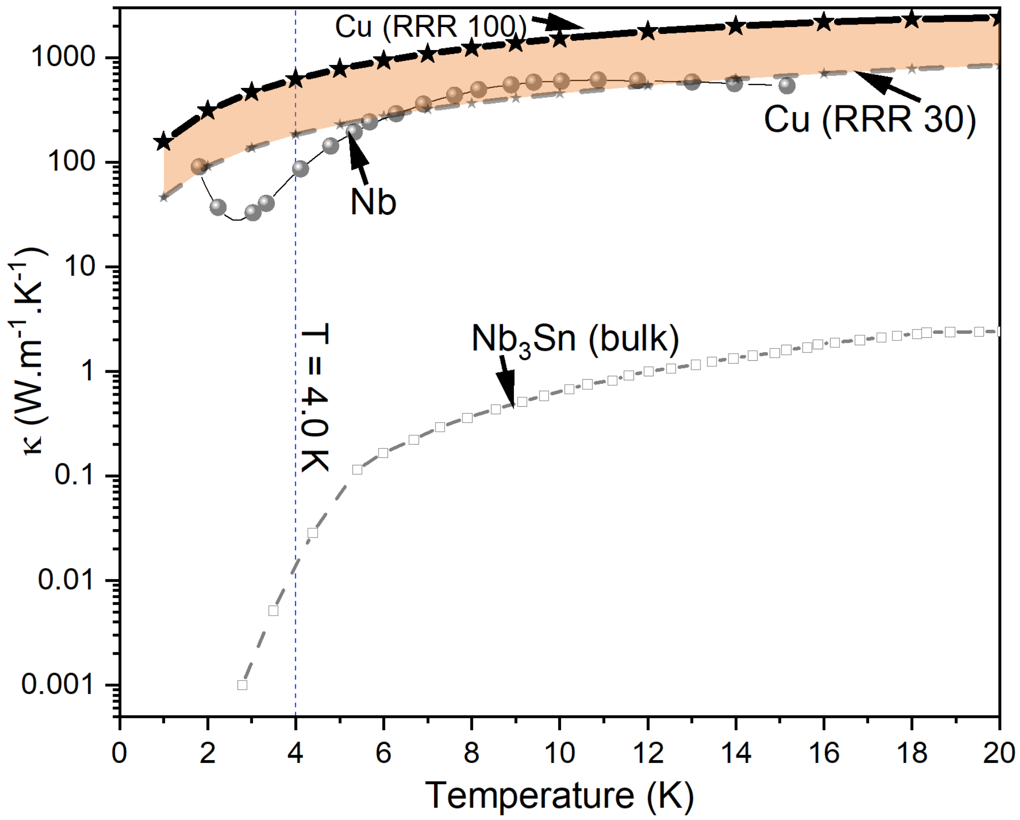
Nb_3Sn on Cu for SRF applications







Cu melts at ~1100°C

Cu-based Nb_3Sn is a widely studied system.

Cost of RRR 100 Cu ~ 1/20 of RRR 300 Nb

~ 5 times improvement in thermal conductivity at 4K with Cu

CVD Nb_3Sn by Nb and Sn chloride reactions

December 1970,
RCA Reviews

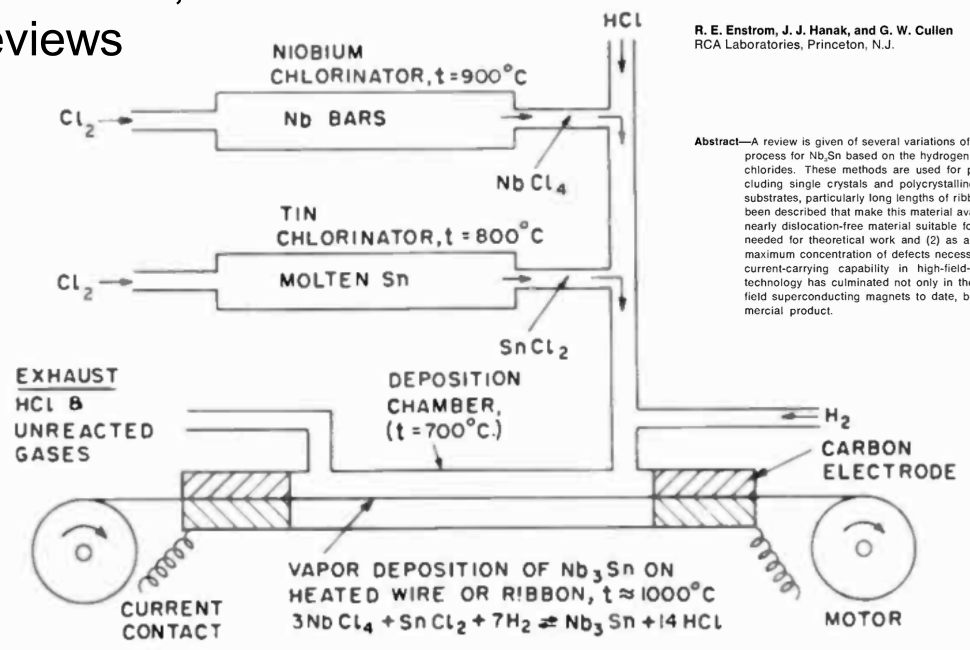
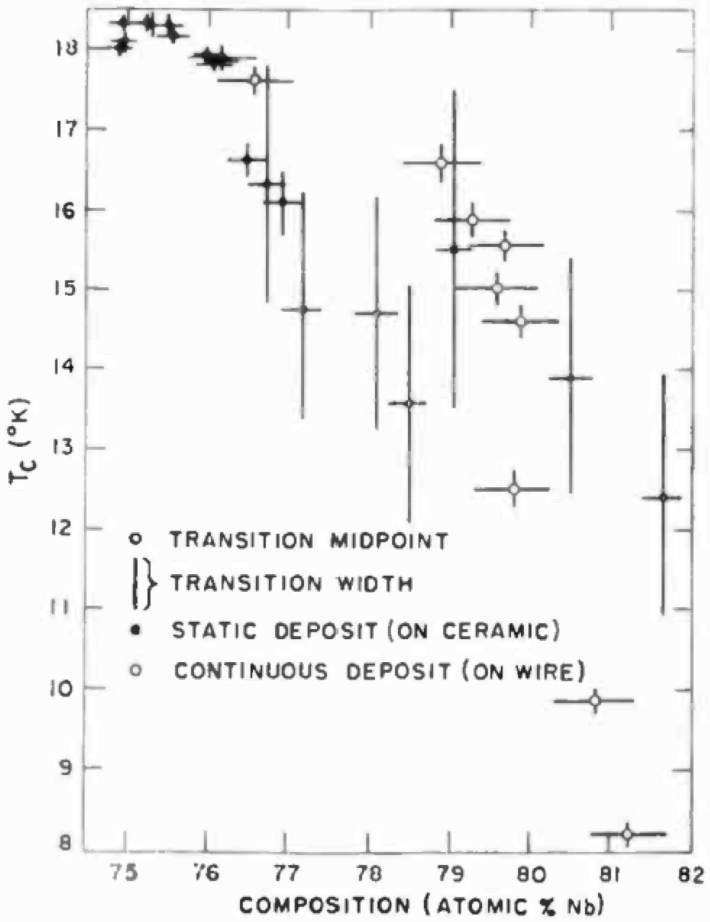


Fig. 2—Apparatus for continuous vapor deposition of Nb_3Sn on metallic ribbon and wire.

Compounds and Alloys for Superconducting Applications

R. E. Enstrom, J. J. Hanak, and G. W. Cullen
RCA Laboratories, Princeton, N.J.

Abstract—A review is given of several variations of a chemical vapor deposition process for Nb_3Sn based on the hydrogen reduction of niobium and tin chlorides. These methods are used for preparing Nb_3Sn in forms including single crystals and polycrystalline films on ceramic or metal substrates, particularly long lengths of ribbon. Growth techniques have been described that make this material available (1) as a highly perfect nearly dislocation-free material suitable for basic studies of properties needed for theoretical work and (2) as a heavily doped material with maximum concentration of defects necessary for flux pinning and high current-carrying capability in high-field-solenoid applications. This technology has culminated not only in the construction of the highest field superconducting magnets to date, but also in a successful commercial product.

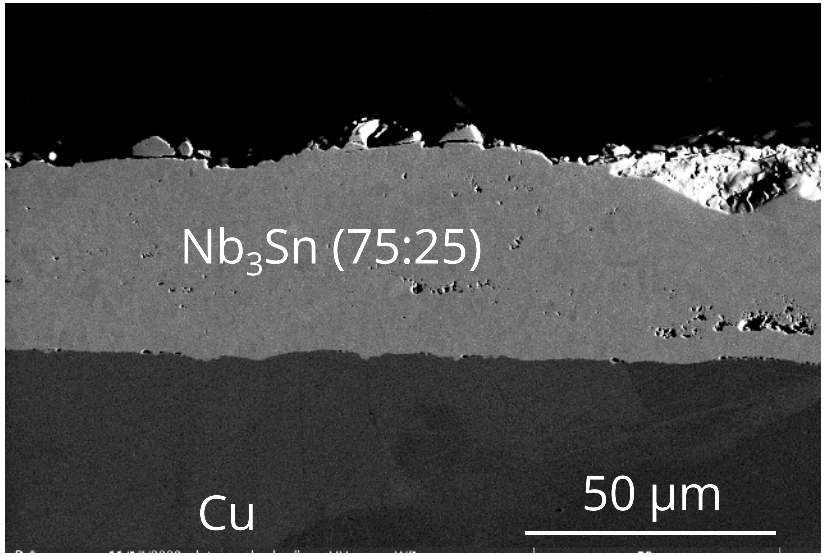


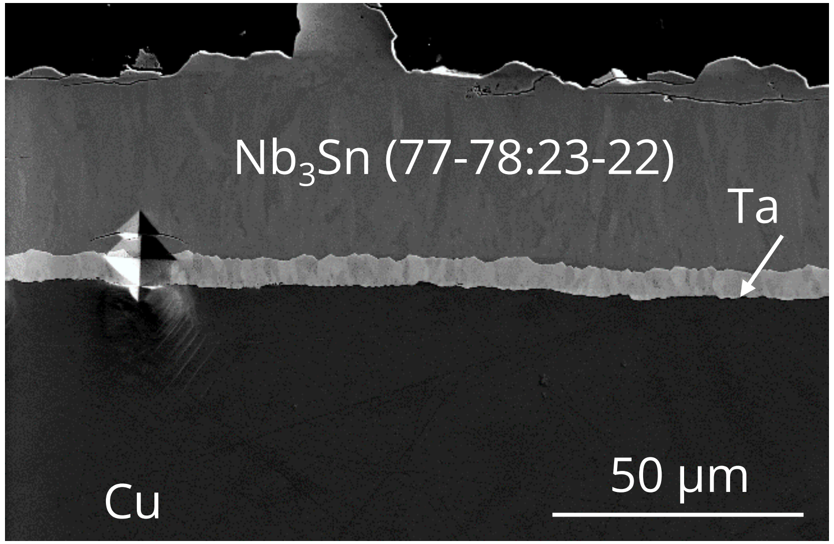
Deposition temperature is 700℃

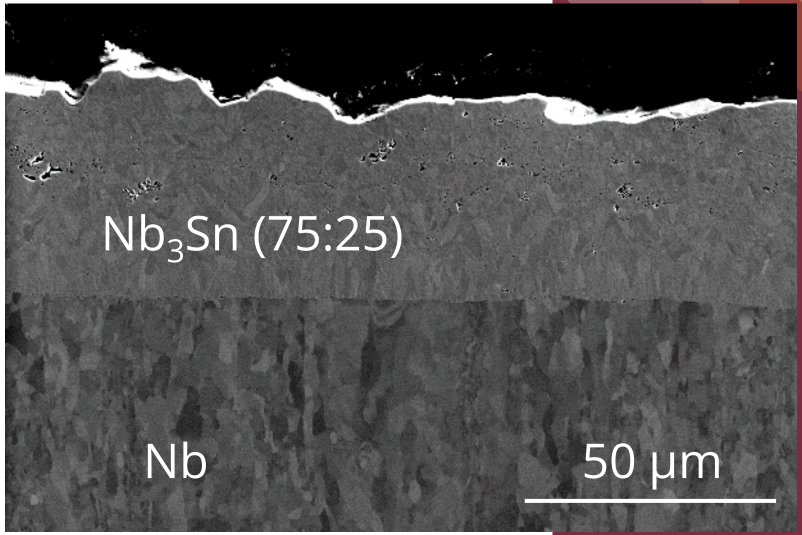
Ribbon or wire heated to ~1000 ℃

Nb: Sn vapor ratio control is important

Ultramet, Inc deposited Nb_3Sn on Cu cavities at temperatures of 750℃ - 900℃







Precursors are largely proprietary.
Process details are unknown.

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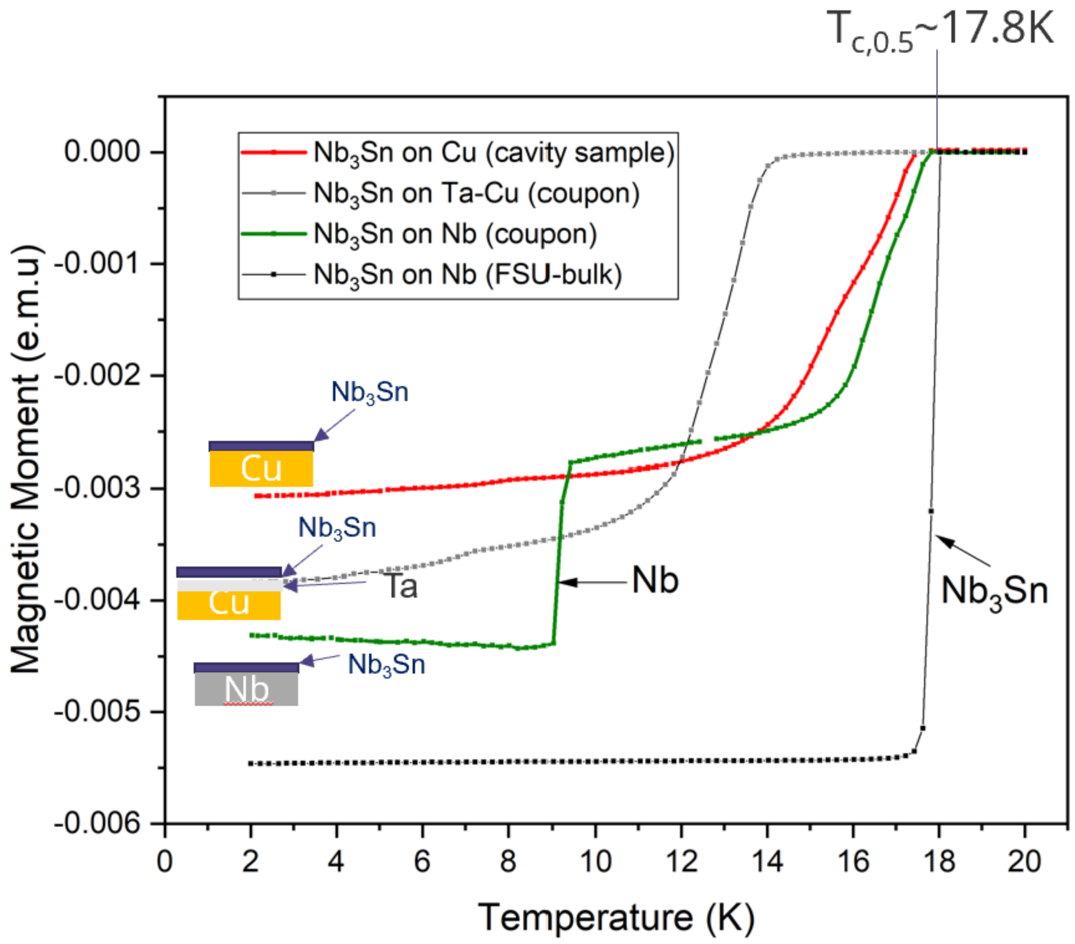
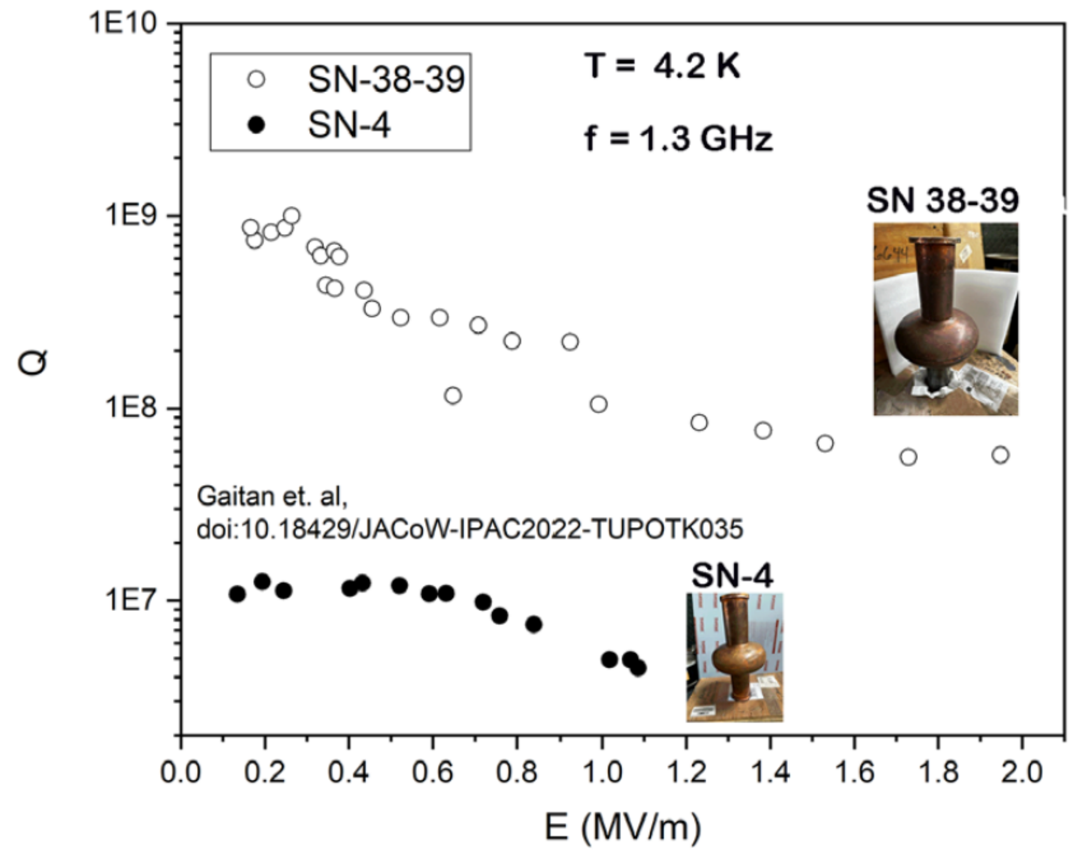
High T_c, Nb_3Sn is possible in the temperature range of 750- 900℃.

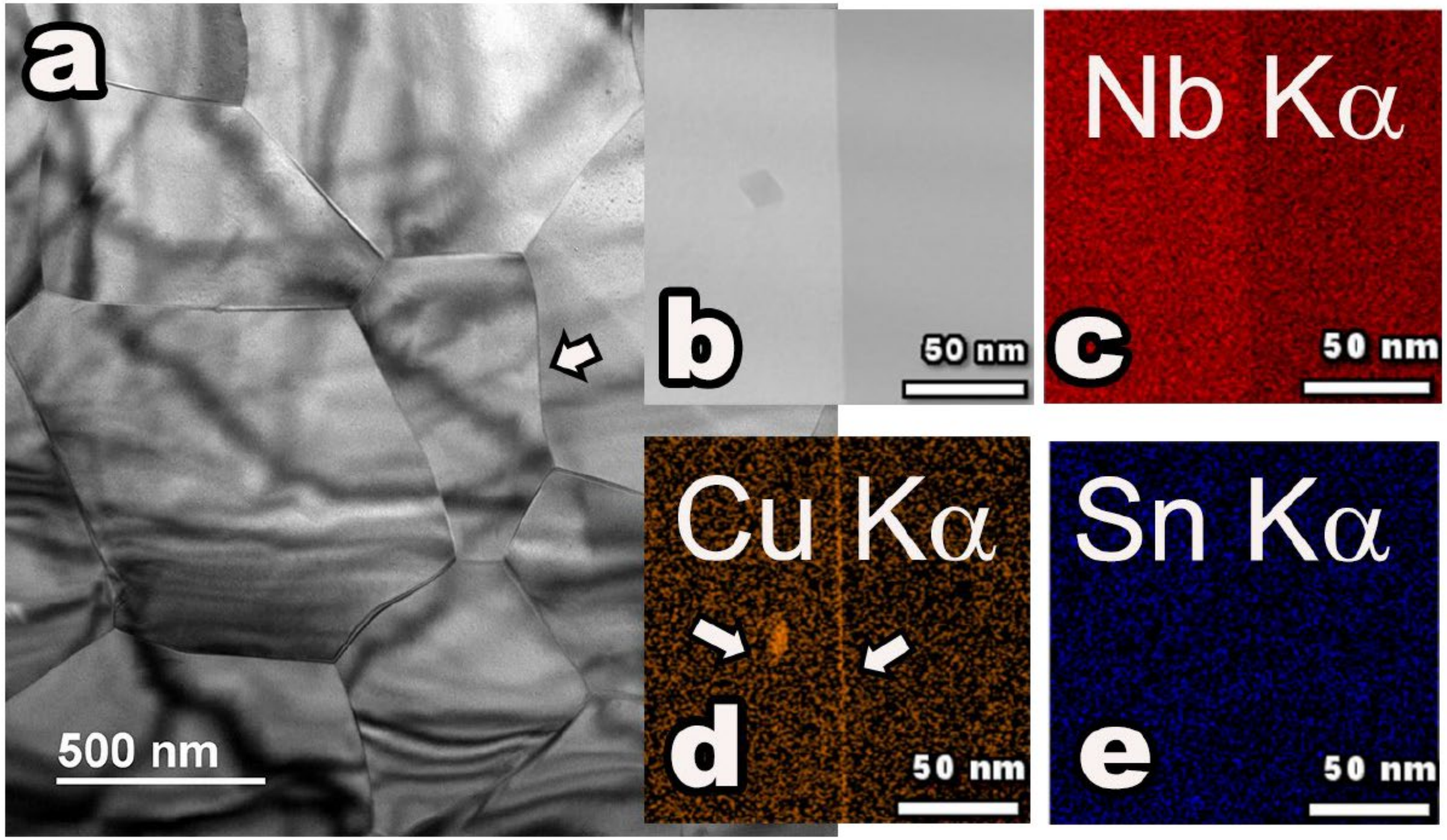


Cavity performance needs to improvement



Issues beyond obtaining high-quality CVD Nb_3Sn need to be addressed for success in SRF applications.

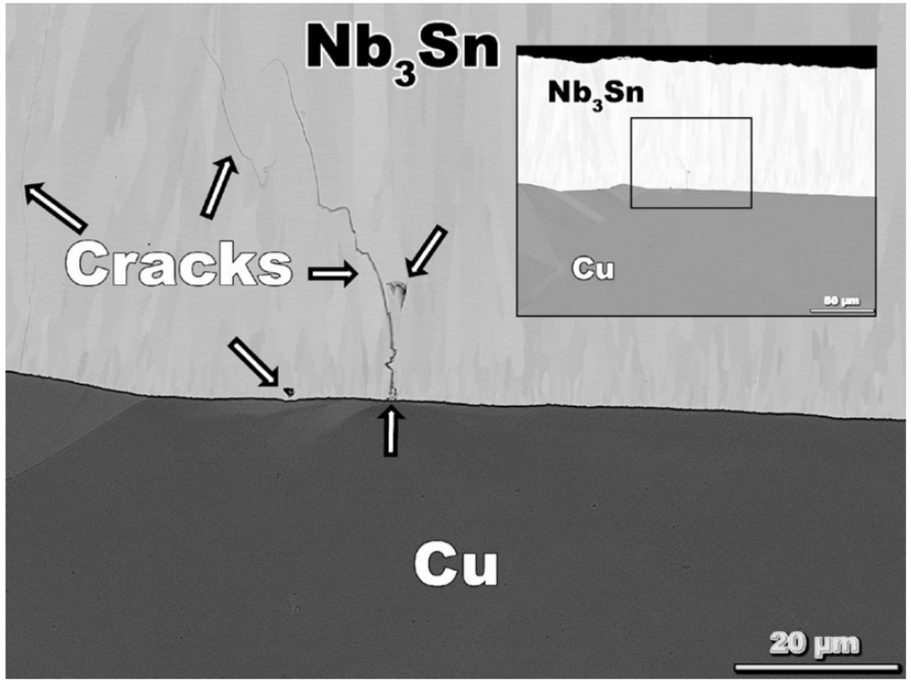
Cu in Nb_3Sn {grain boundaries}

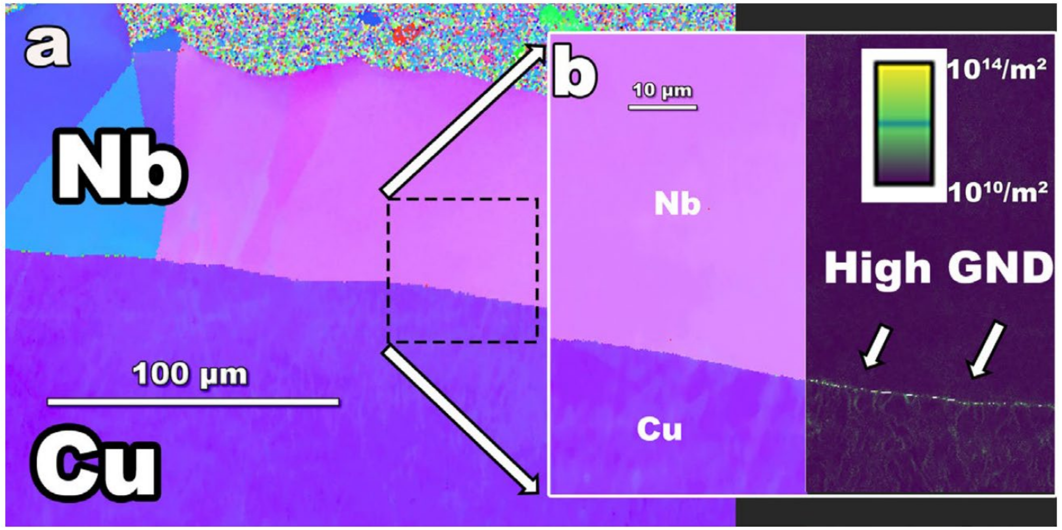


Degradation of performance due to Cu in GB's.

Cu Diffusion barriers are important

Thermal strains: Coefficient of thermal expansion.





Thermal expansion mismatch:

- Cu: 17 x 10^{-6}/°C
- Nb_3Sn: 7.6 x 10^{-6}/°C
- Nb/ Ta: ~8 x 10^{-6}/°C

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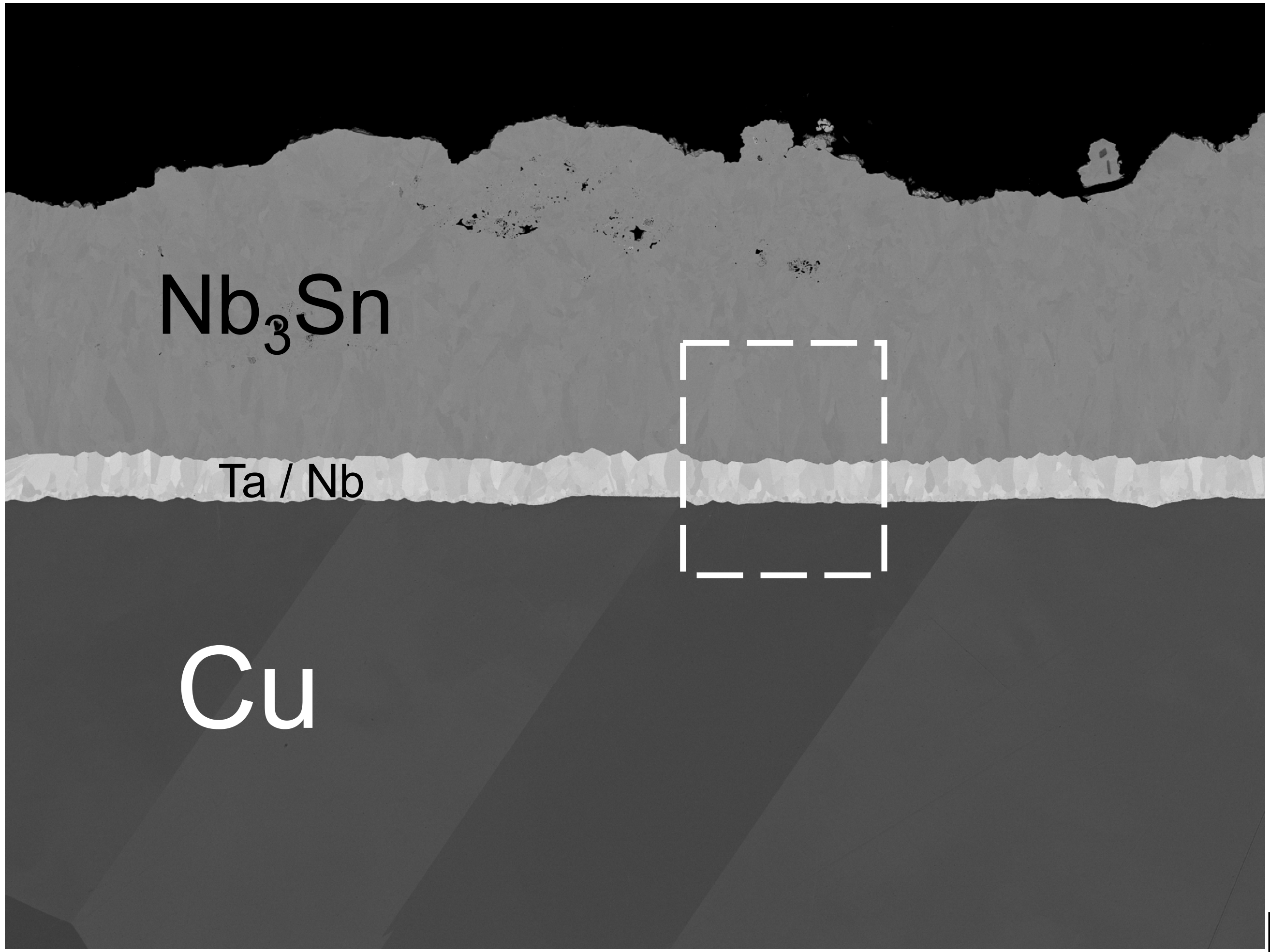
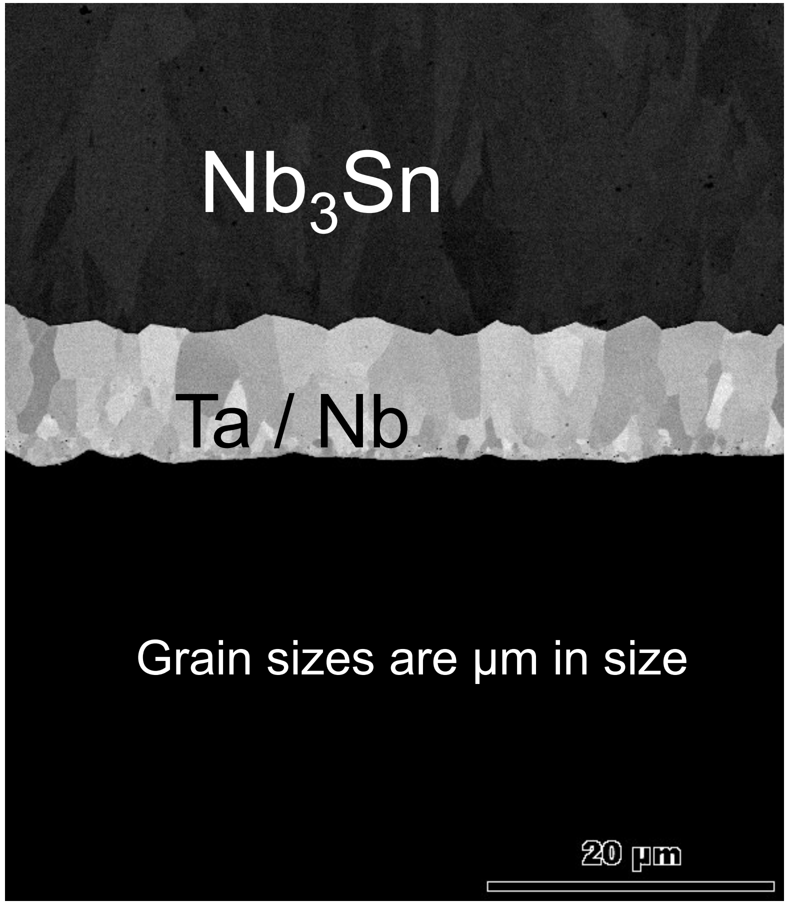
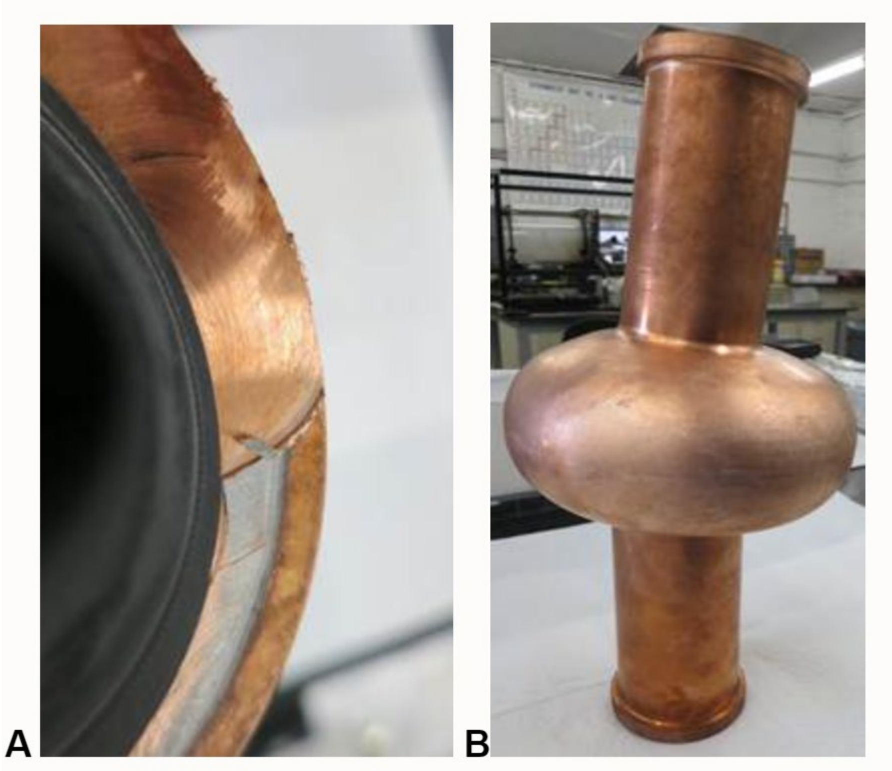
Surface roughness: Substrate + growth

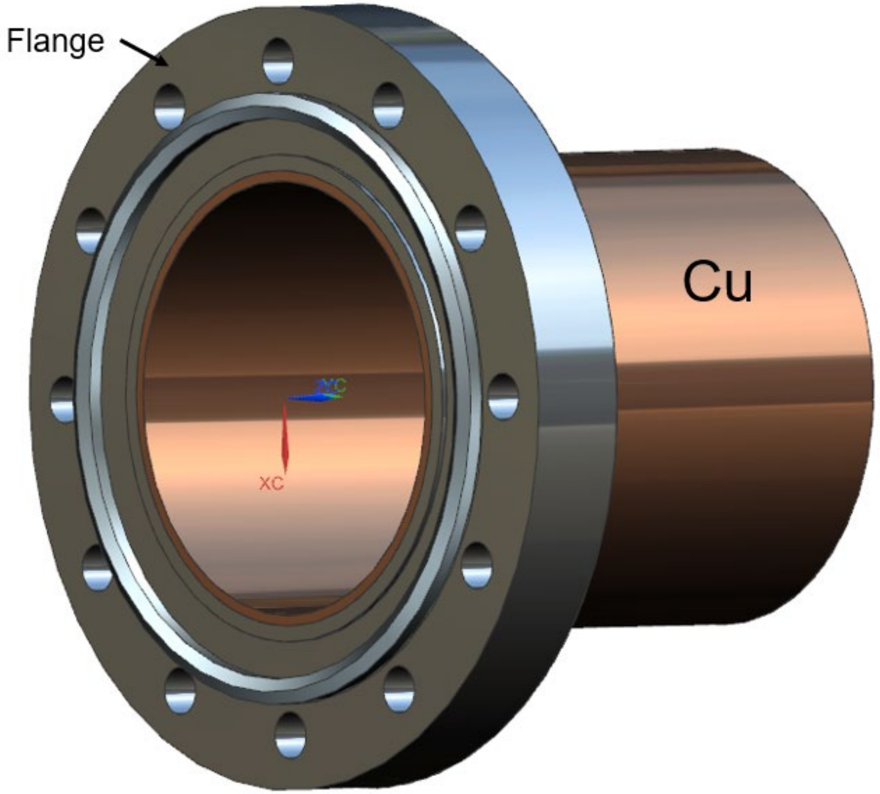




Polishing processes for Nb_3Sn

Structural stability of Cu structures after heat treatments



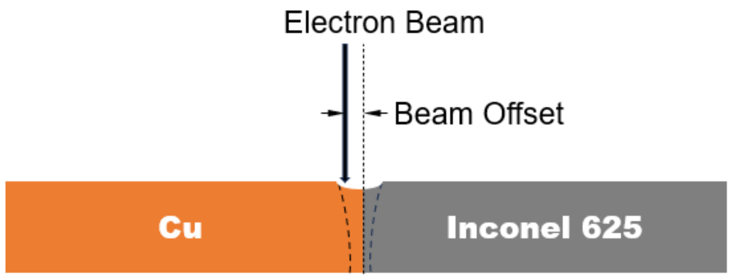


RD&D at Jefferson Lab to weld Inconel 625 to Cu

Inconel 625- 3.1mm sheet and 1 in. plate

Element	Weight percent
Chromium	22.0
Molybdenum	9
Niobium + Tantalum	1.2
Iron	1.8
Aluminum	0.3
Titanium	0.26
Silicon	0.16
Manganese	0.3
Carbon	0.04
Sulphur + Phosphorus	<0.005
Nickel	Bal.

Cu- C10100, off the shelf- 3.1 mm sheet



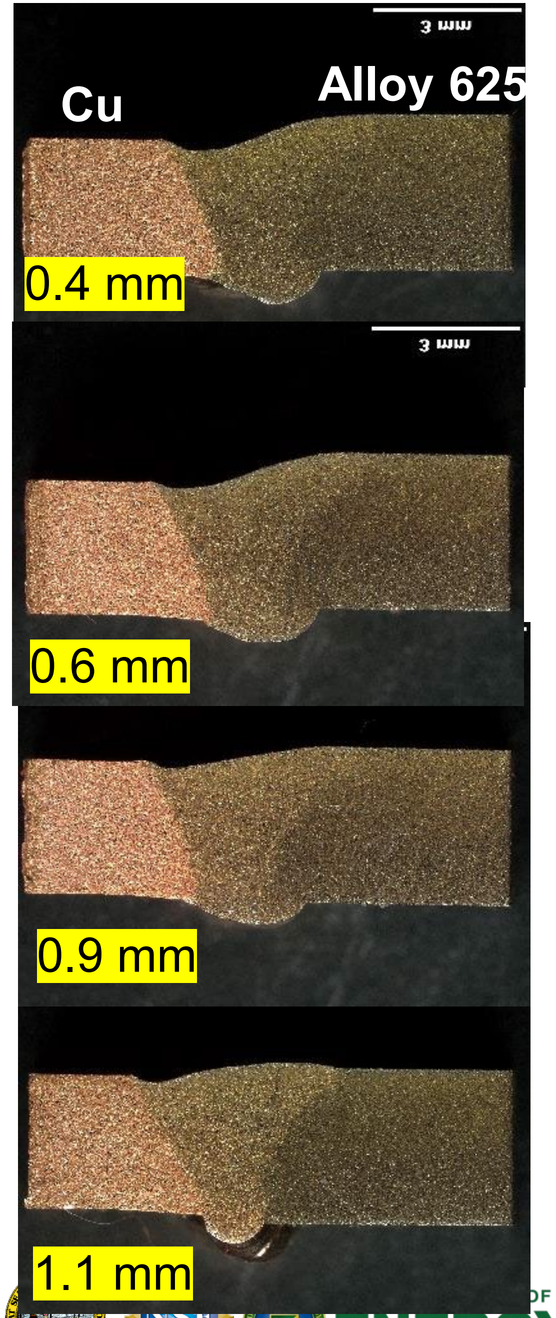
Welding parameters for 3mm thick sheets of Cu and Inconel 625. Beam current = 50 mA, beam Voltage = 50 kV, and oscillation diameter of 2mm, 10 kHz.

Sample ID	Weld speed (mm/s)	Beam Offset (mm)	Energy per unit length (W/mm)	Beam Offset
O1-C	6.8	0.4	328	In Cu
O2-C	6.8	0.6	328	In Cu
O3-C	6.8	0.9	328	In Cu
O4-C	6.8	1.1	328	In Cu
V1-C	7.6	1.0	328	In Cu
V2-C	6.8	1.0	369	In Cu
V3-C	5.9	1.0	422	In Cu
V4-C	5.1	1.0	492	In Cu
O7-I	7.2	0.4	328	In A-625
O8-I	7.2	1.0	328	In A-625

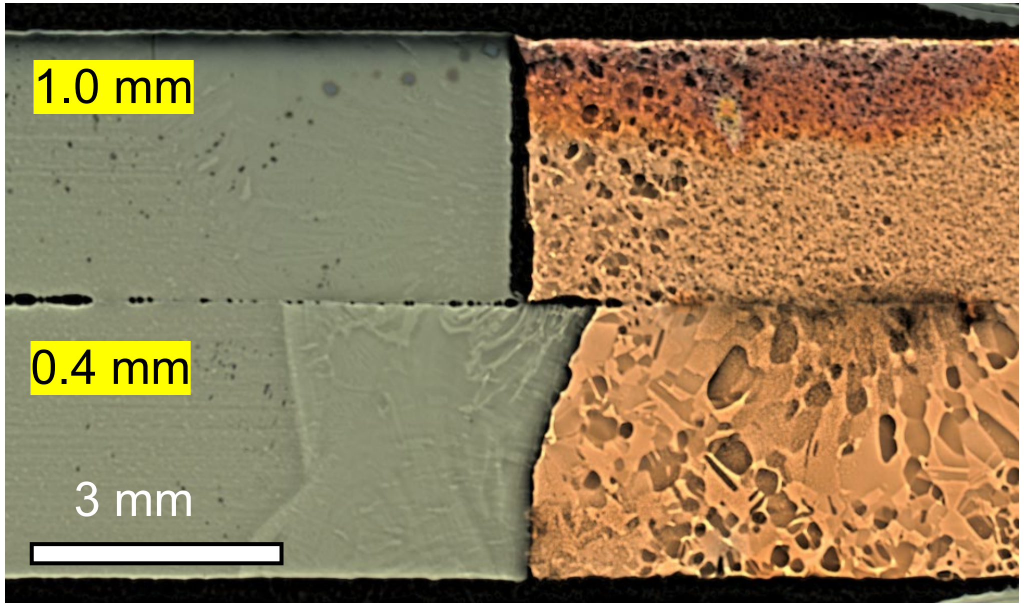
EB welds Cu to Inconel 625.

Offset in Cu NOT in Inconel

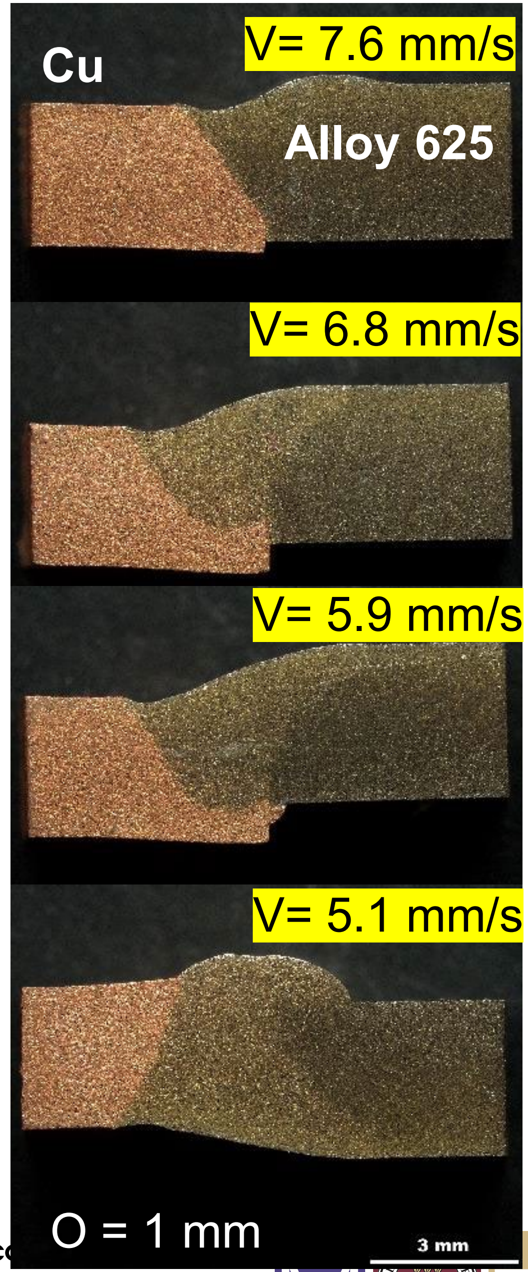
Offset in Cu, v = 6.8 mm/s

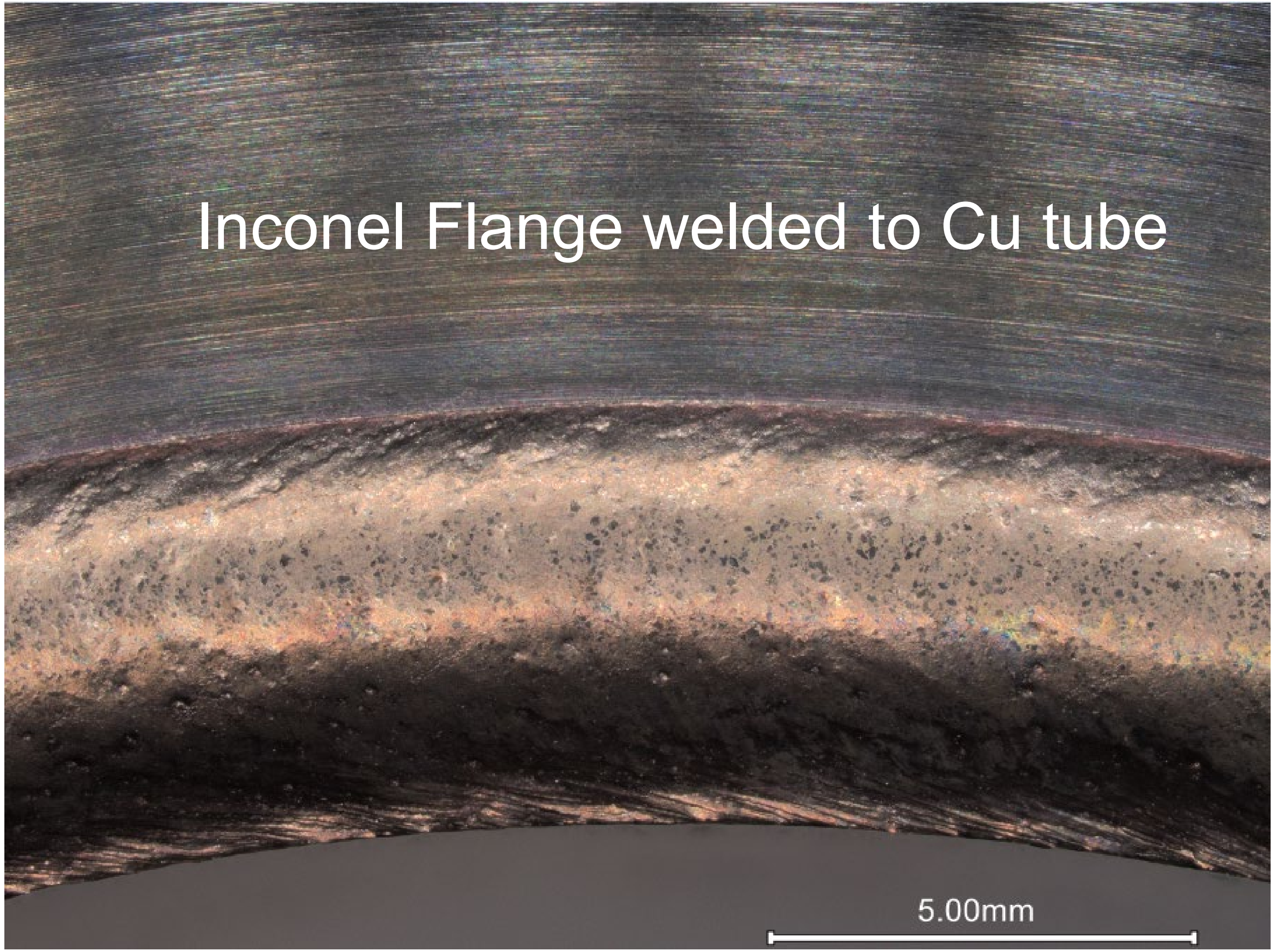


Offset in Inconel 625, v = 6.8 mm/s

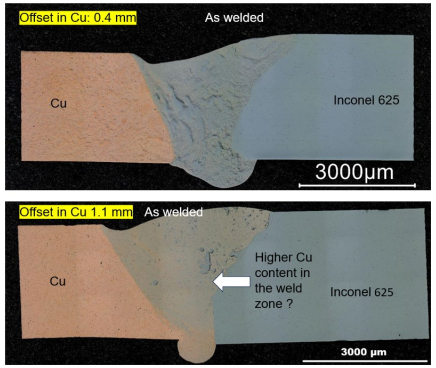


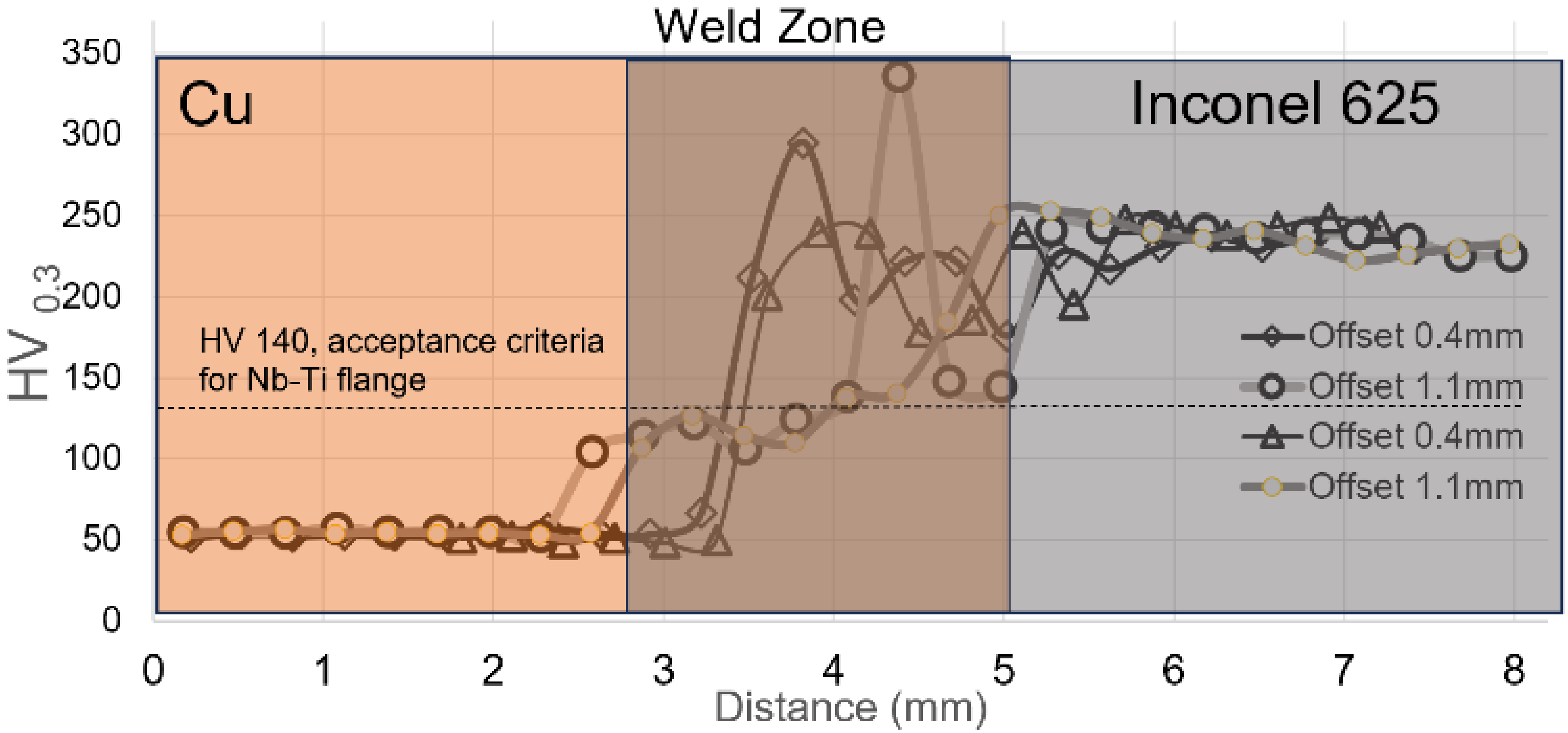
Varying speed, Offset in Cu = 1mm




Inconel Flange welded to Cu tube
5.00mm

Cu- Inconel welds maintain high strength after welding.





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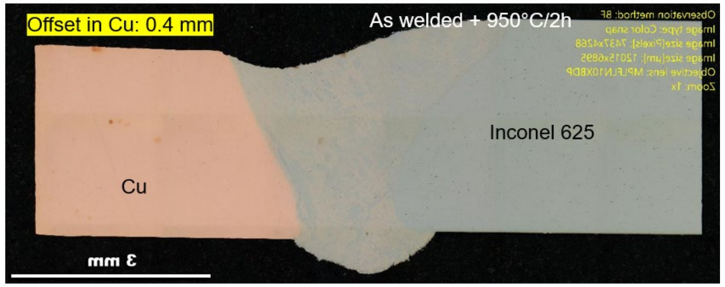
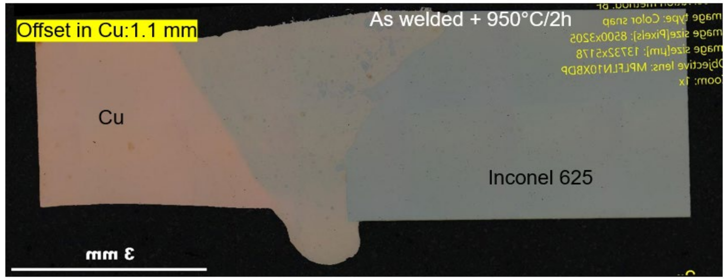
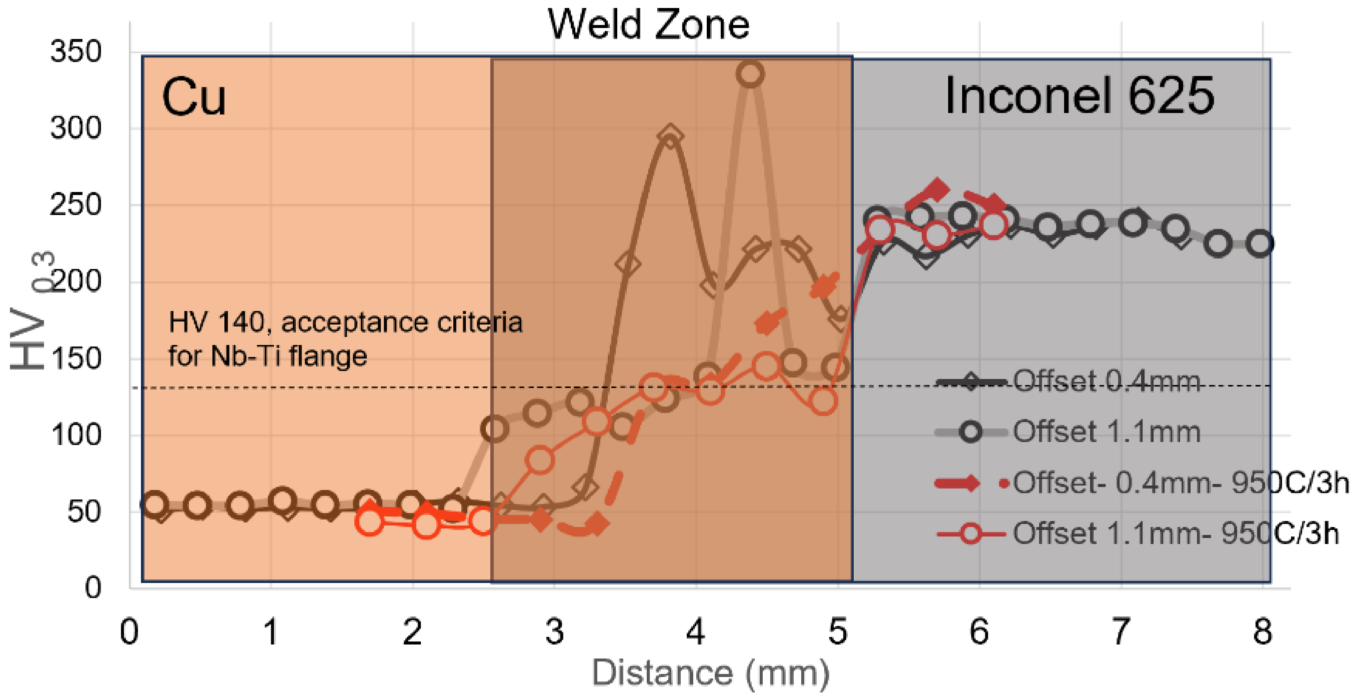
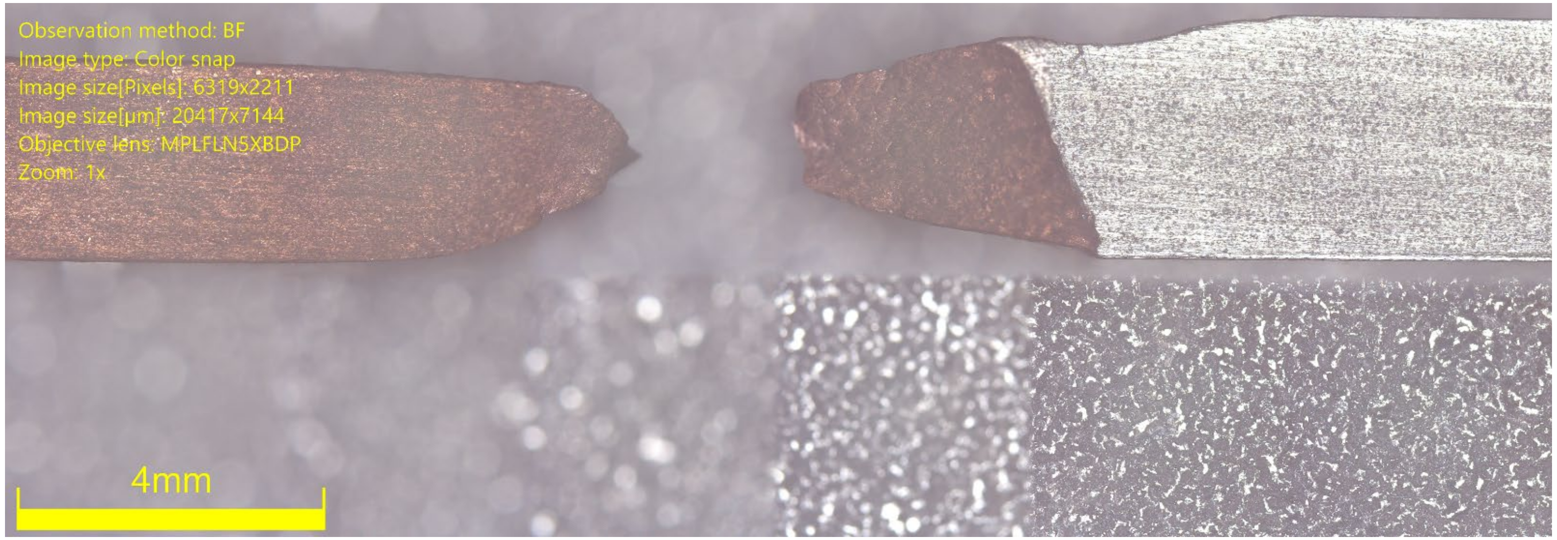
And continue to maintain higher strength after heating to 950℃ for 3 hours.

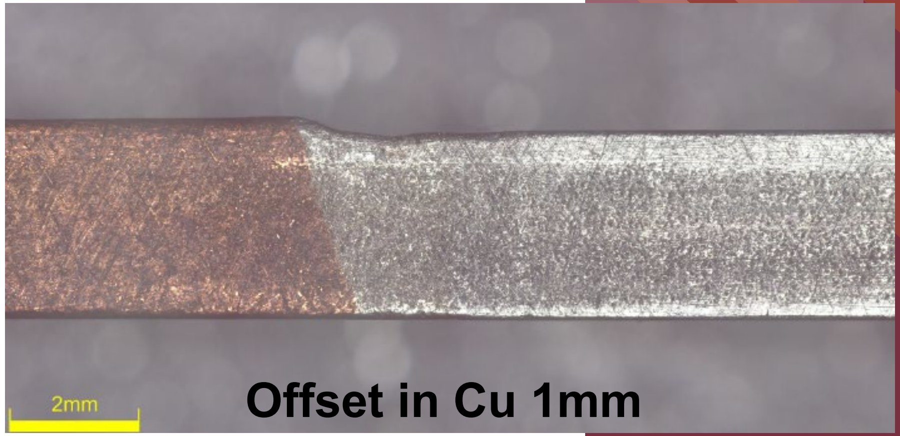


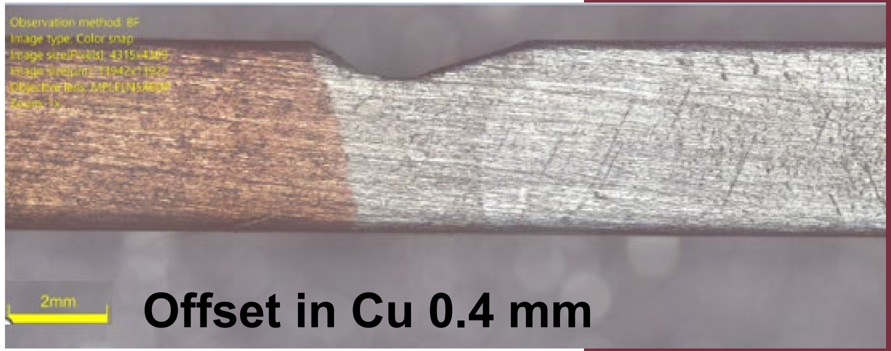




Mechanical testing: Fracture in Cu (weakest spot)







So what?

- Inconel 625 could be further explored for vacuum flanges.
  - Weakly paramagnetic at 4K. Susceptibility of 1.01- 1.03

- How about using Inconel 625 for structural support as needed?

- EBW of Cu- Inconel 625 is straightforward.

Applications in a CVD (hot chloride) environment need to be evaluated

CVD Nb_3Sn on Cu is possible BUT needs significant developments in the following areas

- **Process standardization for Cu cavity preparation.**
  - Polishing method, Metric: Surface roughness?
- **Nb_3Sn deposition on Cu**
  - Process control to obtain a stoichiometric superconductor with desired smoothness.
  - Post processing: No post processing is best…
    - Heat treatment?
  - Thickness control- Address cavity shape
  - Developing Nb_3Sn polishing strategies to remove layers controllably- new electro/ chemical/ mechanical polishing recipes?
- **Dealing with soft Cu structures**
  - Reinforcements
  - Support structures, flanges etc.