Growth Mechanism and Kinetics of Nb_3Sn in Vapor Diffusion Process

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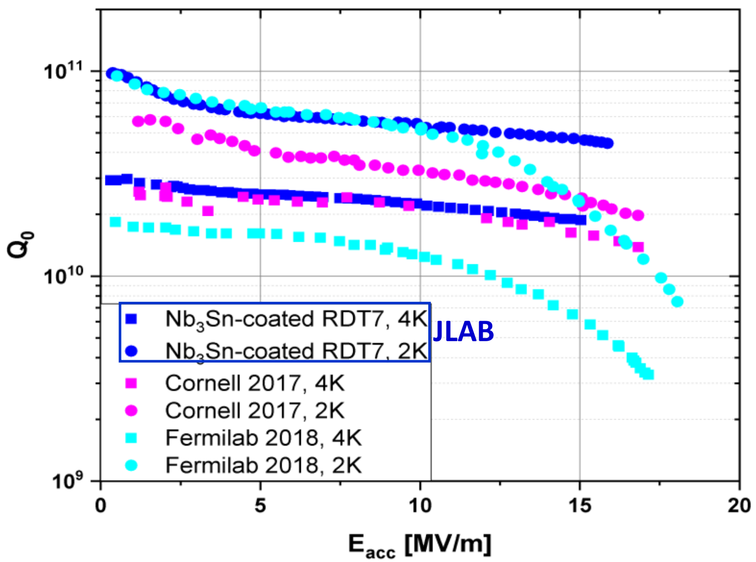
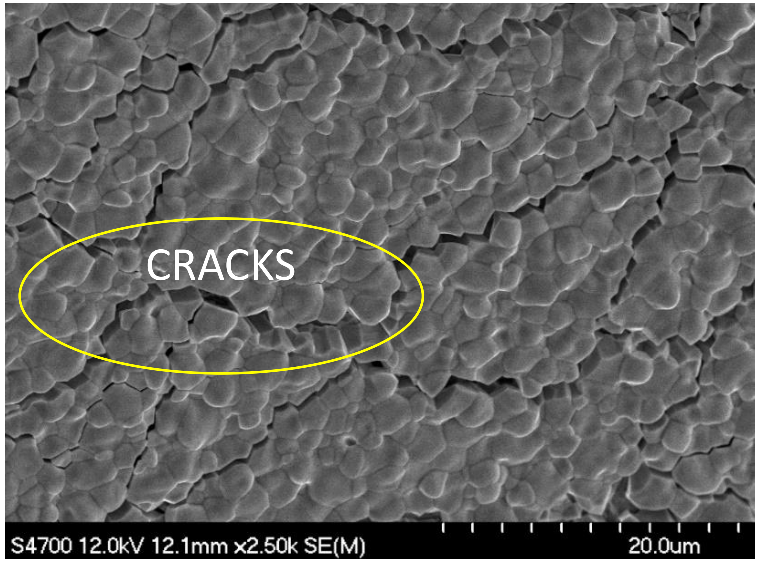
Outline

- Nb_3Sn
- Coating growth in vapor diffusion process
  - Nucleation
  - Growth kinetics
- Summary

Nb_3Sn: future SRF cavity material

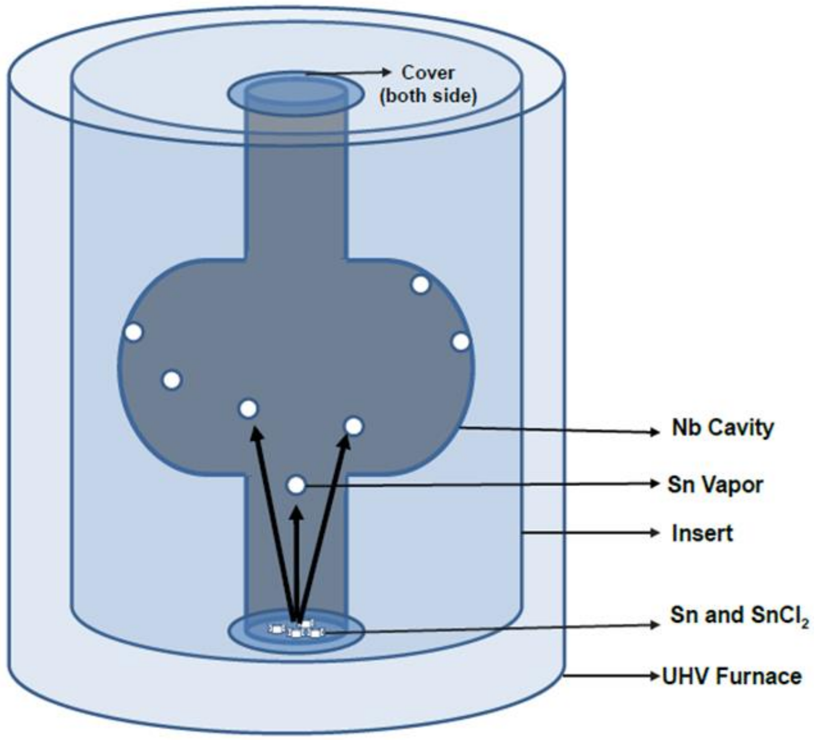
	Nb	Nb_3Sn
T_c (K)	9.25	18.3
H_{sh} (mT)	200	400
Δ (meV)	1.45	3.1
Q^{BCS} at 2K	5×10^{10}	5×10^{14}
Q^{BCS} at 4K	5×10^{8}	5×10^{10}
E_{acc} (MV/m)	50	100

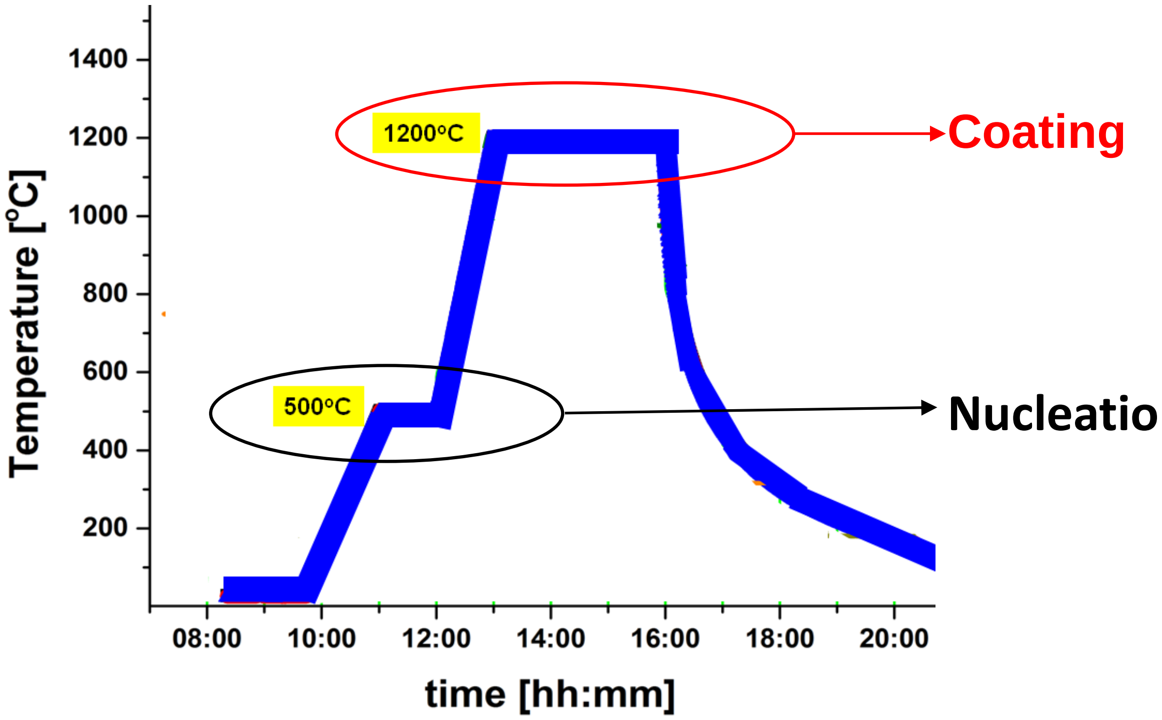




+ Nb cavities are approaching the intrinsic material limit for the pure material.
+ Higher T_c and H_{sh} of Nb_3Sn promise **better RF performance** (Q_0 and E_{acc}) and/or **higher operating temperature** (2 K Vs 4.2 K).
- Extremely brittle material with lower thermal conductivity restricts application into a thin film/coating form.

Vapor diffusion process



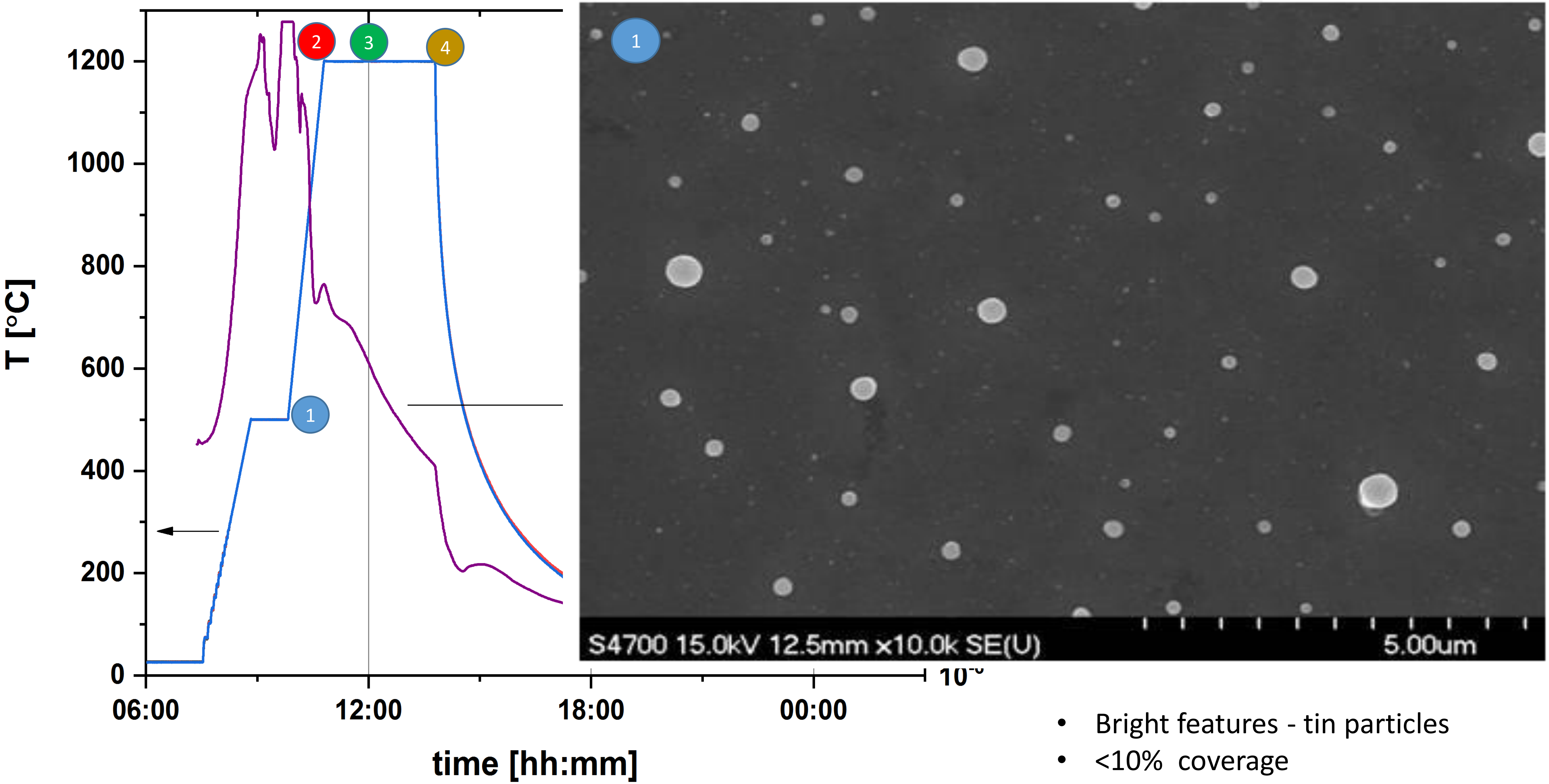


Some variations:

- Separate heater for tin source
- Different temperatures profile for substrate and Sn source
- Pre-anodization
- Active/passive pumping

Most successful technique so far to produce promising cavities.

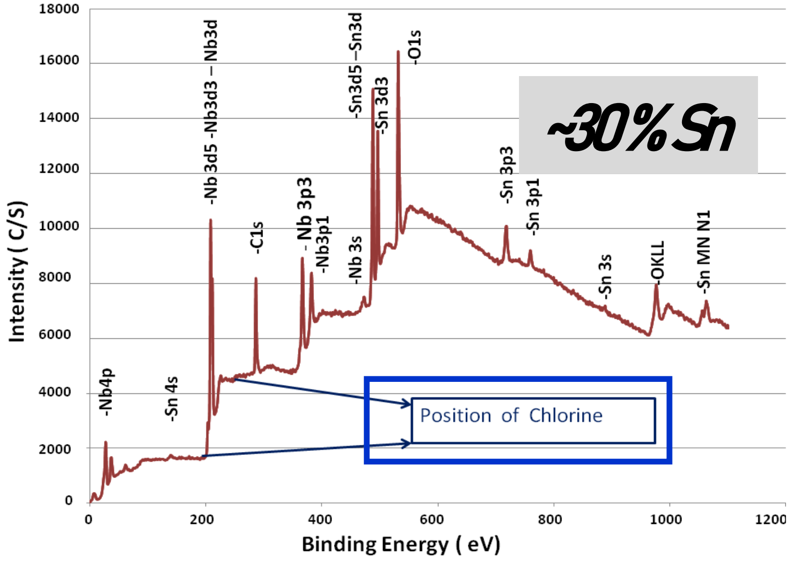
Nb_3Sn coating evolution during vapor diffusion process



- Bright features - tin particles
- <10% coverage

Nucleation

Surface analysis shows ultra-thin tin film of Sn beside Sn particles.



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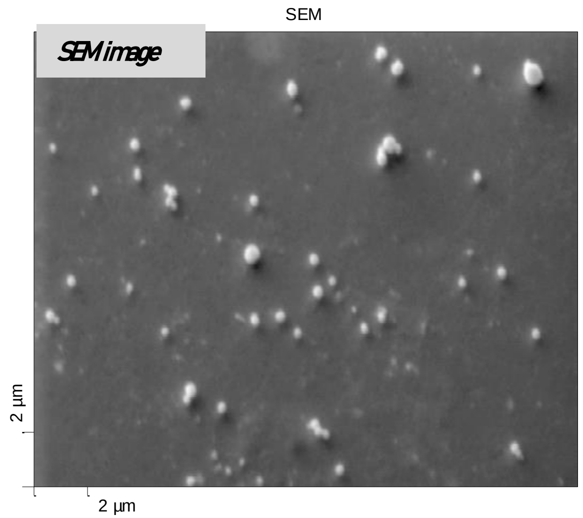
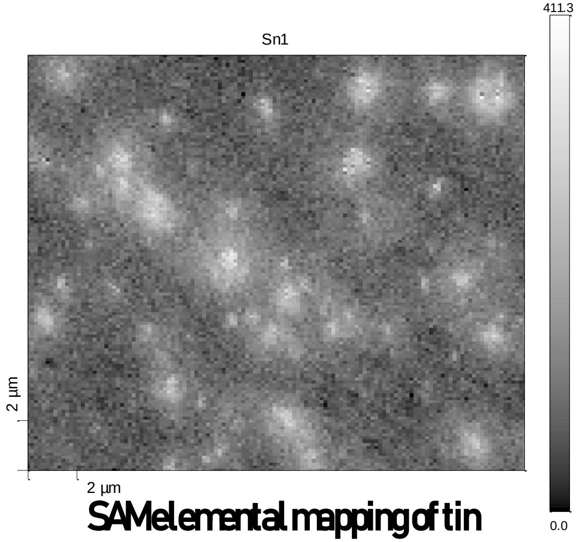
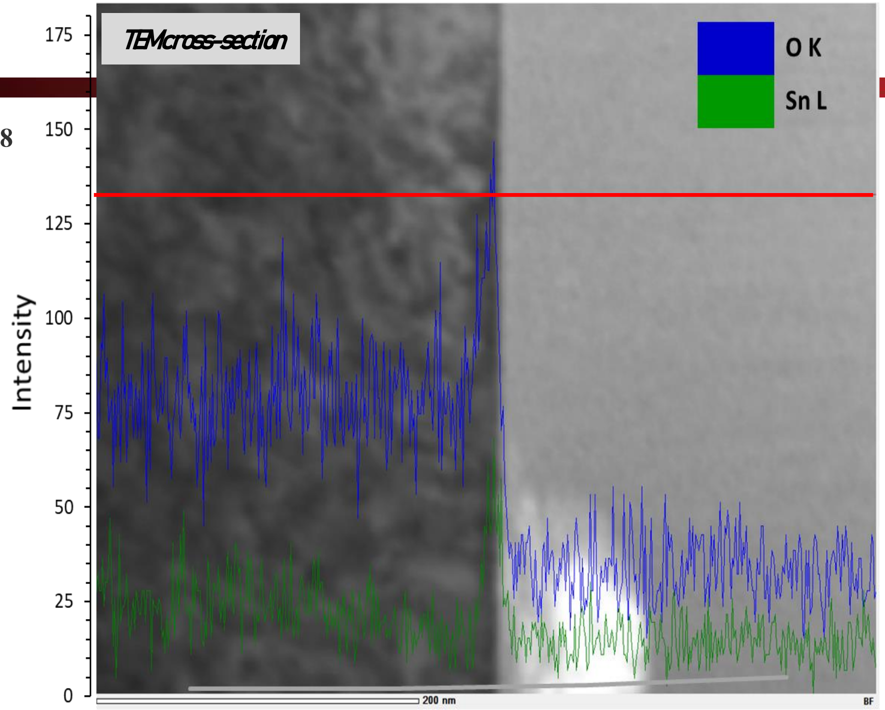
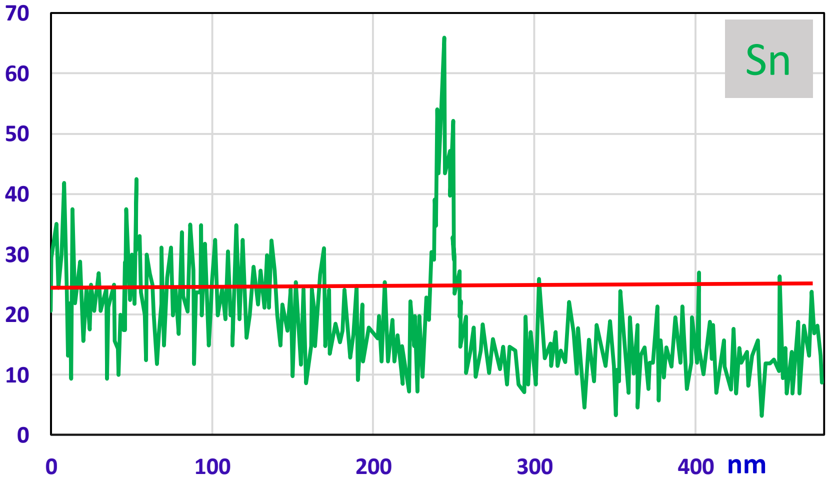


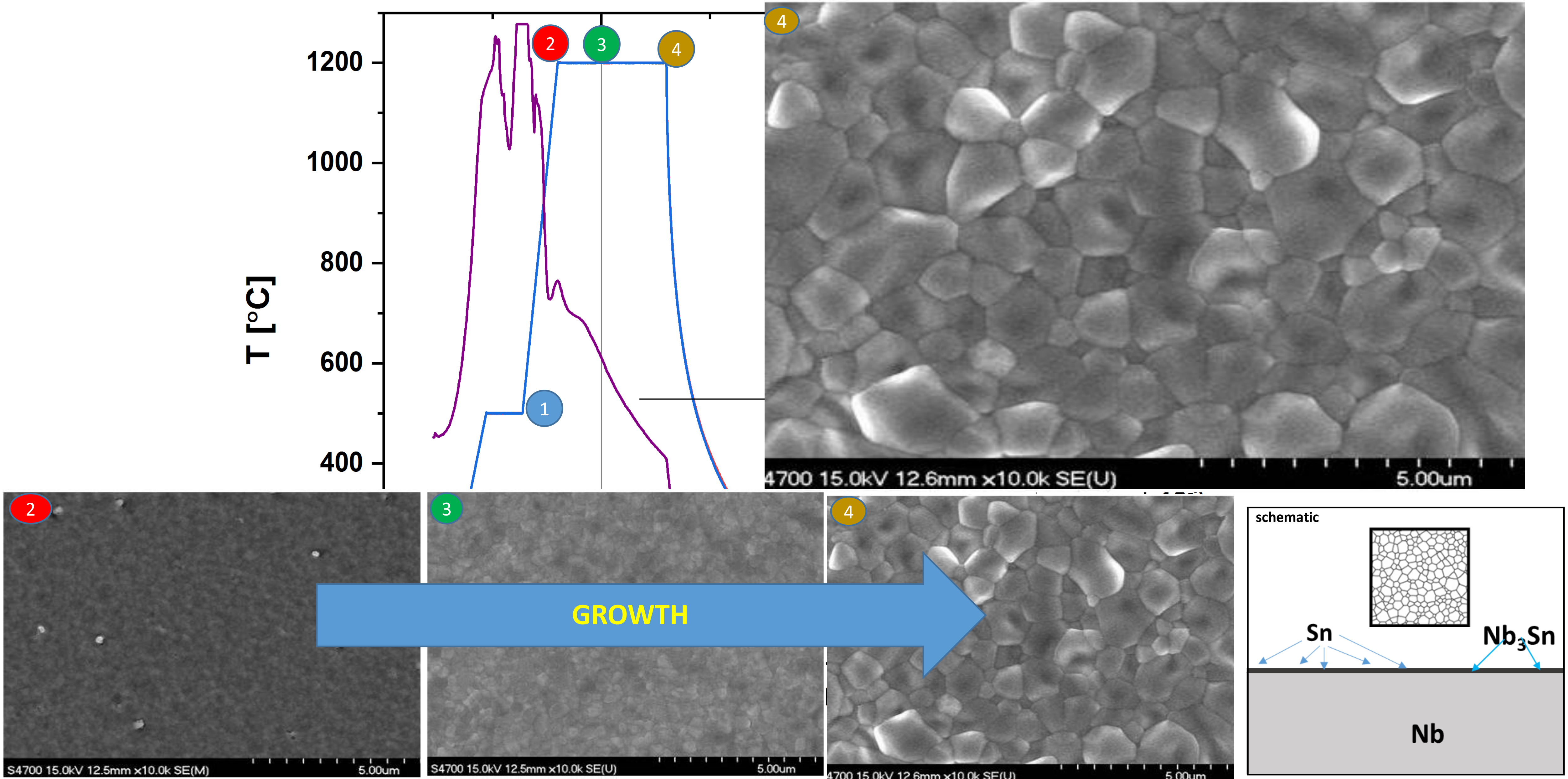






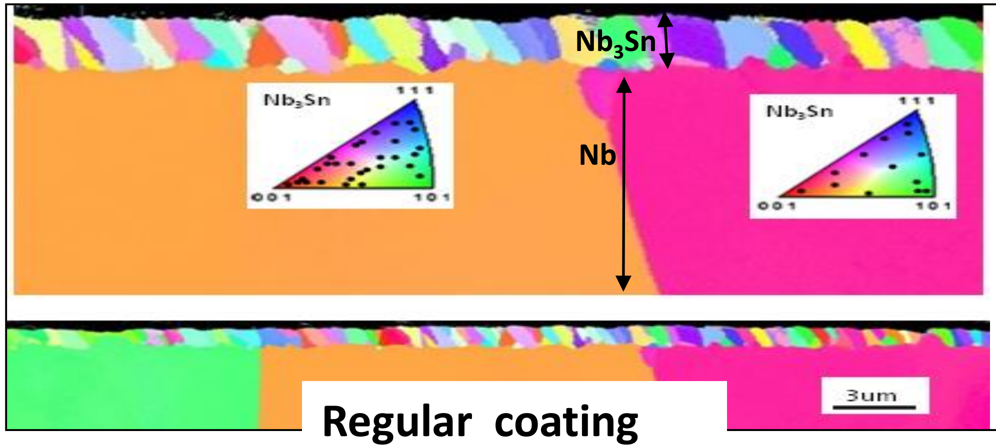
- Significantly lower amount of $SnCl_2$ also produces similar surface with smaller tin particles.
- Advantageous to have uniform coating.

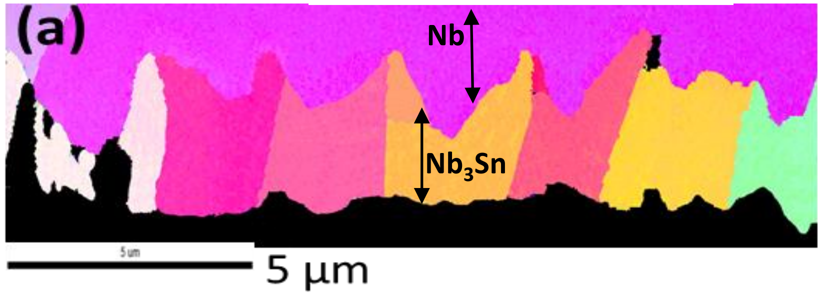
Nb_3Sn coating evolution during vapor diffusion process

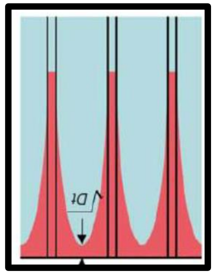


Overcoat experiment: grain boundary diffusion

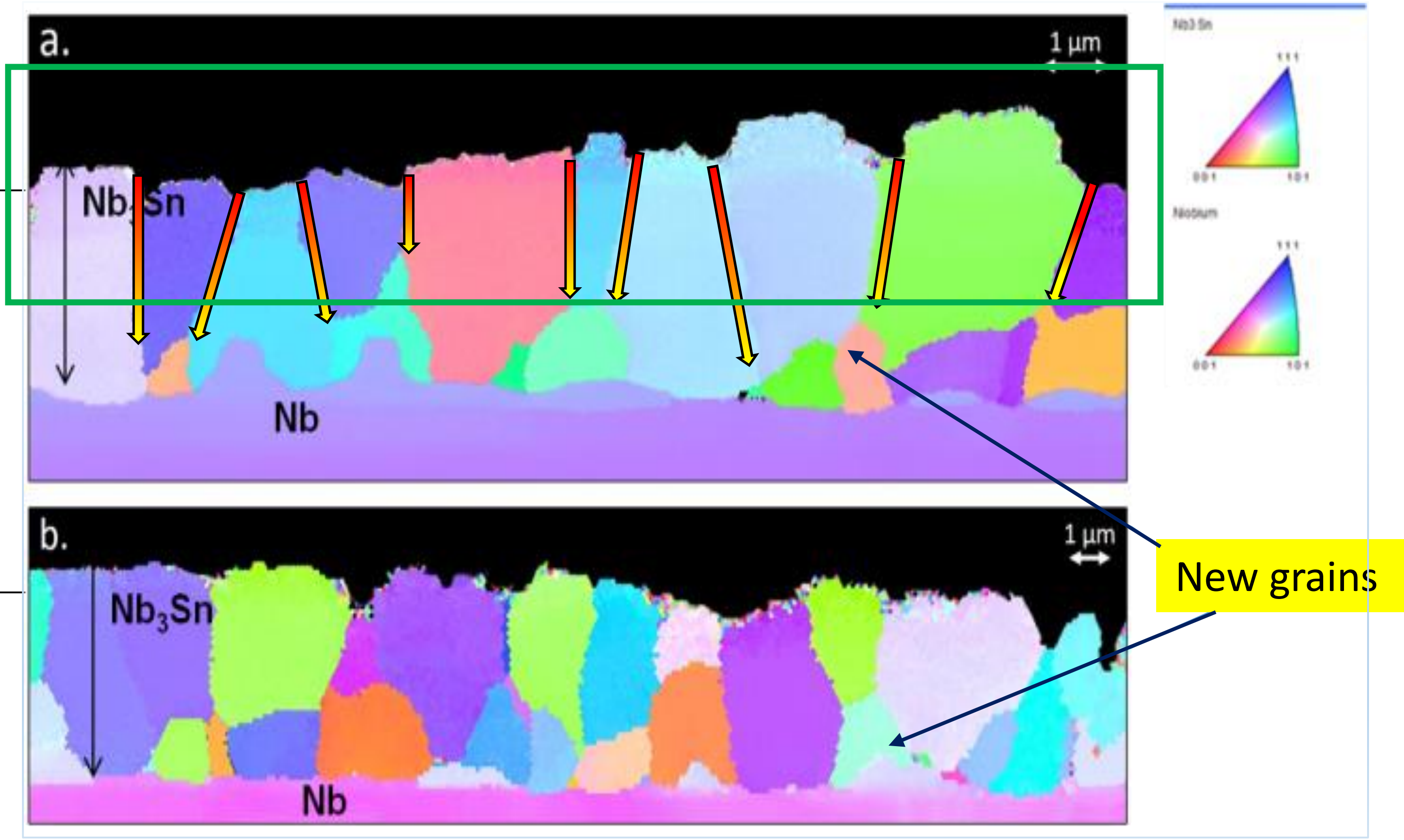
- Grain boundary diffusion is the primary mode of tin transportation.
- Additional coating forms at the interface.





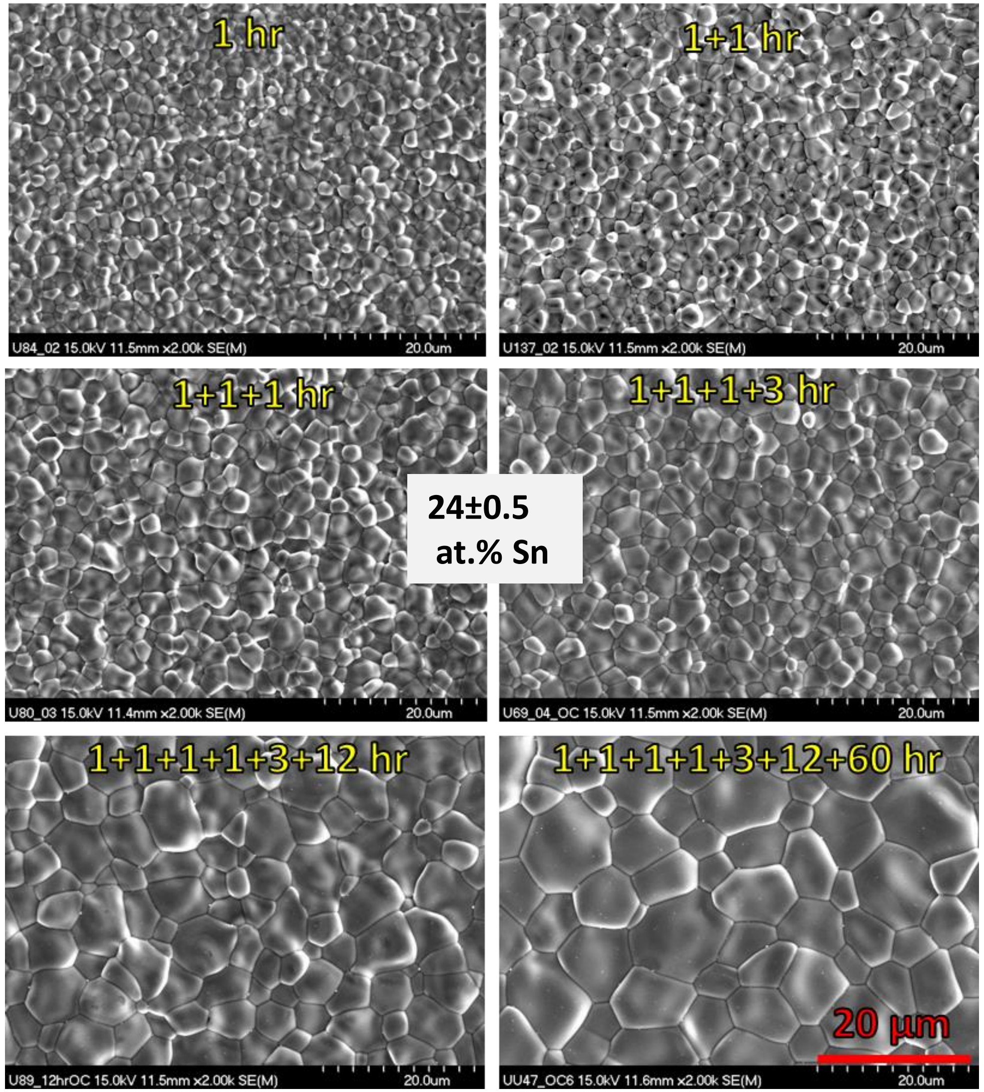


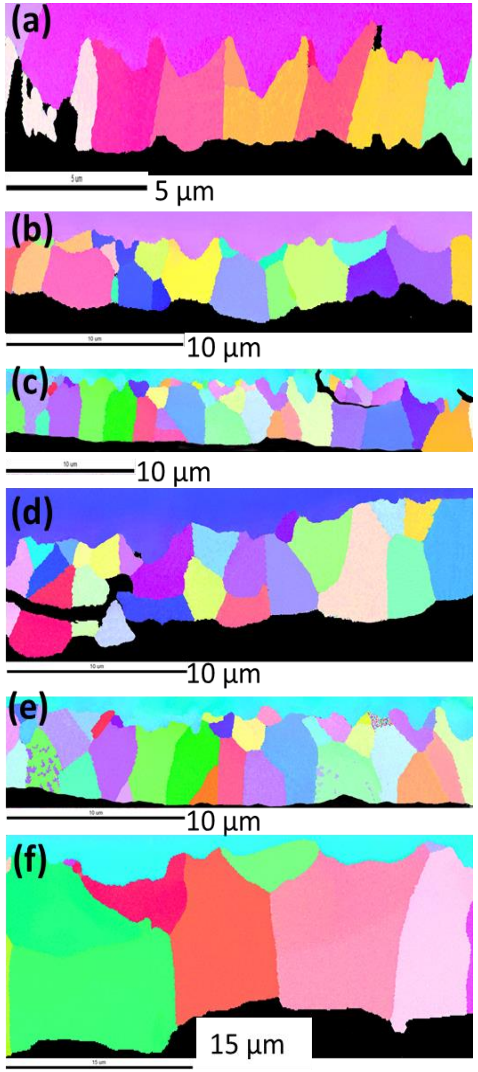
Overcoat



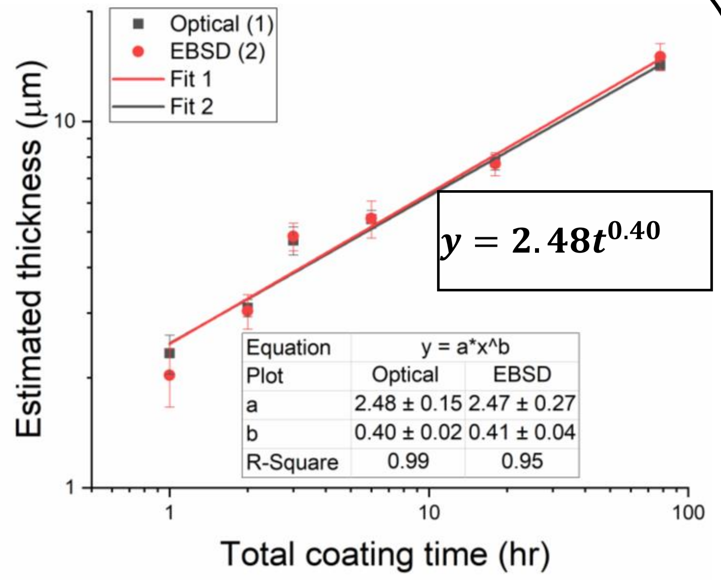
Sequential overcoat experiments

Experiment	Coating time (hr)	Total coating time (hr)
Single coat	1	1
1st overcoat	1	2
2nd overcoat	1	3
3rd overcoat	3	6
4th overcoat	12	18
5th overcoat	60	78

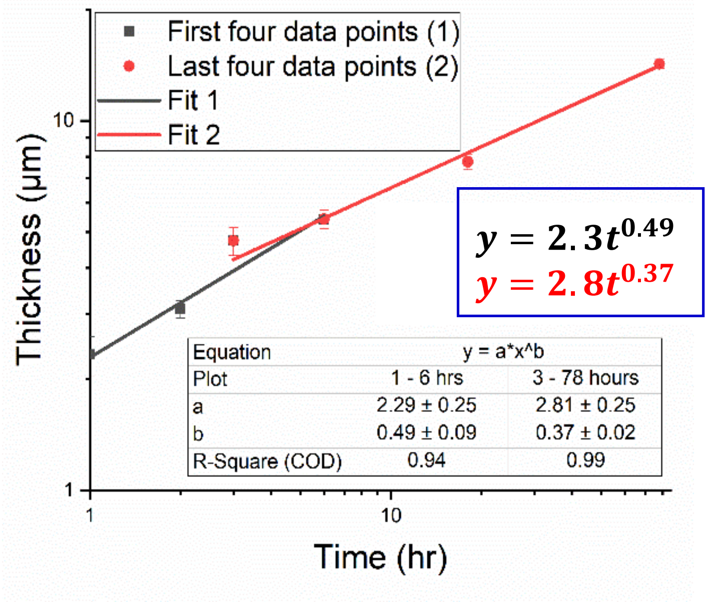




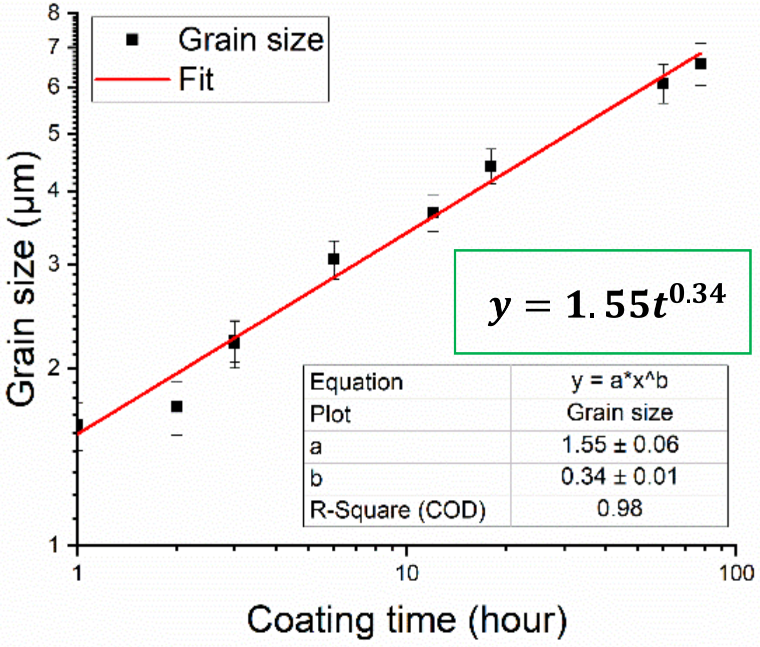
Growth kinetics



- Follows power law: non parabolic growth
- Diffusion controlled??



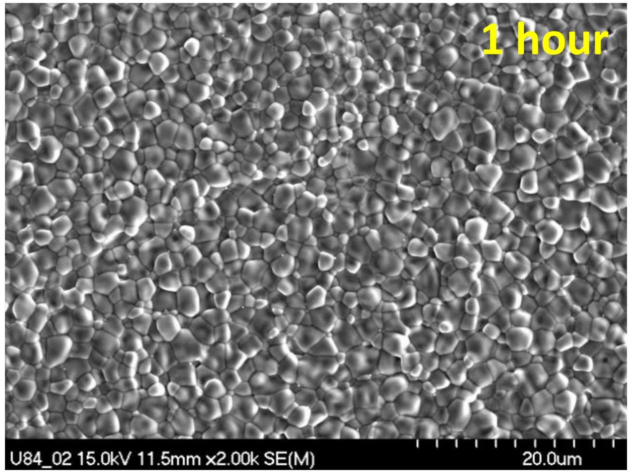
- Faster growth at the beginning, slows down with longer coating

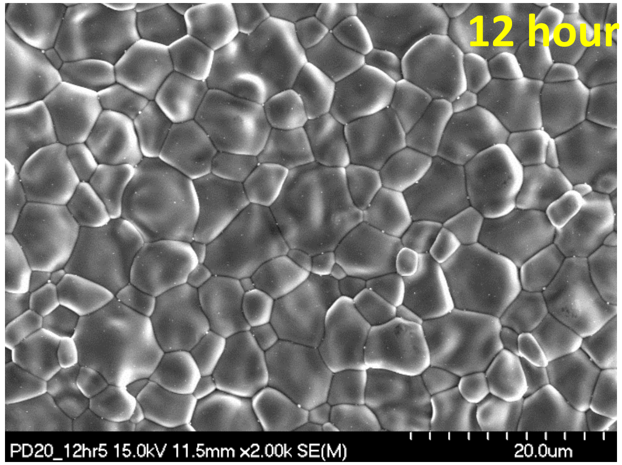


- Grain size follows power law

Coating thickness, grain boundary diffusion and grain growth

- Bulk diffusion or fixed array of GB diffusion – should show parabolic law ($y^2 \propto t$).
- Why coating thickness does not follow parabolic relation with time?





- Substantial increase in grain size: reduced number of diffusion paths
- Reduced number of diffusion path: depletion of Sn supply at the growth interface – reduction in growth rate.
- Longer diffusion path following increased thickness of the coating

$$z = \beta(T)t^{0.5(1-m)}$$

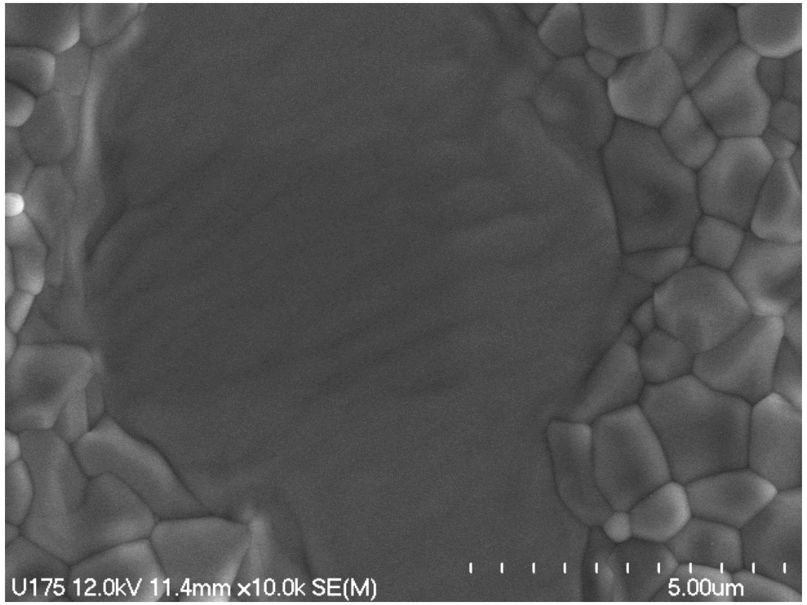
Thickness growth exponent

Grain growth exponent

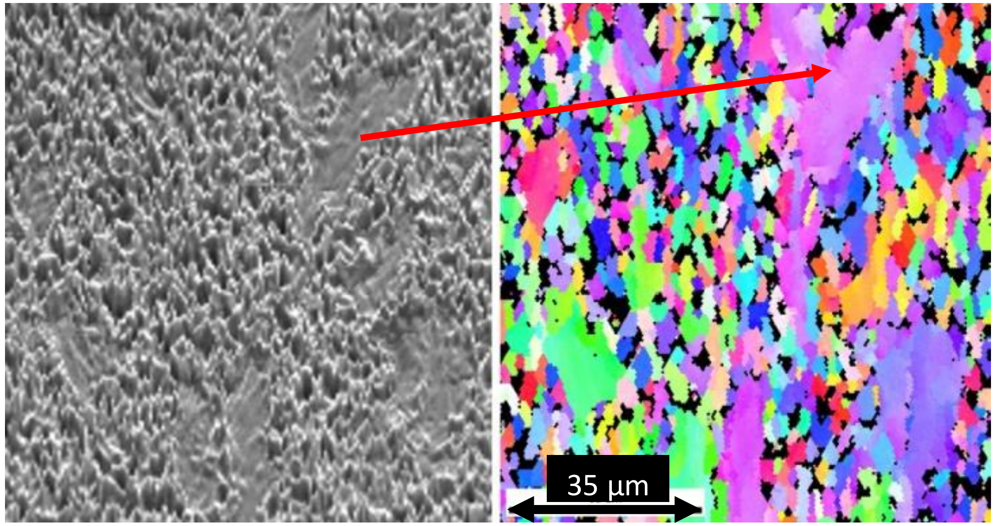
H. H. Farrell, G. H. Gilmer and M. Suenaga, *J. Appl. Phys.*, vol. 45, (9), pp. 4025-4035, 1974.

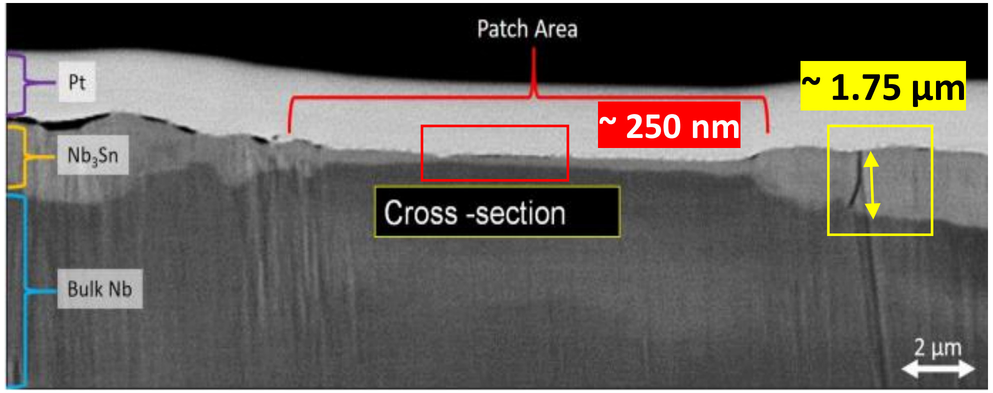
Patchy region

- Consistently reported by several labs
- EDS: Low tin concentration compared to normal coating
- Size: as small as 5 µm to as large as 100 µm
- Cross-section: relatively thin layer
- Potentially affects RF performance



Patchy region has only a few grain boundaries at perimeter for downward diffusion of tin resulting in slowdown of grain growth.





Summary

- **Two-step vapor diffusion** is the technique of choice, producing promising Nb_3Sn cavities.
- 3D Tin particle and 2D tin film formation during the nucleation step of the coating is **advantageous** to have the uniform coating.
- Following nucleation, tin evaporates from tin source to form Nb_3Sn layer at the niobium surface. Grain boundary diffusion of tin to the Nb-Nb_3Sn interface defines further growth of the coating.
- Non-parabolic relationship between coating thickness and time ($y^2 \not\propto \boldsymbol{t}$) is explained by significant grain growth.
- Low density of grain boundaries results in thin coating in patchy regions.

Acknowledgements

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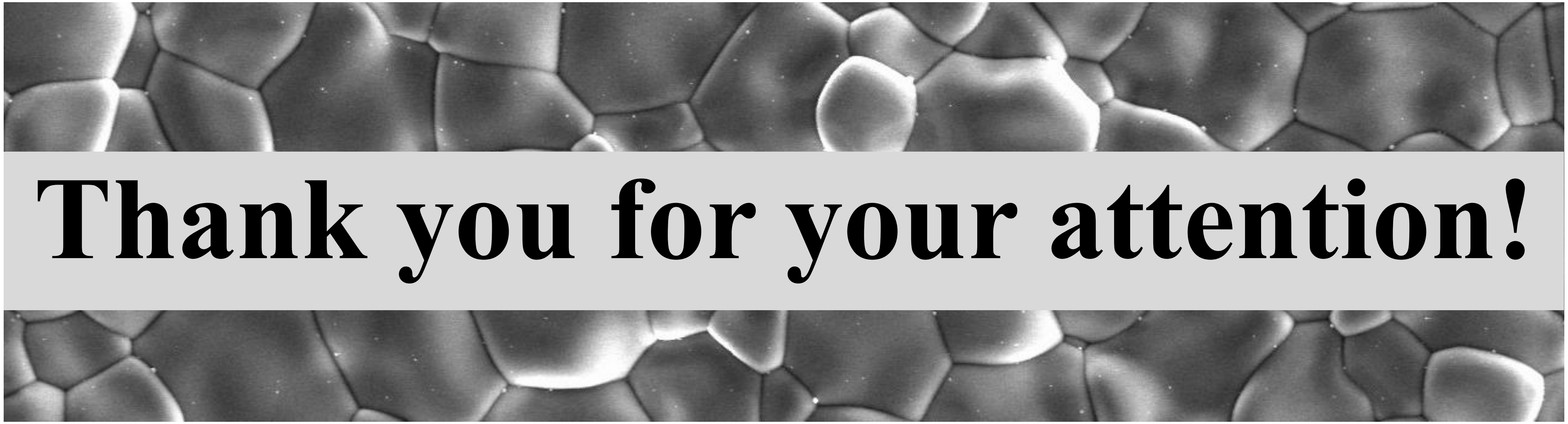
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