10th St Com meeting, 14/12/2023

Oleg B. Malyshev (UKRI) / Claire Antoine (CEA)

WP9 coordinators

WP9 objectives

- Define a strategy for innovative superconducting RF (SRF) cavities coated with a superconducting film.
  - Deposition techniques: PVD and ALD
  - Superconducting films: Nb, NbN, Nb_3Sn, V_3Si (and others) and SIS
  - Optimization of flat SRF thin films production procedure
- Optimise and industrialise the production
  - of seamless copper cavities and
  - of the deposition techniques.
- Produce and test prototypes of SRF (single-cell elliptical) cavities:
  - Initially with pre-prototypes with f = 6 and 3 GHz
  - Scaling up for f = 1.3 GHz.
- Test a new laser treatment of Nb coated cavity.

➢ **Main goal:**

- Improving the performance and reducing the cost of acceleration systems
  - both production and operation

WP9 tasks

- **Task 9.1**: Coordination and strategy for innovative superconducting accelerating cavities
  - *CEA, INFN, HZB, UKRI, USI, JLab MEPHI, PTI.*
    - *Task Leaders: C. Antoine (CEA), O. Malyshev (UKRI)*
- **Task 9.2**: Innovative SC accelerating cavity prototype
  - *INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB, PTI, MEPHI*
    - *Task Leader: C. Pira (INFN)*
- **Task 9.3** : Optimisation of process parameters and target development for SRF cavity coating with A15 material
  - *UKRI, INFN, IEE, USI, HZB, MEPHI, HZDR*
    - *Task Leader: R. Valizadeh (UKRI)*
- **Task 9.4**: Surface engineering by atomic layer deposition (ALD)
  - *CEA, CNRS*
    - *Task Leader: T. Proslier (CEA)*
- **Task 9.5**: Improvement of mechanical and superconducting properties of RF resonator by laser radiation
  - *RTU, UKRI, INFN, IEE, HZB*
    - *Task Leader: A. Medvids (RTU)*
- **Task 9.6**: Optimization of flat SRF thin films production procedure
  - *HZB, INFN, UKRI, USI, CEA*
    - *Task Leader: O. Kugeler (HZB)*

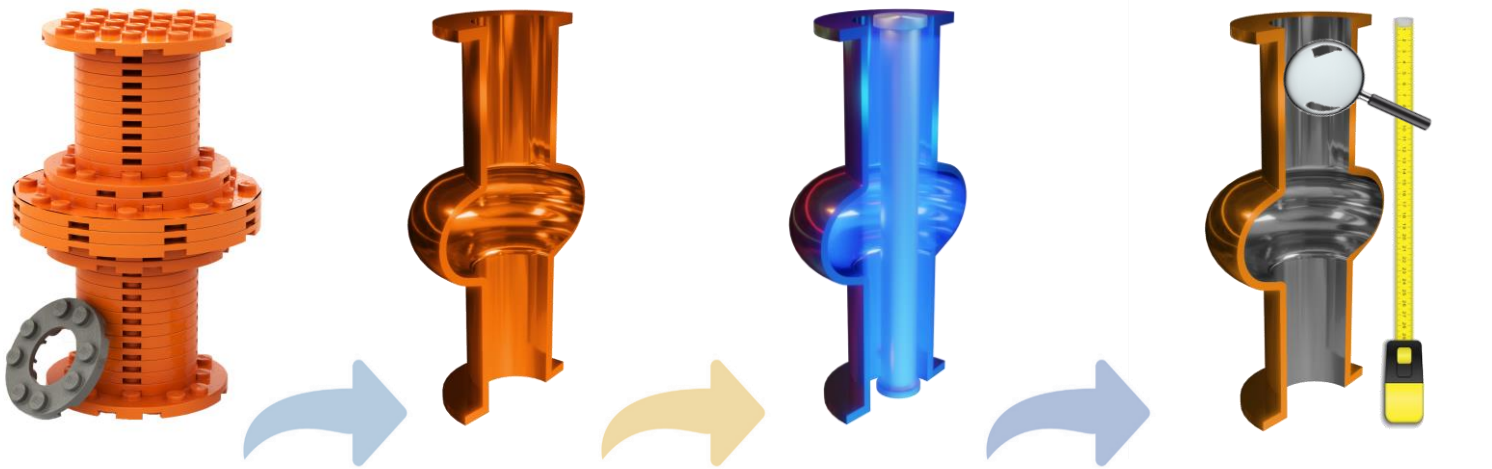
Task 9.1: Coordination and strategy for innovative superconducting accelerating cavities

(CEA, INFN, HZB, UKRI, USI, JLab MEPHI, PTI). *Task Leaders: C. Antoine (CEA), O. Malyshev (UKRI)*

- Coordination:
  - Regular WP9 meeting take place every 3-4 months:
    - 9th WP9 meeting on 18/04/2023
    - 10th WP9 meeting on 14/09/2023
    - 11th WP9 meeting scheduled on 18-19/01/2024
- Strategy
  - Now the representatives of all HEI, where TF SRF programme exist, are invited and present at the WP9 meetings
    - CERN and DESY/Hamburg Uni are not official partners in WP9
  - Implementation of Accelerator Research and Development Roadmap of the European Strategy for Particle Physics (ESPP). Annex 1, https://cds.cern.ch/record/2800190?ln=it)
    - Claire and Oleg are co-chairs in WP on TF SRF
    - All WP9 members are involved in discussion and in providing necessary information for report to the Large Particle Physics Laboratory Directors Group (LDG) mandated by the CERN Council
  - WP9 member were well involved in organising and participating in SRF-23 in USA
  - Organising the 11th International Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity in 2024 is Delivery for WP9.

Task 9.2: Innovative SC accelerating cavity prototype *(INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB)* *Task Leader: C. Pira (INFN)*

4 main steps to develop to get the first 1.3 GHz Nb_3Sn on Cu prototype produced and tested



Task 9.2: Cavity Forming

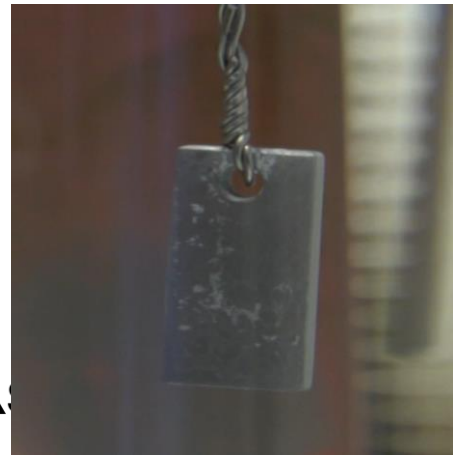
- **Production Protocol has been optimised**
  - CNC machine
  - Reduced Annealing Temperature (400 °C, previous 500 °C)
  - New intermediate Deep Drawing Step
- **Several cavity substrates 1.3 GHz (and 6 GHz for task 9.3) sent to STFC and UniSiegen for coating tests**
- **New optimized die produced by Piccoli**
- **Ready for final prototype substrates production**
- ***Difficulties in procuring OFE copper sheets to produce substrates for final prototypes***
  (some OFE-Cu sheets are already in house, but it would be better to have more)

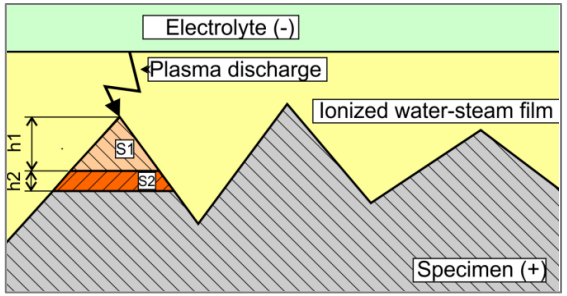
New 1.3 GHz Die for Spinning produced by Piccoli

Task 9.2: Cavity Polishing

- **Polishing via SUBU5 chemical process as baseline established @LNL**
- **Ongoing R&D on innovative Plasma Electrolytic Polishing (PEP)**

PEP Advantages





6 GHz Cu cavity

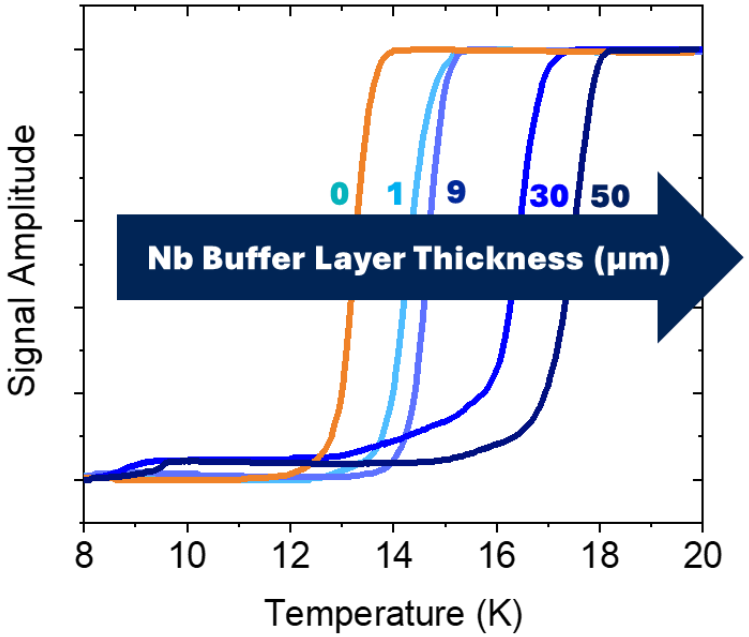
No internal cathode

70 µm removed in 10 minutes

30 A (100 cm2 → 1.3 GHz ~ 300 A)

Task 9.2: 1.3 GHz cavity Coating at INFN/LNL

- 1.3 GHz Coating systems is ready
- First tests on cavity mockup in 2024
- R&D on samples successfully ongoing
  → T_c close to Nb_3Sn nominal one
  (best results on Cu so far in literature)



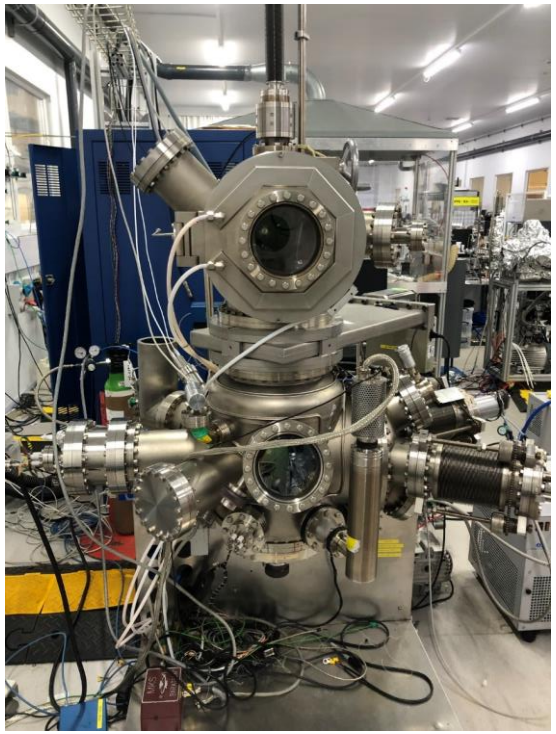
- *More complex process than originally planned at the beginning of the project*
- *Thick Nb buffer layer seems mandatory for high T_c*

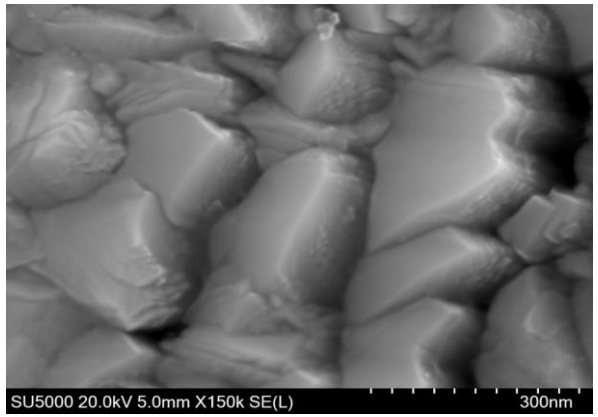
PVD (left) and Dipping (right) coating systems @LNL

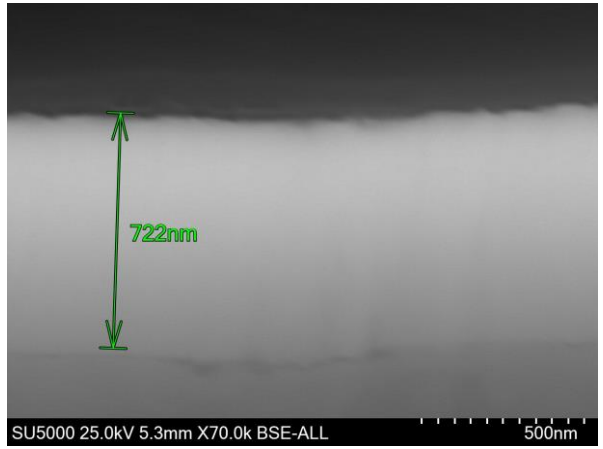
Task 9.2: 1.3 GHz cavity Coating at UKRI/STFC

Science and Technology Facilities Council

- 1.3 GHz Coating systems ready





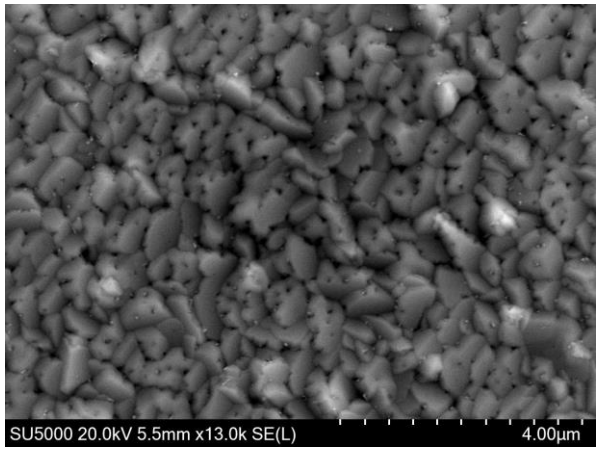


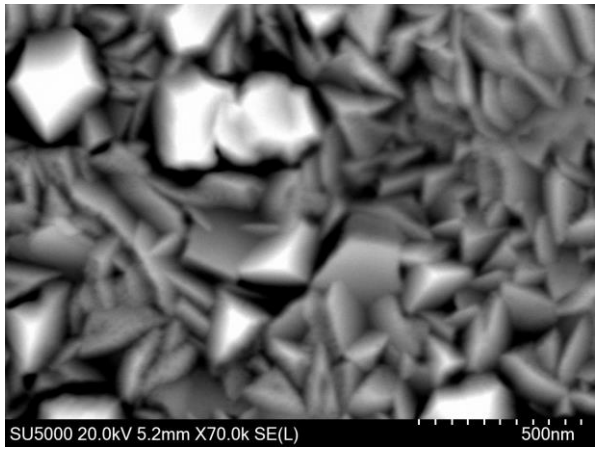
The system is equipped with load lock chamber, rotating arm that can turn and move up and down, the chamber wall is water cooled, fixed magnetron in the centre.
It will be positioned in an ISO 6 clean room with ISO 4 cabinet for final cavity preparation.

Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

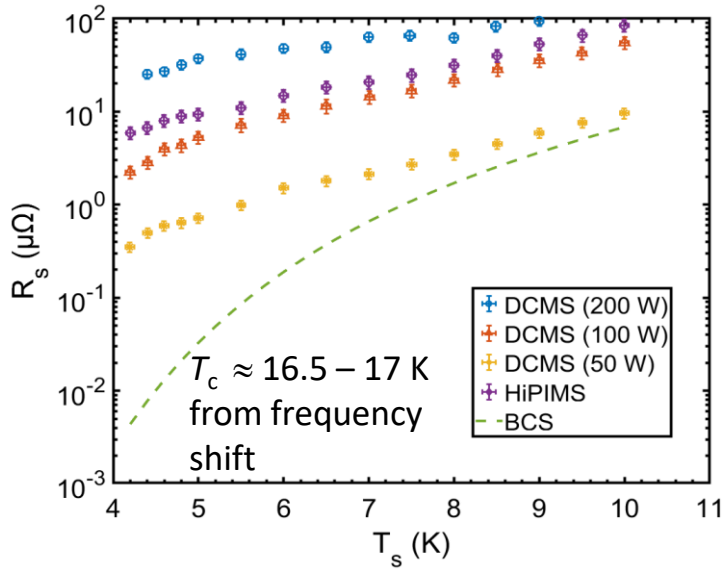
(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

Development of Nb_3Sn thin films on planar copper substrates at UKRI

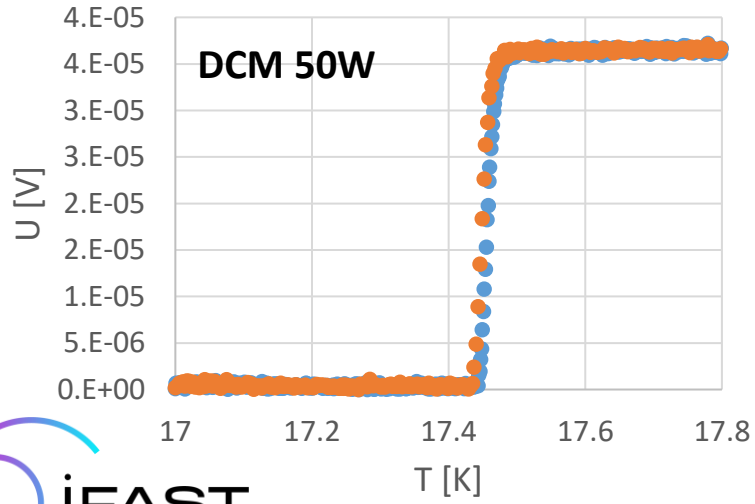


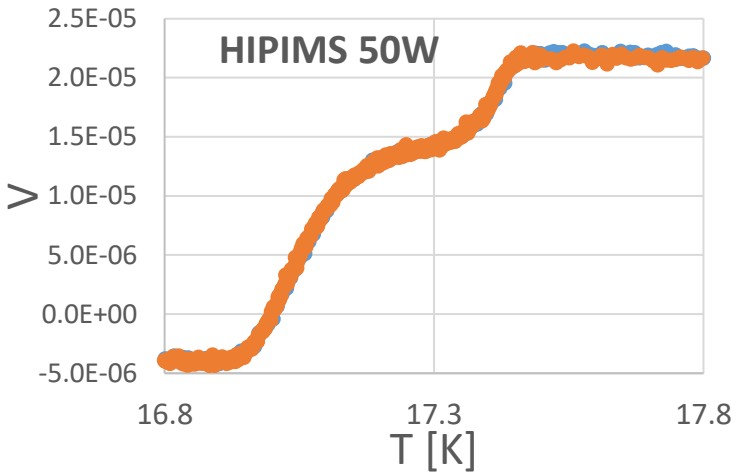


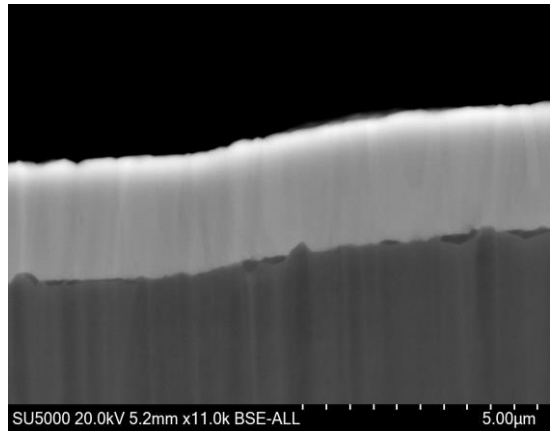
RF surface resistance at 7.8 GHz



T_c measurements



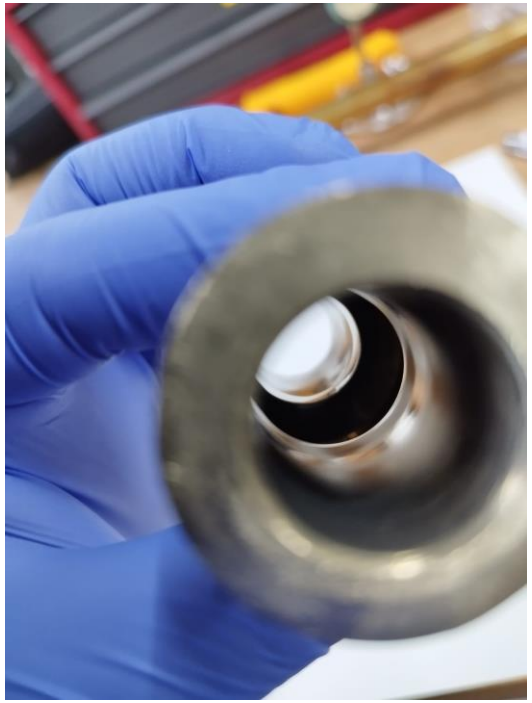




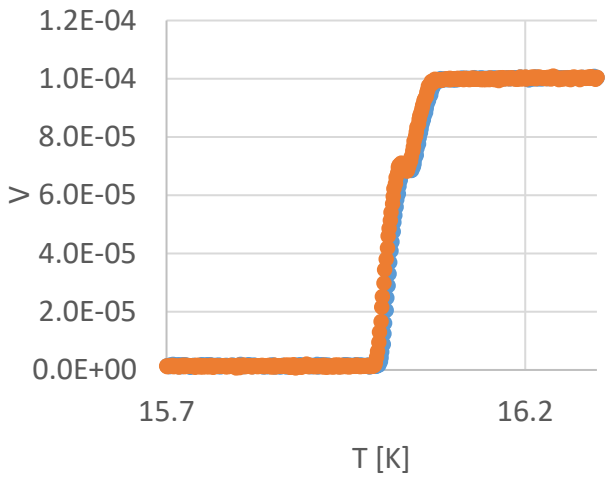
Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

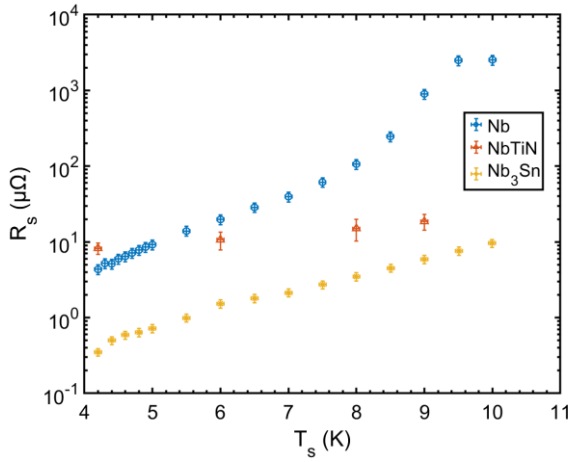
Depositing NbTiN thin films from Nb rod and Ti wire on a 6 GHz RF cavity at UKRI

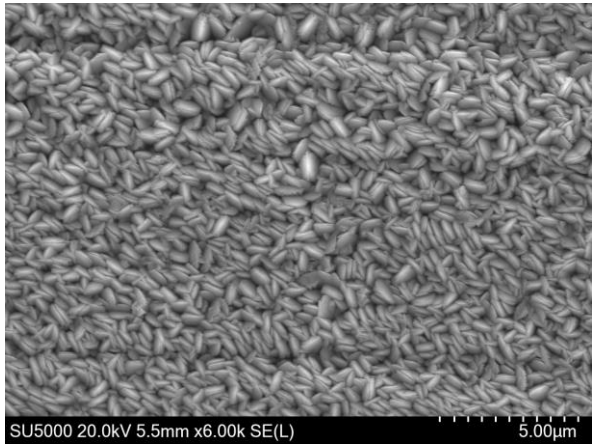


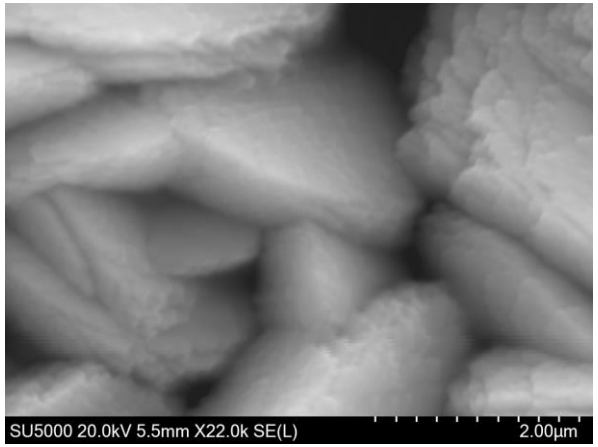
T_c measurements



RF surface resistance at 7.8 GHz





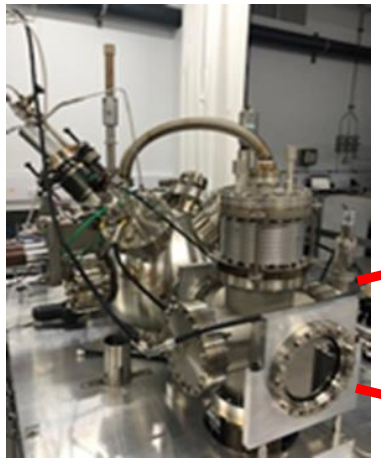


After several iteration of changing Ti wire loops composition of $Ti_{0.5}Nb_{0.5}$ reached

Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material *(UKRI)*

(UKRI/CI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh*

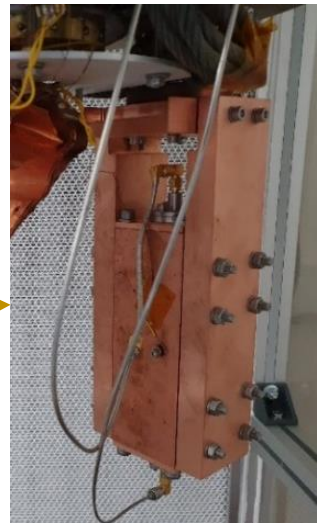
From planar samples to real cavities



Aim: Flat samples → split cavities → 1.3 GHz cavities

3 sets of samples:

1. Nb coated planar samples
   - Low power RF test with choke cavity
   - High power RF test with QPR
2. Split cavity deposited with planar magnetron & planar target
   - RF test
3. Split cavity deposited with cylindrical magnetron & tubular target
   - RF test



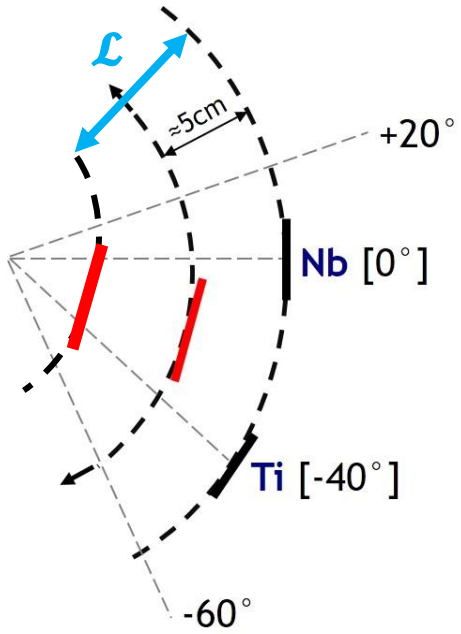
Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

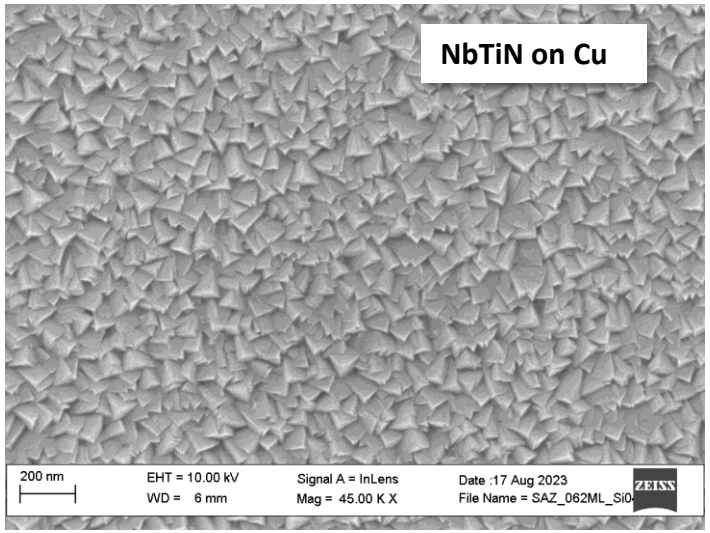
(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

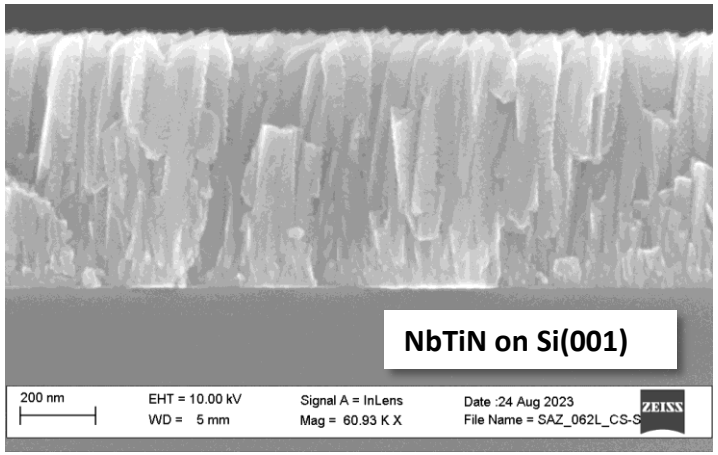
Depositing NbTiN thin films at University of Siegen (A. Zubtsovskii)

co-NbTiN: variation of parameters

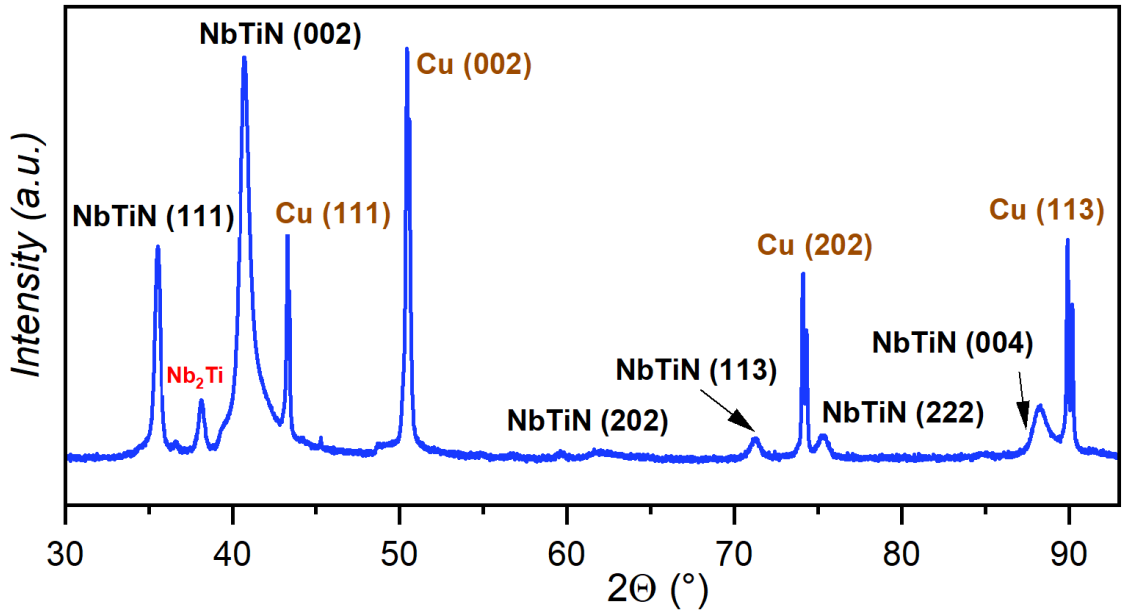
Increase
sub.-target distance $\mathcal{L}$







Conditions:
$\mathcal{P}$(Nb) = 400W, $\mathcal{P}$(Ti) = 400W, p_{dep} ≈ 1.25Pa, 9% of N_2
$\mathcal{L}$ ≈ 13 cm



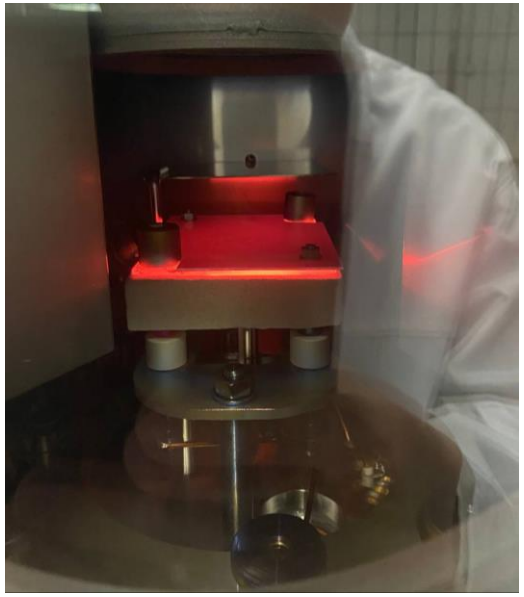
Film composition: Nb/Ti ≈ 0.83/0.17

Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

Depositing MgB_2 thin films at University of Siegen (A. Zubtsovskii)

BoxCoater works!!!

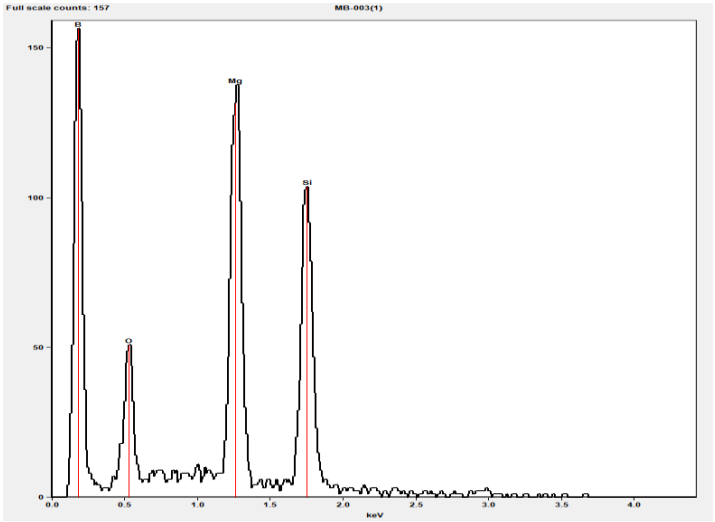


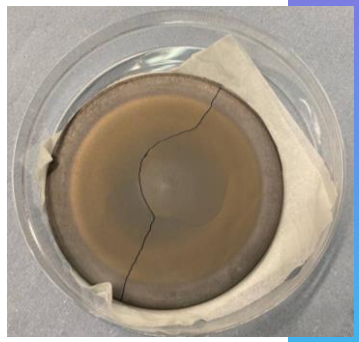
Substrate temperature up to 1500°C

MgB_2 sputtering in Ar

Challenges of the MgB_2 sputtering:

- Brittle material → deposition limits
- Composition ↔ Cathode power
- Oxygen contamination of the surface
- Often high Mg vapor pressure is required...



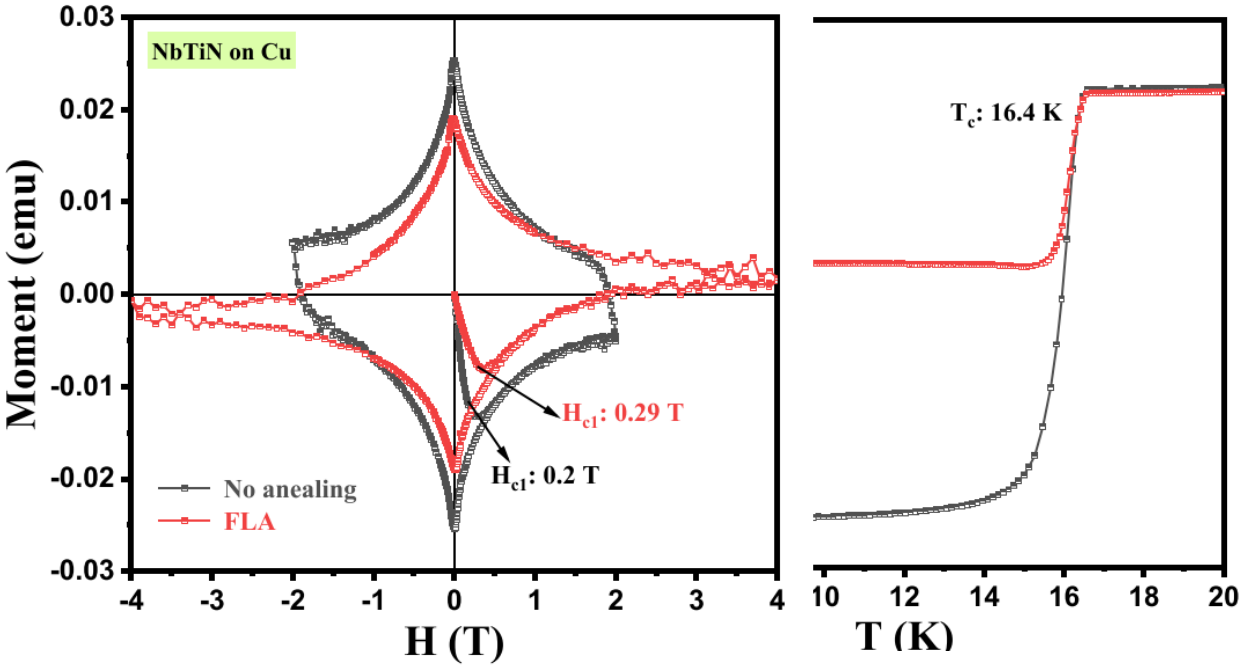


Task 9.3: Optimisation of process parameters and target development for SRF cavity coating with A15 material

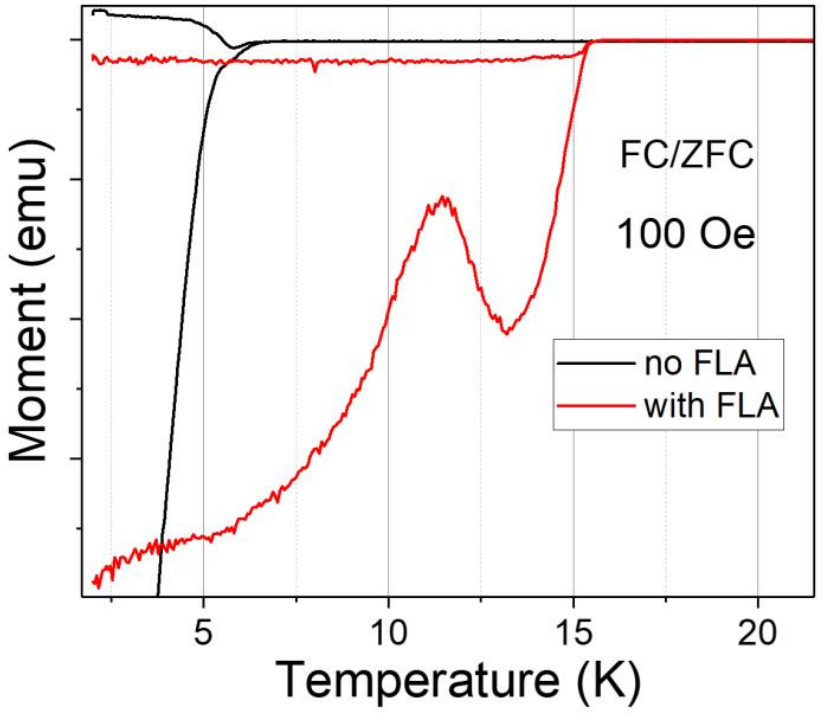
(UKRI, INFN, IEE, USI, HZB, HZDR) *Task Leader: R. Valizadeh (UKRI)*

Flash lamp processing of Nb-alloy at HZDR (S. Prucnal and S. Zhou)

FLA on NbTiN/Cu provided by UKRI



FLA on NbTiN/AlN/Si provided by CEA



- Sample property improvement on small samples
- Aiming larger samples in near future

Task 9.4: Surface engineering by atomic layer deposition (ALD) *(CEA, CNRS) Task Leader: T. Proslier (CEA)*

Team: Y. Kalboussi, I. Curci, M. Lafarie, B. Delatte, A. Four, F. Miserque, J. Leroy, L. Maurice, M. Baudrier, Y. Zheng, D. Hrabovsky, M. Asaduzzaman, T. Junginger, S. Leith, G. Rosaz, D. Bafia, L. Grasselino, S. Dadouch, M. Belhaj, T. Proslier.

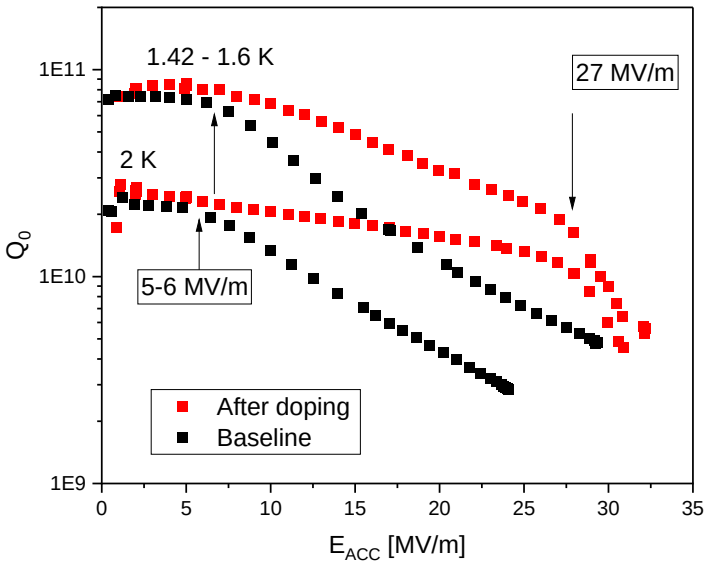
- Engineering superconducting surface for high *Q* operation at low fields by Atomic Layer Deposition (ALD) and thermal treatments.
- Engineering superconducting surface for *Q* operation at medium fields Doping without chemistry
- High gradient operation at by ALD and thermal treatments: multilayers.

✓ Increased *Q* at low field for 3D superconducting resonators 1.3 GHz:
  - New results with Q~9×10^{10} stable in air and HPR at low fields with surface oxide engineering.
  - Other oxide protective layers under studies.

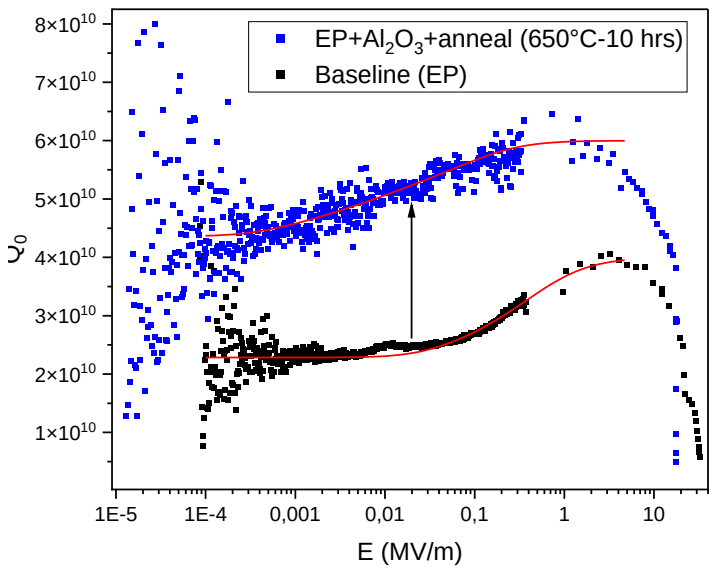
✓ Increased penetration field on samples by 24%.
  - First depositions of multilayers in 1.3 GHz cavities.

✓ N doped cavity by ALD of NbN.
  - Optimization underway.
  - First depositions of multilayers in 1.3 GHz cavities.

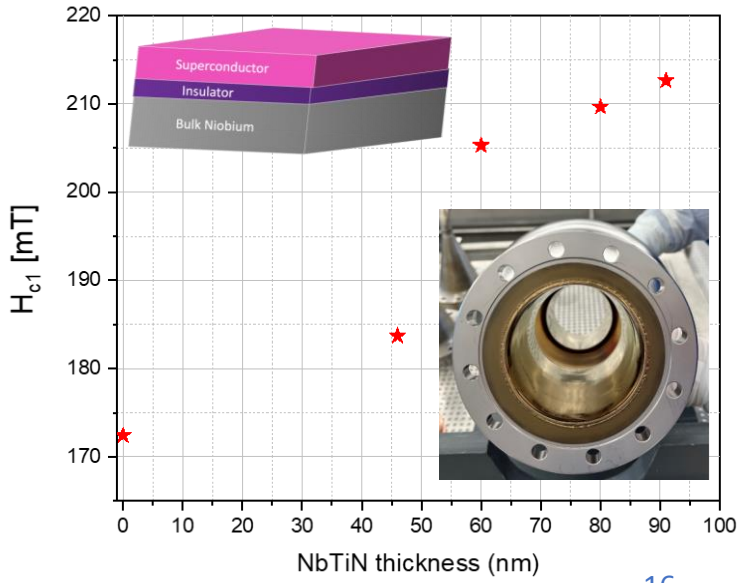
Doping by ALD: NbN (5nm) + thermal annealing



High Q studies for Qubits and accelerators



High Gradient for accelerators increased penetration field.



Task 9.4: Surface engineering by atomic layer deposition (ALD) *(CEA, CNRS) Task Leader: T. Proslier (CEA)*

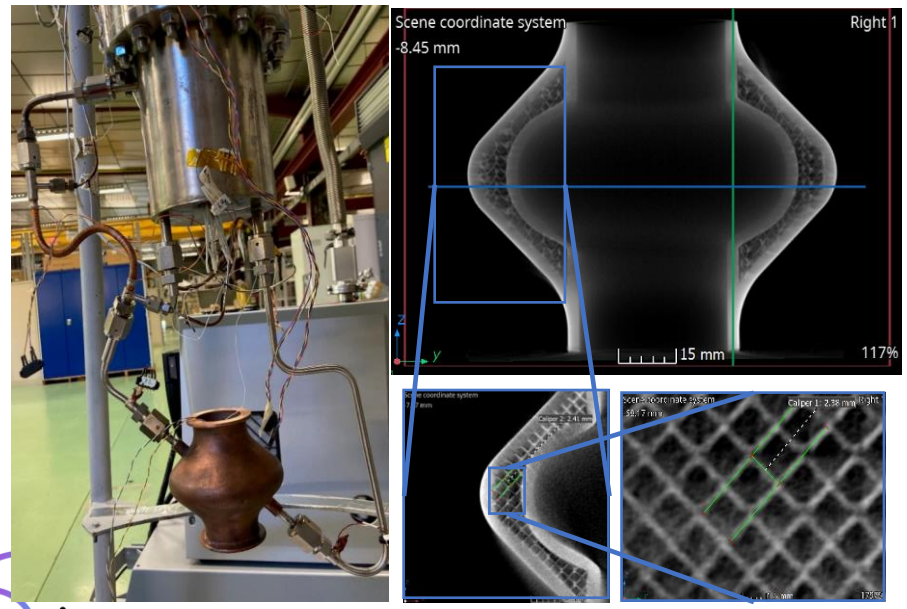
- New cooling techniques: 3D printing of 3.9 GHz cavities with closed loop cryocooler.
- Superconducting characterization of cavities and Qubits by tunneling spectroscopy.
- Engineering TEEY by ALD

✓ Ongoing effort on 3D printed 3.9 GHz cavity cryocooled to 4.2 K. Successful power dissipation studies.

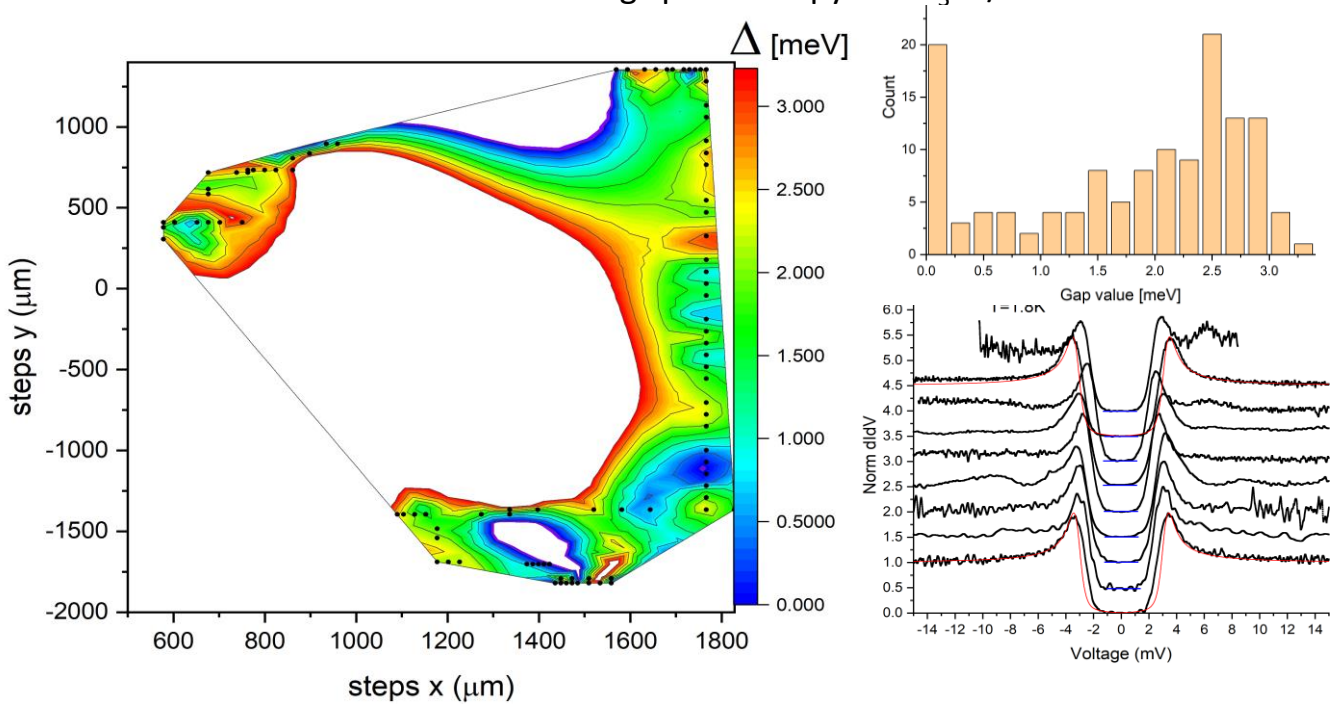
✓ First samples measured: Nb_3Sn/Cu (CERN), future: Qubits resonators (USA).

✓ Carbide synthesized by ALD show TEEY of 1.2 without conditioning.

Cryocooled 3D printed Cu cavity



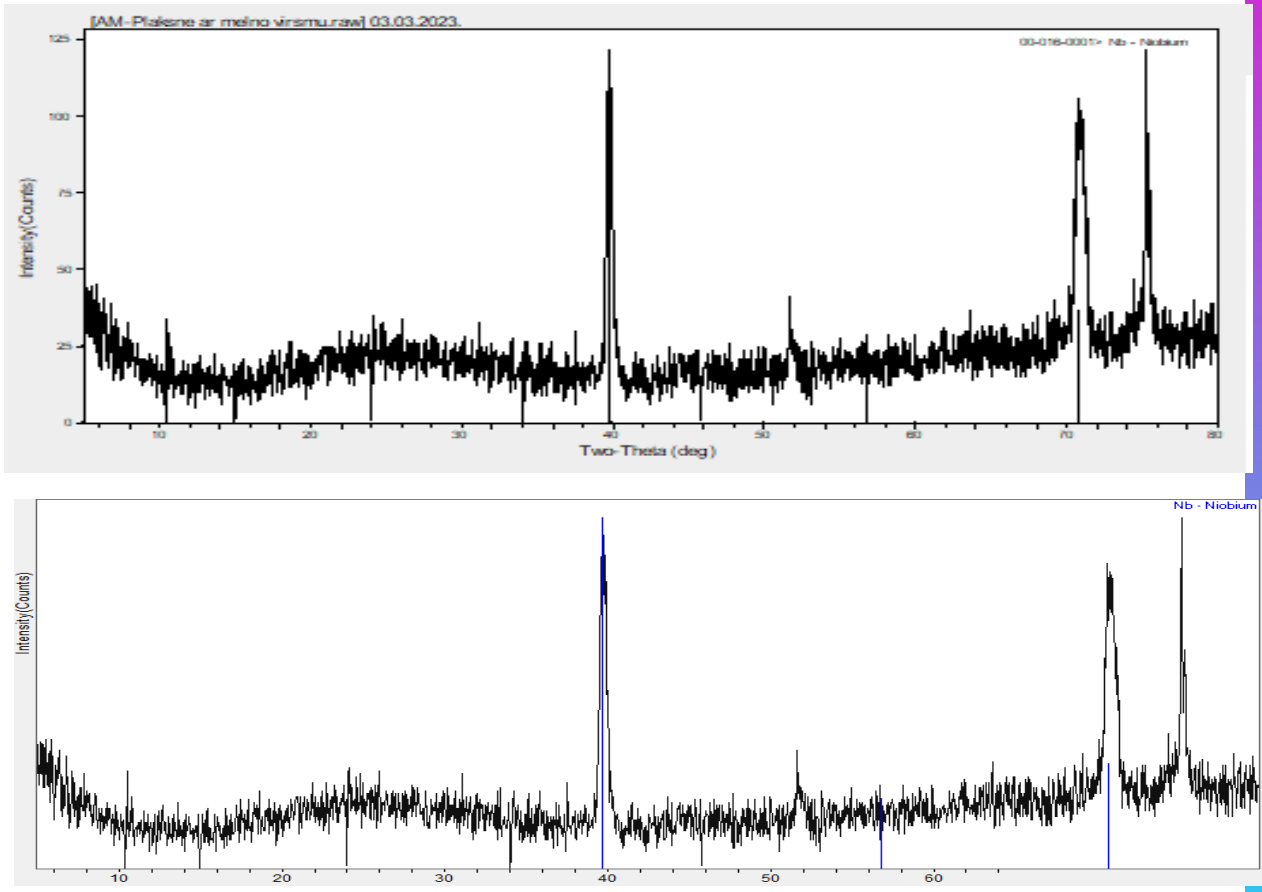
Tunneling spectroscopy of Nb_3Sn/Cu



Task 9.5: Improvement of mechanical and superconducting properties of RF resonator by laser radiation

(RTU, UKRI, INFN, IEE, HZB) *Task Leader: A. Medvids (RTU)*

- Improvement of mechanical properties of Nb/Cu structure after irradiation by nanosecond laser:
  - Analysing XRD patterns in figures (a) and (b) and calculating the size of Nb and Cu crystals using Sherer's formula, it found that Nb crystals increase by 30% and Cu by 100%, too.
  - At the same time, the hardness of the Nb layer increases, but the Cu substrate (more than 1 μm from Nb) hardness decreases. Microhardness was measured by Visker mode.



XRD patterns of Nb/Cu structure (a) before and (b) after irradiation by Nd: YAG laser with wavelength 1064 nm, pulse duration 6 ns, repetition rate of 10 Hz, beam diameter of 0.5 mm, and intensity up to 20 MW/cm^2 in scanning mode.

Task 9.6: Optimization of flat SRF thin films production procedure

(HZB, INFN, UKRI, USI, CEA) *Task Leader: O. Kugeler (HZB)*

- HZB has experienced a cyber attack in summer 2023
  - which led to the encryption of most programming code including virtualised backups for the QPR operation
  - The attack also affected cryogenics, radiation protection, RF operation and utilities.
  - HZB is currently in the process of bringing the systems back online and of recovering and reprogramming the required software.
  - Hence, no QPR measurements have been performed lately.
- QPR samples are in the waiting queue:
  - from UKRI-DL (multilayer), CEA (ALD coating) and INFN-LNL (Nb_3Sn)
  - will be measured after the recovery of the QPR which is expected in January 2024.

IFAST WP9 Milestones		IFAST WP9 Deliverables	
MS37 International thin film workshop organization (web site + Report)	M28	**D9.1:** Thin-Film SRF roadmap report. *Summaries of the results obtained within the workpackage and prospective inspired from WP advances as well as discussions at TF-SRF 2022.*	M35
MS38 First seamless copper 1.3 GHz cavity produced as substrate for the coating of the SC film (Report)	M12	**D9.2:** RF test on coated resonant cavity. *Resonant cavity coated and tested with an alternative material to Niobium with a $Q_0 > 10^9$ at 4.2 K and 1.3 GHz.*	M46
M39 Coating facility built and tested at STFC, USI and INFN (Report)	M12	**D9.3:** First 6 GHz cavity coated and characterised. *Results from the morphological and SC characterisation of first coated cavity with an alternative material to Niobium.*	M36
MS40 Construction and operation of the cavity dedicated ALD system (Report)	M24	**D9.4:** Deposition of superconducting multilayers on cavities. *1.3 and 3 GHz Nb and Cu cavities coated and tested with multilayers.*	M46
MS41 A facility for laser operation for complex 3D treatment is tested on 1.3 GHz cavity (Report)	M36	**D9.5:** 1.3 GHz Nb-coated cavity irradiated by laser in Ar atmosphere and RF tested. *Increasing of the field of magnetic flux entry in Nb coated 1.3 GHz cavity irradiated by laser in argon atmosphere. Standard RF testing.*	M45
MS42 ARIES samples prepared for renewed SC film deposition (Report)	M6	**D9.6:** Test of thin-film samples. *Four thin film samples reprocessed by 4 different techniques and tested with QPR.*	M46

This will be discussed during the 11th WP9 meeting on 18-19/01/2024

Task 10.5: PSD from NEG coated accelerator vacuum chambers

(UKRI, DESY, DLS, Soleil). *Task Leader: O. Malyshev (UKRI)*

- Regular Task meeting
  - Monthly briefing meeting every 1-2 months (~1 h long)
  - Task meeting every 3-4 months (3-4 h long)
  - Last meeting on 7/12/2023
- Problems:
  - Quality of deposition targets (at UKRI)
    - followed by changing a supplier
  - Non-uniform deposition (at UKRI and DESY) on tubes with 20 mm inner diameter
    - 10 cm from the edges were not coated
    - Working with instrumentation:
      - Deposition power supply,
      - Discharge gas pressure,
      - Alignments
      - …
  - ✓Sorted out

Task 10.5: PSD from NEG coated accelerator vacuum chambers

(UKRI, DESY, DLS, Soleil). *Task Leader: O. Malyshev (UKRI)*

- Main progress:
  - Two PSD samples for DLS and Soleil have been deposited at UKRI with a Ti--ZrV columnar film during Nov-Dec 2023
    - Sample will be tested at UKRI for pumping properties after activation to 180 °C for 24 h
    - Then the samples will be shipped to DLS and Soleil for PSD measurements
  - PSD facilities:
    - Samples will be installed at DLS and Soleil during spring shutdowns
- Deliverable Report "First PSD data from NEG coating":
  - Due Date – Month 36 from installation date
  - Too sort from new date of installing on SR beamlines
  - Extension for 6 months is required
- Future plans:
  - Two samples to be coated with Zr
    - Setting up moving magnet to allow higher deposition pressures
  - Two samples to be coated with Ti-Zr-Hf-V
    - Two Ti-Zr-Hf-V alloy targets (rods) delivered
    - Deposit test tubes to assess alloy rod and coating success