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Nanostructure of the penetration depth in Nb cavities: debunking the myths and new findings

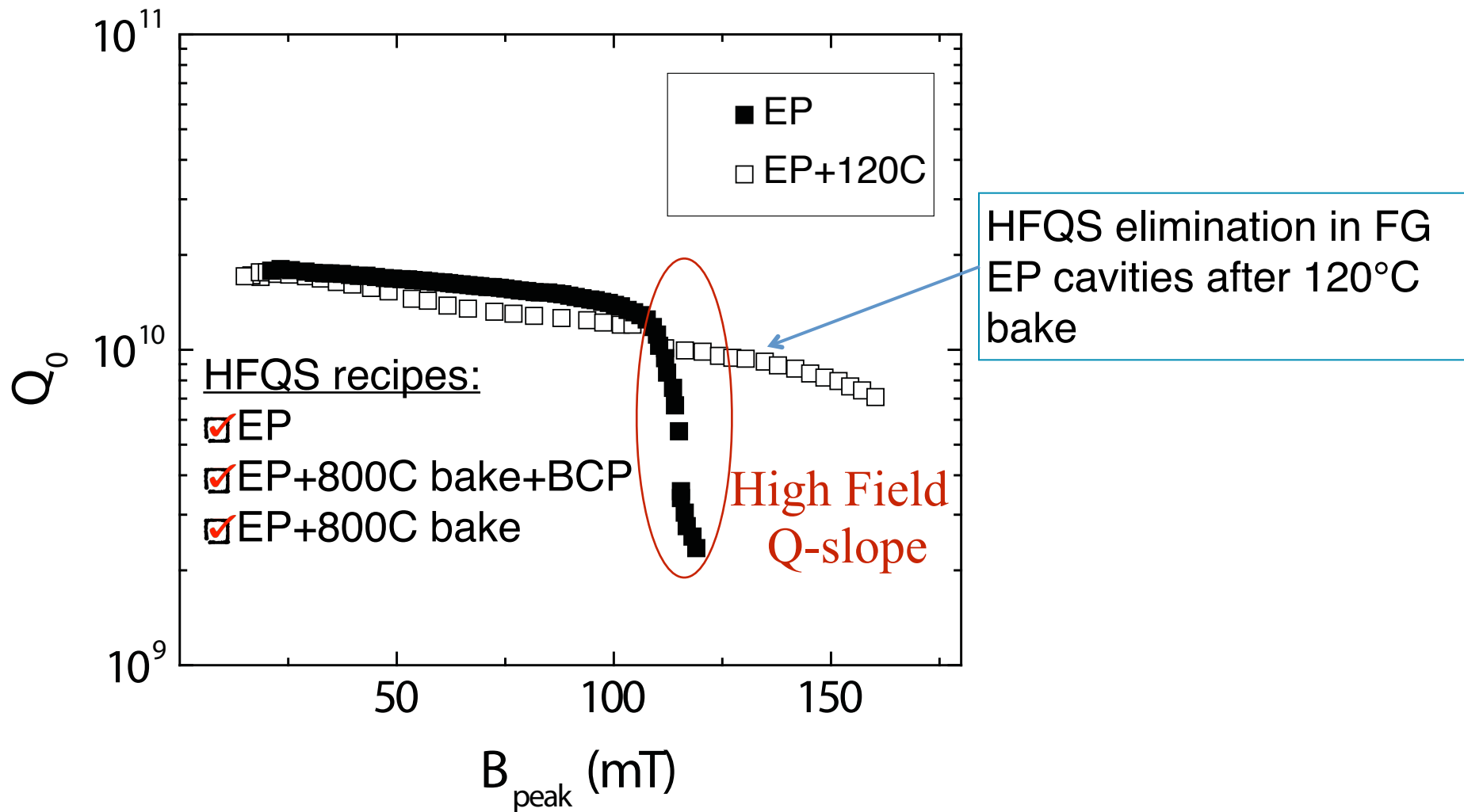
Yulia Trenikhina

SRF 2015

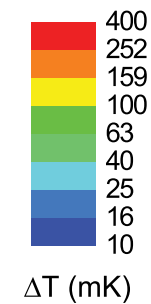
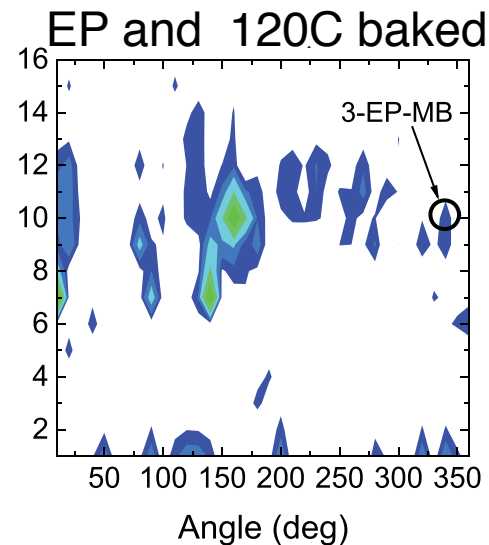
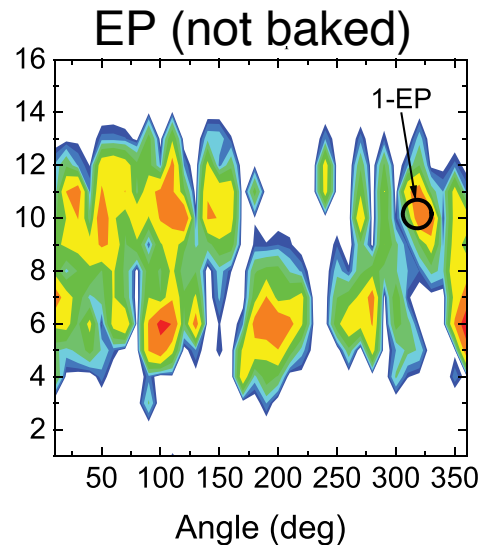
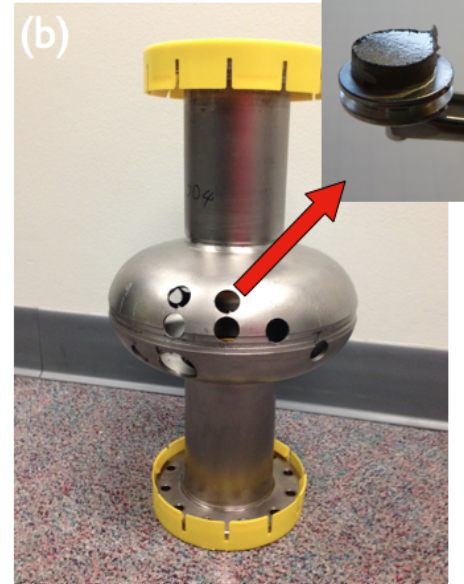
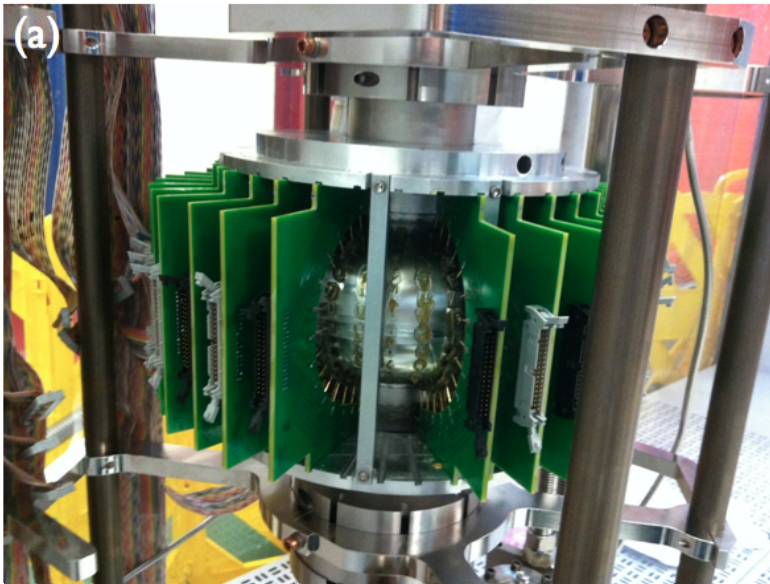
Whistler, Canada

09/16/2015

HFQS-producing treatments



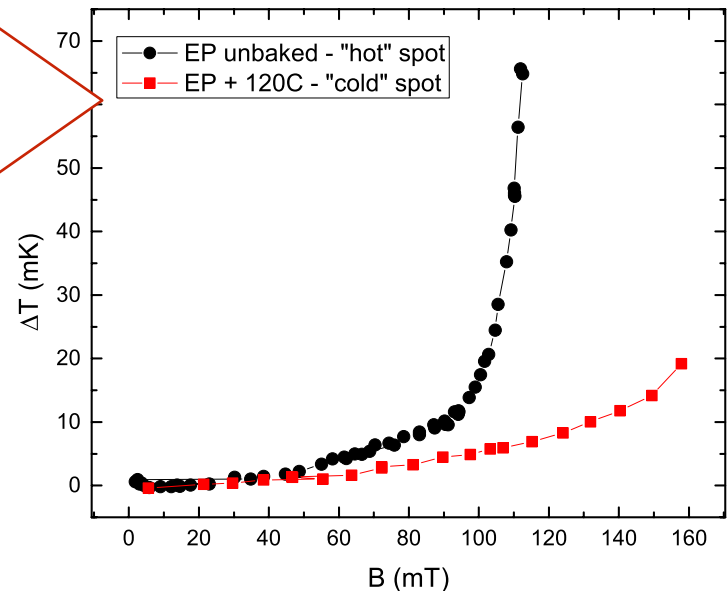
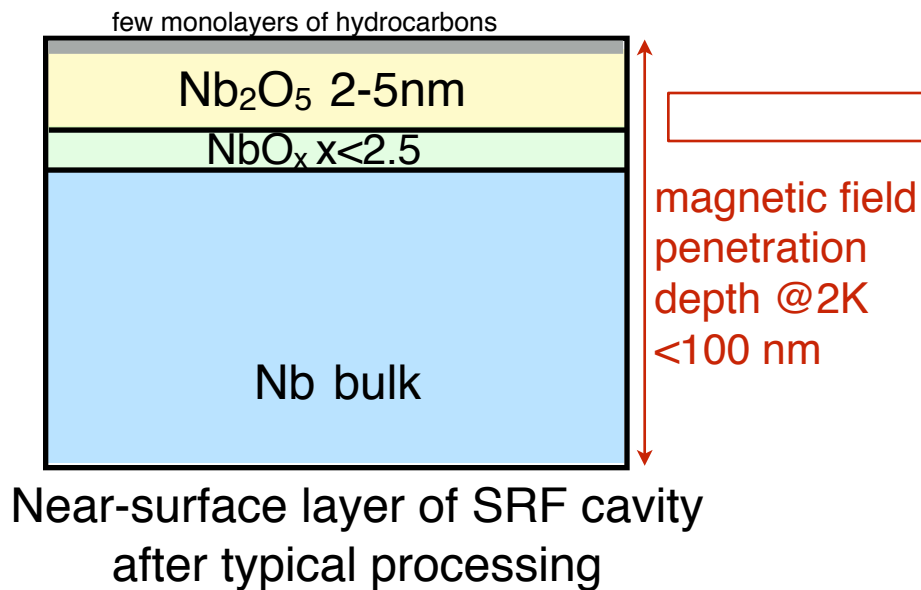
Cavity diagnostics: EP vs. EP+120C baked



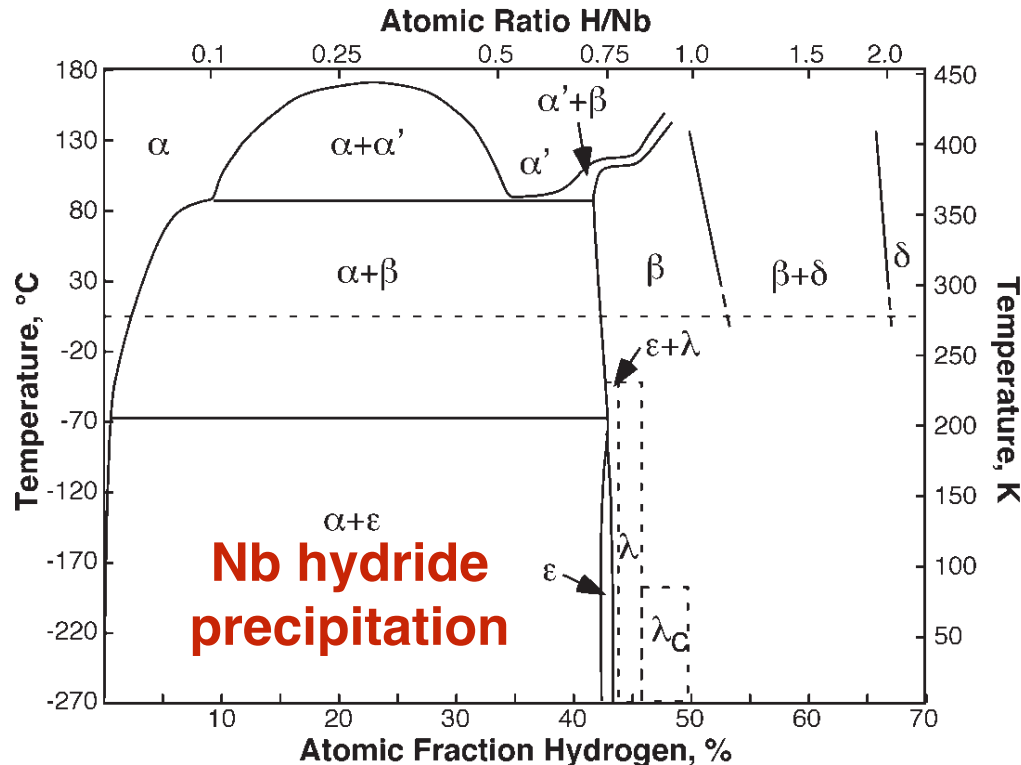
T-maps @ 28 MV/m

EP vs. EP+120C baked: what is causing HFQS?

What in the near-surface is causing different dissipation character?



Hypothesis for the HFQS problem: what is the difference?



Why to look at Nb-H system?

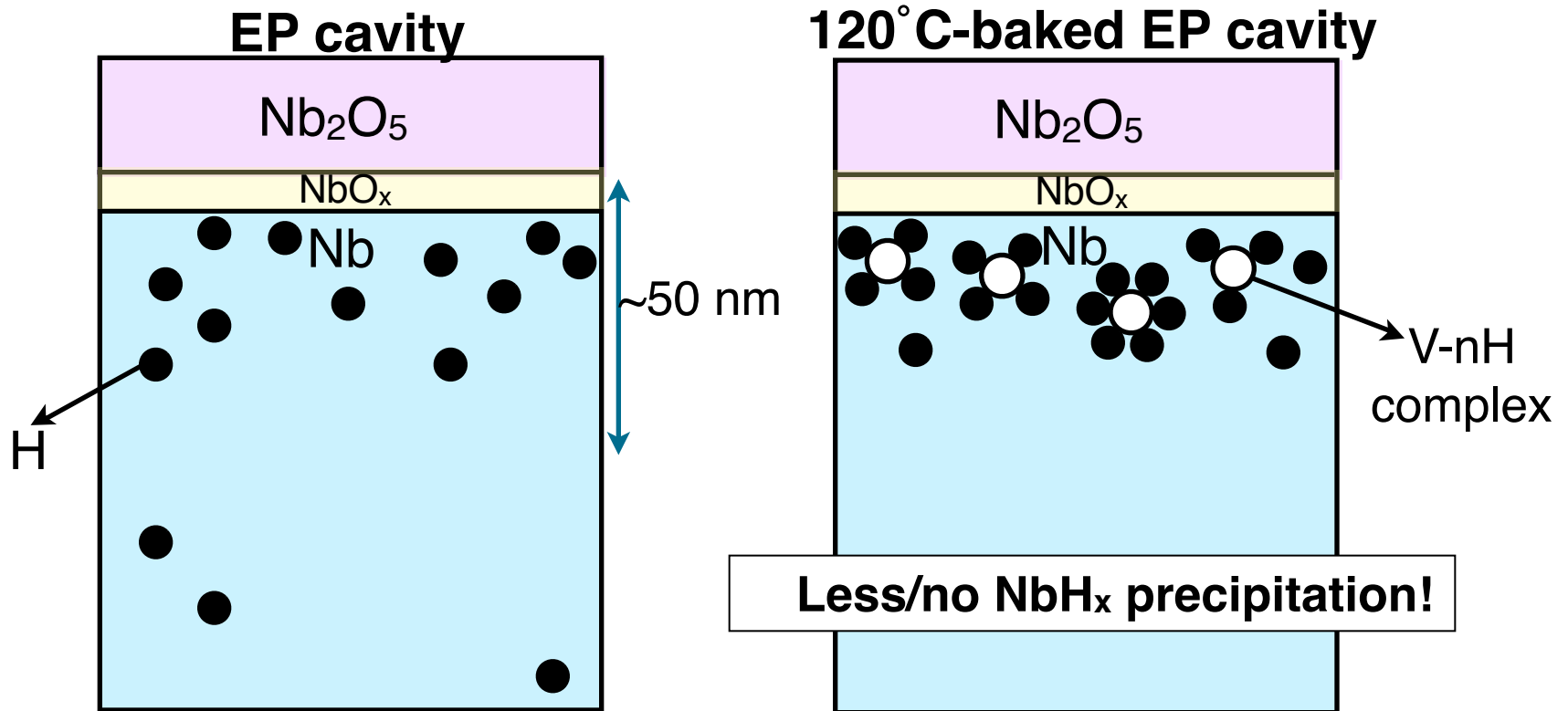
1. H concentration in near-surface of cutouts > 10 at.%
2. ϵ , β are NOT superconducting

Difference in precipitation state of Nb-H in the near-surface?

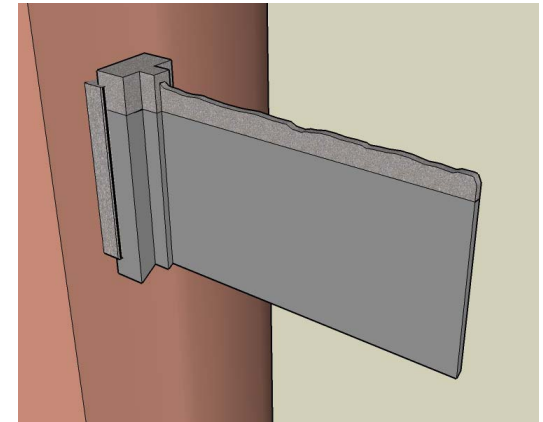
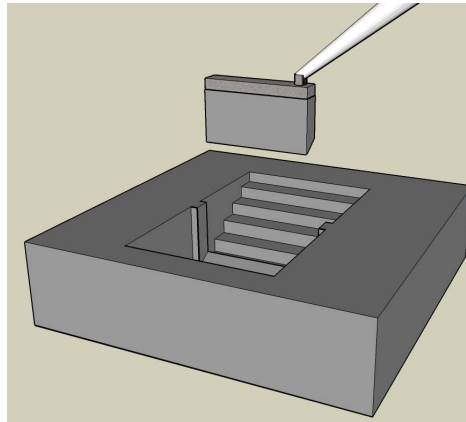
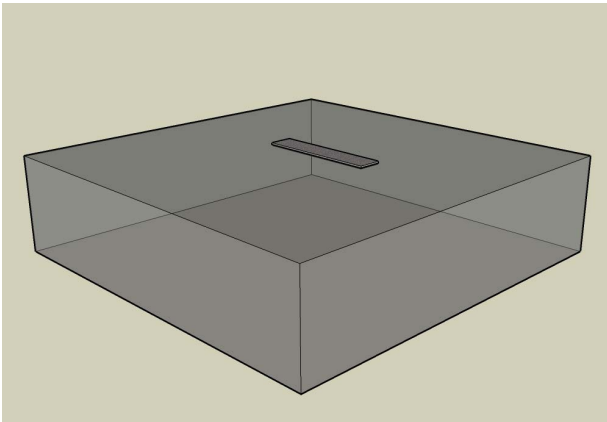
Tool: temperature-dependent TEM electron diffraction phase characterization

Hypothesis: Nb hydrides and HFQS

- Normal conducting Nb hydrides are SC by proximity effect up to $H_{\text{critical}} = \text{HFQS}$ onset (A. Romanenko et.al., Supercond. Sci. Technol. 26, 035003 (2013));
- Major role of vacancies and vacancy-hydrogen complexes in the 120C baking effect (A. Romanenko et.al., Appl. Phys. Lett. 10, 232601 (2013)).

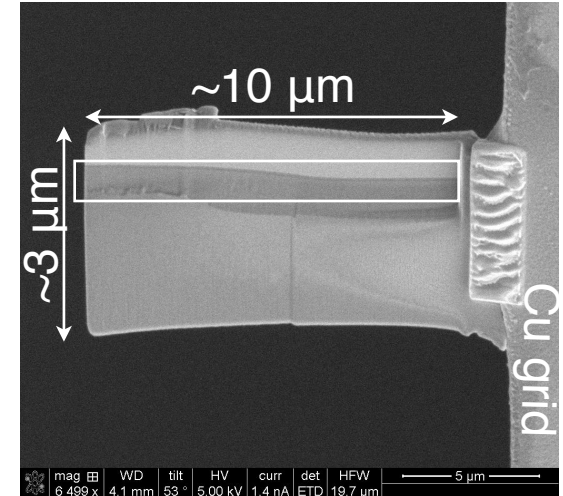
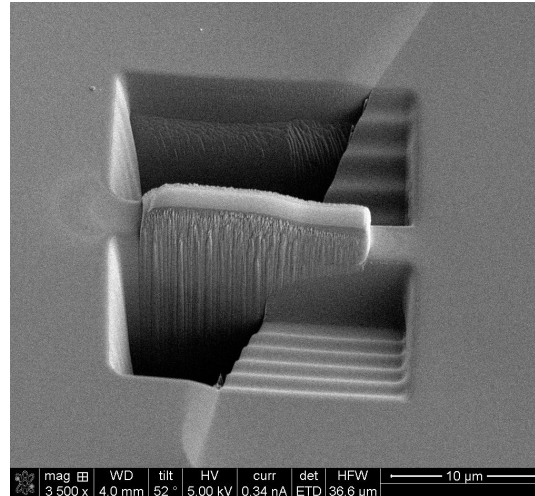
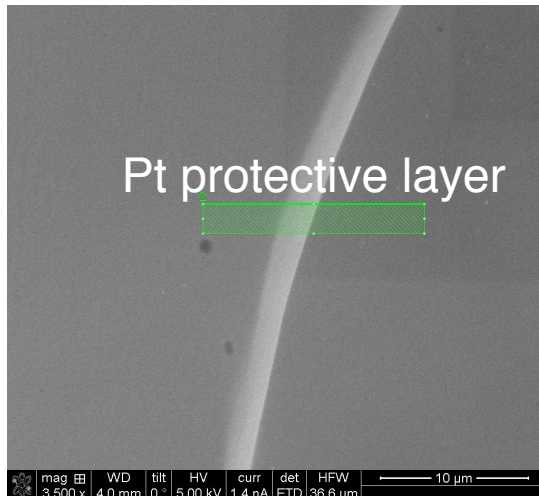


TEM sample preparation: focused ion beam



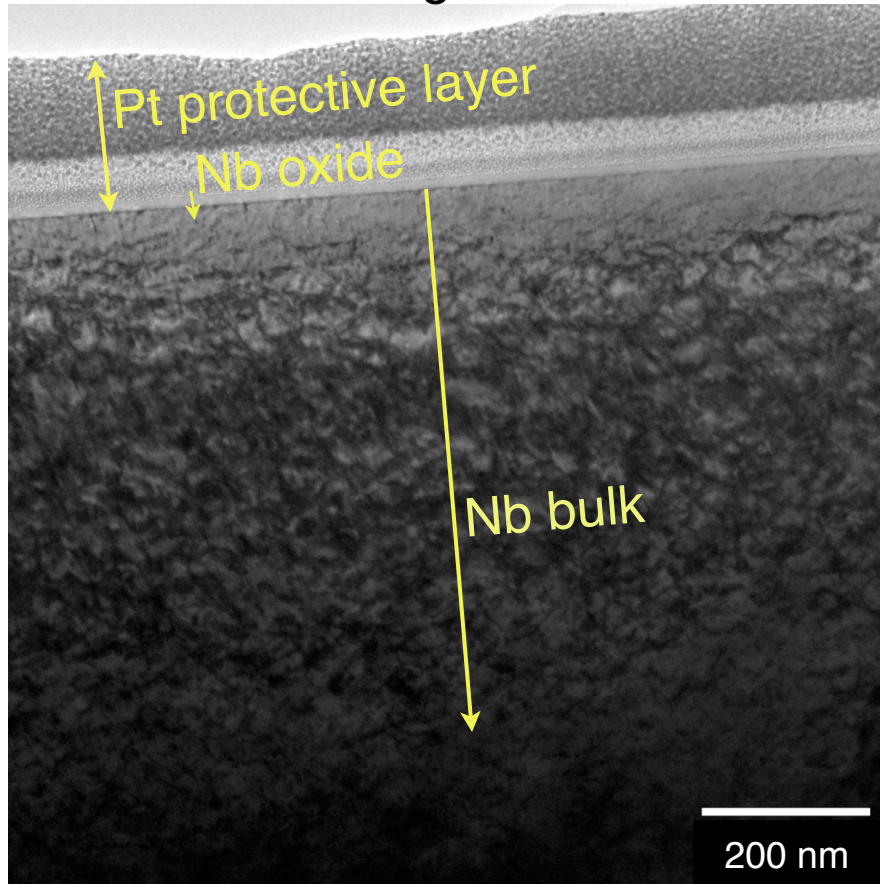
Courtesy of B. Meyer

SEM images during the FIB sample preparation

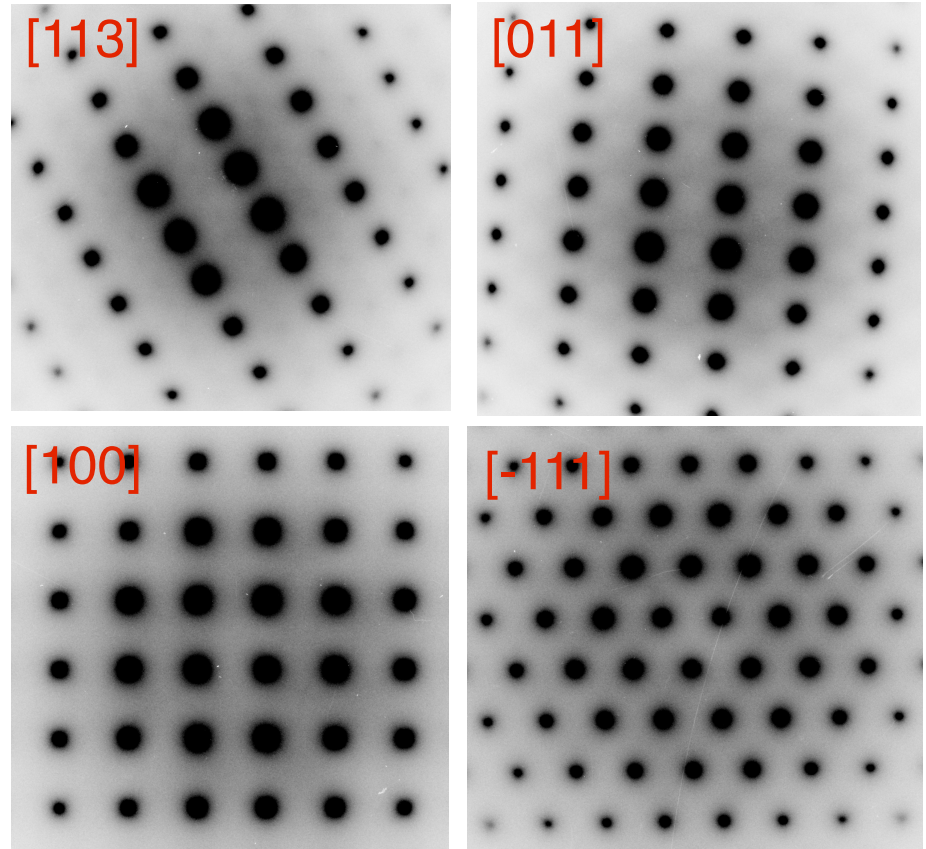


Nb near-surface at room T

TEM: low mag overview



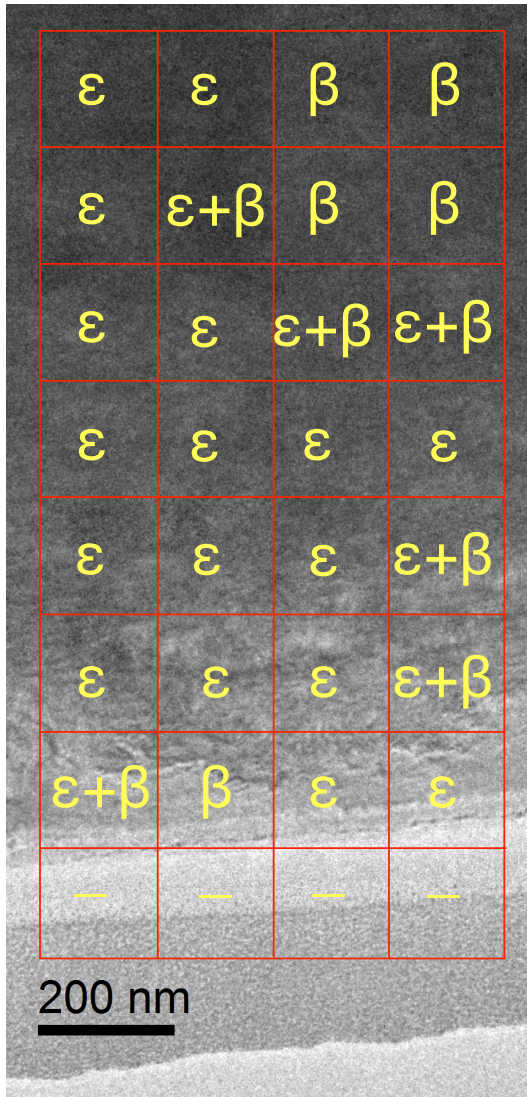
EP and EP+120C baked at room T



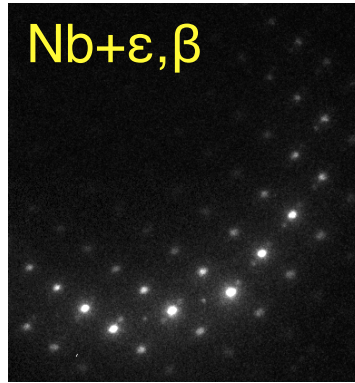
SAD, NED, SEND: only Nb at room T
H in solid solution (α -phase)

Nb near-surface at cryogenic T

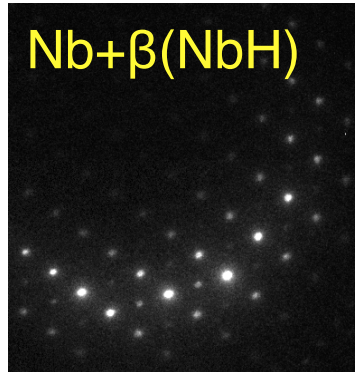
EP at 94K



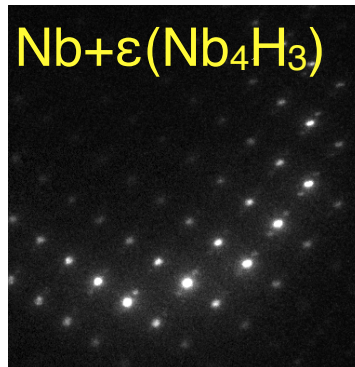
Nb+ ϵ , β



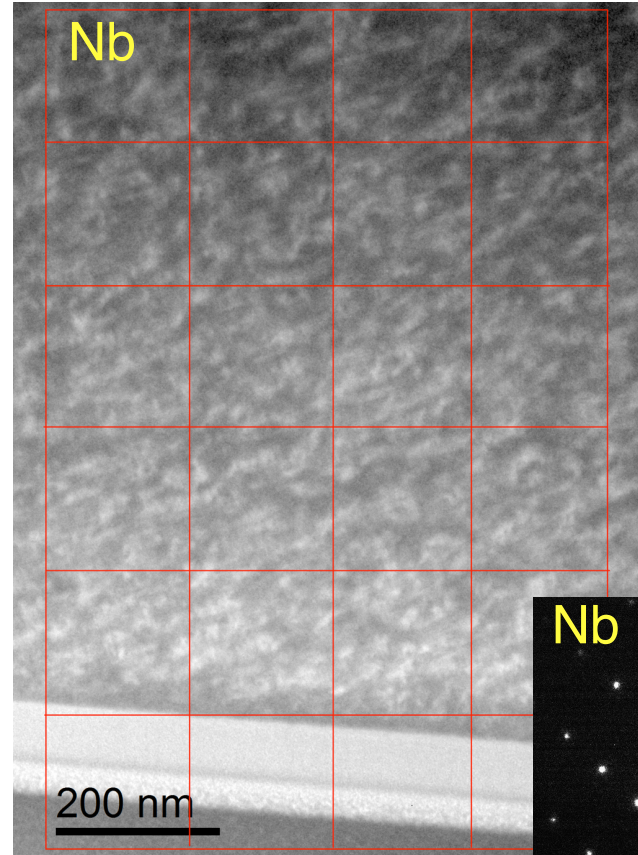
Nb+ β (NbH)



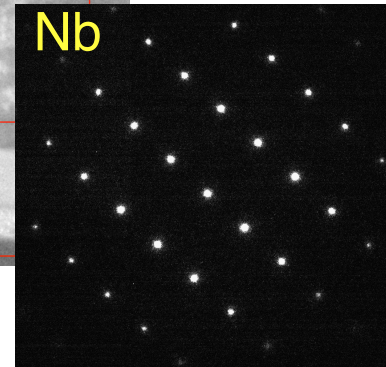
Nb+ ϵ (Nb₄H₃)



EP+120C baked at 94K



Nb

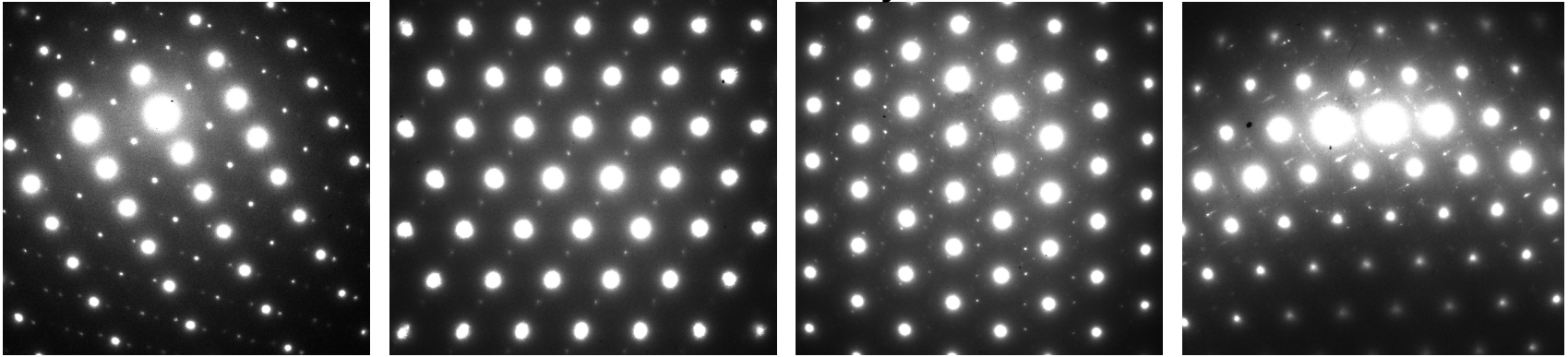


NO Nb hydrides precipitation

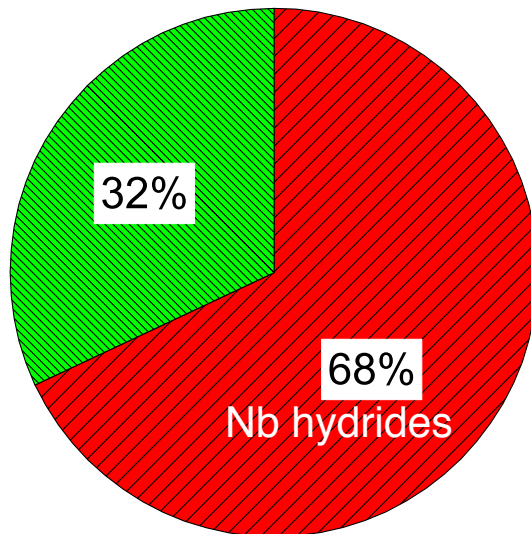
Nb hydrides precipitation

Nb near-surface at cryogenic T continue

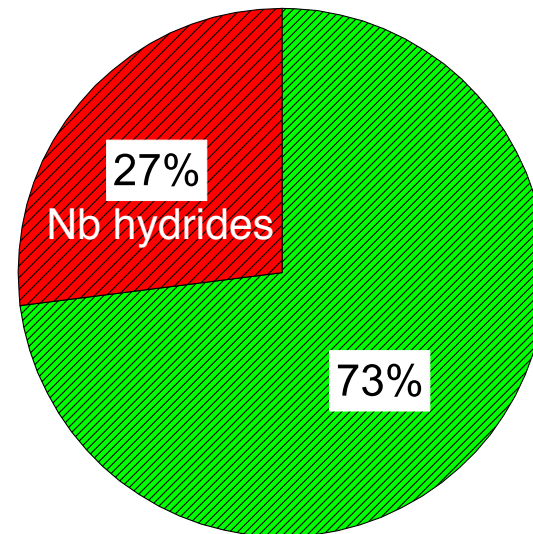
NED: Nb hydrides precipitation in **all cutouts**,
amount and/or size of Nb hydrides is different



EP at 94K

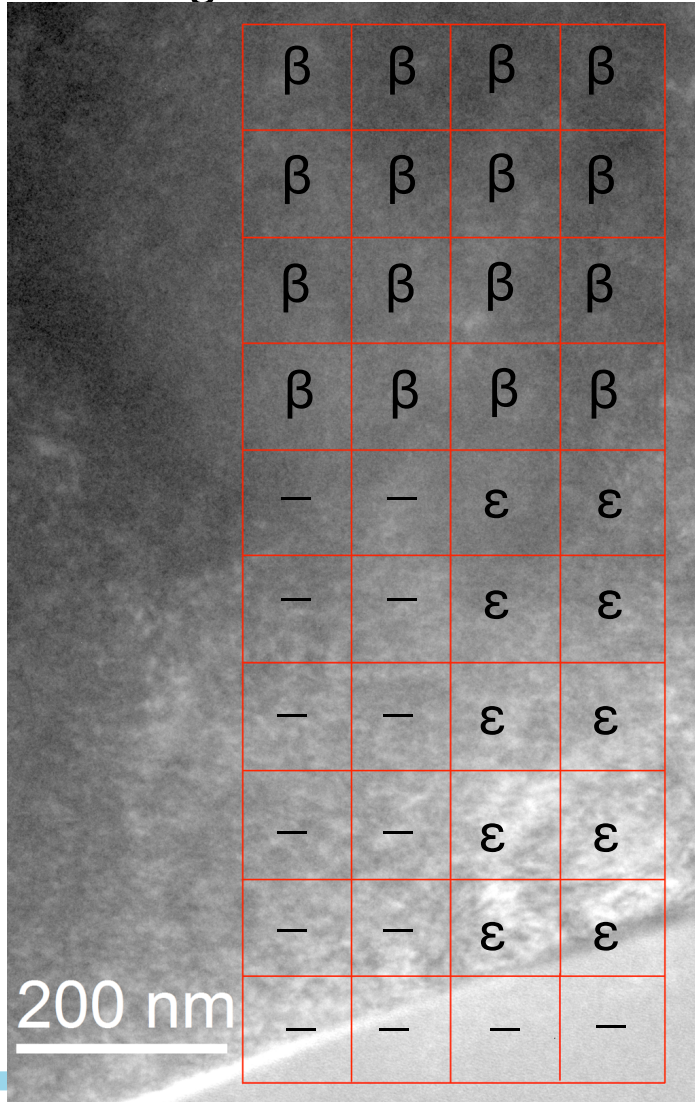


EP+120C baked at 94K

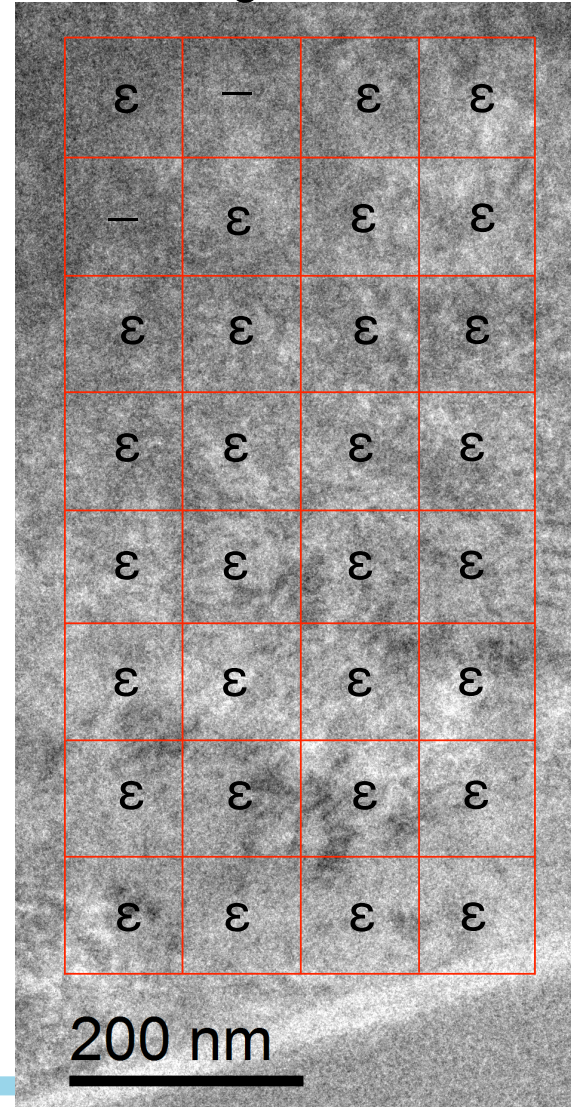


Other treatments show Nb hydrides precipitation

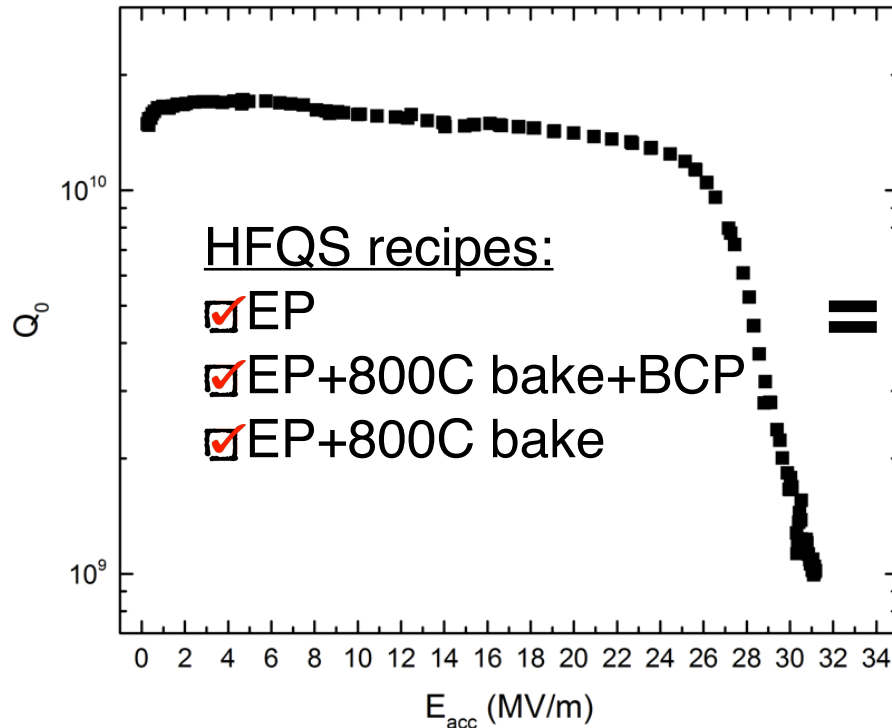
Annealing at 800C° for 3h+BCP



Annealing at 800C° for 3h



Cause of HFQS

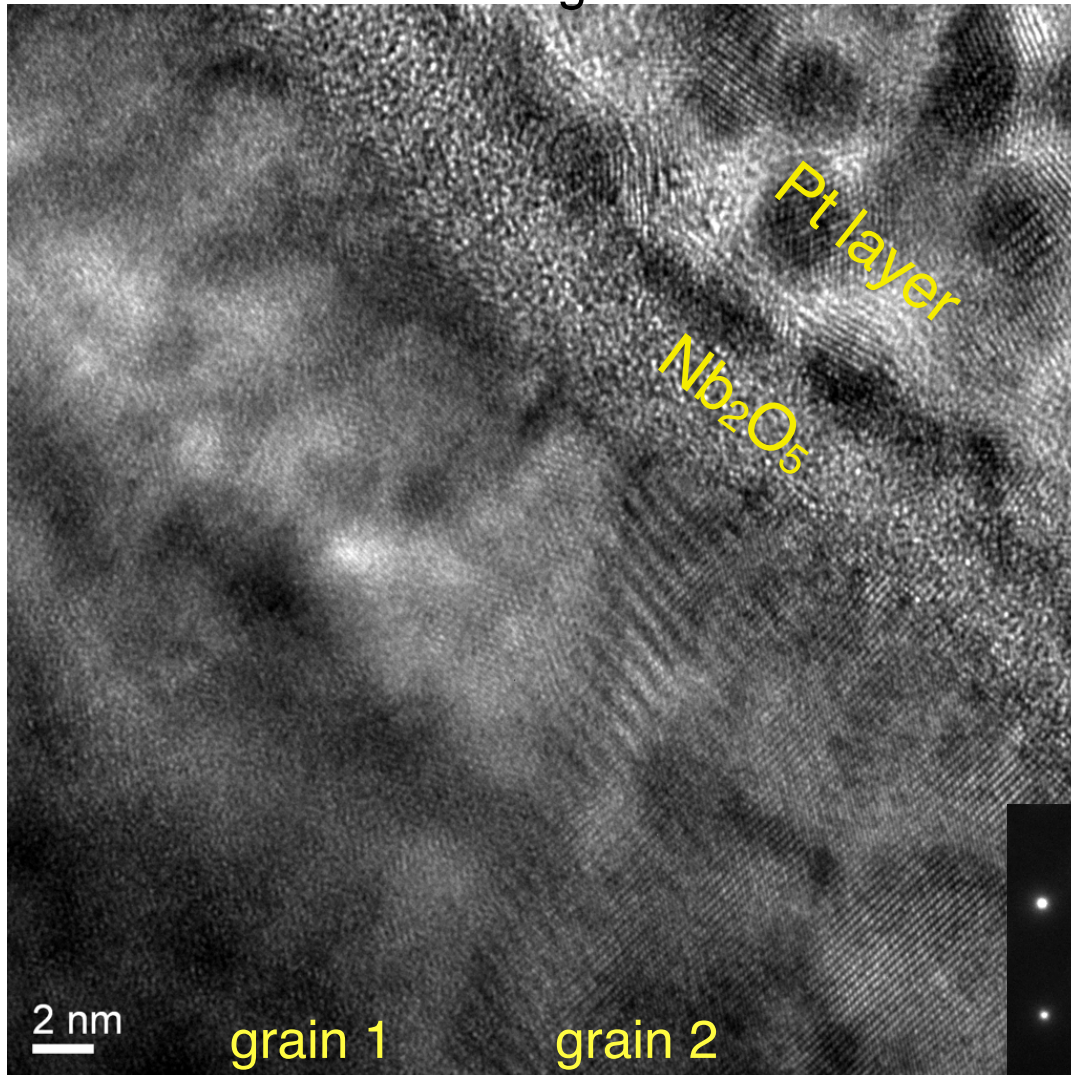


= large size or large amount of Nb hydrides at 94K

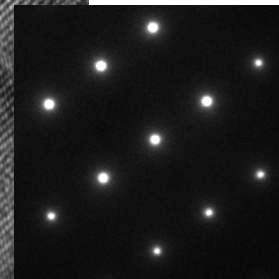
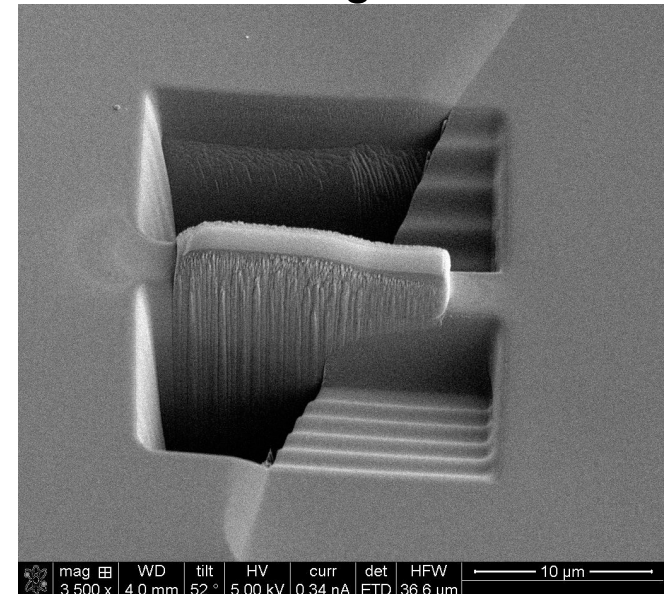
HFQS-free recipe:
EP+120C bake = small/widely spread Nb hydrides at 94K

Grain boundaries in EP and EP+120C baked

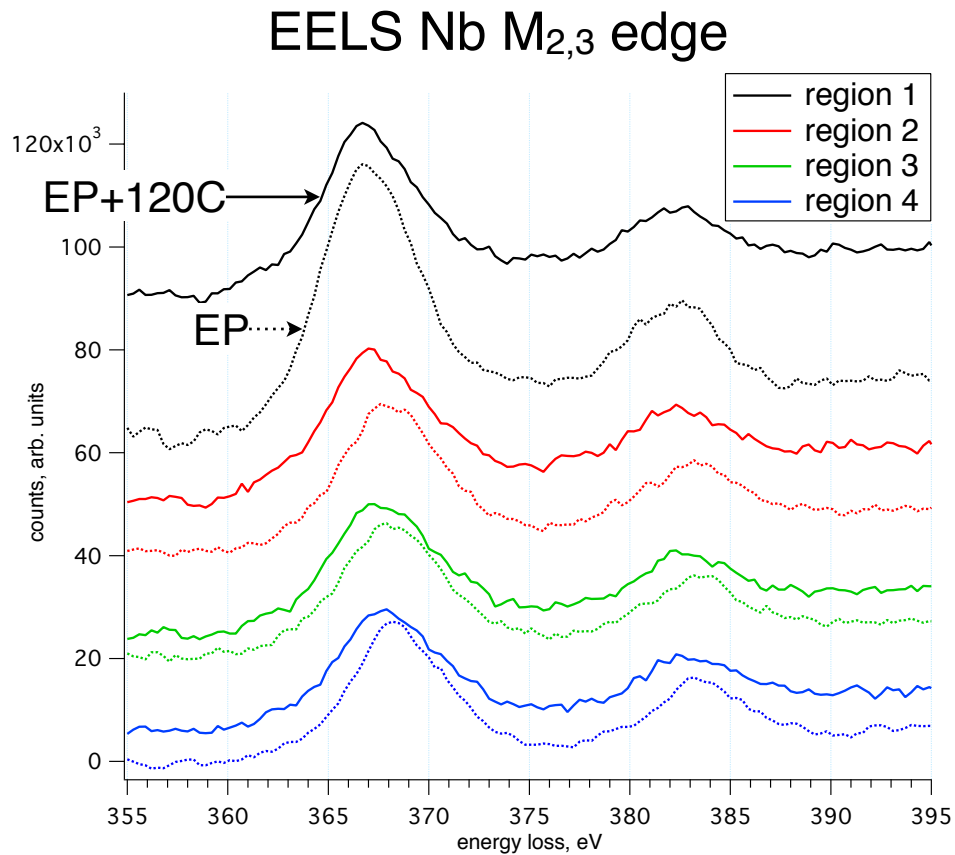
HRTEM image of GB



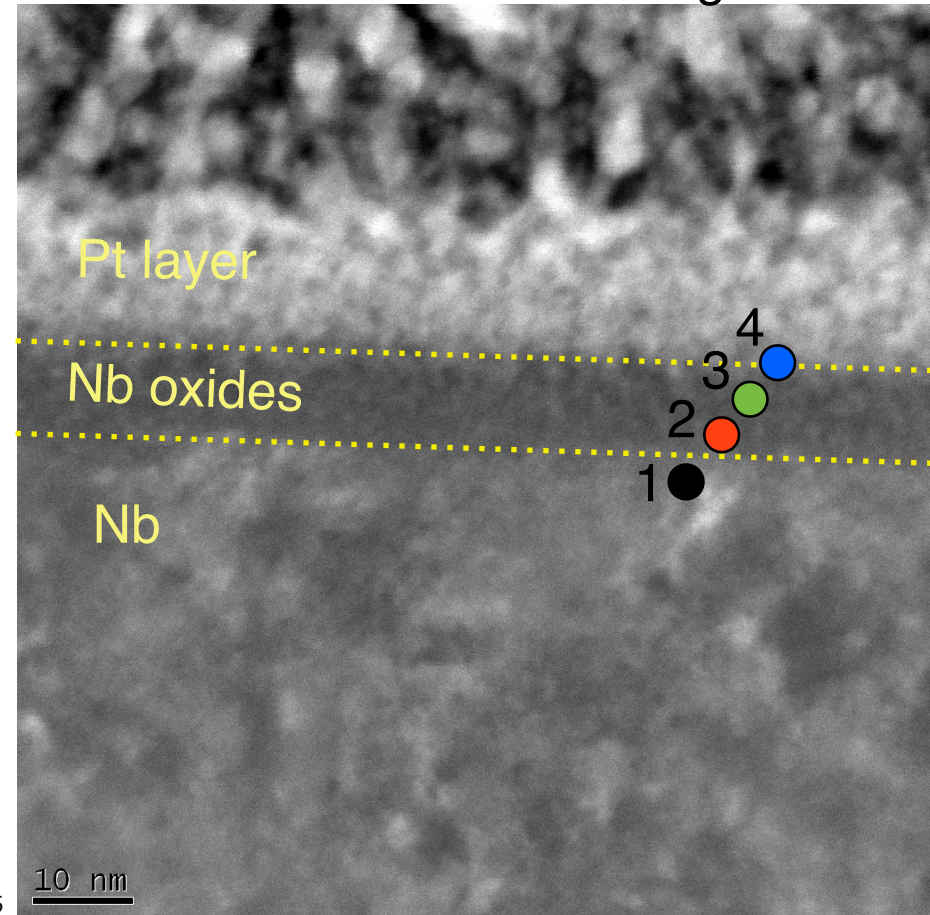
SEM image of GB



EELS study of Nb oxides in EP and EP+120C baked cavities



STEM Z-contrast image

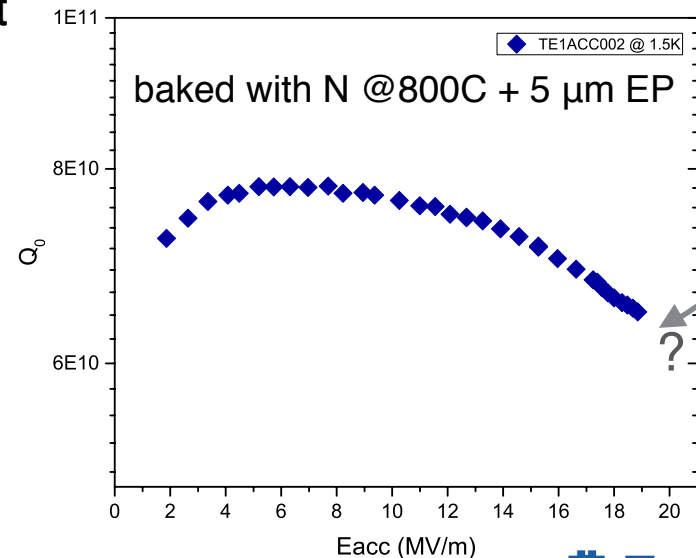
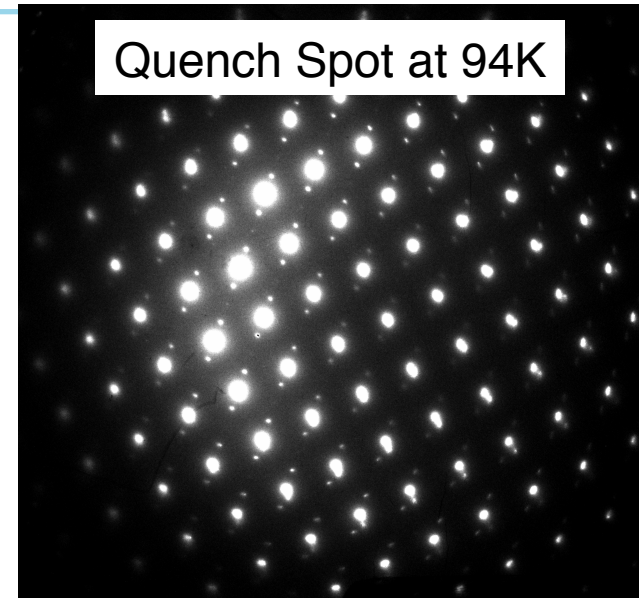


Oxygen inward diffusion during the bake

Nb hydrides in N-doped cavity cutouts and samples

- Nb hydrides **do precipitate** in N doped cavities and samples!
Most of the probed area is affected by hydride precipitation in quench spot.
- Do Nb hydrides cause quench in N doped cavities?
Cryogenic temperature structural characterization of non-dissipating spot is needed.

More about N doped cavities in **MOPB055**



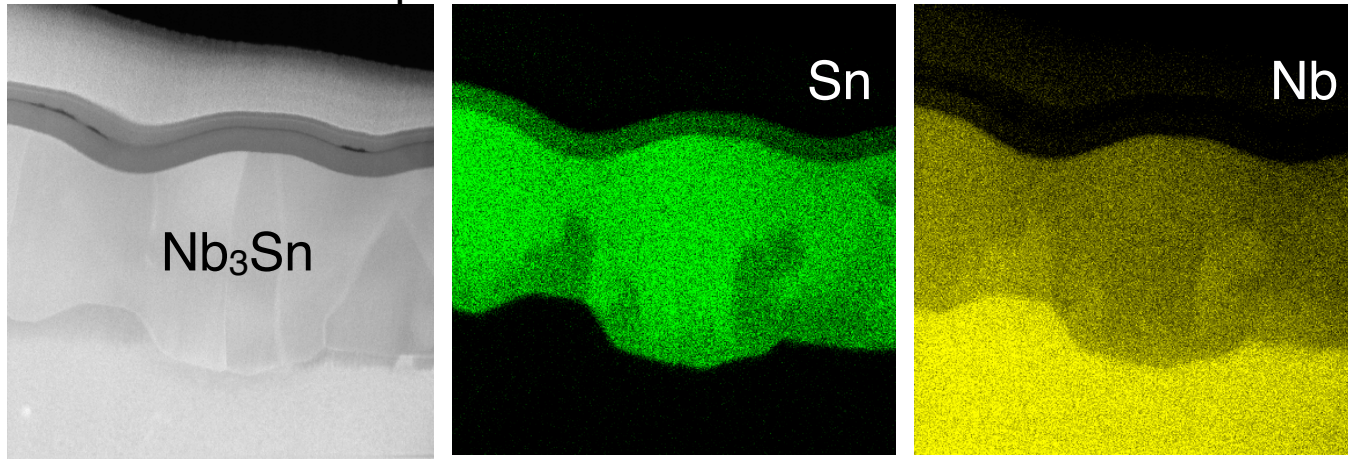
Conclusions

- Combination of T-dependent macro- and microscopic characterization revealed precipitation of Nb hydrides in the state-of-the-art SRF resonators for the 1st time;
- We showed that micro- and nanoscopic characterization gives a valuable insight into mechanisms that governs the performance of SC cavities;
- Routine use of micro- and nanoscopic characterization for the development of new SC materials and treatments for the SRF cavities.

Microscopic characterization for other materials/treatments

We are working on Nb₃Sn coating with Cornell University

Example of TEM/EDS characterization



More about Nb₃Sn in **Sam Posen's** posters
TUPB048, TUPB049 and Yulia's poster **TUPB056**.

Thanks for your attention!