Nb_3Sn multicell cavity coating at Jefferson Lab

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Outline

- Nb_3Sn and tin vapor diffusion technique
- Nb_3Sn Cavity coating at Jefferson Lab
- Results from CEBAF 5-cell cavities coated with Nb_3Sn
- Path forward
- Summary

Nb_3Sn: alternative SRF cavity material

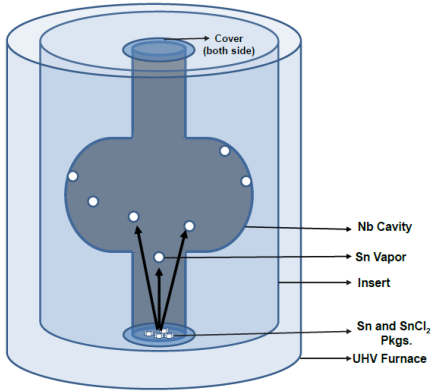
+ Nb cavities are approaching the intrinsic material limit.
+ Higher T_c and H_{sh} of Nb_3Sn promise potential cavity operation at **higher temperatures** and **higher E_{acc}**.
- Extremely brittle material with lower thermal conductivity restricts application into a coating form.

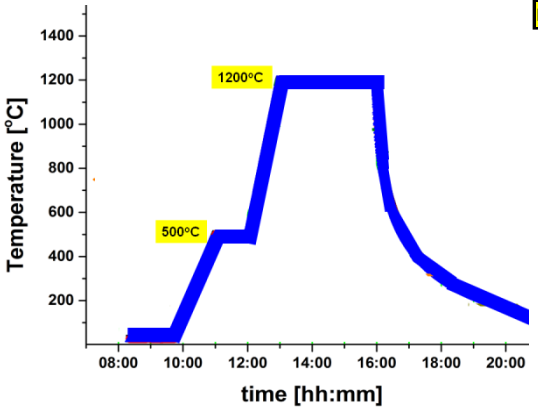
	Nb	Nb_3Sn
T_c (K)	9.25	**18.3**
H_{sh} (mT)	200	**400**
Δ (meV)	1.45	**3.1**
Q^{BCS} at 2K	5.10^{10}	**5.10^{14}**
Q^{BCS} at 4K	5.10^{8}	**5.10^{10}**
E_{acc} (MV/m)	50	**100**

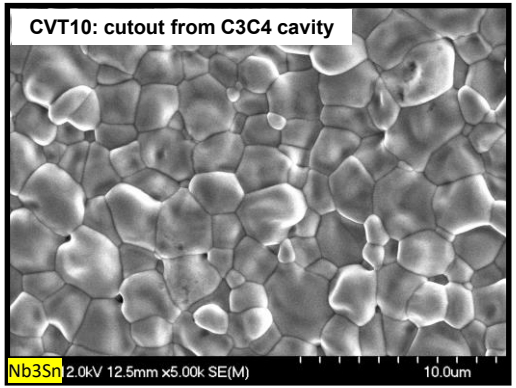
**approximate*

Tin vapor diffusion process for Nb_3Sn coating

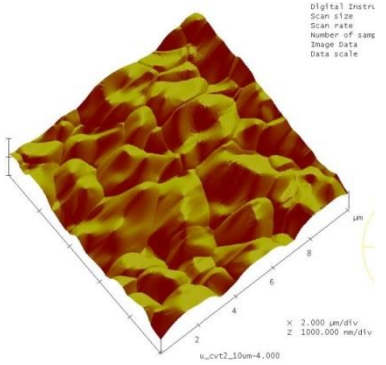
+ Long researched technique.
+ Produces promising RF performance.
+ Simple, yet effective.





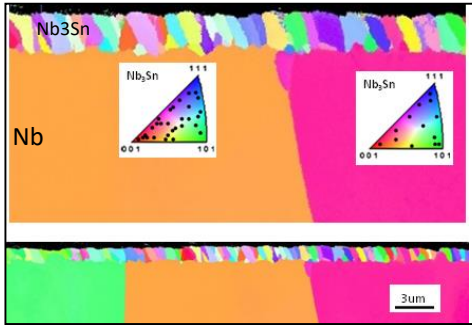


Grain size : 2-3 microns
Composition: 24 -25 at.% Sn.



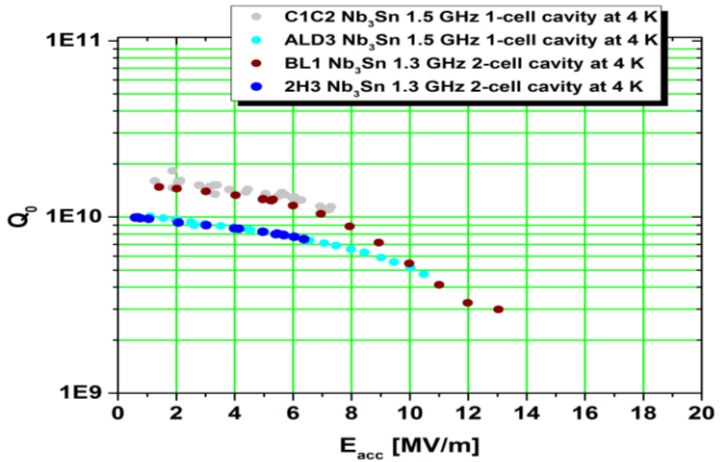
Micro-roughness

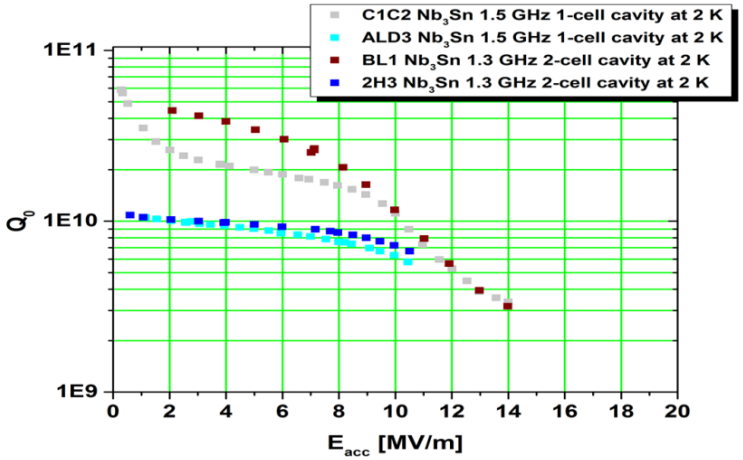
Columnar grains extending all the way to Nb3Sn-Nb interface.
Coating thickness: 2-3 micron



U. Pudasaini et al in proc. *NAPAC'16*

Nb_3Sn Cavity coating at Jefferson Lab



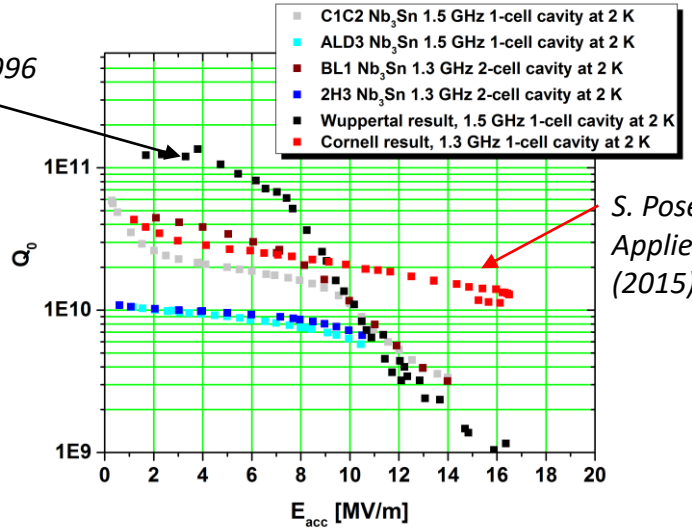


- Starting in 2012, several single cell R&D cavities were coated.
- Encouraging, reproducible results.
- Strong Q-slope present.

G. Eremeev et al in Proc. SRF'15, TUBA05

Nb_3Sn Cavity coating at Jefferson Lab

G. Müller et al., Proceedings of EPAC1996

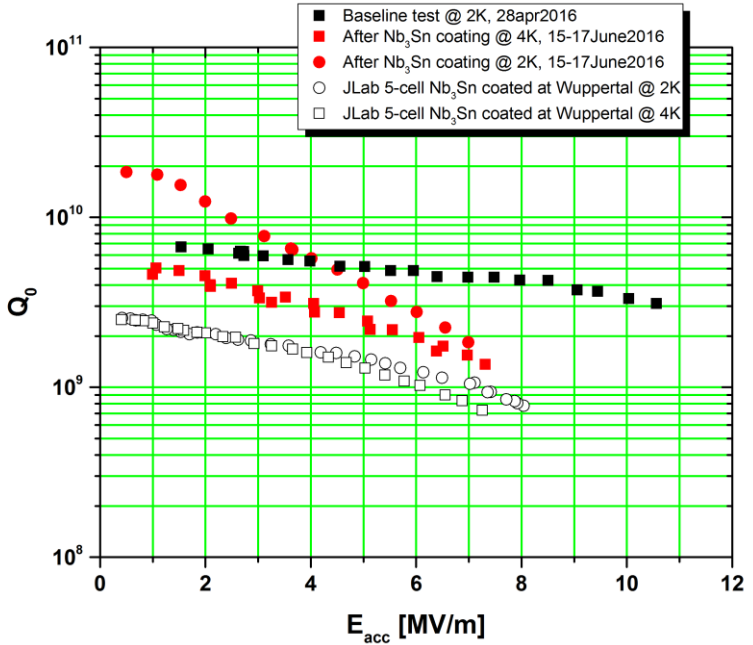


S. Posen, M. Liepe, and D. L. Hall Applied Physics Letters106, no. 8 (2015): 082601

- Starting in 2012, several single cell R&D cavities were coated.
- Encouraging, reproducible results.
- Strong Q-slope present.
- Q-slope is not fundamental.
- Moving toward application: Nb_3Sn multicell cavity?

Nb_3Sn Cavity coating at Jefferson Lab

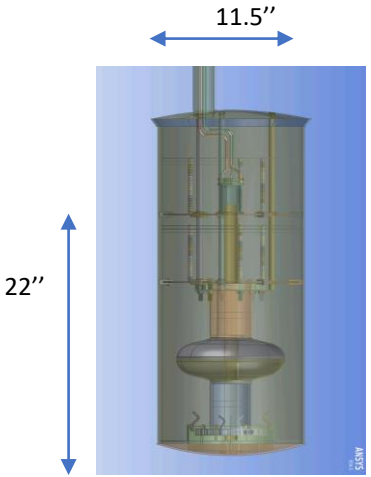
- A 5 cell cavity (with trimmed beam pipe) was coated in the same coating system.



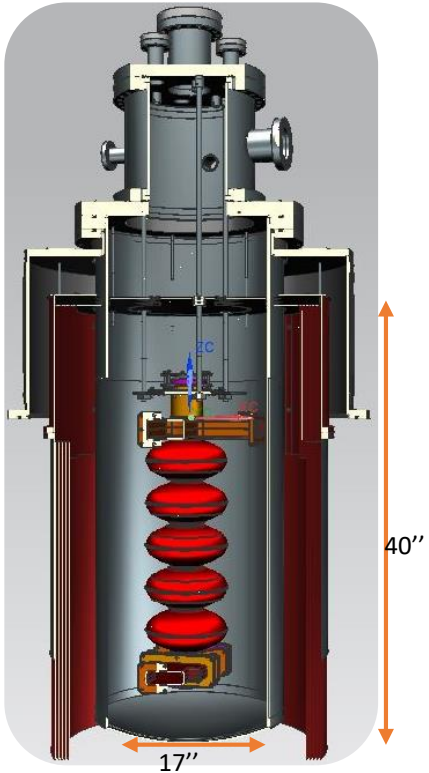
- Pre-existing surface features in the niobium material. Substrate imperfections?

G. Eremeev et al. in proc. LINAC'16

Coating system upgrade



Before upgrade

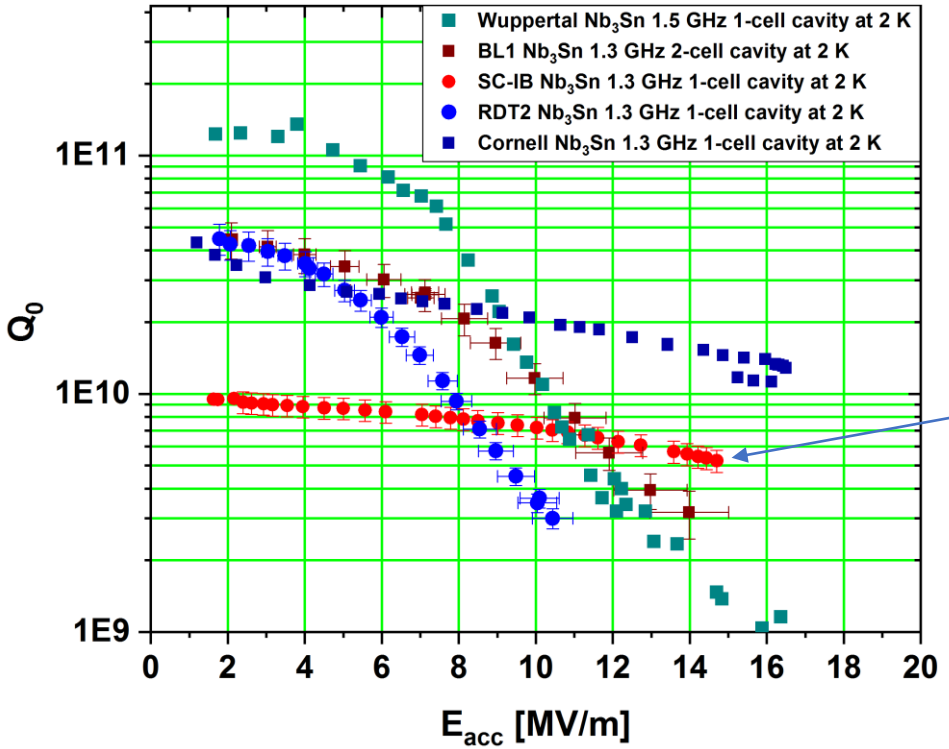


System upgrade design

New coating chamber

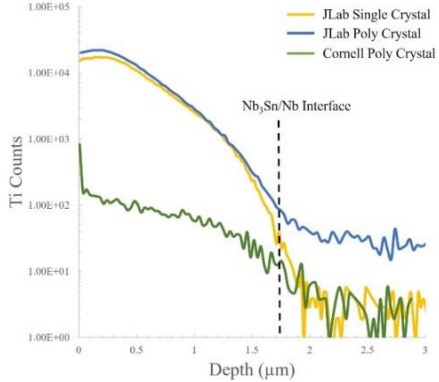
IA320 5-Cell CEBAF cavity

Cavity coating in upgraded coating system



Improved Q-slope after upgrade

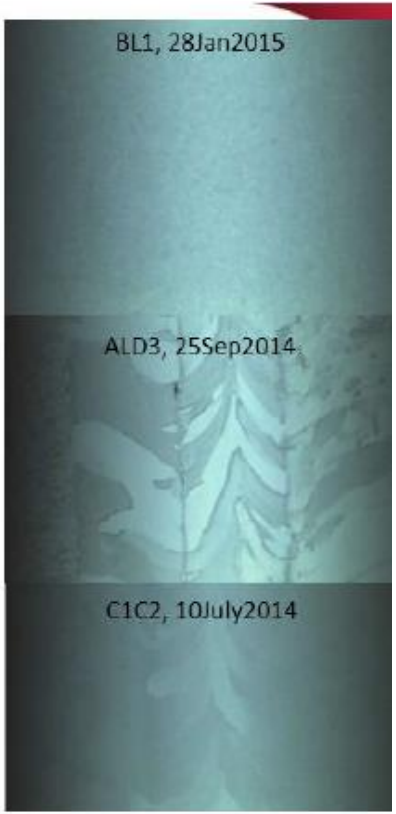
Ti contamination before upgrade

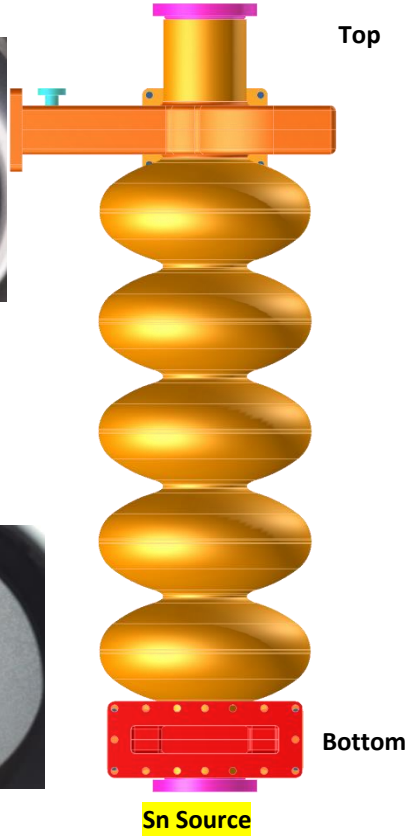


Tuggle, J., et al. "Secondary ion mass spectrometry for SRF cavity materials." *arXiv preprint arXiv:1803.07598* (2018).

- After upgrade, presence of Ti was limited to trace level.
- Process, substrate ??
- Studies are in progress.

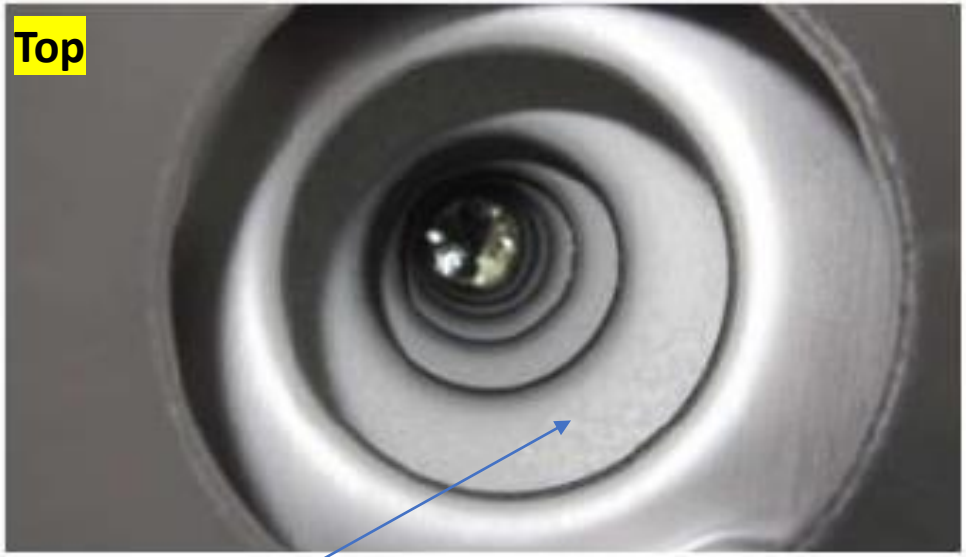
Coating iteration on IA320





- Non-uniform coating with usual recipe.
- Top few cells appeared visually non uniform compared to bottom cells.
- Process dependent not the substrate for IA320.

IA320 coating



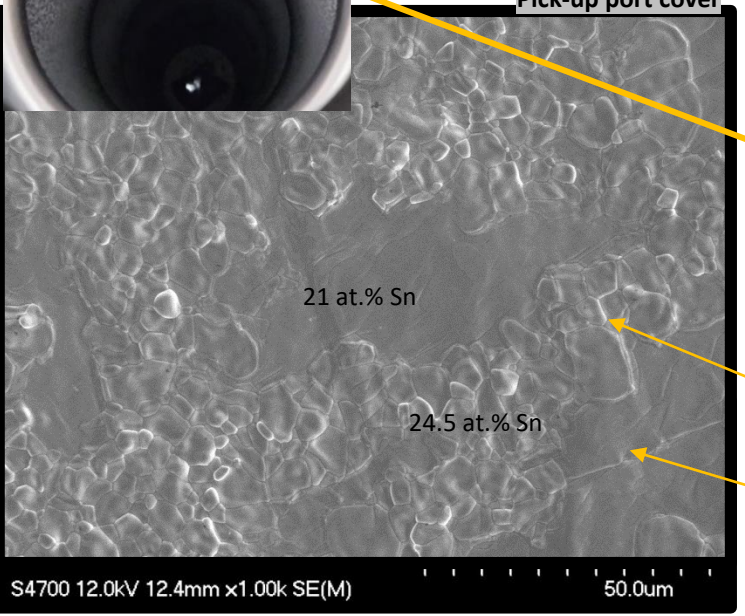
IA114 Coating

Material studies suggests tin deficiency during the coating

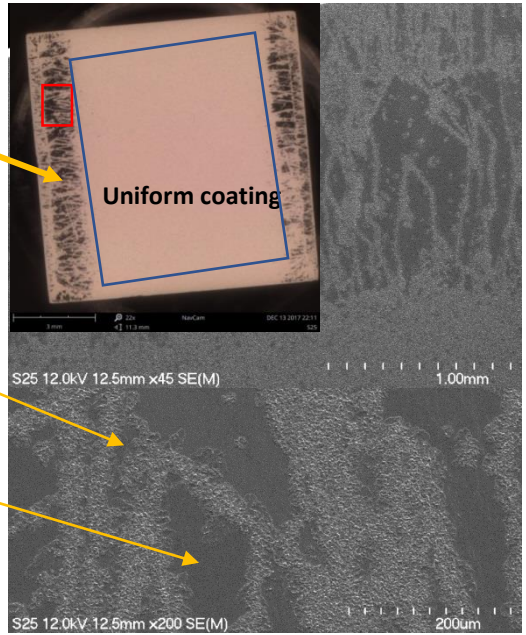
Non uniform

Nb foil from the bottom and pick up port cover from the top were examined as witness samples.

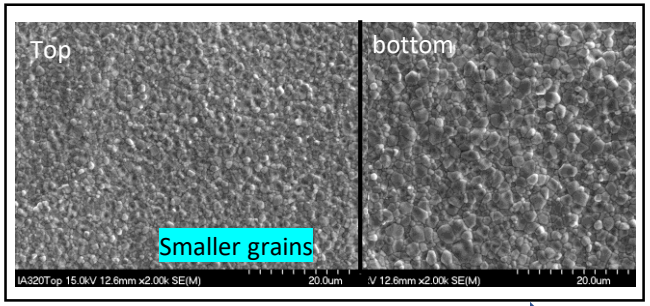
Pick-up port cover



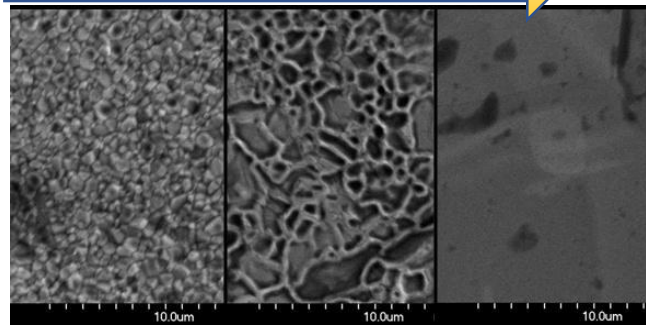
Sitting edge shows similar coating :
Low access to tin



Uniform

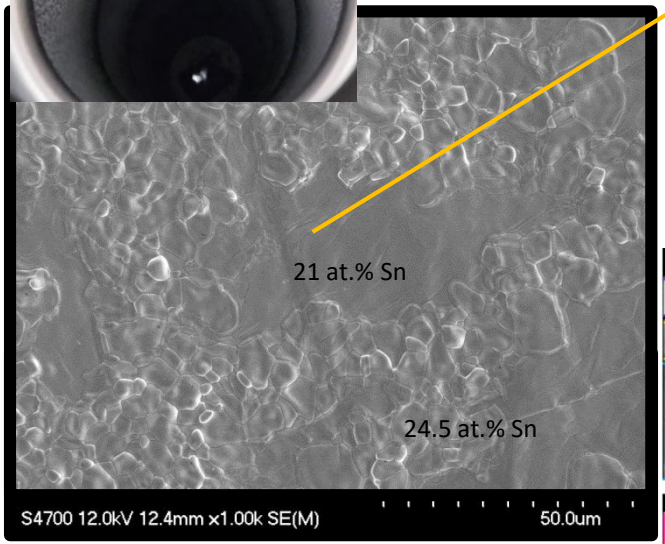


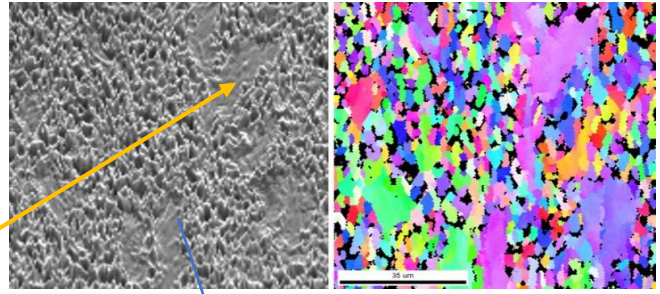
Sn gradient



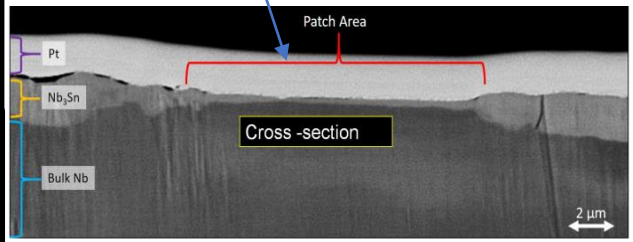
Coating on sitting side of a sample : did not expose fully to Sn vapor.

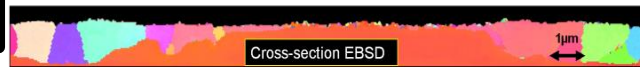
Non uniformity and coating growth



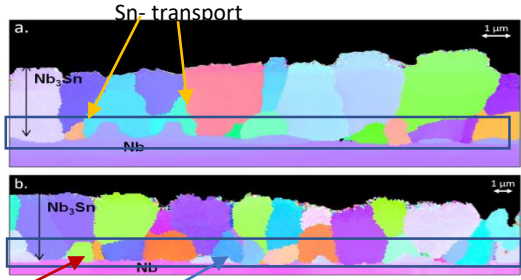


RF penetration depth of Nb_3Sn ~ 100nm.





Nb_3Sn coated samples were subjected to over coat.



New grains

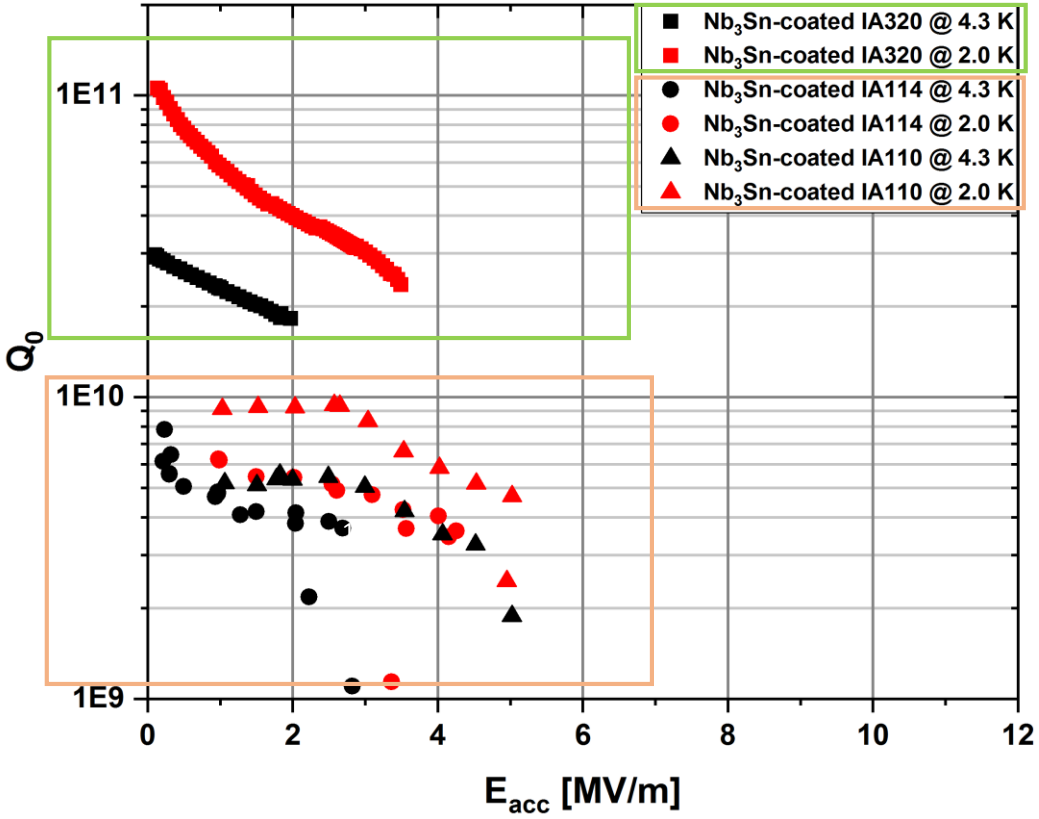
U. Pudasaini et al in proc. SRF'17

- Coating forms at the Nb_3Sn-Nb interface.
- Grain boundary diffusion is the primary mode to transport tin to form Nb_3Sn.

- Application of temperature gradient and procurement of additional Sn supply container is in progress.

More from sample studies: **THPAL130**

Testing results

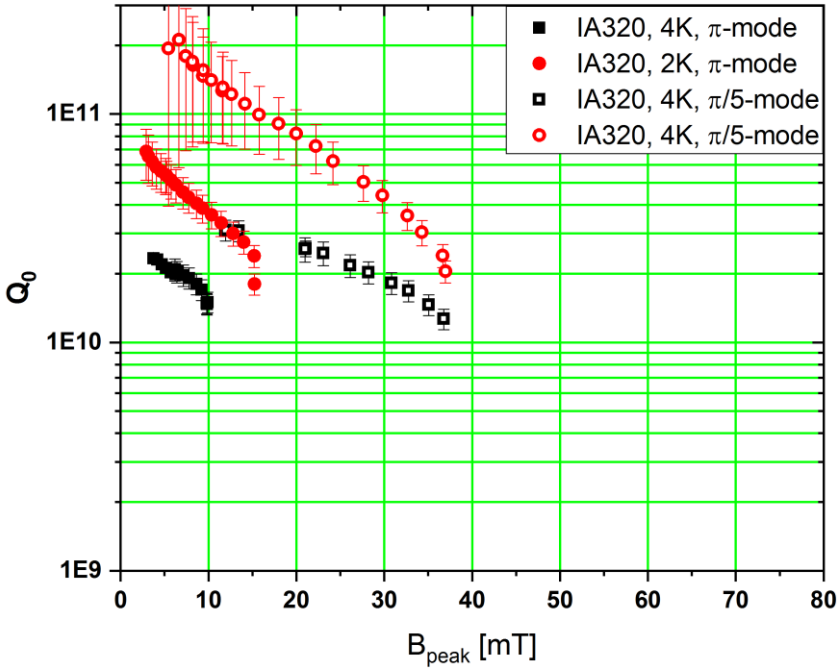


Relatively uniform

Non uniform

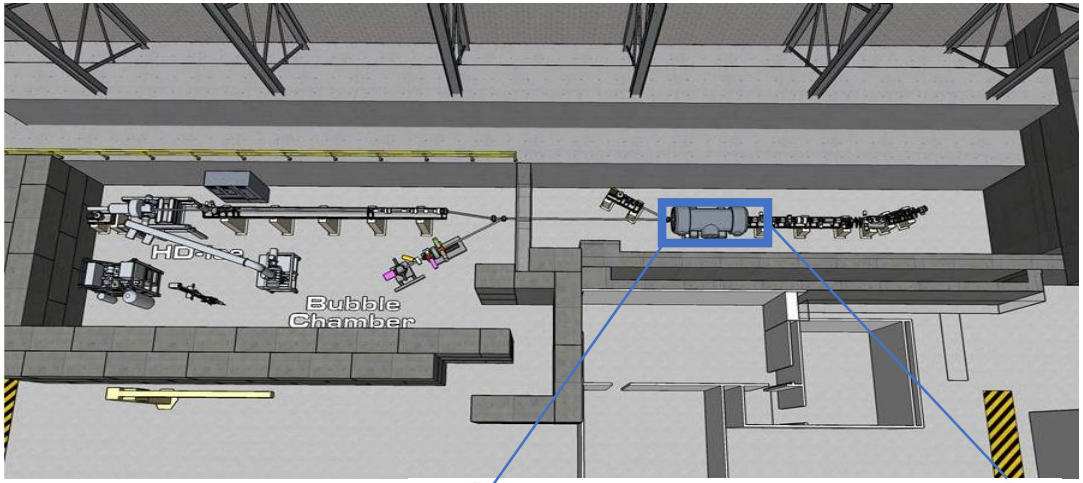
IA320 limitations

- Quality factor was measured close to $2 \cdot 10^{10}$ at 4 K and close to $1 \cdot 10^{11}$ at 2 K at low fields.
- Both higher quality factors and higher magnetic fields were measured in $\pi/5$-mode
- The cavity limitations in π-mode was likely due to coating non-uniformity in the end cell.

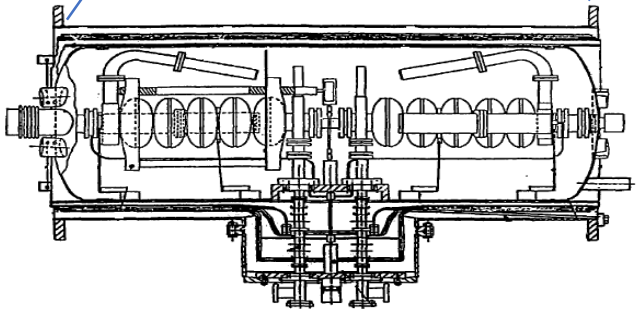


Path forward

- Additional measures are in progress to establish the uniformity of coating.
- Several 5-cell CEBAF cavities will be coated with Nb_3Sn.
- Plan includes a Nb_3Sn quarter cryo-module, to be tested at CEBAF UITF, but cavity gradients need to be improved.



JLab Upgraded Injector Test Facility (UITF). The quarter-cryomodule is seen in the center of the picture and will be used to accelerate electron beams up to 10 MeV.



Summary

- Several 1-cell and CEBAF 5-cell cavities were coated and tested in the upgraded Nb_3Sn deposition system.
- Single-cell measurements indicated possibility of reaching $E_{acc} \cong 15$ MV/m without "Wuppertal" Q-slope in the upgraded system.
- Early results with CEBAF 5-cell cavities coated at Jefferson lab shows promising quality factors, $3 \cdot 10^{10}$ at 4.2 K and $> 1 \cdot 10^{11}$ at 2 K, but suffered a steep Q-slope.
- CEBAF 5-cell coating uniformity is suffering from tin deficiency
- Further work is in progress to improve the coating non-uniformity and to achieve accelerating gradients useful for cryomodule use.

Acknowledgements

- Jefferson Lab technical staff.
- G. Ciovati , I. Parajuli, Larry Phillips, Tony Reilly, Bob Rimmer, Md. N. Sayeed, J. Tuggle, Anne-Marie Valente-Feliciano.
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Thank you for your attention !