Investigation of Nucleation and Growth for Nb_3Sn Diffusion Coatings on Niobium SRF Cavities

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Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity
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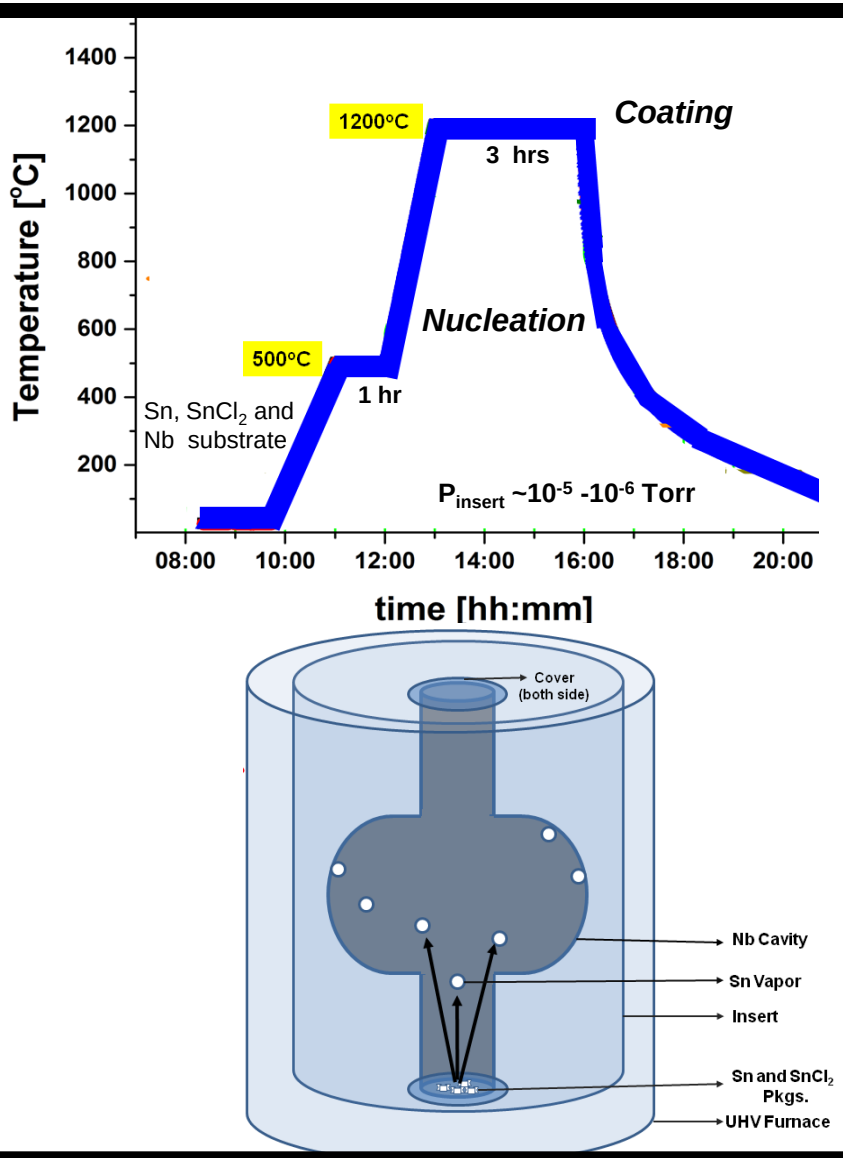
Outline

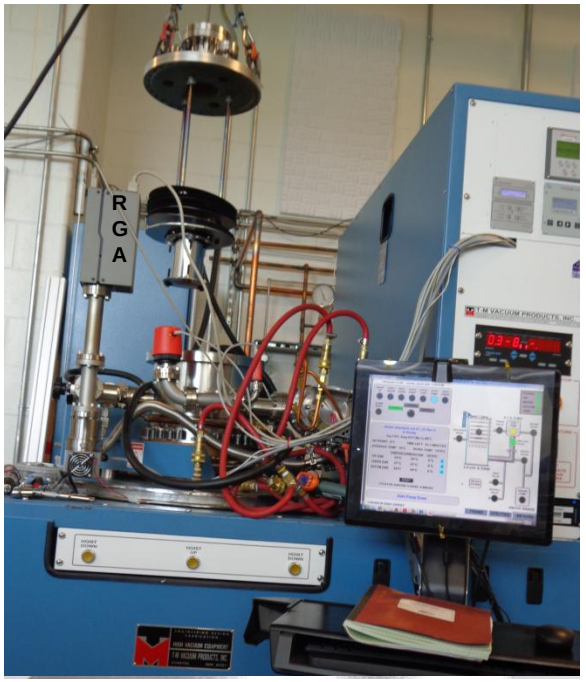
- Motivation
- Nb_3Sn coating process
- Nucleation and growth
- Summary

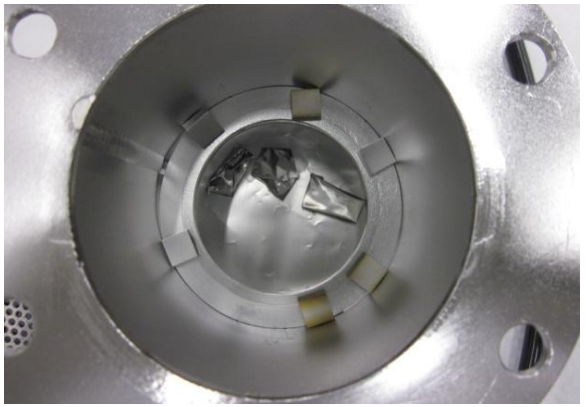
Motivation

- Superior superconducting properties (H_{sh} , T_c ~ twice of Nb)
- Higher accelerating gradient
- Operate at 4.2 K instead of 2 K
- Recent promising results

Nb_3Sn Coating Process at Jlab

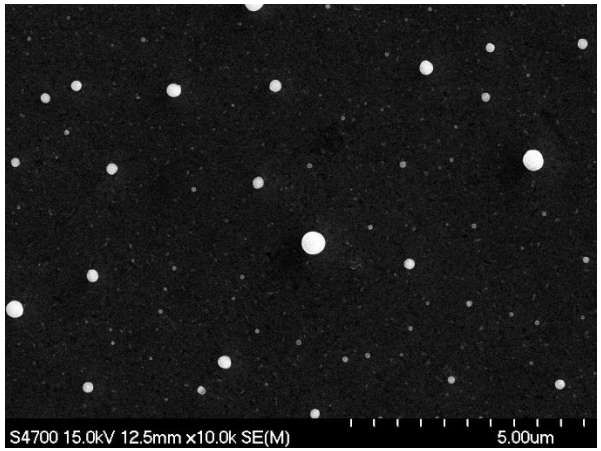




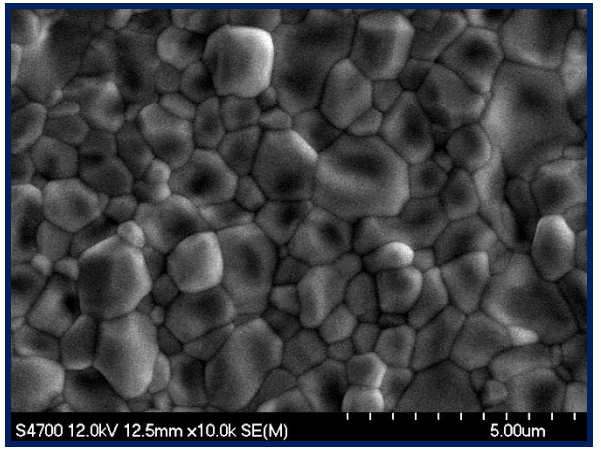


(Assumed) Coating Growth Mechanism

- Niobium surface covered with native oxide and some hydroxyl
- $SnCl_2$ reacts with surface to deposit Sn



- Evaporated Sn arrives and joins existing tin
- Phase formation and grain growth



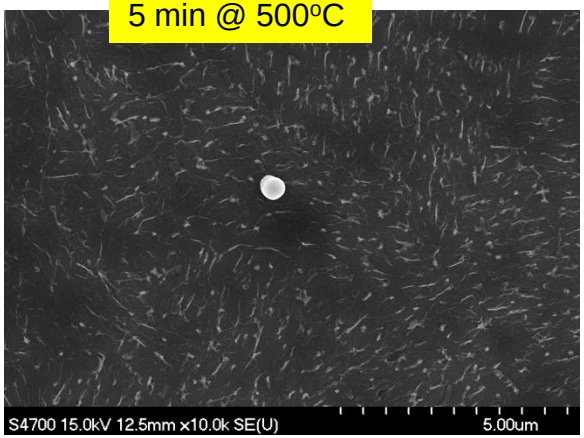
Nucleation

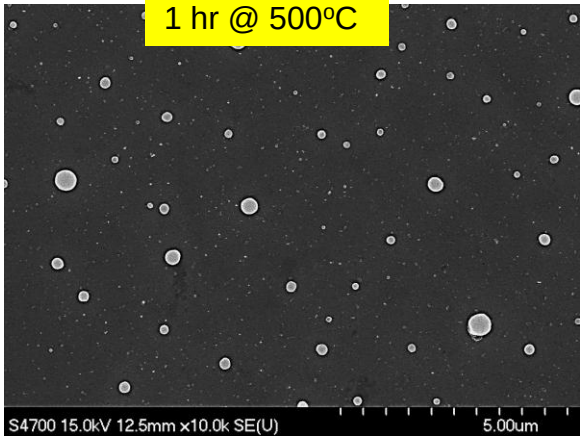
- Action of $SnCl_2$: Generates tin-enriched locations early
- Effect on uniformity and coverage?
- Controls the final structure of coating ?
- Experiments :

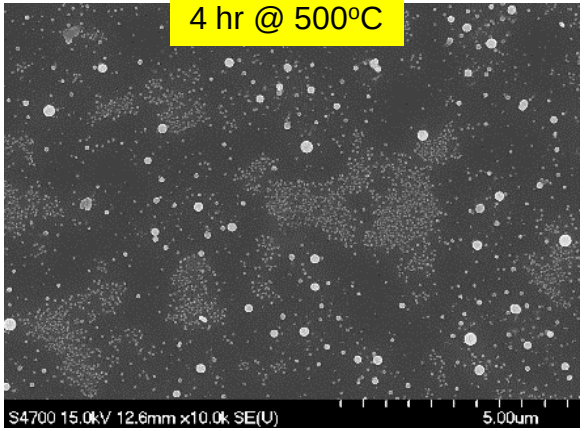
  - Usual Nb_3Sn coating set up
  - Vary nucleation parameters
  - Process interruption
  - Examination of samples

SEM/EDS Examination

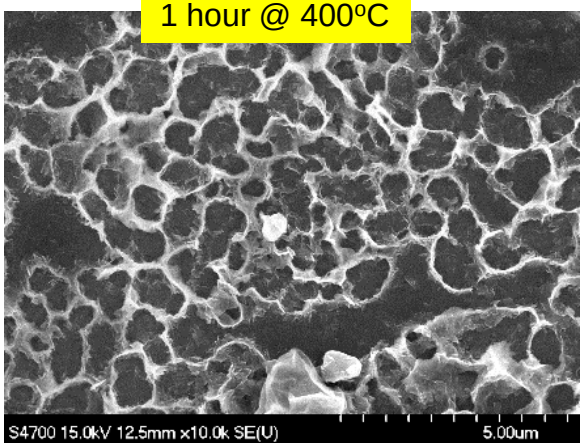
Time Variation @ 500°C

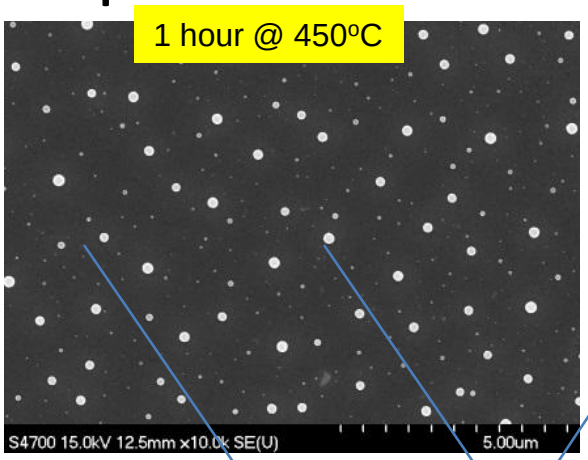


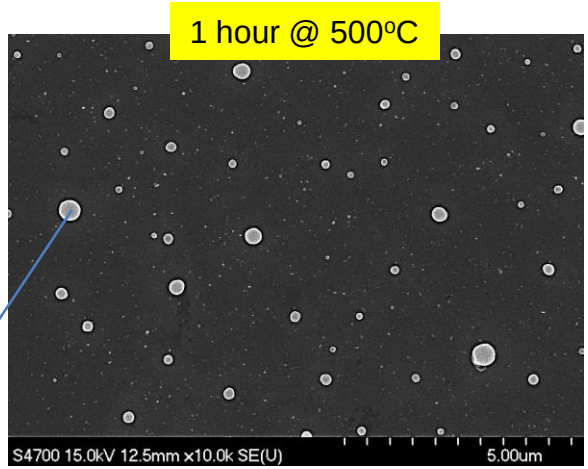




Temperature Variation







Nb

Sn

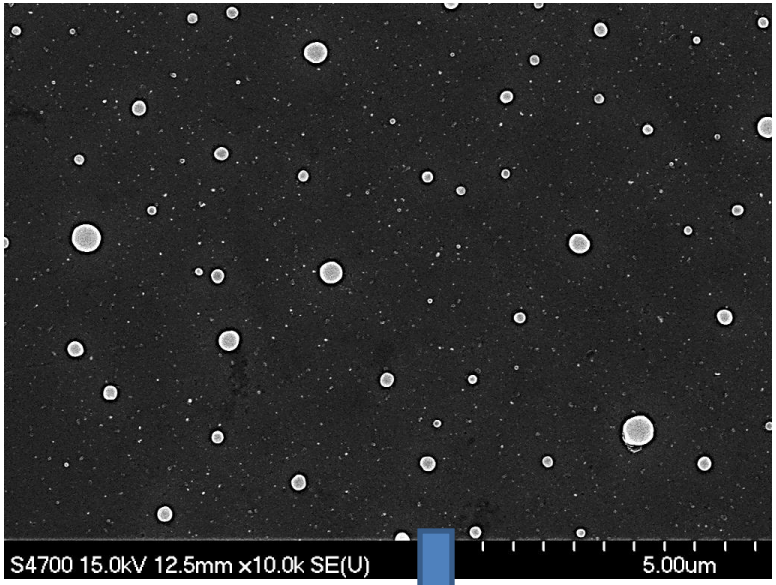
No Chlorine !

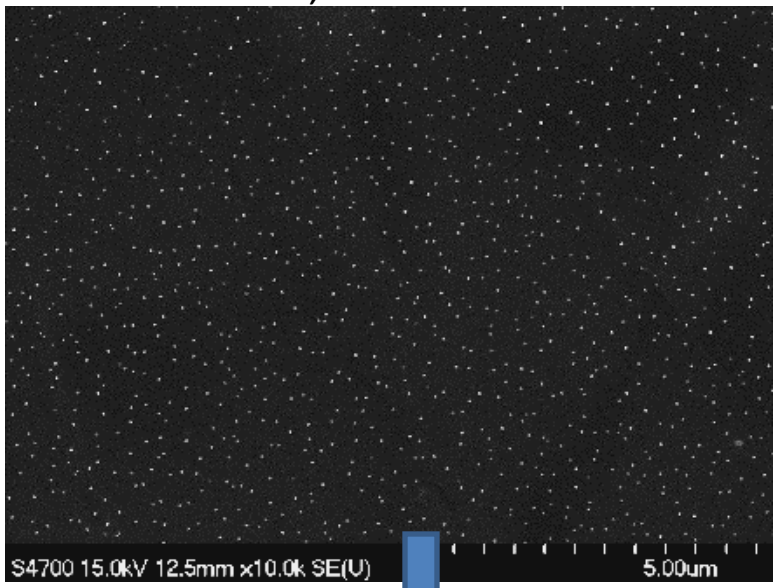
1 g $SnCl_2$, 500°C for 1 hr

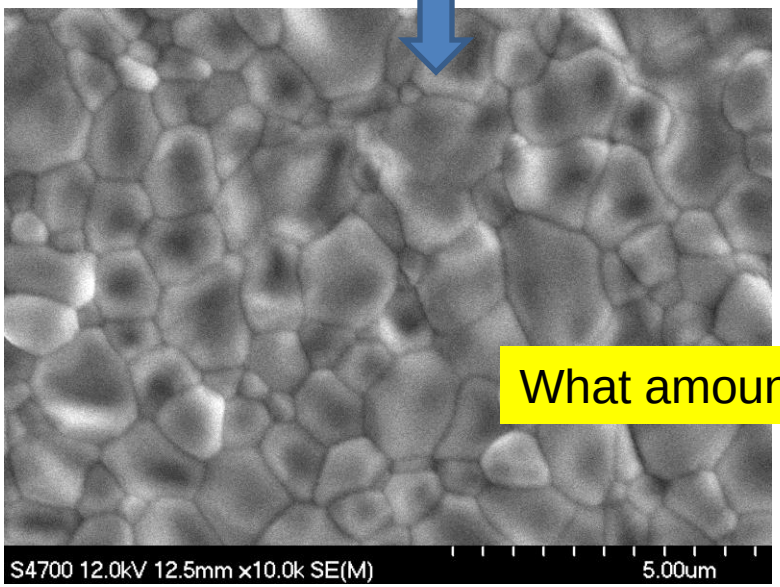
3 mg $SnCl_2$, 500°C for 5 hrs

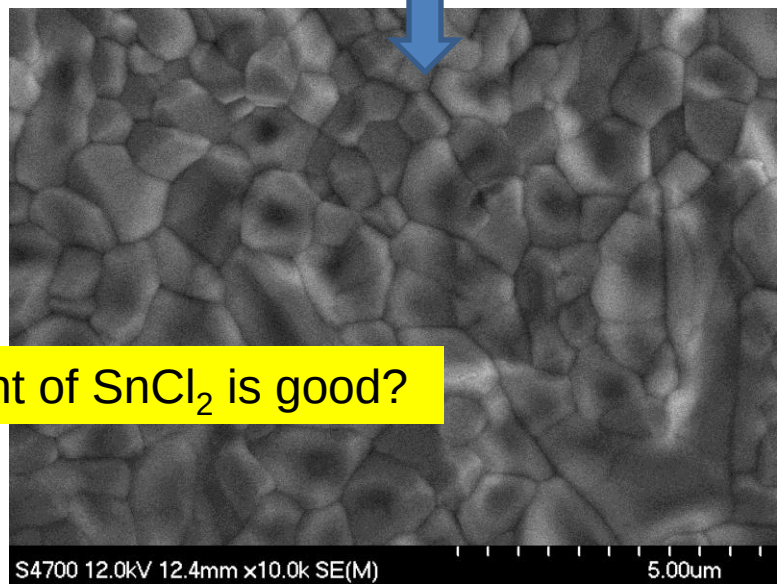
2mg/cm^2

~7µg/cm^2





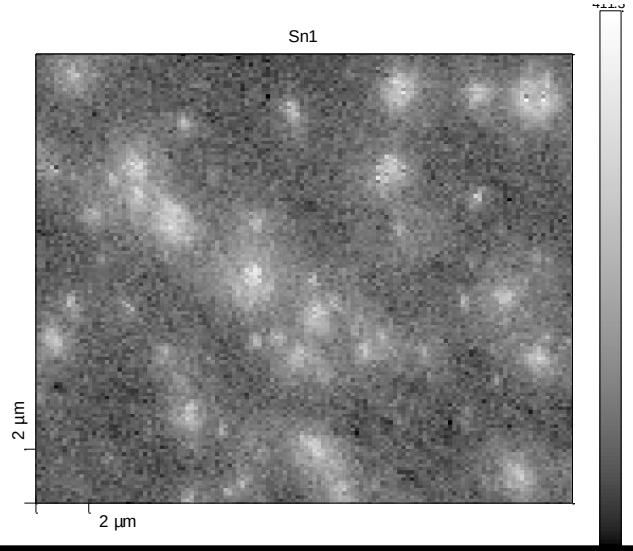


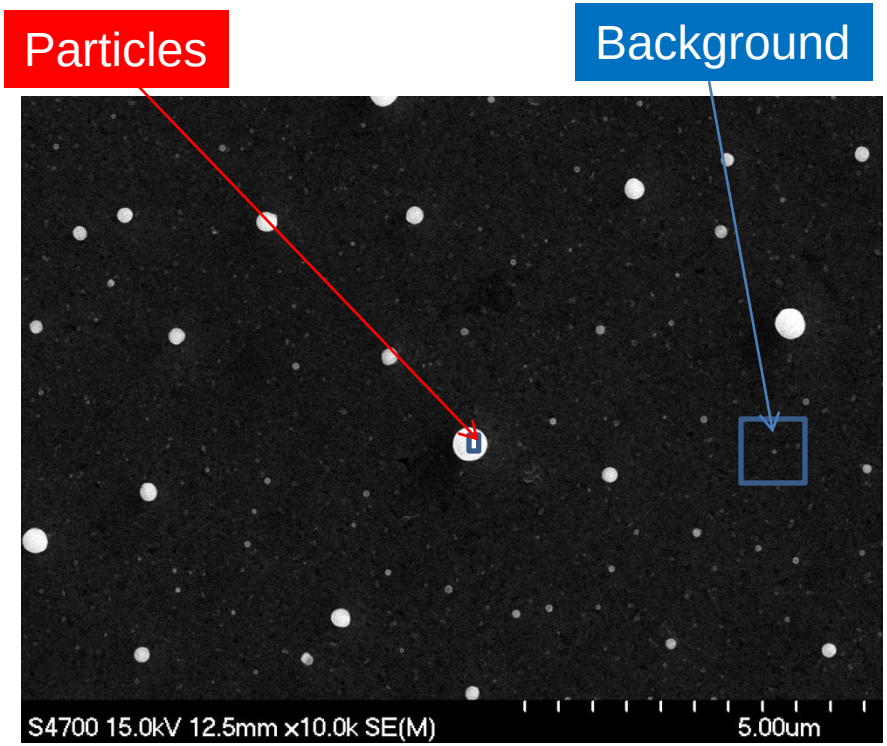


What amount of $SnCl_2$ is good?

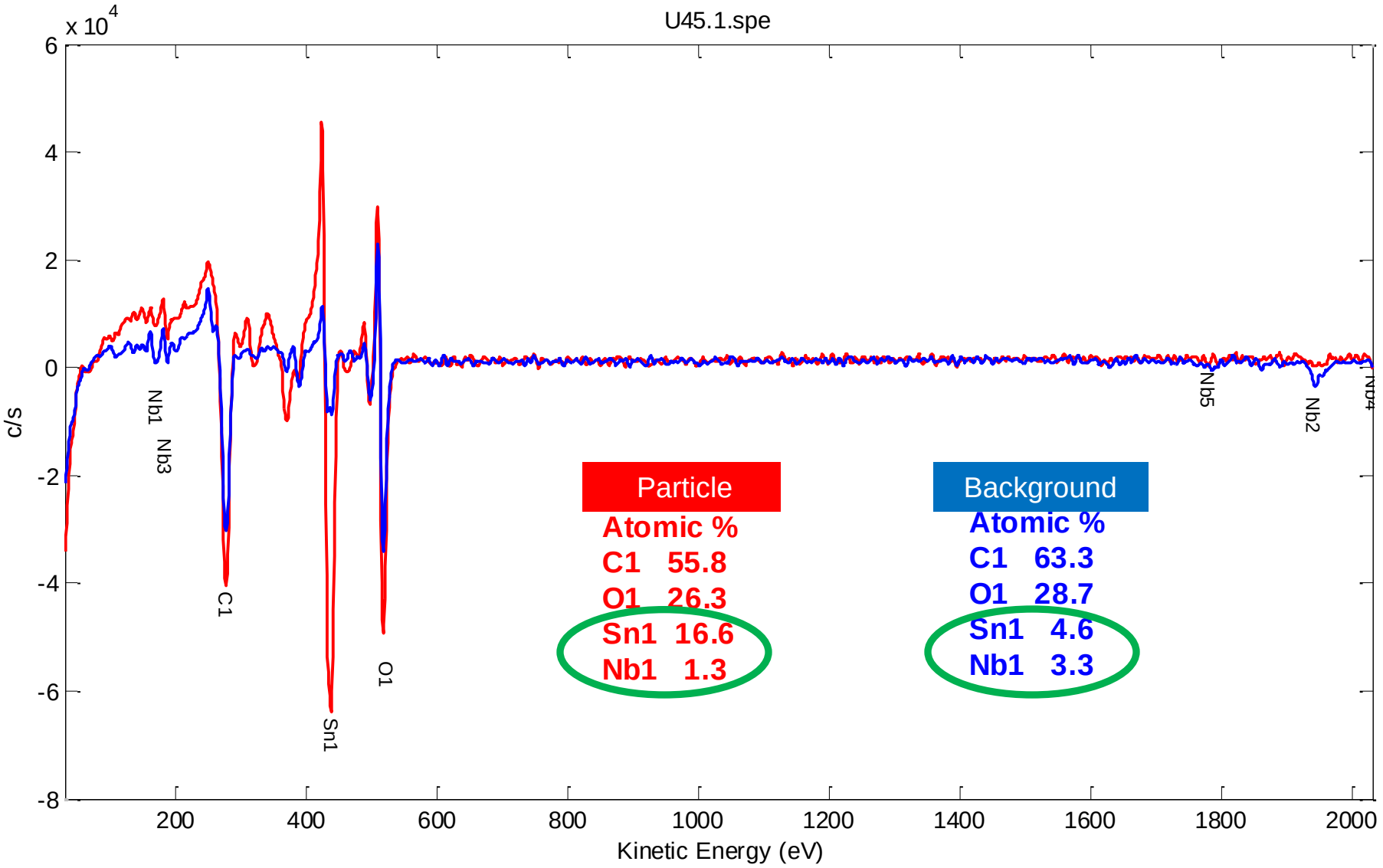
XPS and SAM Result

- More Sn coverage (Sn:Nb >1) than SEM/EDS observation (Nb:Sn>>1) for each experiment
- Surface covered with Sn particles as well as Sn film
- No Chlorine



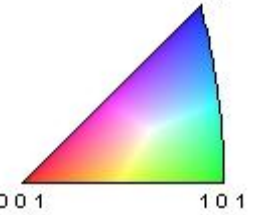


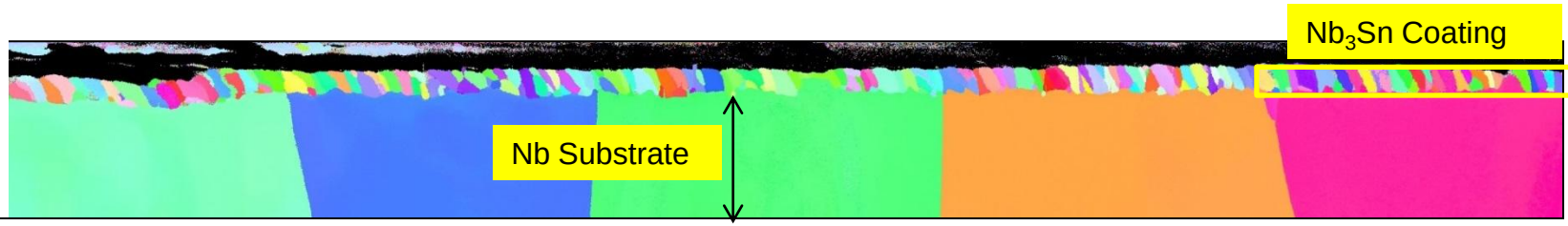
SAM Result

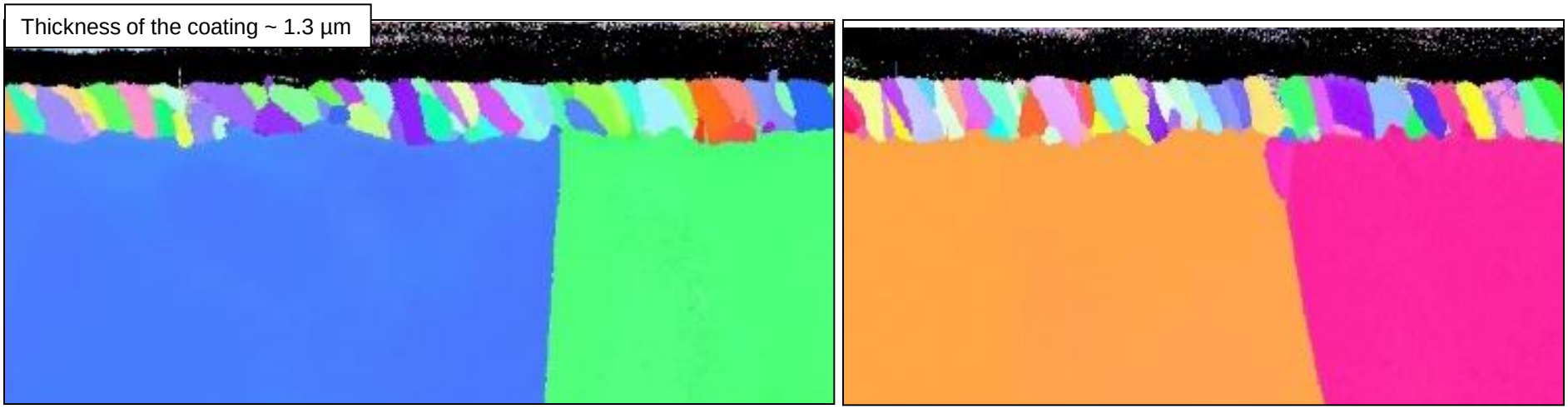

U45.1.spe
x 10^4
6
4
2
0
-2
-4
-6
-8
c/s
Nb1
Nb3
C1
Sn1
O1
Nb5
Nb2
200
400
600
800
1000
1200
1400
1600
1800
2000
Kinetic Energy (eV)
Particle
Atomic %
C1 55.8
O1 26.3
Sn1 16.6
Nb1 1.3
Background
Atomic %
C1 63.3
O1 28.7
Sn1 4.6
Nb1 3.3

Growth of Coating

- Columnar Growth
- Grain orientation independent of substrate
- No effect of Nb substrate grain boundary







Sample U3

Summary and Future Works

- Examined nucleated samples prepared with different variables.
- No Chlorine observed.
- XPS/SAM analysis confirms deposition of Sn during nucleation step in form of particle and film that possibly contributes to the uniformity and coverage of final coating.
- Complete coating experiments with different nucleation profiles are underway to establish relation between nucleation variables and final coatings.
- Material studies of cutouts from Nb_3Sn coated cavity.

Acknowledgement

- Jay Tuggle for EBSD images
- Daniel Hall and Matthias Liepe for Cornell Nucleation profile
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Applied Research Center

Jefferson Lab
Thomas Jefferson National Accelerator Facility

NCFL
ICTAS Nanoscale Characterization and Fabrication Laboratory

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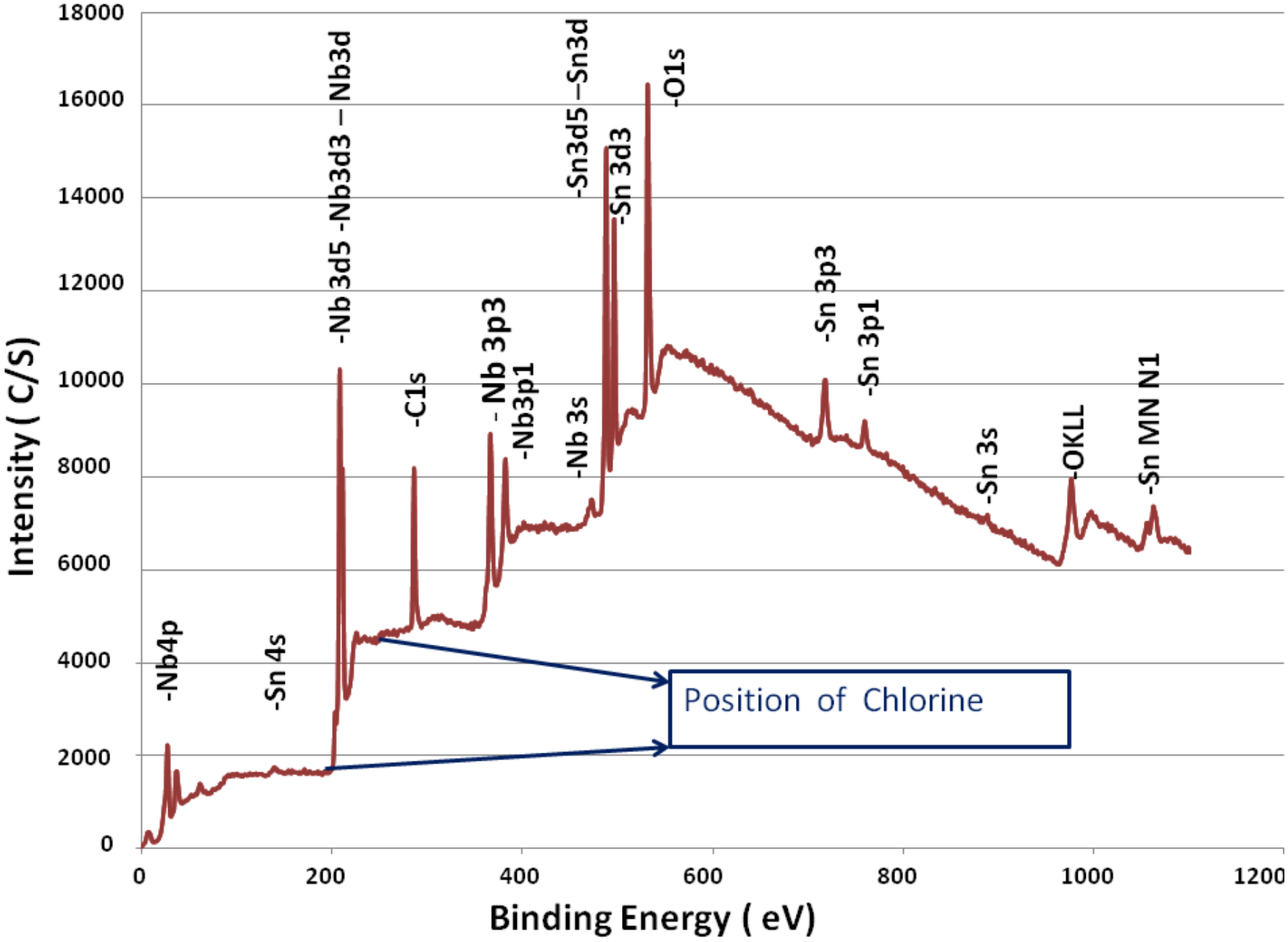
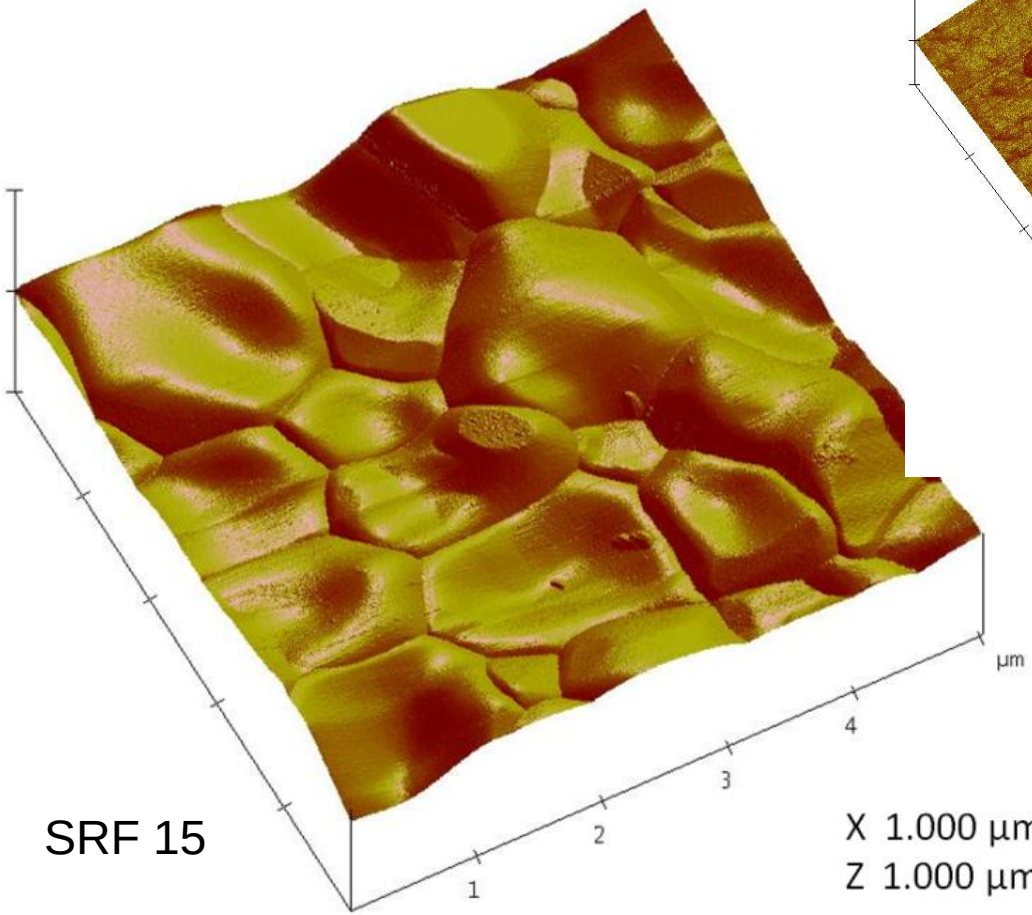
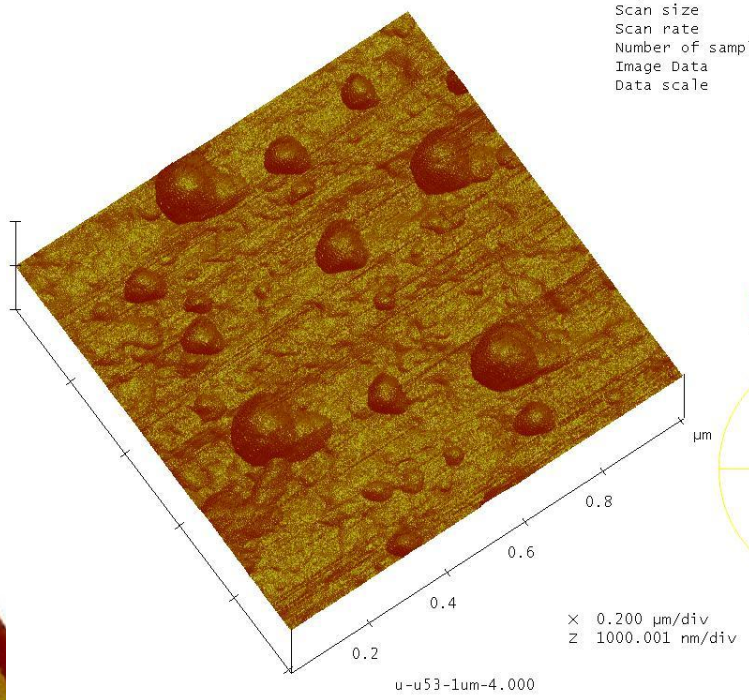

Intensity (C/S)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
Binding Energy (eV)
-Nb4p
-Sn 4s
-Nb 3d5 -Nb3d3 – Nb3d
-C1s
- Nb 3p3
-Nb3p1
-Nb 3s
-Sn3d5 –Sn3d
-Sn 3d3
-O1s
-Sn 3p3
-Sn 3p1
-Sn 3s
-OKLL
-Sn MN N1
Position of Chlorine

XPS result



SRF 15



Thanks to Olga Trofimova for helping with AFM