Limiting defects on Nb_3Sn coating cavity at Fermi National Accelerator Laboratory (FNAL)

Tesla Technology Collaboration (TTC) meeting
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Outline

1. Backgrounds

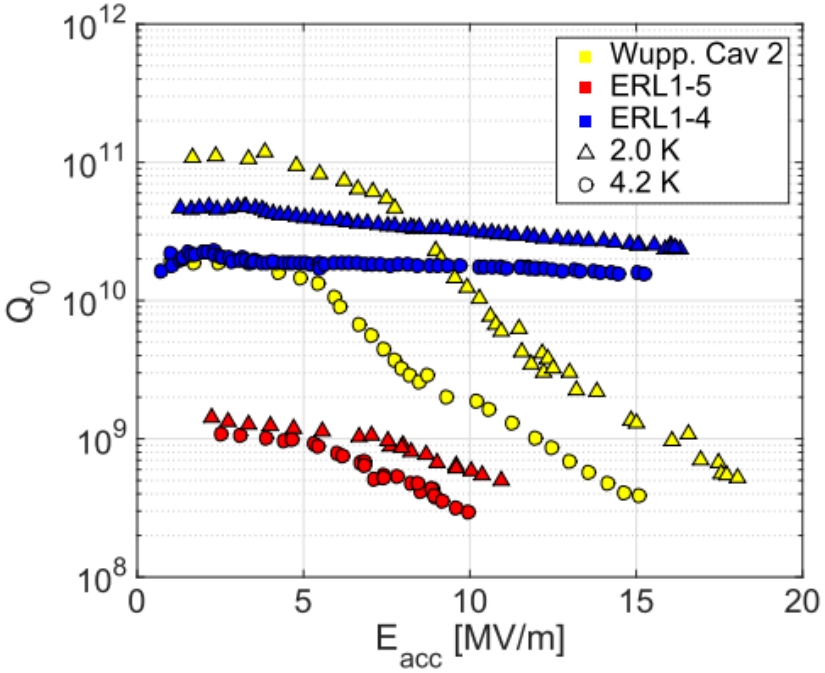
2. Growth process of Nb3Sn coating

3. Limiting defects on Nb3Sn

    - Thin regions
    - Sn-deficient regions
    - grain boundaries

4. Conclusion

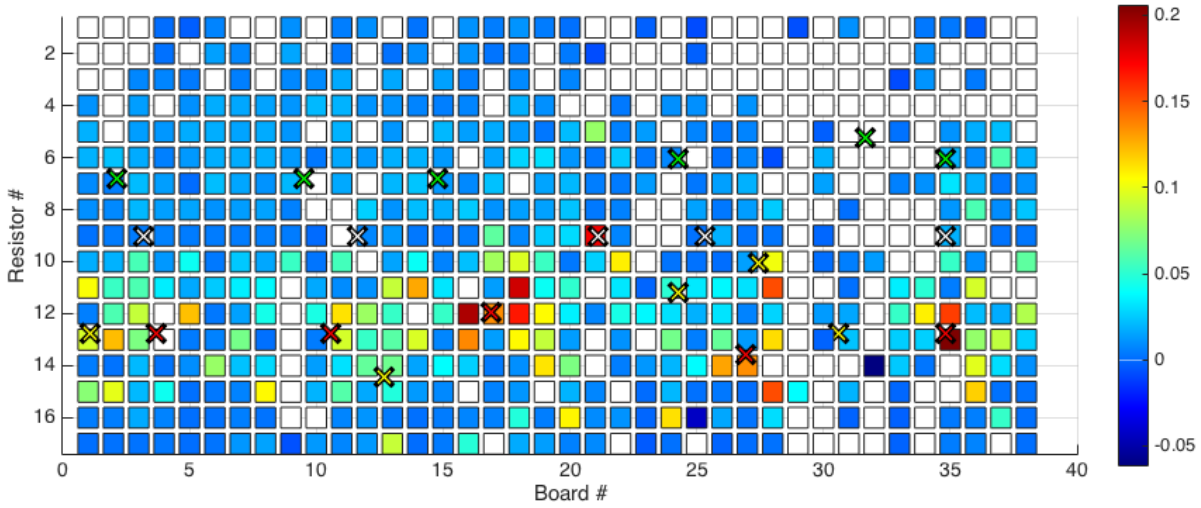
Challenges in Nb_3Sn cavities



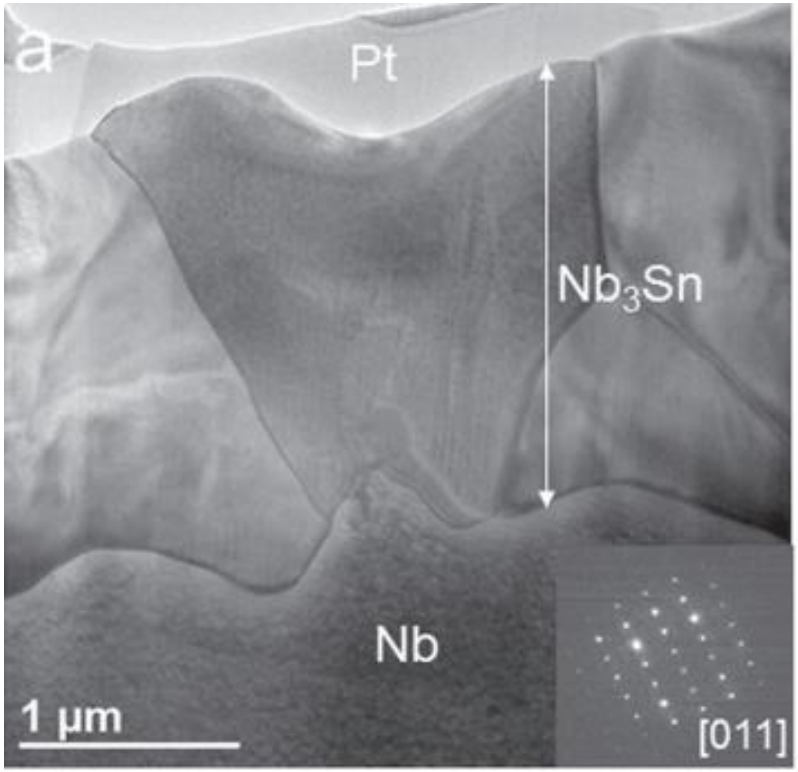
Y Trenikhina et al 2018 Supercond. Sci. Technol. 31 015004

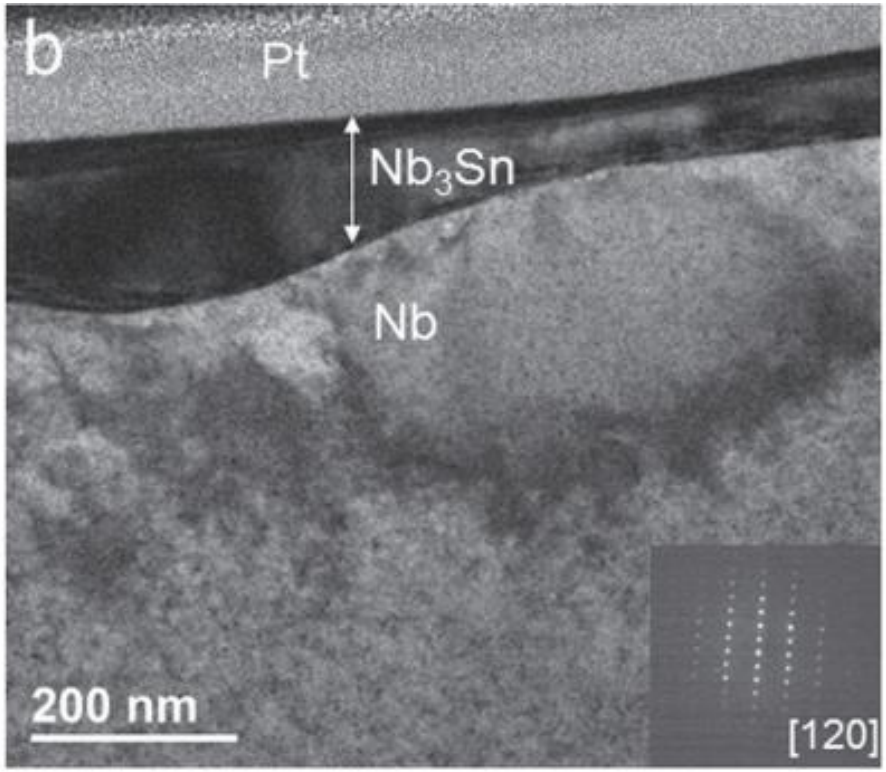
- **Q-factor decrease or quench at high accelerating field**
- **What are the origins of Q-slop and quench?**

→ **Defects in Nb_3Sn coating**



Correlating cavity performance and defects





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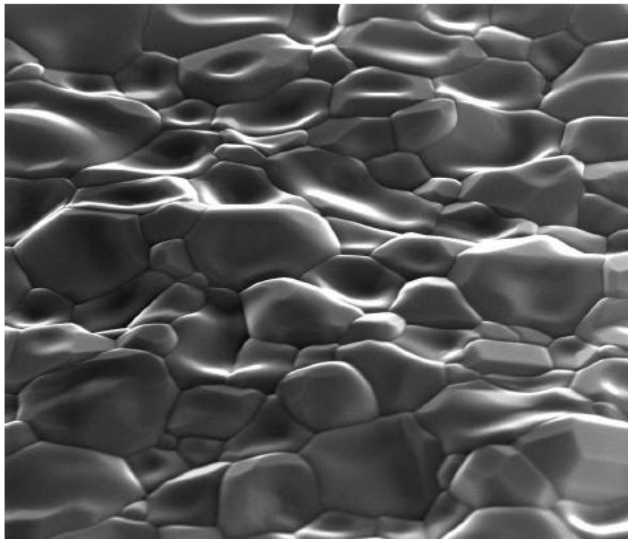
- **Hot regions in T map showed too thin Nb_3Sn coating**

→ **Thin regions are highly correlated to the cavity performance.**

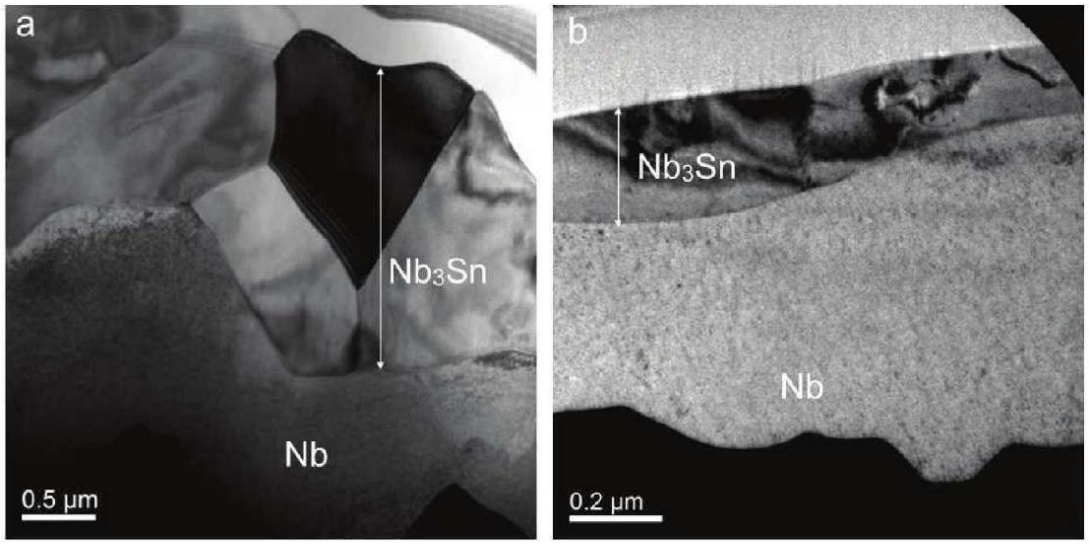
Candidates of Q-slope and quenching in Nb_3Sn

1. Surface roughness



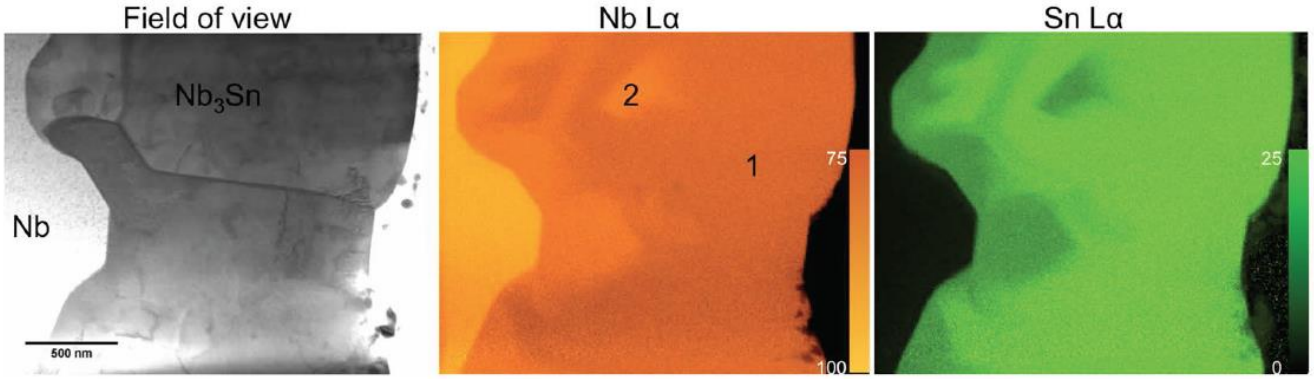
S Posen, PhD thesis, Cornell University (2015)

2. Thin regions



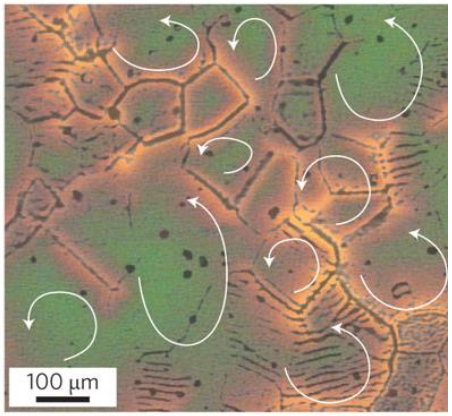
Y Trenikhina et al 2018 Supercond. Sci. Technol. 31 015004

3. Composition variation (Sn-deficient region)



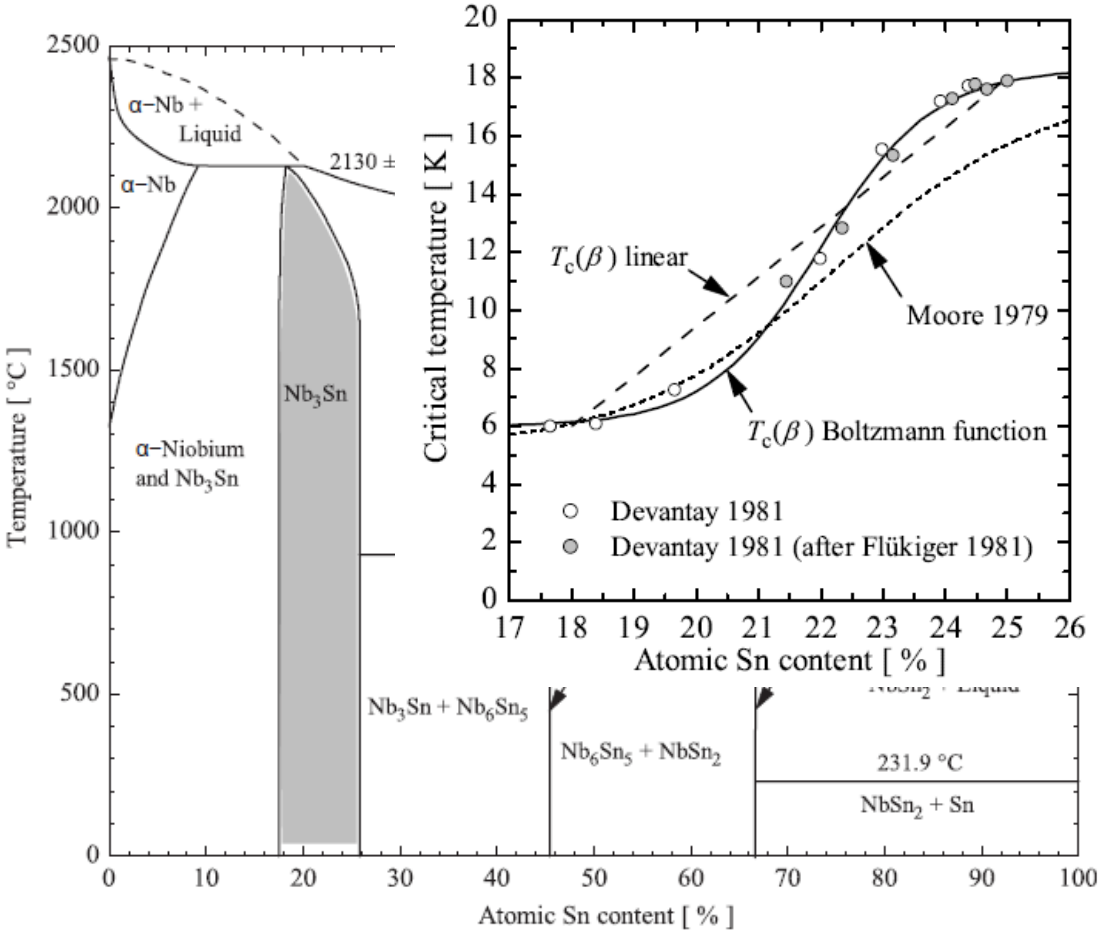
C Becker et al, APL 106, 082602 (2015)

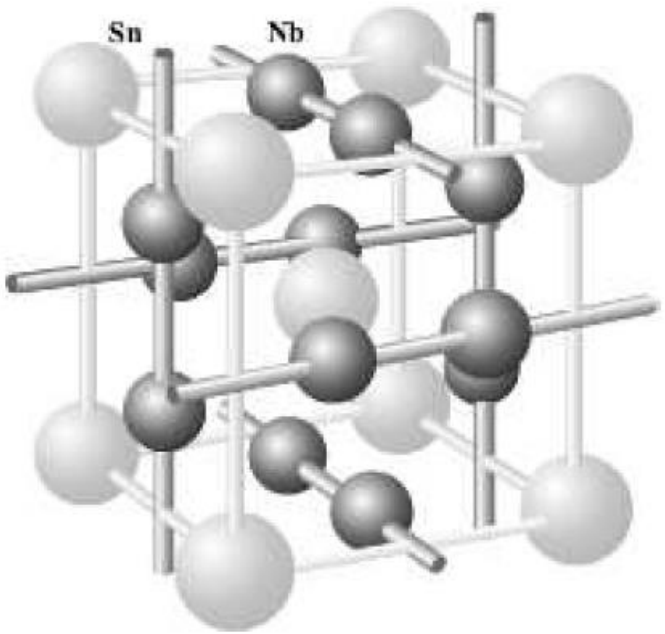
4. Grain boundary



A. Gurevich, Nature Materials 10, 255–259 (2011)

Properties of Nb_3Sn

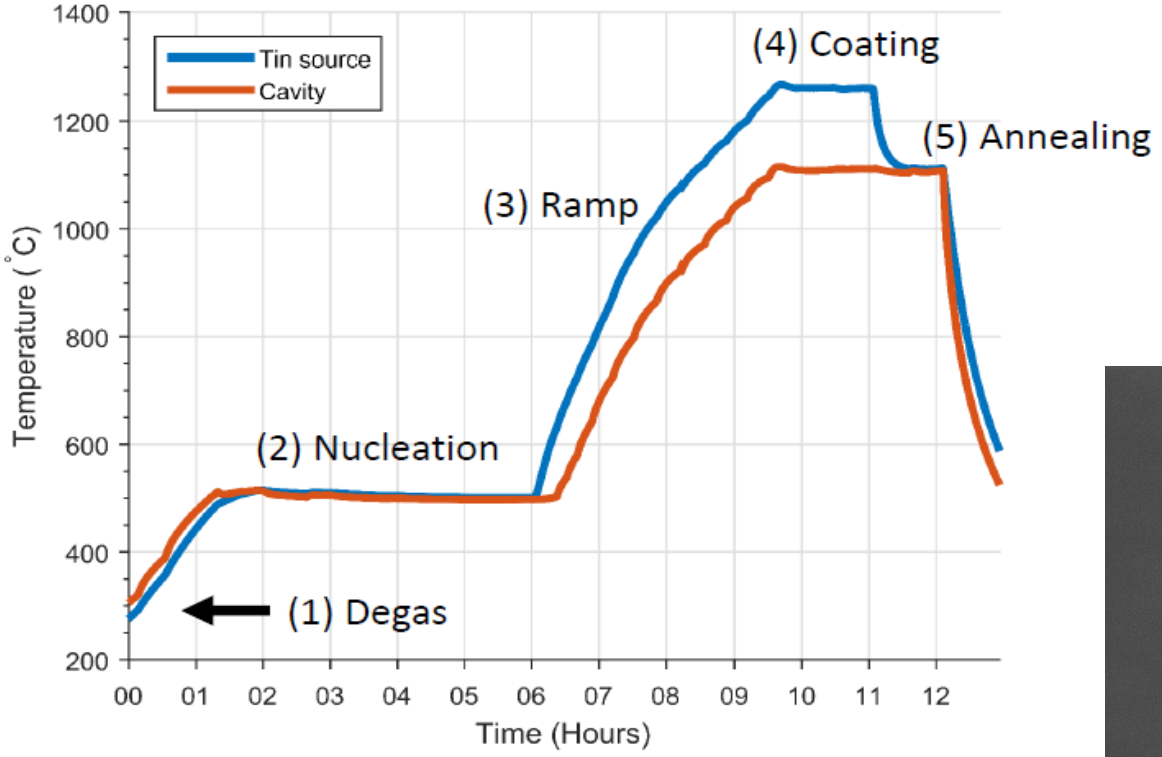




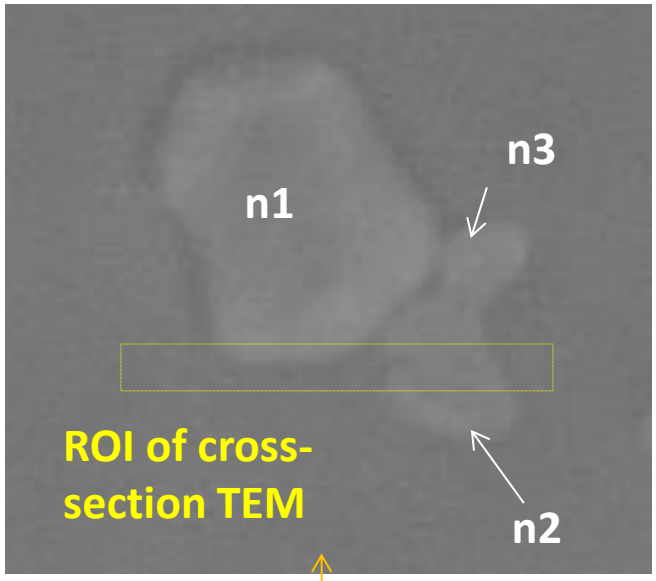
Cubic a=0.529 nm

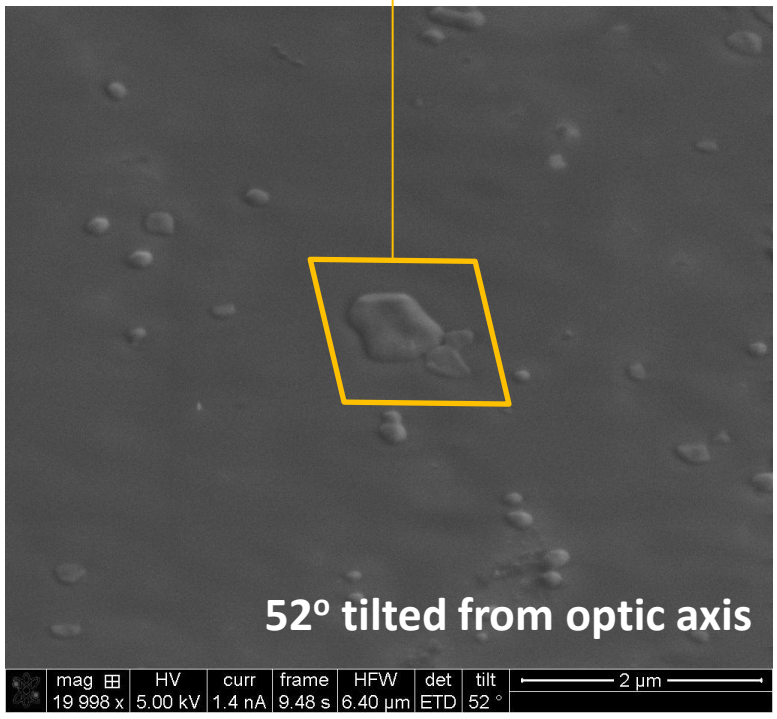
Sn at bcc lattice
Nb bisecting the bcc cubeface

Nucleated Nb_3Sn grains

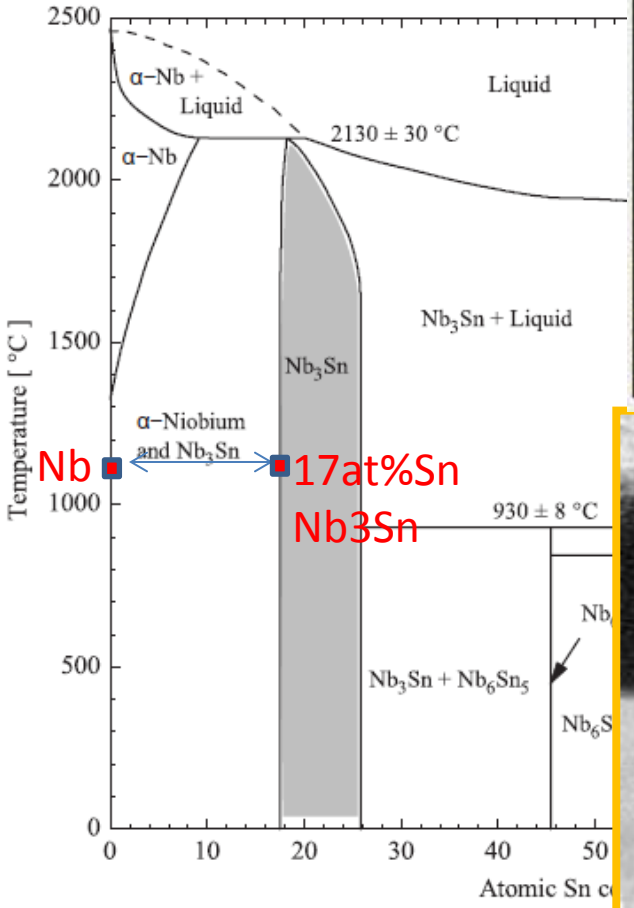


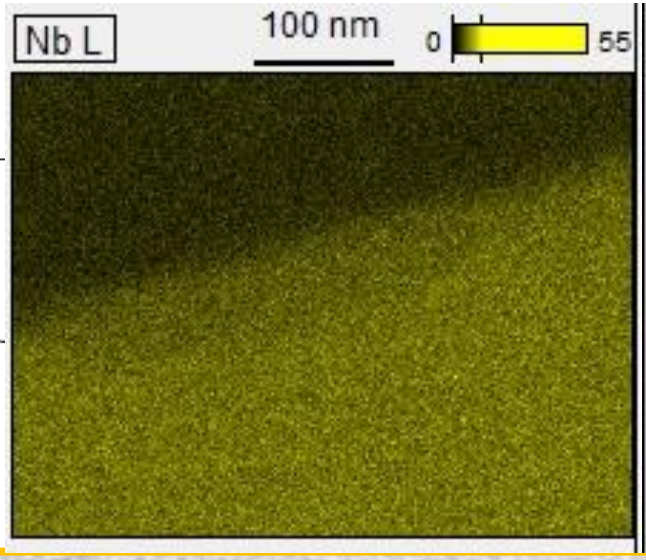
S Posen, D Hall, Supercond. Sci. Technol. 30 (2017) 033004

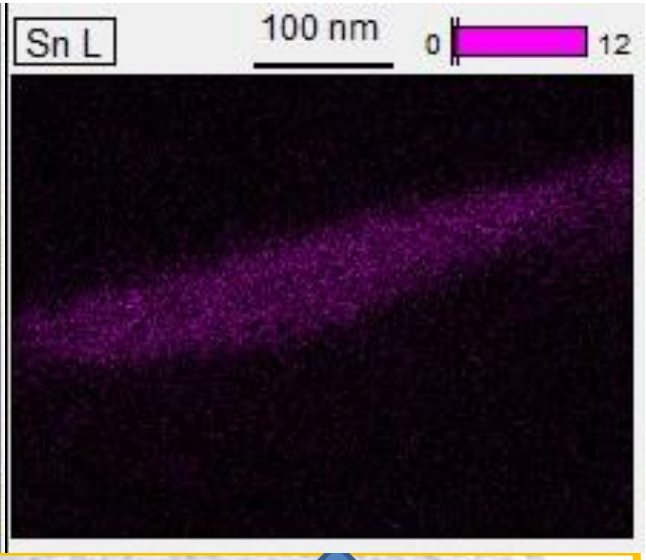


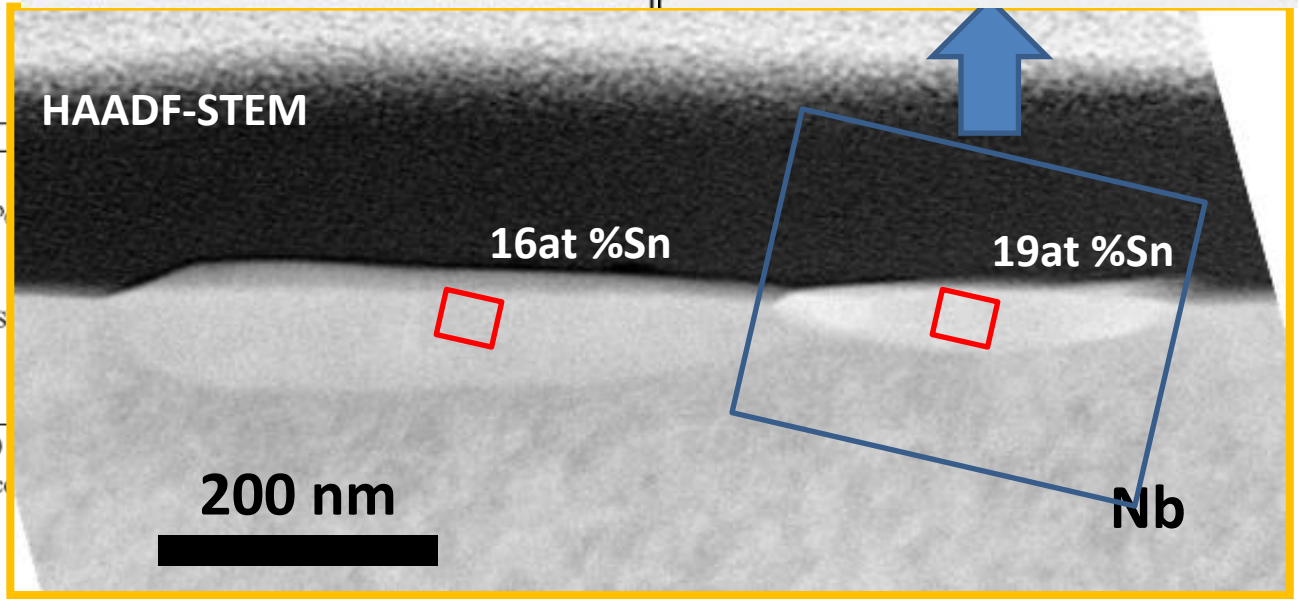


Composition of nucleated Nb_3Sn grains



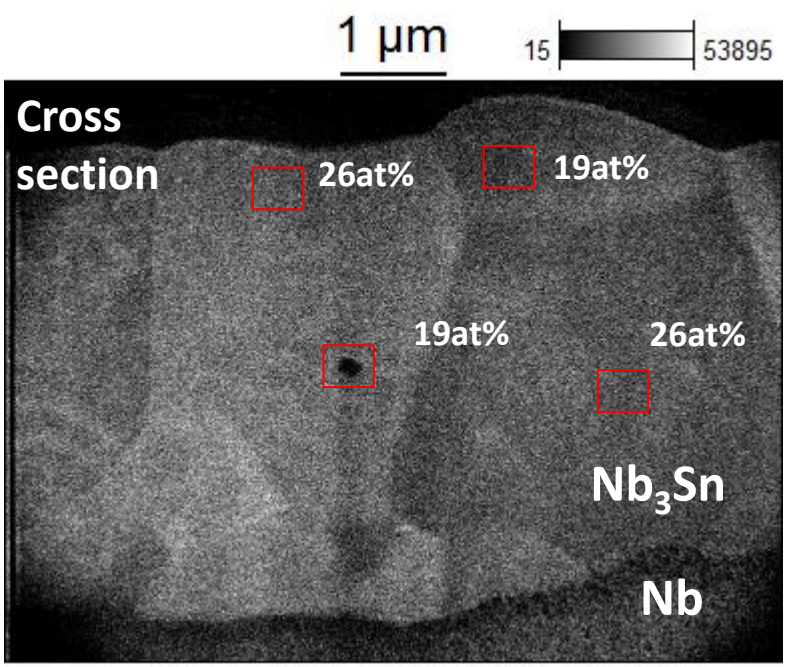


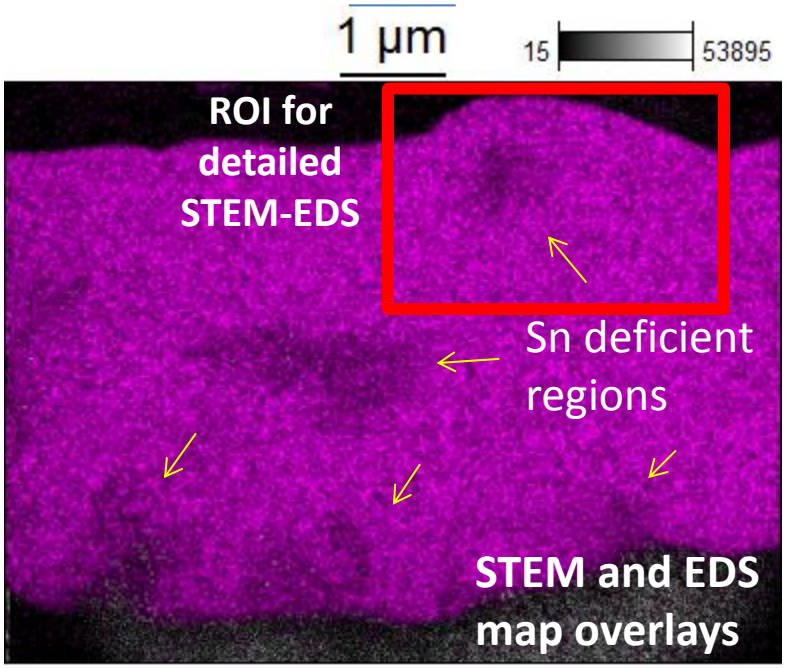


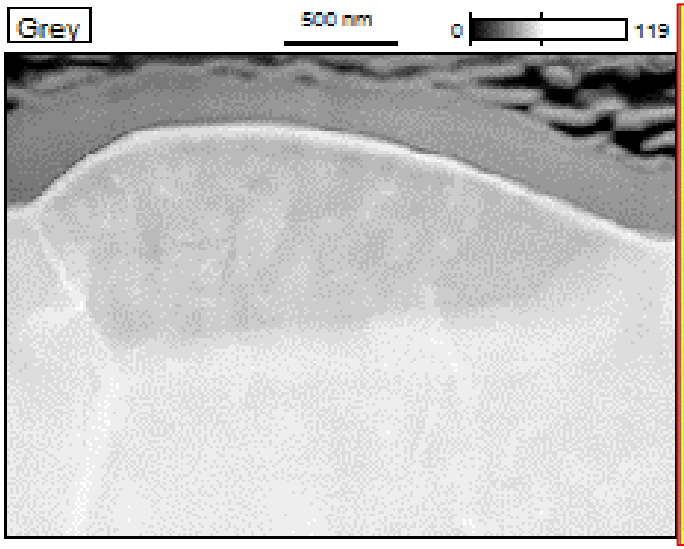


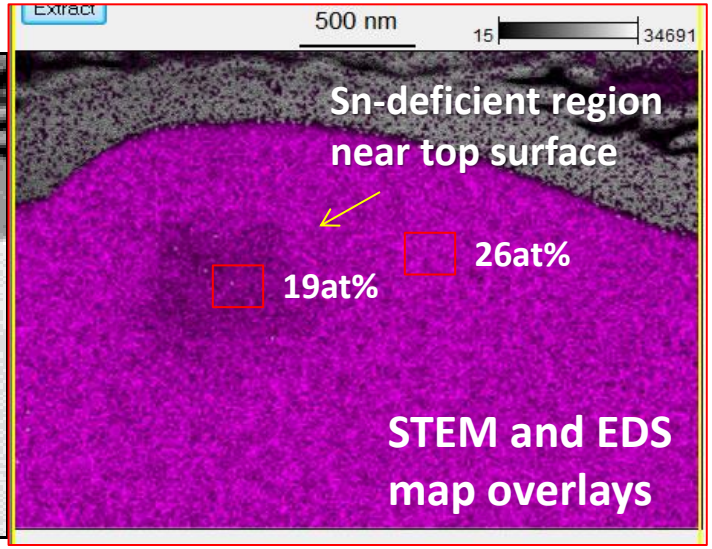
STEM-EDS implies that nucleated Nb_3Sn grain have low Sn-composition
→ It agrees to the phase diagram: low Sn-Nb_3Sn and Nb at Nb_3Sn/Nb interface.

Distribution of Sn-deficient regions in Nb_3Sn





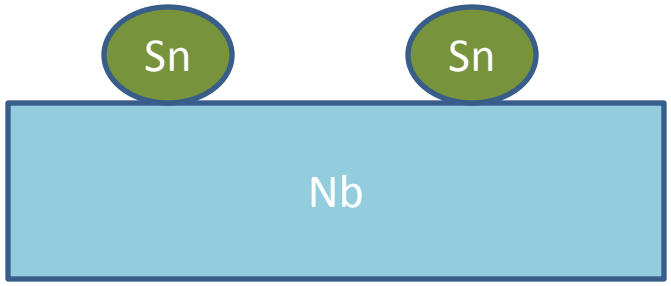




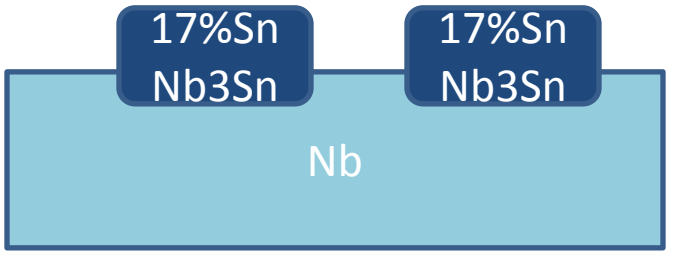
Proposed hypothesis of growth mechanism of Nb_3Sn coating

Steps analyzed by TEM

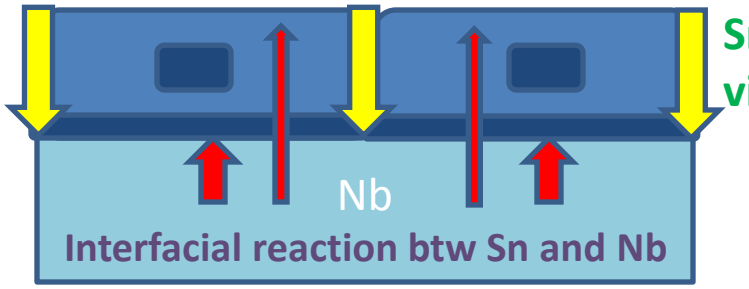
1. Formation of nucleation site



2. Nucleation of Nb3Sn



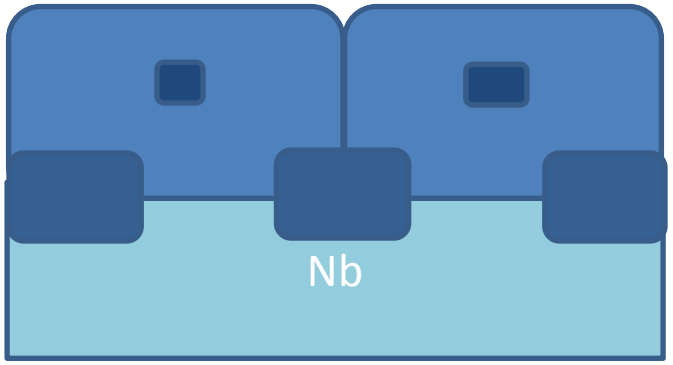
3. Grain growth of Nb3Sn



Sn-deficient region

25at%Sn Nb_3Sn

4. Completion of Nb3Sn coating



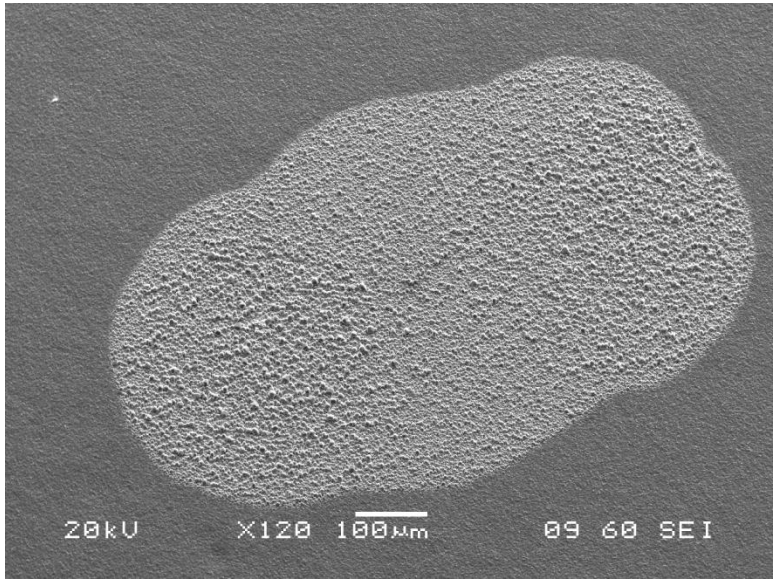
Sn-deficient region

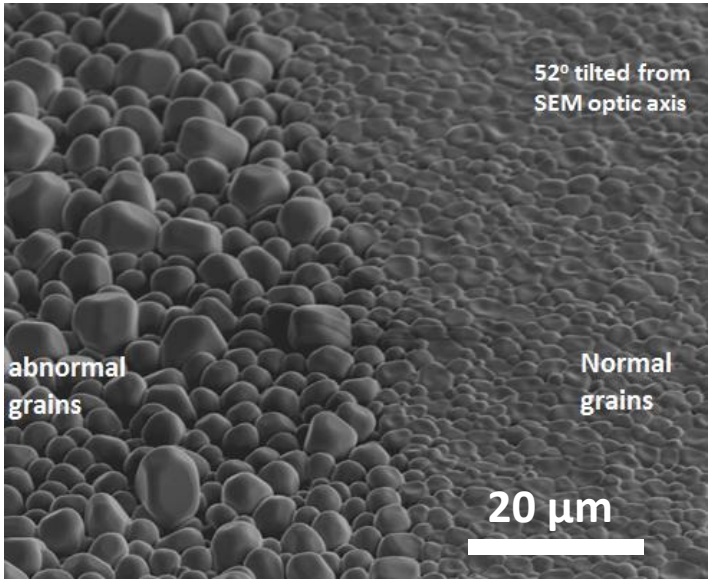
25at%Sn Nb_3Sn

1. Sn-deficient regions are formed during the early stage of Nb_3Sn formation.
2. Slow Sn-diffusion results in some of Sn-deficient left in Nb3Sn grains

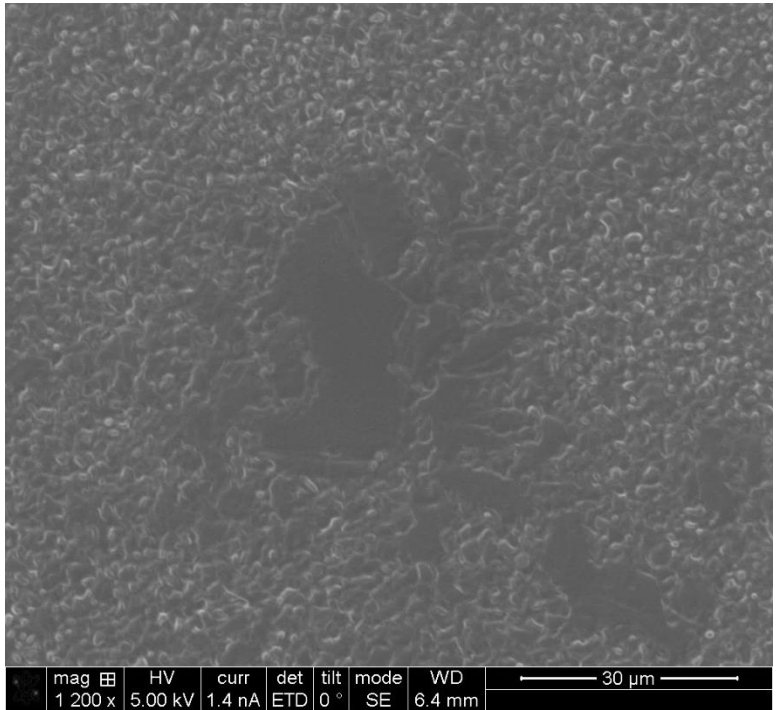
Effect of Sn supply on the growth process of Nb3Sn coating

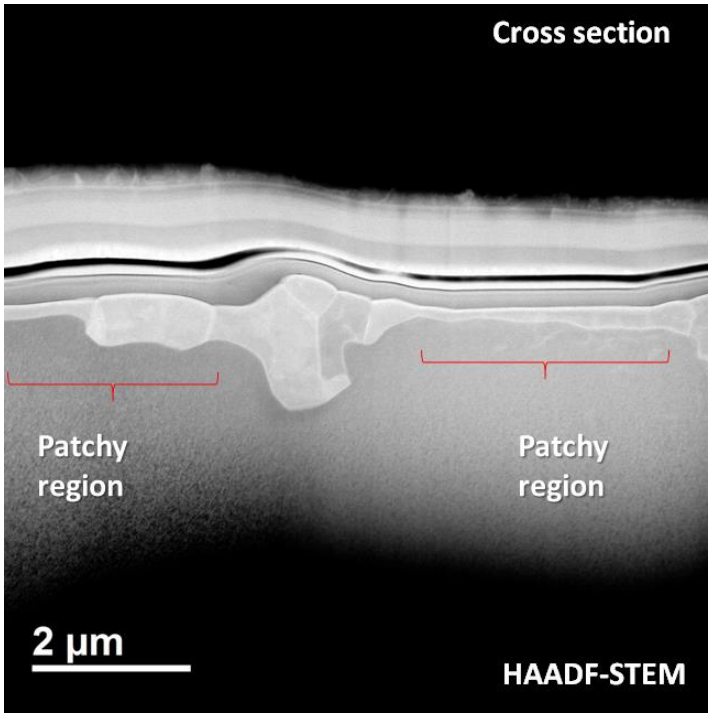
High Sn supply





Low Sn supply

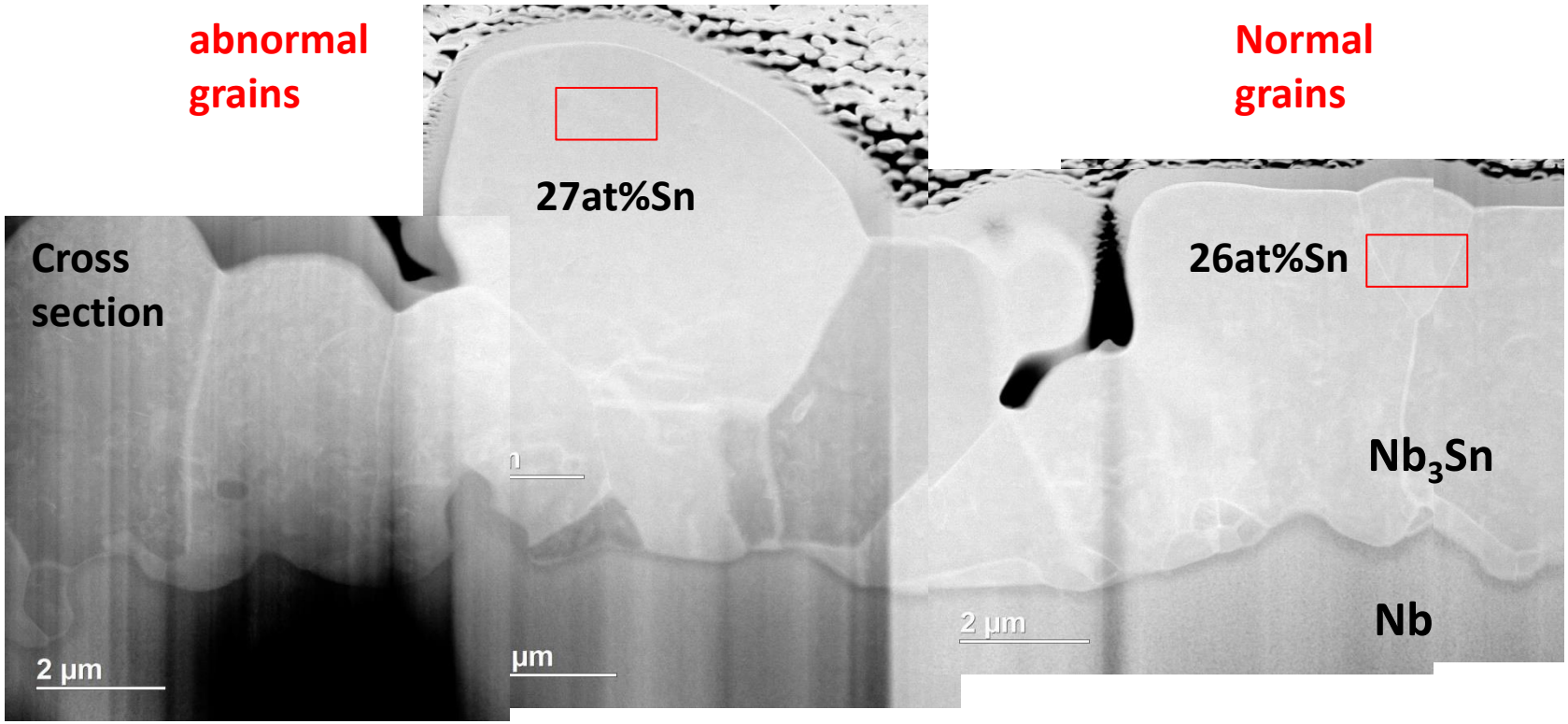




Tin spot_HAADF-STEM-EDS images

abnormal grains

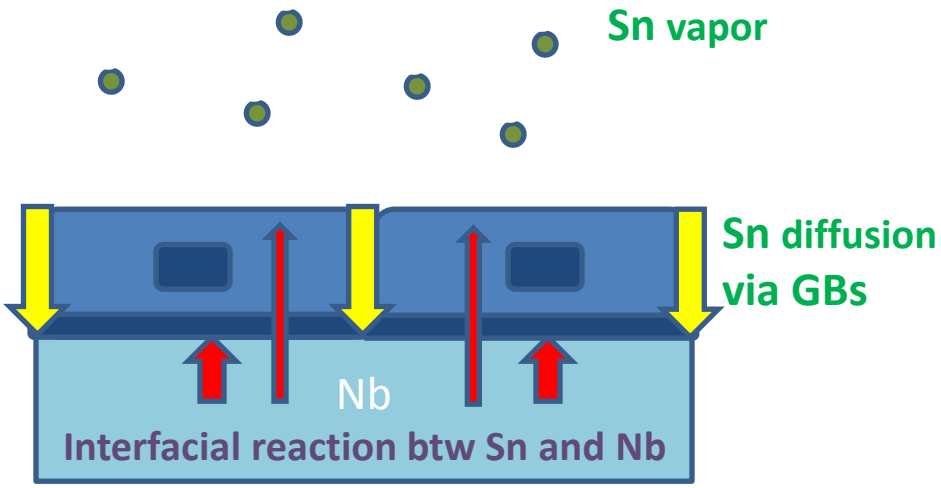
Normal grains



Same Nb_3Sn phases in both regions

Proposed hypothesis of the formation of Sn spots

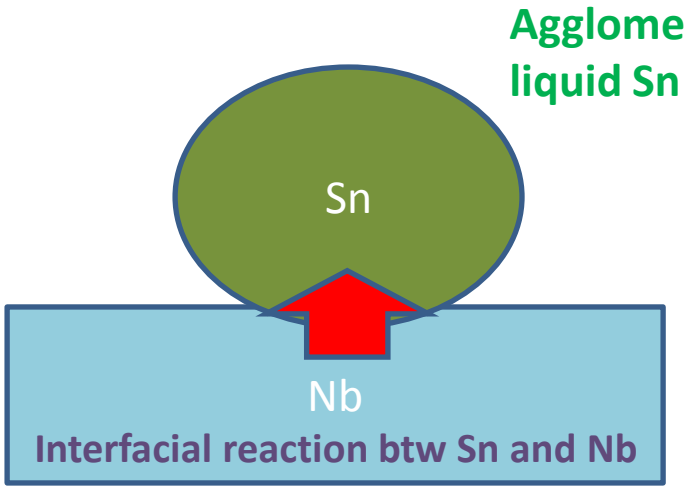
Normal Sn flux



Sn-deficient region

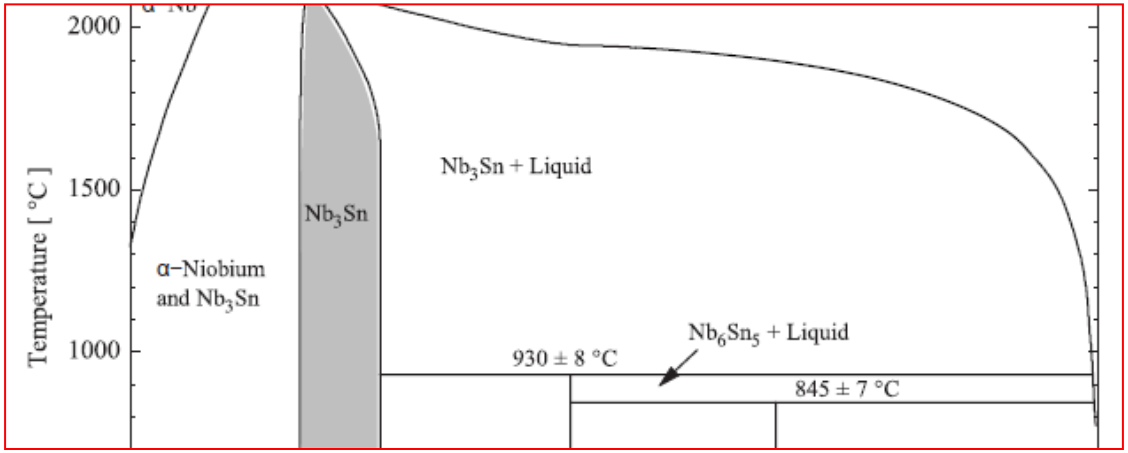
25at%Sn Nb_3Sn

High Sn flux

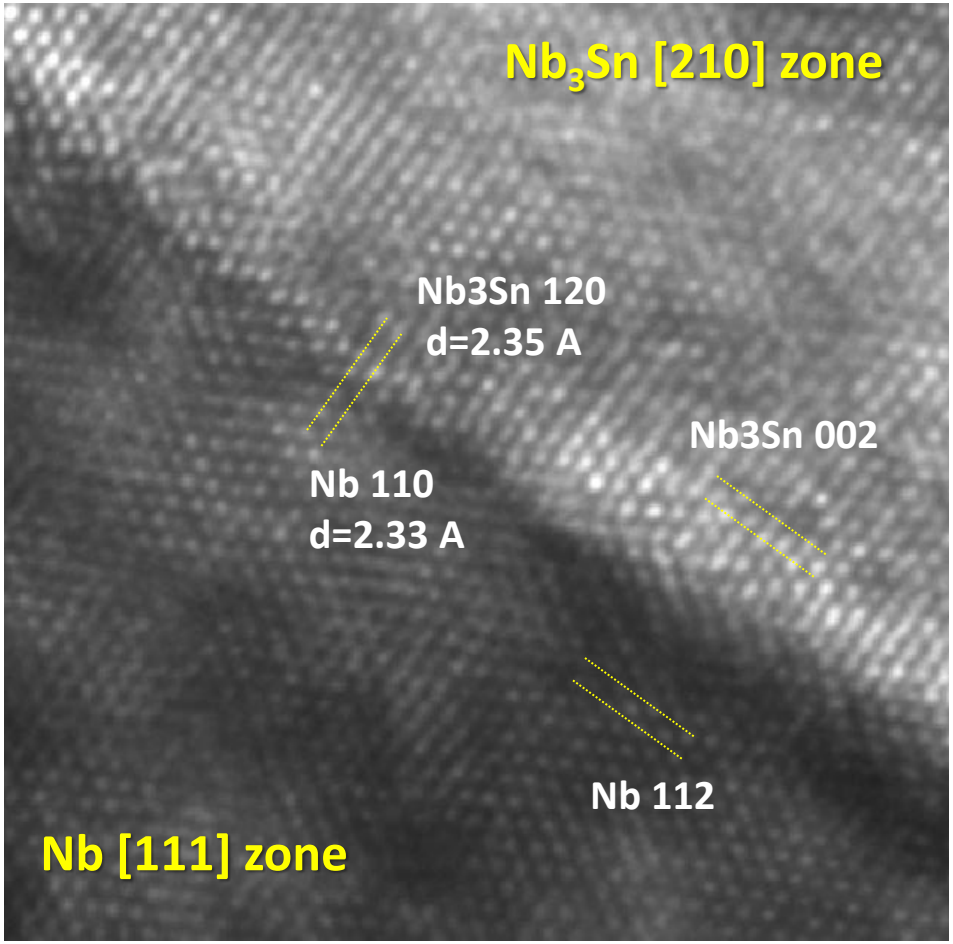


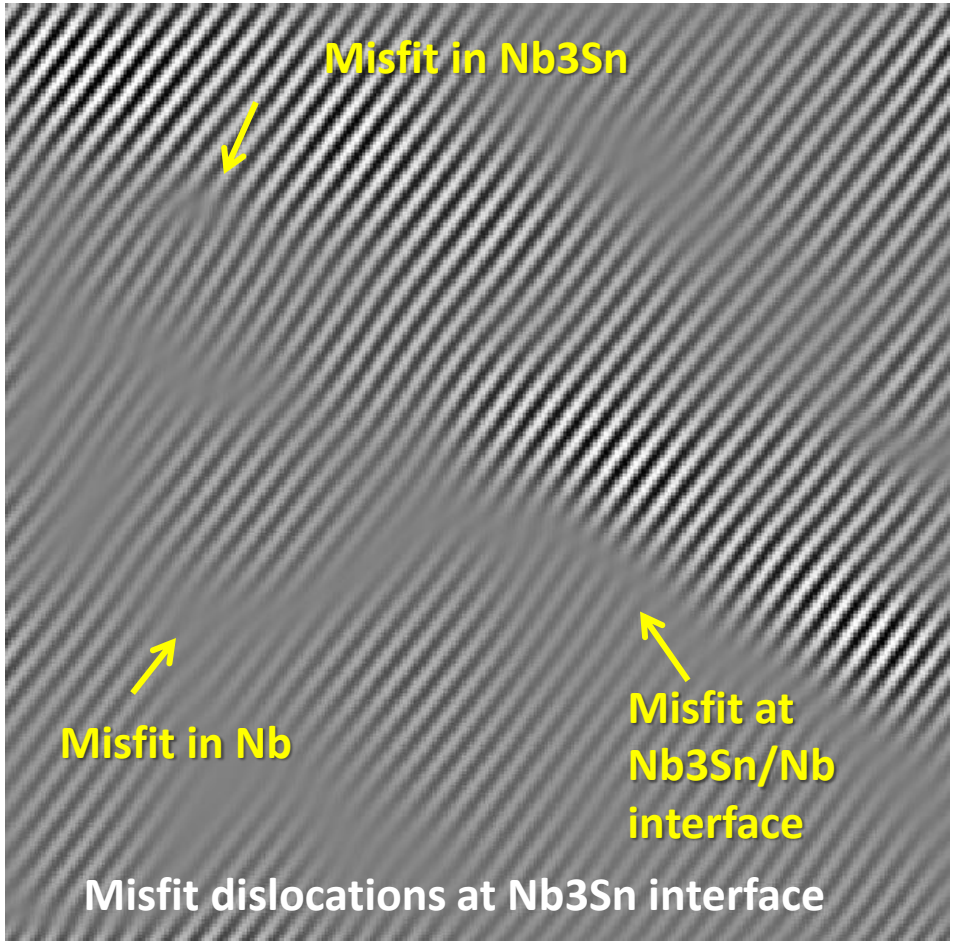
Sn-deficient region

25at%Sn Nb_3Sn



Misfits at Nb3Sn/Nb interface





Semicoherent interface between Nb_3Sn and Nb

Orientation relationship vs Strains, Sn-deficient regions, GBs

Orientation A
$Nb_3Sn(120)//Nb(111)$
$Nb_3Sn(120)//Nb(110)$

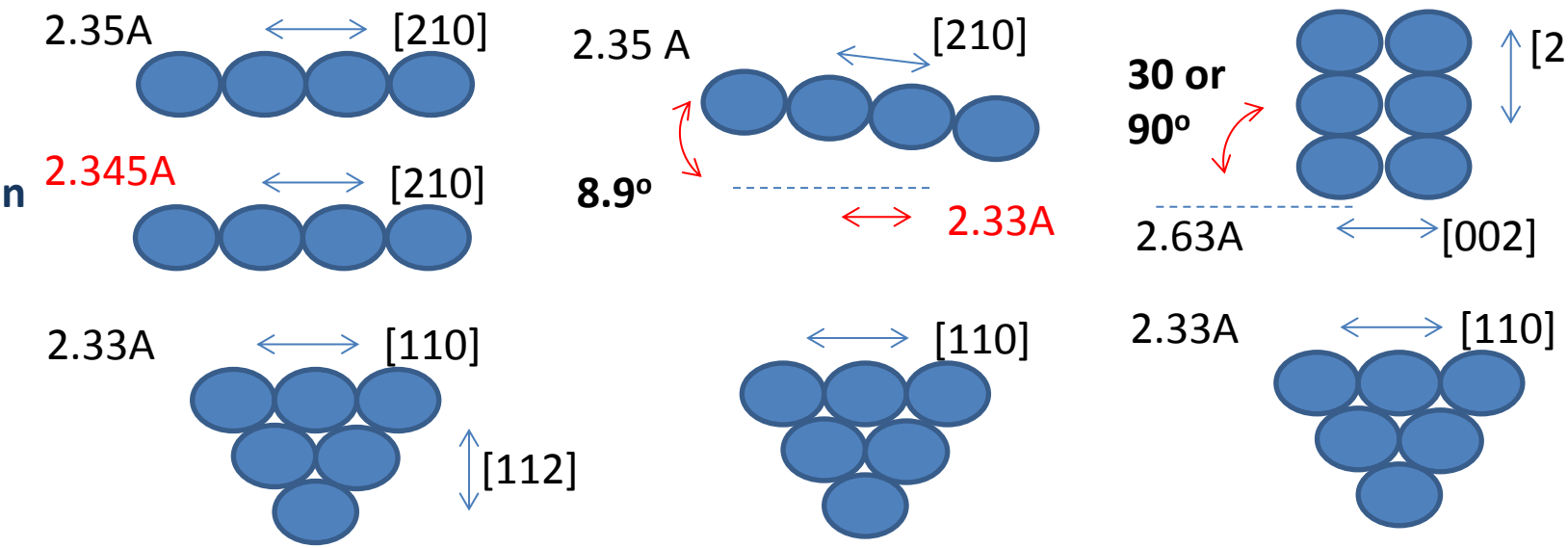
Orientation B
Nb3Sn(120)//Nb(111)
Nb3Sn(002)//Nb(123)

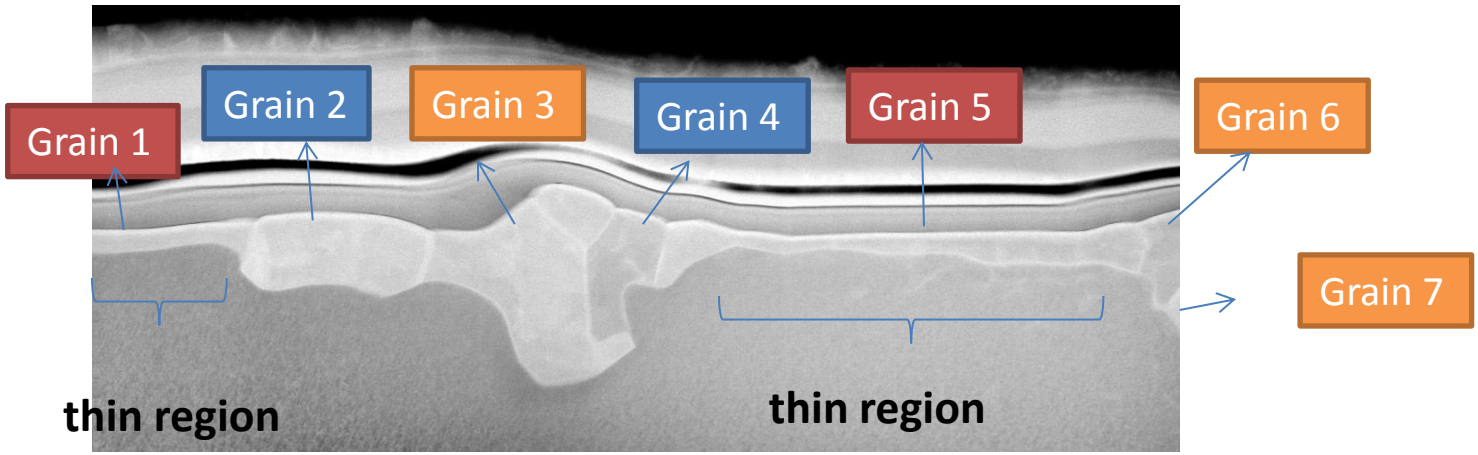
Orientation C
Nb3Sn(120)//Nb(111)
Nb3Sn(002)//Nb(110)

Nb3Sn

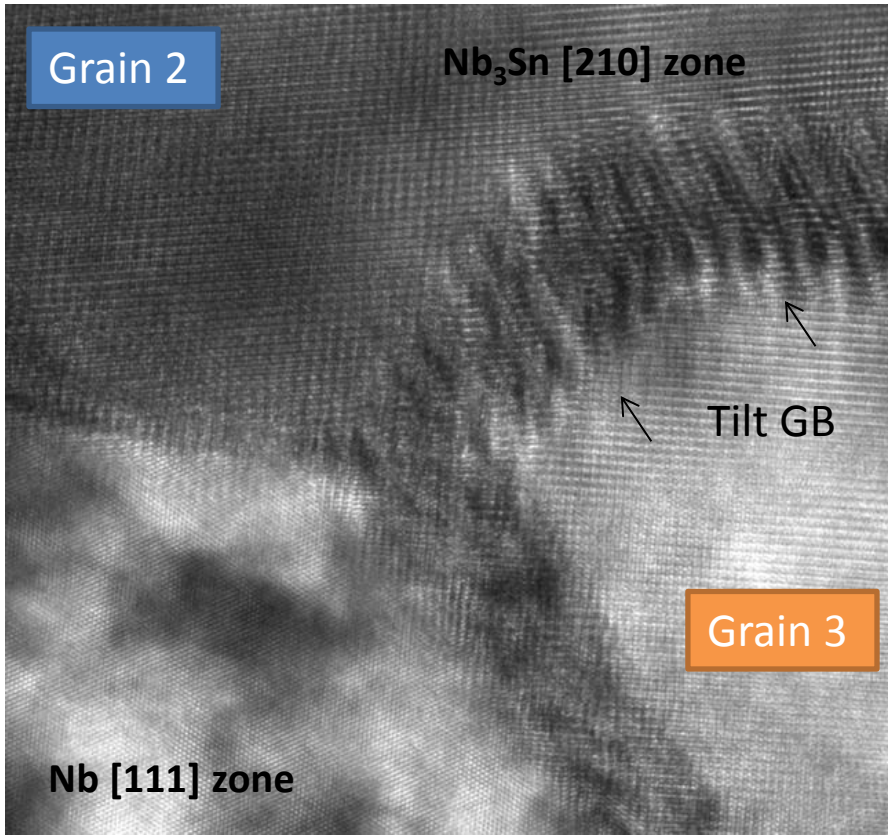
17% Nb3Sn

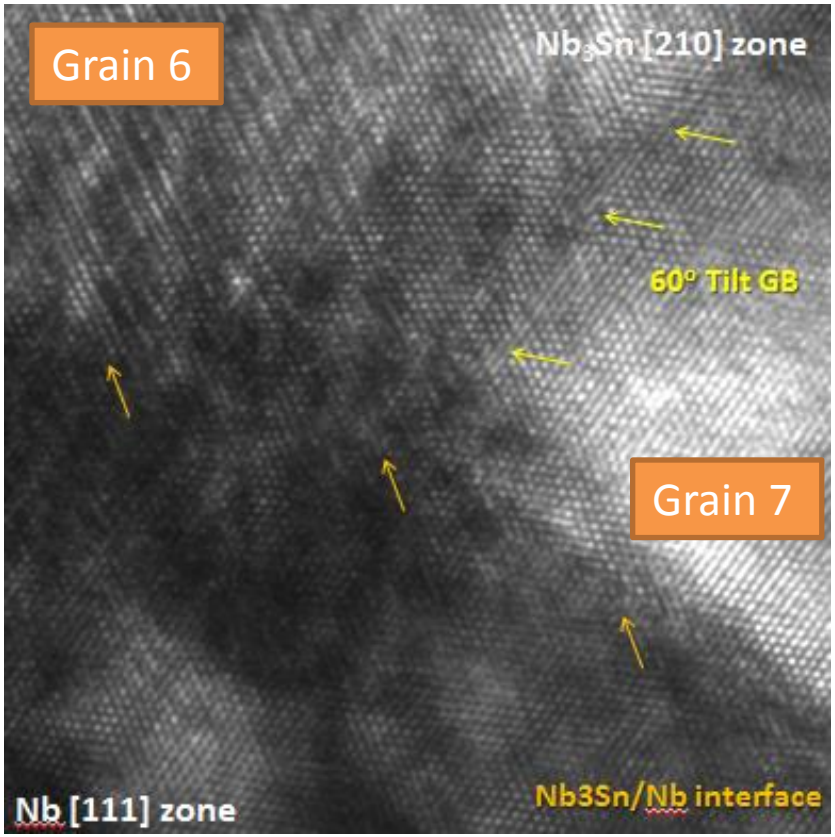
Nb

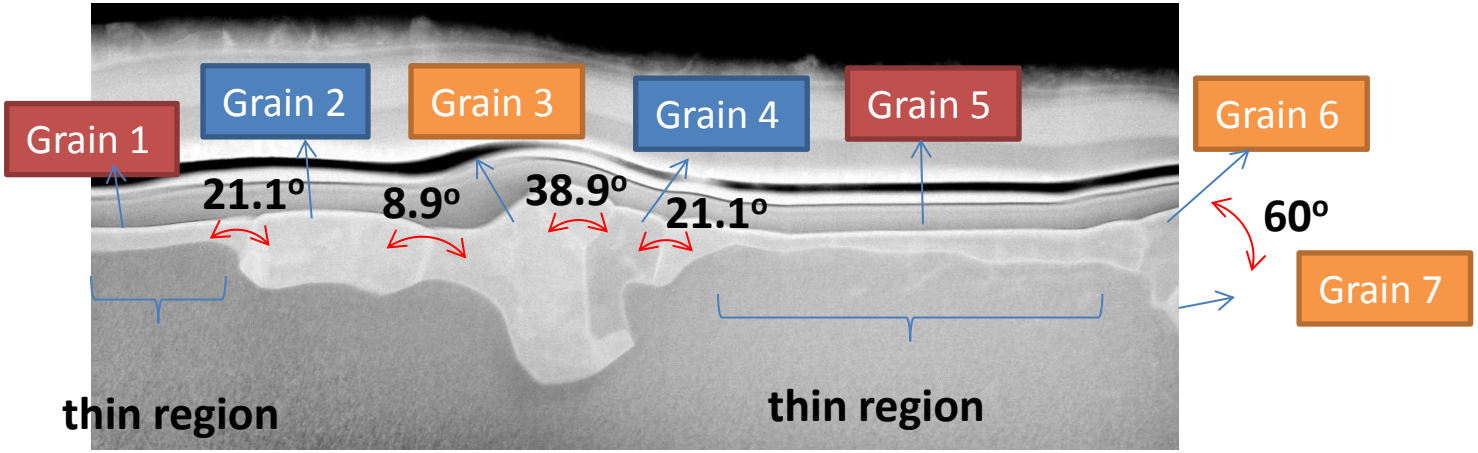




Orientation relationship vs Strains, Sn-deficient regions, GBs

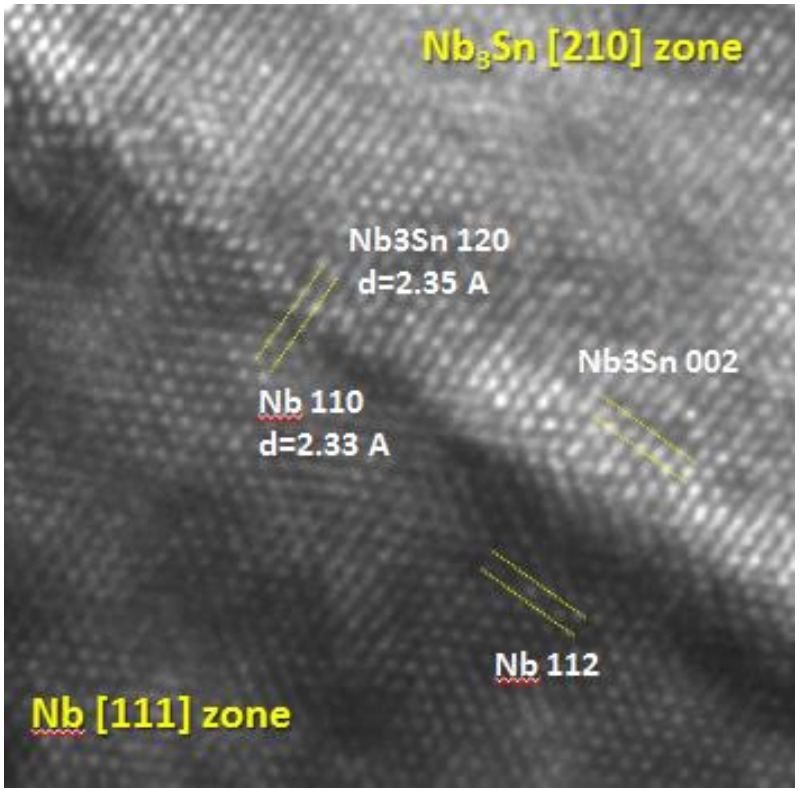






Conclusion

1. Growth mechanism of Nb3Sn proposed
2. Orientation relationships are found
3. Limiting defects in Nb_3Sn are characterized
   - Thin regions
   - Sn-deficient regions
   - Grain boundaries



Future works