SRF 2023
GRAND RAPIDS

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Bundesministerium
für Bildung
und Forschung

DESY.

CHyN
Centre for Hybrid Nanostructures

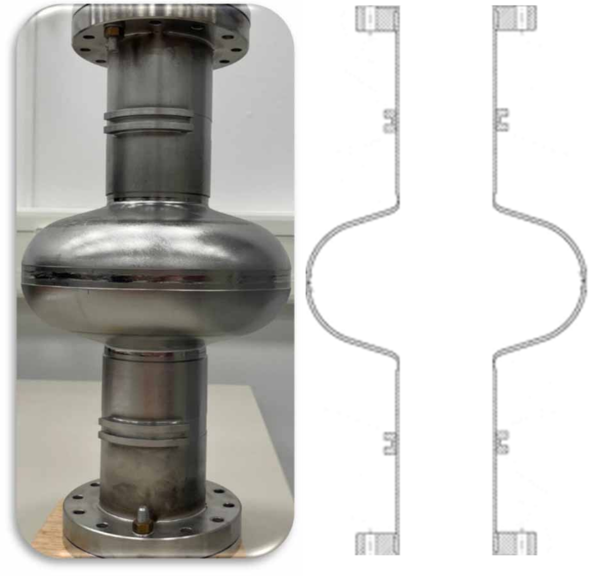
Successful SIS multilayer activities on cavities and samples using ALD

Isabel González Díaz-Palacio on behalf on SRF R&D team

igonzale@physnet.uni-hamburg.de

Pushing SRF cavities performance beyond Nb limits

Depositing thin-film **superconductor-insulator-superconductor (SIS) multilayers** *on* *<u>the inner surface of a SRF cavity</u>*



Single-cell 1.3 GHz SRF cavity

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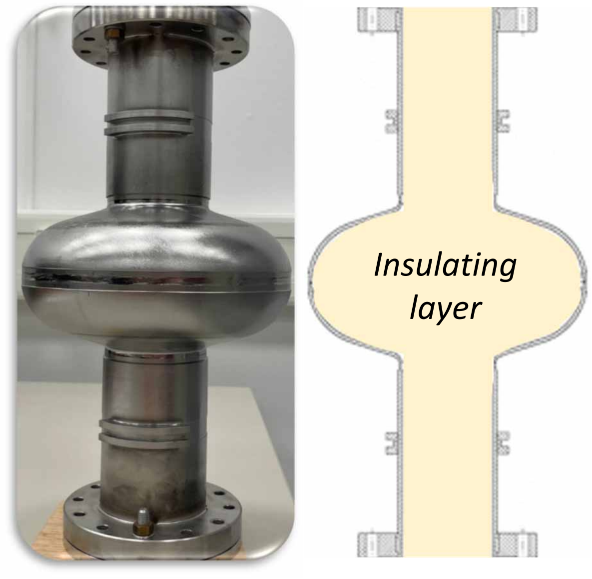

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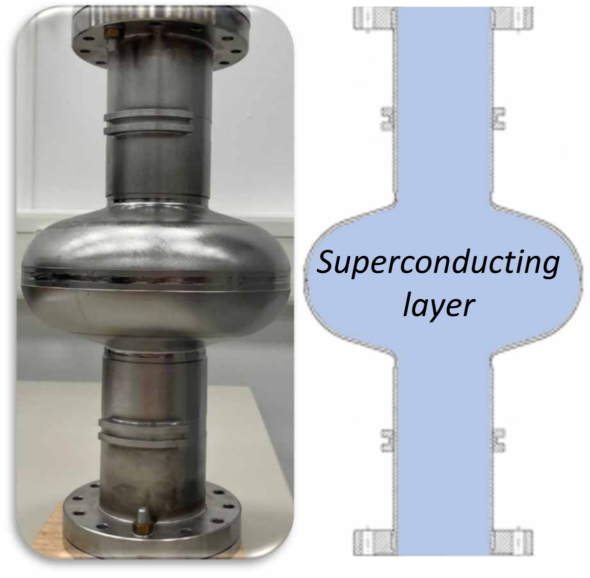

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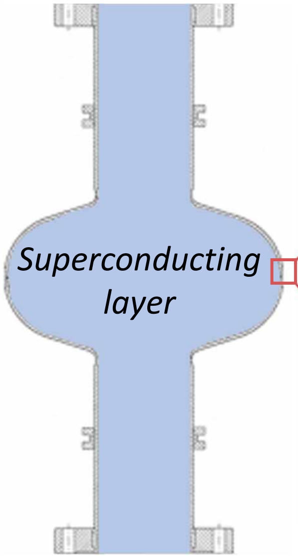
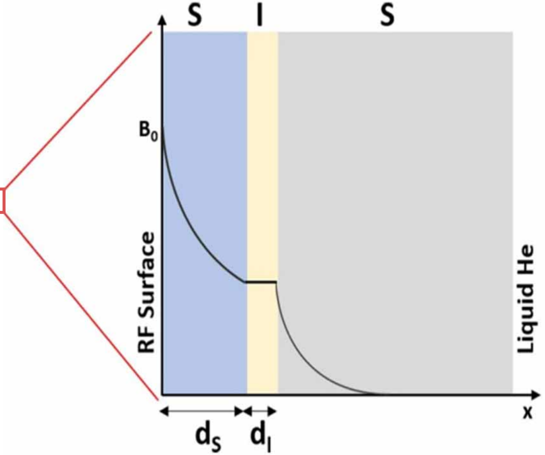


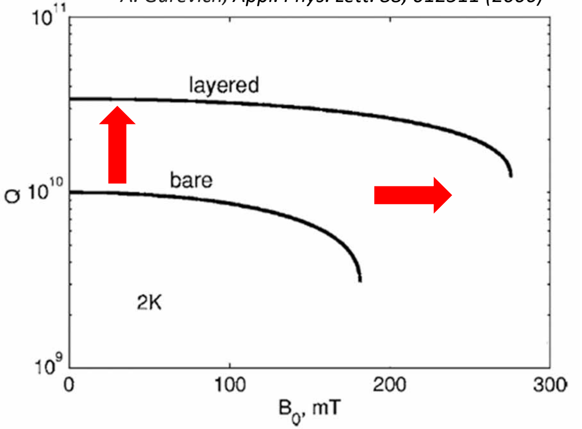
Single-cell 1.3 GHz SRF cavity

higher accelerating fields



higher quality factors →

A. Gurevich, Appl. Phys. Lett. 88, 012511 (2006)



Material candidates for SIS

- *S:* NbN, NbTiN, *Nb_3Sn, V_3Si, MoN, …*
- *I:* AlN, Al_2O_3, *Nb_2O_5, MgO, …*

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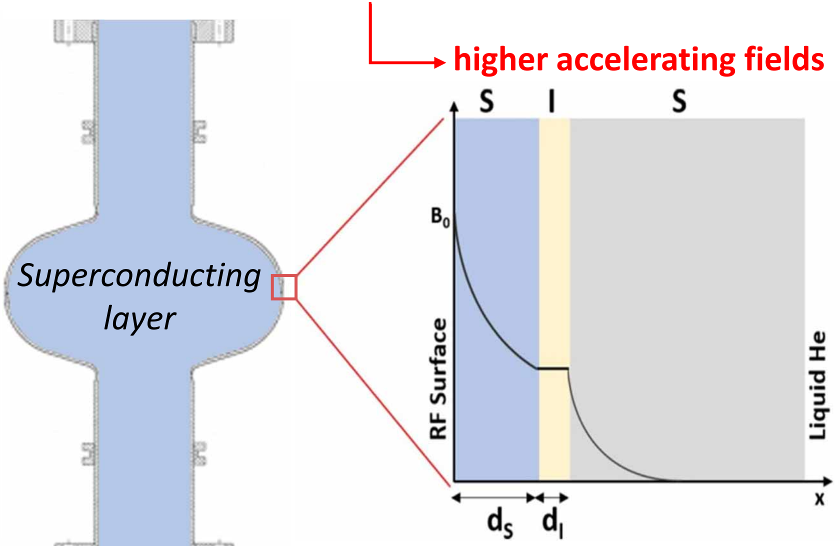

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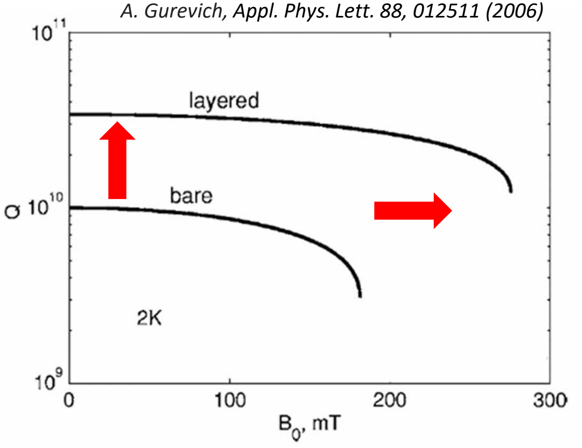

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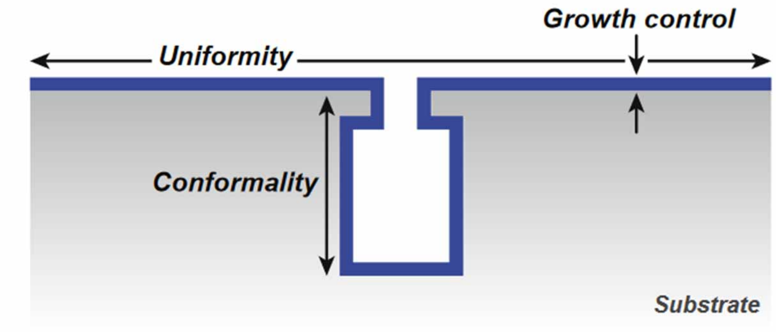
How is the inner surface of the cavity coated?

- **Atomic layer deposition (ALD)**

Why ALD is an ideal deposition technique for coating SRF cavities

ALD is a chemical vapor phase deposition technique that is distinguished by the key aspects:

*** Surface controlled (gas-solid surface reactions)** *** Self-saturating** *** Sequential**



Knoops et al., Handbook of Crystal Growth Vol III, 2nd ed. (2015)

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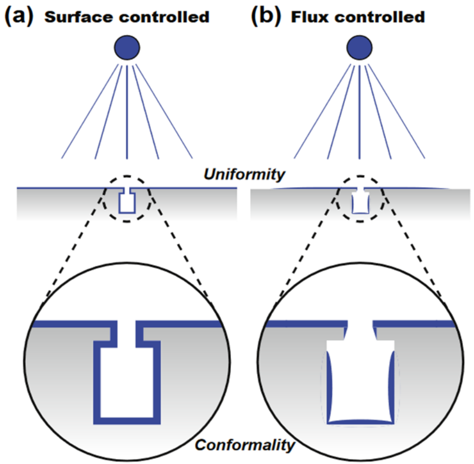
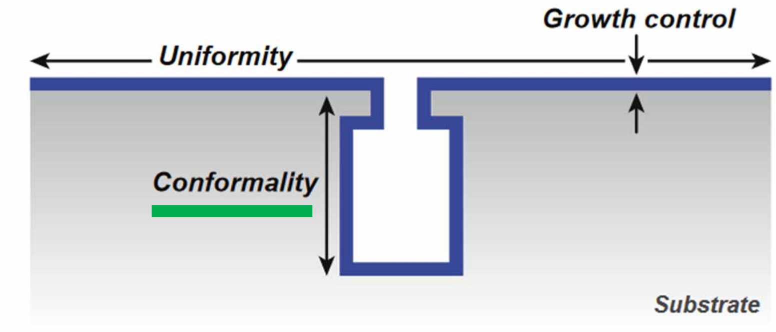
ALD **Line-of-sight deposition (PVD, CVD)**





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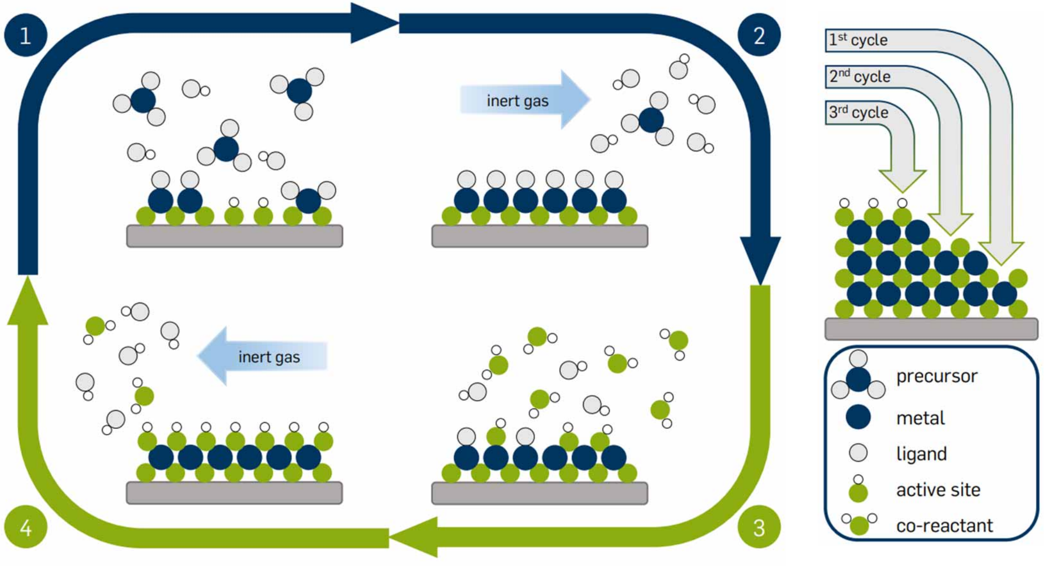
How does ALD work? Thermal and plasma-enhanced ALD (PEALD)

Thermal ALD



L. Mai, (2020), DOI:10.13154/294-7658.

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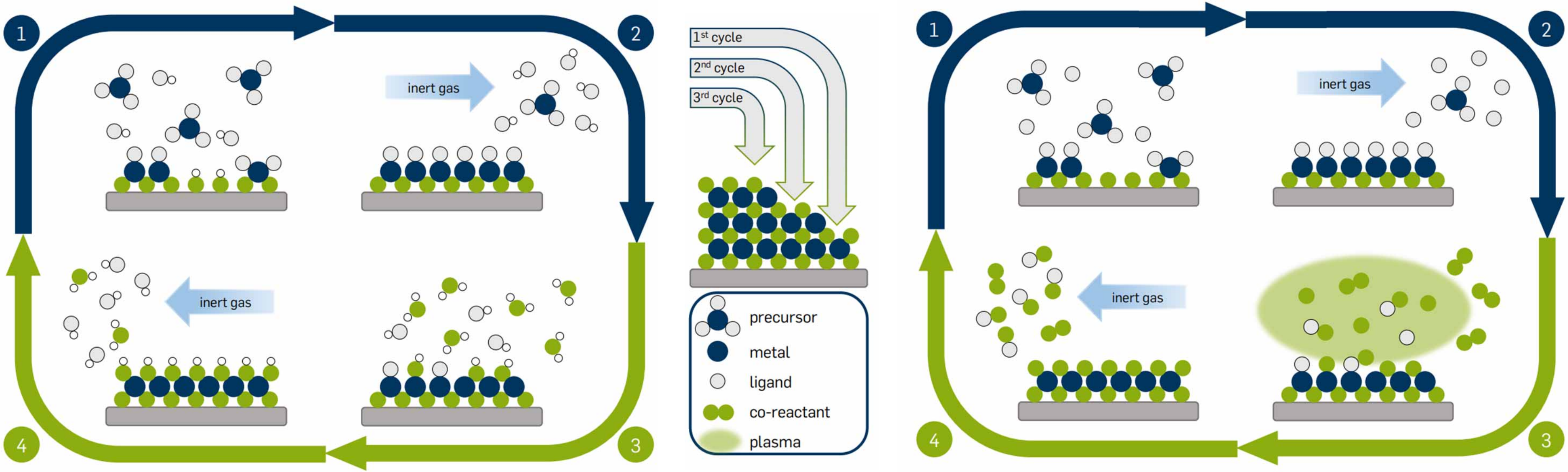
Thermal ALD **PEALD**



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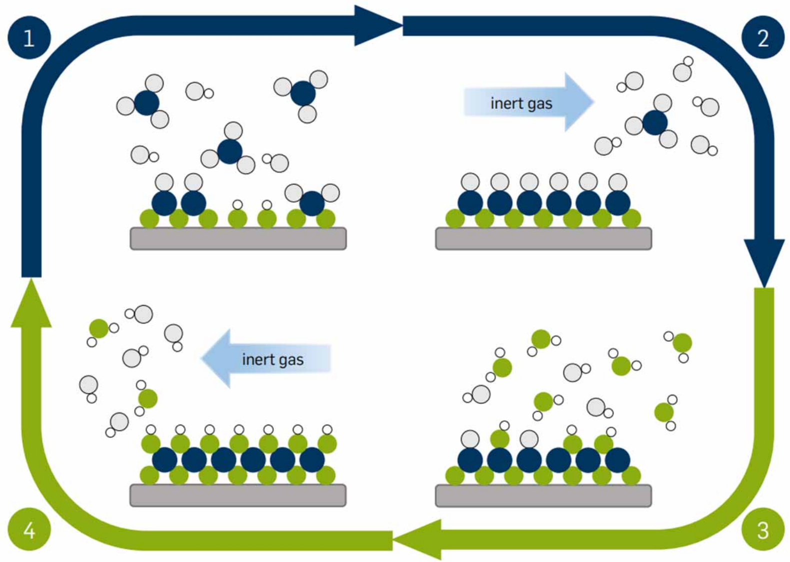
Deposition choice at UHH: **Thermal ALD**/**PEALD**

Thermal ALD



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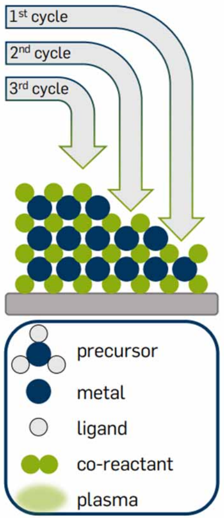
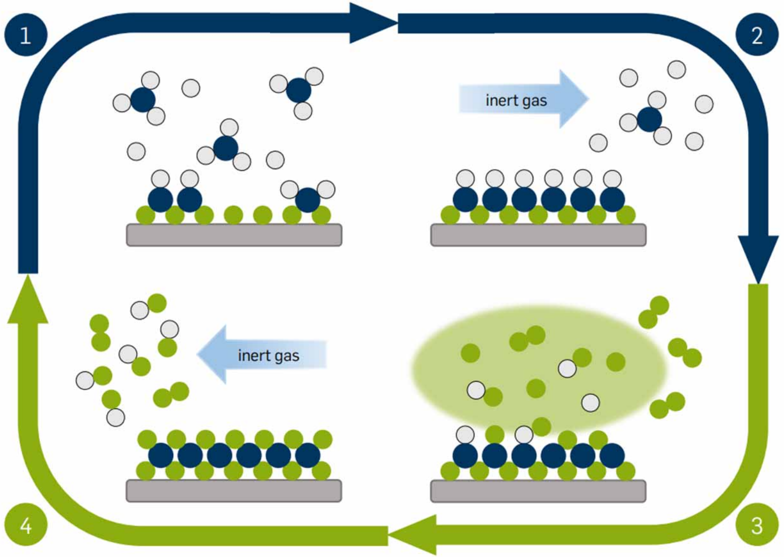


PEALD



SIS multilayers (PE)-ALD investigation at UHH

Thermal ALD: Al_2O_3

Capability for coating *<u>single-cell cavities</u>*

PEALD: AlN, NbTiN, NbN

Capability for coating *<u>planar samples</u>*

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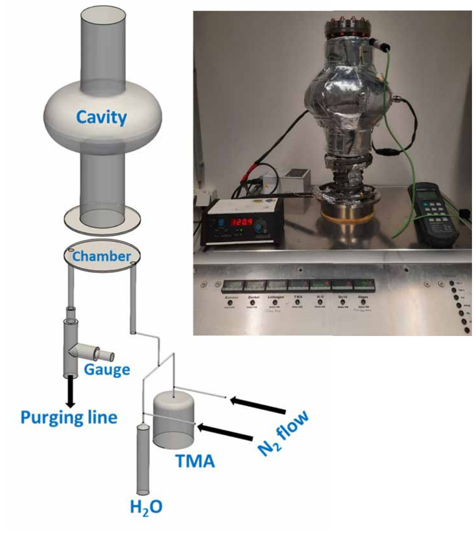
Capability for coating <u>planar samples</u>

Successful Al_2O_3 coating of high-gradient 1.3 GHz cavities by thermal ALD

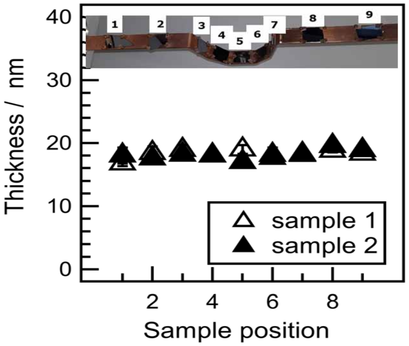
- ✓ **Proof-of-principle experiment**
  - *Process optimization*
  - *Thermal ALD Process Simulation*
- ✓ **Several single-cell cavities successfully coated**
- ✓ **Gradients above 40MV/m without any deterioration in Q-value**

Thermal ALD setup

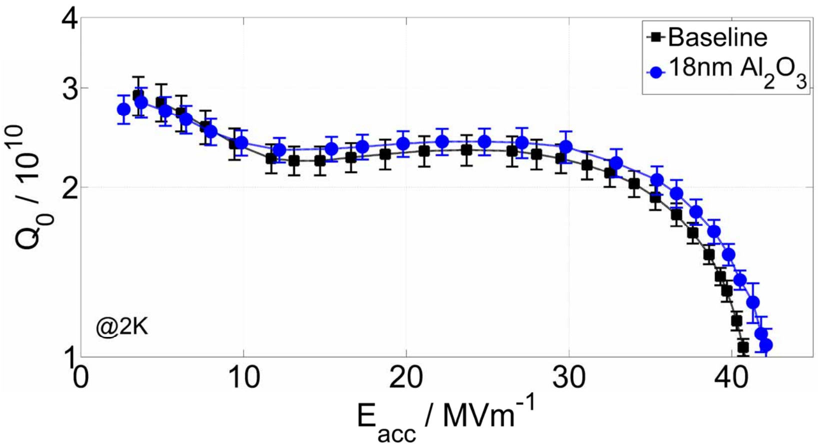


Process optimization

Precursors	TMA/H_2O
Temp.	120 °C
Thickness	~18 nm



Cavity performance



Marc Wenskat et al 2023 Supercond. Sci. Technol. **36** *015010* **DOI** *10.1088/1361-6668/aca83f*

For detailed information look at poster ID: **MOPMB016** *(Getnet Kacha Deyu)*

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Thermal ALD: Al_2O_3

Capability for coating <u>single-cell cavities</u>

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Capability for coating <u>planar samples</u>

How we grow AlN-NbTiN multilayers by PEALD

DEPOSITION PARAMETERS
Temperature: 250 °C
Plasma power: 300 W
Base pressure: 1E-1 mbar

GEMStar XT-P
from Arradiance

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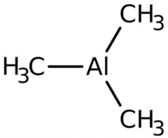
Precursors: Al, Ti, and Nb

TMA: *Trimethylaluminum*



+

H_2/N_2 *PLASMA*
Plasma reactive species

= **AlN**

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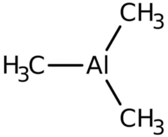

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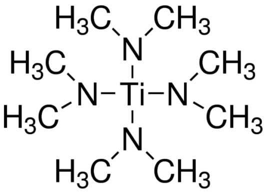
TDMAT: *tetrakis(dimethylamino)titanium(IV)*



+ = **TiN**

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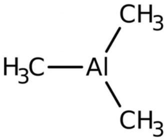

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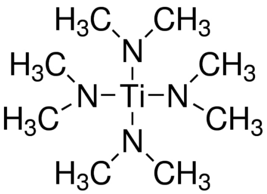

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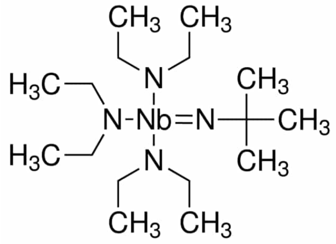
TBTDEN: *(t-Butylimido)tris(diethylamino)niobium(V)*



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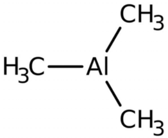

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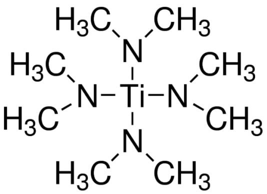

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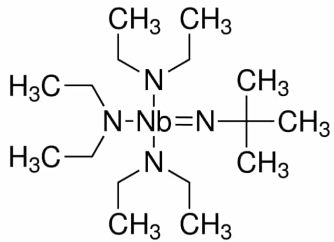

+

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NbN

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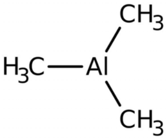

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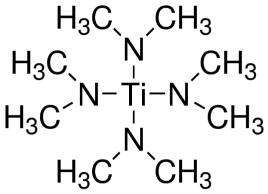

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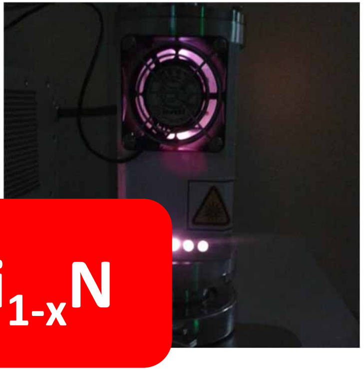

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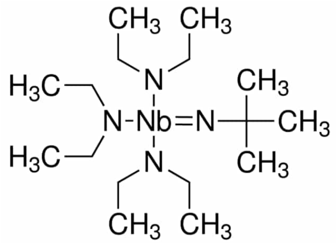

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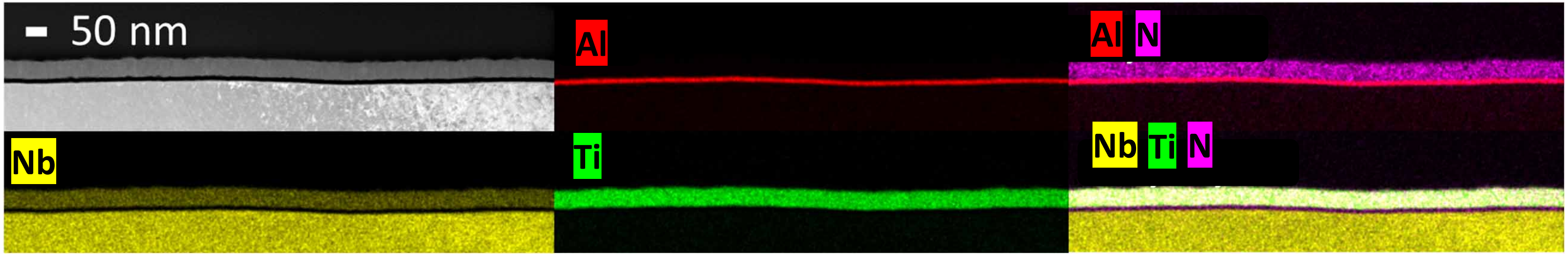
= **NbN**

$Nb_xTi_{1-x}N$

Tailored AlN-NbTiN multilayers deposited by PEALD on Nb and Si substrates

- *Elemental analysis*



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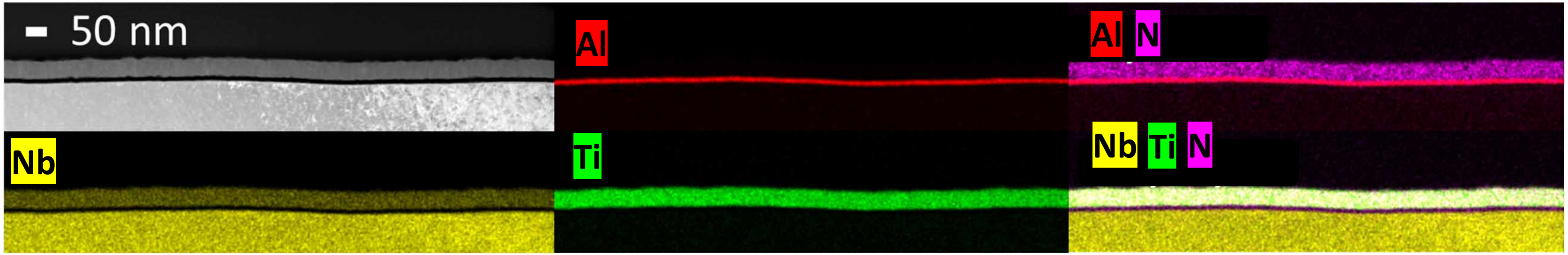

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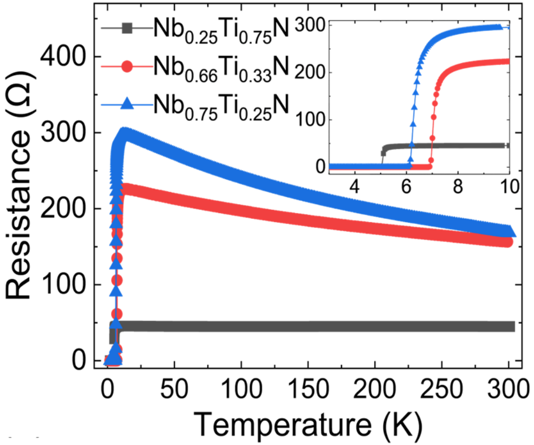

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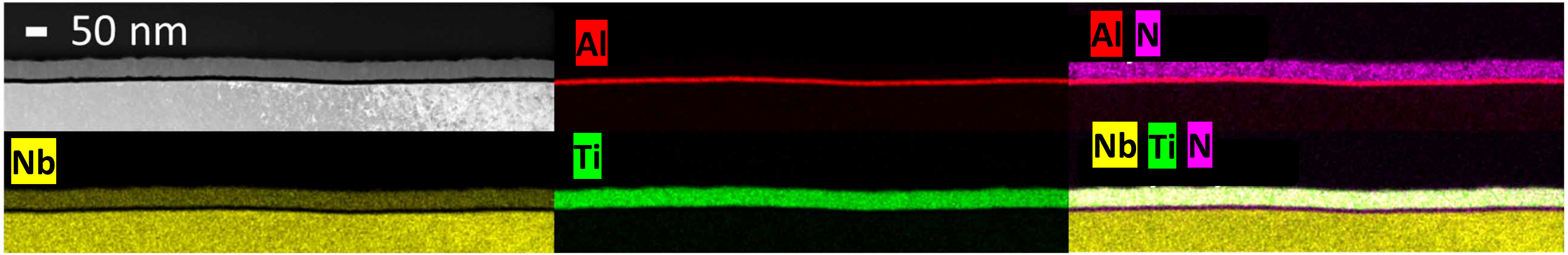

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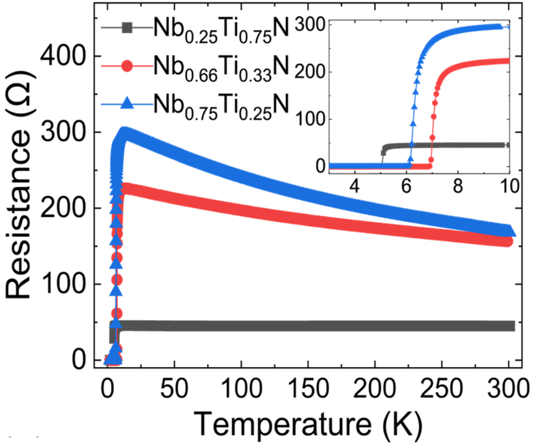
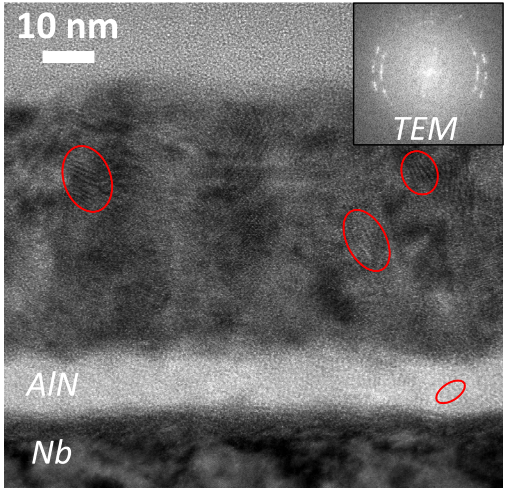


- *Crystallinity*



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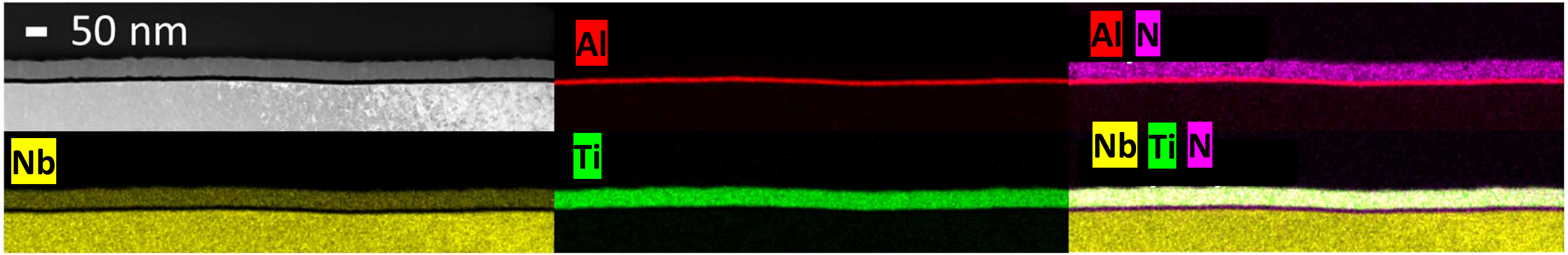

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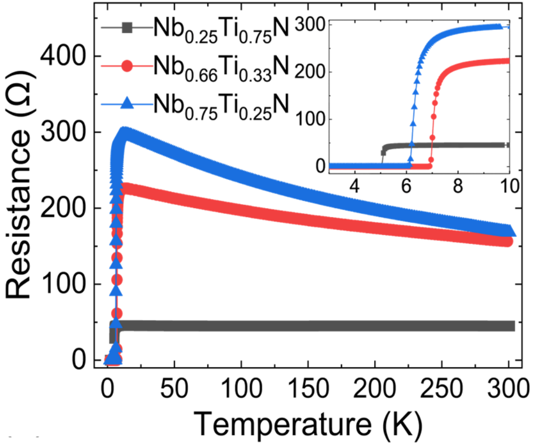

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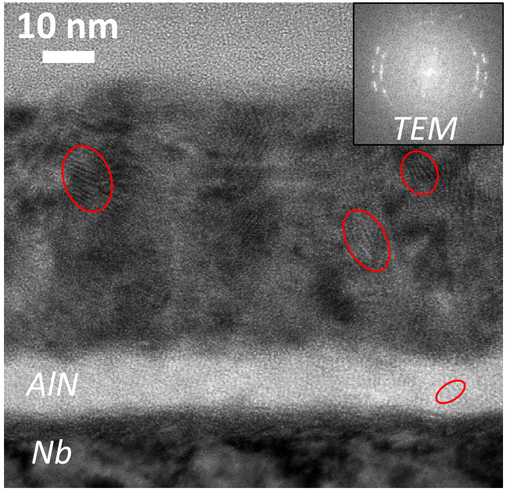
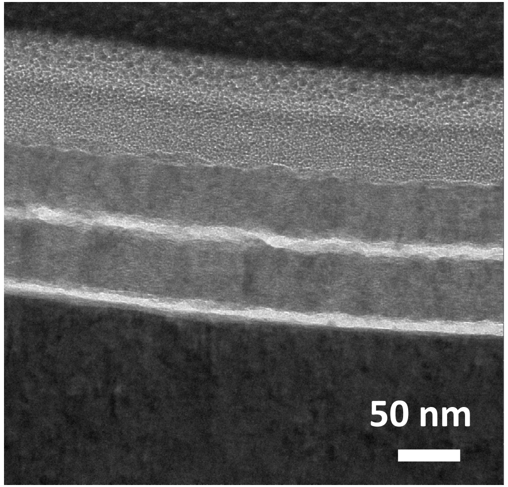


- *Nb – (AlN – NbTiN) x2*

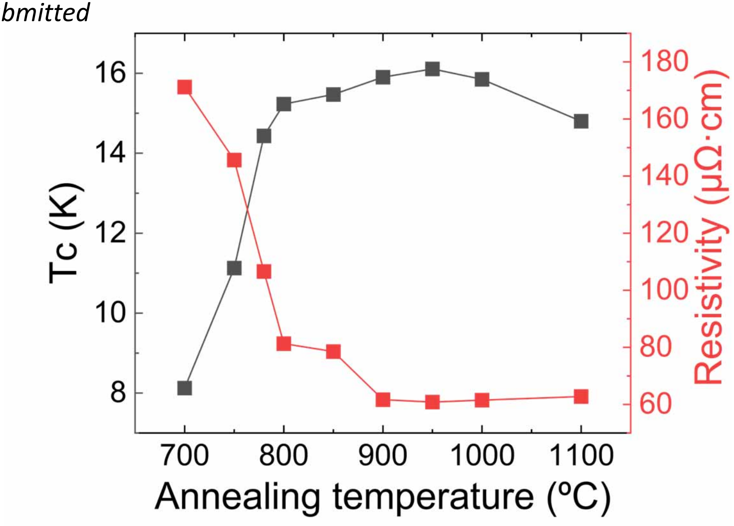


SRF2023, Isabel González Díaz-Palacio, UHH

AlN-NbTiN multilayers by PEALD are ready to move on to cavities

- *Enhancement superconducting properties annealing AlN-NbTiN multilayers*

Detailed info: I. González Díaz-Palacio et al., Journal of Applied Physics, submitted



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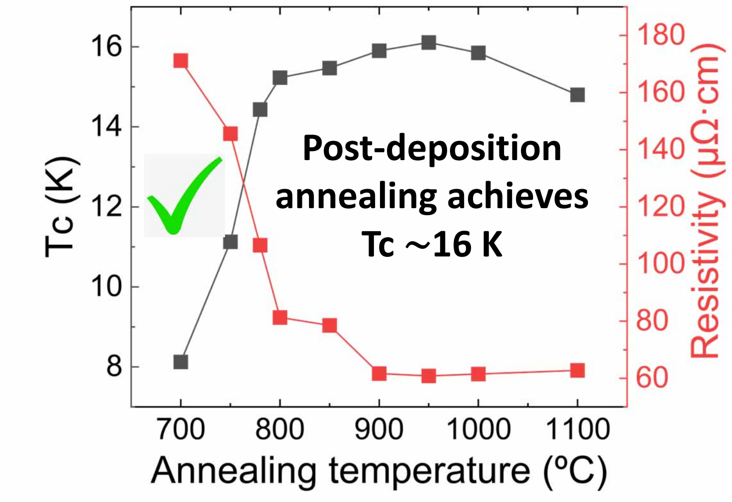

Post-deposition annealing achieves Tc ~16 K

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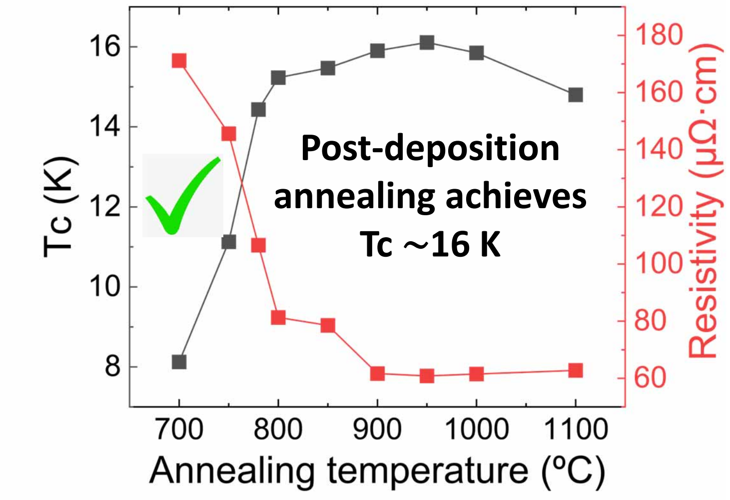
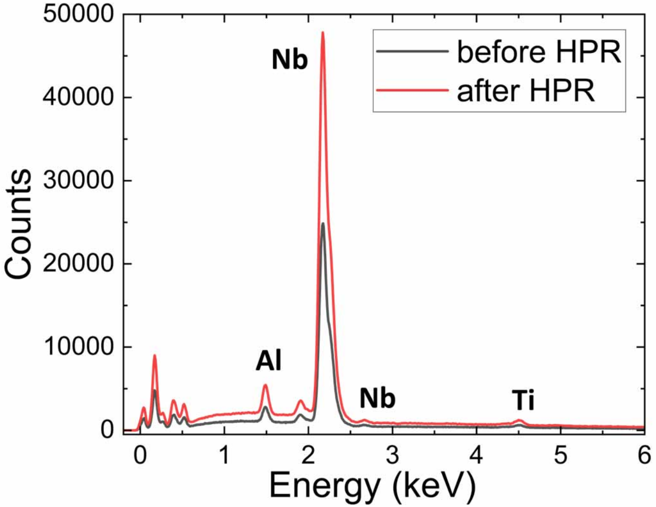


✓ **Post-deposition annealing achieves Tc ~16 K**

- *Success AlN-NbTiN multilayers to cavity preparation techniques: high pressure rinsing (HPR)*



DESY facilities Cleanroom ISO4

✓ **Layers deposited by (PE)-ALD survive 7 HPR**

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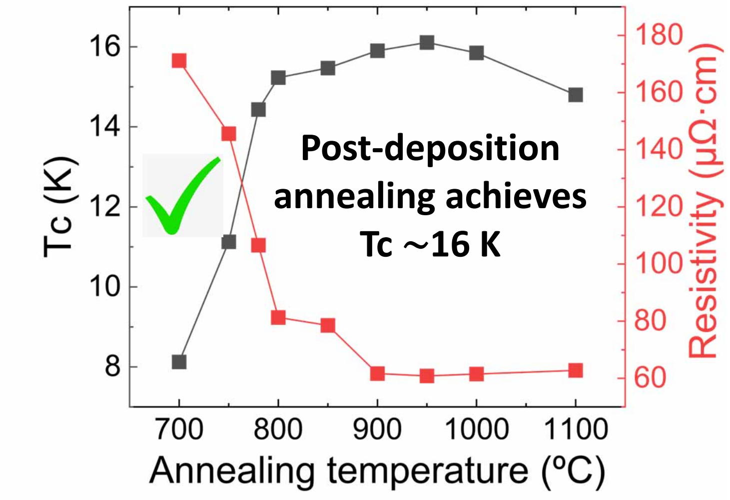

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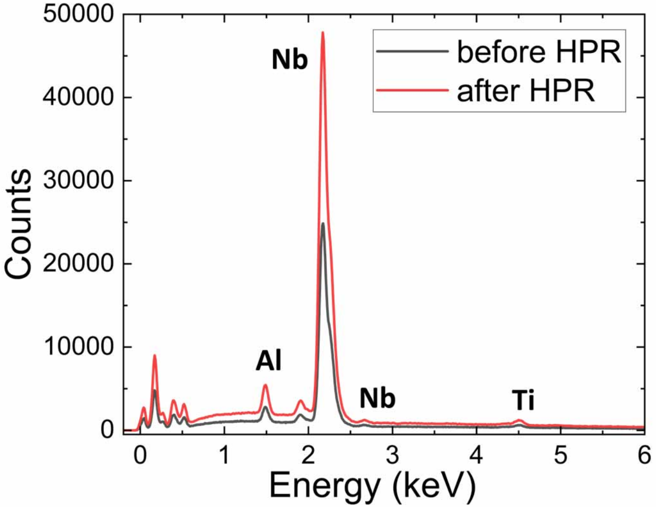

DESY facilities
Cleanroom ISO4

- *Field emission from planar films threshold voltage of:*

✓ **Annealed: 281 MV/m**
As-deposited: 95 MV/m

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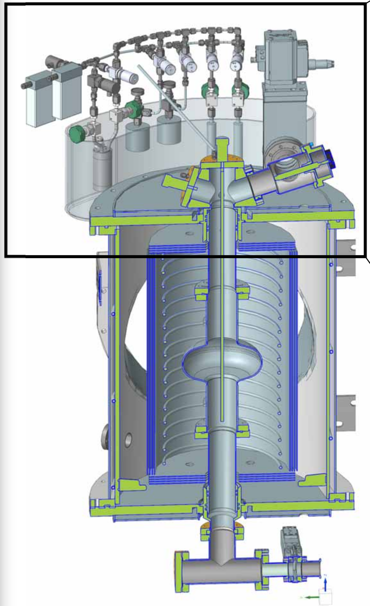
✓ **Layers deposited by (PE)-ALD survive 7 HPR**

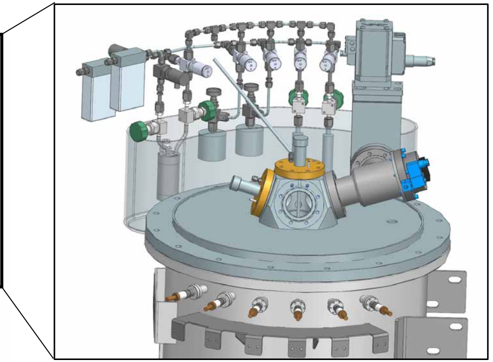
PEALD AlN-NbTiN cavity coating on the next SRF 2025

For detailed information about the furnace look at poster ID: **WEPWB111** *(Marc Wenskat)*

EXTEND SINGLE-CELL FURNACE TO PEALD-SINGLE-CELL COATING SYSTEM

Upgraded system





Status:

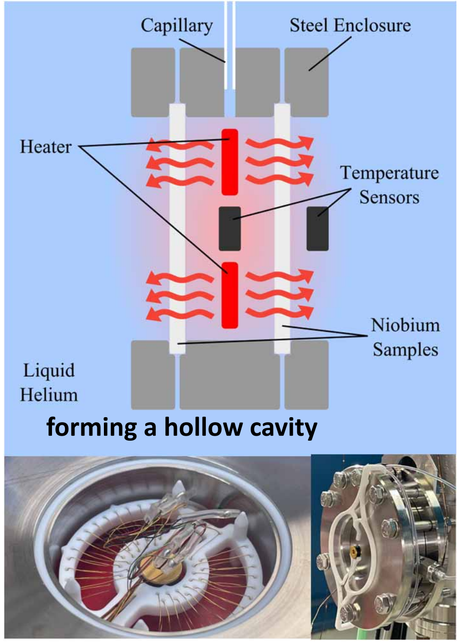
- ✓ *Design*
- ✓ *Fabrication*
- ○ *Commissioning*

High versatility *in one system:*

- *PEALD and thermal ALD*
- *Capable depositing:*
  - ○ *NbTiN / NbN*
  - ○ *AlN*
  - ○ *Al_2O_3*
- *In-situ annealing*
  - ○ *dissolve oxide layers before coating*
  - ○ *after coating*

Related activities ongoing

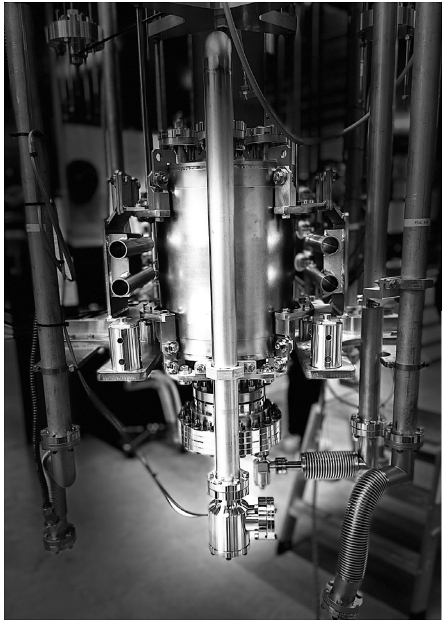
- *Thermal conductivity studies at UHH/DESY*



For detailed information look at

poster ID: **MOPMB017** *(Cem Saribal)*

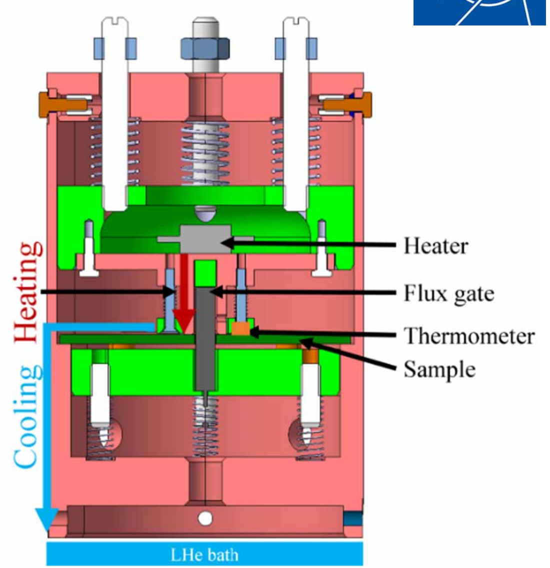
- *Commissioning of the UHH Quadrupole Resonator (QPR) at DESY*



For detailed information

talk ID: **THCAA02** *(Ricardo Monroy-Villa)*

- *Flux expulsion studies at CERN*



For detailed information look at

poster ID: **MOPMB003** *(Daniel A. Turner)*

Take home messages

- ✓ *Achieve coated cavities by thermal ALD and sustain high accelerating gradients without any performance deterioration*
- ✓ *SIS multilayers by PEALD and post-deposition annealing have been optimized on planar substrates – move on to cavities*
- ✓ *SRF2025 SIS coated cavity by PEALD: new setup under development*

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Thank you for your attention

Please, feel free to contact via: igonzale@physnet.uni-hamburg.de

SRF 2023 GRAND RAPIDS