Nb_3Sn growth by multilayer sequential sputtering for SRF application

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Outline

- Research motivation and approach
- Characterization results
- RF surface impedance characterization results
- Cylindrical magnetron for cavity coating

Research motivation

Why Nb_3Sn and why magnetron sputtering?

- 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}.
- Disadvantage- brittle structure and lower thermal conductivity.

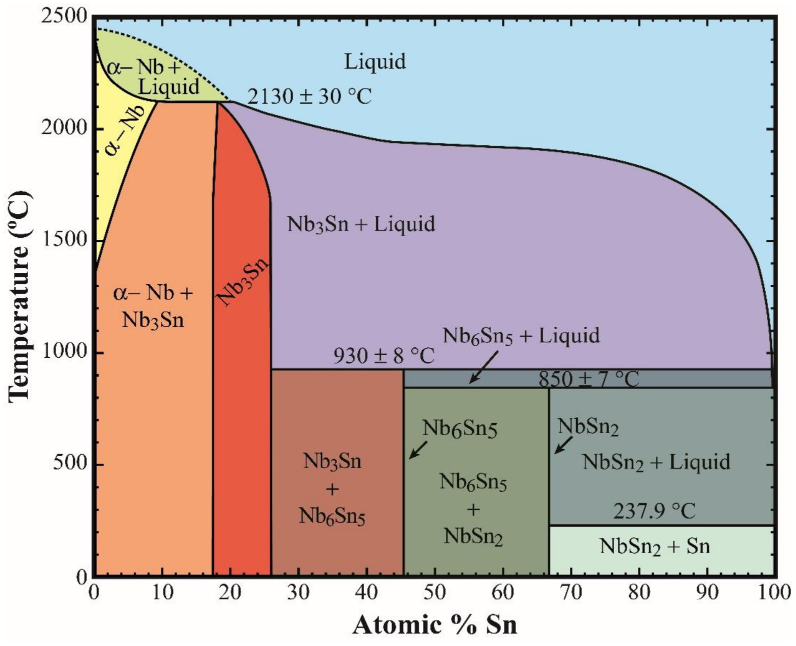
Phase	T_c (K)	H_{sh} (mT)
Nb	9.25	200
Nb_3Sn	18.3	400

Research motivation

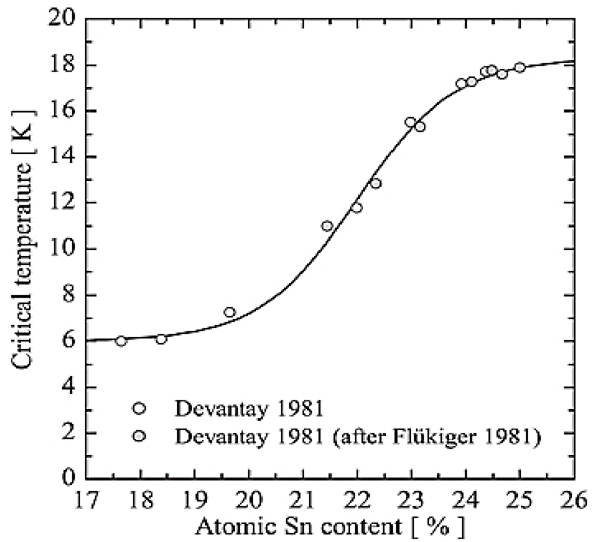
Why Nb_3Sn and why magnetron sputtering?

Advantages of magnetron sputtering:

- Stoichiometry of Nb and Sn can be controlled.
- Uniform Sn composition throughout the grain can be obtained.
- Relatively less annealing temperature is required- possible to use in copper cavities.



Binary phase-diagram of Nb and Sn, adapted from [1].

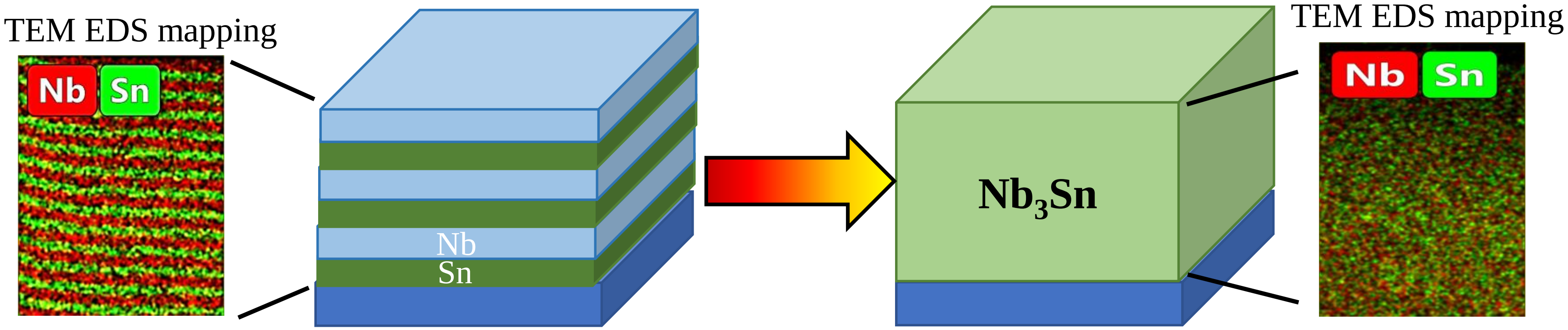


Critical temperature of Nb_3Sn as a function of atomic Sn content [2].

[1] S Posen and D L Hall 2017 Supercond. Sci. Technol. 30 033004
[2] A Godeke 2006 Supercond. Sci. Technol. 19 R68

Nb_3Sn by multilayer sequential sputtering

- Multiple layers of Nb and Sn sputter sequentially.
- Deposition rate: 1 Å/s.
- Sputtering pressure: 3 mTorr 20 SCCM.
- Substrate rotation: 30 rpm.
- Multilayers annealed: 850- 1200 °C, 1- 12 h.



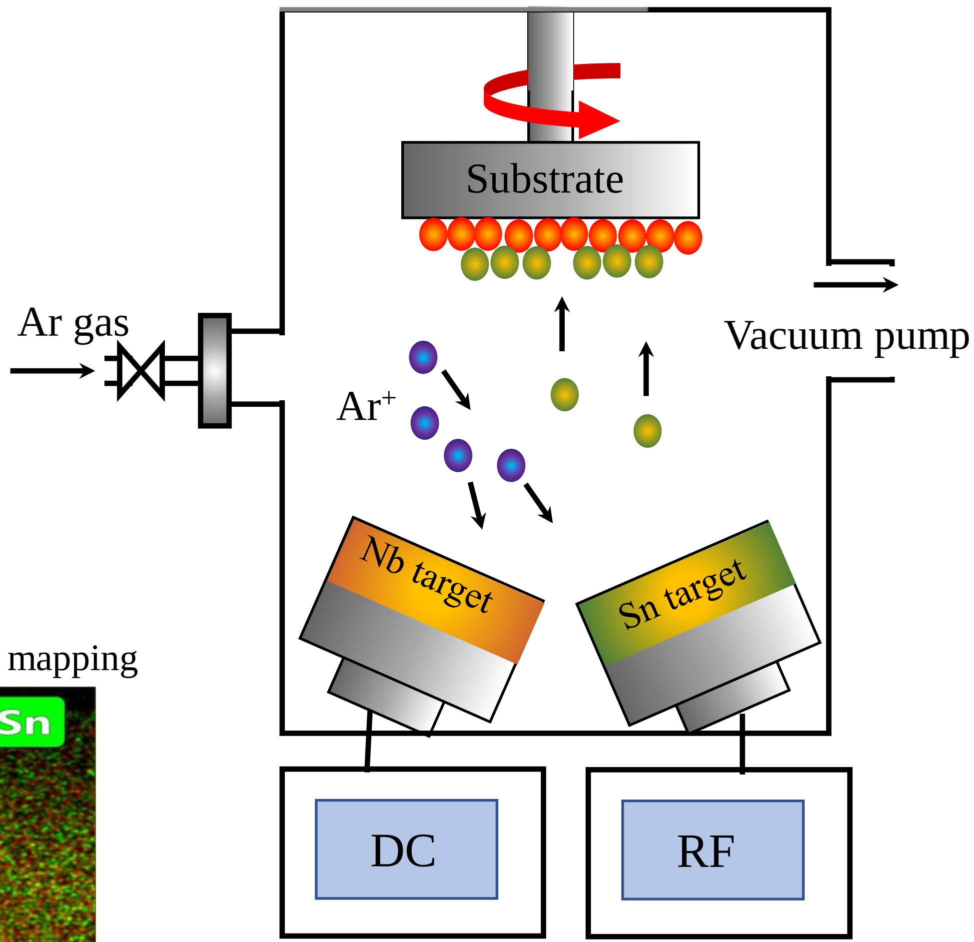


Figure: Schematic diagram of the sequential sputter deposition.

Nb_3Sn by multilayer sequential sputtering

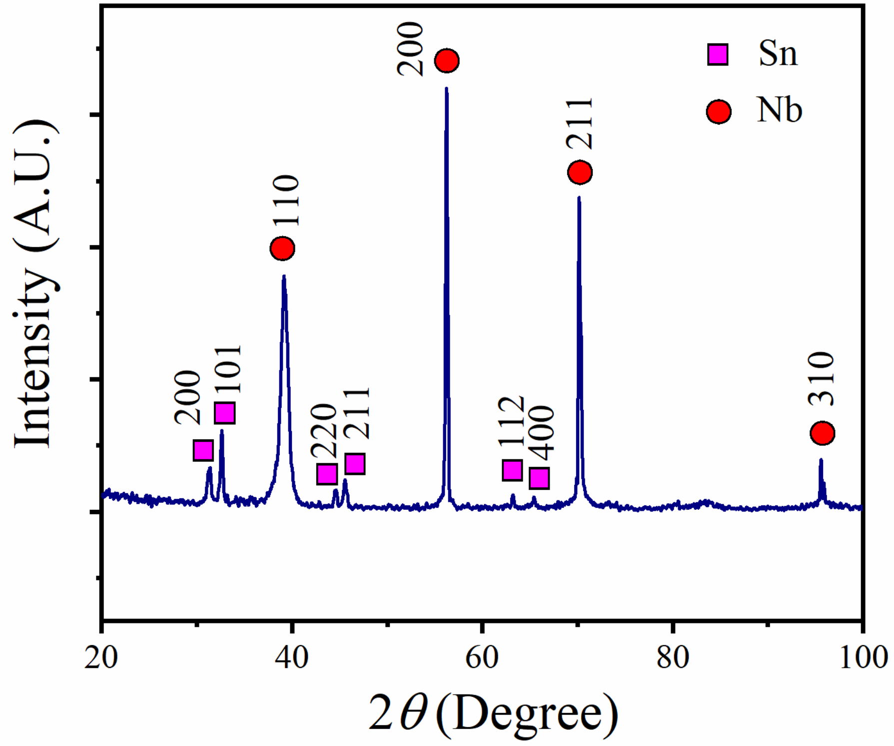
- Parameters to optimize
  - Effect of annealing temperature and time,
  - Effect of thickness,
  - Effect of substrate temperature,
  - Effect of annealing ramp rate.

Effect of annealing temperature

- 1 µm thick multilayer of Nb (20 nm thick) and Sn (10 nm thick) deposited.
- Annealed temperature: 850, 950, 1000, 1100, and 1200 °C for 3 h.

Structural properties

As-deposited film



Annealed film at 950 °C

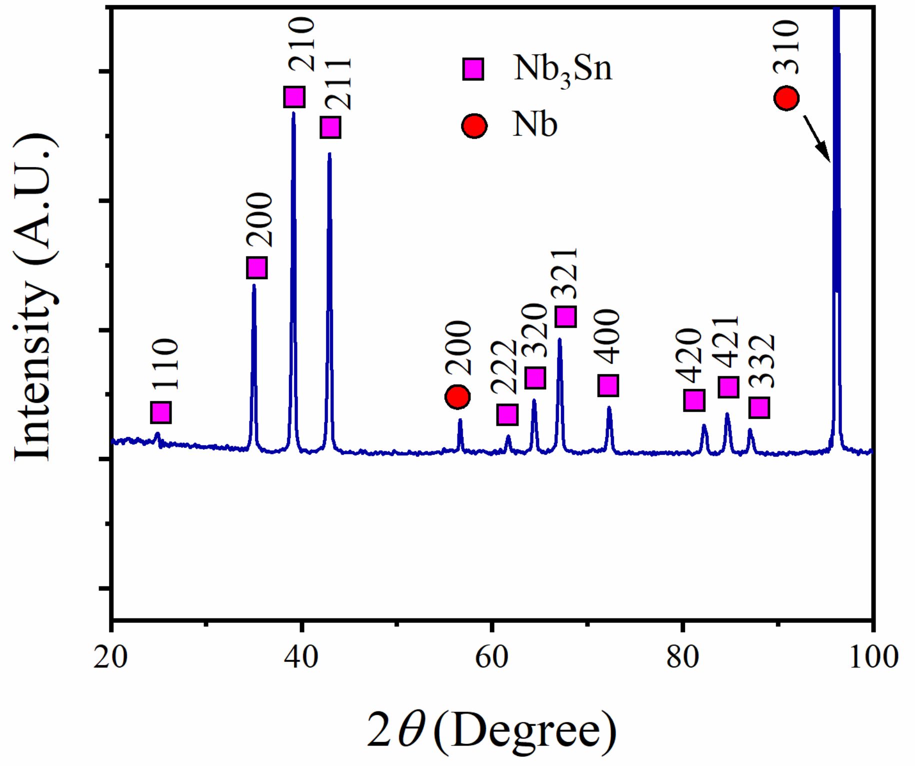
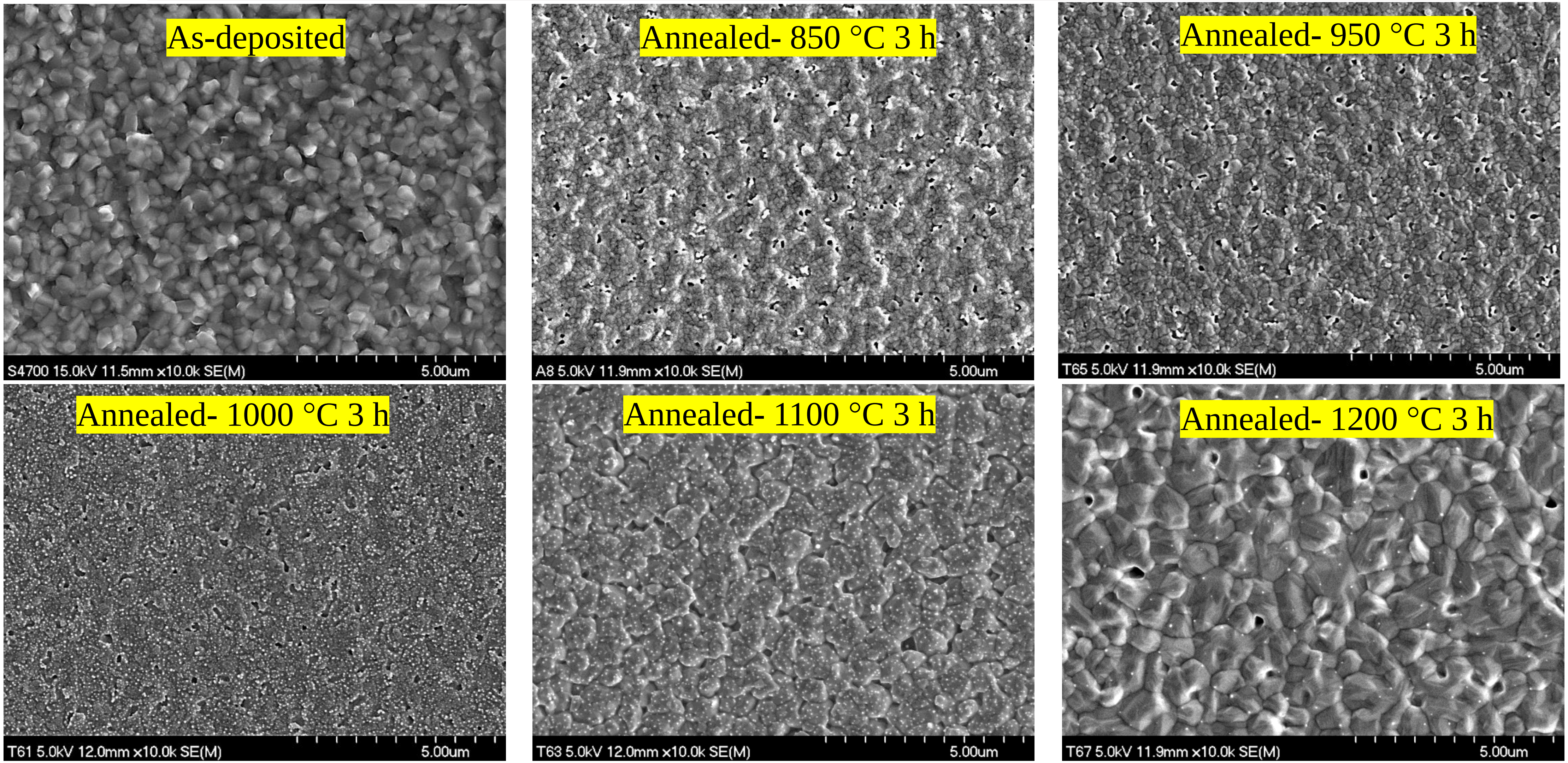


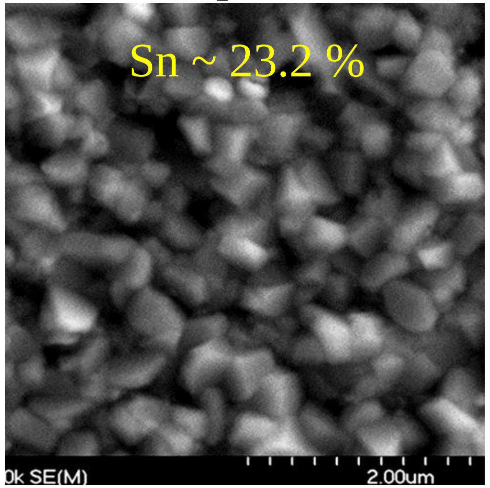
Figure: X-ray diffraction pattern of as-deposited and annealed films.

Effect of annealing temperature

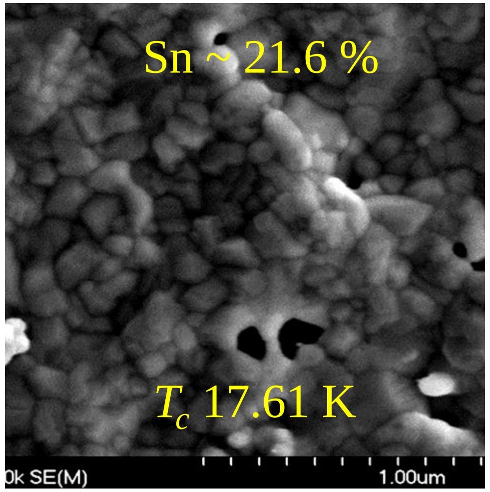


Effect of annealing temperature

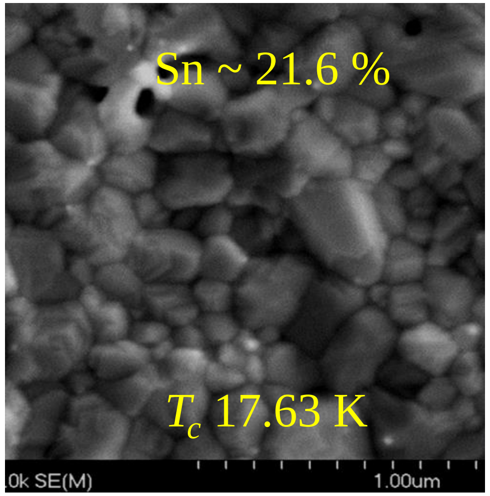
As-deposited



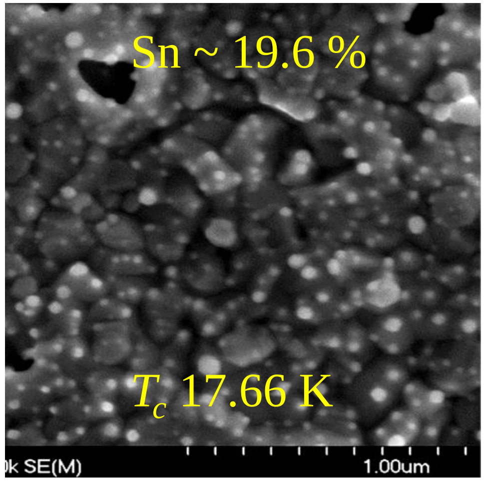
Annealed- 850 °C 3 h



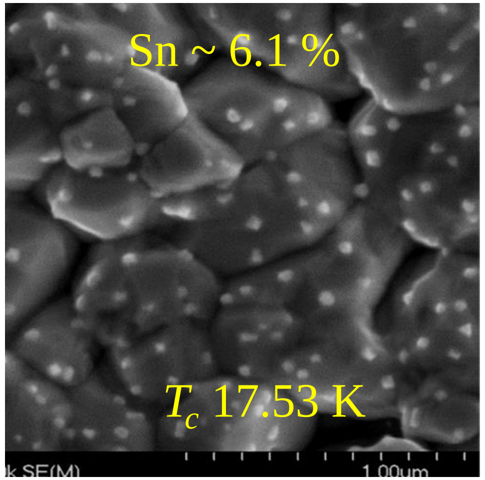
Annealed- 950 °C 3 h



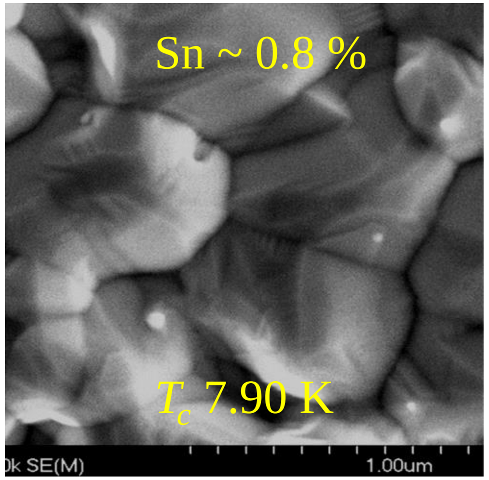
Annealed- 1000 °C 3 h



Annealed- 1100 °C 3 h



Annealed- 1200 °C 3 h



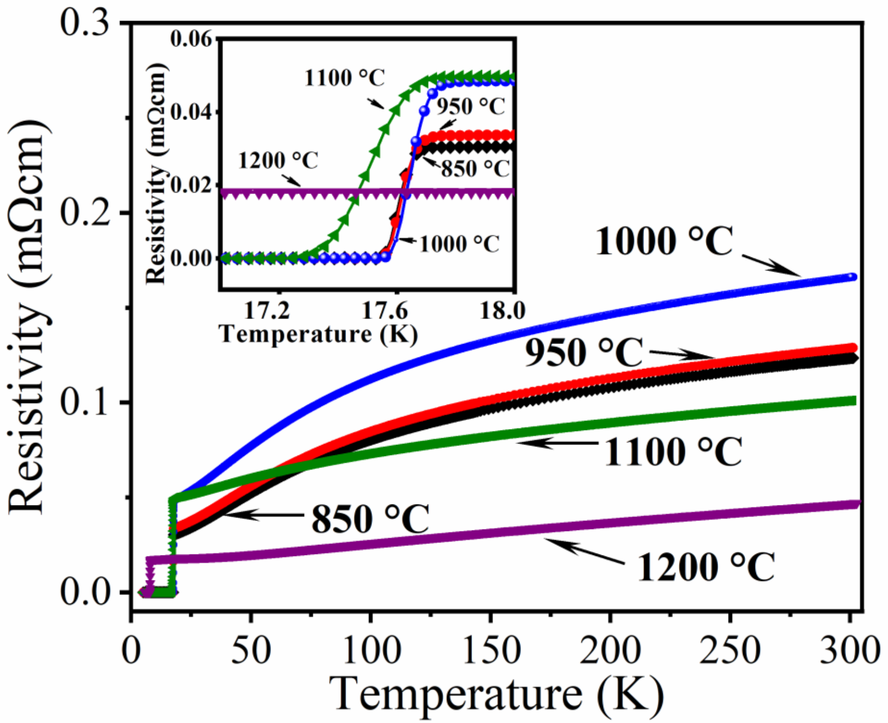


Figure: Resistivity vs temperature.

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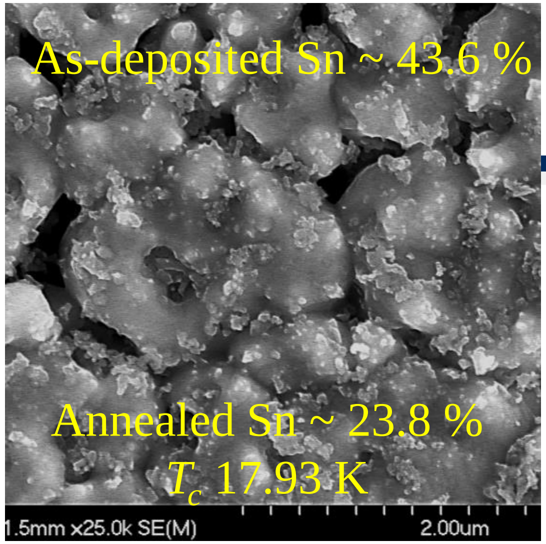
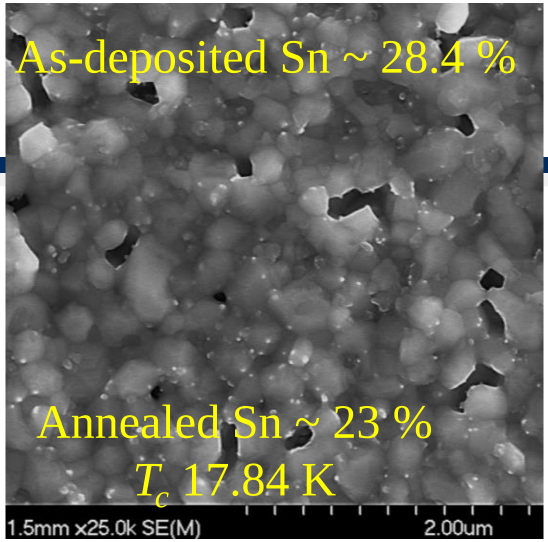
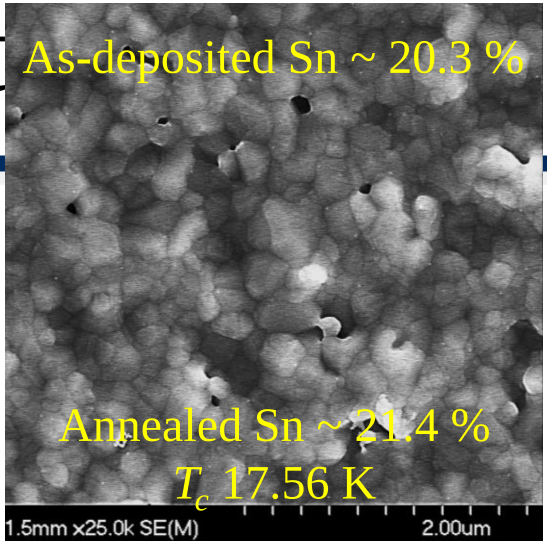
Nb:Sn 10 nm:10 nm



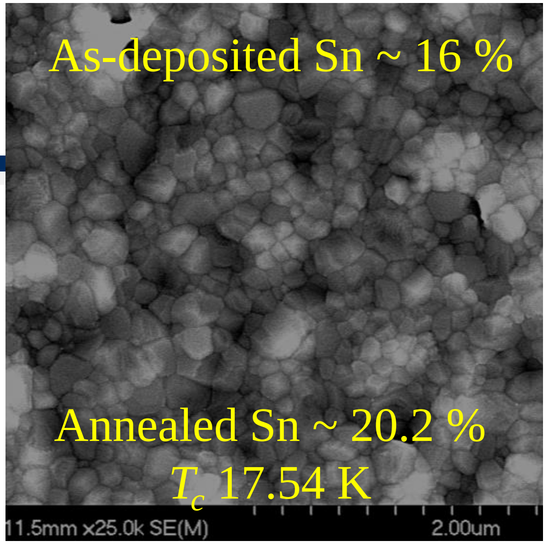
Nb:Sn 20 nm:10 nm



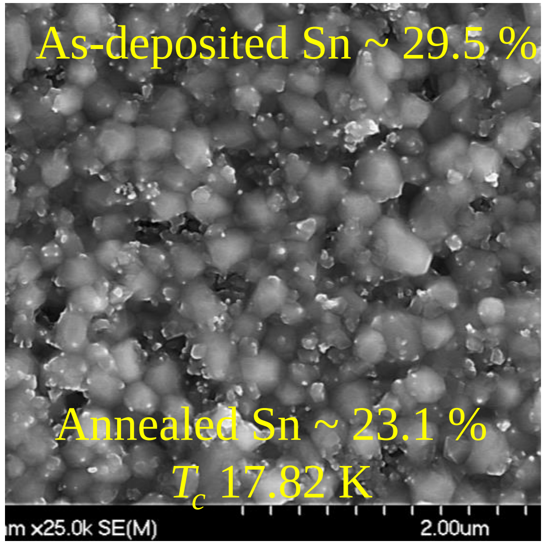
Nb:Sn 30 nm:10 nm



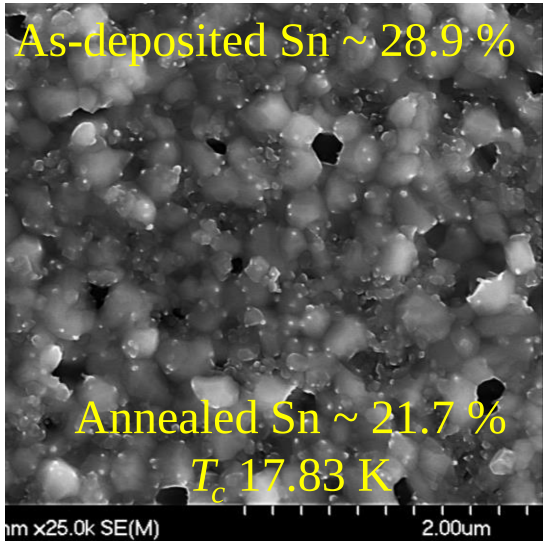
Nb:Sn 40 nm:10 nm



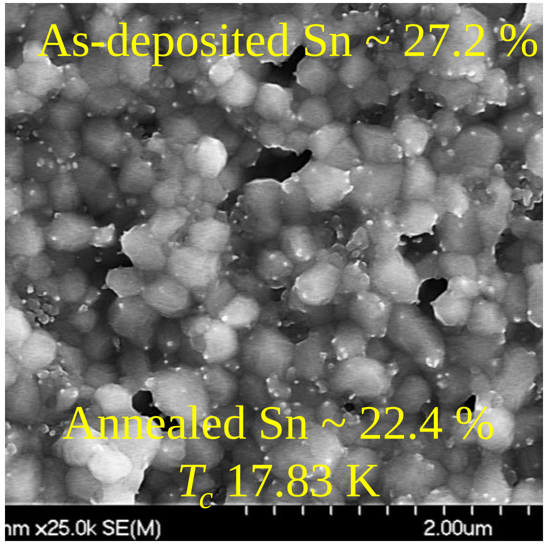
Nb:Sn 10 nm:5 nm



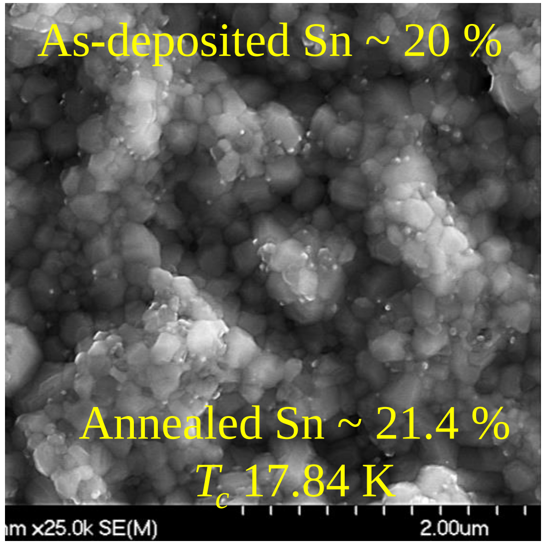
Nb:Sn 20 nm:10 nm



Nb:Sn 50 nm:25 nm



Nb:Sn 200 nm:100 nm



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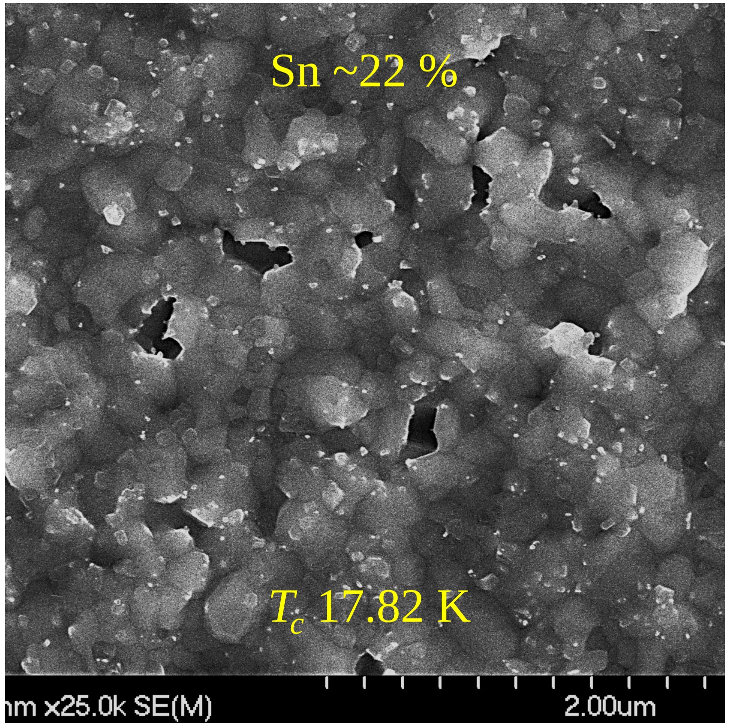
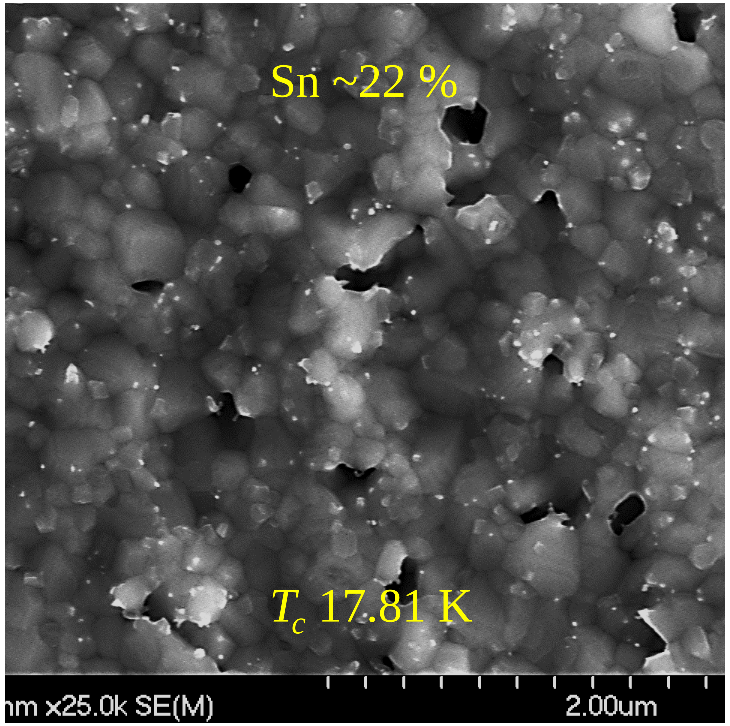
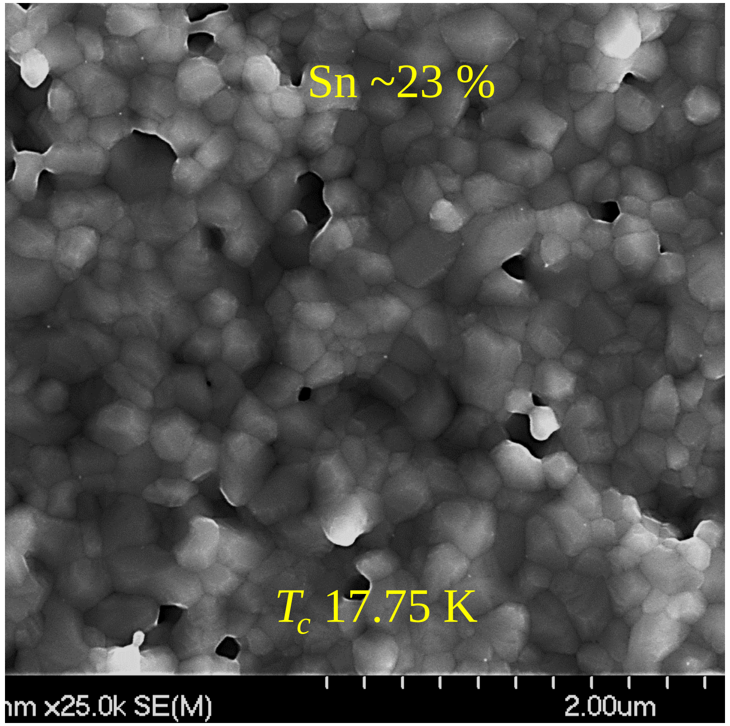
Effect of Nb buffer layer thickness



No buffer layer



20 nm buffer layer



100 nm buffer layer

Figure: SEM images of the annealed films with different buffer layer thicknesses.

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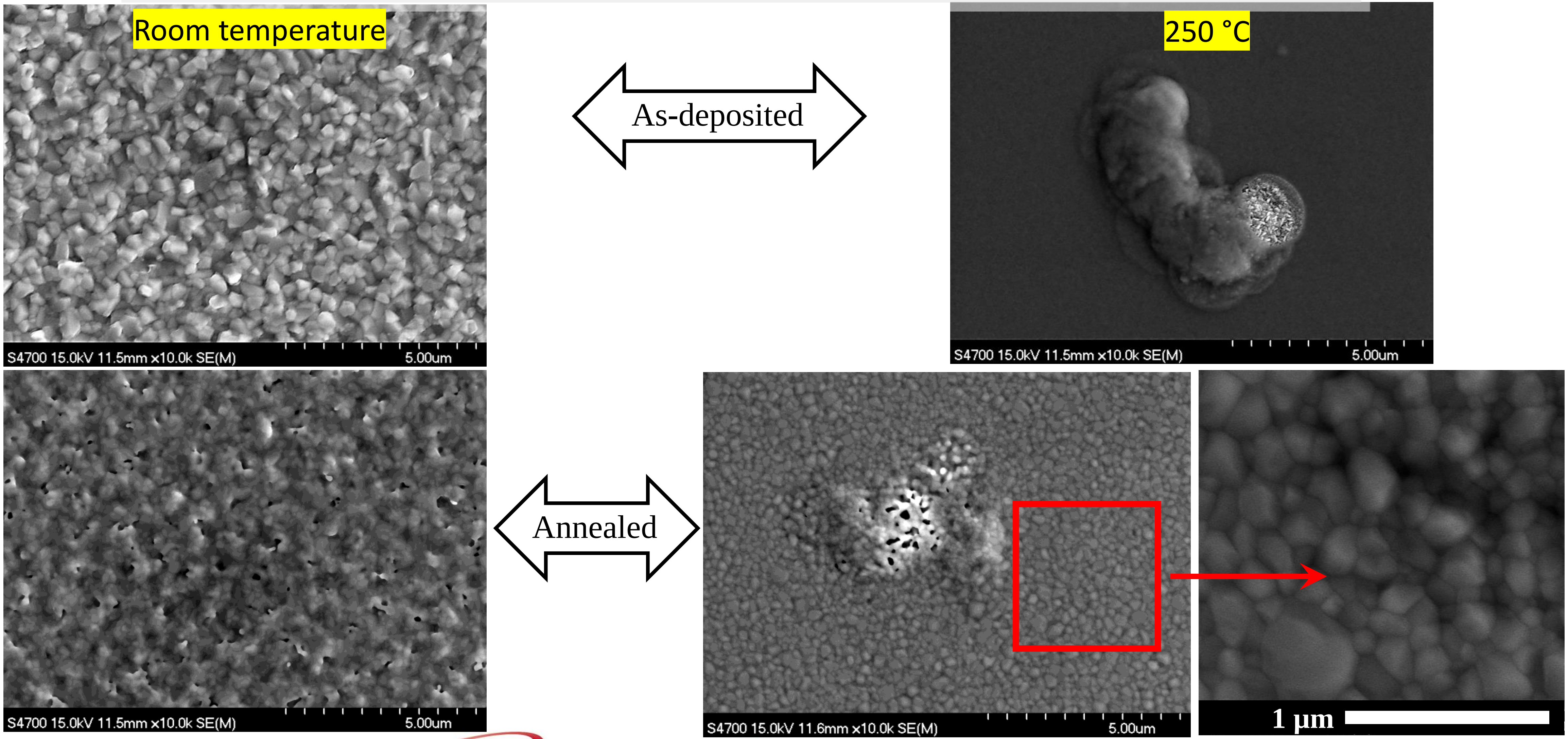
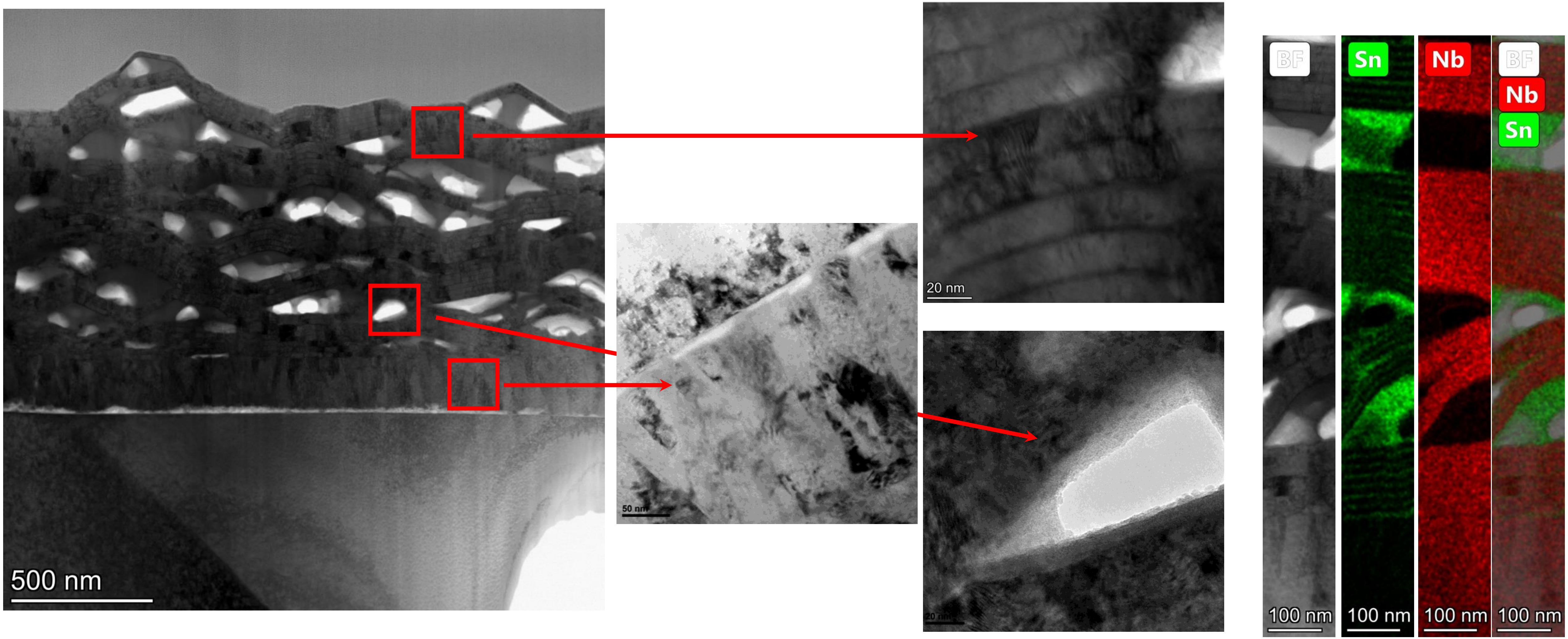
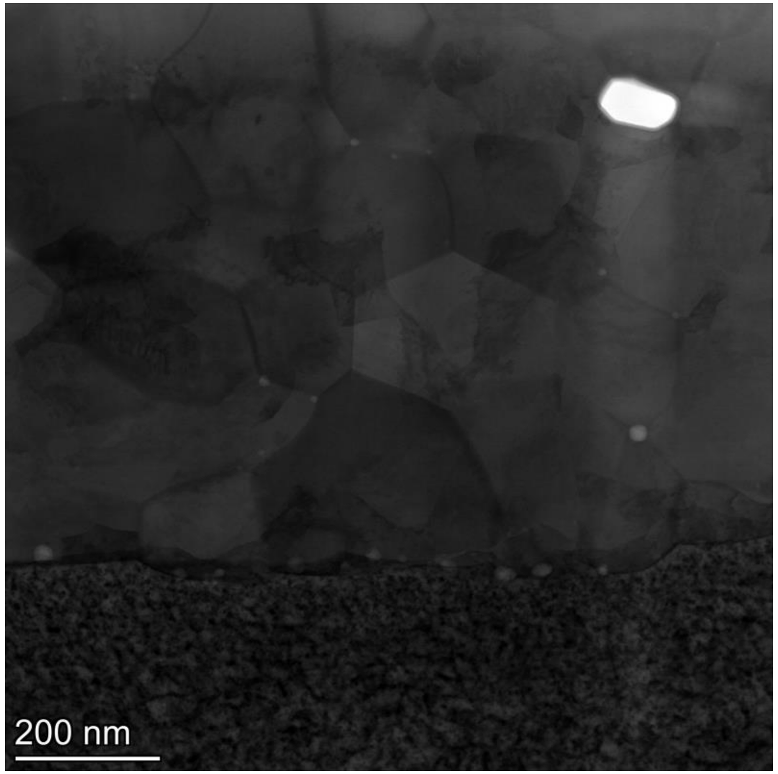
Effect of substrate temperature (S.T.)

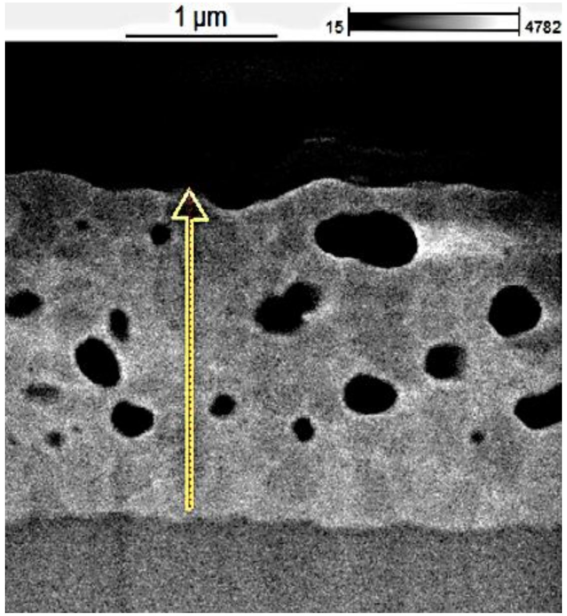


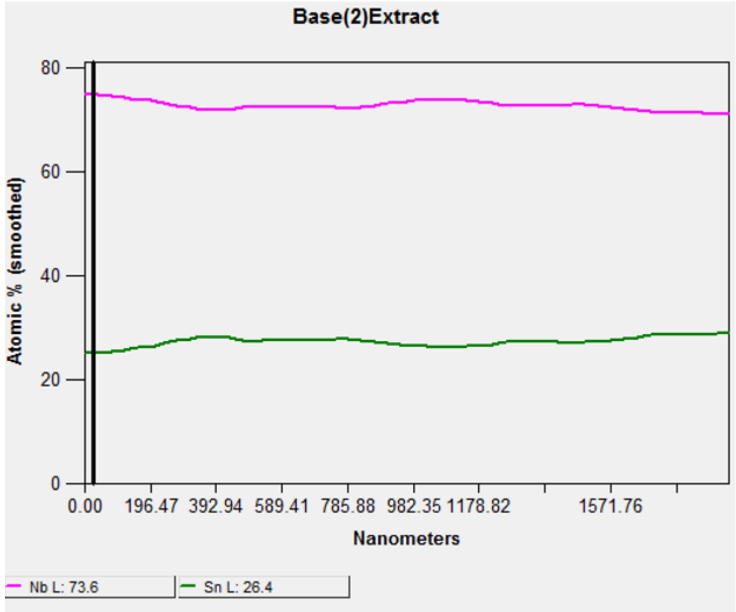
As-deposited – S.T. room temperature

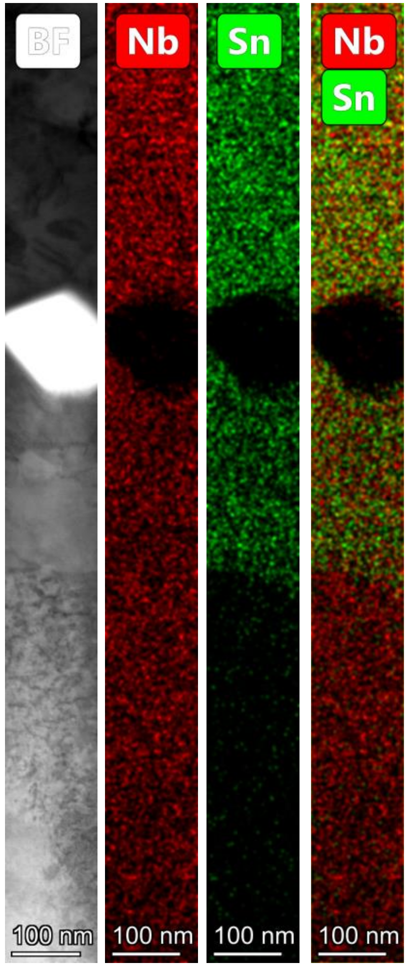


Annealed at 950 °C × 3 h- S.T. room temperature

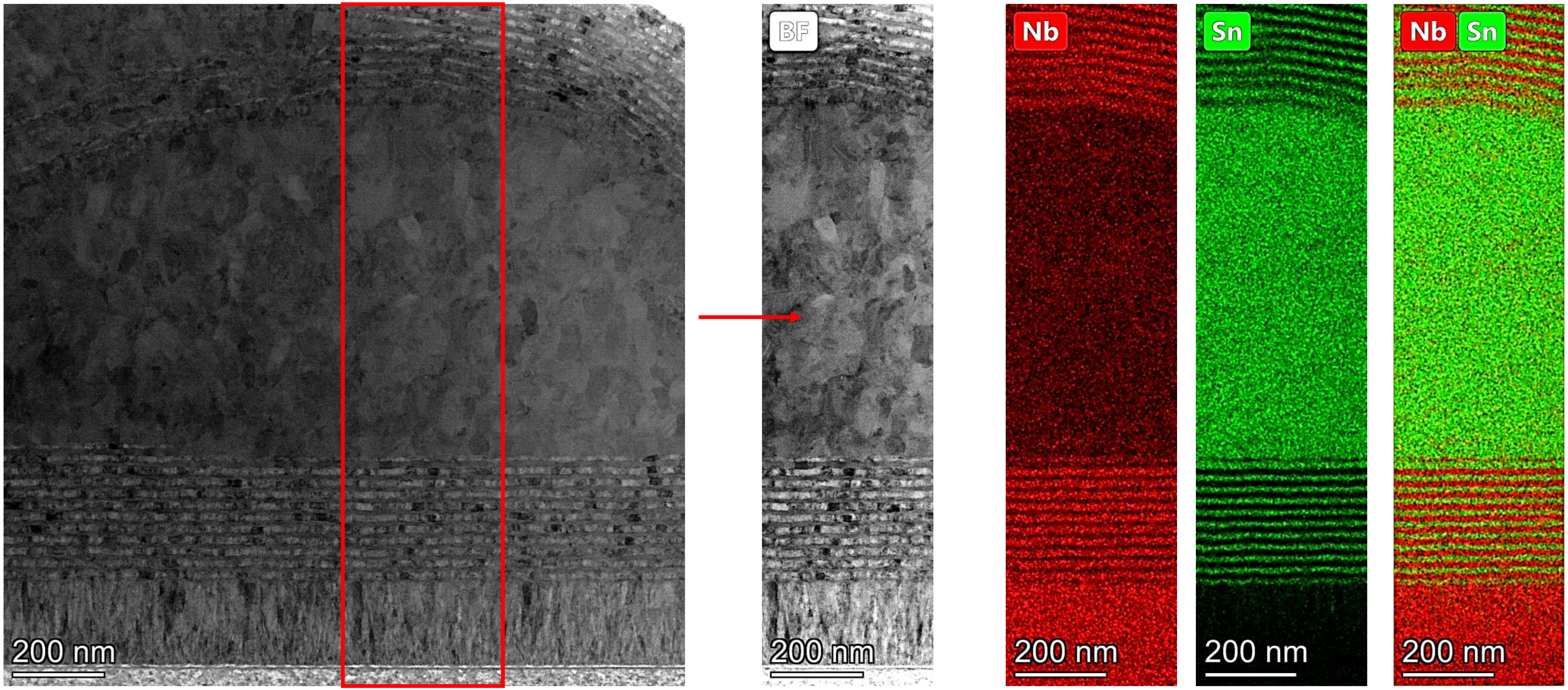




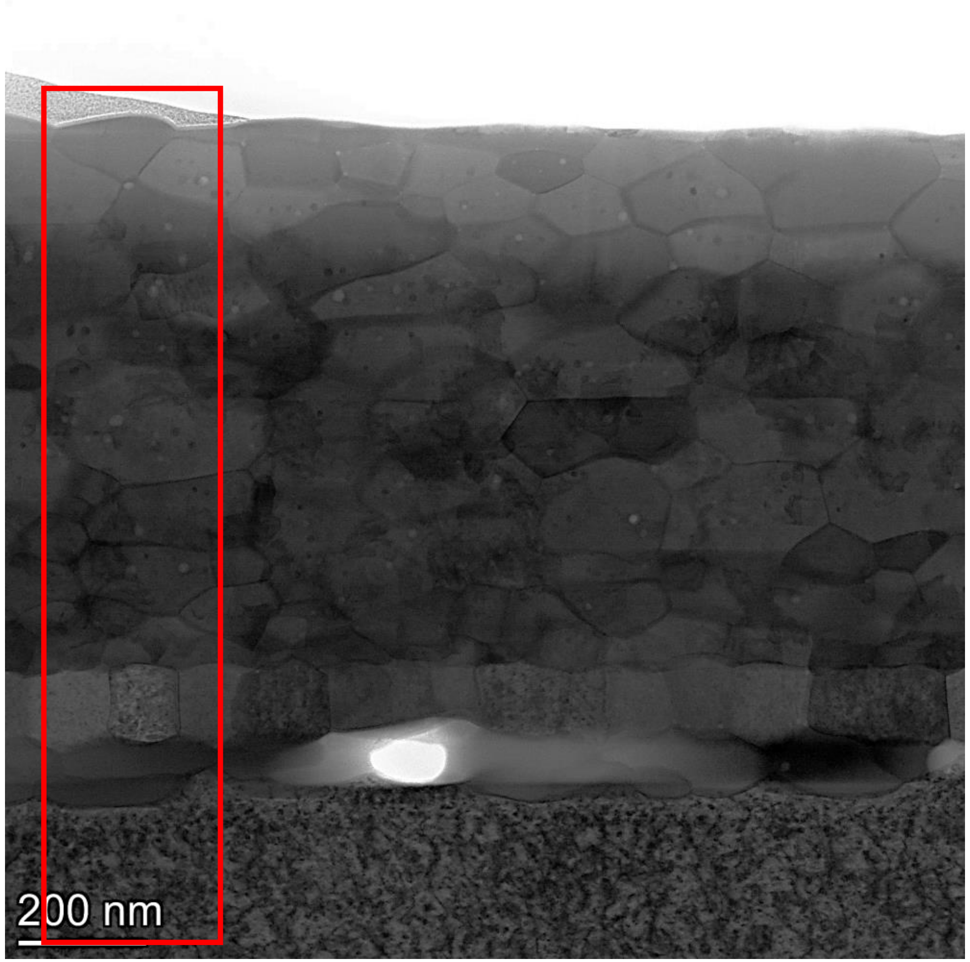


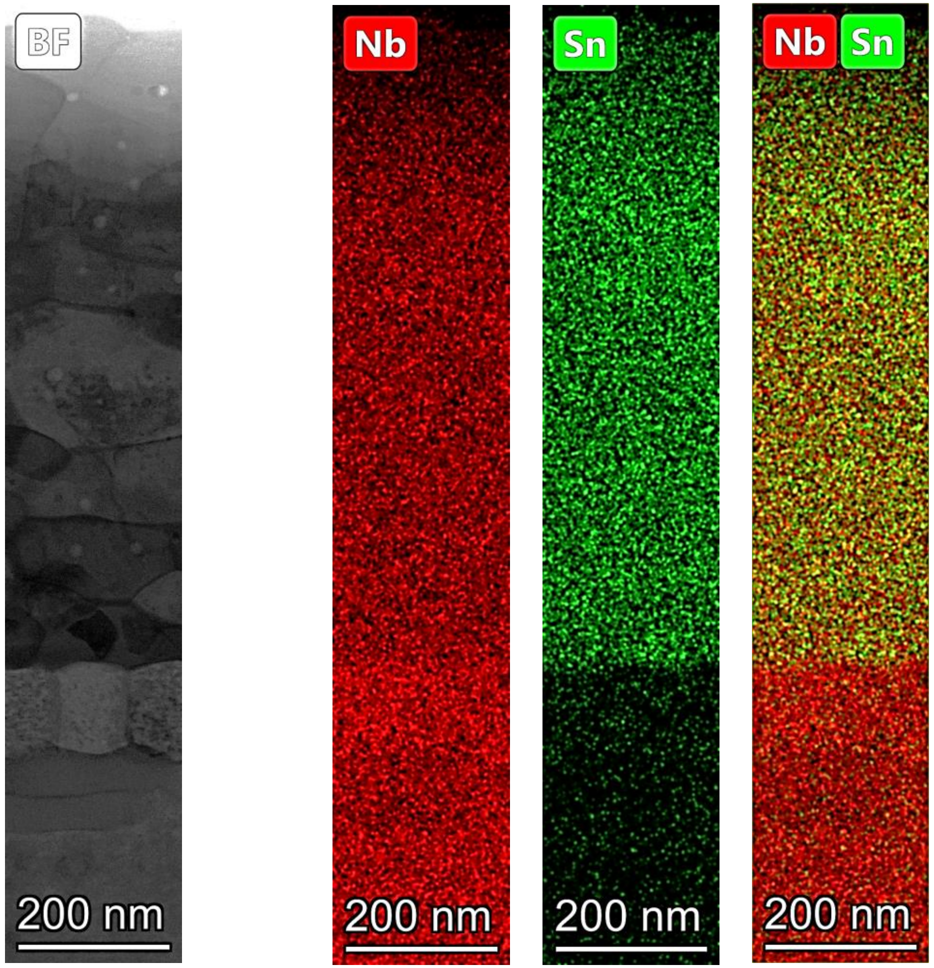


As-deposited- S.T. 250 °C



Annealed at 950 °C × 3 h- S.T. 250 °C





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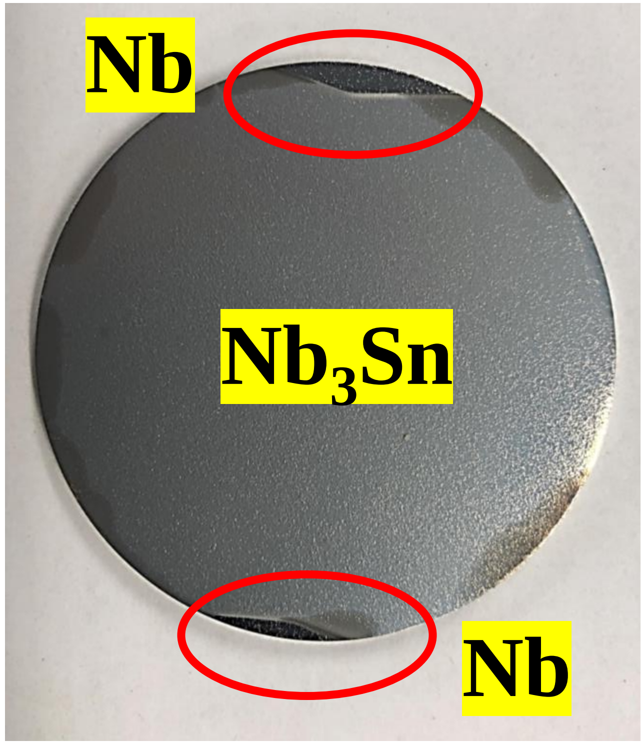
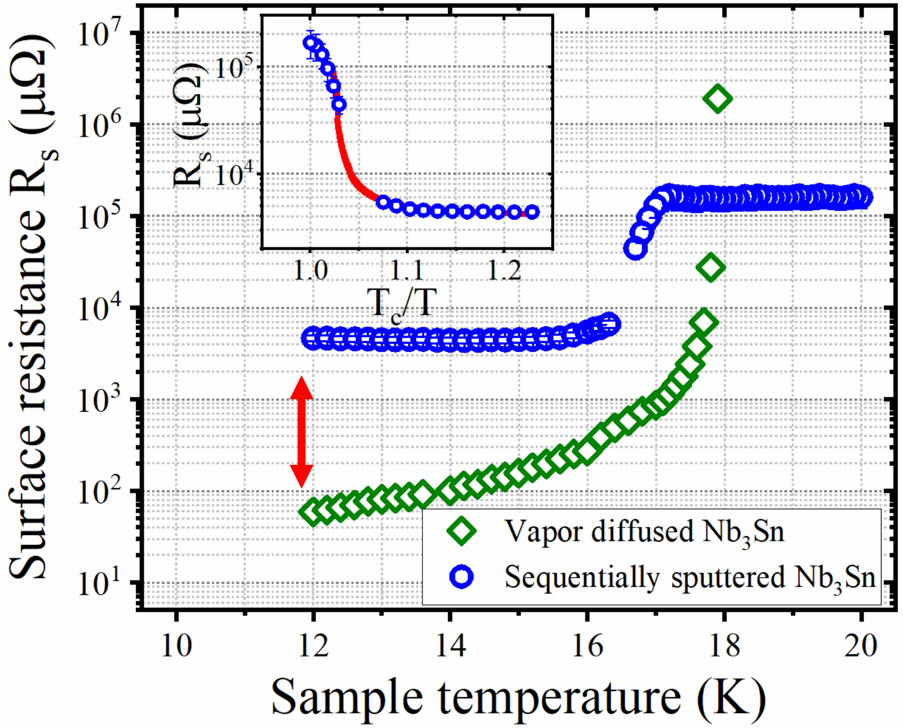
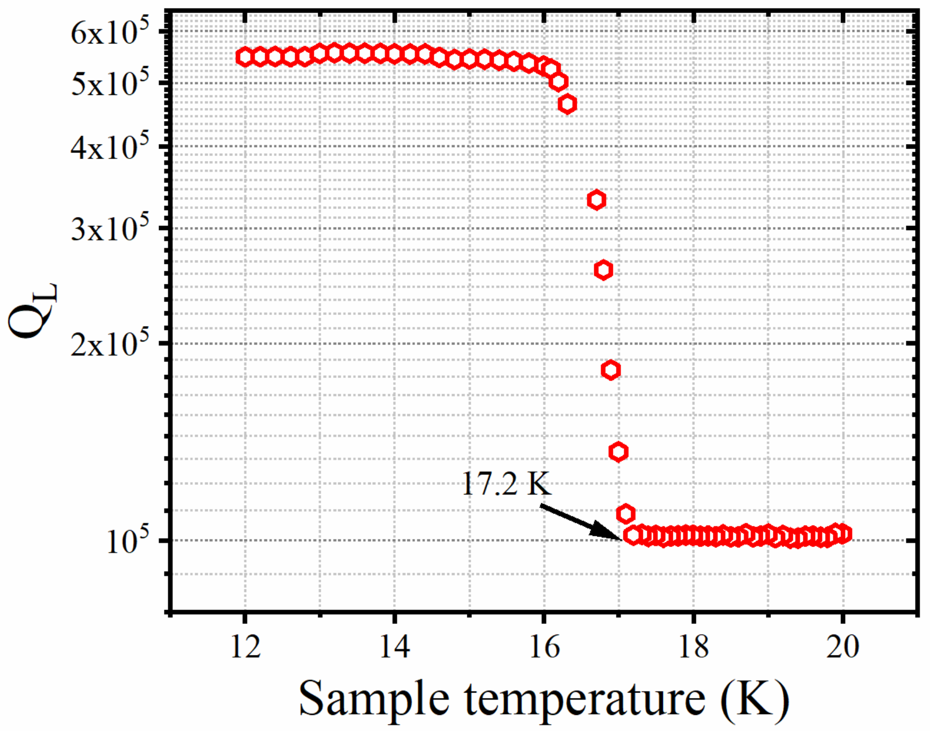
RF surface resistance measurement







Residual resistance: 3.87 ± 0.28 mΩ
Gap: 2.52 ± 0.96 meV

Critical temperature: 17.20 K

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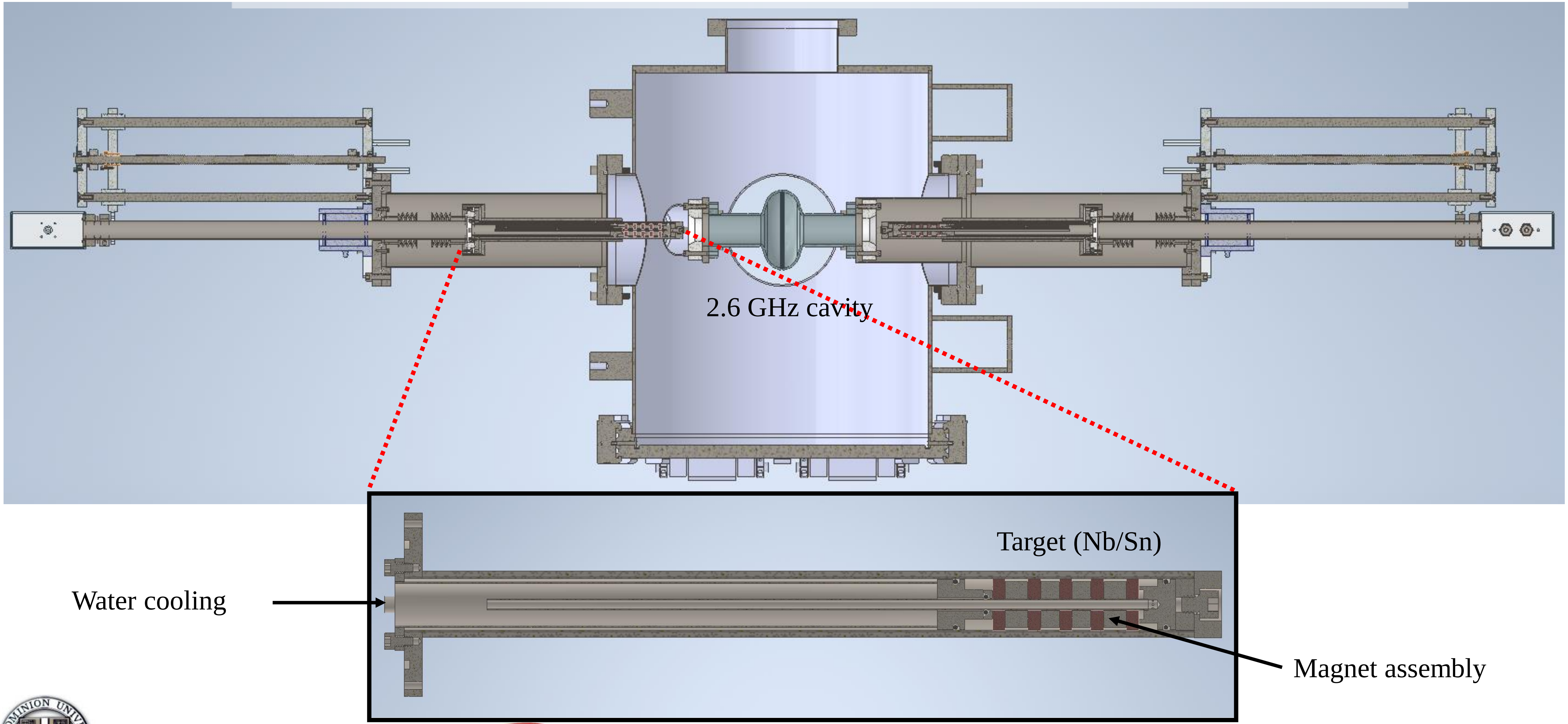
Construction of cylindrical magnetron



Summary

- Superconducting Nb_3Sn with a T_c up to 17.93 K have been achieved.
- Film morphology modified with niobium buffer layer and increased substrate temperature.
- Uniform Sn composition through the whole surface after annealing.
- RF superconducting transition at 17.2 K.
- Problems to solve- Sn loss due to evaporation.

Acknowledgement

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