FCC

Progress with bipolar HiPIMS-deposited Nb_3Sn films on Cu for SRF applications

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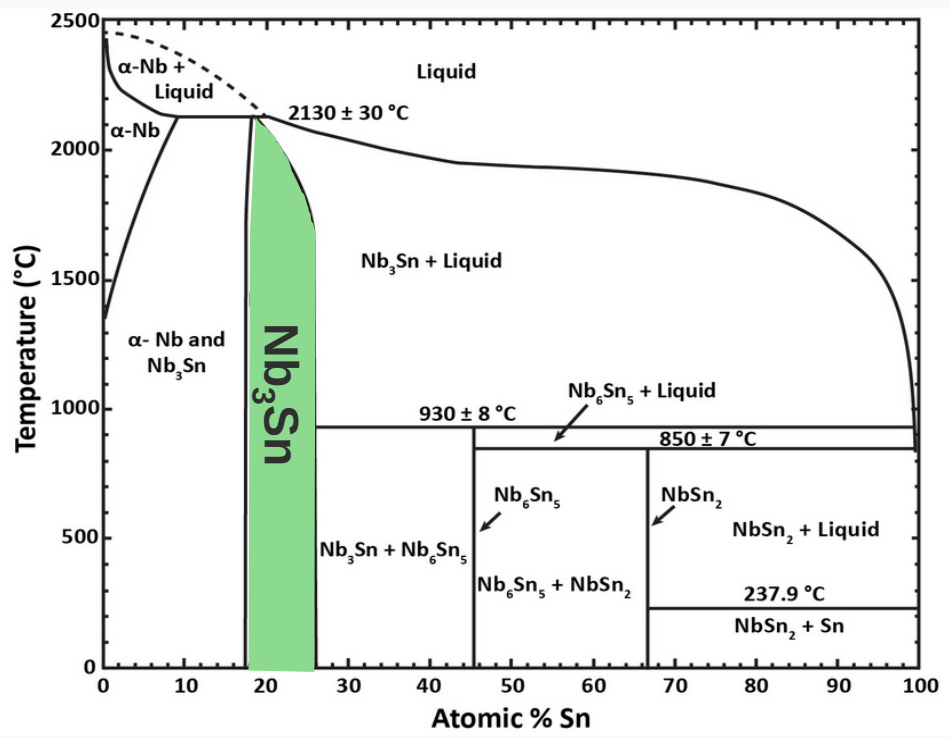
Motivation

- Nb_3Sn: Q_0 at 4.2 K ~ bulk Nb at 2 K

T_c	Nb ~ 9.2 K
	Nb_3Sn ~ 18.3 K
R_{BCS} @4.2K and 500MHz	Nb ~ 45nΩ
	Nb_3Sn ~ 0.4nΩ

Challenges

- A15 phase formation (typically high temperature)
- Stoichiometry control (Sn at. % 18 - 26 at. %)
- Copper substrate influence



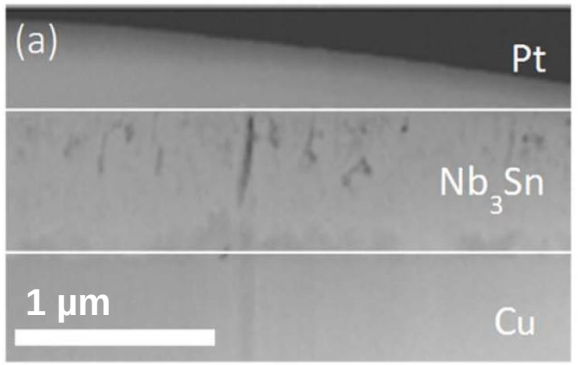
Binary phase diagram of the Nb-Sn system [1]

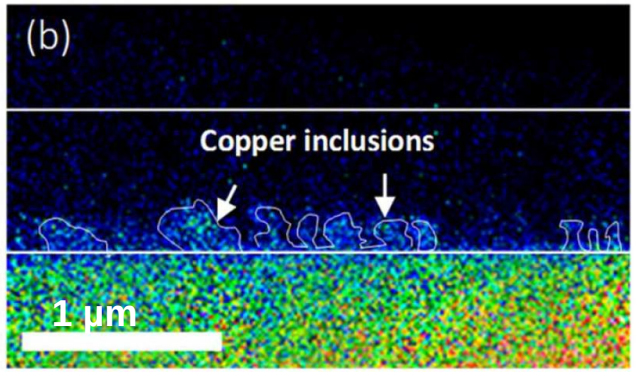
[1] J. Charlesworth, I. MacPhail, and P. Madsen, J. Mater. Sci. 5, 580 (1970).

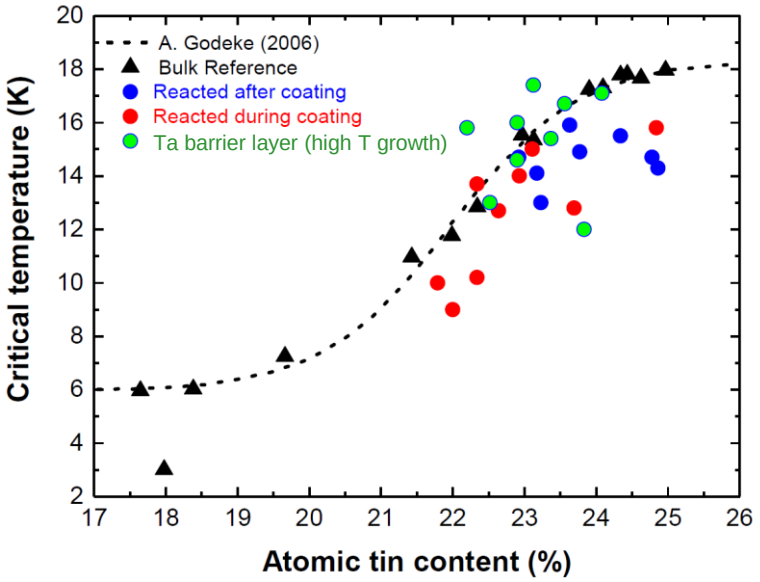
DC MS Coatings @ CERN

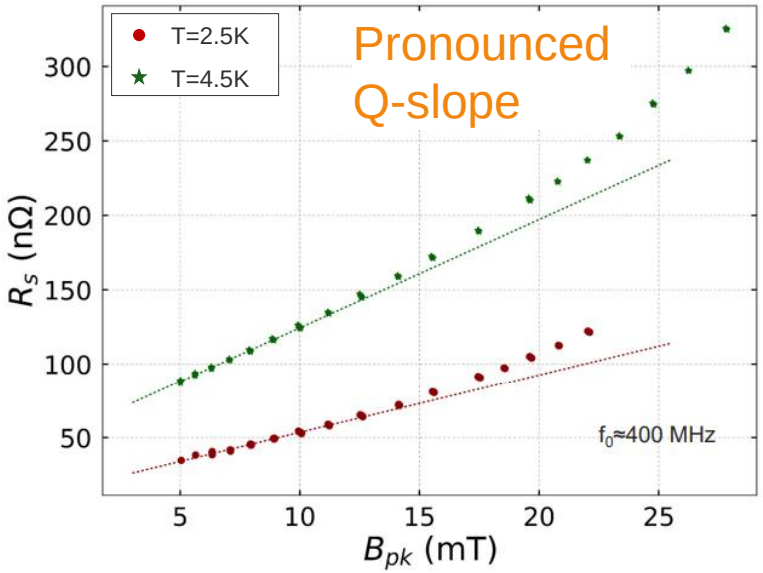
- **Formation of A15 phase**
  - High temperatures required!
- **Cu Diffusion**
  - Interlayer required (Ta/Nb)
- **Surface cracking**
  - Mitigated with Kr
- **Impressive T_c**
  - Sn dependent (increased with Kr)
  - Increased with Ta interlayer
- **Q-slope**

Film porosities and Cu inclusions/interdiffusion







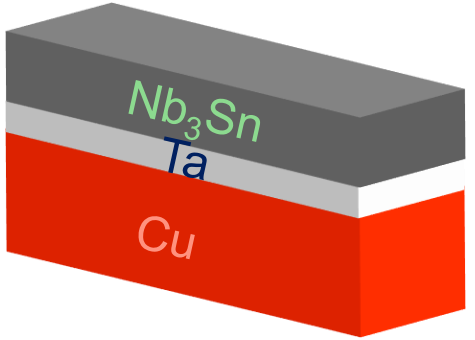


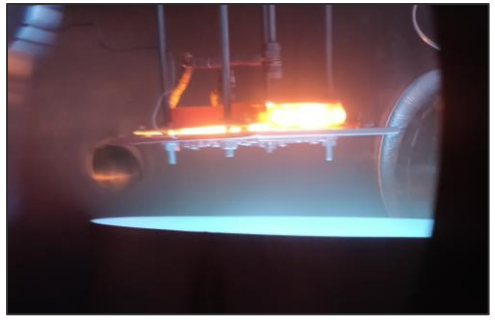
[2] K. Ilyina et al. *Supercond. Sci. Technol., 32 (2019)*
[3] M. Arzeo et al. FCC Week 2018

Bipolar HiPIMS Nb_3Sn/Ta/Cu

- Improved density required for RF performance
  - Proven with Nb/Cu
- Lessons learnt dictate starting coating parameters

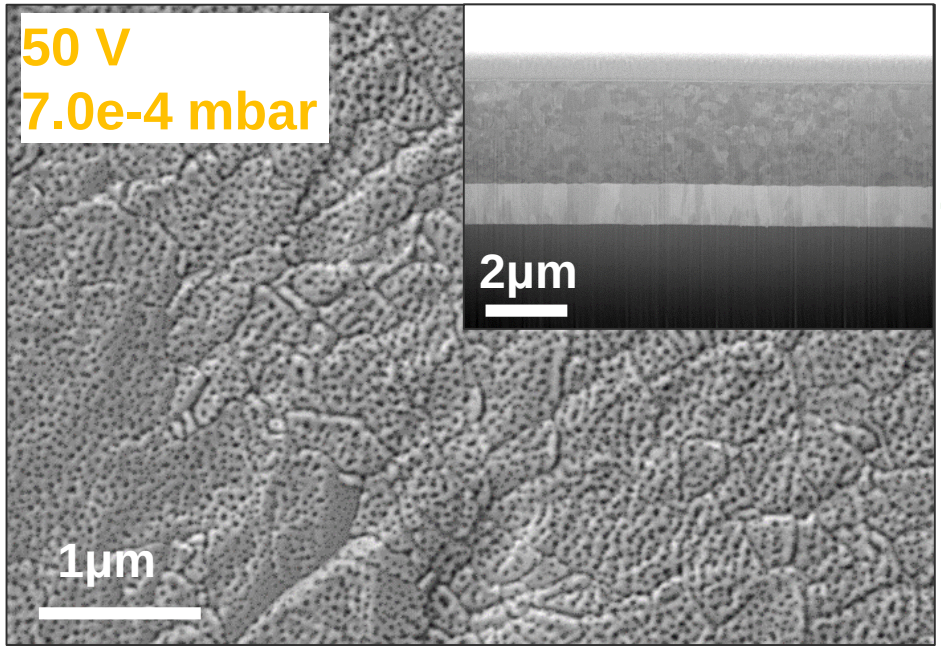
Coating parameters:
- *Gas: Kr*
- T_s: 650 … 750°C
- *P:* $7 \cdot 10^{-4}$ … $5 \cdot 10^{-2}$ *mbar*
- *PP:* 35 … 100 V
- *Post anneal:* 0 … 72 hrs





Crystallinity and Morphology

- Correct A15 phase within studied parameter regime
  - Further analysis ongoing
- Morphology mainly affected by pressure and positive pulse
  - Dense, crack free, porous surface
  - Dense cross section. Grainy Nb_3Sn

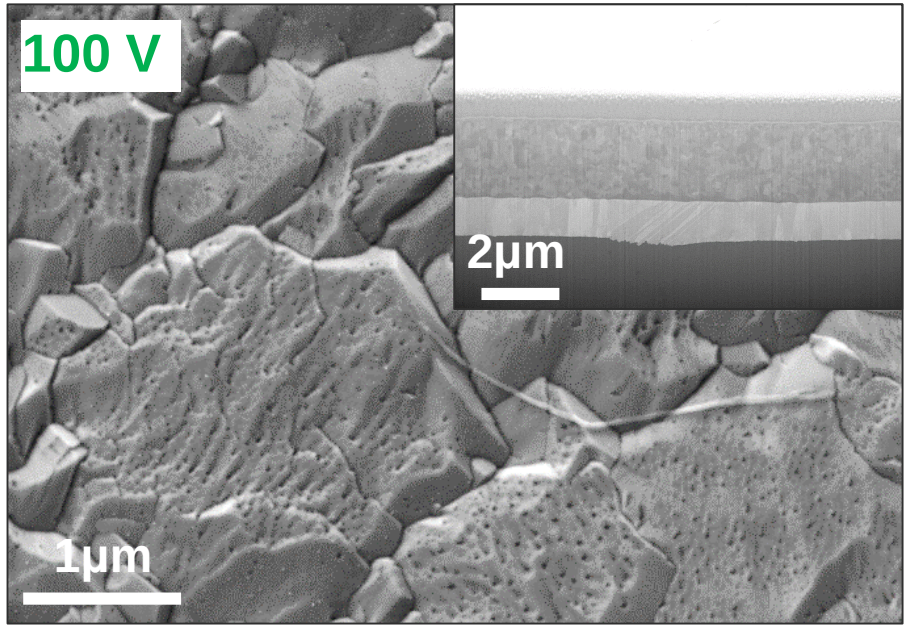


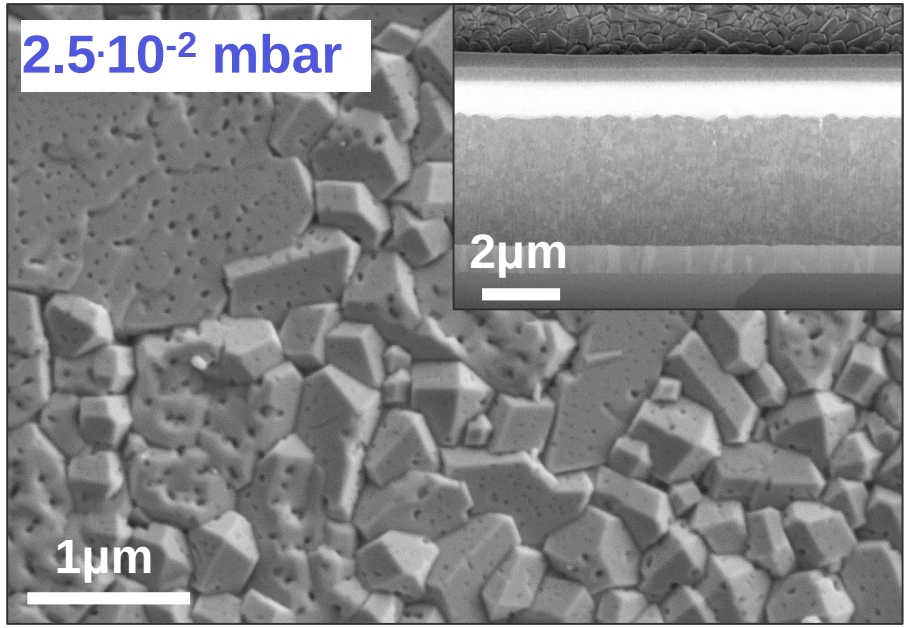
Pt

Nb_3Sn

Ta

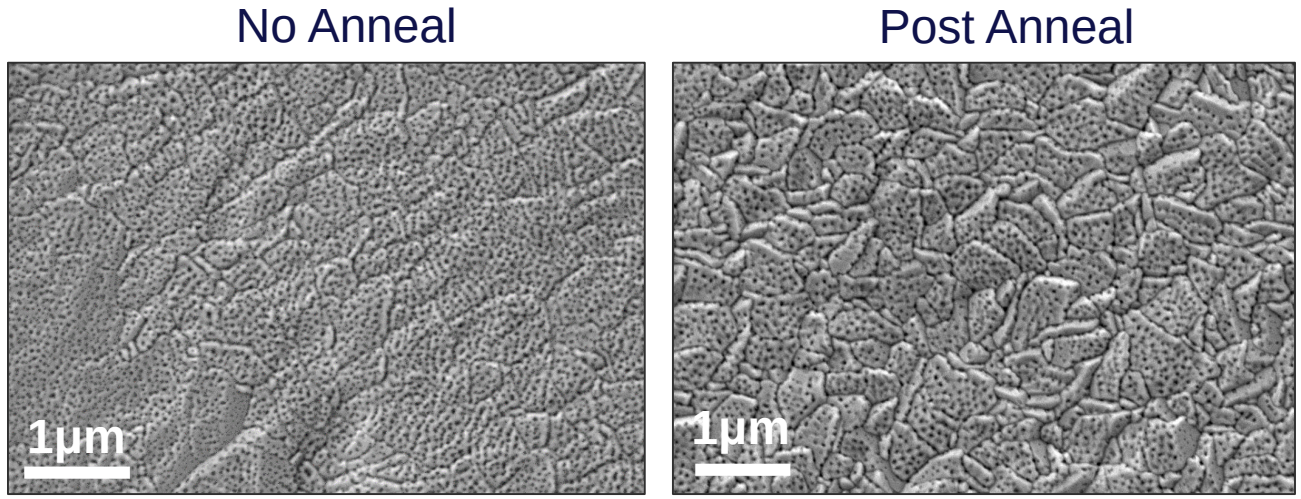
Cu

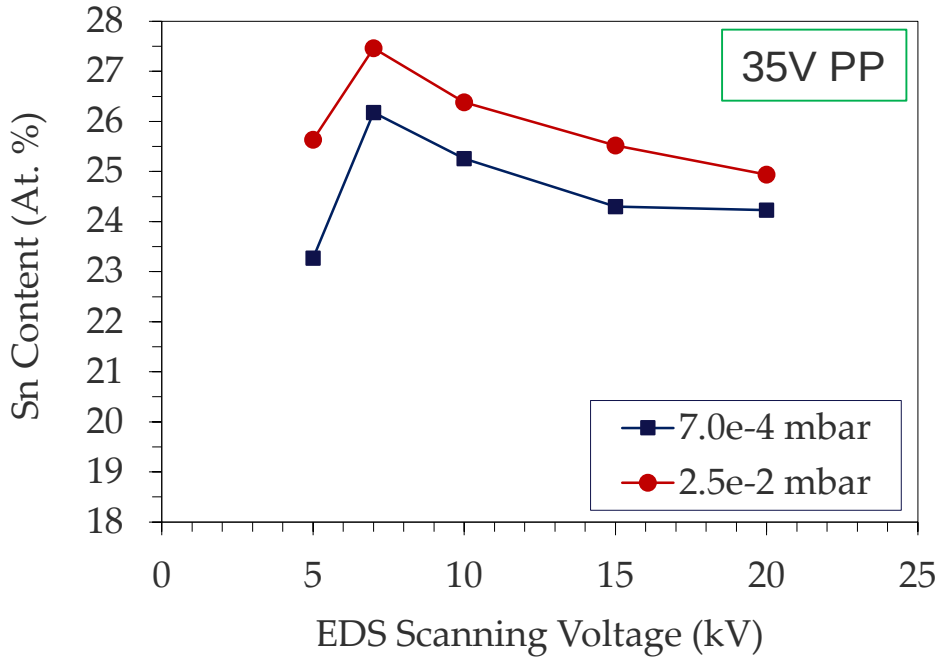


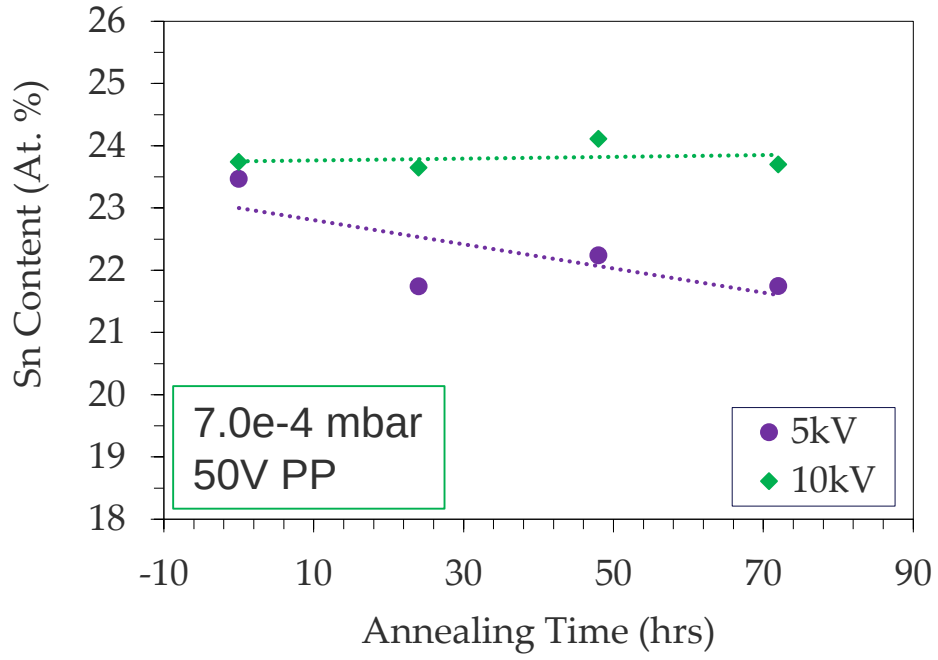


Compositional Analysis

- Correct stoichiometry range
  - Sn % = 19.8 to 26.4 at. % (EDS)
- Sn depleted near surface region
- Sn reduction with annealing
  - Near surface only

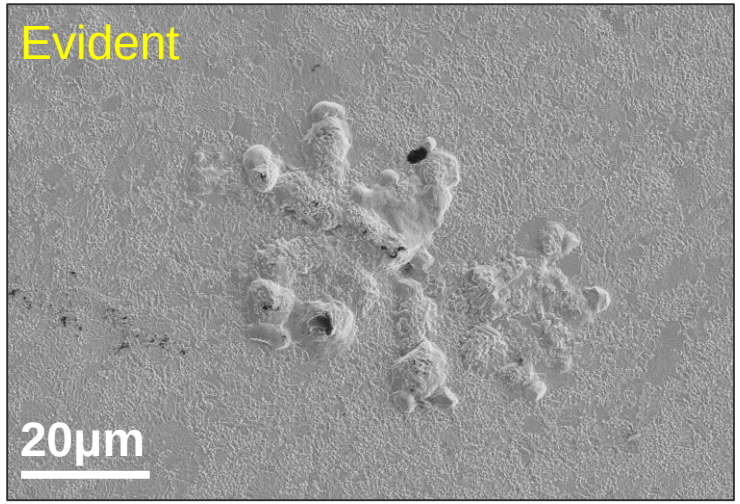




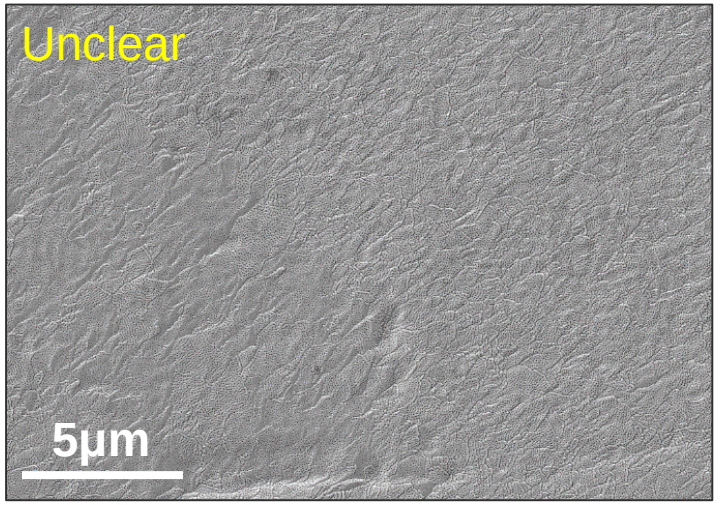


Surface Contamination

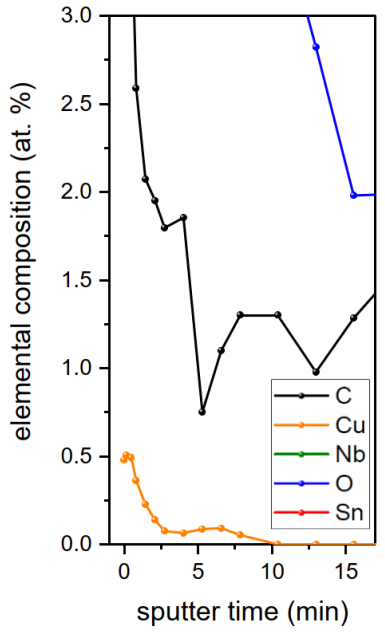
- Presence of Cu on film surface
  - Evident/unclear in SEM (XPS vs. EDS)
    - Evaporation from uncoated Cu surfaces
    - Diffusion through Ta
- Reduction methods
  - Decreased Ta coating temp
  - Stainless steel substrate holder
  - Annealing
    - Sublimation? (3.9e16 / m^2s @ 750°C)
  - Further investigations ongoing



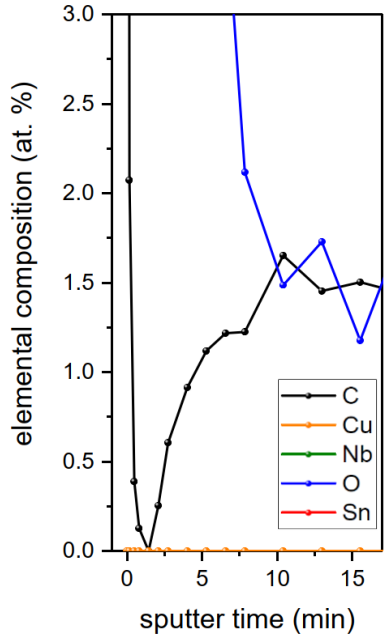
XPS and EDS



XPS only

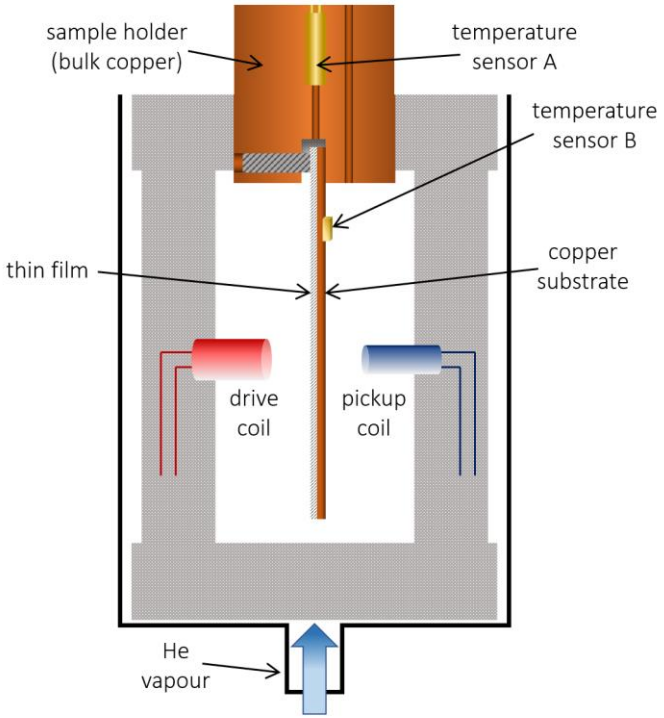


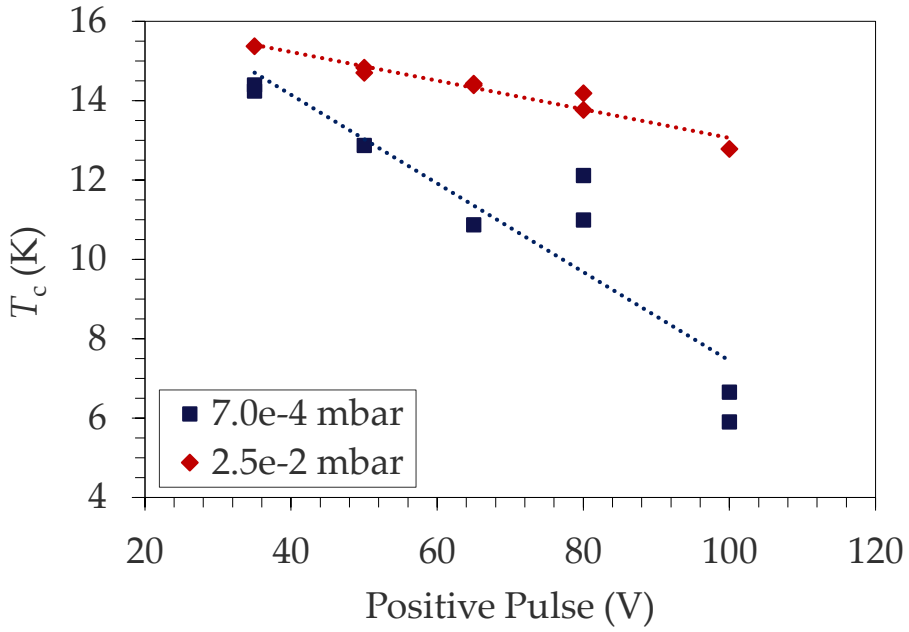
72h, 750°C Anneal

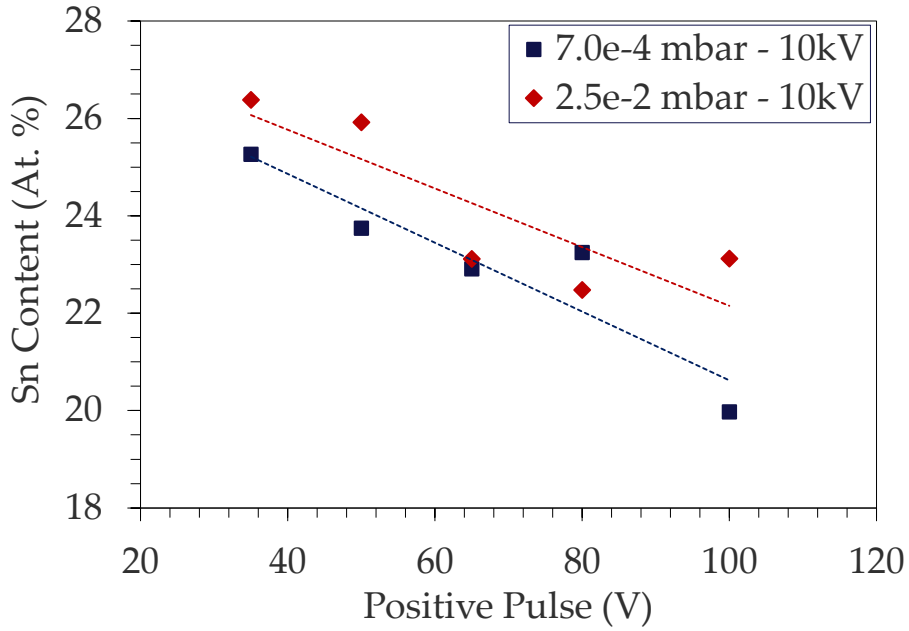


Superconducting Performance

Inductive T_c measurement

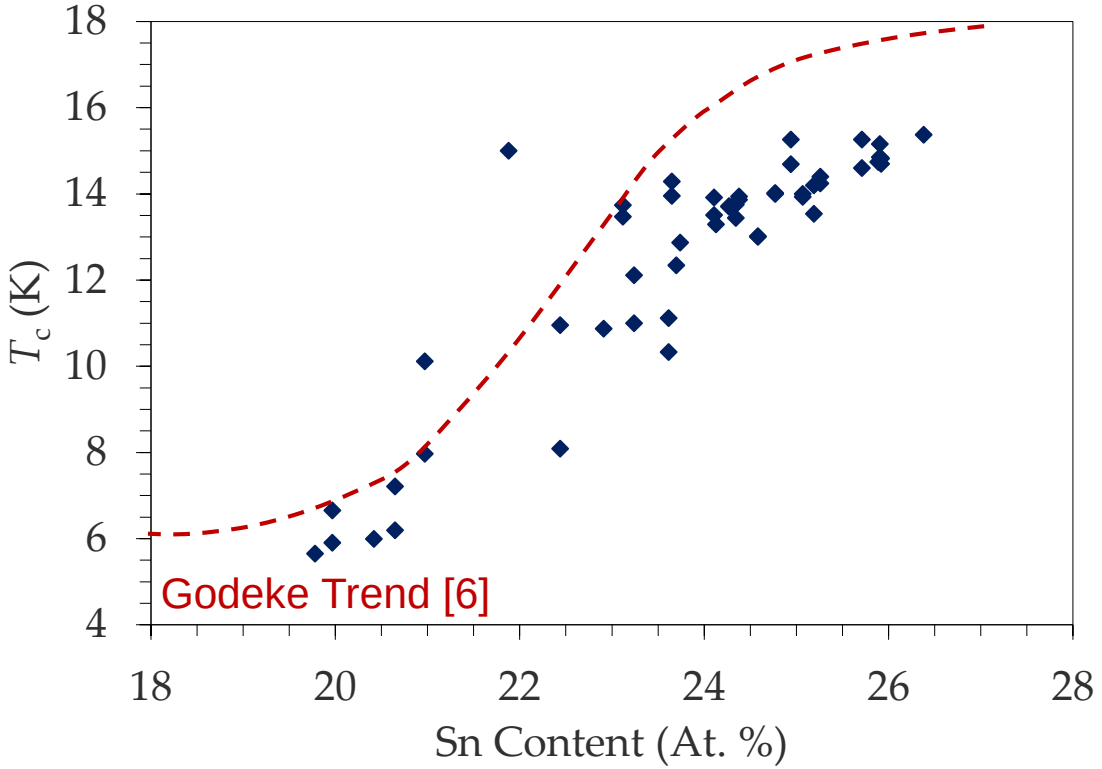


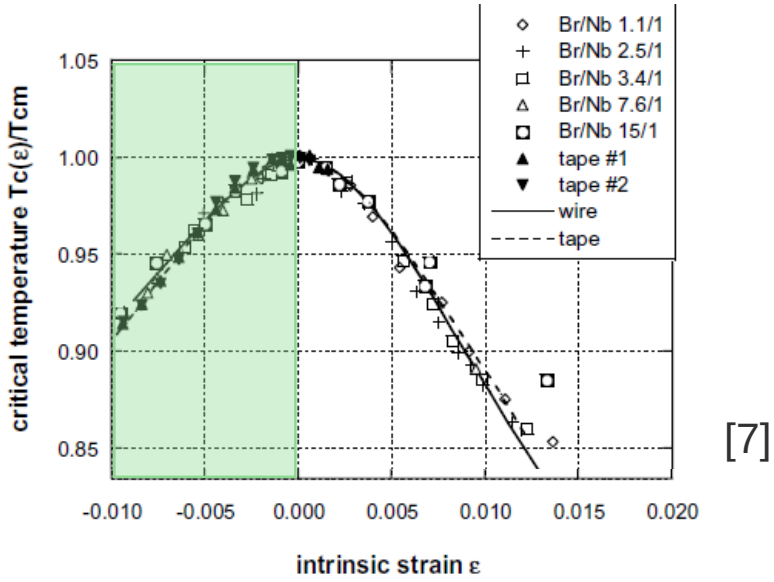




[5] D. Fonnesu - PhD Thesis (to be published)

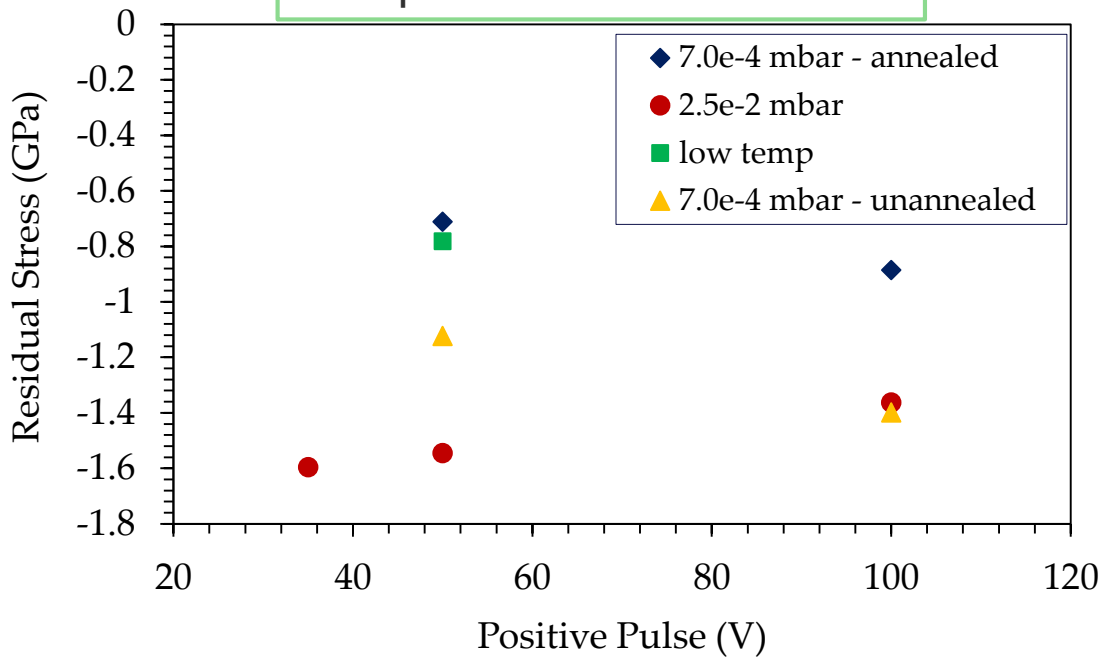
Superconducting Performance





[7]

Compressive residual stress



[6] A. Godeke. *Supercond. Sci. Technol.*, 19 (2006)
[7] G. De Marzi et al. *J. Phys.: Condens. Matter* 25 (2013)

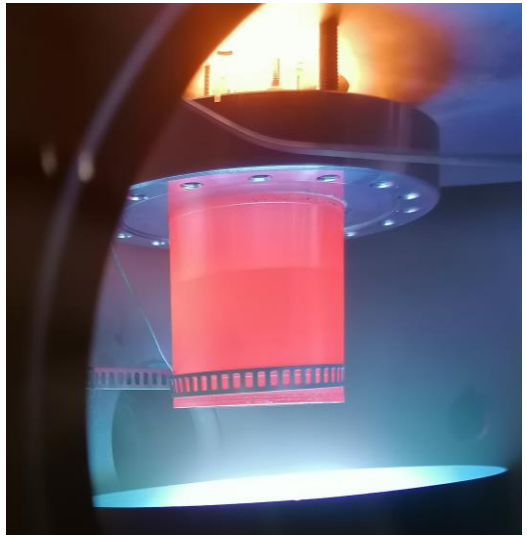
Superconducting Performance

- QPR Coating for RF measurements
  - Targeting High T_c

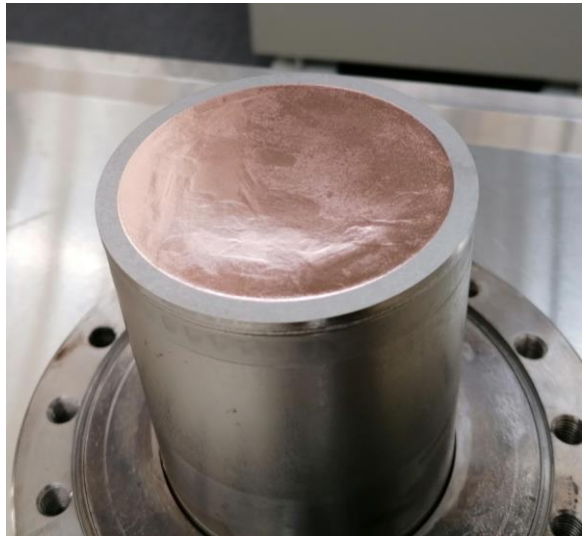
Ta Coating:
P = $1.0 \cdot 10^{-3}$mbar
No heating
PP = 50V

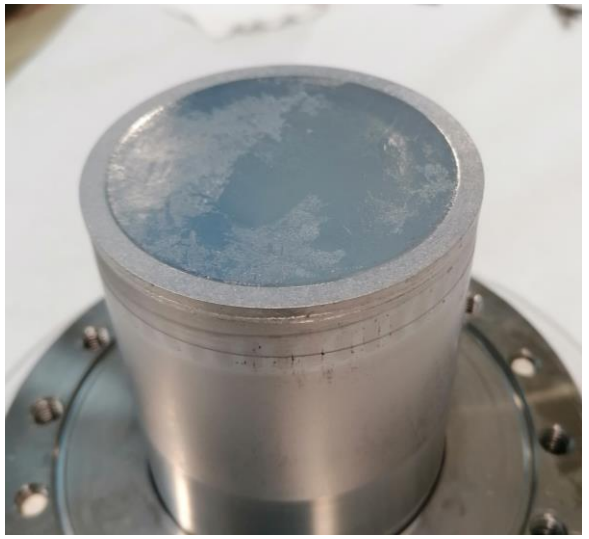
Nb_3Sn Coating:
P = $2.5 \cdot 10^{-2}$ mbar
T_s = 750°C
PP = 35 V
No anneal

Ta Coating



Nb_3Sn Coating





Summary and Future Work

- A15 phase deposited
  - Sn % within required stoichiometric range
  - Encouraging 15.4 K T_c soft limit
- Surface Cu contamination
  - Lower coating temperature
  - Interlayer optimisation
- Minimisation of residual stress
  - Film thickness optimisation
  - Post coating annealing
- Deposition of further QPR samples

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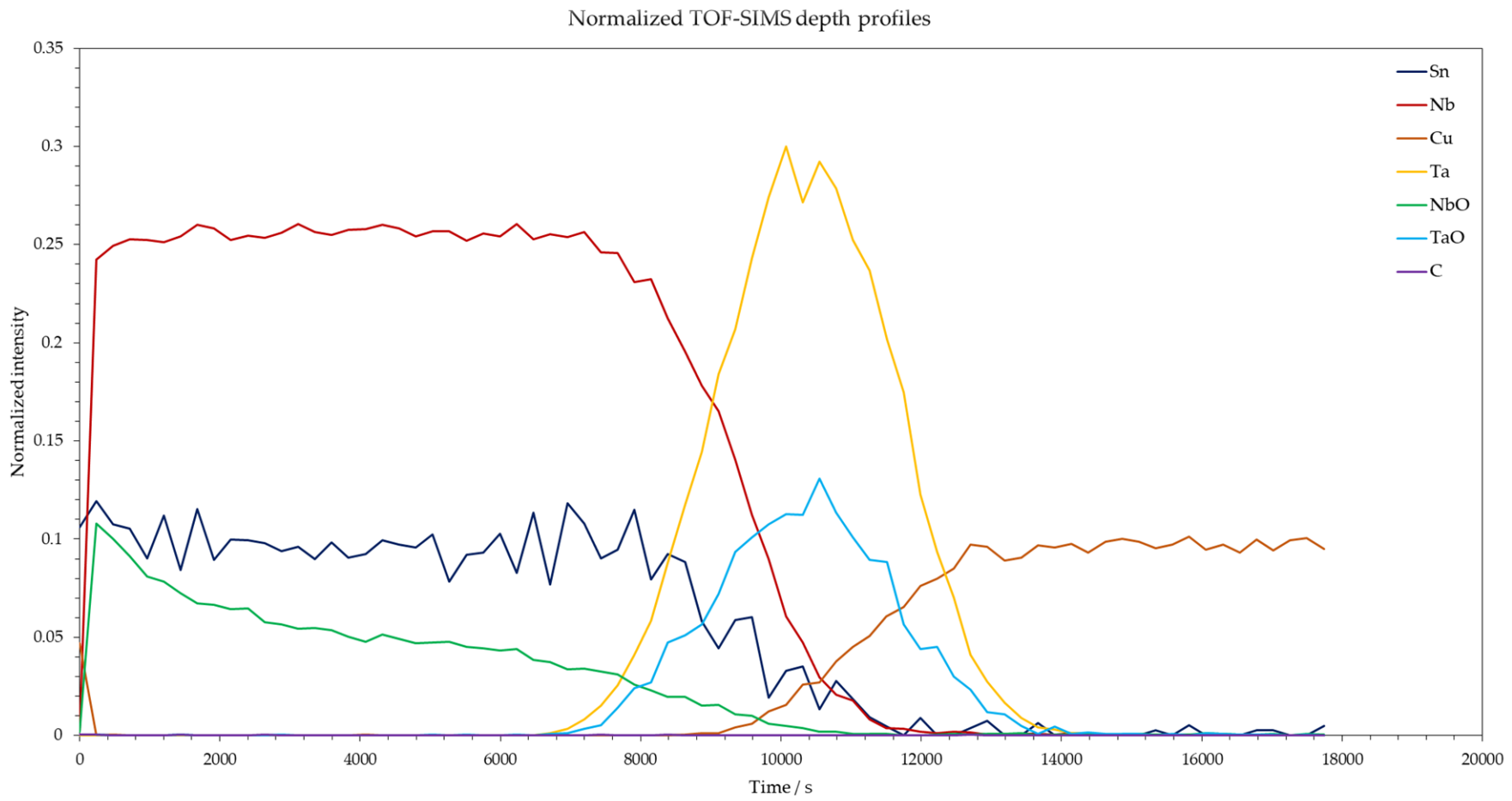
Thank you
for your attention!

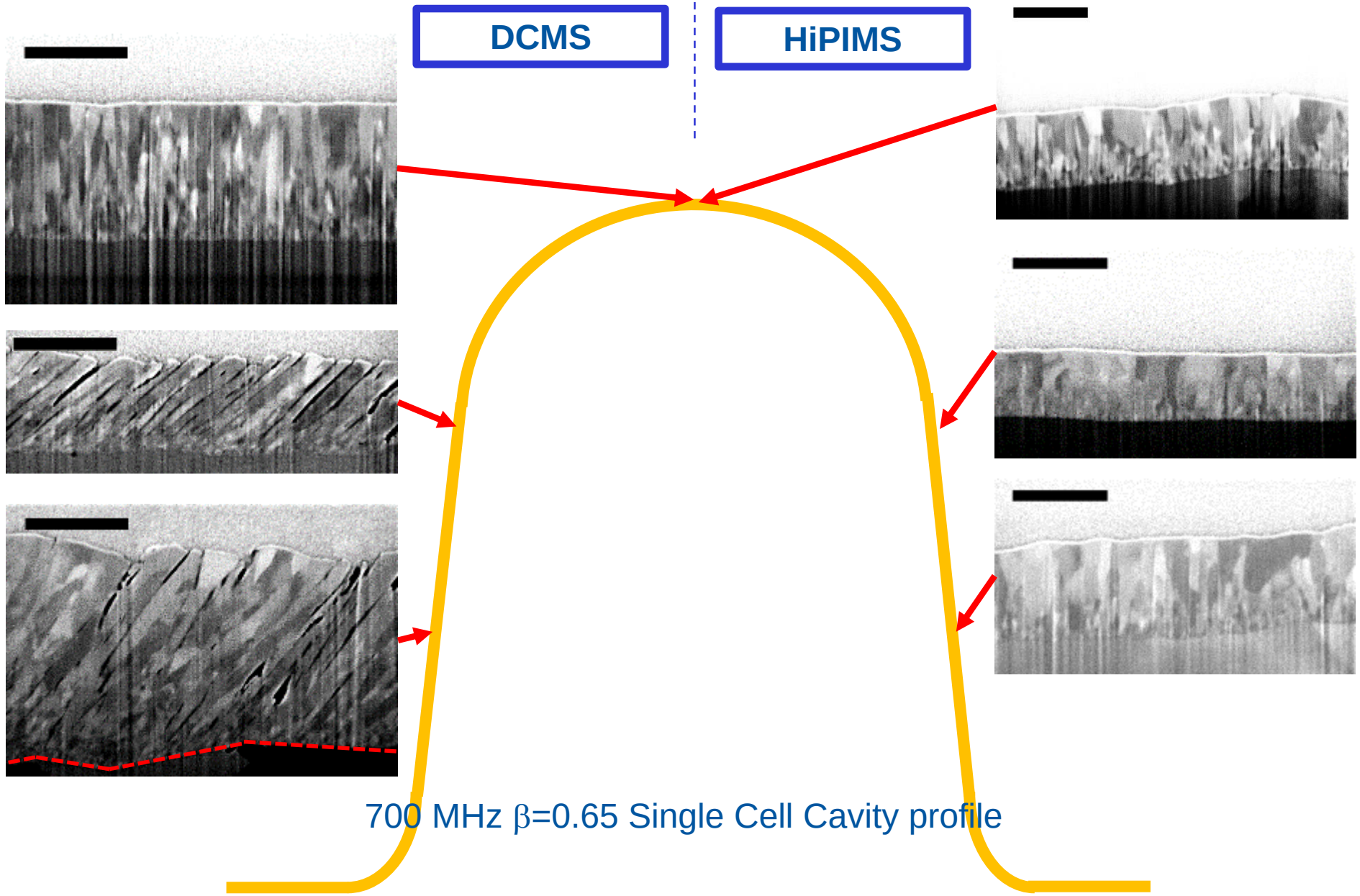
Extra Slides

Thermal expansion Coefficients

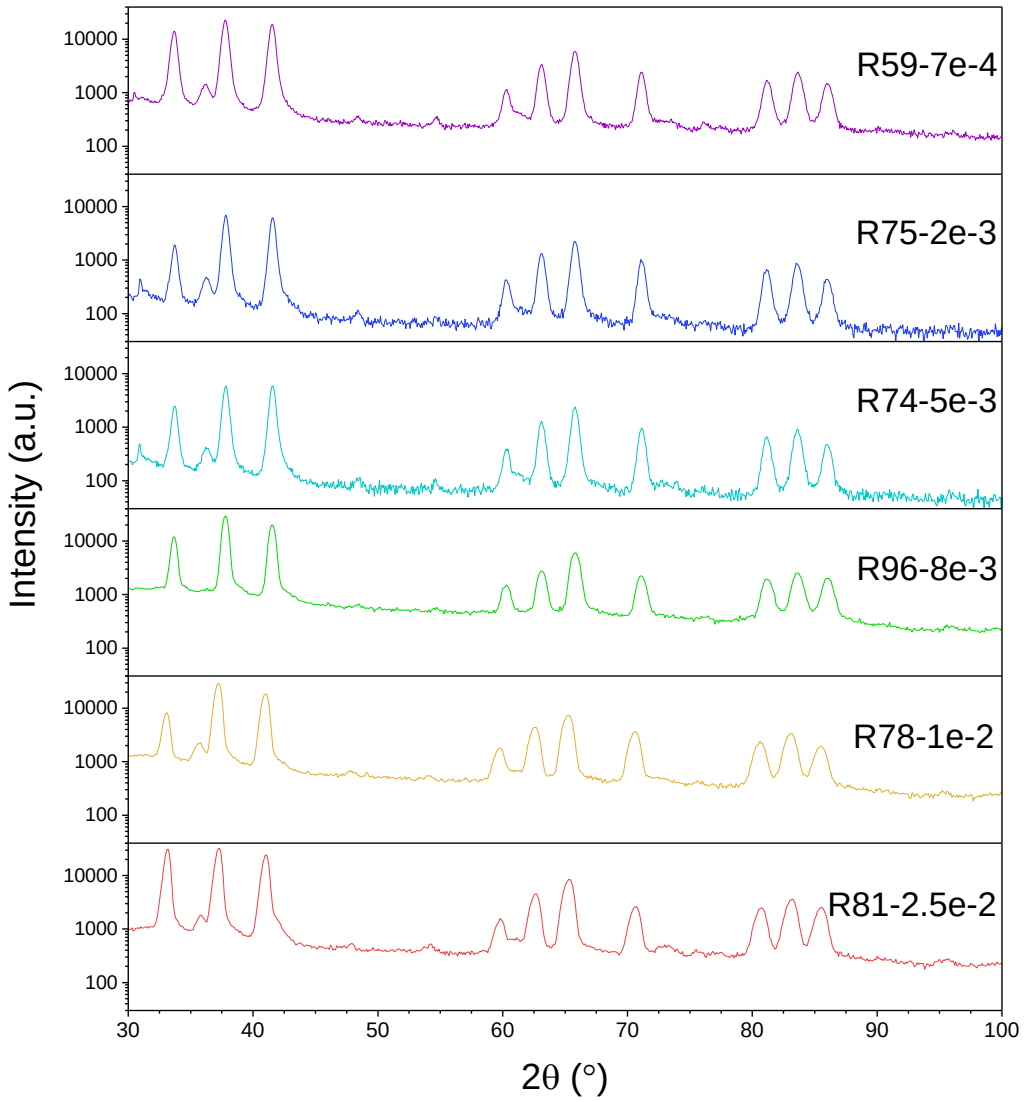
Element	α (x 10^{-6}) K^{-1}
Cu	16.8
Ta	7.64
Nb	7.02
Nb_3Sn	6.3

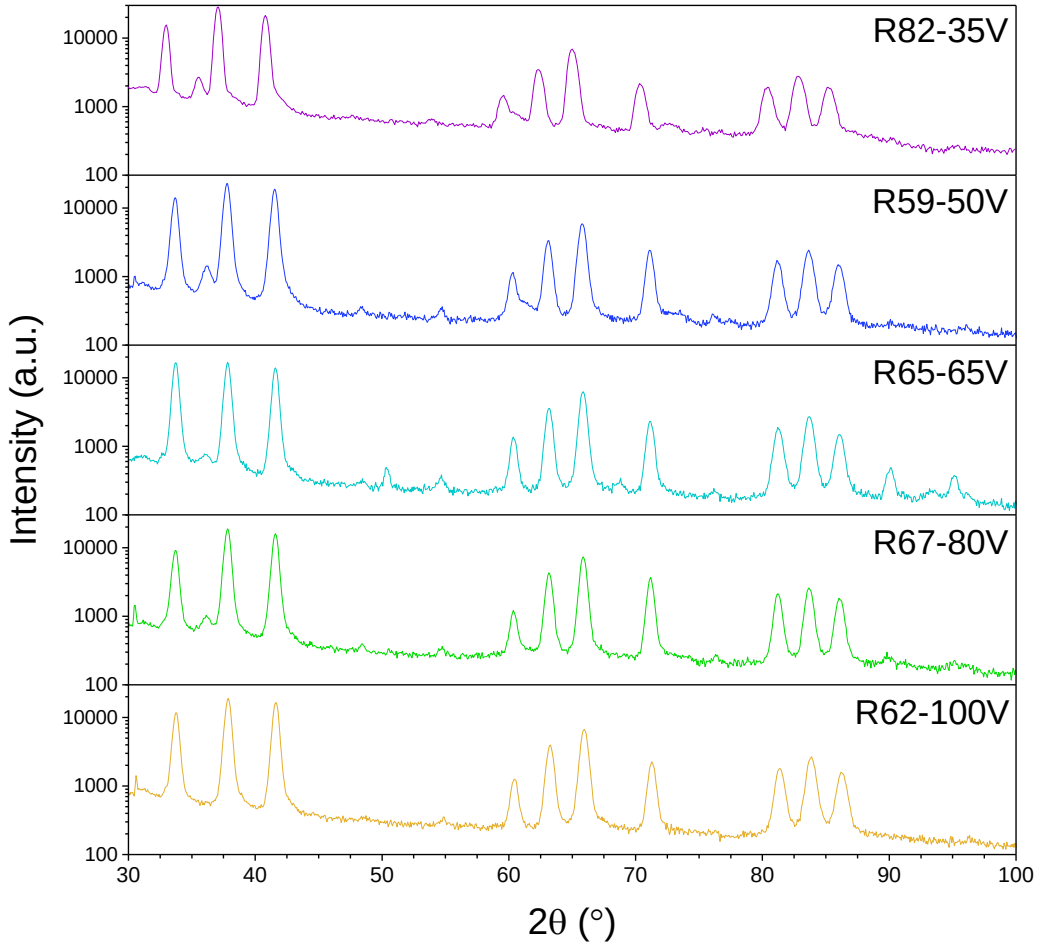
SIMS Results





700 MHz β=0.65 Single Cell Cavity profile


R59-7e-4
R75-2e-3
R74-5e-3
R96-8e-3
R78-1e-2
R81-2.5e-2
Intensity (a.u.)
10000
1000
100
30
40
50
60
70
80
90
100
2θ (°)


R82-35V
R59-50V
R65-65V
R67-80V
R62-100V
Intensity (a.u.)
10000
1000
100
30
40
50
60
70
80
90
100
2θ (°)