Recent $\text{Nb}_3\text{Sn}$ Cavity Results from Fermilab

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Nb3SnSRF’20

13 November 2020
Fermilab Nb$_3$Sn Program Overview

- Nb$_3$Sn 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$_3$Sn SRF research program
  - Improve Nb$_3$Sn 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 $\text{Nb}_3\text{Sn}$ Coatings

Changes in coating procedures led to shiny cavity appearance

$\leftarrow$ Matte cell (typical)

$\uparrow$ Shiny cell (atypical)
New Shiny Nb$_3$Sn Coatings

- First shiny cavity (1.3 GHz single cell) reached 24 MV/m with high $Q_0$ – compare to previous best for Nb$_3$Sn 18 MV/m
- Promising both for near term applications and progress towards reaching full potential
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
New Shiny Nb$_3$Sn 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
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
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 $\text{Nb}_3\text{Sn}$
• 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

~1 W dissipation at 10 MV/m, 4.4 K

Multipacting (limitation that was overcome during testing)

B9AS-AES-002, 4.4 K
B9AS-AES-002, 2.0 K

Multipacting (limitation that was overcome during testing)

e.g. Cryomech PT420 has cooling capacity of 2.0 W at 4.2 K
Cryocooler-Based Cooling

- Nb$_3$Sn-coated 650 MHz single cell cavity reaches gradient >6 MV/m with a single cryocooler
- No liquid helium – conduction cooling only

See talk by R. Dhuley in next session

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

9-cell Cavity TB9ACC014
After Coating
Coating Practical Accelerator Structures

Nb$_3$Sn-coated 9-cell cavities TB9ACC014 and TB9AES005

Includes correction for stainless steel flanges 2x0.8 nΩ
**Nb₃Sn SRF R&D – Studying Microstructure & Growth**

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


### Correlation of Orientation Relationships & Thin Grains


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


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

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

• Sincere thanks to DOE for supporting this research, including through an Early Career Award
• 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