mERLin: materials enhanced ERL for increased sustainability

Márton Major, Amir Farhood, Alexey Arzumanov and Lambert Alff

Technical University of Darmstadt, Darmstadt, Germany

SuperSurfer meeting

Wuppertal University

16th June 2025

BMBF project plan / funding

- Novel dual target sputtering process for energy-efficient SRF technology (not funded)
- Sustainable operation of electron accelerators (not funded)
- Combined electromagnetic-thermal numerical simulations considering layered surface structures (funded)

Novel dual target sputtering process for energy-efficient SRF technology

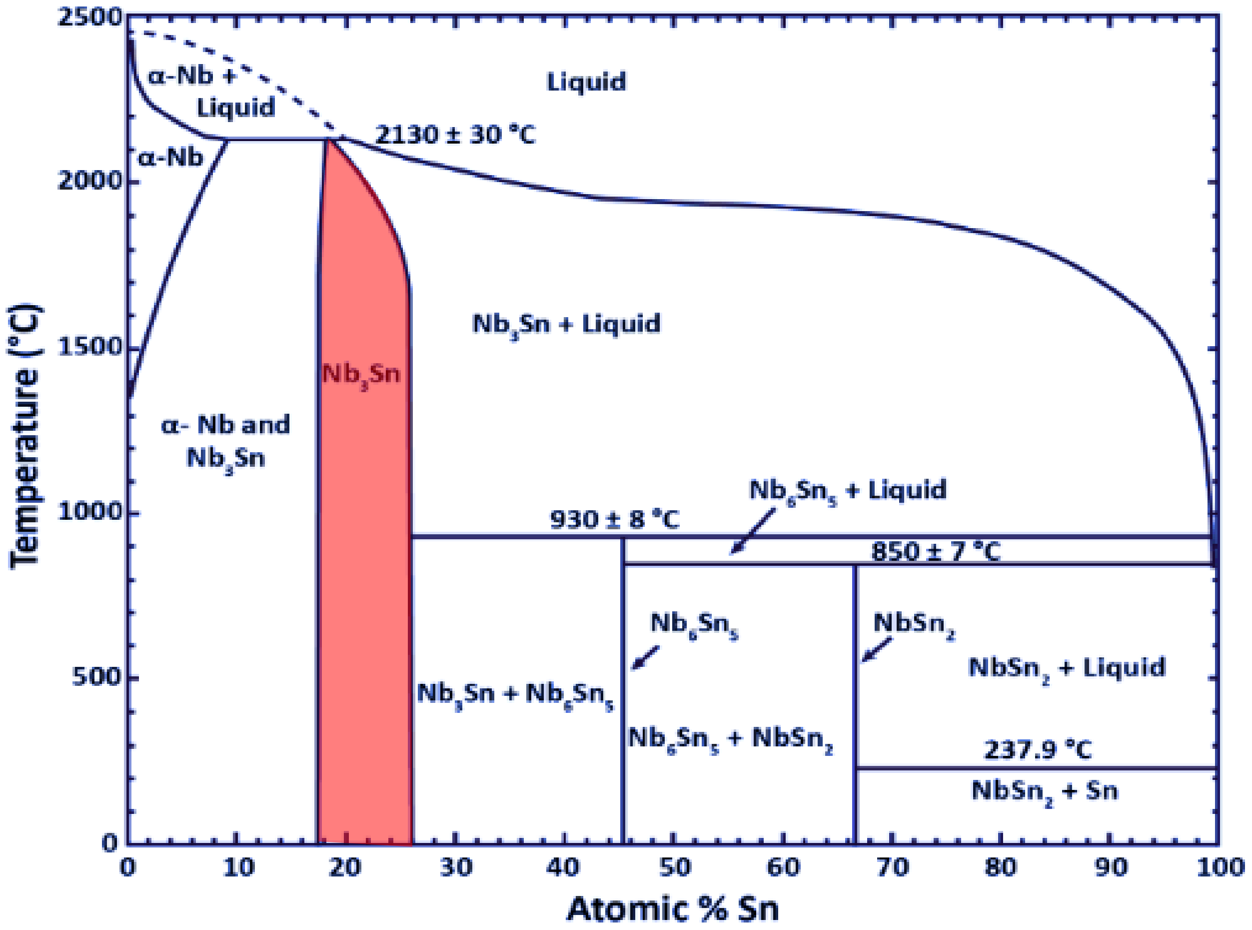
- Coating of RF samples for the Quadrupole Resonator (QPR)
- Realization of novel in-cavity dual target sputtering process
- Inner coating of copper cavities
- Performance tests on QPR samples and cavities
- Coating of structures for the consortium partners (HOM antennae, QPR cups, samples)

Possible superconducting materials for RF cavities

Material	Critical Temp. T_c [K]	Normal-state resistivity ρ_n [μΩcm]	Critical Field $H_c(0)$ [T]	Lower Critical field $H_{c1}(0)$ [T]	Upper Critical field $H_{c2}(0)$ [T]	Penetration depth $\lambda(0)$ [nm]	Δ [meV]	Type
Nb	9.23	2	0.2	0.18	0.28	40	1.5	II
Pb	7.2		0.08	N/A	N/A	48		I
NbN	16.2	70	0.23	0.02	15	200-350	2.6	II, B1 comp.
NbTiN	17.3	35		0.03		150-200		II, B1 comp.
Nb_3Sn	18	20	0.54	0.05	30	80-100	3.1	II, A15
V_3Si	17				24.5	179		II, A15
Mo_3Re	15		0.43	0.03	3.5	140		II, A15
MgB_2	40	0.1-10	0.43	0.03	3.5-60	140	2.3/7.2	II- 2 gaps
YBCO	93		1.4	0.01	100	150	20	d-wave
Pnictides	30-55		0.5-0.9	30	>100	200	10-20	

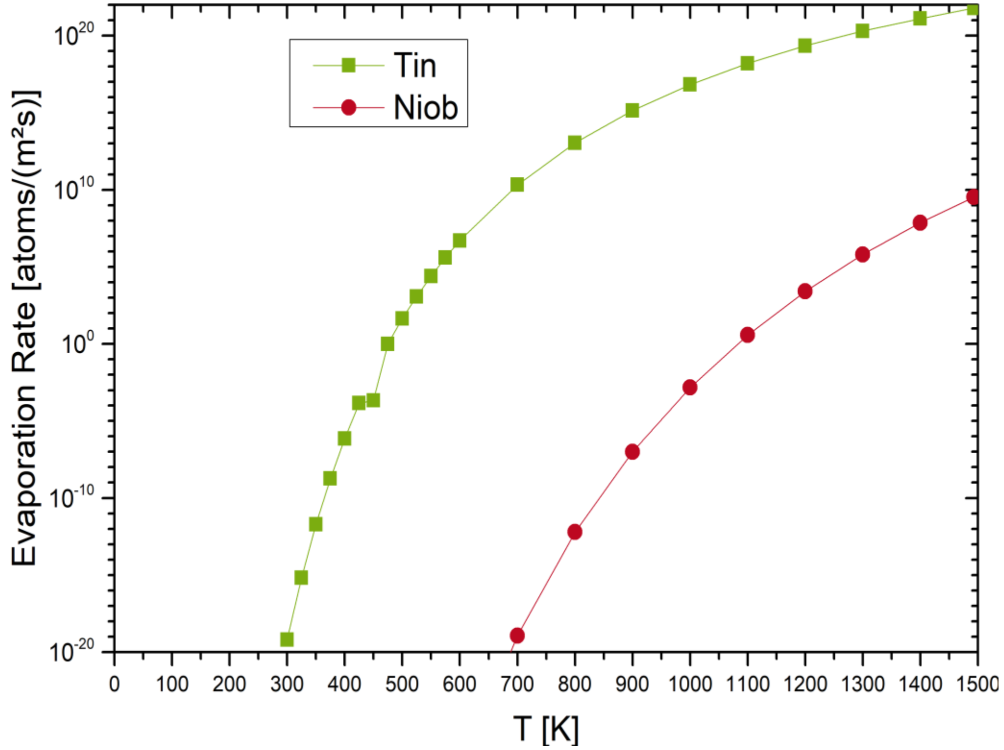
Whistler 2015, SRF Tutorial - Pushing Nb Performance - A.-M. Valente-Feliciano

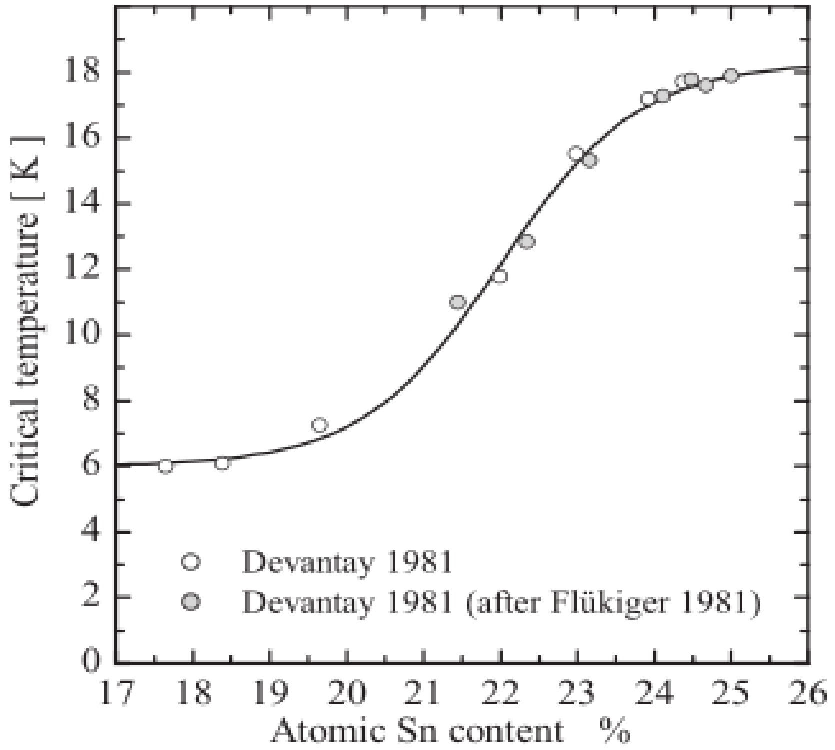
Nb-Sn phase diagram



Charlesworth JP, Macphail I, Madsen PE., Journal of Materials Science. 1970 Jul 1;5(7):580-603.

Challenge: Vapor-pressure of Sn





Literature results for the critical temperature as functions of Nb–Sn composition.

A Godeke 2006 Supercond. Sci. Technol. 19 R68

TU Darmstadt approach: Nb_3Sn co-sputtering

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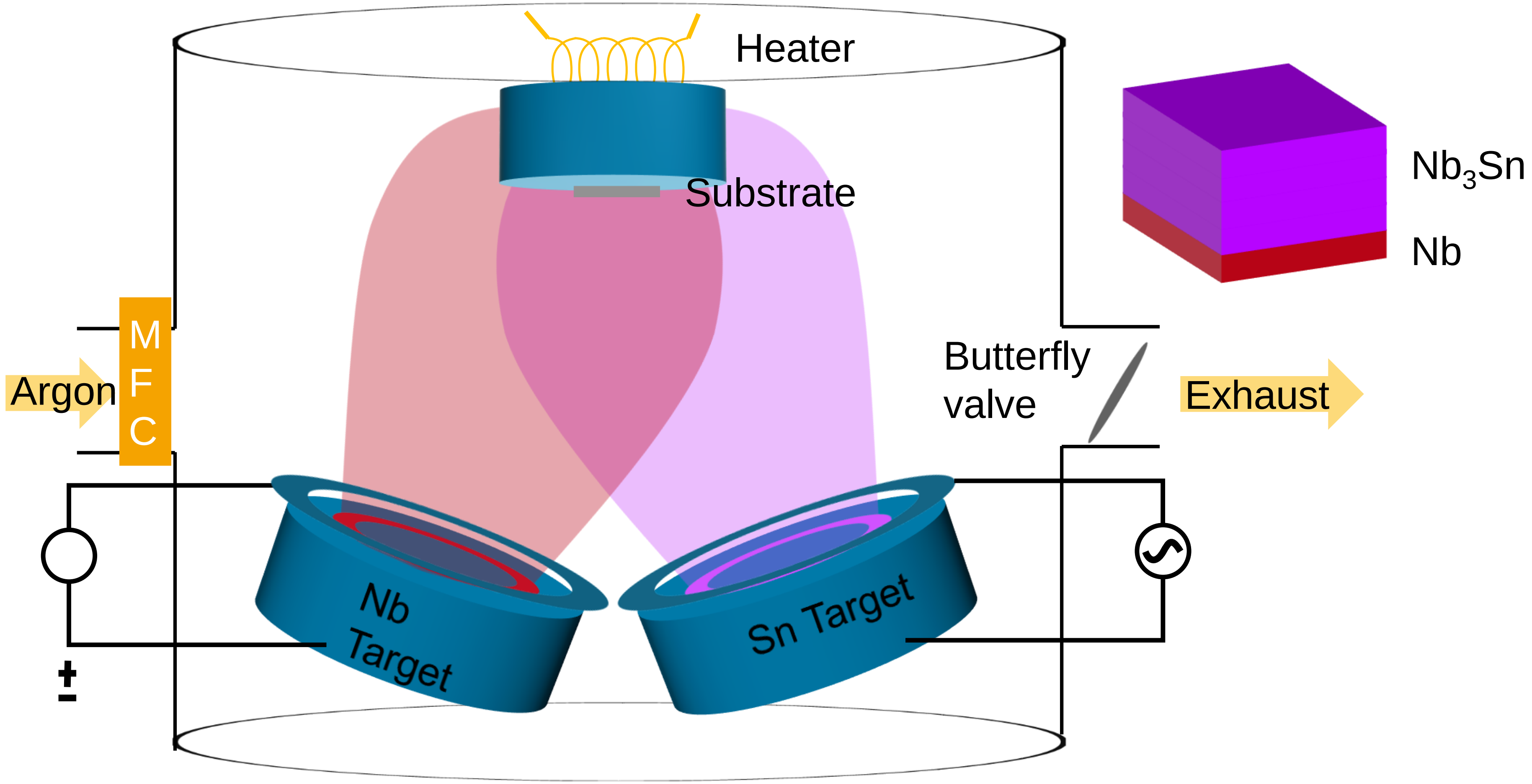


Nils Schäfer

Nb_3Sn cavity roadmap

1. Optimization of the sputtering parameters (sputter power, substrate temperature, etc.) on fused silica substrate
2. Adaptation of the growth parameters (further optimization of growth temperature etc.) for copper substrate
3. Upscaling of the sputtering process to the cavity geometry:
   a. Optimizing the sputtering parameters for the new (larger) sputtering chamber
   b. Design and production of the mini double ring magnetron for cavity sputtering
   c. Inner coating of Cu cavities

N. Schäfer, N. Karabas, J. P. Palakkal, S. Petzold, M. Major, N. Pietralla, and L. Alff, **Kinetically induced low-temperature synthesis of Nb_3Sn thin films,** J. Appl. Phys. **128**, 133902 (2020)

E. Barzi, B. C. Barish, R. A. Rimmer, A. Valente-Feliciano, C. M. Rey, W.A. Barletta, E. Nanni, M. Nasr, M. Ross, M. Schneider, S. Tantawi, P. B. Welander, E. I. Simakov, I. O. Usov, L. Alff, N. Karabas, M. Major, J. P. Palakkal, S. Petzold, N. Pietralla, N. Schäfer, A. Kikuchi, H. Hayano, H. Ito, S. Kashiwaji, H. Monjushiro, H. Hama, F. Hona, K. Umemori, K. Takahashi, T. Takahashi, Y. Kondo, K. Yamakawa, K. Kon, T. Kubo, **An Impartial Perspective for Superconducting Nb_3Sn coated Copper RF Cavities for Future Accelerators,** arXiv:2203.09718 [physics.acc-ph] (2022)

N. Schäfer, D. Günzing, T. Jiang, N. Karabas; A. Arzumanov, D. Motta-Meira, K. Ollefs, P. Komissinskiy, M. Major, M. Arnold, N. Pietralla, H. Wende, L. Molina-Luna, D. Lützenkirchen-Hecht, L. Alff, **Role of kinetic energy on Nb_3Sn thin films by low-temperature co-sputtering,** J. Appl. Phys. **134**, 043903 (2023)

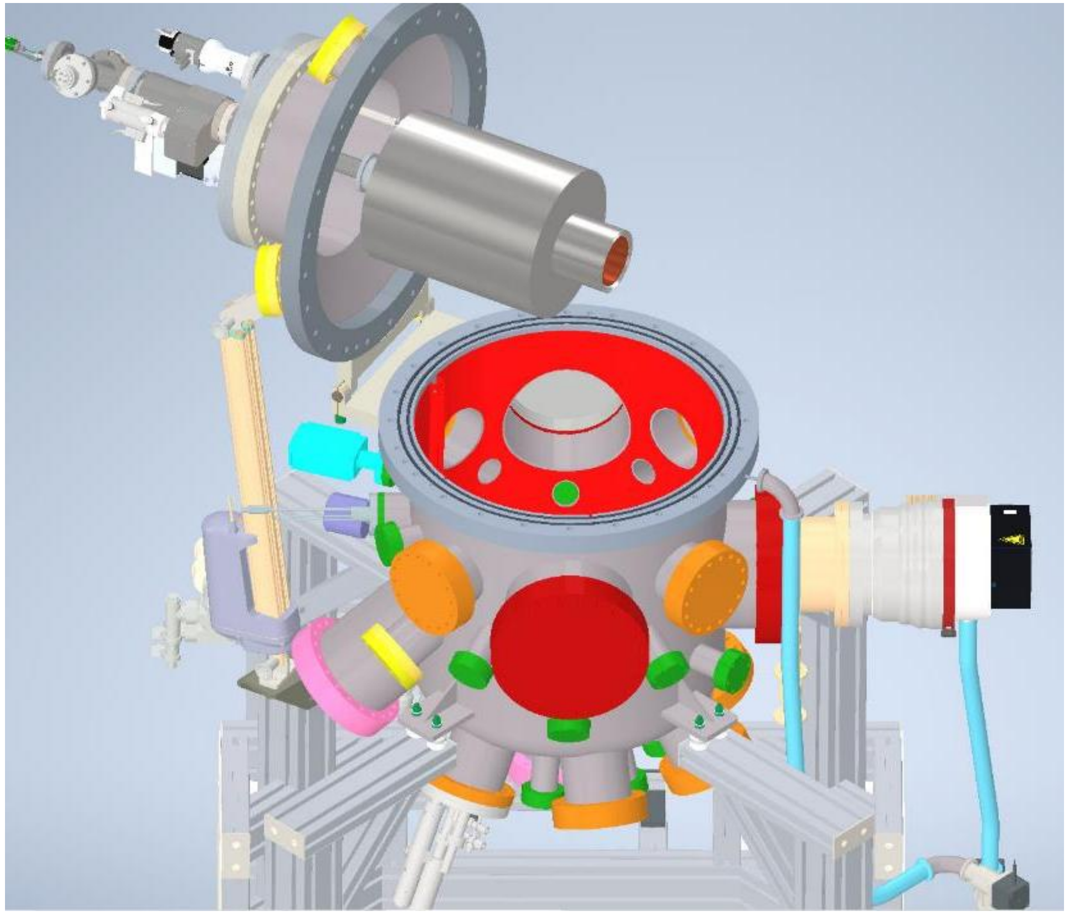
Physical properties of Nb_3Sn films grown on Cu – conclusions

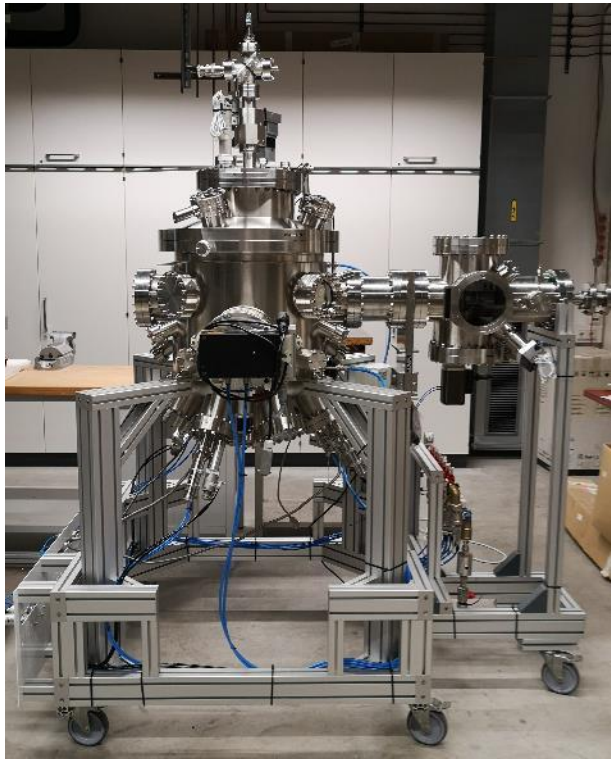
The thin film synthesis results in Nb_3Sn layers with overall highly beneficial properties for their application as coatings in copper based SRF cavities.

At processing temperatures where copper diffusion is negligible, around 480 °C, a critical temperature of 16.8K can be achieved. At the same time, H_{c1} is enhanced which enhances the applicable acceleration gradients. Low surface roughness and high mechanical stability further makes these coatings excellent candidates for cavity applications.

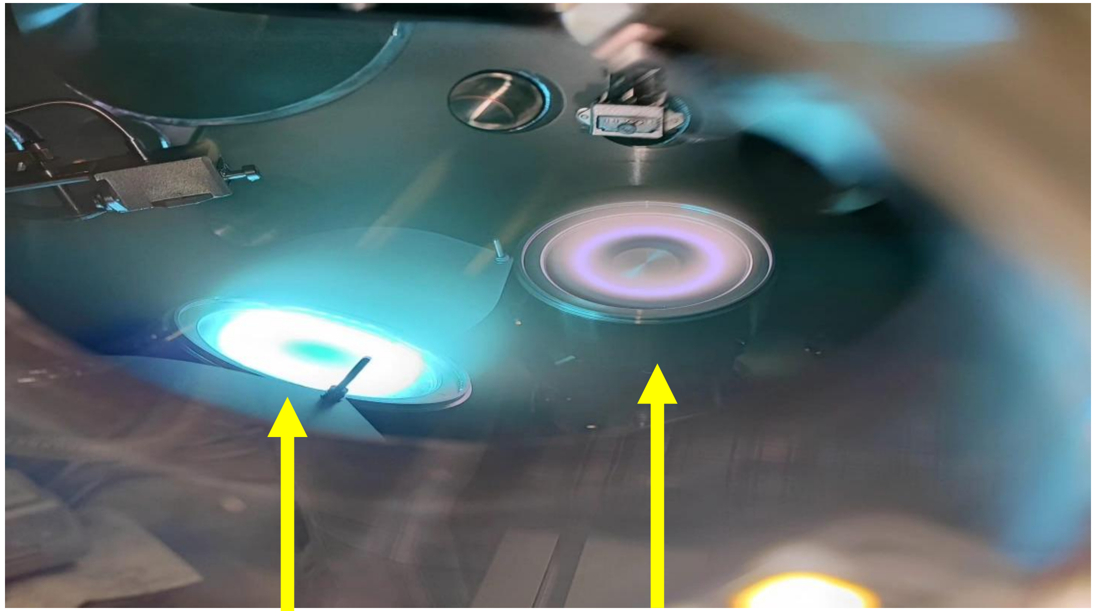
N. Schäfer *et al.* to be published

Upscaling to copper cavities





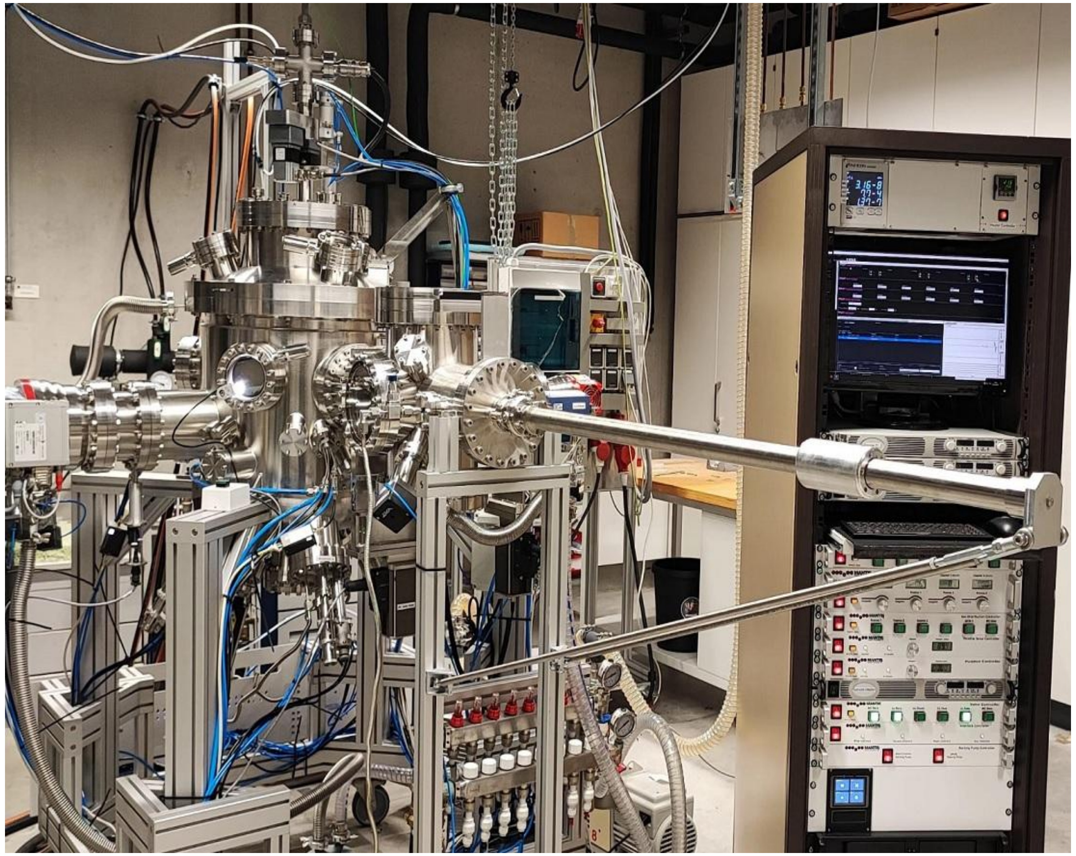
Upscaling to copper cavities



Sn

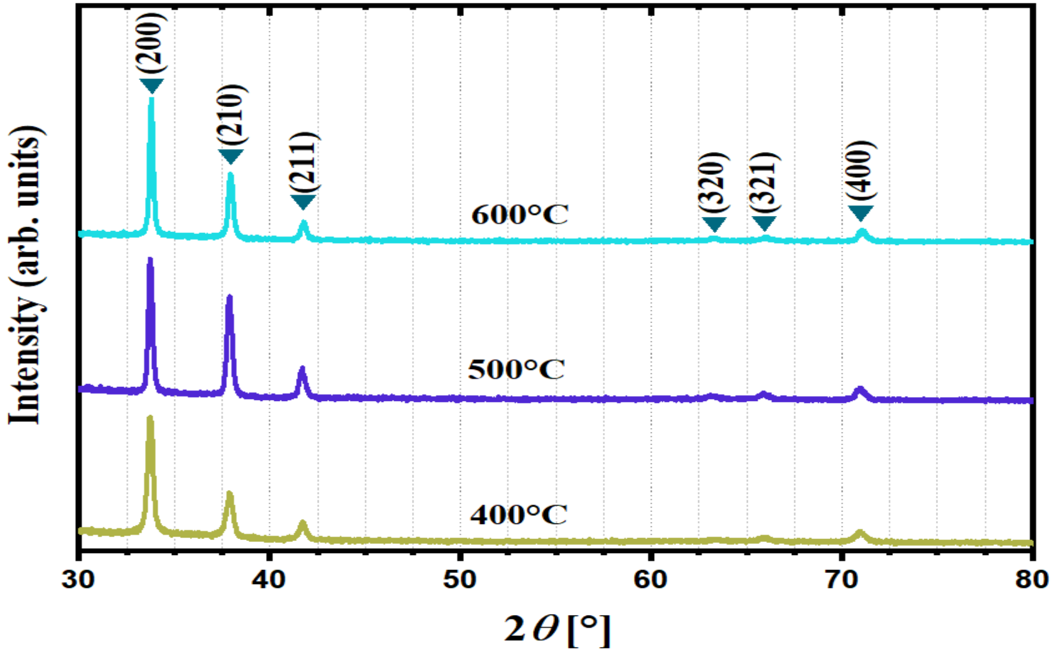
Nb

Alexey Arzumanov

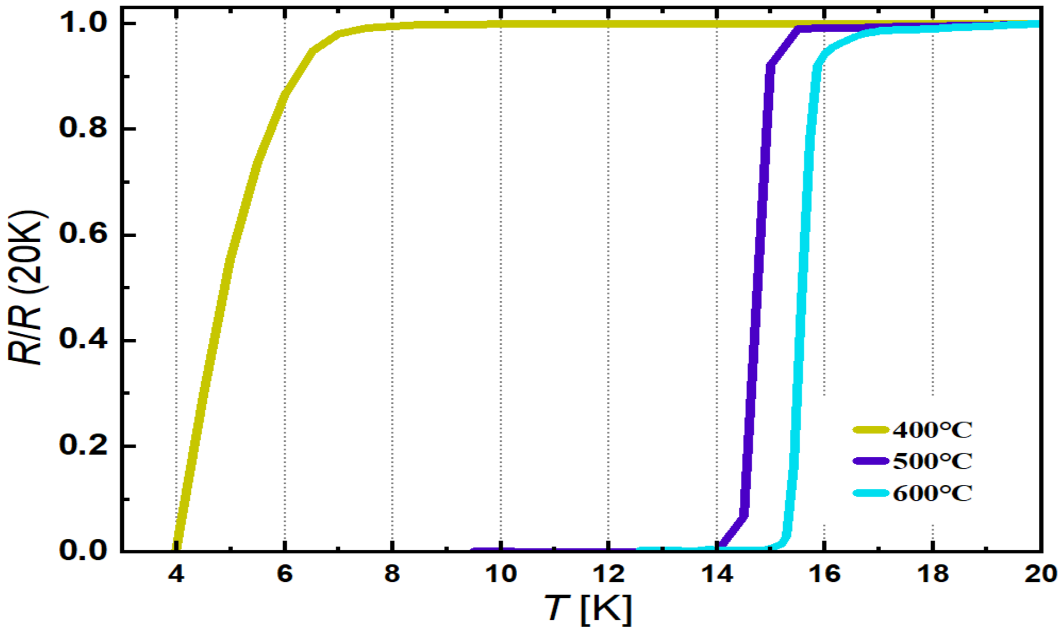


Upscaling to copper cavities

300 nm Nb_3Sn films grown at different substrate temperature on fused silica substrate



X-ray diffraction patterns



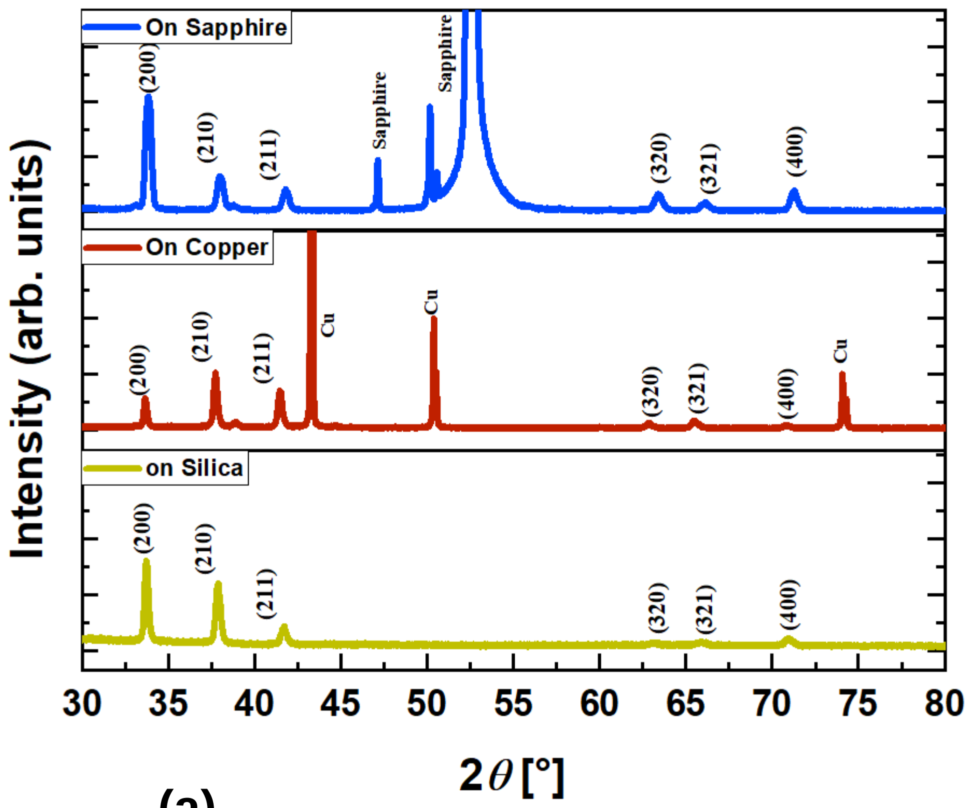
Resistivity normalized to the resistivity at 20 K

T_s (°C)	400	500	600
Nb (at%)	74.9±1.6	74.6±0.4	74.0±0.4

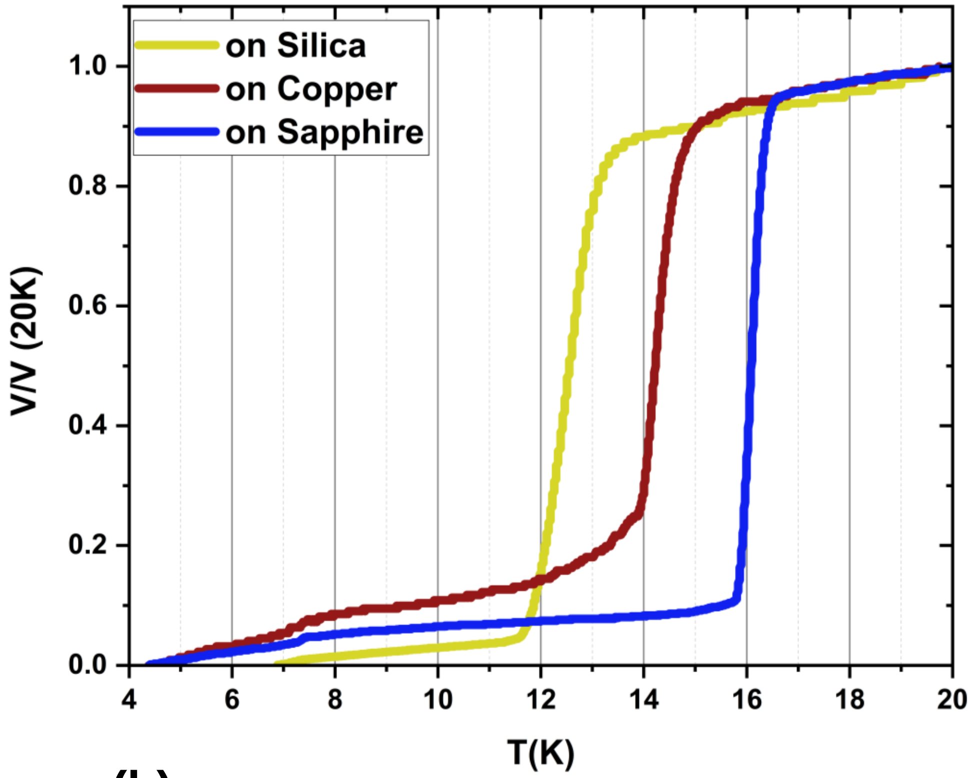
Sputtering parameters:
DC sputtering
I_{Nb} = 450 mA
I_{Sn} = 80 mA

Amir Farhood

Nb$_3$Sn sputtered on substrates of fused silica, sapphire and copper at 500 °C to investigate the impact of substrate



(a)



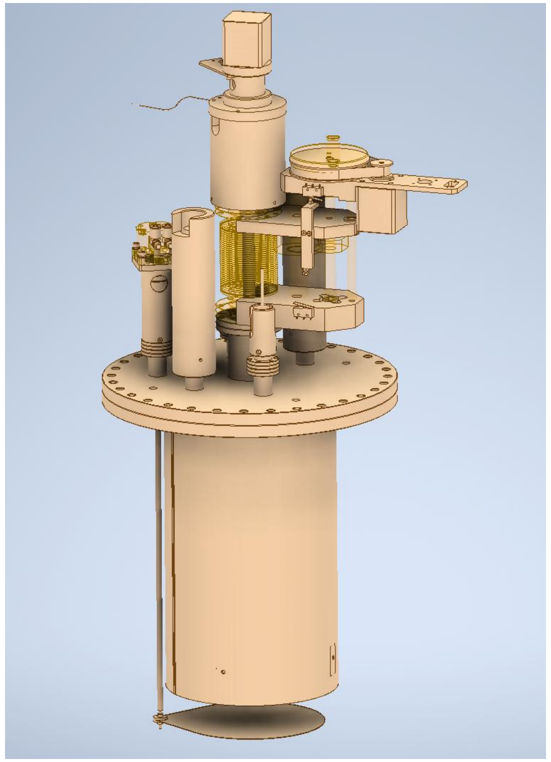
(b)

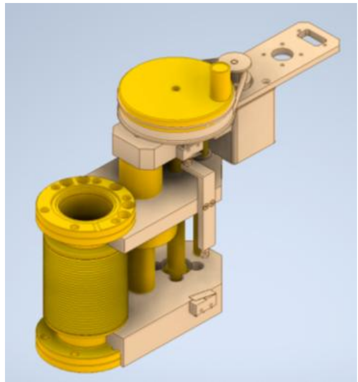
a) XRD patterns of Nb$_3$Sn thin films grown on different substrates
b) Voltage normalized to the voltage at 20 K of thin films measured by coil amplitude method (Meissner effect)

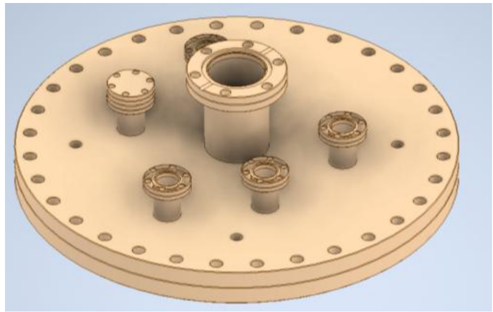
Amir Farhood

- Disc coating (for Hamburg)
- Antenna coating with Nb_3Sn (for Mainz)

New top cover with Z-shift for the antenna coating







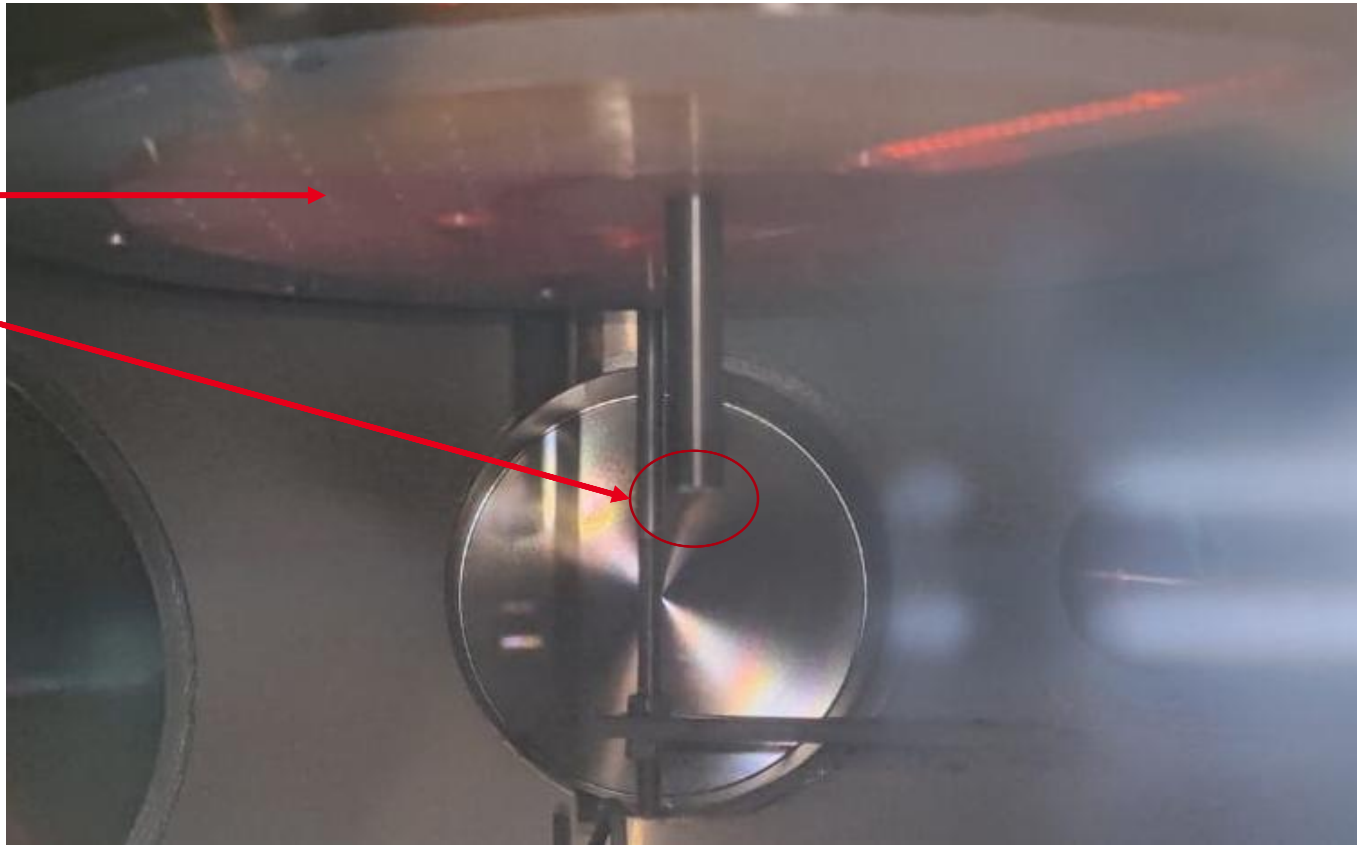
Alexey Arzumanov

Cylindric test shape

Sputtering condition at the top surface of antenna like shape (on silica substrate)

Best sputtering condition:

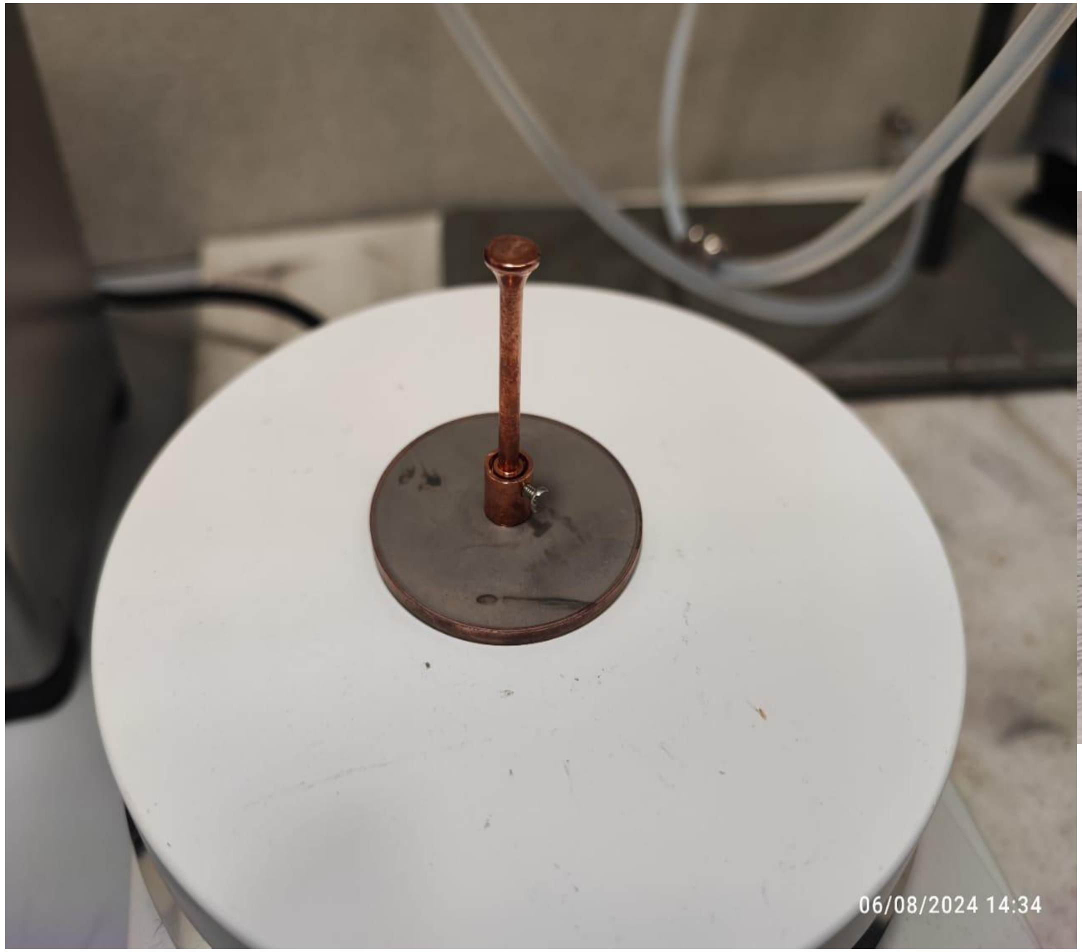
Fused Silica substrate
Pressure: $2*10^{-2}$ mbar
I Sn: 80 mA
I Nb: 450 mA
P_{Nb}/P_{Sn}= 4.4
R speed = 1 rpm
Duration: 2 hour
Approx. thickness≈ 500 nm



Amir Farhood
Alexey Arzumanov

ANTENNA COATING

sputtering condition:
Pressure: $2*10^{-2}$ mbar
I Sn: 79 mA
I Nb: 450 mA
P_{Nb}/P_{Sn}= 4.4
Duration: 2.5 hour
Approx. thickness: 600 nm



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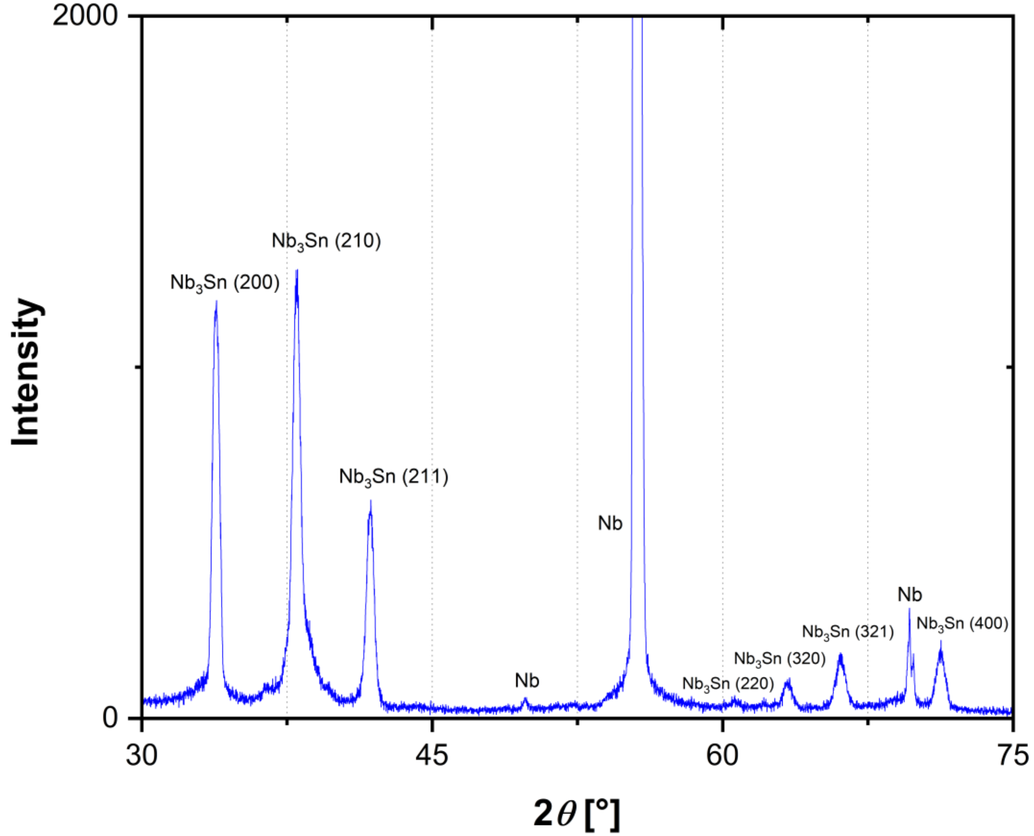
Coating of 2 inch Nb disc by Nb_3Sn

Nb disc before coating



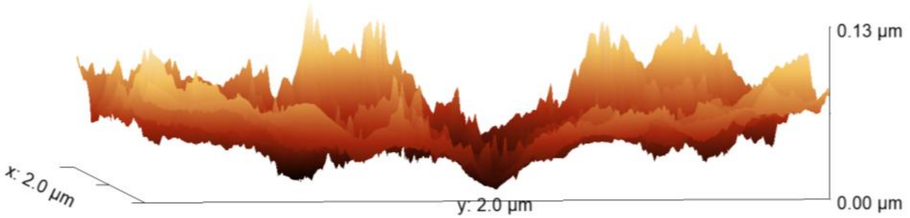
Phase pure Nb_3Sn, with Nb peaks from the substrate

Marc Wenskat

Amir Farhood

AFM measurements

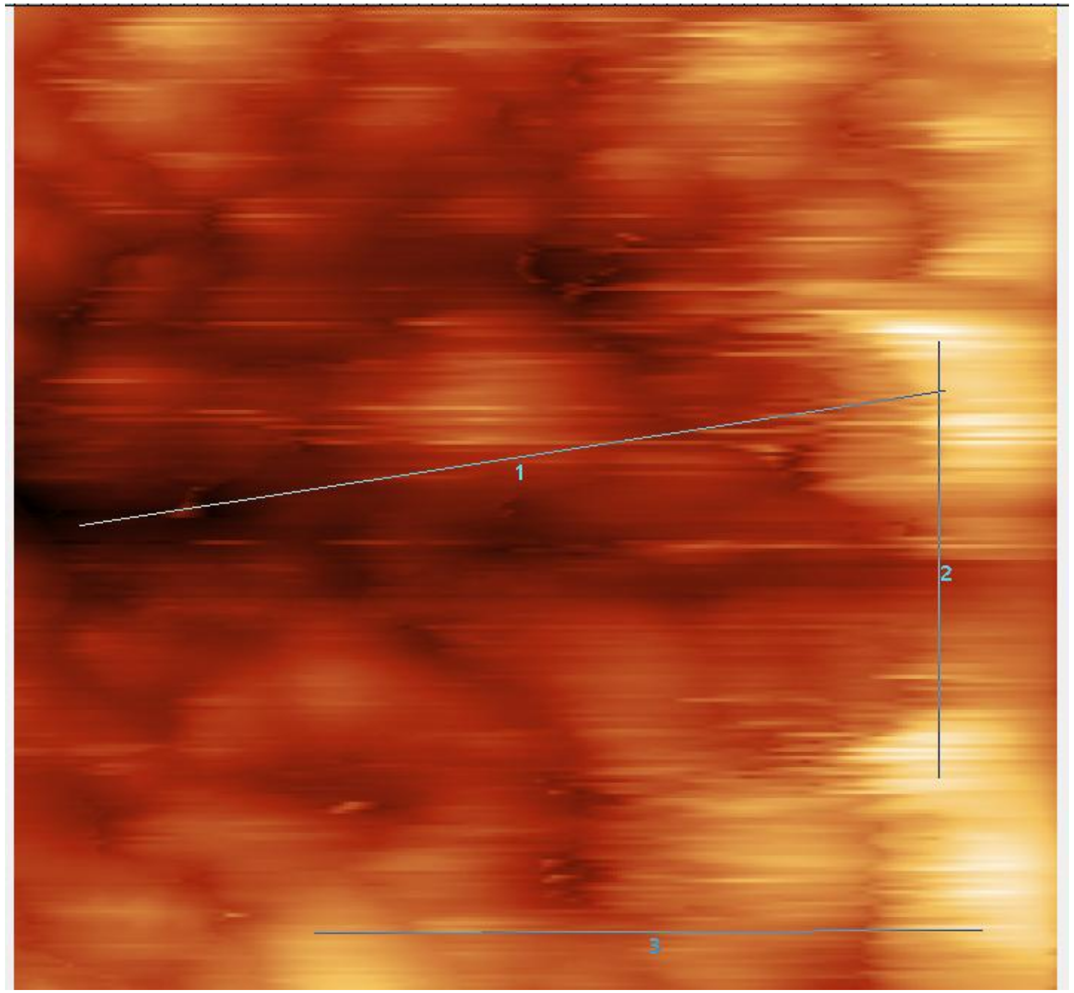
Before Nb_3Sn coating

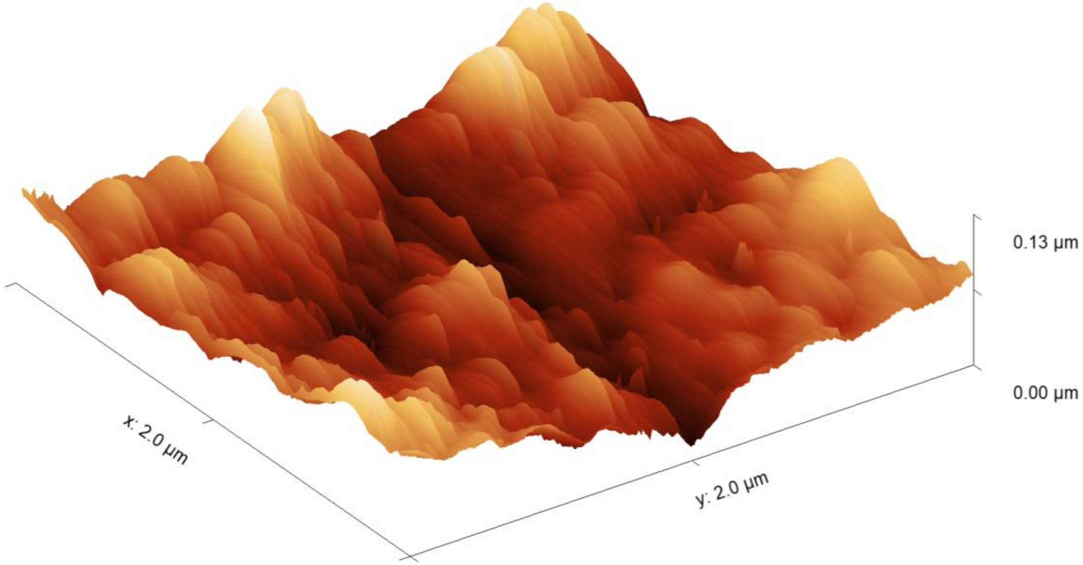


1: 112 nm

2: 23 nm

3: 29 nm



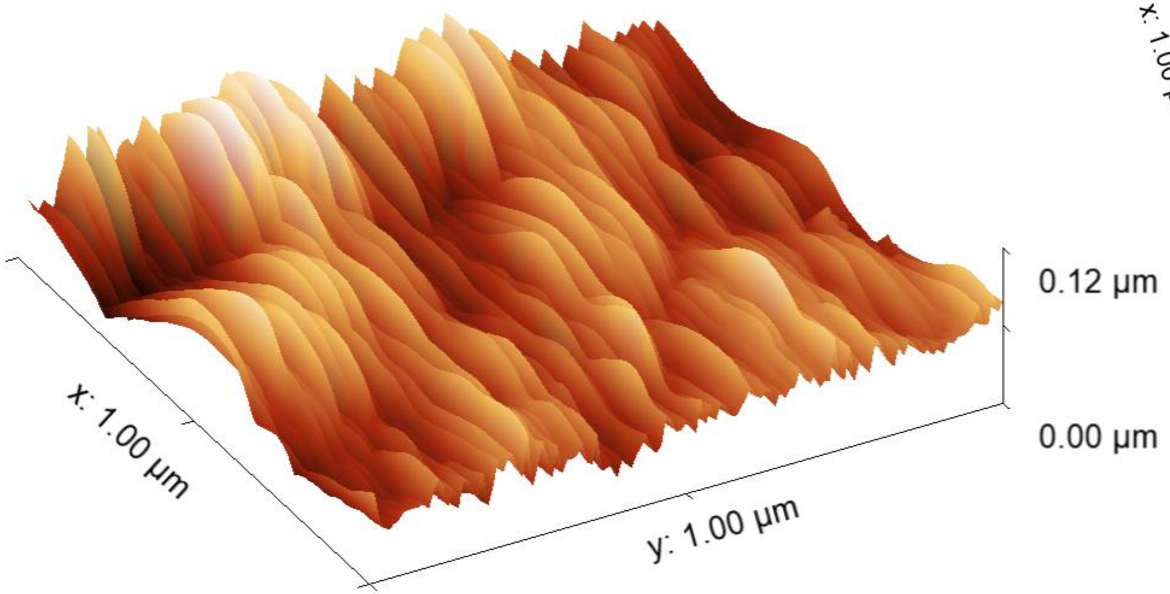


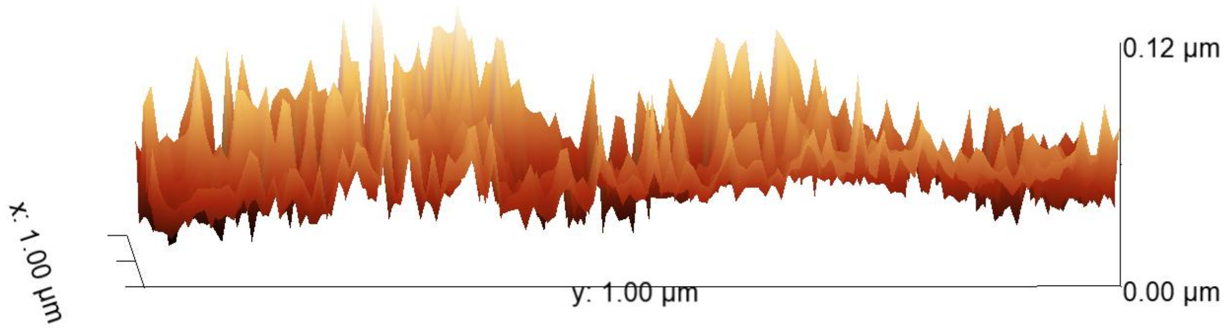
Area: 2µm * 2µm

RMS: 39.1 ± 6.6 nm

AFM measurements

Before Nb_3Sn coating



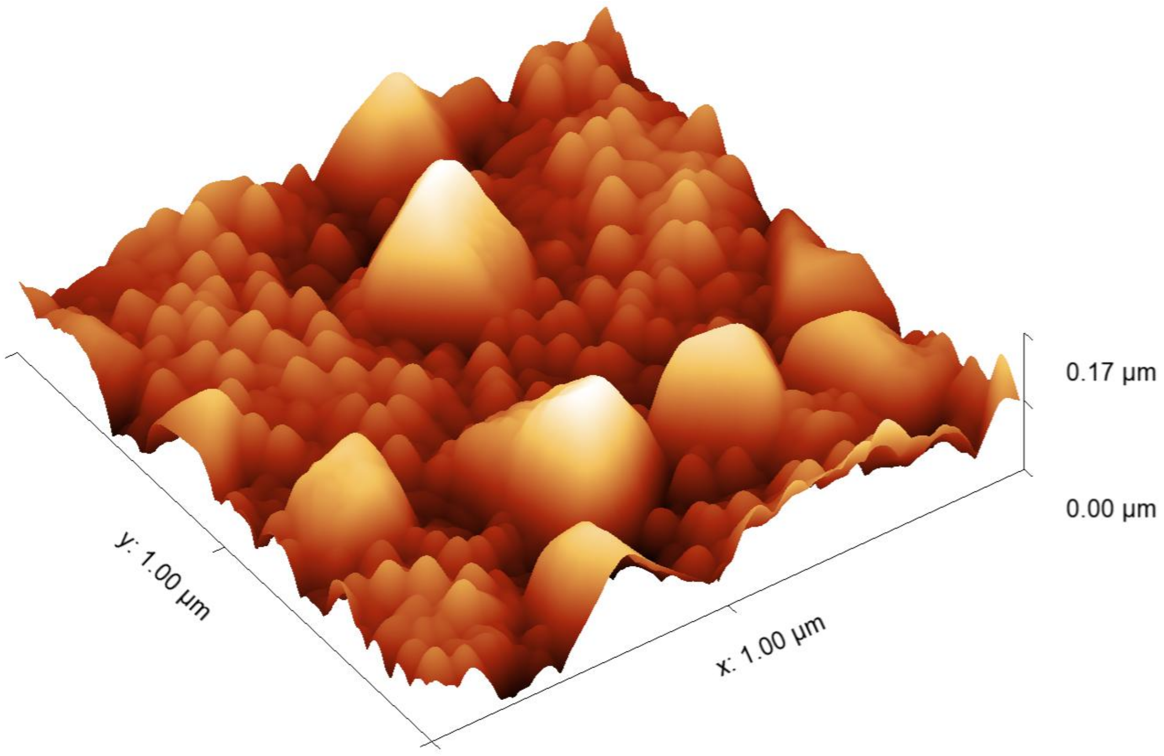


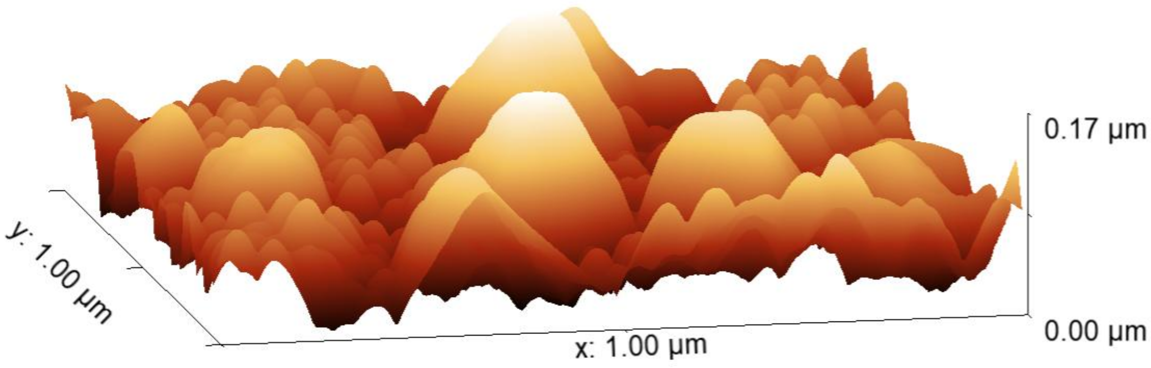
Area: 1µm * 1µm

RMS: 31.3 ± 8.1 nm

AFM measurements

After Nb_3Sn coating



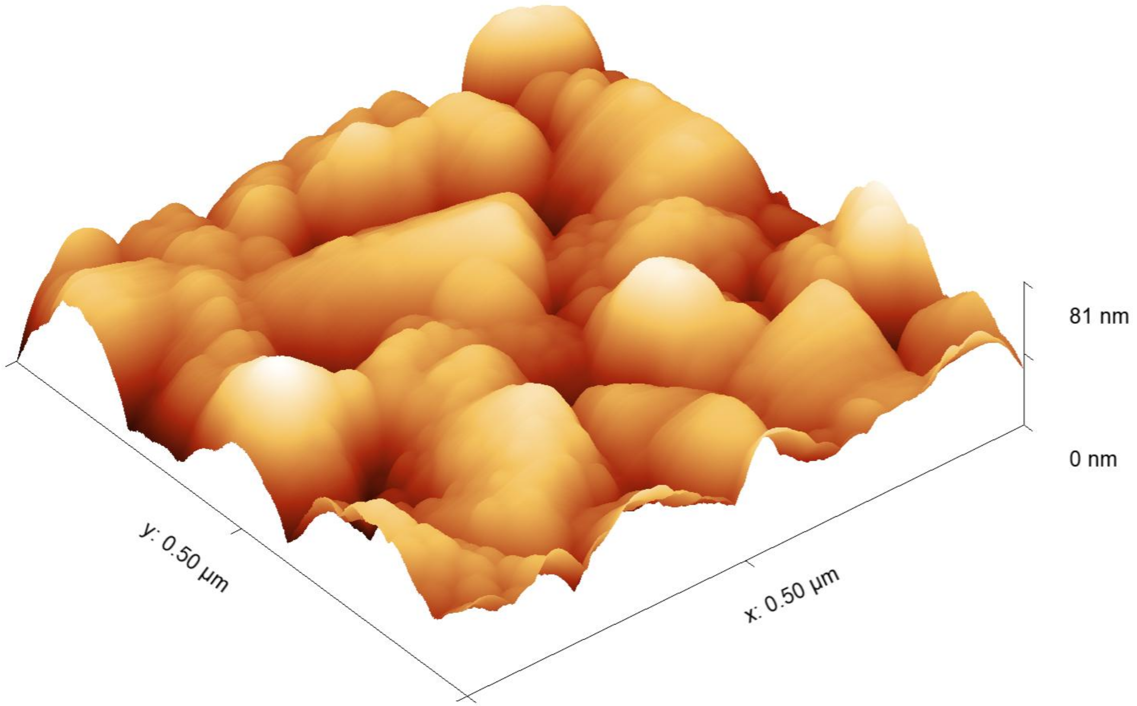


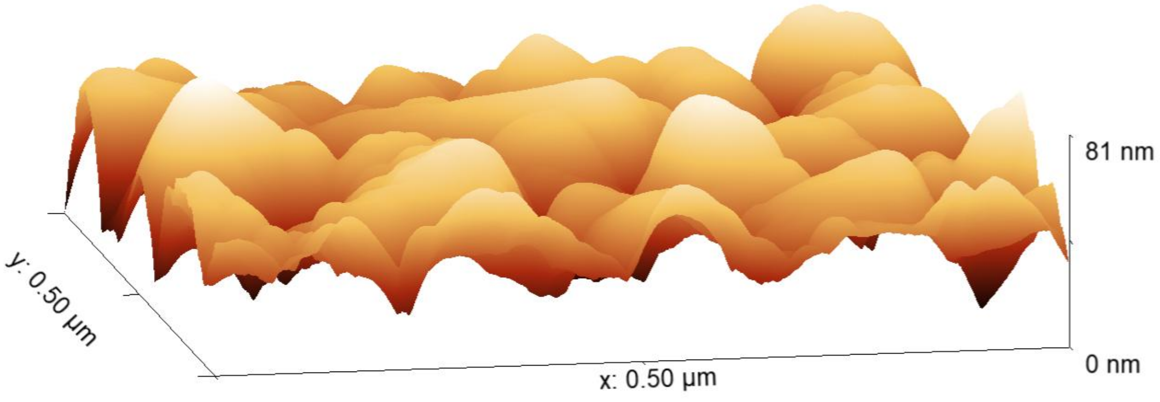
Area: 1µm * 1µm

RMS: 18.9 ± 9.5 nm

AFM measurements

After Nb_3Sn coating





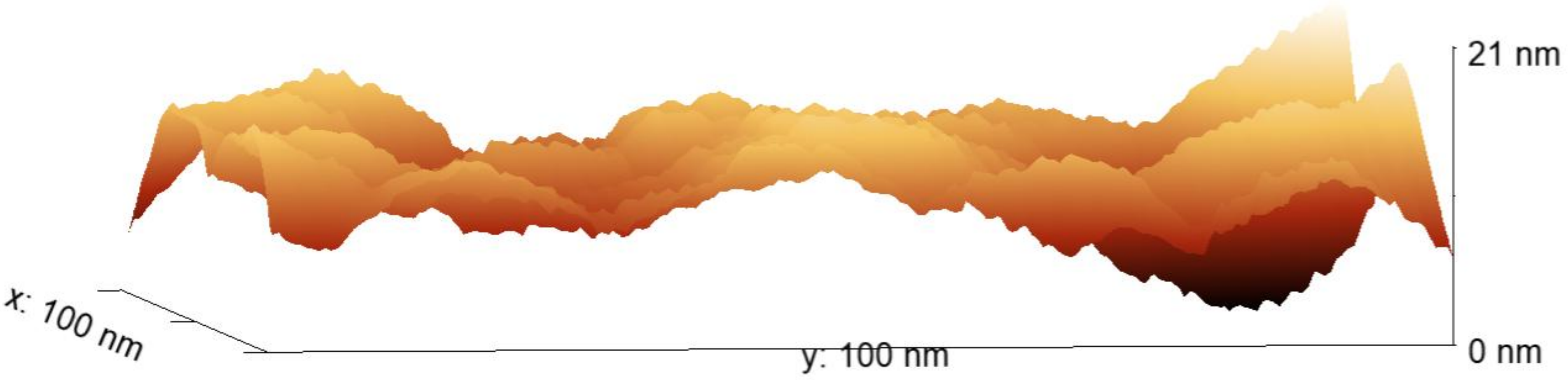
Area: 0.5 µm * 0.5 µm

RMS: 11.5 ± 2.8 nm

AFM measurements

After Nb_3Sn coating

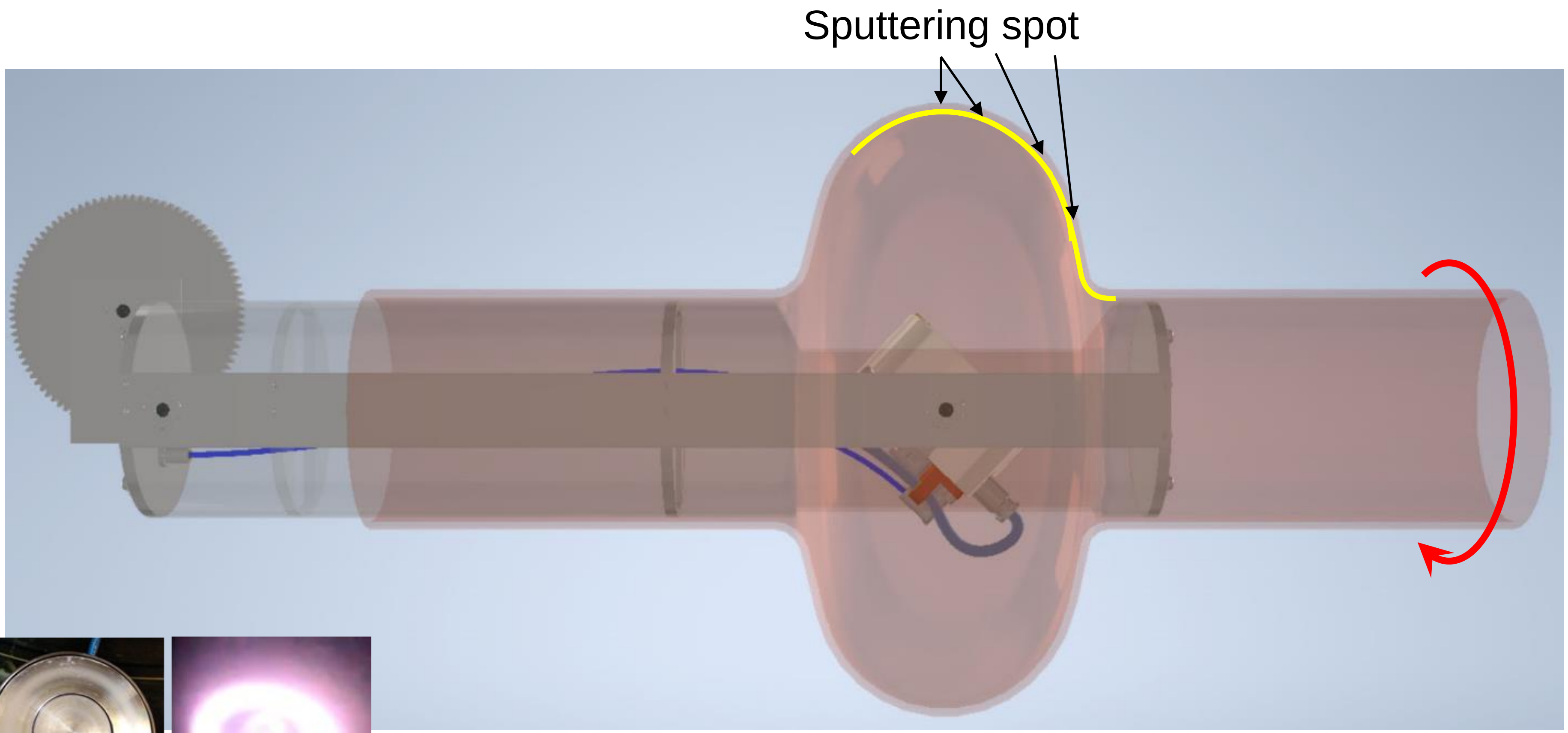
High resolution measurement: 1Å (lateral resolution)



Area: 0.1 µm * 0.1 µm

RMS: 7.7 ± 4.5 nm

Cavity sputtering



In cooperation with Fraunhofer FEP, Dresden

Acknowledgement

Nils Schäfer
Matthias Mahr
Philipp Komissinskiy
Jürgen Schreeck
Gabi Haindl

Norbert Pietralla
Michaela Arnold

funded by the DFG

Thank you for your attention!

With funding from the:

Federal Ministry of Research, Technology and Space

DFG Deutsche Forschungsgemeinschaft German Research Foundation

Funded by BMBF Project 05H21RDRB1 and the German Research Foundation (DFG) through grant GRK2128 (AccelencE)