Nb_3Sn films grown by low temperature co-sputtering for SRF cavity application

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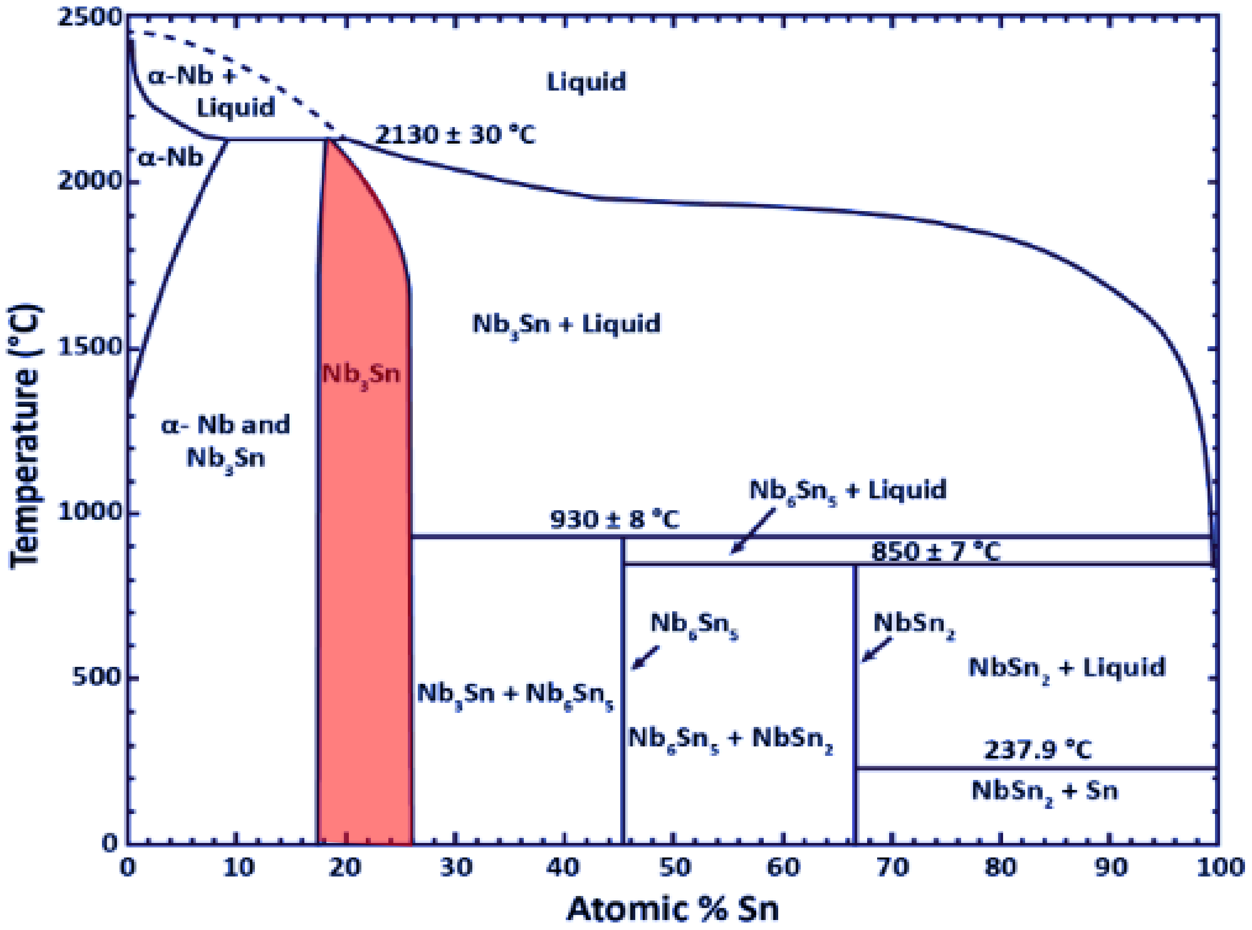
TOSCA collaboration meeting

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	

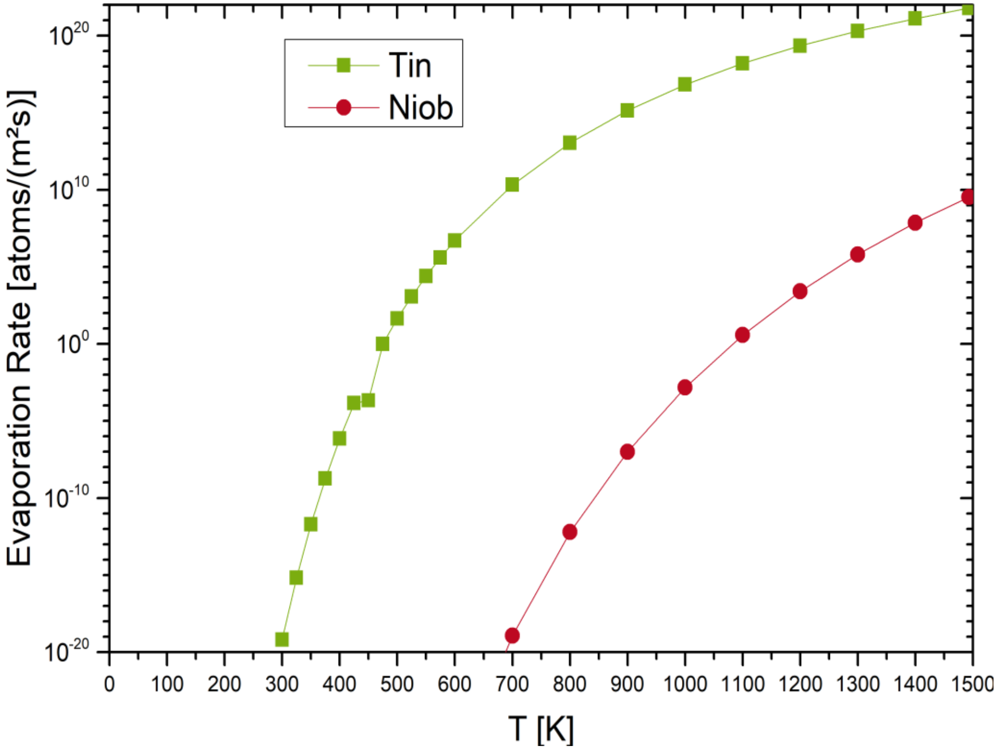
Whistler 2015, SRF Tutorial - Pushing Nb Performance - A.-M. Valente-Feliciano

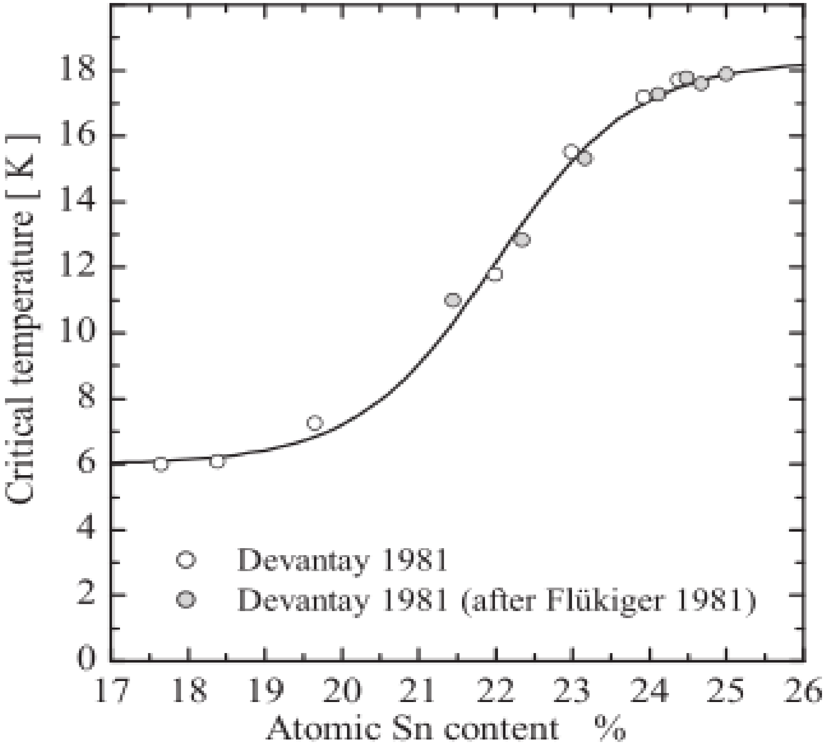
Nb-Sn phase diagram



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

Challenge: Vapor-pressure of Sn

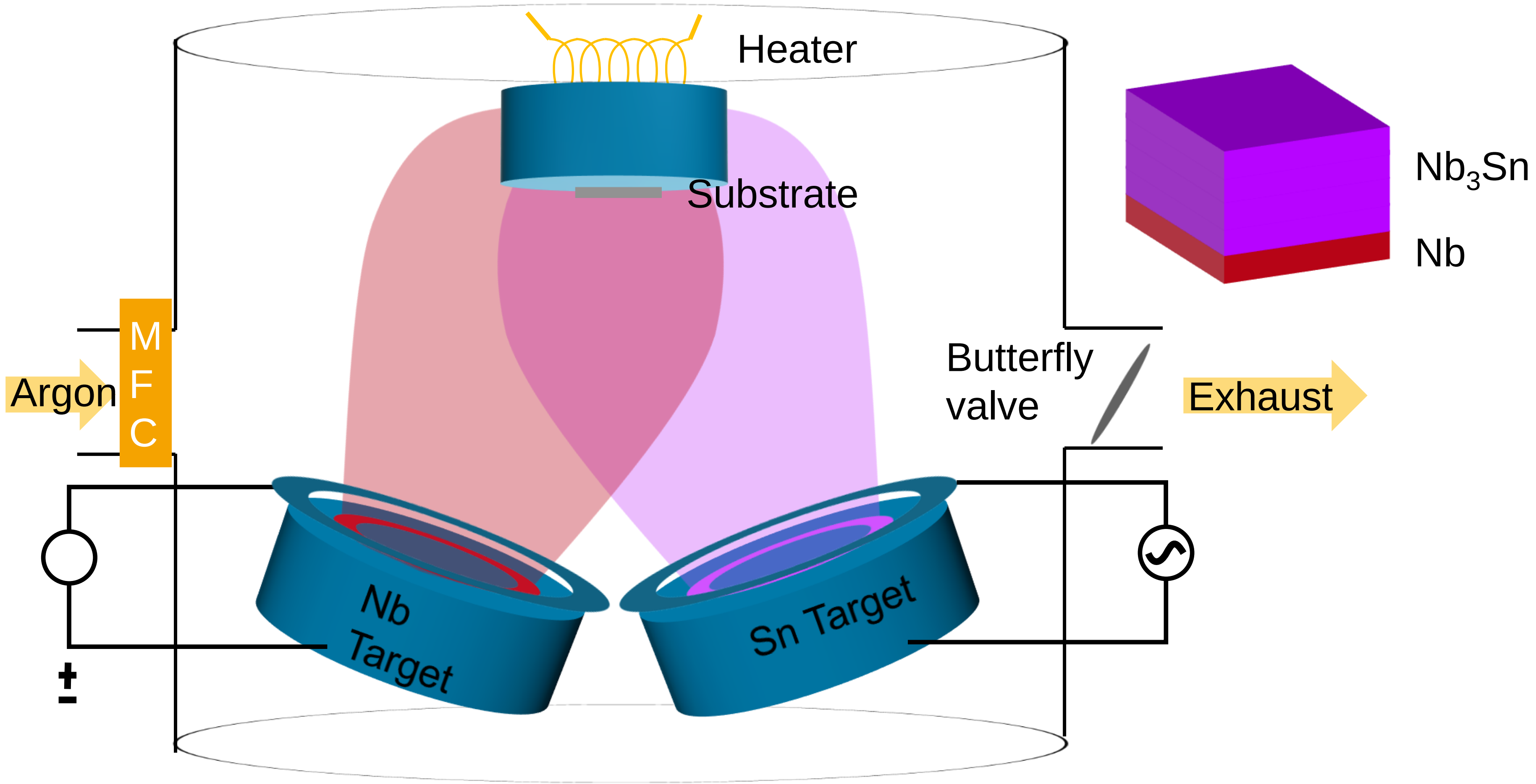




Literature results for the critical temperature as functions of Nb–Sn composition.

A Godeke 2006 Supercond. Sci. Technol. 19 R68

TU Darmstadt approach: Nb_3Sn co-sputtering



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

Nb_3Sn cavity roadmap

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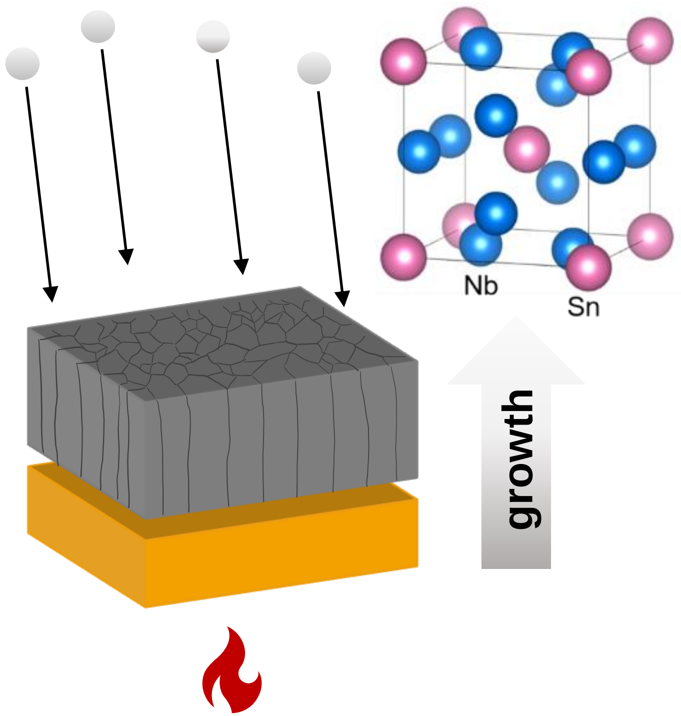
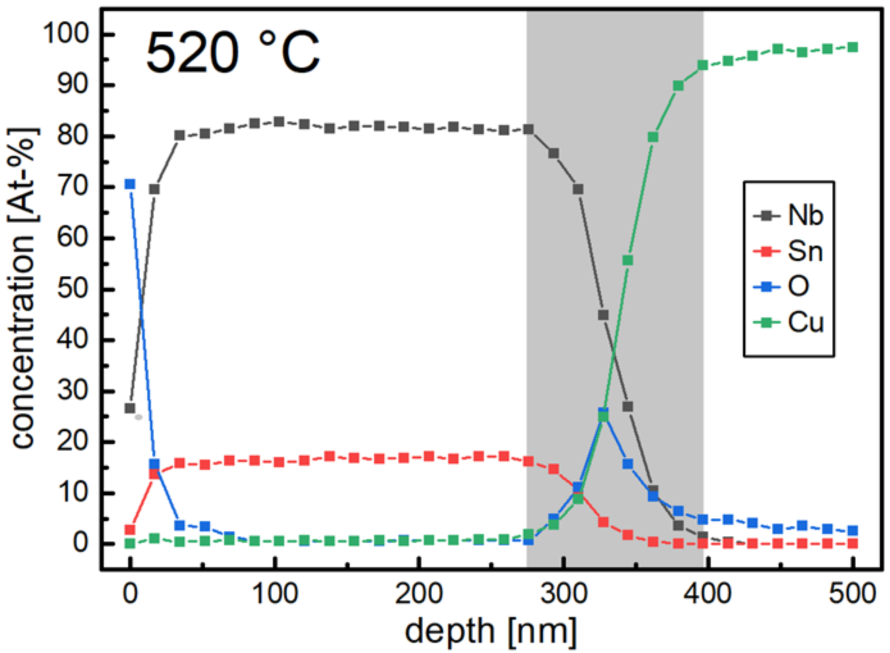
Physical properties of Nb_3Sn films grown on Cu



< 520 °C @ 60 min.

XPS Depth Profile



Nb, Sn, Cu and O content measured by XPS plotted as a function of the distance from the surface (0 nm) for a sample deposited at 520 °C. They left part (0-275 nm) is the Nb_3Sn film. The interface region (~120 nm broad) between the film and the Cu substrate is marked by the grey area. The right side (starting at ~ 400 nm) represents the copper substrate.

N. Schäfer *et al.* (2024) to be published

Physical properties of Nb_3Sn films grown on Cu

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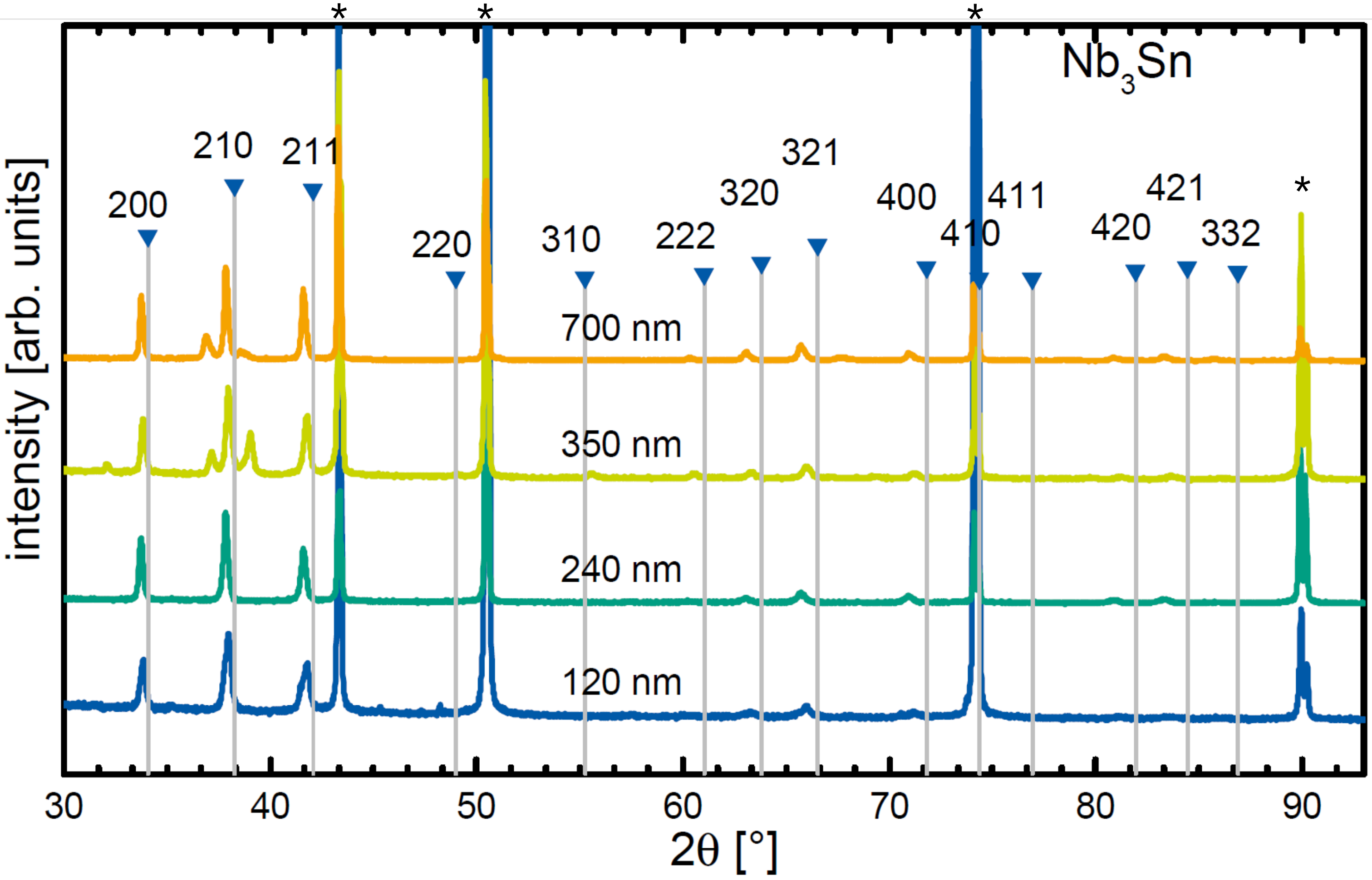
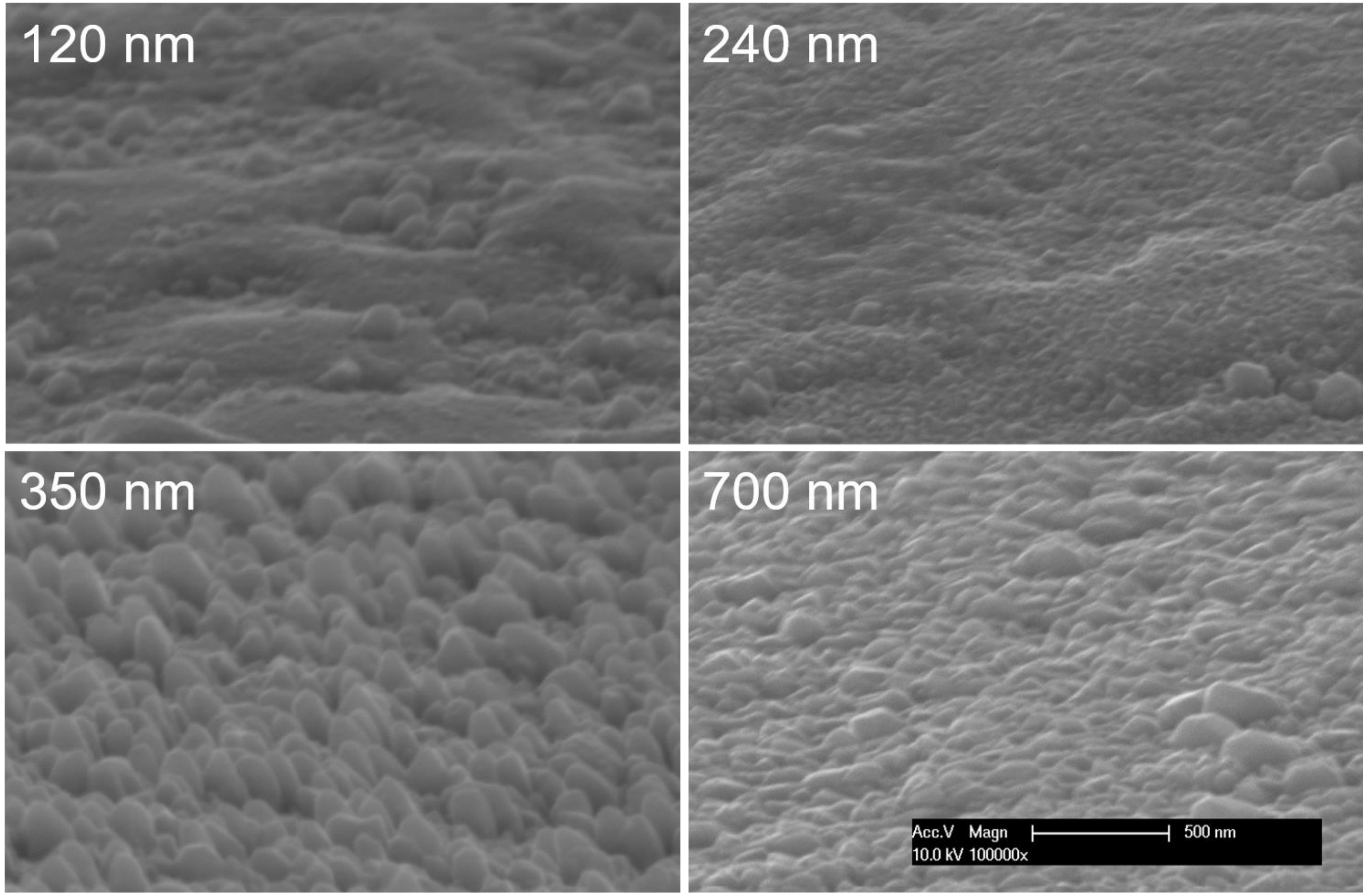


XRD patterns of Nb_3Sn thin films grown on copper substrates at elevated temperature (480 °C). The coating duration is increased from 10 min to 60 min resulting in 120 nm to 700 nm film thickness. Calculated Nb_3Sn Bragg peaks are marked by tip down triangles in their respective intensity. The Cu substrate peaks are marked with *. Additional reflections appear for the samples of 350 nm and 700 nm thickness.

N. Schäfer *et al.* (2024) to be published

Grain size, surface roughness



SEM images of Nb_3Sn thin films synthesized by co-sputtering on copper substrates. The coating duration was increased from 10 min to 60 min (10 min, 20 min, 30 min and 60 min) resulting in the indicated 120 nm to 700 nm film thicknesses.

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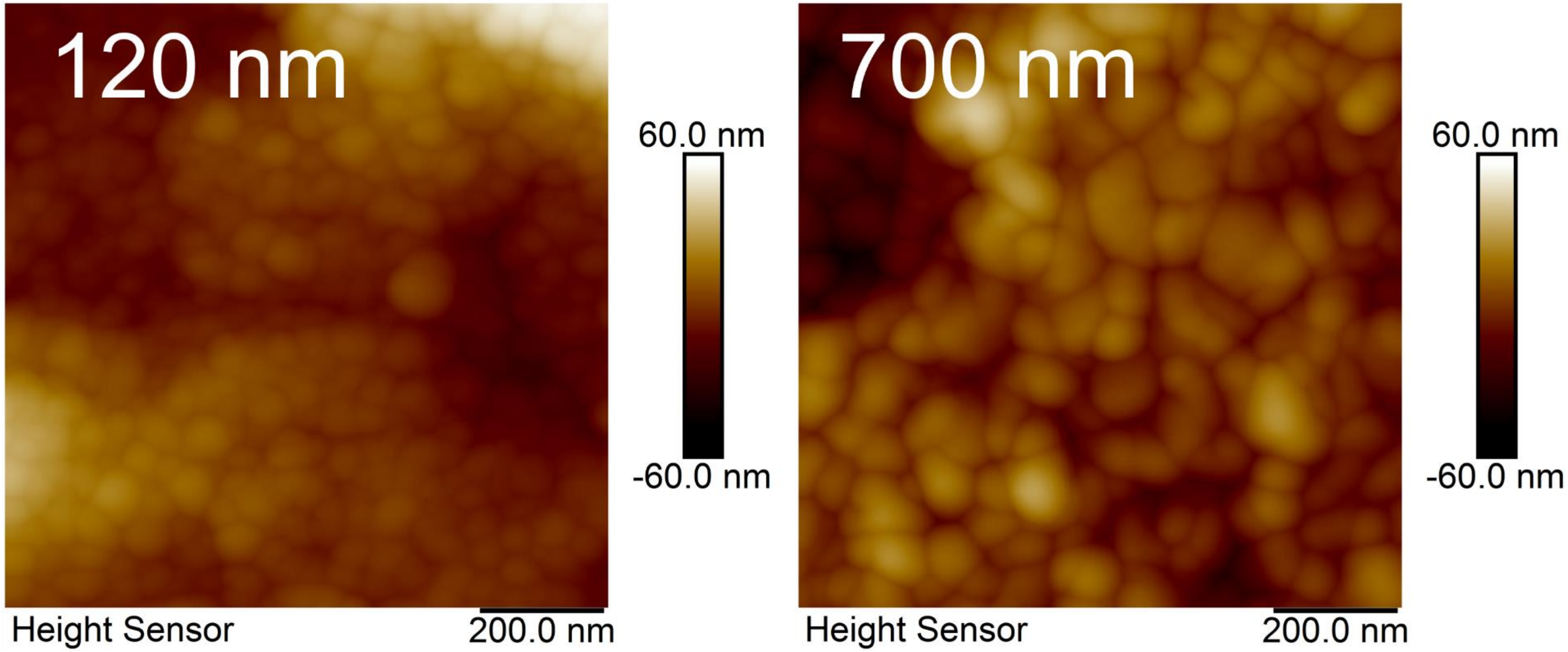
Grain size, surface roughness



AFM topography images of Nb_3Sn thin films synthesized by co-sputtering on copper substrates. The coating duration was 10 min and 60 min resulting in 120 nm and 700 nm film thickness, respectively.

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Performance *vs* film thickness

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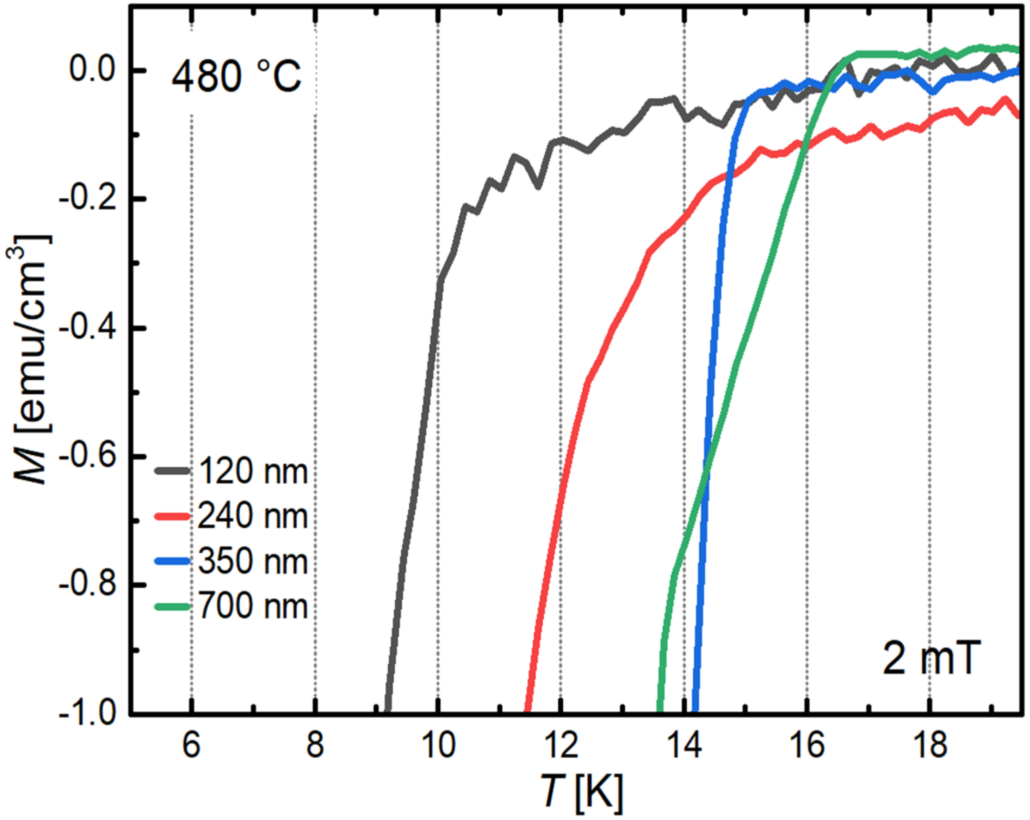
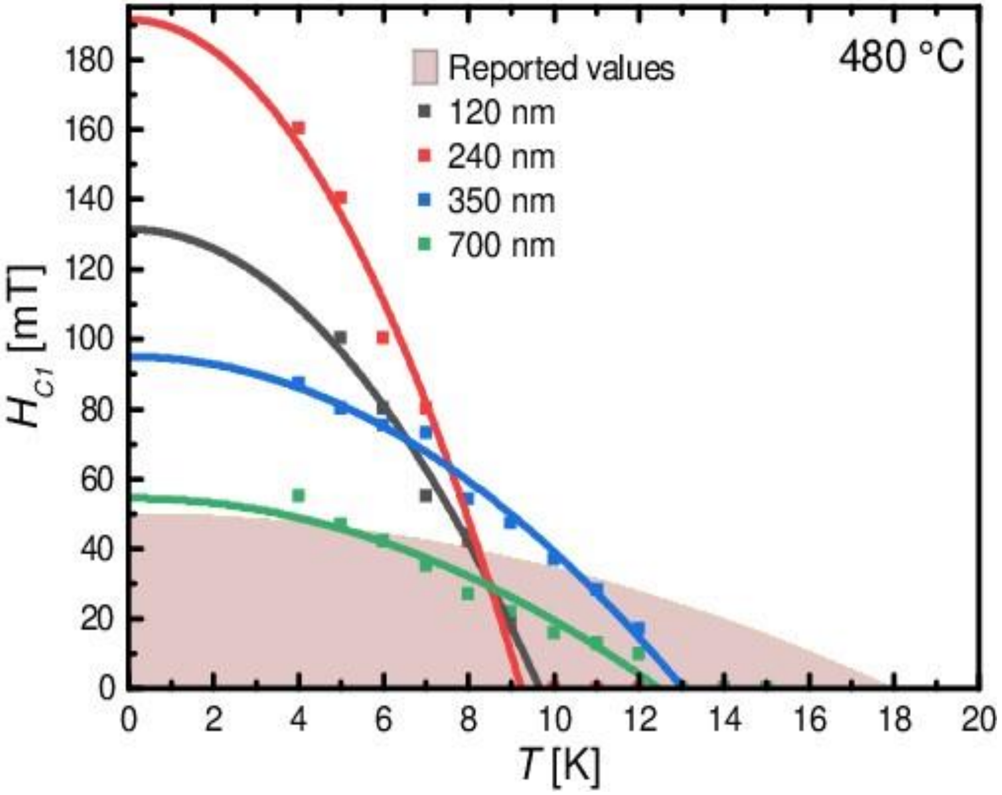
Magnetization Parallel to Field



Temperature dependence of H_{c1}



Performance *vs* film thickness

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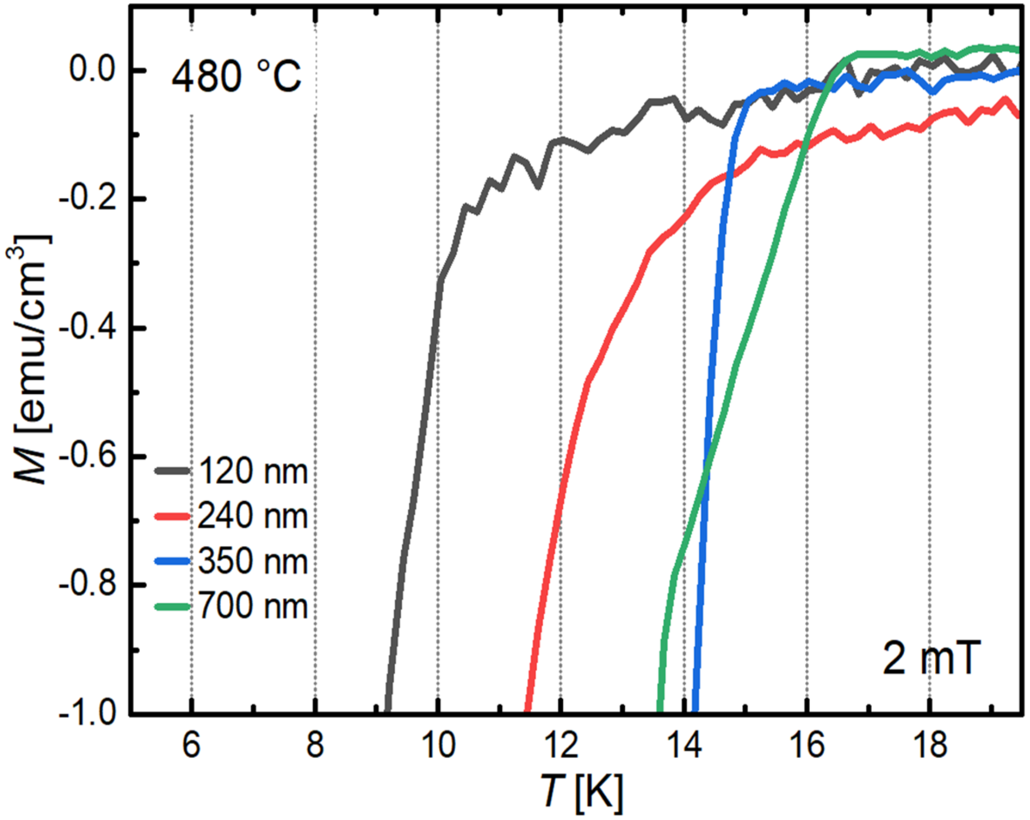
Magnetization Parallel to Field

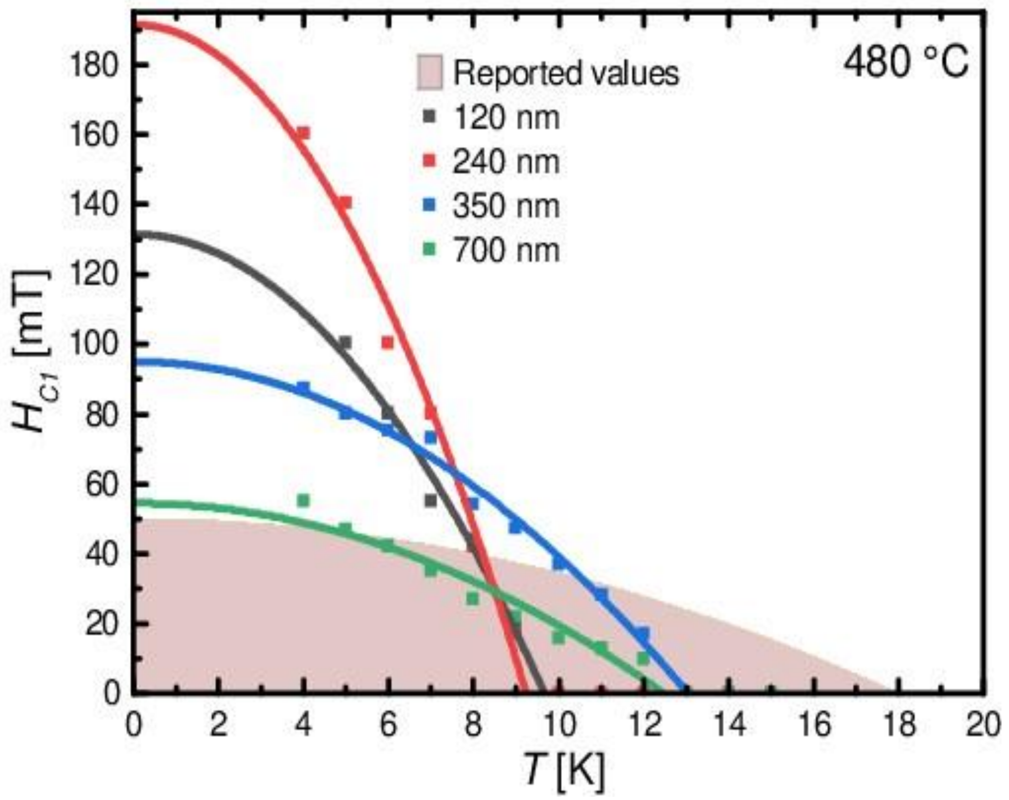


- Increasing thickness beneficial for critical temperature
- $T_{c,0}$=16.8 K @ 480 °C!
- 120 nm < λ (140 nm), still shielding

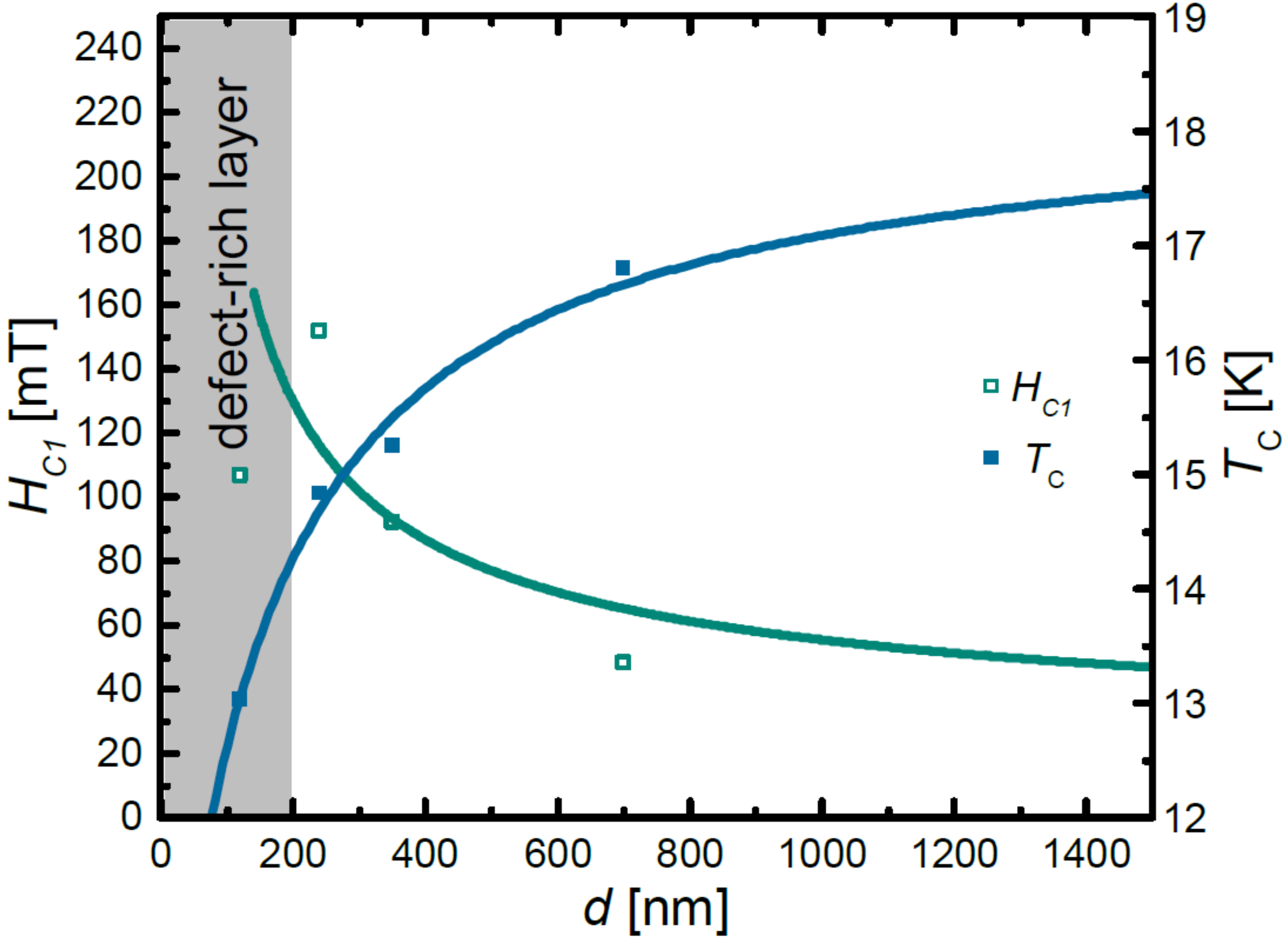
Performance *vs* film thickness

Temperature dependence of H_{c1}

- Bulk performance for 700 nm thickness.
- Below 700 nm enhancement of H_{c1} (known below λ=140 nm)
- Decreasing film thickness beneficial for H_{c1}



Performance *vs* film thickness



Critical temperature T_c determined from M-T measurements and critical field H_{c1} from M-H measurements at 4K of Nb_3Sn thin films on copper substrates as a function of film thickness.

The grey box marks the defect-rich layer in the beginning of the growth process leading to low performance.

The solid lines provide a guide to the eye.

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.

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Nb_3Sn cavity roadmap

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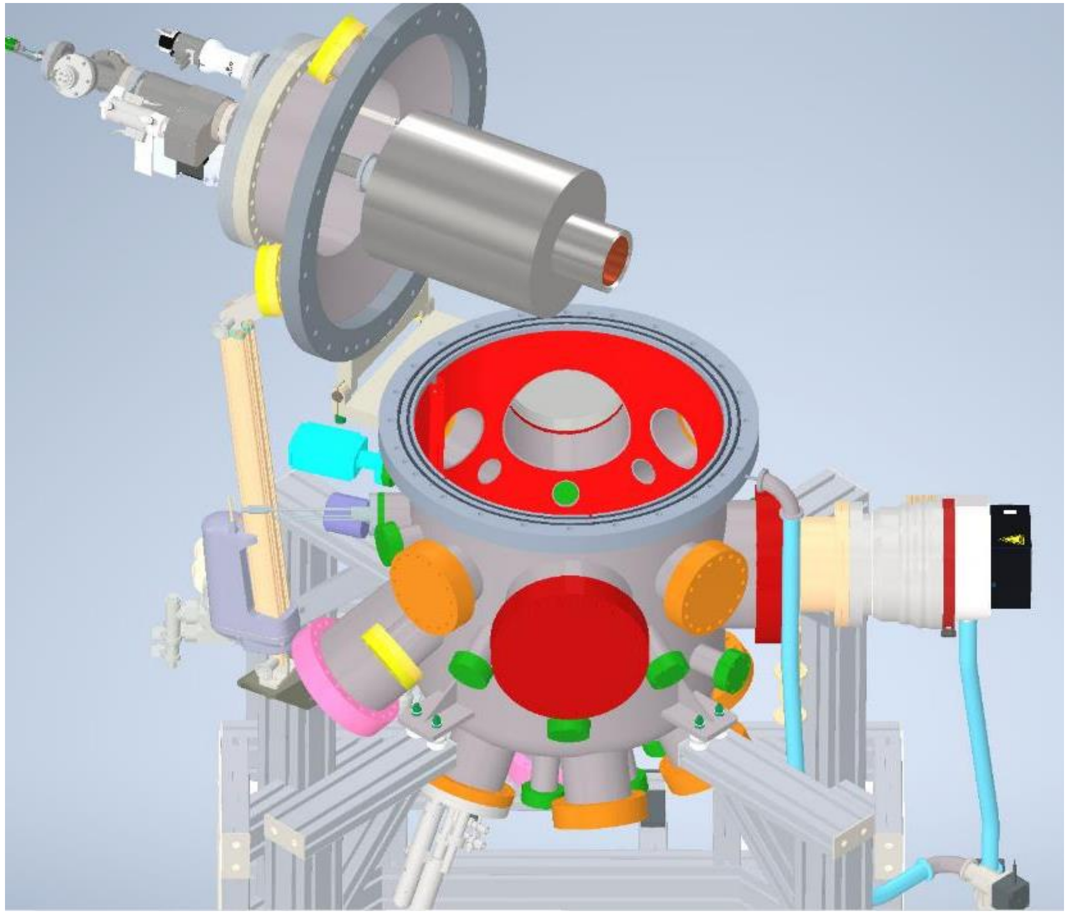
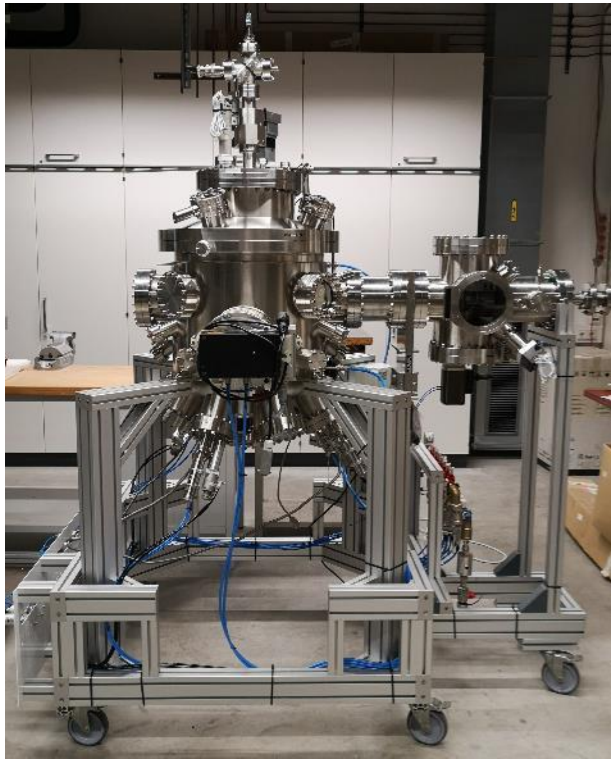
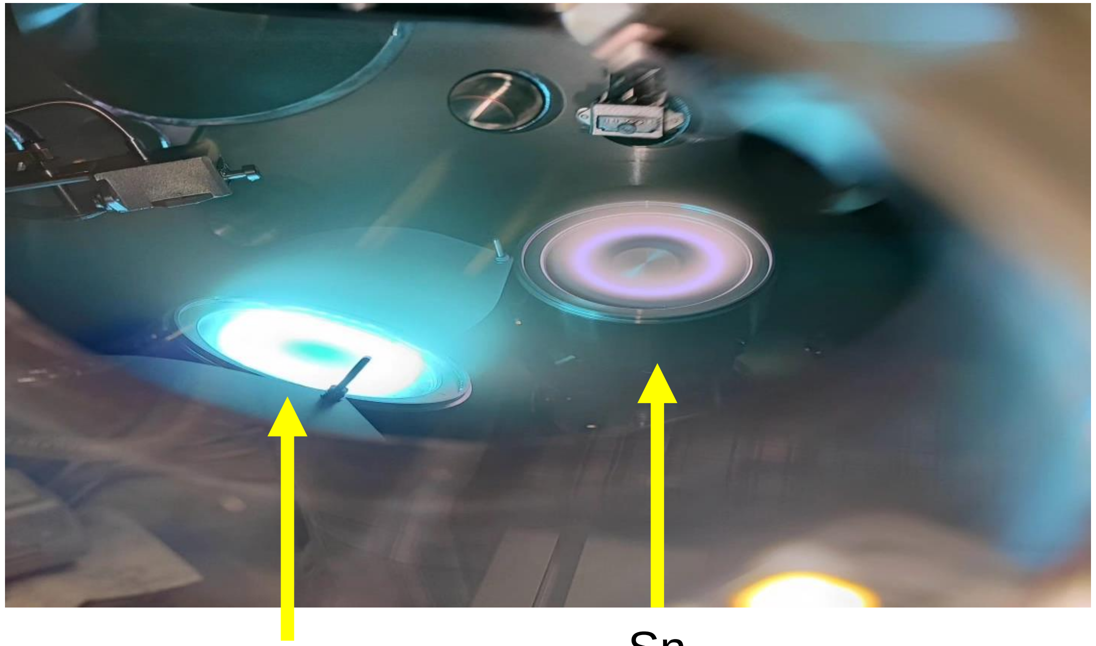
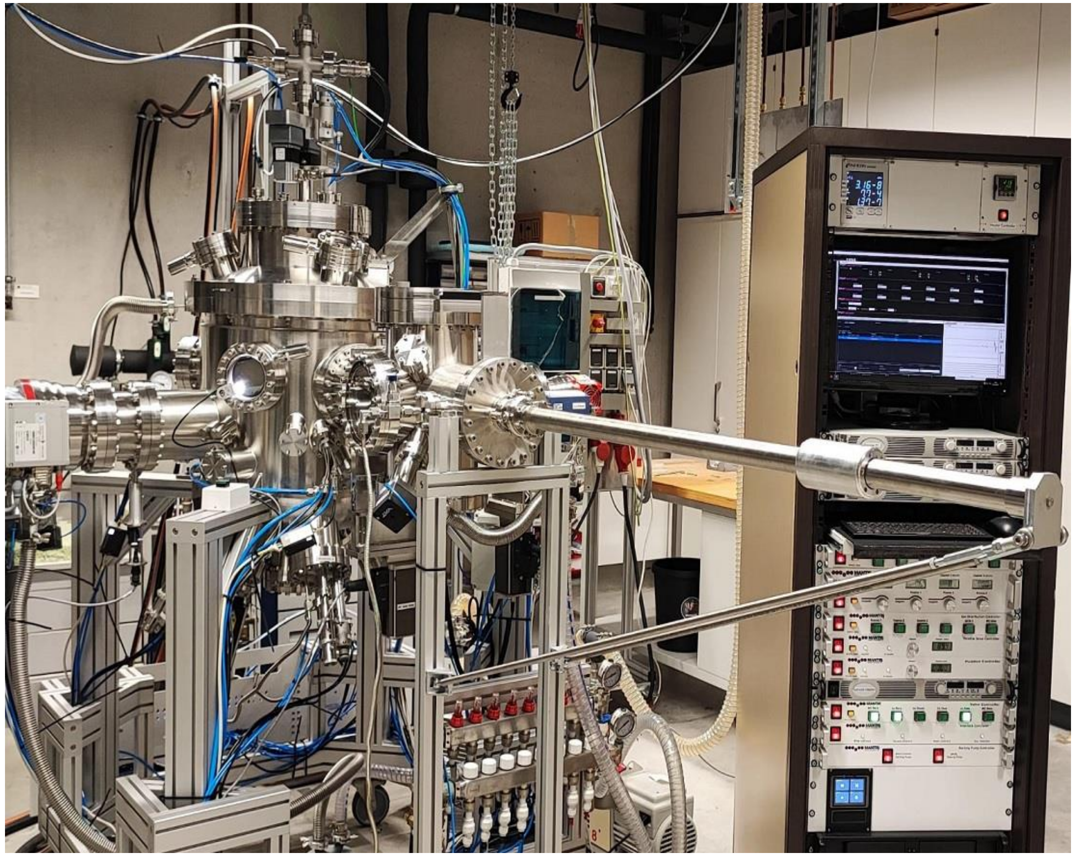
Upscaling to copper cavities





Upscaling to copper cavities

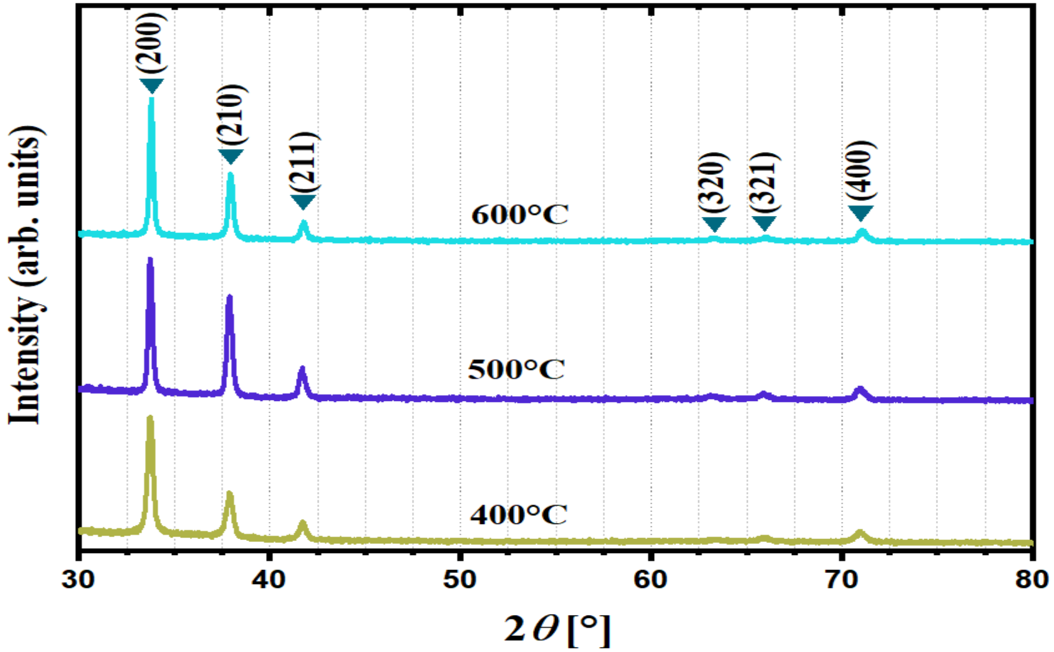




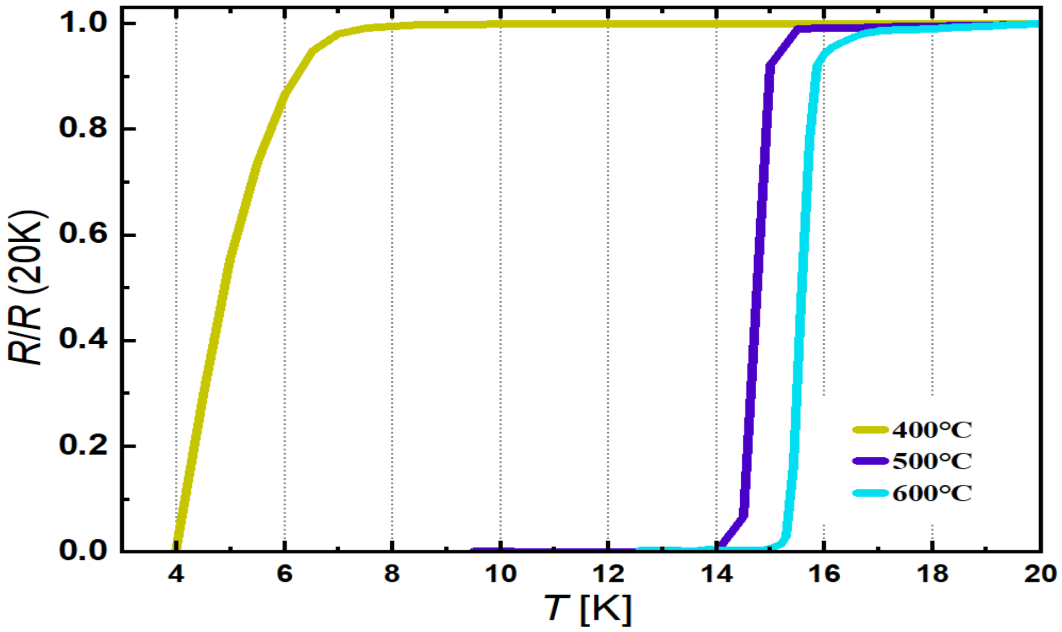
Alexey Arzumanov

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

TOSCA co-operation

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

New top cover with Z-shift for the antenna coating

Alexey Arzumanov

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Cavity sputtering

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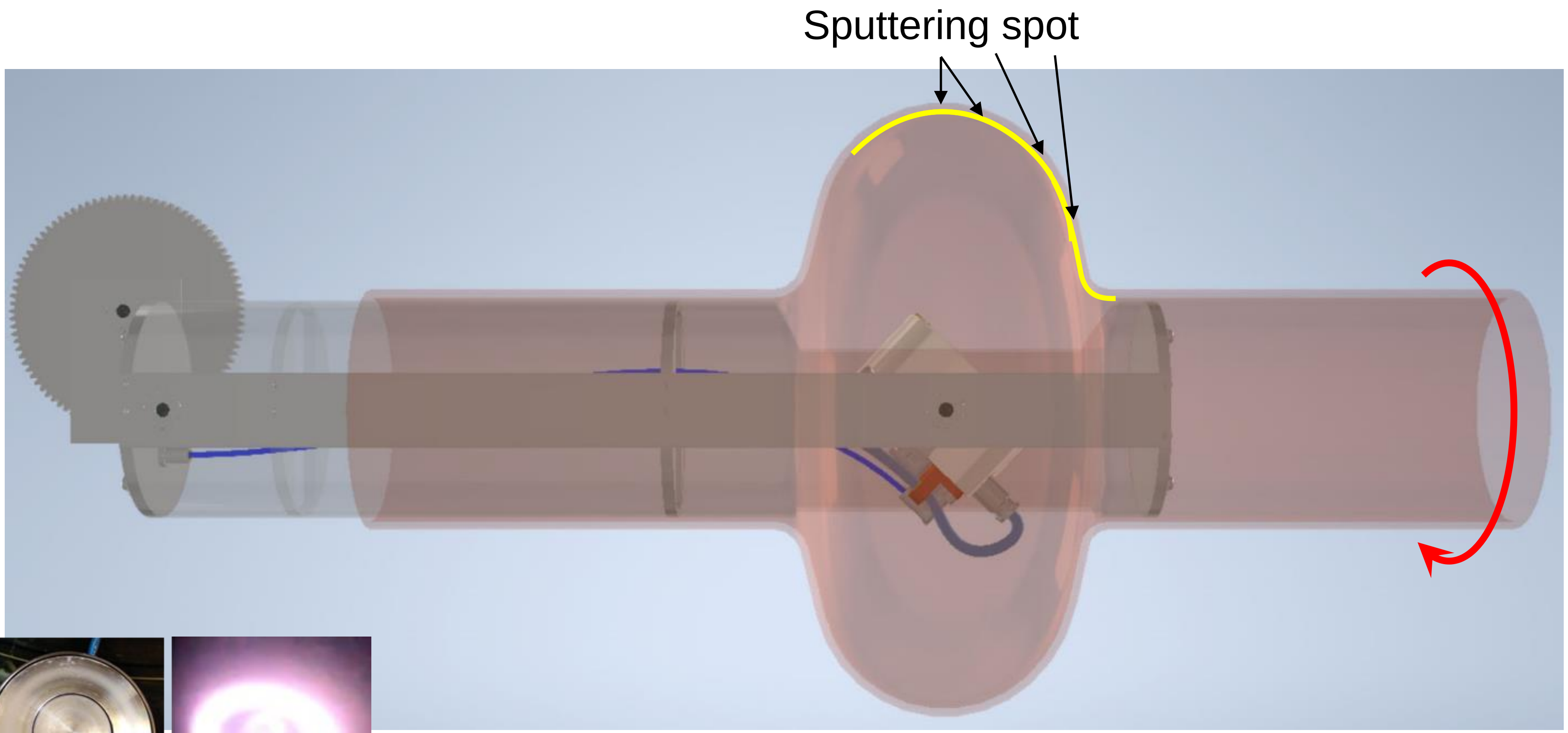

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