AF7 - Subgroup RF - MiniWorkshop on Cavity Performance Frontier
16-17 February 2021

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An Impartial Perspective for Superconducting Nb_3Sn coated Copper RF Cavities for Future Linear Accelerators

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- *National Institute for Materials Science, Japan*: Akihiro Kikuchi
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Outline

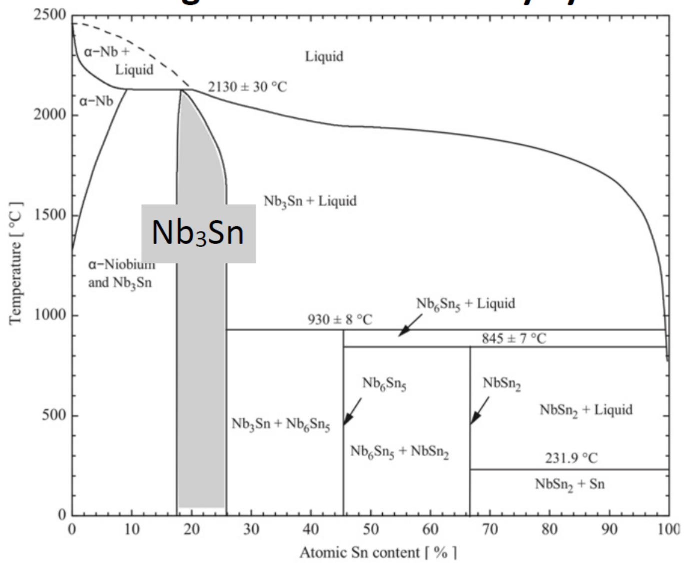
- *Motivation*
- *Short overview of Nb_3Sn coating methods applicable to Cu or Bronze*
- *Conclusion*

Motivation

- Make the case that more funding should be invested in the U.S. and elsewhere on Cu or Bronze based cavities coated with Nb_3Sn. Producing Nb_3Sn on inexpensive and thermally efficient metals such as Cu or bronze exploits the full potential of this advanced superconductor.
- The maximum accelerating gradient expected for Nb cavities is ~50 MV/m. With a theoretical H_{sh} of 0.42 T (Dynamic superheating field 40% larger. i.e. 0.59 T), as compared to 0.25 T (0.35 T) for Nb, Cu cavities with a thin layer of Nb_3Sn coated onto their inner surface should produce accelerating gradients larger than 100 MV/m.
- With a higher T_{c0} of up to 18 K vs. 9.2 K for Nb, SRF Nb cavities coated with Nb_3Sn also produce very high quality factors Q_0 , and the cavities operate at 4.5 K. This would decrease capital and operation costs for the cryogenic plant.
- With Nb as one of the main cost driver of SRFs, a devoted global effort in developing Cu cavities lined with Nb_3Sn would make the ILC, or an electron-positron Higgs factory with c.m. energy of 250 GeV, more affordable and more likely to be built.
- A successful technology would readily apply to other HEP accelerators, such as a Muon Collider, and to accelerators for Nuclear Physics, for Spallation Sources and would expand the market for much more economical Light Sources / FELs.

Formation Temperature has to be accessible for Cu

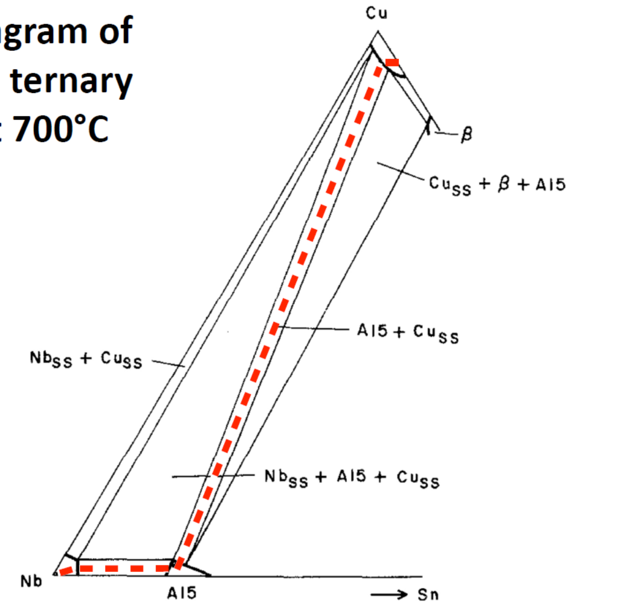
Phase diagram of Nb-Sn binary system



A. Godeke, Superconductor Science and Technology, 19(8):R68–R80, jun 2006.

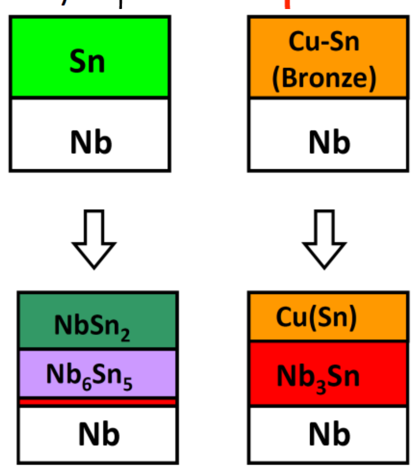
In the vapor diffusion method, we require a temperature of above ~ 1000°C to form Nb_3Sn stably.

Phase diagram of Nb-Cu-Sn ternary system at 700°C

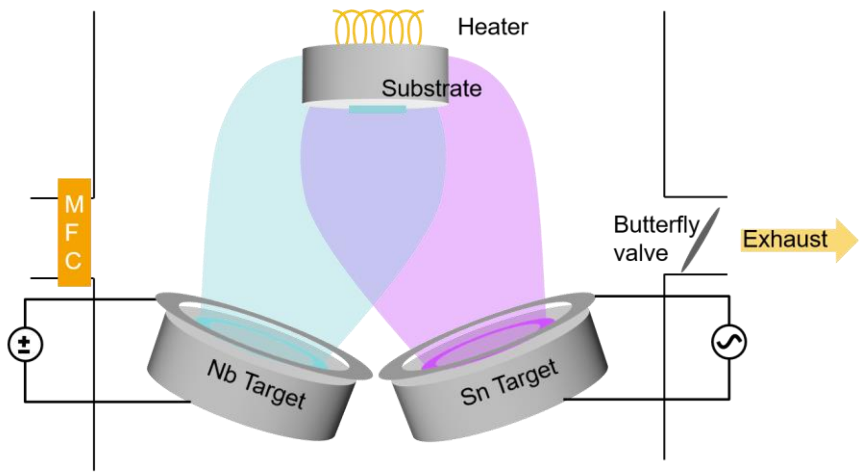


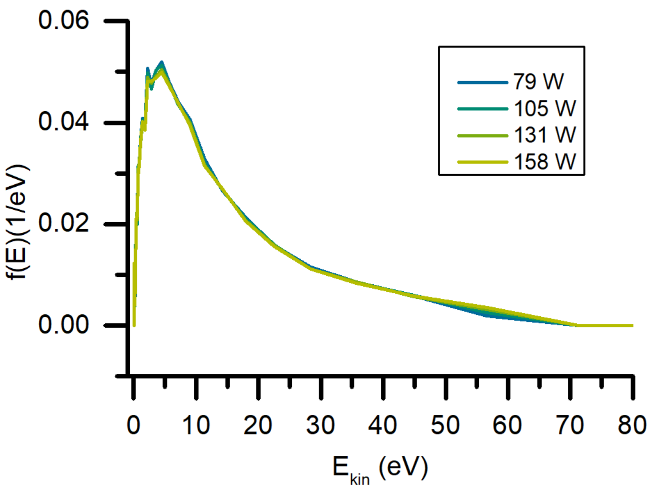
D. Dew-Hughes and T. S. Luhman, Journal of Materials Science, 13(9):1868-1876, Sep 1978.

We can obtain the Nb_3Sn phase at 700°C by the bronze route.

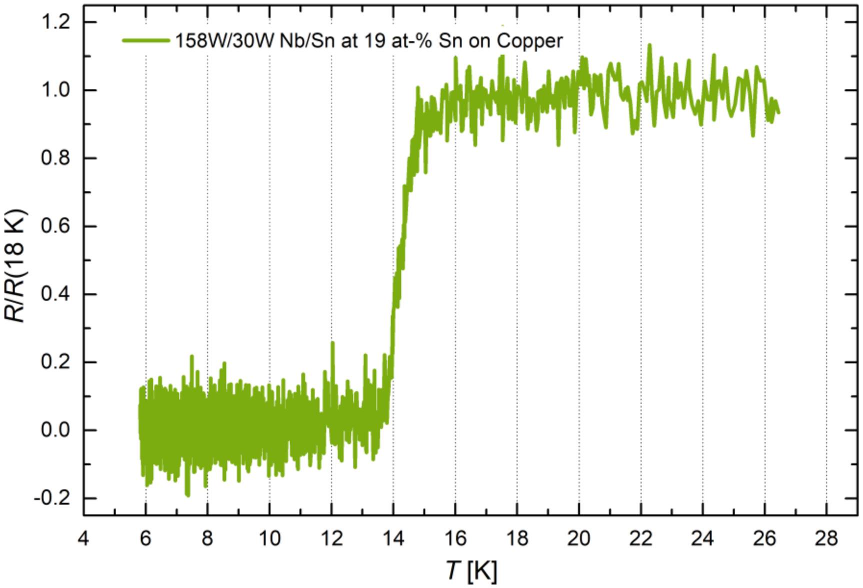


Magnetron Sputtering





1. **Can be performed either sequentially to form a multi-layer structure of Nb and Sn followed by post-reaction;**
2. **From a single stoichiometric target [CERN].**
3. **In a co-sputtering mode from two targets [Technische Universität Darmstadt]. Using two separate targets in a co-sputtering setup allows tuning the kinetic energies of both elements independently.**



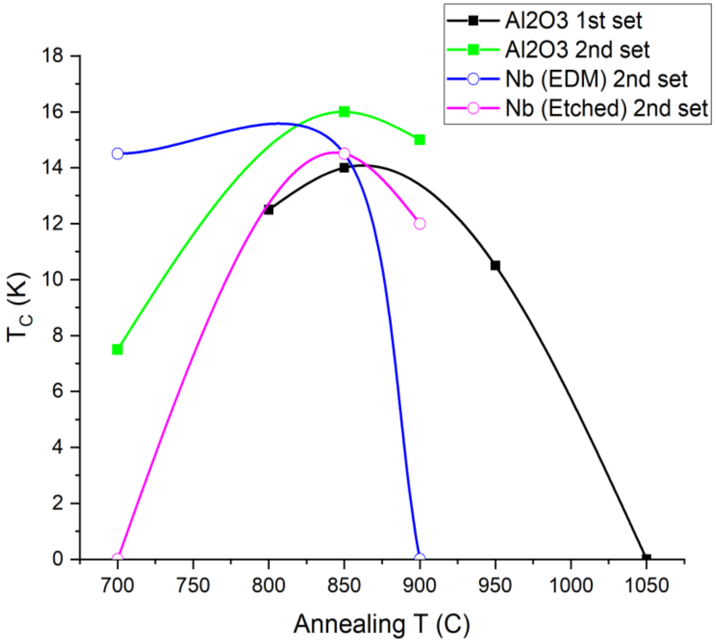
Nils Schäfer et al.

This process leads to the superconducting phase formation at much lower substrate temperatures as compared to thermal diffusion conditions. **For instance, at Darmstadt direct Nb_3Sn deposition was achieved on Cu by magnetron co-sputtering at 435°C.**

Nb_3Sn work at LANL

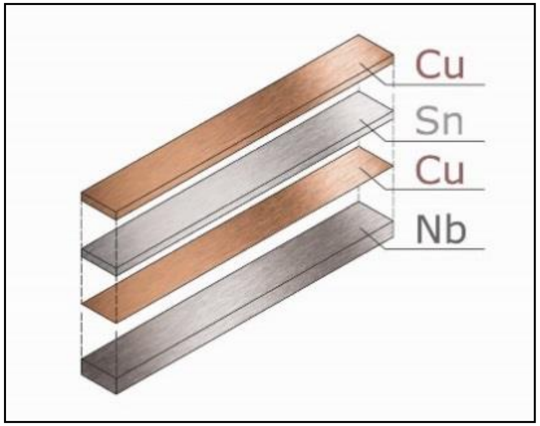
Four sets of 5 x 5 mm^2 test coupons were fabricated and evaluated:

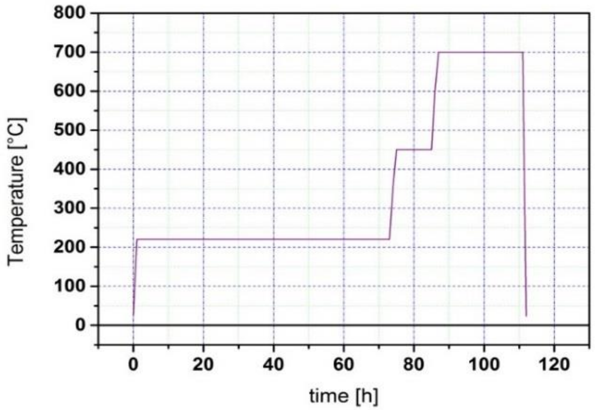
- Two sets were on sapphire substrates.
- Two sets were on Nb substrates.
- One sample on Nb substrate was annealed at 700 C and demonstrated superconducting transition at 14 K.
- The measurements of stoichiometry demonstrated composition of approximately 80 at% of Nb and 20 at% of Sn. We are working to improve stoichiometry.

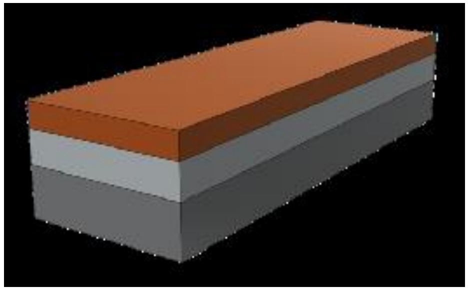


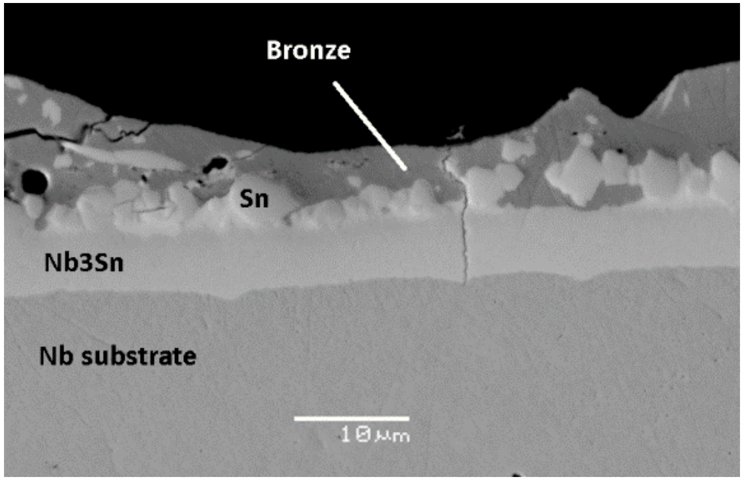
LDRD by Evgenya Simakov

Electro-Chemical Deposition –FNAL within US/ Japan HEP Collaboration



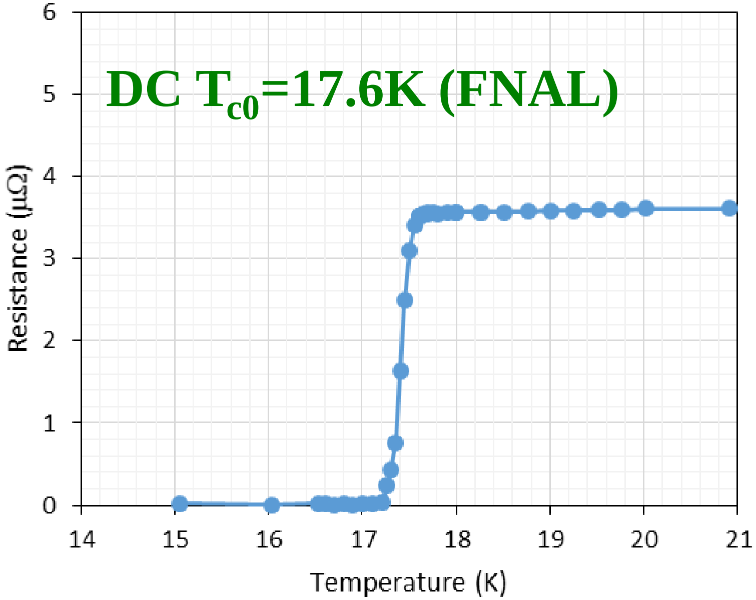




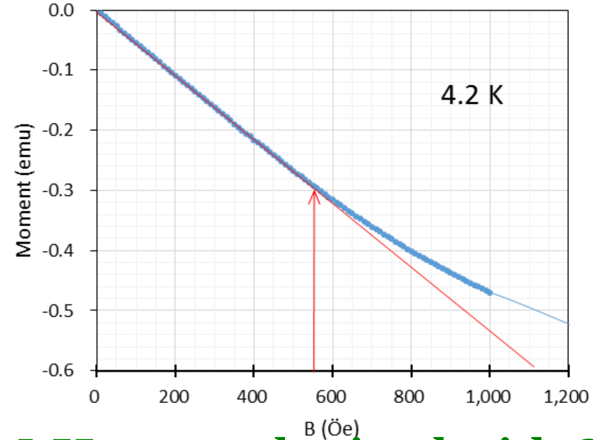


[1] "Synthesis of Superconducting Nb_3Sn Coatings on Nb Substrates", E. Barzi, M. Bestetti, F. Reginato, D. Turrioni and S. Franz, Supercond. Sci. Technol. 29 015009.

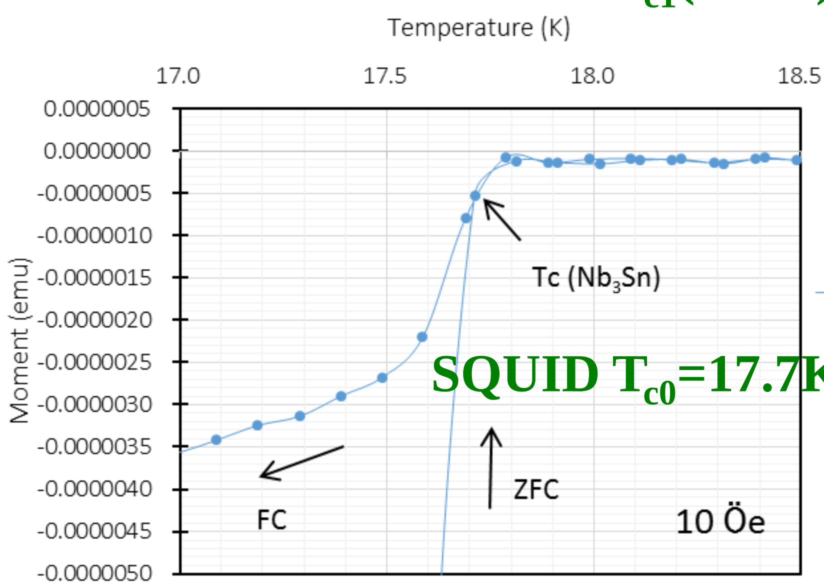
Electro-Chemical Deposition



DC T_{c0}=17.6K (FNAL)

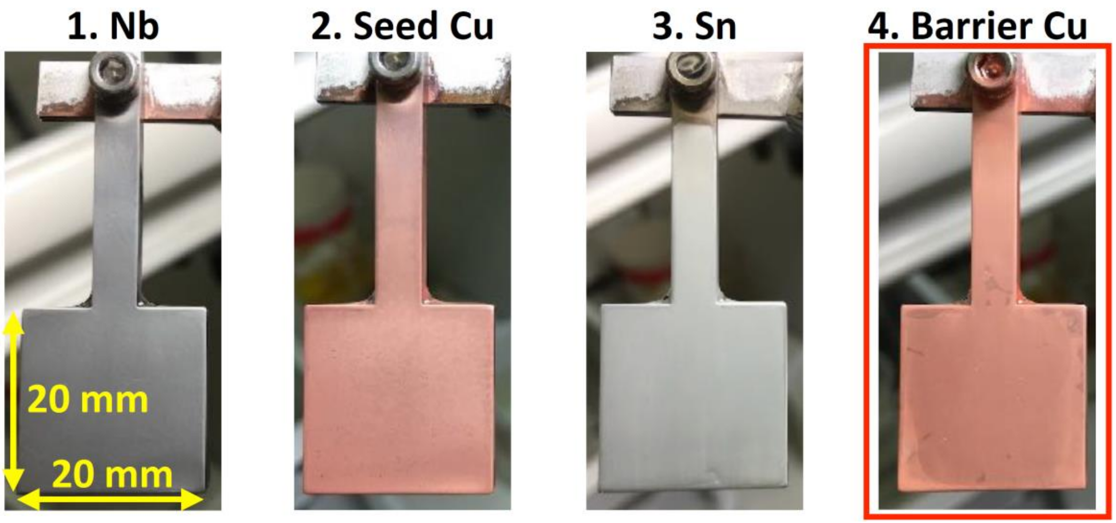


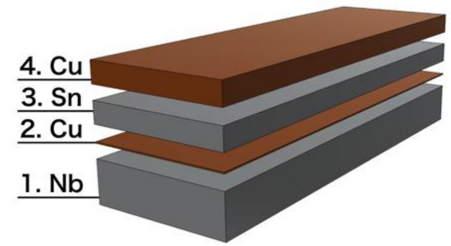
M-H curve obtained with SQUID magnetometer (NIMS).
H_{c1}(4.2 K) = 550 Oe.

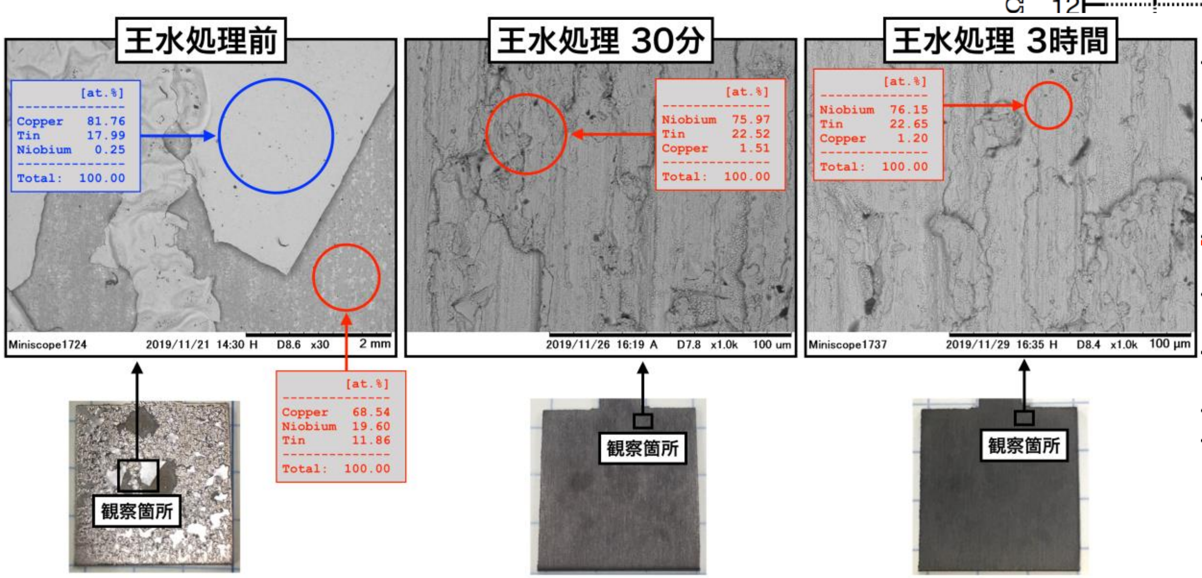


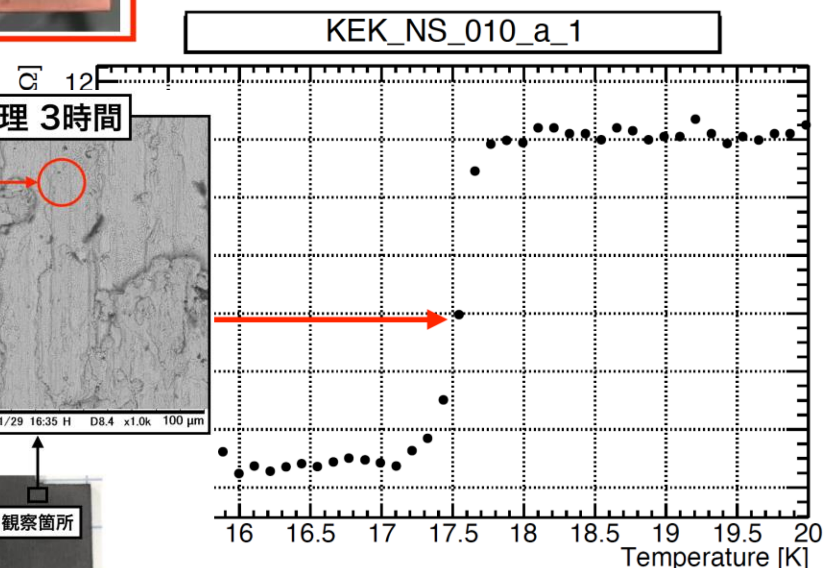
SQUID T_{c0}=17.7K (NIMS)

Electro-Chemical Deposition – KEK Results



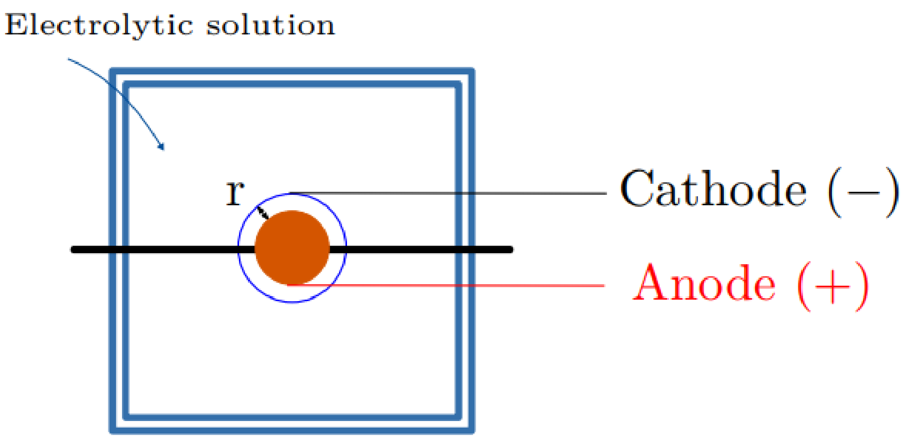






Aqua regia (HCl: HNO3=3: 1) treatment for 30 minutes removed external bronze layer.

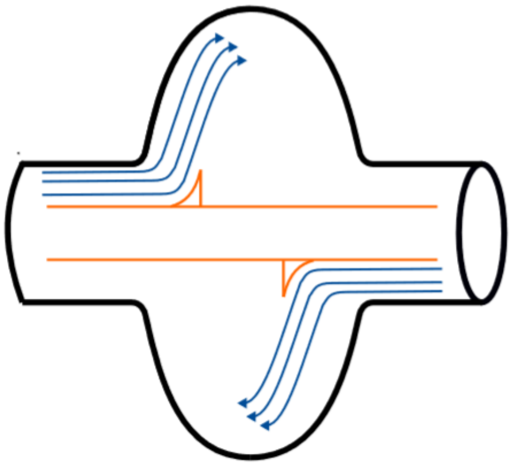
Electro-Chemical Deposition – NEXT STEPS



HOW TO USE THE METHOD ON CU

*** Sputter Nb on Cu cavity**

*** Proceed with the electro-chemical recipe to layer Cu, Sn and Cu**



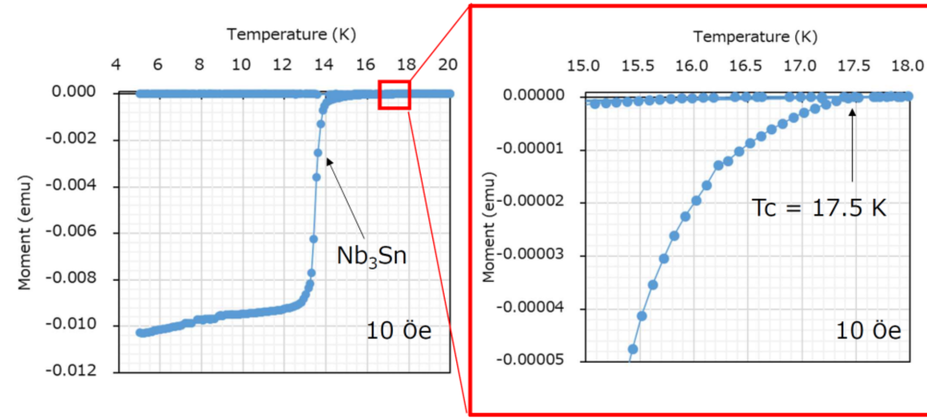
TO INCREASE ACCELERATING GRADIENT

Based on the properties of Nb_3Sn (quenching field, residual resistance, etc.) optimization codes can be run to get the best possible shape based on the desired goals of max gradient and minimum cooling power for a given beam parameters (Sami Tantawi et al.)

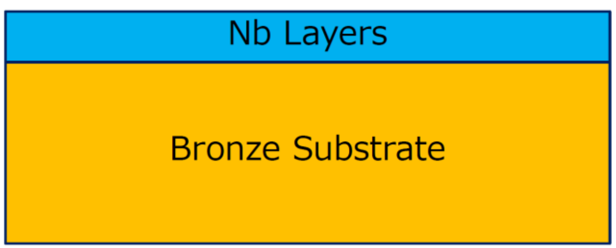
Thick Nb_3Sn Layers via Bronze Route

REPRODUCE PRODUCTION MODEL OF Nb_3Sn WIRES:

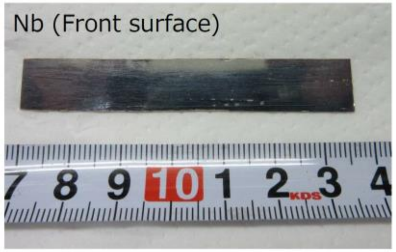
- Billet assembly
- Hot extrusion
- Cold-Die Drawing
- Intermediate annealing
- Heat treatment in inert atmosphere

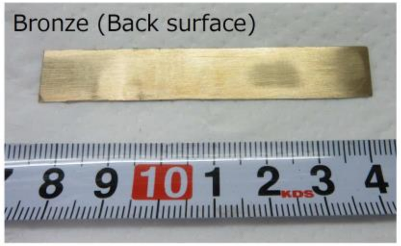


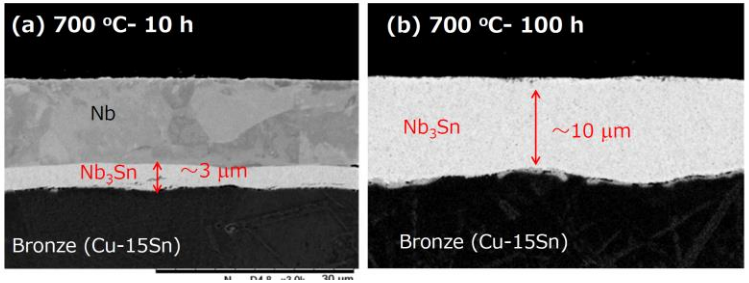
HOT PRESSING + COLD FLAT ROLLING



10 μm



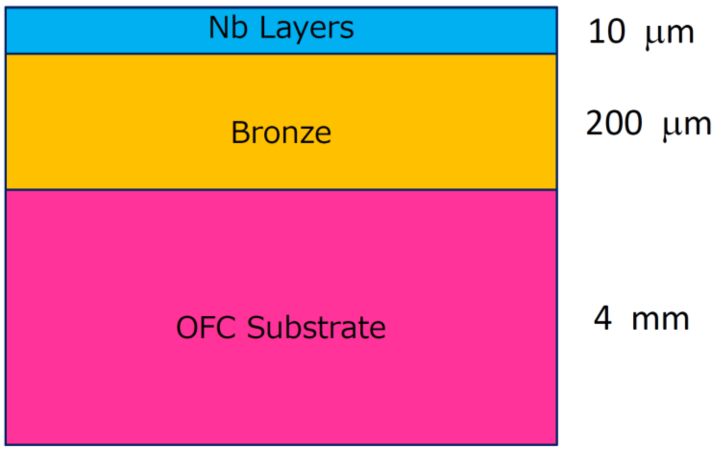




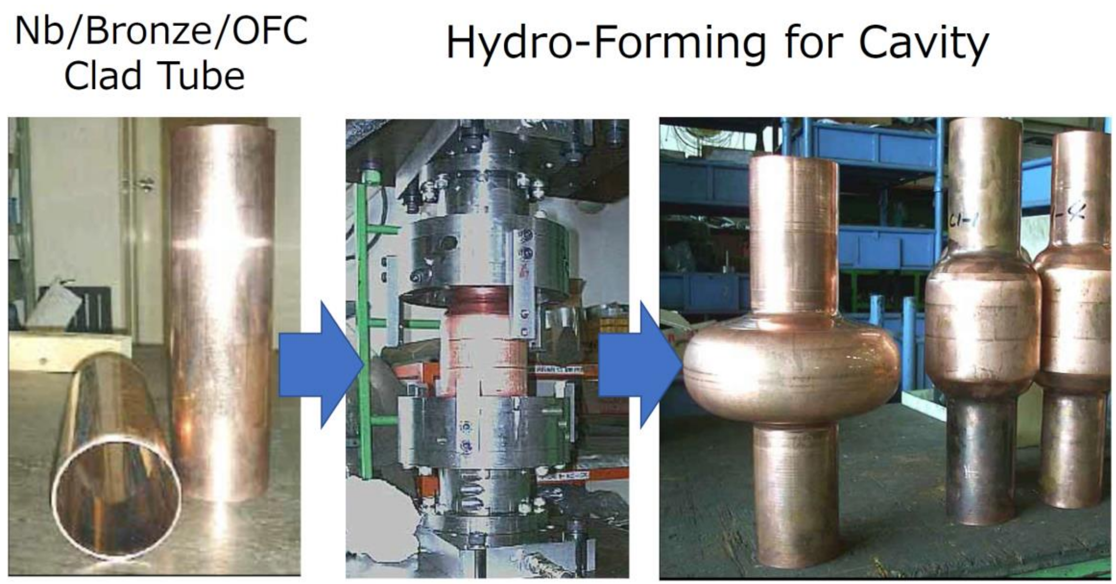
Akihiro Kikuchi, NIMS

Thick Nb_3Sn Layers via Bronze Route

HOT FLAT ROLLING + COLD FLAT ROLLING



Akihiro Kikuchi, NIMS



Conclusion

- https://indico.classe.cornell.edu/event/1806/timetable/#20201112.detailed

Acknowledgments

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