Lehrstuhl für Oberflächen- und Werkstofftechnologie (LOT)

UNIVERSITÄT SIEGEN

The *Next Generation* Materials for SRF Cavities

08.10.2020

EASISchool 3 - Student Workshop (Virtual) – Genoa / Italy

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Universität Siegen

Outline

1. General motivation.
2. Technological motivation & S-I-S structures.
3. The project SMART & LOT, USiegen
4. The experimental set-up & the deposition technique (DCMS).
5. Results & Discussions.
6. Next steps.

General motivation: S&T Advancement

Q. What are **the scientific and technological impacts** of **R&D endeavors** for particle accelerators?

…at cosmic scales: e.g., the study of dark matter in relation to the Standard Model.

…at atomic scales: e.g., the real-time imaging and measurement of structural and electronic dynamics at the quantum scale ➔ the workings of matter at the quantum scale.

…new possibilities and capabilities beyond those existing currently so as to allow us to address fundamental scientific questions while contributing to the technological advancement in favor of societies.

Technology-specific motivation

<u>The Challenge</u>

The bottleneck set by bulk niobium.

→

<u>The possible solution(s)</u>

Advanced material structures: mono- and/or multi-layer (S-I-S) structured superconducting thin films (TFs).

"Optimized multilayers of Nb_3Sn, NbN, some of the iron pnictides, or alloyed Nb deposited onto the surface of the Nb resonator cavities could potentially double ***the rf breakdown field****, pushing* ***the peak accelerating electric fields*** *above* ***100 MV/m*** *while protecting the cavity from* ***dendritic thermomagnetic avalanches*** *caused by* ***local penetration of vortices****."* [AIP Advances 5, 017112 (2015)]

The Project **SMART** & LOT- USiegen

SIS Multilayer Structures for Applications in Superconducting Radio-Frequency Technology (SMART) [https://www.mb.uni-siegen.de/lot/forschung/projekte/smart.html?lang=de]

ALD

PVD

Computational EM

QPRs

SRF

Bundesministerium für Bildung und Forschung

Verbundforschungsprojekt:

- Universität Hamburg
- Universität Siegen
- Technische Universität Darmstadt
- Helmholtz-Zentrum Berlin (HZB)
- Deutsches Elektronen-Synchrotron (DESY)
- European Organization for Nuclear Research (CERN)
- Commissariat à l'énergie atomique et aux énergies alternatives (CEA) Paris-Saclay

Additional expertise, in particular in QPRs

Additional expertise in (ALD)-based ML TFs

- Thermal CVD
- MWCVD
- ECRMWCVD
- HFCVD
- **DCMS, HiPIMS**
- **RFMS**
- Electroplating

Some available in-house know-how.

- ALD: Atomic Layer Deposition
- PVD: Physical Vapor Deposition
- QPR: Quadrupole Resonator

Management

Head
Prof. Dr. Xin Jiang

Deputy
Dr. Thorsten Staedler

Secretary
Andrea Brombach

Coatings Technology

Group leader
Michael Vogel

Superhard materials

'Sensing' materials

Superconductive thin films

Thin fims for particle accelerators

TCO thin films

Photoelectron emission materials

Nanomaterials

Group leader
Dr. Yang Nianjun

Metal oxide nanowires

DNA nanosensors

Energy storage and conversion

Catalyst for sustainable chemistry

Materials Characterization

Group leader
Dr. Thorsten Staedler

Failure analysis

High resolution direct imaging of surface morphology and cross-sections

Structural analysis

Elemental mapping and depth profiling

Mechanical and tribological materials characterization down to the nanometer regime

[https://www.mb.uni-siegen.de/lot/lehrstuhl/organisation/?lang=de]

The Objectives of LOT, UniSiegen in the Project SMART

Systematic investigations of surface properties of novel materials – formed by coating of mono- or multi-layers of varying:

Composition (e.g., Nb, Nb(Ti)N, Nb_3Sn, AlN, etc.)

Thickness (multilayer S-I-S).

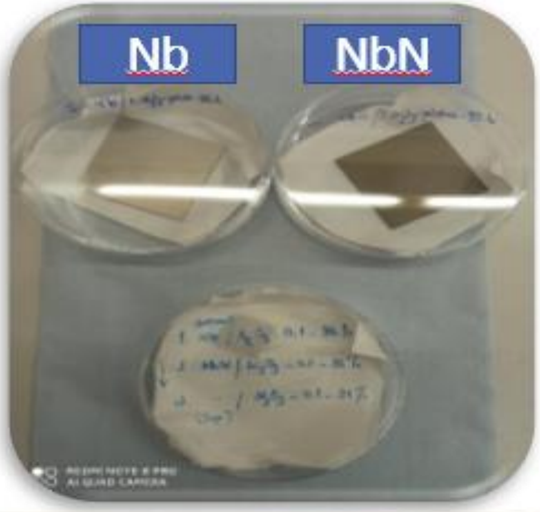
KEY CHALLENGES	
Materials:	Stoichiometric films with low defect density for high crystalline quality.
Coating Processes:	Up-scaling capacity.

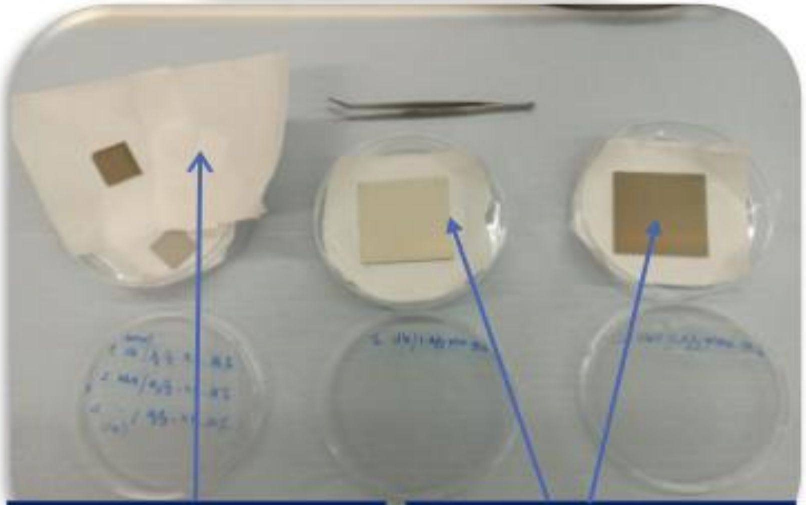
→

Optimization studies to determine feasible deposition parameters:

- Cathode Power,
- Gas pressure,
- Target/substrate materials,
- Substrate temperature,
- Substrate bias,
- Process gas.

Experimental Set-up

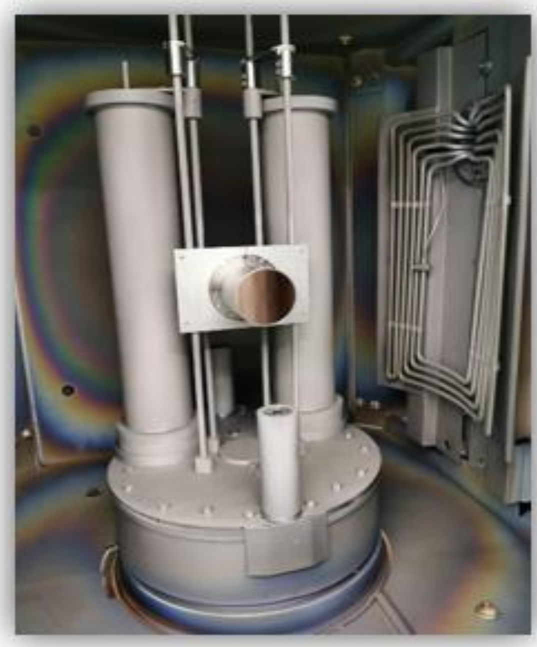




Alumina
Goodfellow
(25*25*0.1mm³)
Purity: 96%

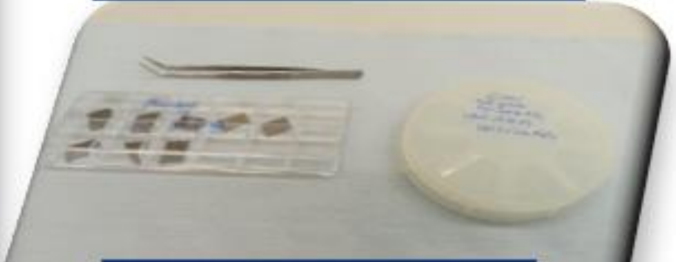
Alumina
Goodfellow
(60*60*1mm³)
Purity: 99.6%

Target: Nb
(RRR300)
(100*88*10mm³)



CC800 - DCMS

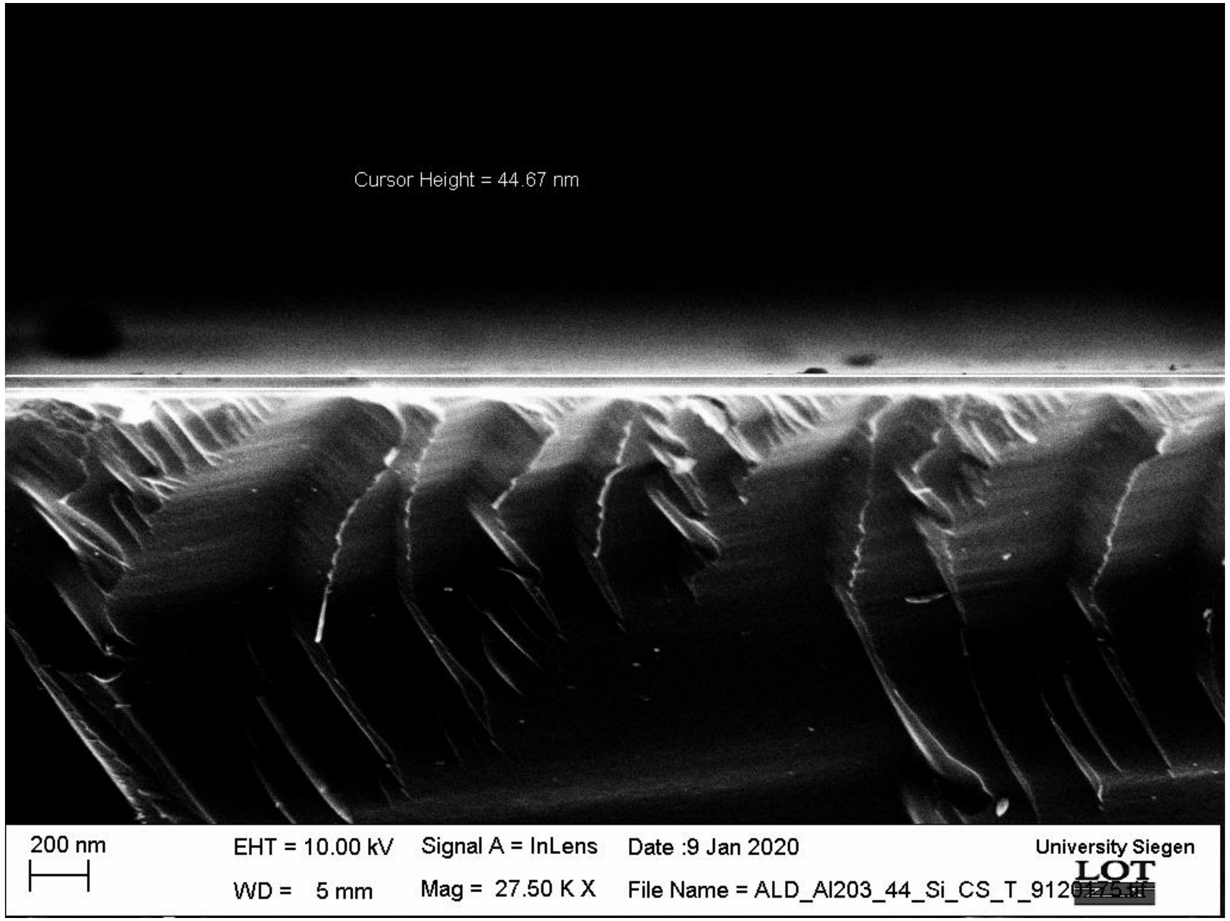
ALD –Alumina
(44nm) / Si<100>
Wf ~ Hamburg



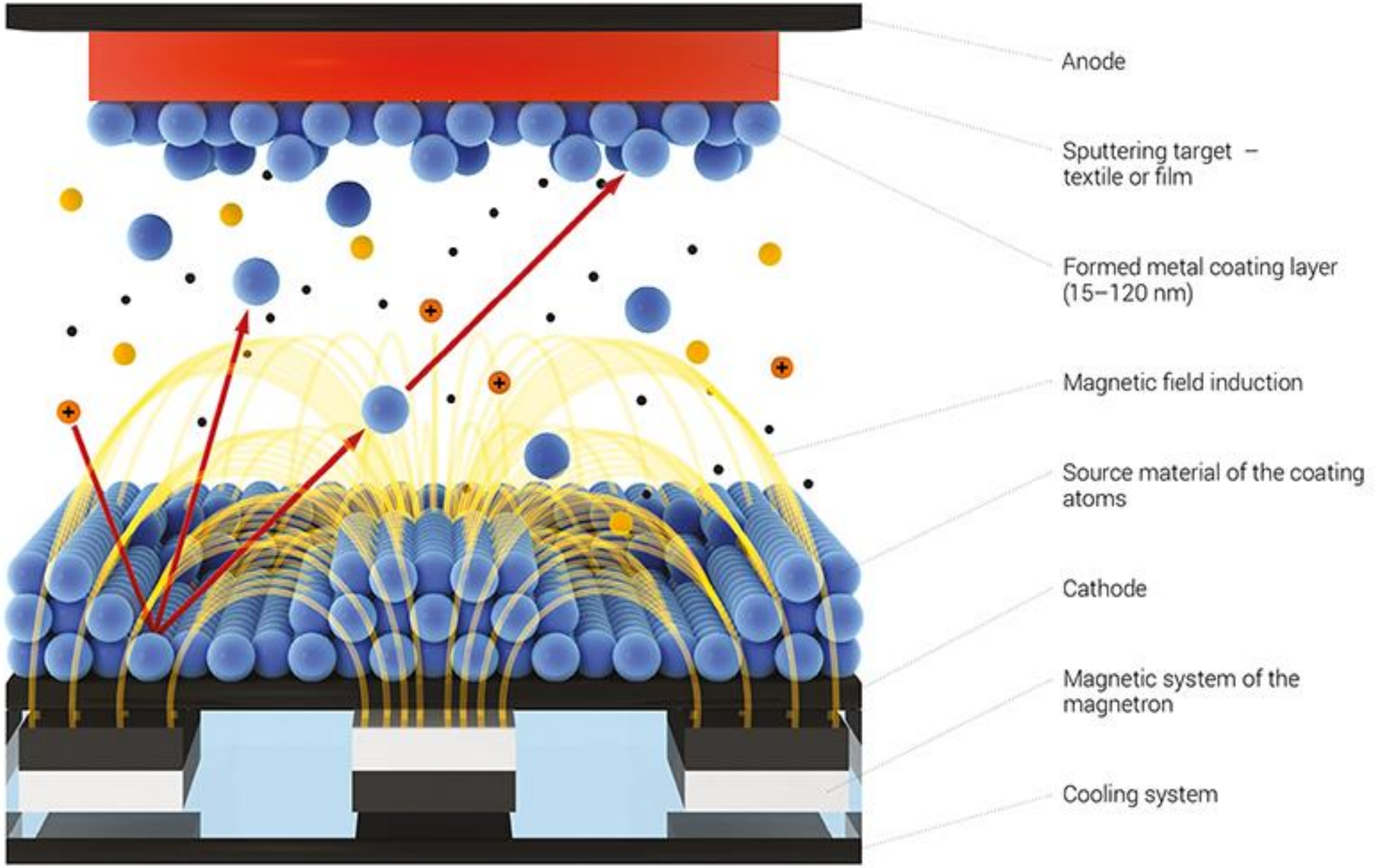
Cleaved
Wf

Coated
substrates

ALD-alumina on Si wafer



Direct Current Magnetron Sputtering (DCMS)

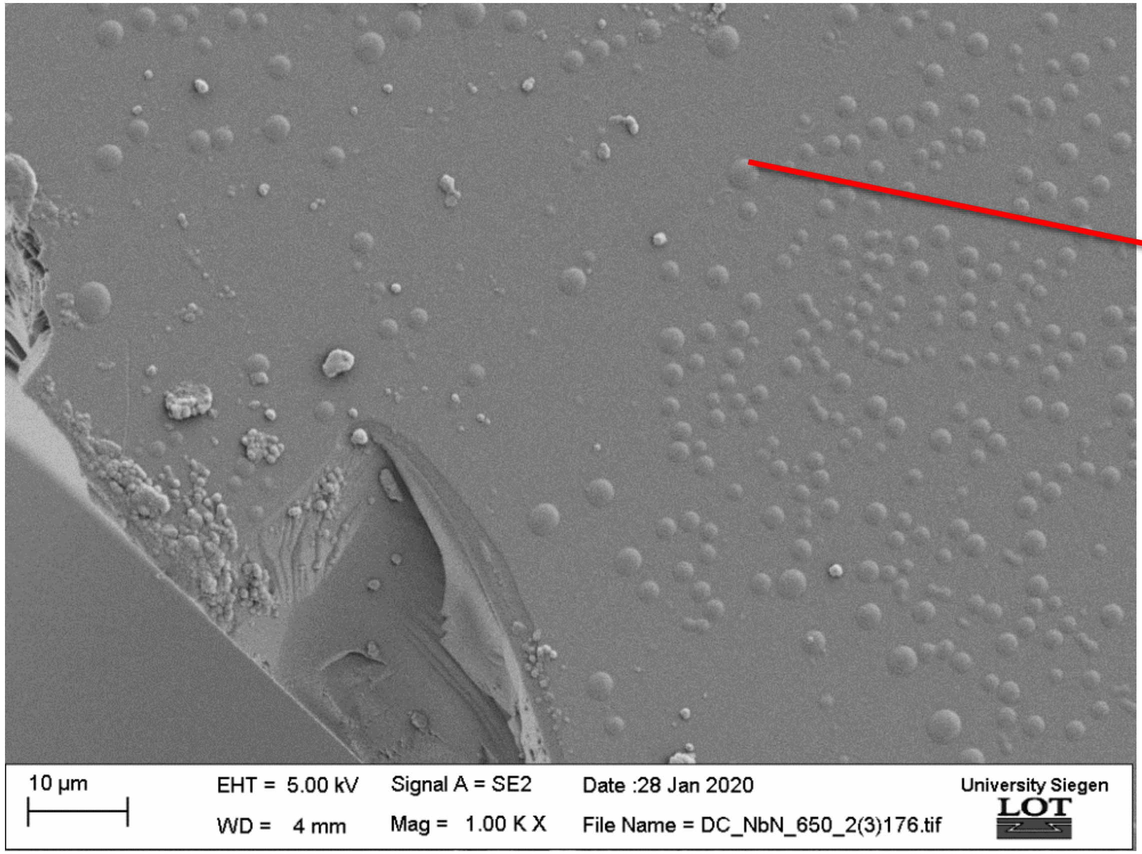


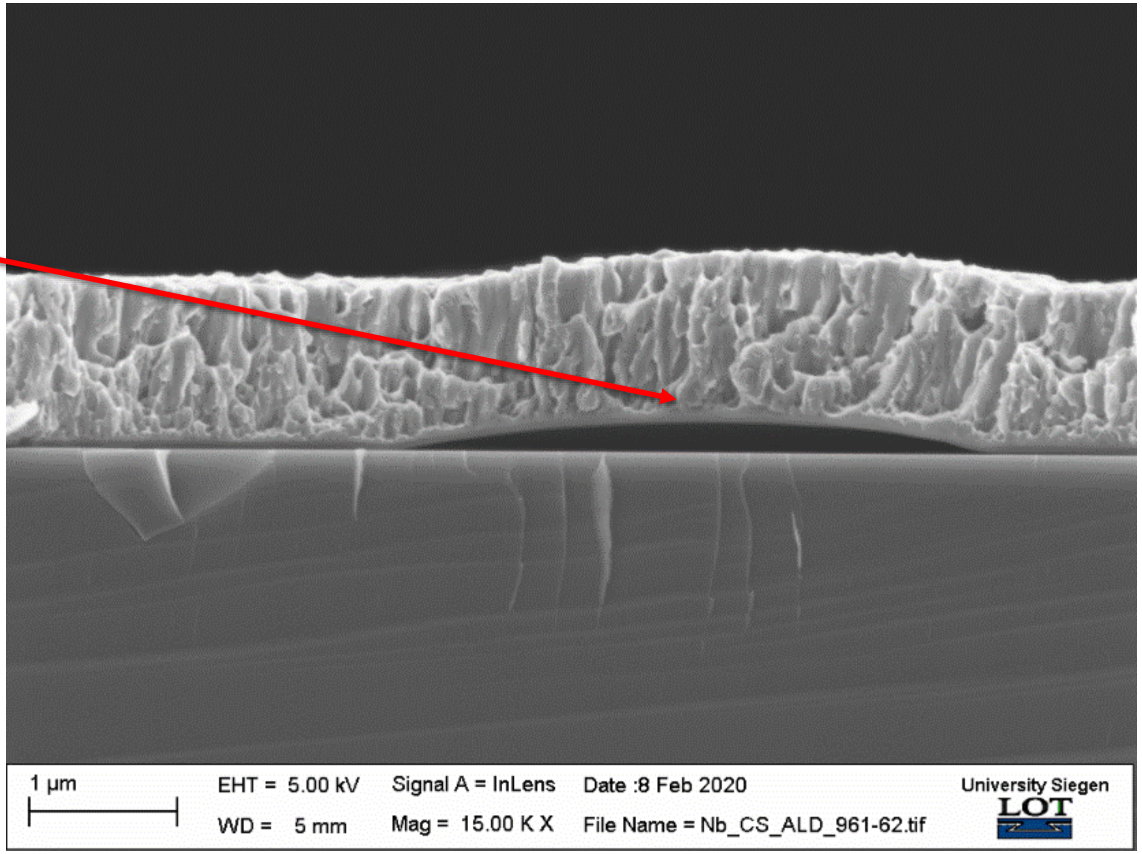
[https://www.visual-science.com/projects/magnetron-sputtering/technical-illustration/]

Process	Substrate Temperature T [ºC]	Process Gas Pressure p[mPa]	Process Gas	Process Gas Mass Flow Rate [sccm]	Cathode Power [W]	Substrate Bias [V]	Coating Time t_c [min]
1. 964	650	1200	Ar / N_2	500 / 43	400	0	30

CemeCon CC800

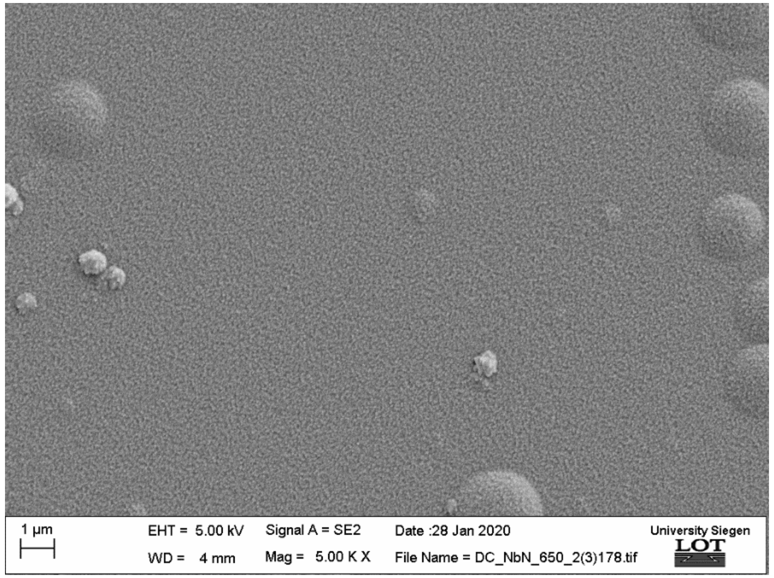
Results & Discussions



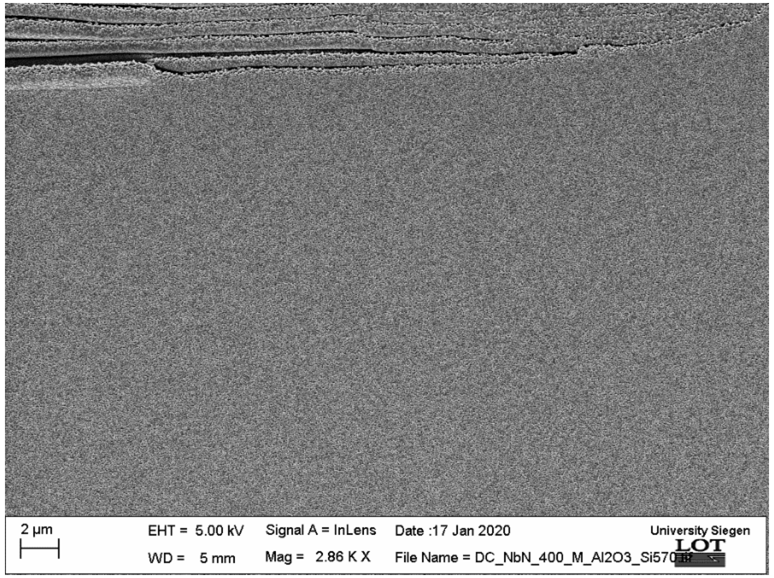


Results & Discussions

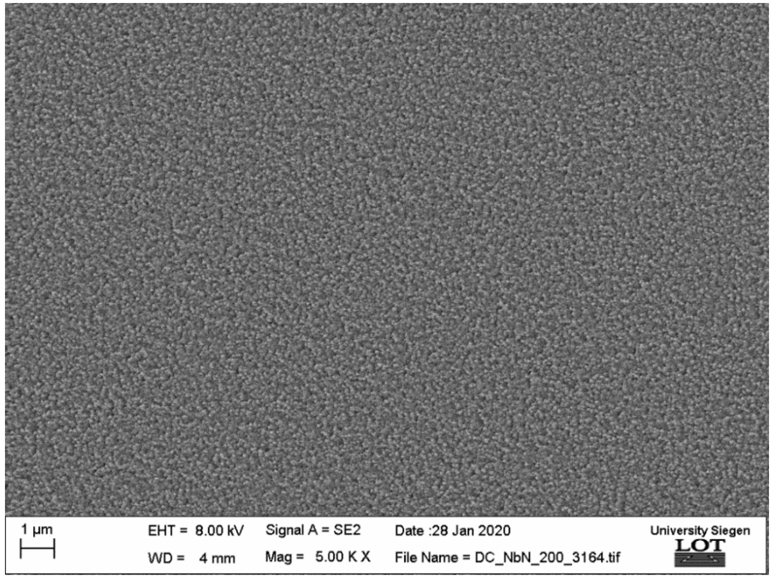
T650



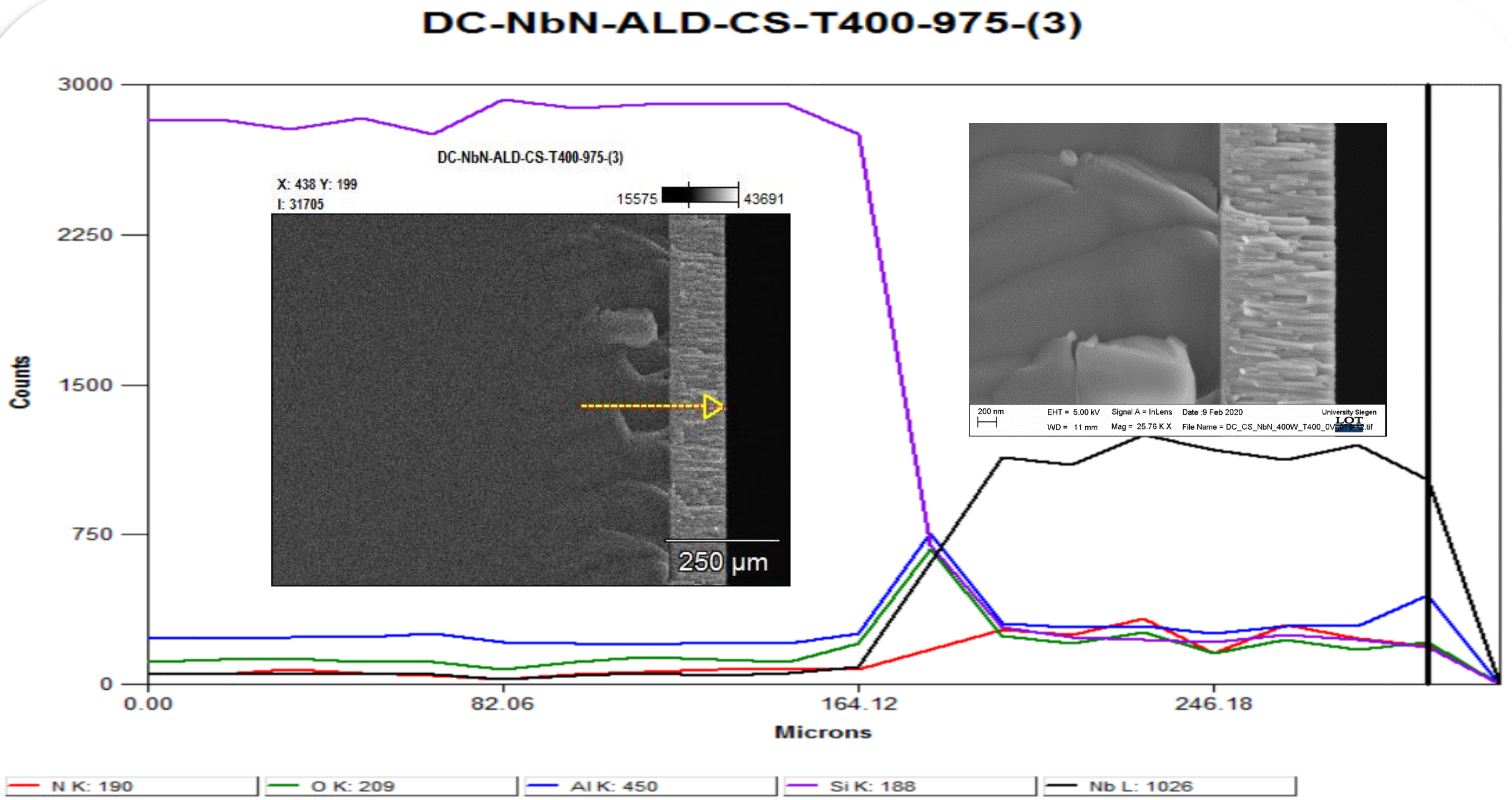
T400



T200



Results & Discussions



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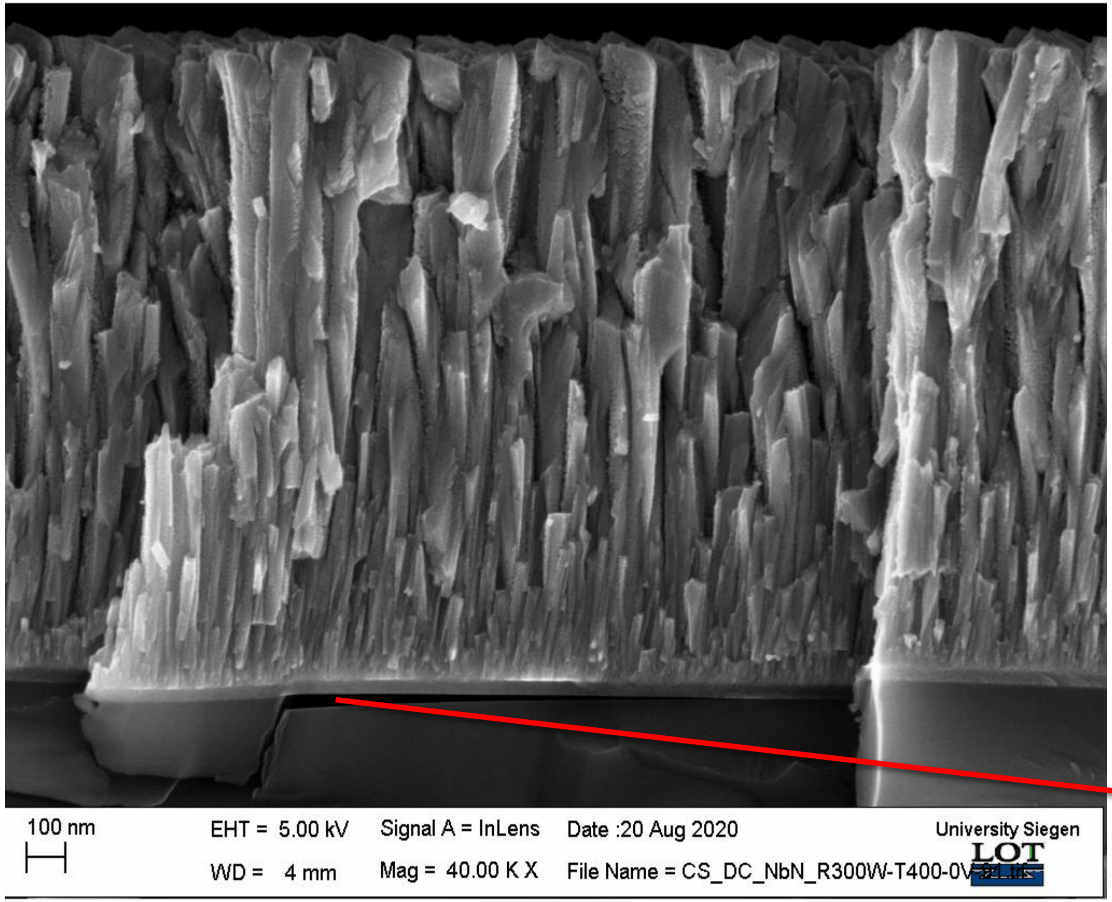
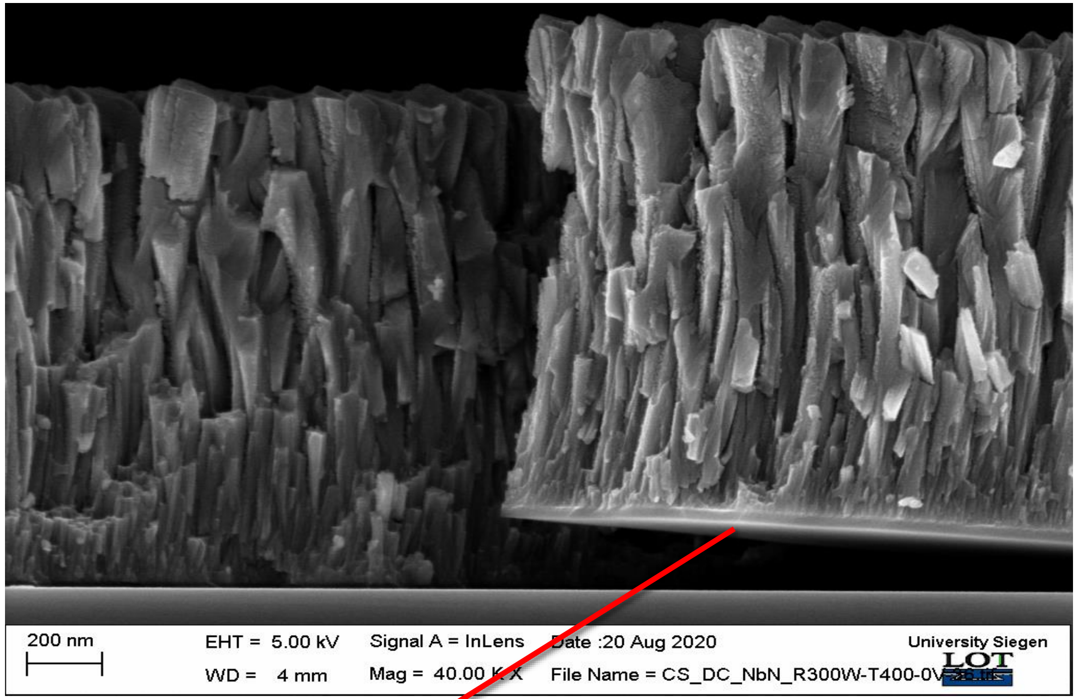
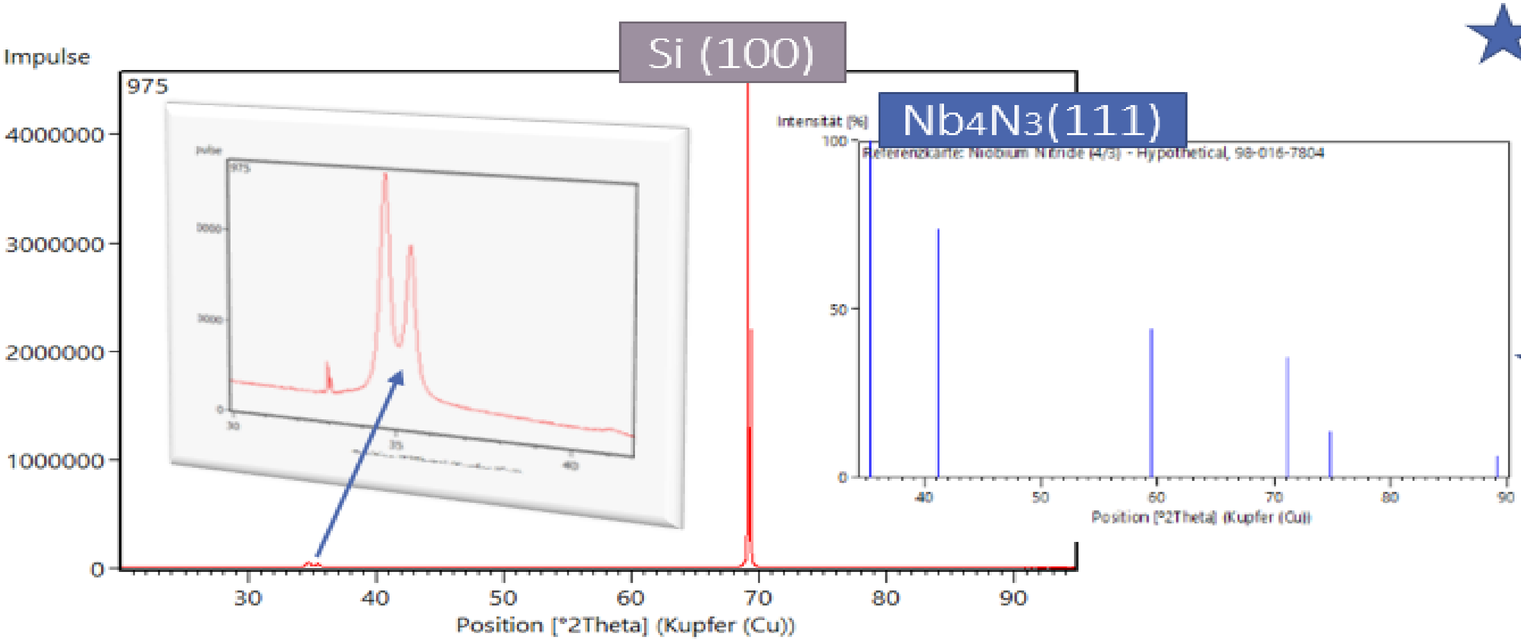




The delamination of the insulating layer (alumina).

Results & Discussions



★ **NbN**

- $T_c = 17.3K$
- $H_c = 230mT$ $(wrt\ Nb, H_c = 200mT)$

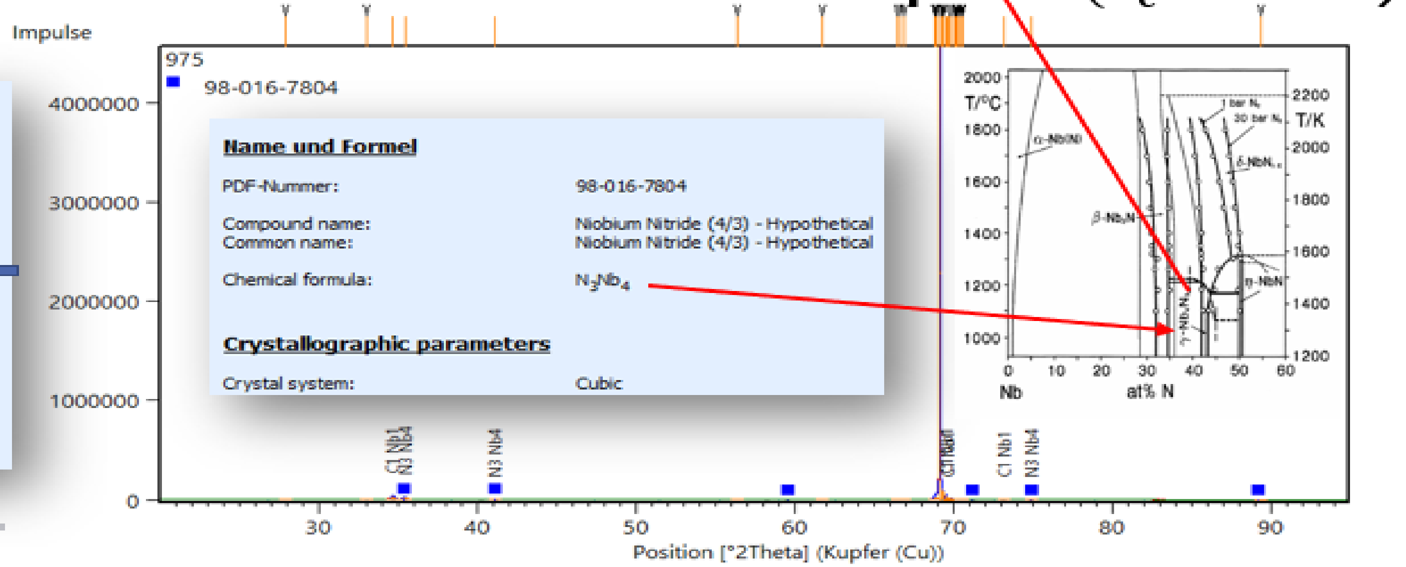
Superconducting NbN Phases:

★ γ – phase (Nb_4N_3) (T_C=12 – 15 K)

- δ – phase (NbN_x) (T_C = 15 – 17.3 K)
- ϵ – phase (T_c ~ 11.6 K)

Peak list

No.	h	k	l	d [Å]	2θ [°]	I [%]
1	1	1	1	2,53457	35,386	100,0
2	0	0	2	2,19500	41,089	73,7
3	0	2	2	1,55210	59,510	44,2
4	1	1	3	1,32363	71,177	35,7
5	2	2	2	1,26728	74,866	13,9
6	0	0	4	1,09750	89,154	6,6



Next Steps

*** The on-going experimental design of deposition processes regarding:**

- **mono-layer and / or**
- **multi-layer (S-I-S) structured superconducting materials**

…based on Nb(Ti)N, Nb_3Sn TFs on ALD-alumina / Si and niobium substrates with various deposition techniques (e.g., DCMS, HiPIMS, RFMS etc.),

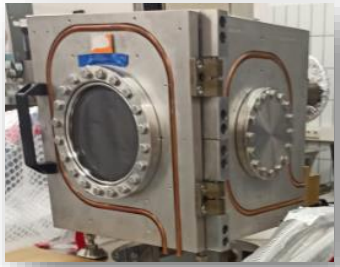
*** Further material (surface & interfacial) characterizations (e.g., SEM /EDX, XRD, AFM, TEM, SIMS, EBSD etc.),**

*** The thickness studies of the coated-layers (e.g., uniformity, (U)TFs),**

*** Superconductivity characterizations (e.g., T_c[K], B_{en}[Oe], etc.).**

* UTFs: Ultra-thin films

The on-going construction of the RF box-coater:



THANK YOU

FOR

YOUR ATTENTION !

If there is any further curiosity, please feel free to contact via
oezdem.sezgin@uni-siegen.de