TEM analysis of coatings for RF cavities

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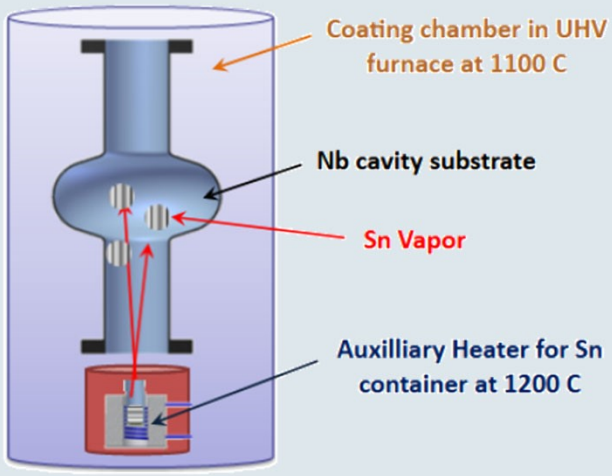
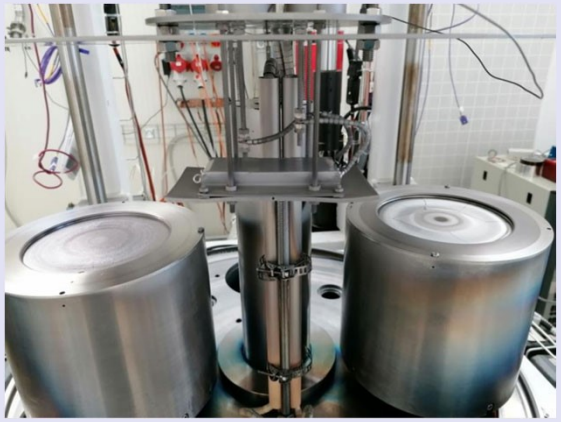
Thin film Nb_3Sn RF cavities

Vapor diffusion coating



M.Liepe, Cornell University, FCC Week 2015

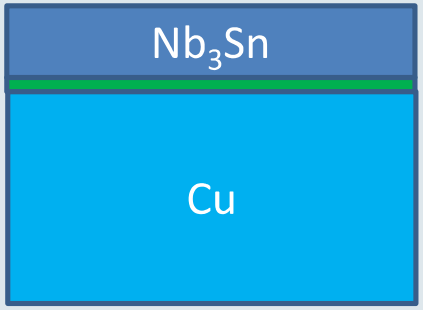
High Power Impulse Magnetron Sputtering (HiPIMS)



Challenges:

- Homogeneity, constant Sn concentration
- Surface roughness
- Localized defects

The perfect cavity coating



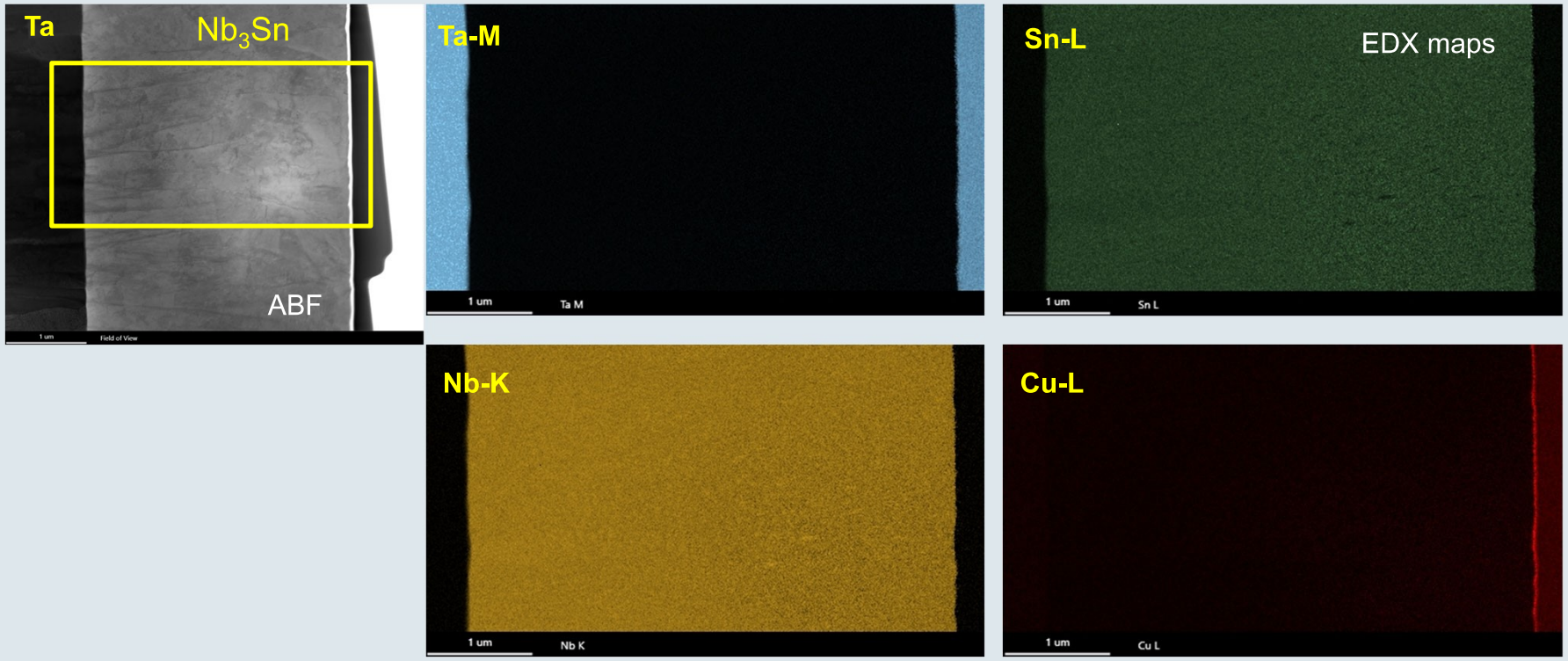
Cu substrate with high heat conductance

- Thin Nb_3Sn coating
  - higher operating temperature than pure Nb
  - low surface resistance
  - high acceleration gradients
- Homogeneous microstructure, no defects
- Smooth surface
- Constant Nb:Sn ratio
- No Cu diffusion into A15 film
- Ta interlayer
- Low costs

Preparation conditions

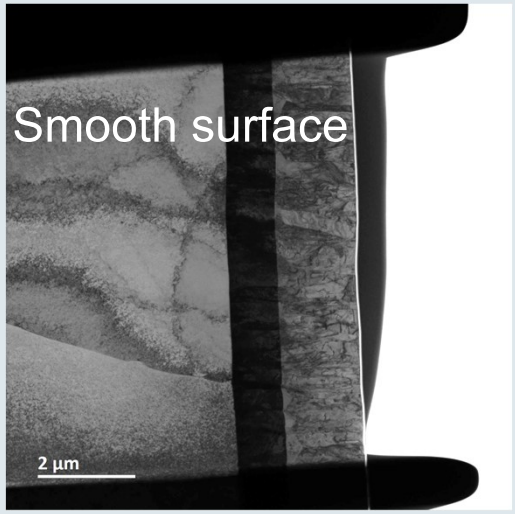
- **Ta Interlayer** — Kr atmosphere, 0.001 mbar
  - High temperature — Deposition @ 750 °C + annealing @ 750 °C
  - Low temperature — Deposition @ 175 °C
- **Nb-Sn target** — Sn 25 at% or Sn 27 at%
- **Nb-Sn coating pressure**
  - High pressure — 2.50×10^{-2} mbar
  - Low pressure — 7.00×10^{-4} mbar
- **Annealing of Nb-Sn**
  - reaction during coating — Deposition @ 750 °C / 2 hrs
  - reaction after coating — Deposition @ 260 °C / 2 hrs + annealing @ 750 °C / 24 hrs

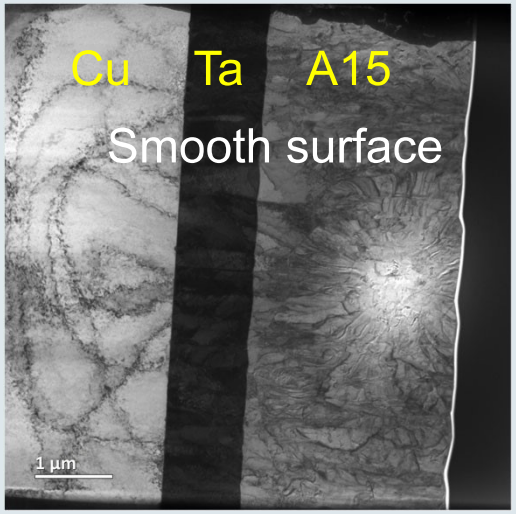
A perfect microstructure?

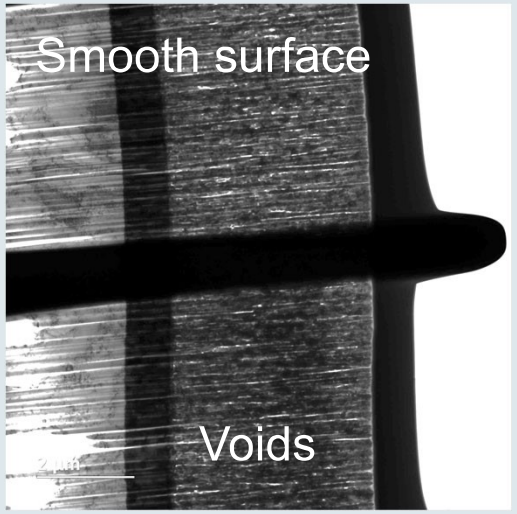


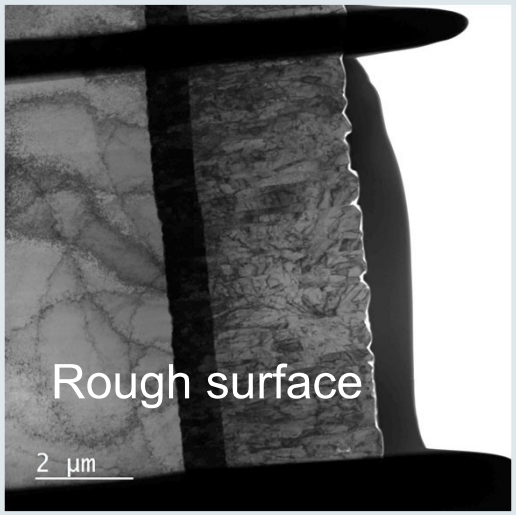
SUBU, 25% Sn, Ta 750°C, Nb_3Sn 8.0E-03, reaction during coating (at 750 °C)

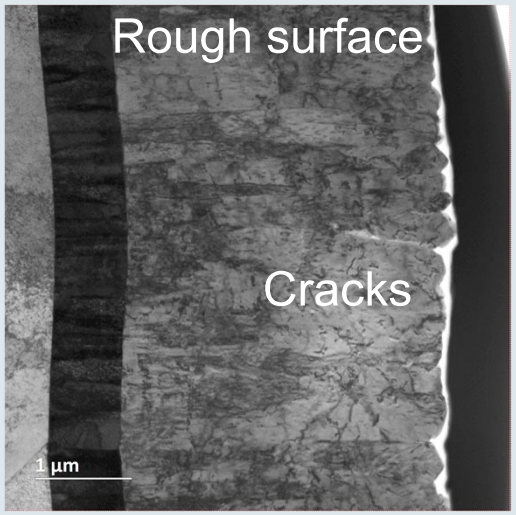
The real surface (microscopically)

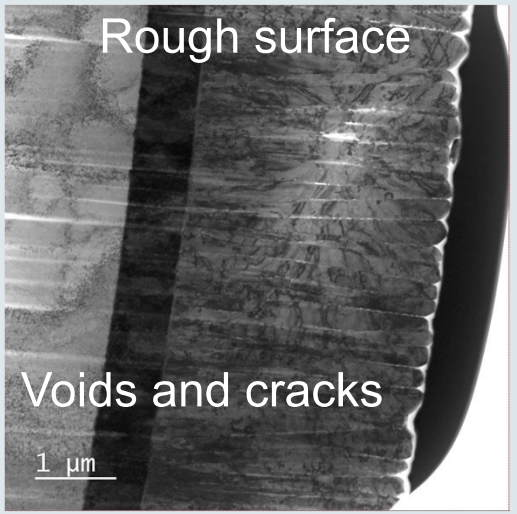




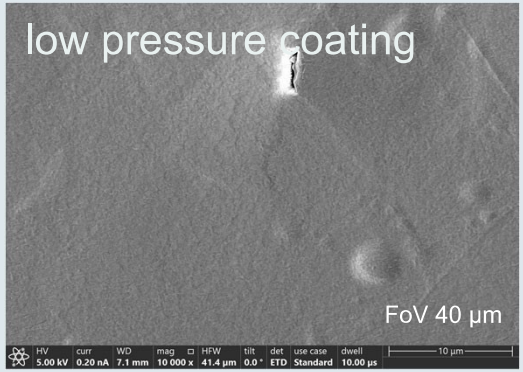


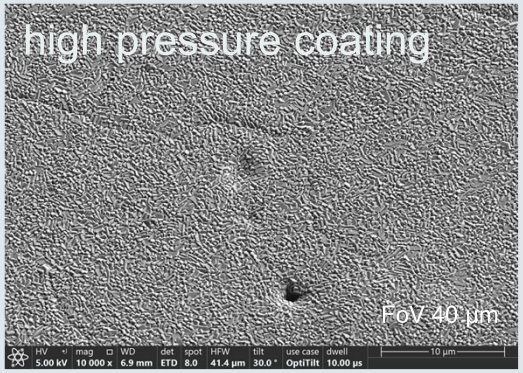


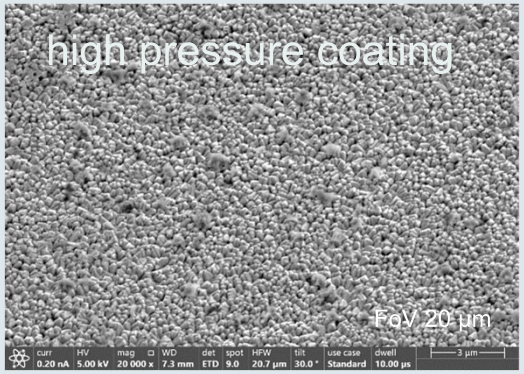


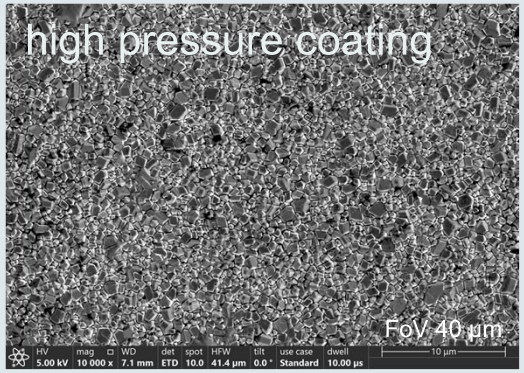


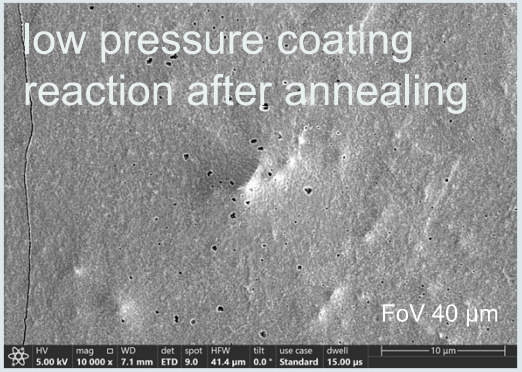
The surface (macroscopically)

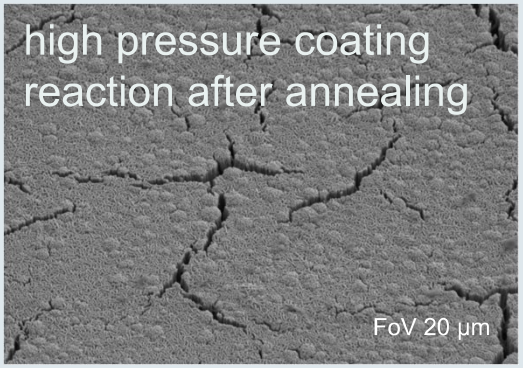






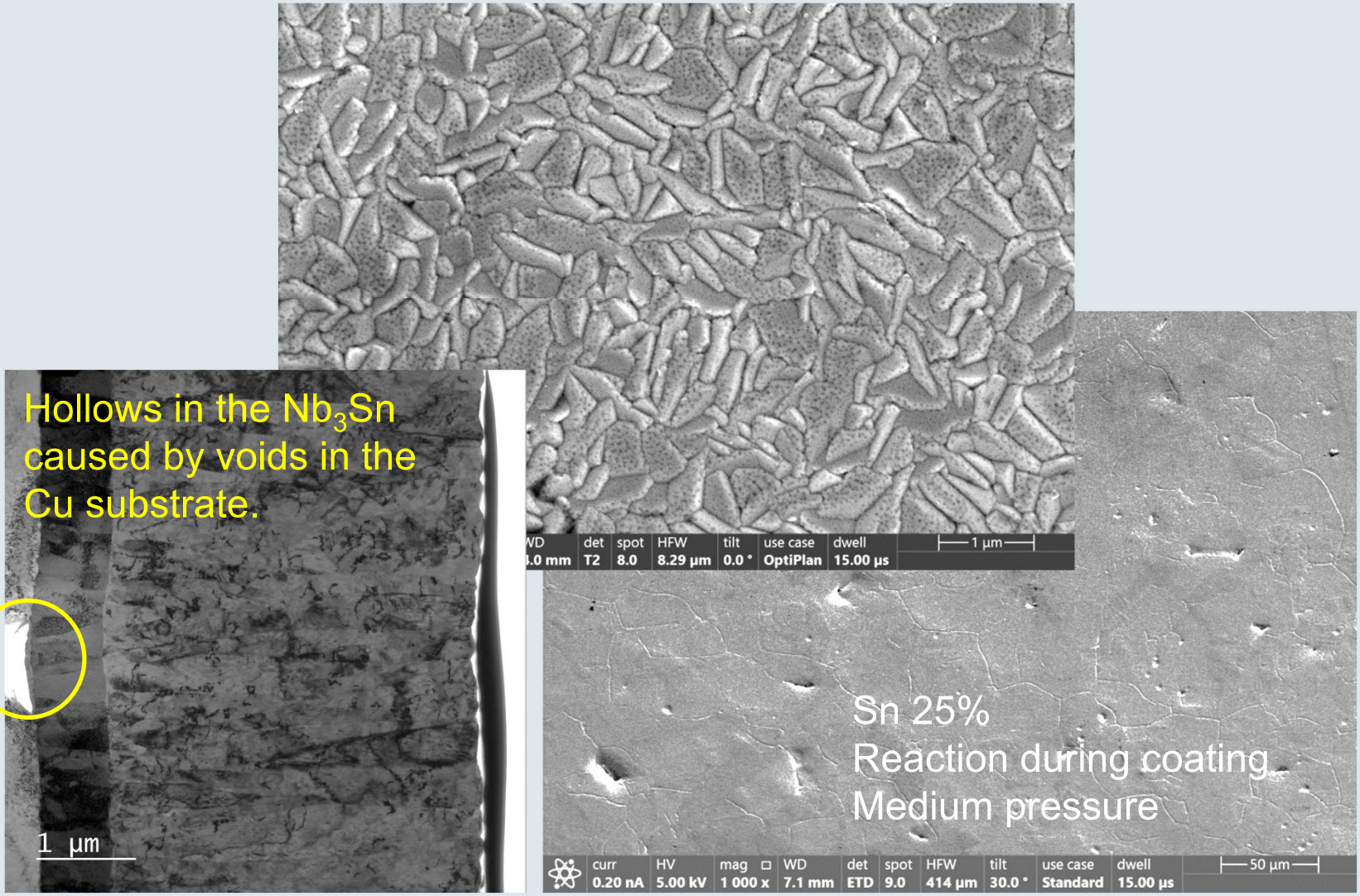




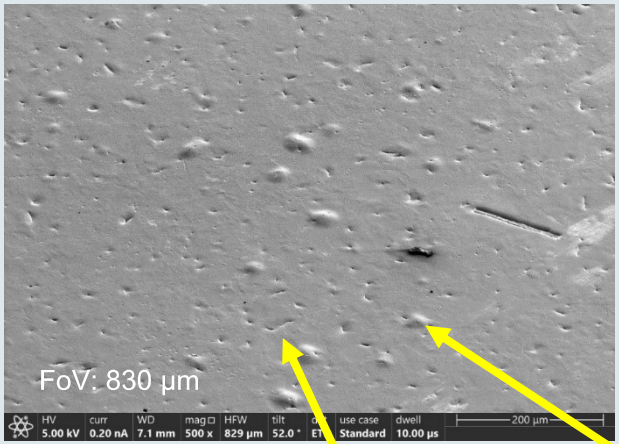


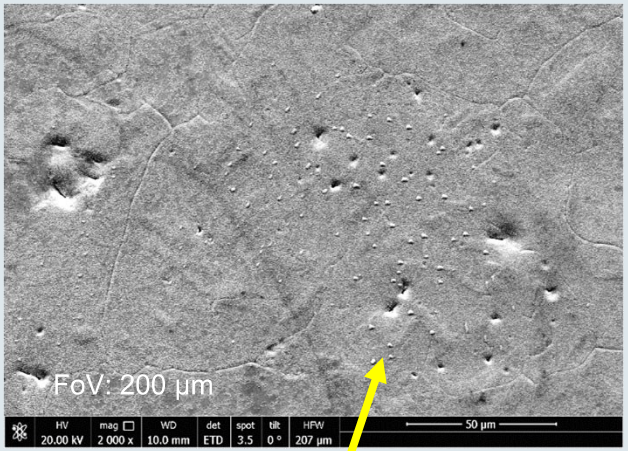
What‘s beneath the surface?
What causes the defects (hillocks, hollows, cracks)?

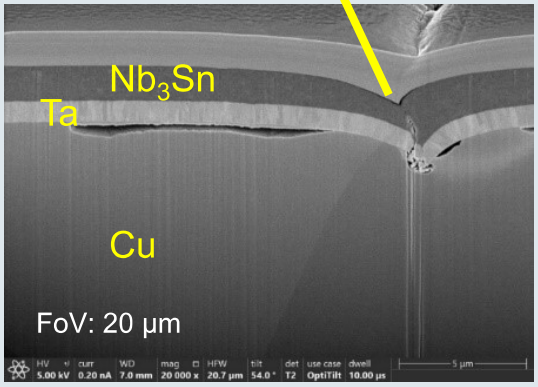
Hillocks and hollows

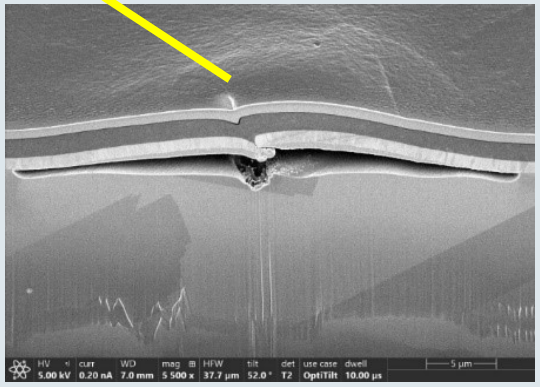


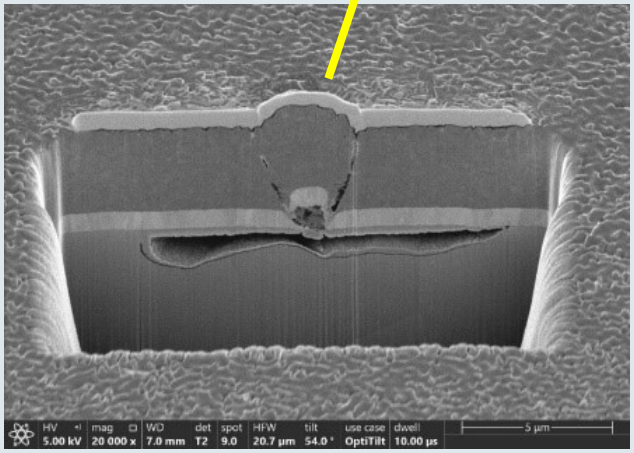
Damages in Cu substrate



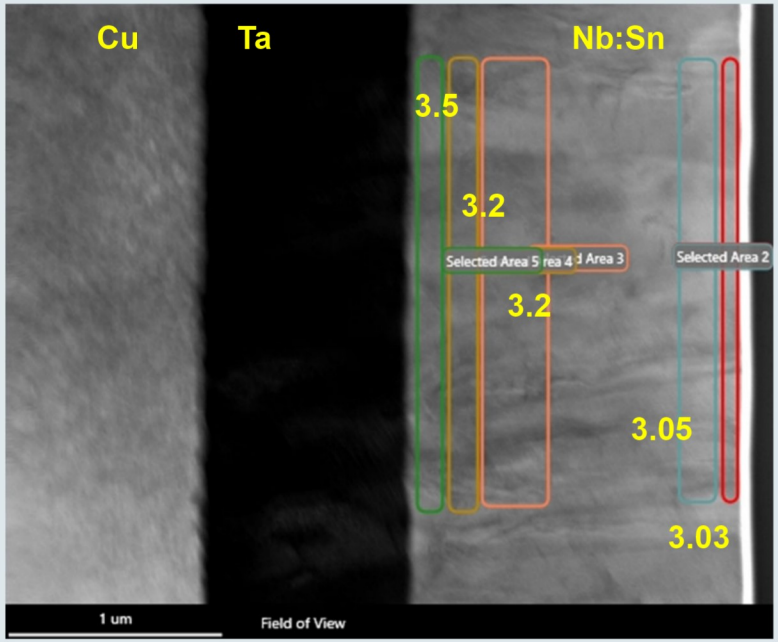




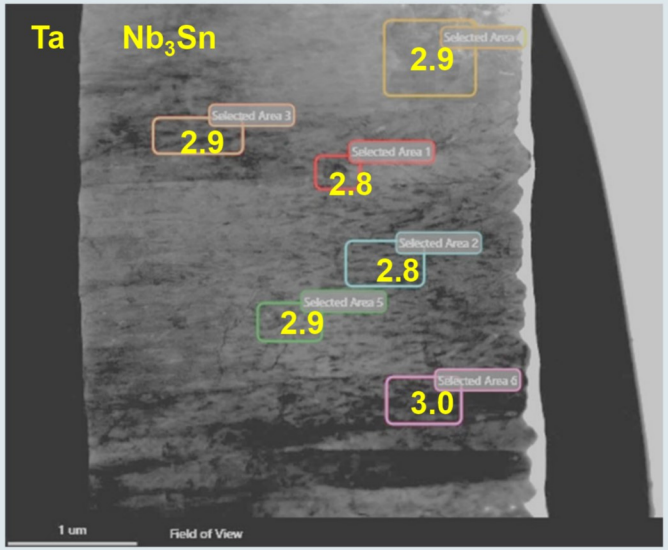




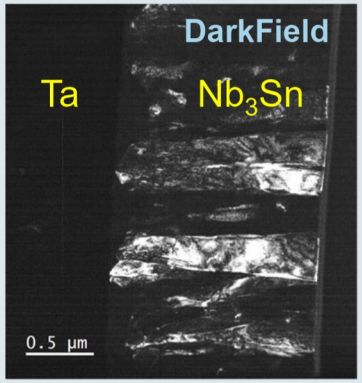
Homogeneity of Nb_3Sn film



	Ta Layer		Annealing		Coating				Annealing	
#	(°C)	(min)	(°C)	(min)	Sn %	(mbar)	(°C)	(min)	(°C)	(mbar)
A	750	40	750	45	25%	7,00E-04	750	120		



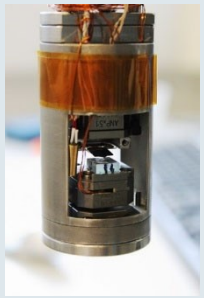
	Ta Layer		Annealing		Coating				Annealing	
#	(°C)	(min)	(°C)	(min)	Sn %	(mbar)	(°C)	(min)	(°C)	(mbar)
B	750	40	750	45	25%	2,50E-02	750	120		

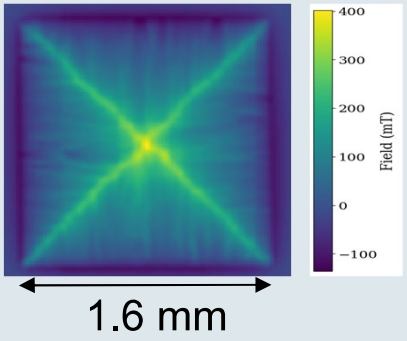


- Smooth surface
- Large columnar grains
- No Cu at GB
- But: Inhomogeneous Nb:Sn ratio

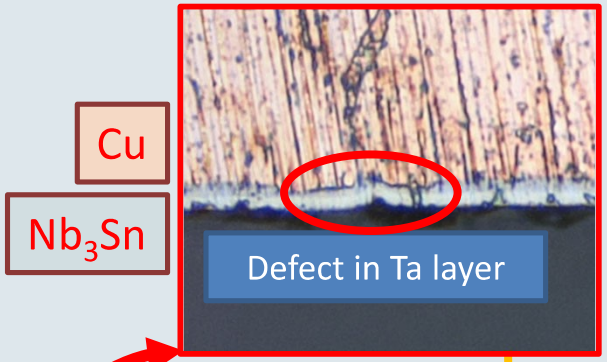
- Rougher surface
- Defects on Cu → surface defects
- Homogeneous Nb:Sn ratio

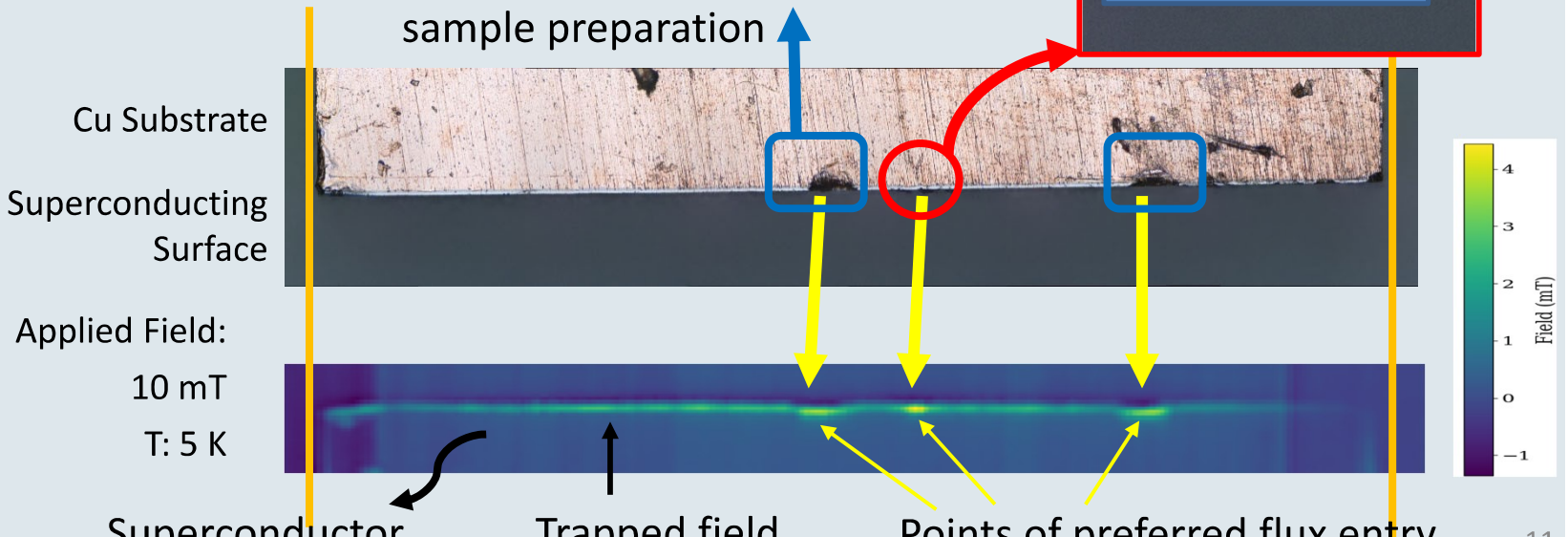
Remnant (trapped) field at one edge



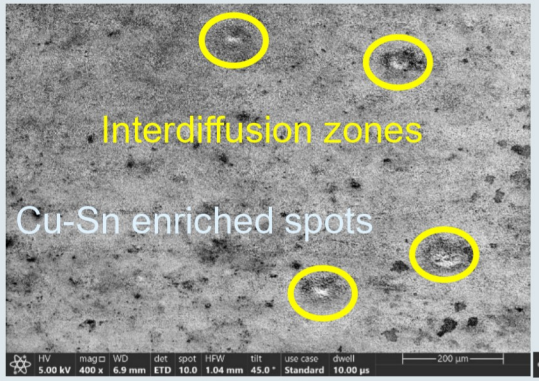


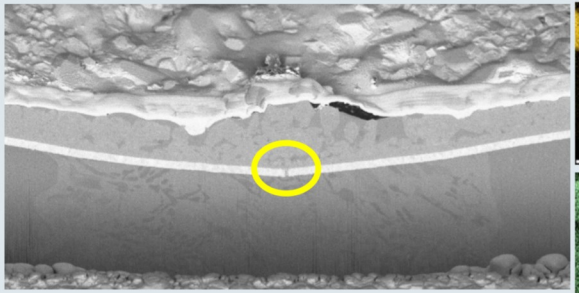
Scanning Hall measurements
Macroscopically homogeneous sample

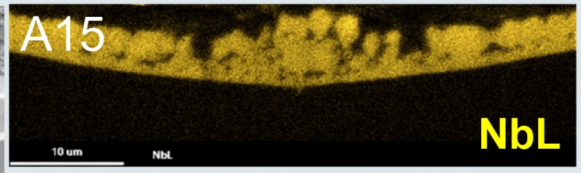


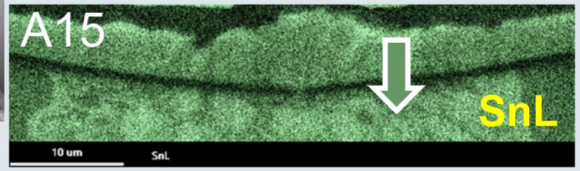


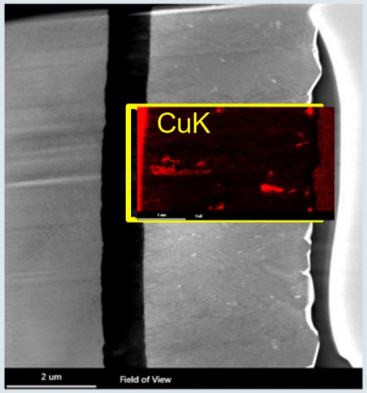
Damaged Ta interlayer

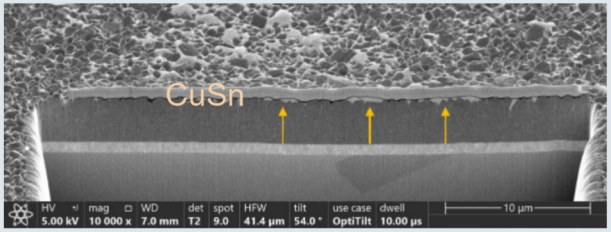


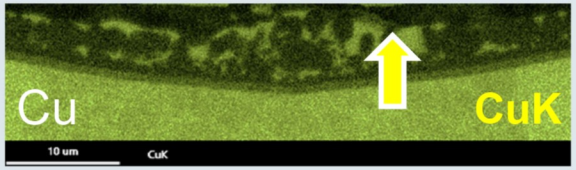


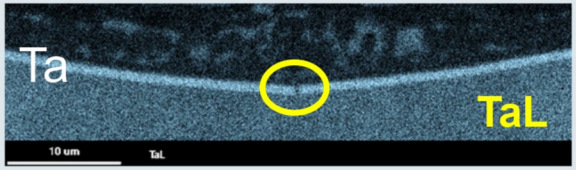








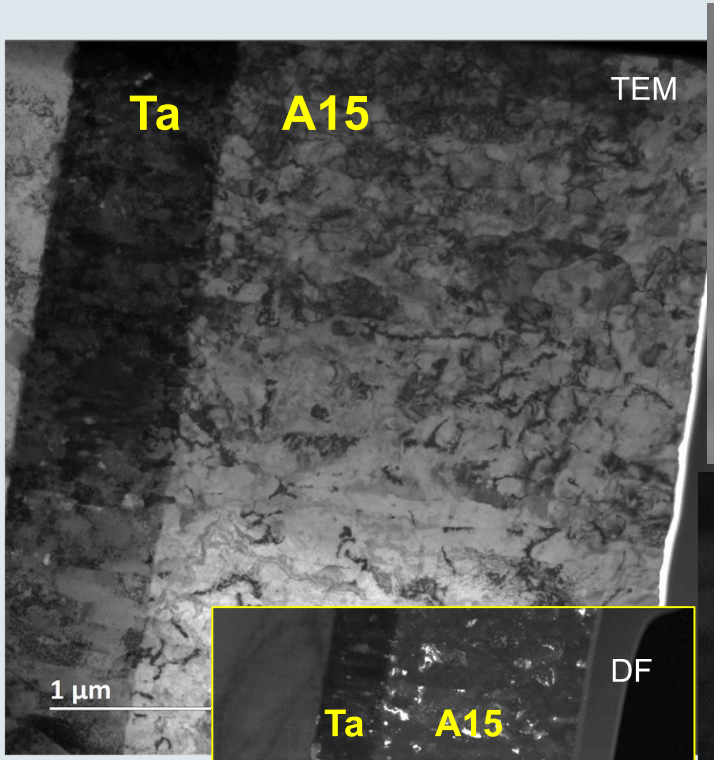


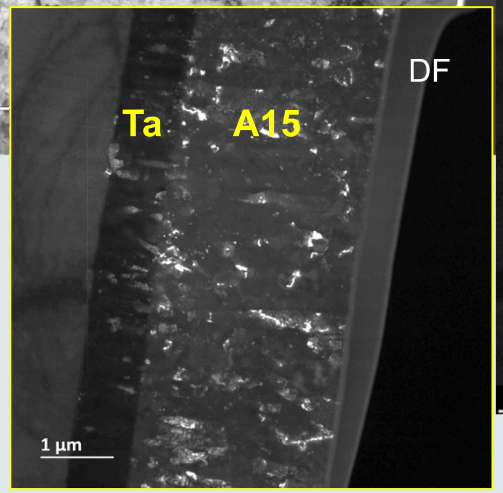


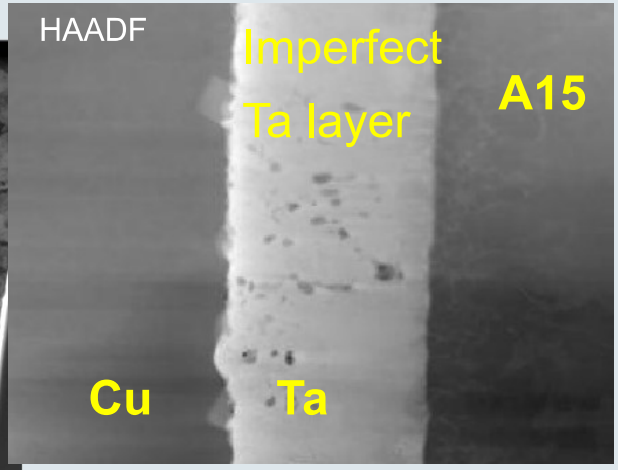
	Ta Layer		Annealing		Coating				Annealing	
#	(°C)	(min)	(°C)	(min)	Sn %	(mbar)	(°C)	(min)	(°C)	(mbar)
C	175	40			27%	2,50E-02	750	120		

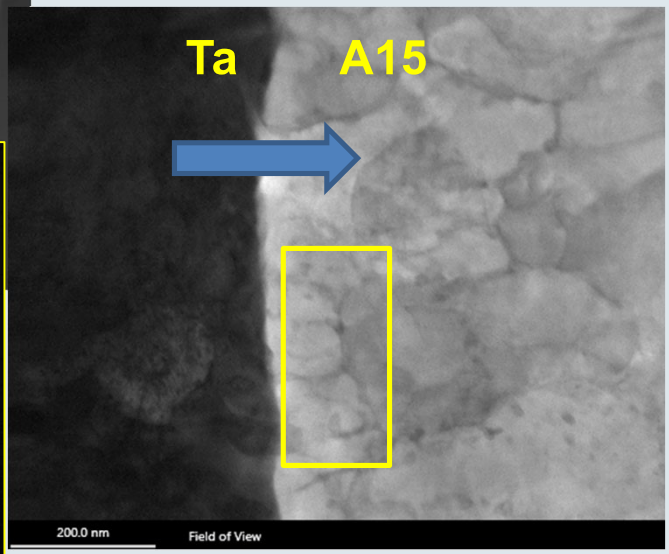
- Crack in Ta layer → interdiffusion of Cu
- High pressure coating → rough surface
- Cu and Sn enriched areas on the surface

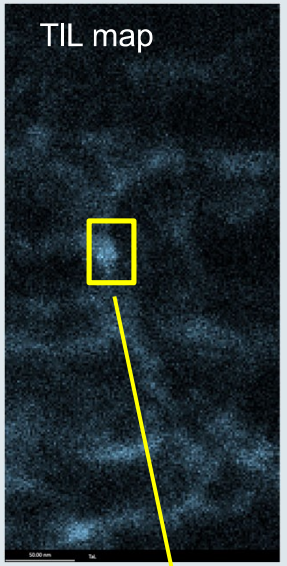
Imperfect Ta interlayer

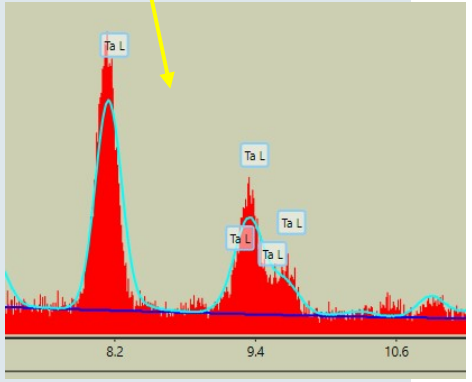




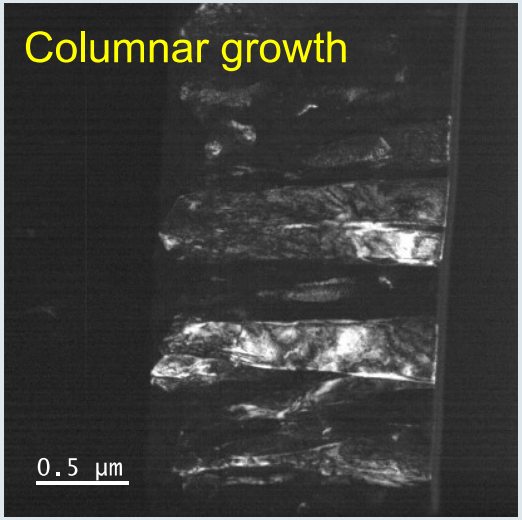


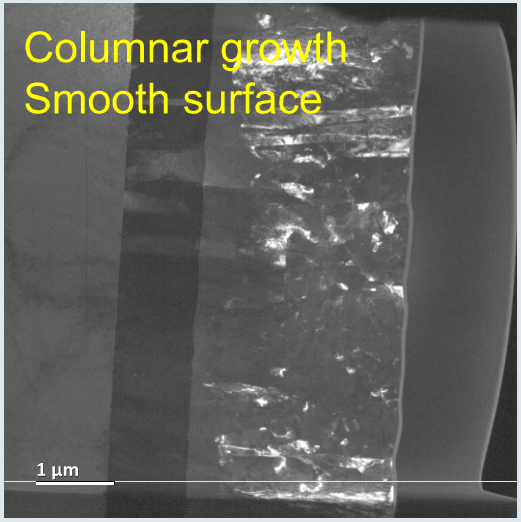


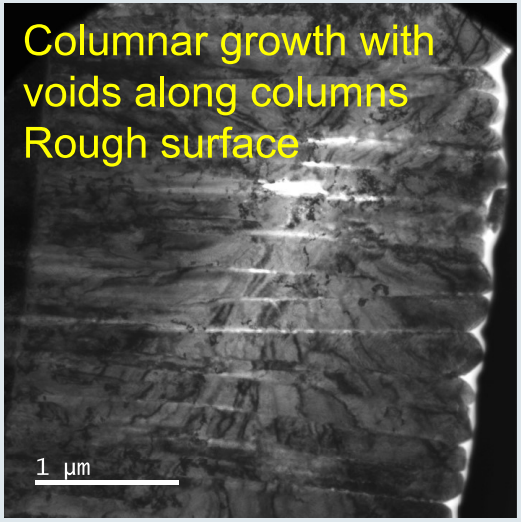


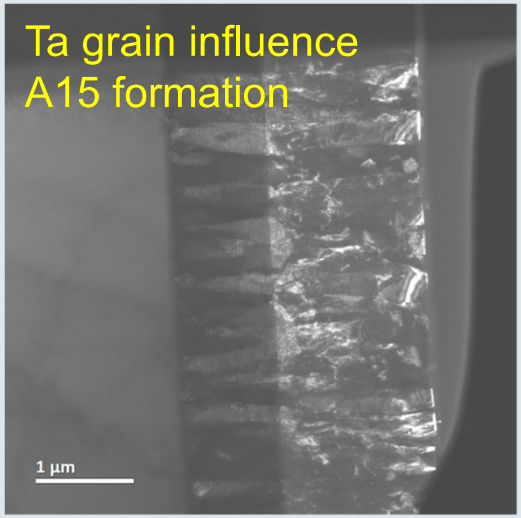


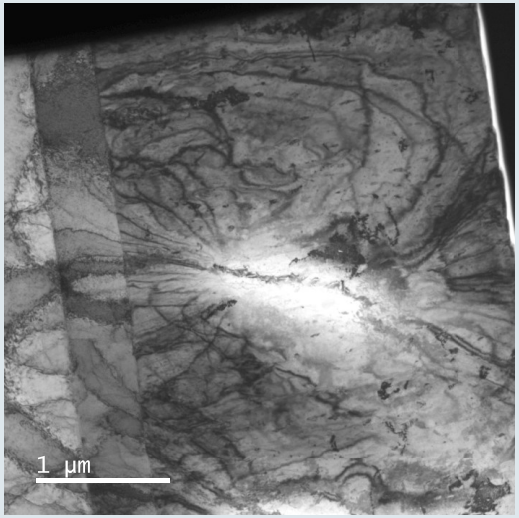
Microstructure of Nb_3Sn layer

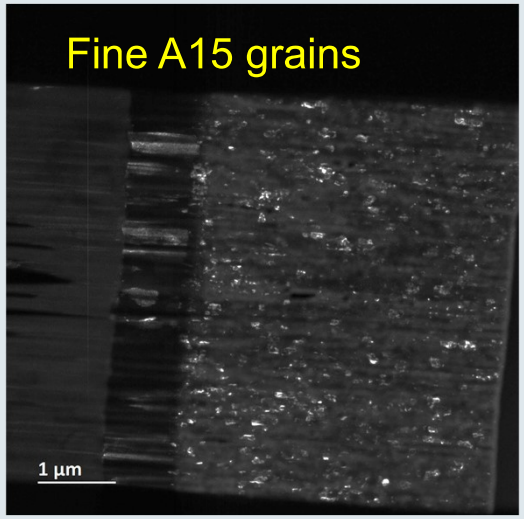




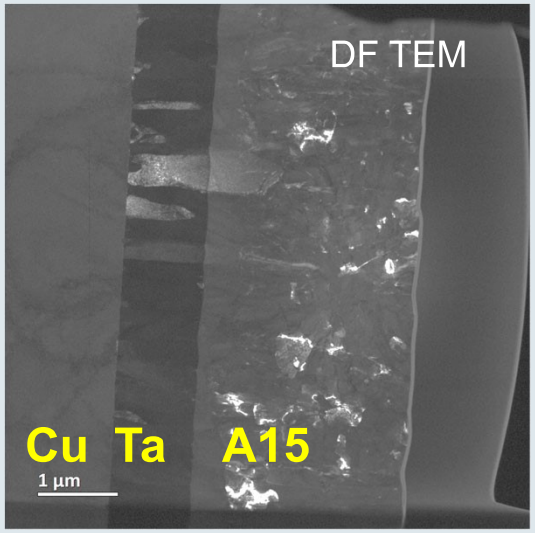


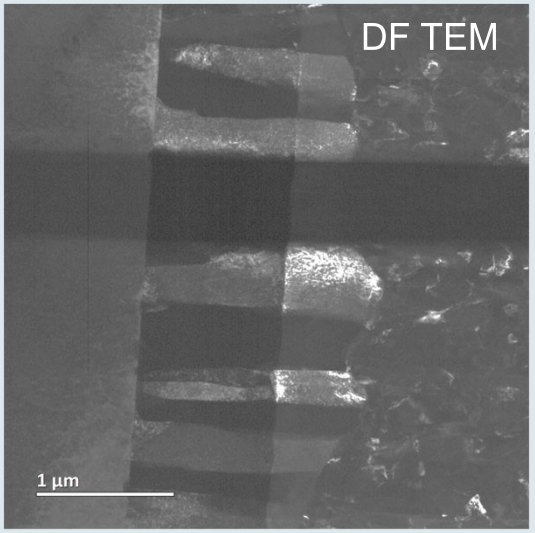


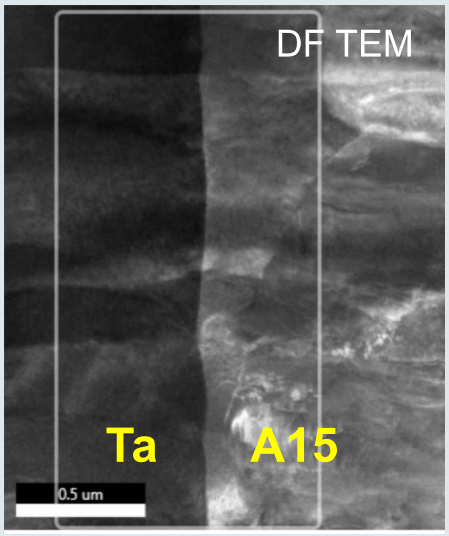




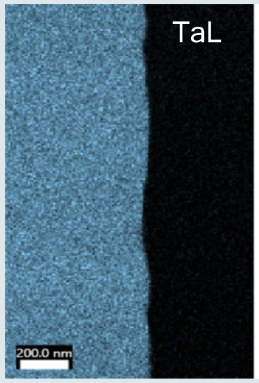
Ta - A15 interface

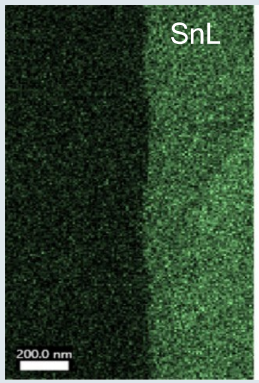


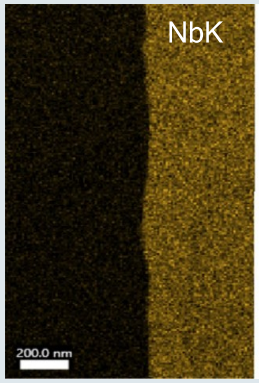




The orientation of the Ta grains appears to influence the orientation of the A15 grains.







Summary RF cavities

- ☺ Bipolar HIPIMS: suitable technique for producing good Nb_3Sn layers
- ☺ Homogeneous Nb_3Sn layers can be formed

Surface quality depends on pressure during coating

- ☛ Quality of the Ta interlayer is decisive for homogeneous Nb_3Sn layers
- ☛ Purity of the Cu surface is the top priority