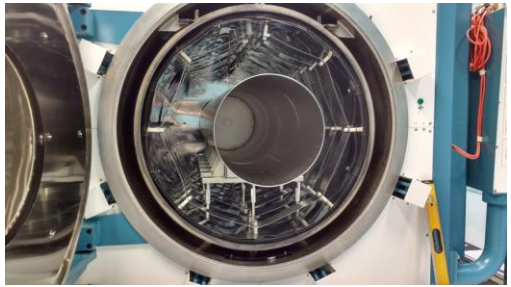
Recent Nb_3Sn Cavity Results from Fermilab

Sam Posen

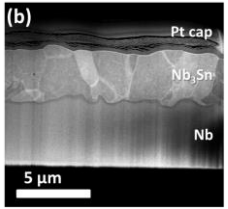
Nb3SnSRF’20

13 November 2020

Fermilab Nb_3Sn Program Overview



- Nb_3Sn coating infrastructure established with support from Fermilab LDRD
  - Large 20” diameter coating chamber capable of coating even 650 MHz multicell cavities
- DOE Early Career Award supports primary Nb_3Sn SRF research program
  - Improve Nb_3Sn SRF performance (this talk)
  - Practical demonstrations towards accelerator applications (this talk)
  - Materials science in collaboration with D. Seidman’s group in Northwestern University (see J. Lee and T. Spina talks)



- In addition to ECA-supported research program, also several exciting smaller collaborations:
  - With Fermilab’s IARC to push towards industrial applications (R. Dhuley’s talk)
  - With Euclid Tech Labs as part of UED focused SBIR (R. Kostin’s talk)
  - With Argonne for NP applications

New Shiny Nb_3Sn Coatings

← Matte cell (typical)

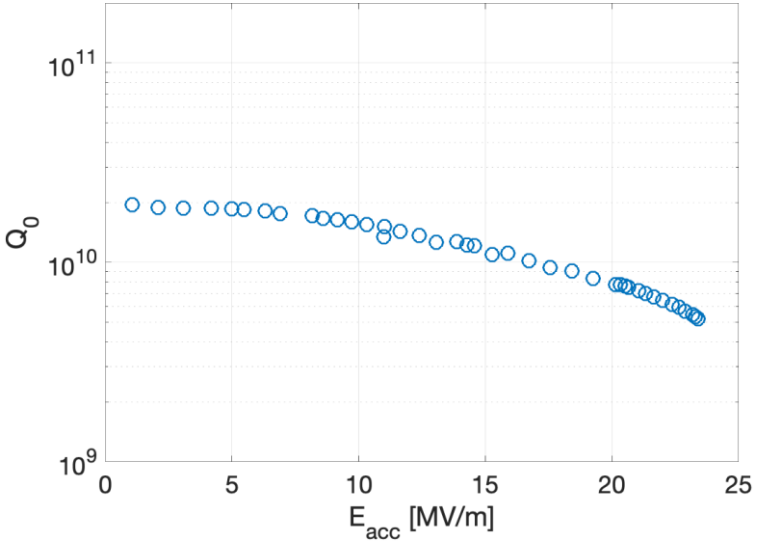
↑ Shiny cell (atypical)

Changes in coating procedures led to shiny cavity appearance

Accepted in SuST, doi: 10.1088/1361-6668/abc7f7

New Shiny Nb_3Sn Coatings

- First shiny cavity (1.3 GHz single cell) reached 24 MV/m with high Q_0 – compare to previous best for Nb_3Sn 18 MV/m
- Promising both for near term applications and progress towards reaching full potential



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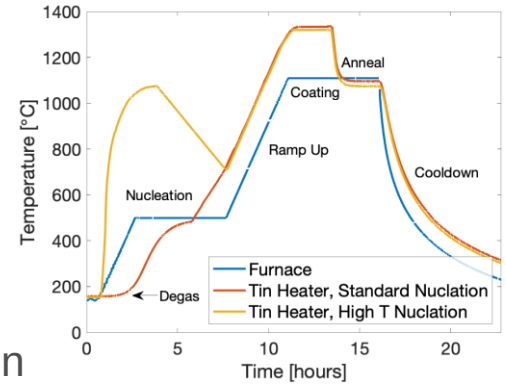
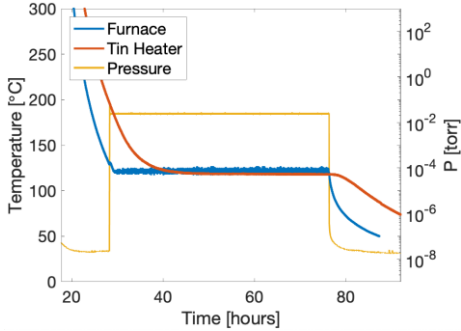
Shiny Coatings

- Common features among shiny coating procedures:
  - The niobium cavity substrates were EP'd prior to coating
  - The niobium substrates were anodized to 30 V in ammonia
  - To encourage high vapor pressure, the Sn heater was driven with maximum power available (~1200C-1250C in Sn crucible based on previous calibration)
  - To encourage high vapor pressure, a relatively large crucible diameter was used
  - To prevent condensation of Sn droplets on the surface due to a high vapor pressure in a closed volume, one or more ports of the cavity were kept open to the chamber (similar to the Cornell setup)
  - The nucleation step was substantially modified, to have a rapid ramp to high temperatures ~1000C – "High temperature nucleation"
  - A nitrogen infusion step was added at the end of the coating process





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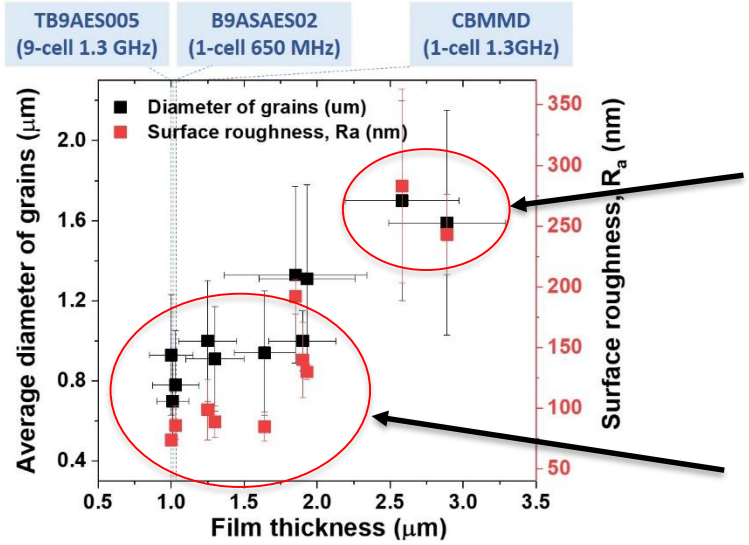
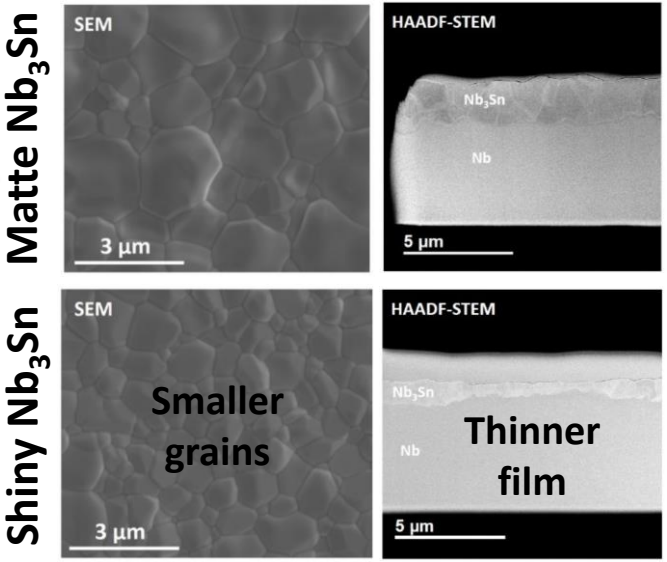
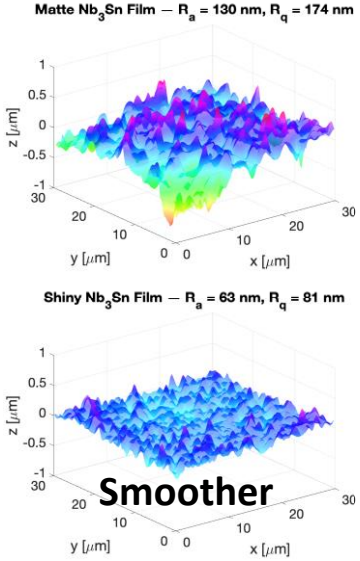
New Shiny Nb_3Sn Coatings

- Microscopy of shiny coatings show low surface roughness, small layer thickness, and small grain size – could explain improved gradient (reduced field enhancement and/or thermal impedance)
- Still working on reproducibility







Microscopy by Jae-Yel Lee (Northwestern University / Fermilab)

Accepted in SuST, doi: 10.1088/1361-6668/abc7f7

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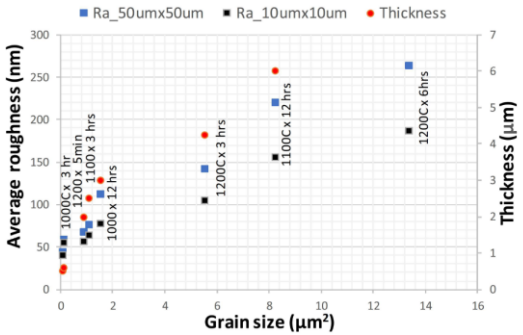
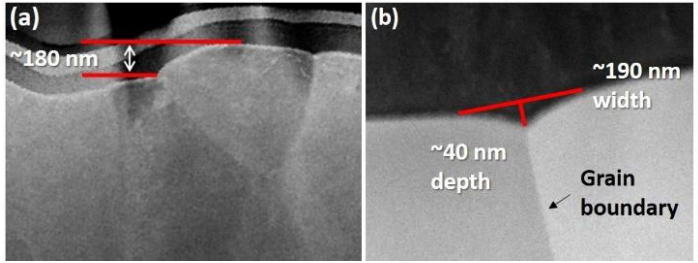
Surface Roughness and Grain Size

- Note that the trend between grain size, thickness, and roughness was previously observed by researchers at JLab
- Consistent with expectations from other systems in which surface roughness derives from high differences between grains
- Smaller grains -> less height difference -> smoother surface



Plot from U. Pudasaini, G. V. Eremeev, C. E. Reece, J. Tuggle, and M. J. Kelley, THPAL130, IPAC2018



Microscopy by Jae-Yel Lee (Northwestern University / Fermilab)

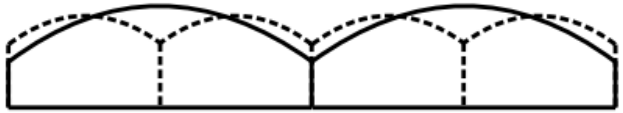
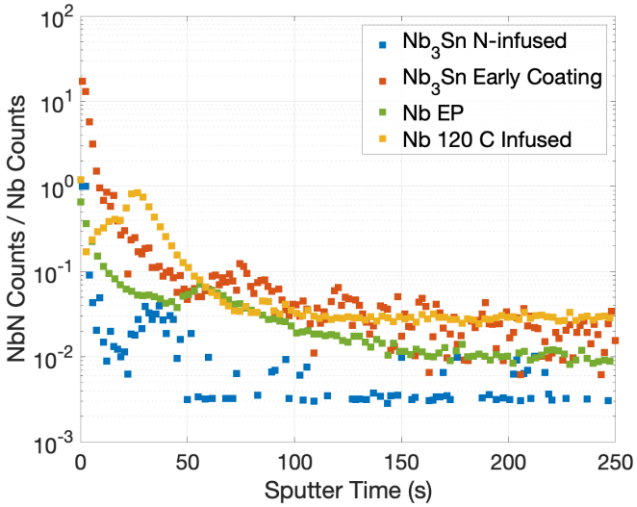


Image from M. J. Rost, D. A. Quist, and J.W. M. Frenken, PRL 91 2 (2003)

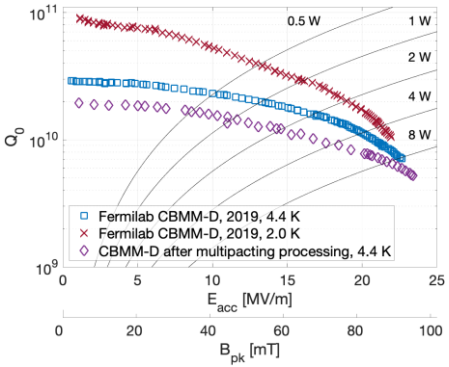
Role of Nitrogen

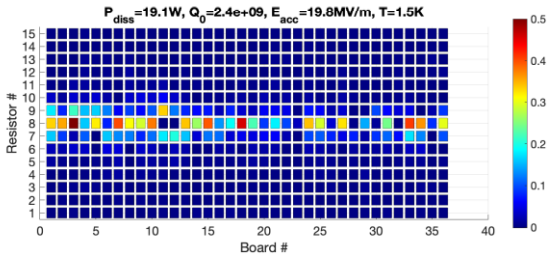
- Nitrogen added in low opportunity cost attempt to try to create “dirty” layer on surface
  - f vs T data fitting and PPMS measurements suggest our coatings are in clean limit for Nb_3Sn
- SIMS data suggest minimal nitrogen absorption if any (probably consistent with DFT presentations earlier this week)
- Nitrogen not expected to be playing a role in performance, but we continued to do it for consistency

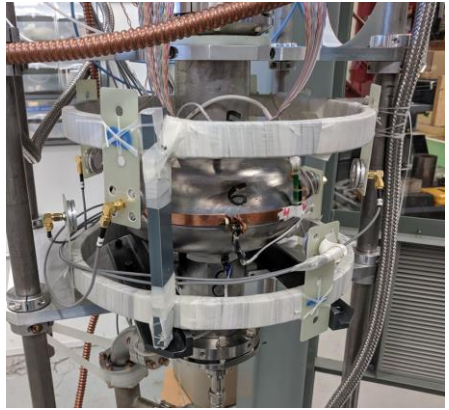


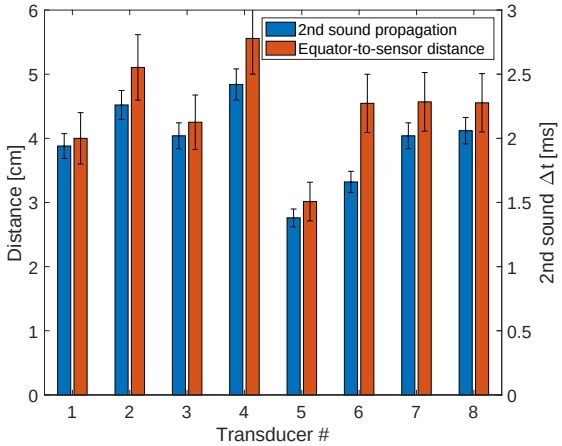
Likely Multipacting Quenches

- Cavity plotted in previous slides showed strange quench behavior
- Line of heating at equator after quench
- 2nd sound transducers show quench behavior all around equator
- Suspected cause is multipacting
- Processing resulted in increased maximum field



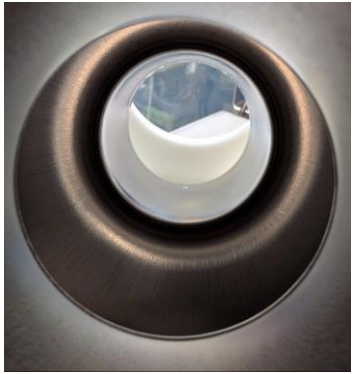


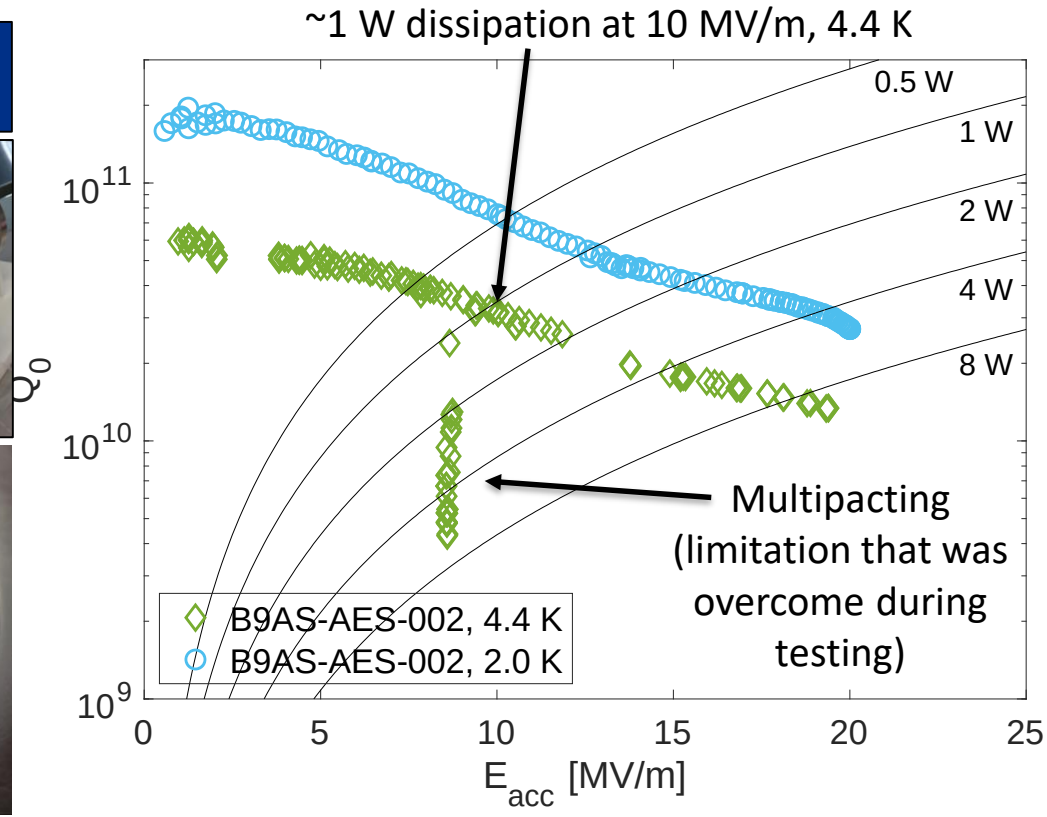




Cryocooler-Based Cooling

650 MHz cavity
B9AS-AES-002





e.g. Cryomech PT420 has cooling capacity of 2.0 W at 4.2 K

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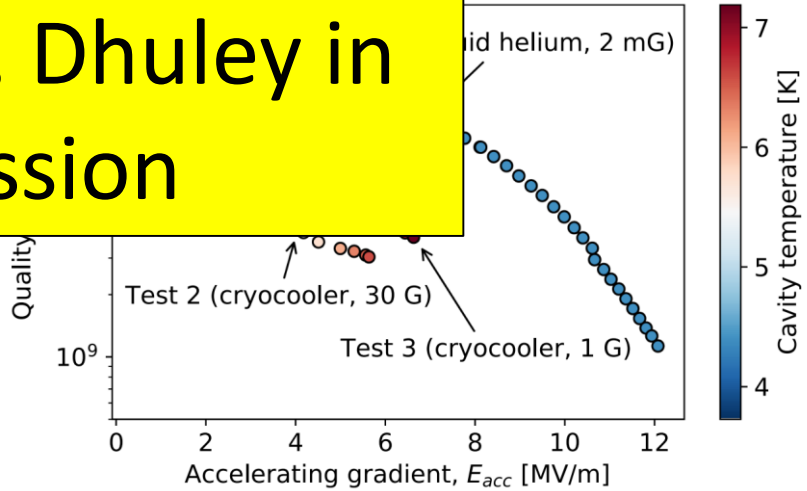
Cryocooler-Based Cooling

- Nb_3Sn-coated 650 MHz single cell cavity reaches gradient >6 MV/m with a single cryocooler
- No liquid helium – conduction cooling only

High purity aluminum cooling links between cavity and cryocooler

Nb_3Sn-coated cavity with welded Nb rings for attaching cooling links

See talk by R. Dhuley in next session



R.C. Dhuley et al, *Supercond. Sci. Technol.* 33 06LT01 (2020)

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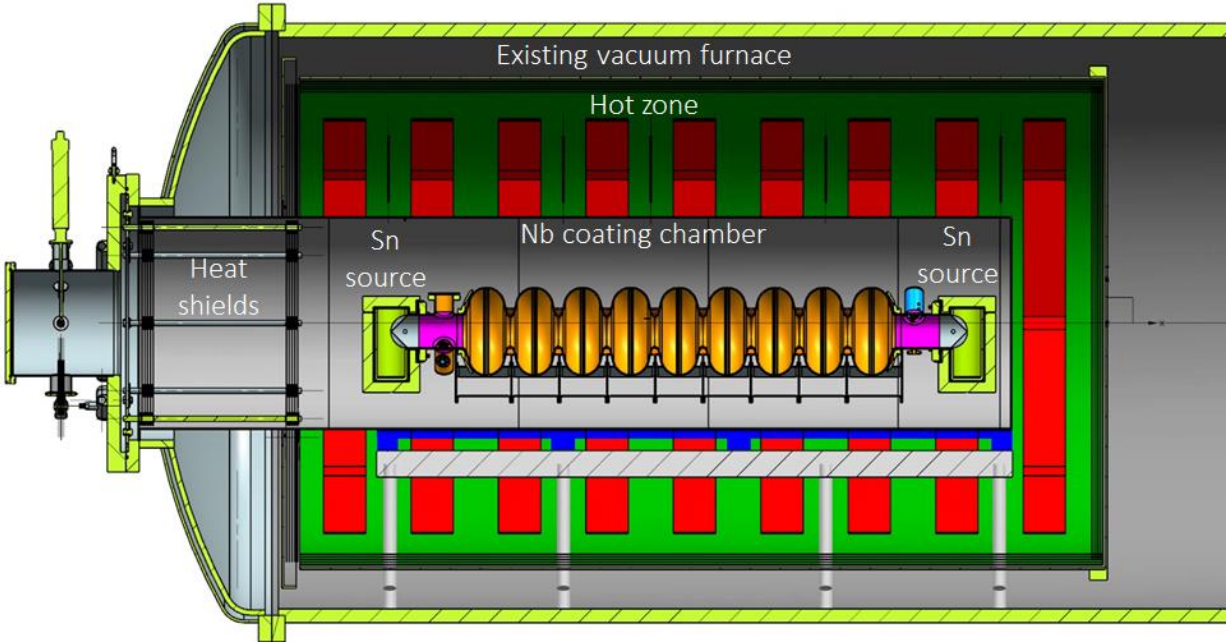
Coating Practical Accelerator Structures

- After our good performance, we decided to try coating 9-cell cavities: cavity type widely applied in accelerators such as European XFEL and LCLS-II

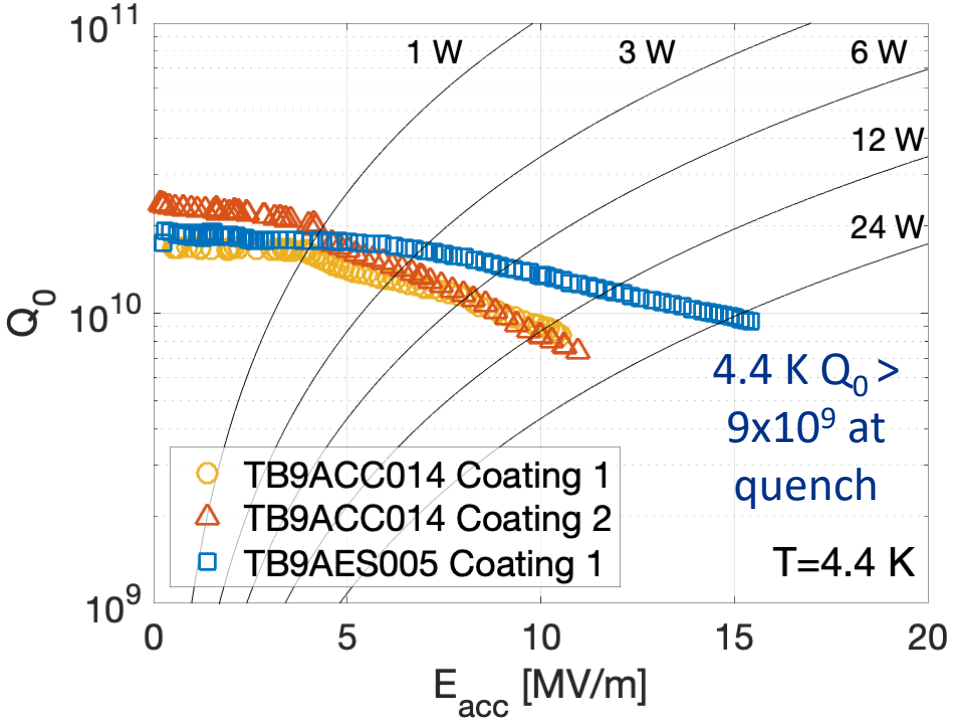


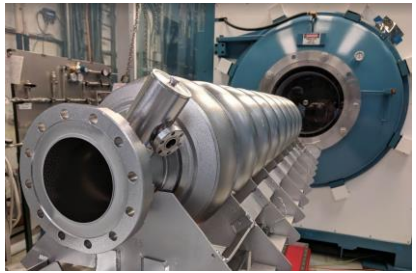
Set-up of a 9-cell ILC cavity in Fermilab coating furnace (two tin sources)

Coating Practical Accelerator Structures

Coating Practical Accelerator Structures

Nb_3Sn-coated 9-cell cavities TB9ACC014 and TB9AES005





Includes correction for stainless steel flanges 2x0.8 nΩ

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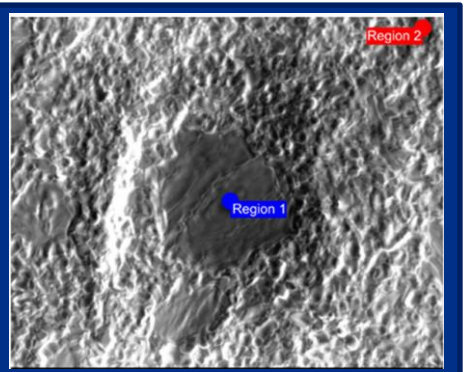
Nb_3Sn SRF R&D – Studying Microstructure & Growth

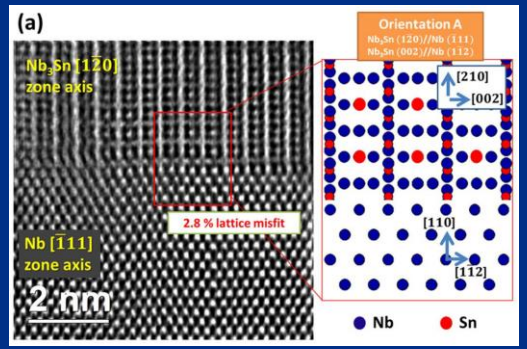
Anomalously Large Thin Grains & Performance Degradation [collab with Cornell U.]

Y. Trenikhina et al. *Supercond. Sci. Tech.* 31 (2018)



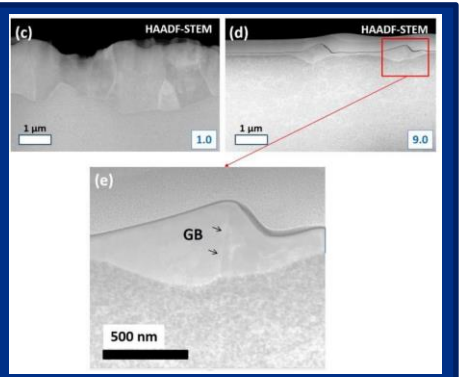
Correlation of Orientation Relationships & Thin Grains

J. Lee et al. *Supercond. Sci. Tech.* 32 (2019)



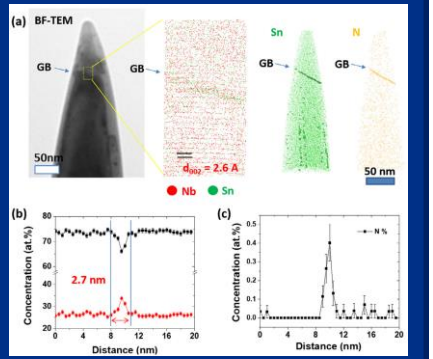
Model for Growth of Anomalously Large Thin Grains, Why High Sn Flux Helps Prevent Their Growth

T. Spina et al. *Supercond. Sci.* [recently accepted] (2020)



Segregation of Sn in GBs Observed in Early Fermilab Coatings, but not in High Performing Cavities

J. Lee et al. *Acta Materialia* 188 (2020)



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Acknowledgements

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- Thanks to the dedicated efforts of the SRF processing team at FNAL and ANL, the FNAL VTS testing team, and the FNAL machine shop and welding experts
- Electron microscopy was carried out at Northwestern University by Jae-Yel Lee under the supervision of David Seidman, using the NUANCE facilities (supported by the NSF, the Keck Foundation, and the State of Illinois)
- Many thanks for useful discussions with many colleagues