I.FAST

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730

DELIVERABLE REPORT

RF test on coated resonant cavity

DELIVERABLE: D9.2

Document identifier:	IFAST-D9.2
Due date of deliverable:	End of Month 51 (July 2025, extended to October 25)
Report release date:	31/10/2025
Work package:	WP9: Innovative superconducting cavities
Lead beneficiary:	INFN
Document status:	Complete

ABSTRACT

The goal of D9.2 is to coat and test a resonant cavity with an alternative material to Niobium with a $Q_0 > 10E9$ at 4.2 K and 1.3 GHz. In Task 9.2, two lines of development were carried out to achieve the goal: the first concerning the copper cavities serving as substrates, and the second focusing on the deposition set-ups. For both, alternative solutions had to be identified compared to what was originally foreseen in the proposal, due both to technological challenges that emerged during the R&D phase of task 9.3 and to the loss of key partners.

In this document are reported the advancement in seamless Cu cavities production and polishing, the description of the two Nb_3Sn coating system designed and built in INFN and UKRI, the protocol adopted for the first 1.3 GHz Nb_3Sn cavity coated by PVD in Europe and finally, the SRF performances of Nb_3Sn coatings are reported and discussed.

I.FAST Consortium, 2021

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730. IFAST began in May 2021 and will run for 4 years.

Delivery Slip

	Name	Partner	Date
Authored by	C. Pira R.Valizadeh, O.Malyshev O. Kugeler T. Proslier	INFN UKRI HZB CEA	xx/09/2025
Reviewed by	M. Vretenar, L. Celona [on behalf of Steering Committee]	CERN	
Approved by	Steering Committee		

TABLE OF CONTENTS

Executive summary

This document reports on the RF measurements and developments achieved during the four years of the I.FAST project for the production of the first prototype of a 1.3 GHz Nb_3Sn cavity via PVD with deposition parameters compatible with Cu substrates. D9.2 brings together all the results and optimizations for the production of SC thin films developed within the different tasks of WP9. During this work, thanks to the results obtained in previous WP9 deliberations, it was possible to achieve remarkable results that led to advances in all stages of the thin-film SRF cavity production chain. These results place the European laboratories of the I.FAST collaboration in a leadership role within the thin-film SRF community for the development of cavities operating at 4 K.

In particular: the production of seamless cavities via spinning has been automated, a new copper polishing technology has been developed and successfully tested, a protocol for the deposition of Nb_3Sn coatings via PVD has been developed and tested (current state of the art in the SRF community), two systems for Nb_3Sn coating in 1.3 GHz cavities with innovative solutions have been designed and built, the first Nb_3Sn cavity has been deposited via PVD.

1 Introduction

The objective of Deliverable 9.2, and more generally of WP9, is to produce a resonant cavity coated and tested with an alternative material to Niobium with a $Q_0 > 10E9$ at 4.2 K and 1.3 GHz. At the conclusion of ARIES, Nb_3Sn was identified as the most promising superconducting material to replace Nb and to enable operation at 4.2–4.5 K instead of 2 K. Consequently, Task 9.3 of I.FAST focused on developing a deposition recipe for Nb_3Sn on Cu, starting from planar samples and tested on QPR. The results, presented in Deliverables 9.3 [1], 9.6 [2] and [9-14], demonstrate that the recipes developed by INFN and UKRI, measured at HZB, exhibit surface resistance values on the order of tens of nΩ at 400 MHz, which represents the current state of the art at 4.5 K.

In Task 9.2, two lines of development were carried out: the first concerning the copper cavities serving as substrates, and the second focusing on the deposition set-ups. For both, alternative solutions had to be identified compared to what was originally foreseen in the proposal, due both to technological challenges that emerged during the R&D phase of task 9.3 and to the loss of key partners.

In particular, the impossibility of continuing the collaboration with PTI prevented access to electron-beam welding, which is necessary for welding the flanges to the seamless copper cavities. The developments in Task 9.3 subsequently highlighted that a thick buffer layer of Nb is required to grow Nb_3Sn with a $T_c > 17$ K. Task 9.3 also revealed major difficulties in cylindrical Nb_3Sn

targets production. However, some solutions were adopted to still achieve Deliverable 9.2 by the end of the project.

The first solution adopted was to use the Piccoli seamless copper cavities without flanges for prior R&D testing and then a bulk Nb cavity as a substrate to replace the copper one for the final prototype. The second was to develop alternative coating configurations to the traditional cylindrical configuration, thus allowing the use of commercially available planar Nb_3Sn targets. Two different set-ups were explored at INFN and UKRI.

2 Cavity manufacturing

In Task 9.2, two industrial partners were originally involved in copper cavities production: Piccoli Srl (Italy) and PTI (Belarus). Piccoli should be providing seamless copper cavities, while PTI was going to manufacturing copper and niobium cavities by hydroforming as well as to provide an expertise in EB welding for both the cavity produced by PTI and for the flange welding of cavities produced by Piccoli. In 2022 the PTI was excluded from IFAST, and such key expertise was missing for the WP9.

The solution adopted was to use the Piccoli seamless copper cavities without flanges for prior R&D testing and then a bulk Nb cavity as a substrate to replace the copper one for the final prototype.

2.1 COPPER CAVITY MANUFACTURING

INFN, in collaboration with Piccoli Srl, aims to improve the quality of seamless Cu cavity production, in particular the reproducibility, by using numerically controlled machines instead of traditional semi-automatic lathes used up to now. Efforts are also being made to reduce surface defects by studying the effect of annealing temperature and evaluate new strategies for reducing cold work stress.

Full details on the definition of the process parameters are reported in I.FAST M38 Report [3].

A total of 10 optimized Cu seamless cavities have been produced by Piccoli in the entire project.

5 cavities have been polished by INFN and used for coating tests in task 9.2 and task 9.5 [4].

2.1.1 1.3 GHz seamless copper cavity production at Piccoli

The Cu cavities were produced from 3 mm thick OFE Cu sheets. The process consists of 4 stages and the annealing temperature of 400 °C was defined during the development phase described in I.FAST M38 Report [3].

The cavities produced do not have flanges for vacuum sealing, as they are used for coating tests. However, some cavities have a lip that can be used with an adapter and indium gasket.

A test was also performed on the mechanical strength of the cavity after annealing at temperatures between 600 and 650 °C, which are defined as optimal for the Nb_3Sn coating process (see I.FAST D9.3). The test highlighted the possibility of cavity collapse during the pumping phase, which can be avoided with appropriate supports, as shown in Figure 1. This problem is not a limitation to the production of the first prototypes to demonstrate the performance of Nb_3Sn coatings, but it must certainly be taken into account in the next stages of development to ensure the correct tunability of the cavities.

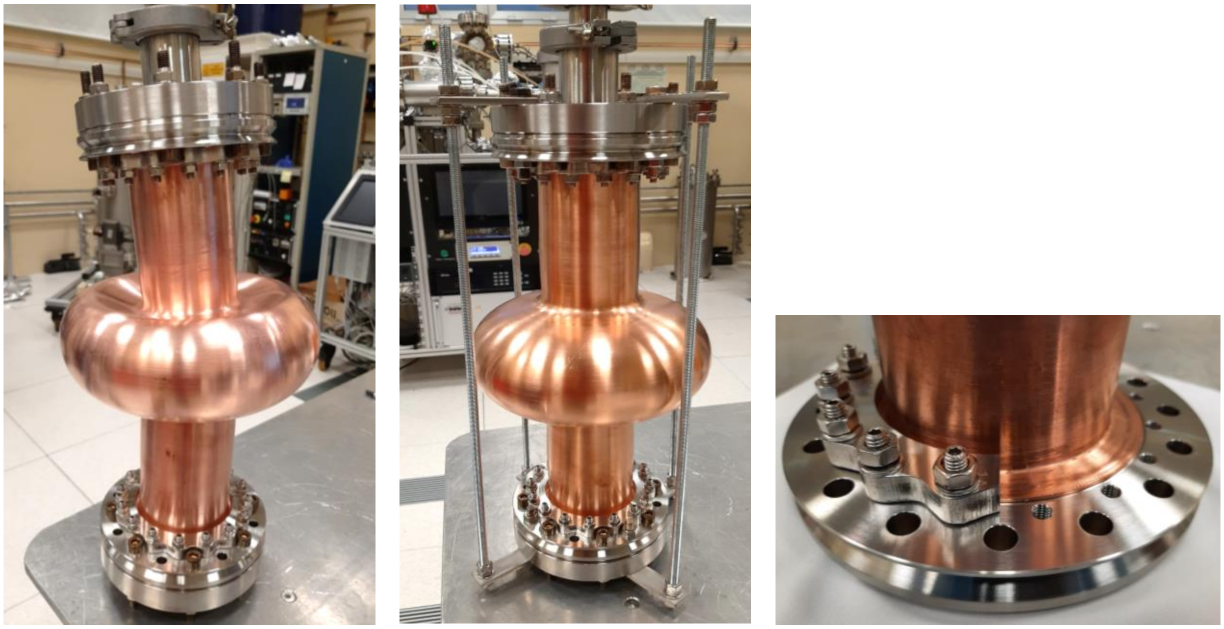


Figure 1: From left to right: cavity collapsed after heat treatment at 650°C, cavity mechanical supported that passed the anneling test, cavity lip.

2.1.2 Copper cavity polishing at INFN

PROJECT SUBSTRATES

The copper cavities used in this project were all polished at LNL using the SUBU chemical polishing technique, tested in ARIES [5].

The protocol used is as follows:

- Degreasing: in NGL 1740 bath
- Activation in sulfamic acid (H_3NO_3S, 5 g/l)
- Chemical polishing in "SUBU5" solution
- Pre-rinsing with acid: samples immersed in sulfamic acid (H_3NO_3S, 5 g/l)
- Rinsing with water: samples immersed in demineralized water
- Spraying with alcohol to enhance drying
- Drying with Nitrogen

PLASMA ELECTROLYTIC POLISHING

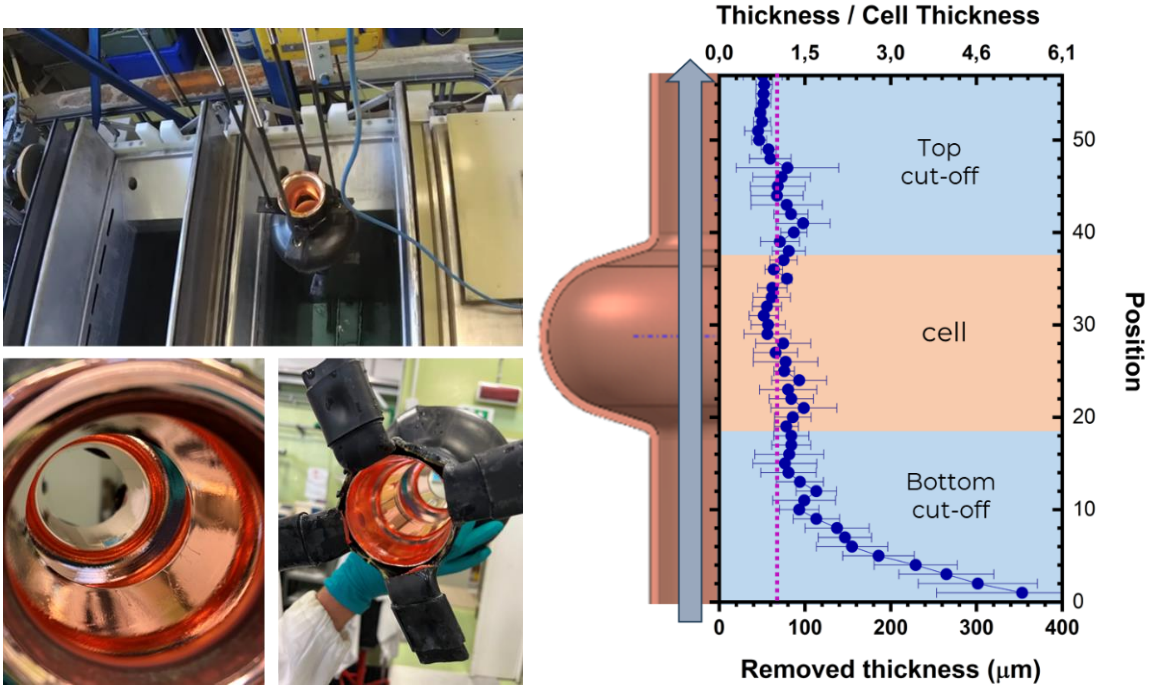


Figure 2: First cavity polished by PEP. On the 3 pictures on the left the cavity during the insertion in the chemical bath, the surface after the polishing process. The black cover is used to force the polishing only in the internal surface, preventing the polishing of the external surface. On the right the removal rate in function of the cavity position.

In parallel, in synergy with the INFN ESPP project “SRF R&D for FCC-ee,” the applicability of the PEP process to 1.3 GHz copper cavities was studied. Compared to traditional treatments, it offers removal speeds that are 10 times faster and has a lower environmental impact. For the first time, a 1.3 GHz cavity was entirely polished using PEP technology with a good uniformity if we exclude the initial cut-off part (Figure 2). The results obtained are extremely promising, and the study will continue by evaluating the implementation of this technique in the FCC-ee cavity production protocol. More information in [8].

2.2 BULK NIOBIUM CAVITY

Three bulk niobium cavities have been received from UKRI, along with one pair of flanges with mounted coupler and pick-up antennas. The two remaining pairs are expected to be shipped before the end of 2025.

The Nb cavity I has been treated with HPR + flanges mounting and leak testing at CEA. Nb cavity II and Nb cavity III will be electropolished, annealed in high vacuum, HPR and leak tested prior to sending them back to UKRI.

2.2.1 PIPPS I cavity treatments

The Nb cavity I has received the following treatments in the class 4 clean room:

- HPR for 1 hrs (2 cycles), drying overnight.
- Leak tested with flanges and gaskets provided by UKRI: a leak was detected during the test.
- HPR again for 1 hrs (2 cycles), drying overnight.
- Leak tested again with flanges from UKRI and new gaskets and nuts from CEA: no leak detected.
- Shipment back to UKRI with cavity under vacuum.

Treatment of the remaining two cavities is scheduled for November 2025.

3 Thin film deposition facilities and deposition process

The results of D9.3 provided the requirements for the PVD system to be designed and built for the deposition of Nb_3Sn coatings on Cu.

In particular, the system must operate in UHV at temperatures of 700°C. Another requirement from task 9.3 is that it is currently impossible to use cylindrical Nb_3Sn targets due to difficulties encountered in their development. Therefore, a source capable of using planar targets, which can be obtained by sintering and are therefore available on the market, must be designed.

Two deposition facilities were designed, one at INFN and one at UKRI. The two setups differ radically. INFN opted for a rectangular magnetron covering the entire length of the cavity, designed specifically for this system. The coating is made uniform by rotating the cavity. UKRI, on the other hand, has created a configuration with two standard circular planar magnetrons that move along the axial axis of the cavity to uniform the deposition thickness.

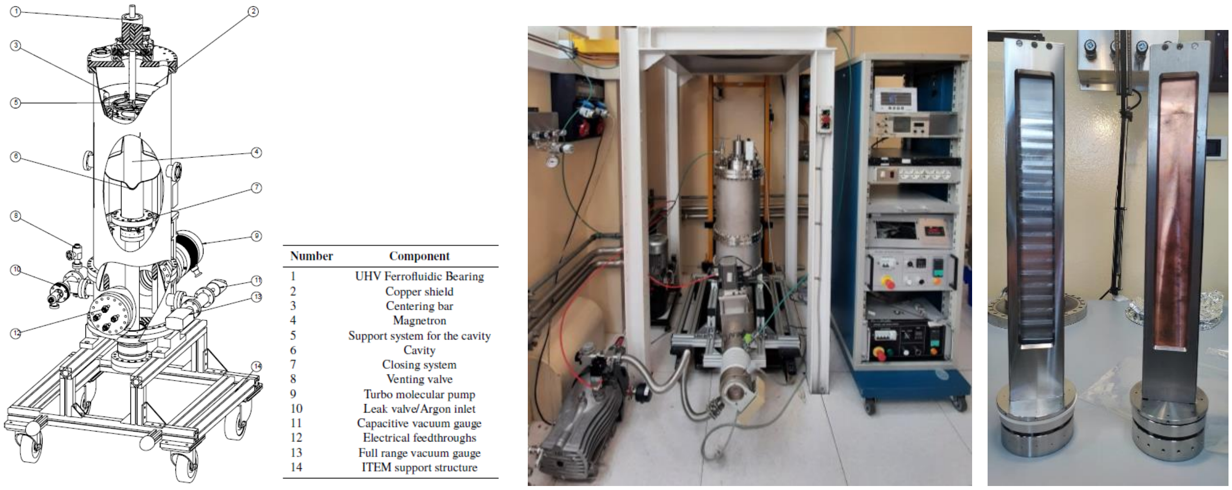
The INFN configuration has the advantage of ensuring, in principle, better control of thickness uniformity, but the rectangular magnetron required a long design and testing time. The UKRI configuration, however, using standard planar magnetrons, has the advantage of being a set-up that is more versatile and quicker to build, ensuring the first deposition of 1.3 GHz cavities within the project timeline.

3.1. DEPOSITION FACILITY AT INFN

The setup (Figure 3) consists of a single vertical chamber, designed such that both the process gas injection and the diagnostic measurements occur at the bottom. The chamber is housed within an ITEM rack structure. Vacuum is achieved through a combination of a primary scroll pump and a turbomolecular pump. The baking system employs DC-powered heating bands wrapped around the chamber. Before processing after the baking phase, the pressure inside the chamber reaches values in the range of 10E-9 mbar. The 1.3 GHz cavity is mounted on a dedicated support structure designed to ensure mechanical stability at the high temperatures required for Nb_3Sn sputtering. To ensure proper alignment of the support axis—and consequently of the cavity itself—four stainless steel rods are inserted into the chamber, serving as centering guides for the support.

The sputtering source consists of a rectangular, balanced magnetron (Figure 4) inserted into the cavity from the bottom of the chamber. This design allows for easy handling, particularly during installation and replacement. The baseplate supporting the target features an internal housing with a dual function: continuous water flow for cooling, and accommodation of magnets, which can be configured in three different arrangements with different magnetic field intensity.

Magnetic confinement can be adjusted by physically replacing the magnets, allowing for flexible composition and field control. The target has a total surface area of 120 cm^2 and thickness can be 3 or 5 mm. Two main technical challenges were successfully addressed in system design. First, the magnetron must be inserted into the cavity through the cut-offs, requiring it to fit within a diameter of 76 mm. Second, precise alignment between the cavity's rotational axis and the magnetron's symmetry axis is essential. This alignment is ensured by a 50 µm ferromagnetic UHV bearing, which enables cavity rotation, and a standard DN100CF flange, which secures the magnetron in a fixed position. Two materials are under testing for the baseplate: copper and aluminum to keep the weight reasonably low.



Number	Component
1	UHV Ferrofluidic Bearing
2	Copper shield
3	Centering bar
4	Magnetron
5	Support system for the cavity
6	Cavity
7	Closing system
8	Venting valve
9	Turbo molecular pump
10	Leak valve/Argon inlet
11	Capacitive vacuum gauge
12	Electrical feedthroughs
13	Full range vacuum gauge
14	ITEM support structure

Figure 3: From left to right: scheme of deposition system, picture of the deposition system at INFN, Al and Cu Rectangular Magnetron mounted.

The magnetron has been tested and characterized by I-V curve with the medium magnetic pack configuration. An image in Figure 4 is demonstrating the plasma produced by the magnetron source in the classical rectangular planar configuration and the I-V experimental curve that present a quadratic behaviour as described by Westwood [5]. The first tests on samples in this innovative configuration have begun, and the deposition of the first 1.3 GHz cavity at INFN is expected in the first half of 2026.

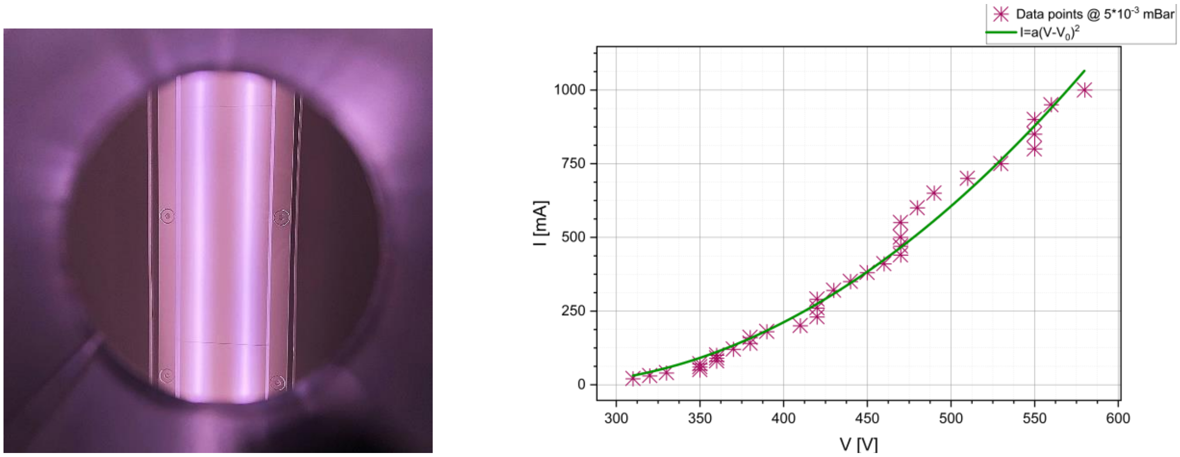


*Figure 4: On the left the first injection of the new rectangular magnetron designed and built for 1.3 GHz cavity coating at INFN. On the right Magnetron I-V curve a P=5*10^{-3} mbar.*

2.3 DEPOSITION FACILITY AT UKRI/STFC

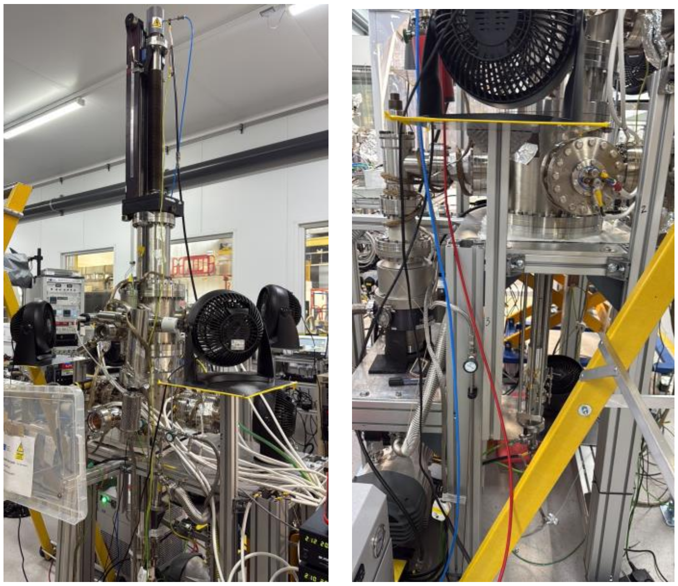


Figure 5: Deposition facility used for Nb_3Sn coating on 1.3 GHz cavity at UKRI.

The deposition facility used for depositing the Nb_3Sn inside the 1.3 GHz Nb cavity is shown in Figure 5. It is 600 mm length, 400 mm ID, SS chamber with eight side ports. The system is pumped with 400 l/s Maglev turbo pump and scroll pump as a backing pump. The base pressure is monitored with RGA and cold cathode penning gauge. The working pressure is monitored with capacitance monometer gauge. The cavity assembly is set up in an iso-6 clean room inside an iso-4 cabinet as shown in Figure 6 (left). The assembly holds twenty-four 400W halogen lamps connected in series to provide heating power for elevated temperature deposition (600°C to 800 °C). Three SS layers 0.25 mm thick separated by 1 mm gap, is wrapped around the cavity assembly to provide heatshield. This can be seen in Figure 6 (right).

Figure 6: Preparation of cavity assembly in iso-4 cabinet (left) and fully assembled Nb cavity for deposition (right).

The cavity is then transported into an iso-5 mobile unit and housed on the bottom flange of the chamber. The chamber is then built around the cavity assembly and making sure that the cavity is precisely at the center. After all the electrical connections were made, the two magnetrons assembly is mounted to the chamber, the chamber is pumped down.

2.4 DEPOSITION PROCESS AT UKRI/STFC

In Report 9.3, we reported on the progress and achievement of synthesising Nb_3Sn thin film with optimum SRF properties. However, we failed to produce viable cylindrical target. This was a major deal breaker for achieving the main IFAST objective, which was to produce a prototype of 1.3 GHz SRF cavity coated with Nb_3Sn by method other that Sn diffusion.

As breakthrough solution to such problem, STFC has designed and built a designated 2inch planar magnetron that is able to travel through the cavity. This is shown below in Figure 7.

Figure 7: The 2-inch planar magnetron for coating internal surface of 1.3 GHz SRF cavity designed and build at UKRI/STFC.

To check the viability of coating a 1.3 GHz with a planar magnetron we set a series of tests.

The initial test was done using the hemispherical part of the cavity. The Magnetron was placed at the iris and quoted with Nb. The setup is shown in Figure 8.

Figure 8: The copper half-cell cavity with magnetron at iris (left), magnetron as seen from the iris (center), coated two half-cell cavities (right).

The initial test was done with Nb target and the optimum deposition condition for Nb_3Sn which was DC power at 50 W and 3 x 10^{-3} mbar of Kr. The substrate was biased at –50 V DC. The visual inspection showed a uniform coating over the entire half-cells as seen in Figure 8 (right).

The next step was to deposit Nb_3Sn at elevated temperature and with witness samples. This time two half-cell copper cavity with slot was used in the same geometry. At the slot a series of samples (two 10 x10 mm copper pieces were placed on each side of the cells equator for film thickness and film morphology seen in Figure 9. Two sapphire pieces for Tc measurements were placed further apart.

Figure 9: Slotted two half-cell cavities and witness samples attached with copper foil.

This experiment was carried out twice, due to lack of adequate heat shielding and thermal power. The first time, the available thermal power only sustained a 340 °C temperature at the full cell. Figure 10 represents the cross section (left) and planar (center) SEM images of the Nb_3Sn grown on copper witness sample. Both images represent a columnar growth that is expected for Nb_3Sn growth at low temperatures. The EDS analysis of the planar sample depicts the superconducting phase stoichiometry of Nb to Sn ratio of 3:1.

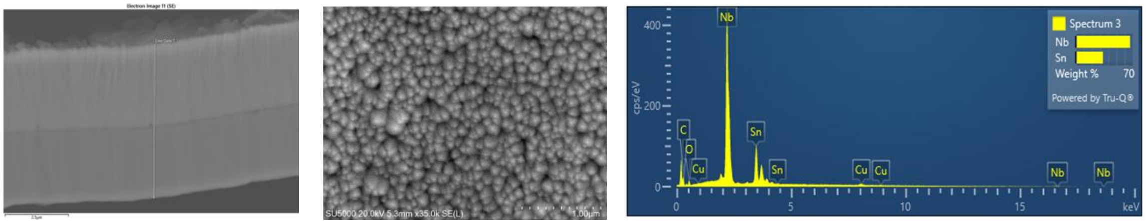


Figure 10: SEM images of Nb_3Sn deposited on witness Cu sample placed in the cell equator: cross section (a) and planar (b) and the EDS spectrum (c).

This set up was repeated with more thermal power and slight improvement in the heat shield. The changes increased the temperature to 440 °C. The deposition parameters of 50 W DC and 3 hours of deposition stayed the same. Figure 11 shows the cross section (upper left) and planar (upper right) SEM image of Nb_3Sn deposited on the witness copper sample placed near the cell equator. The higher temperature facilitated a more compact biaxial growth both in in-plane and out of plane with cubic edges protruding out of the surface. In both cases there is a very sharp interface between the substrate and the film as shown in Figure 11 (a) and Figure 11 (b). The four point probe measurement on film grown on sapphire substrate determined a superconducting critical temperature of 16.22 +/- 0.11 K which is quite remarkable for such temperature.

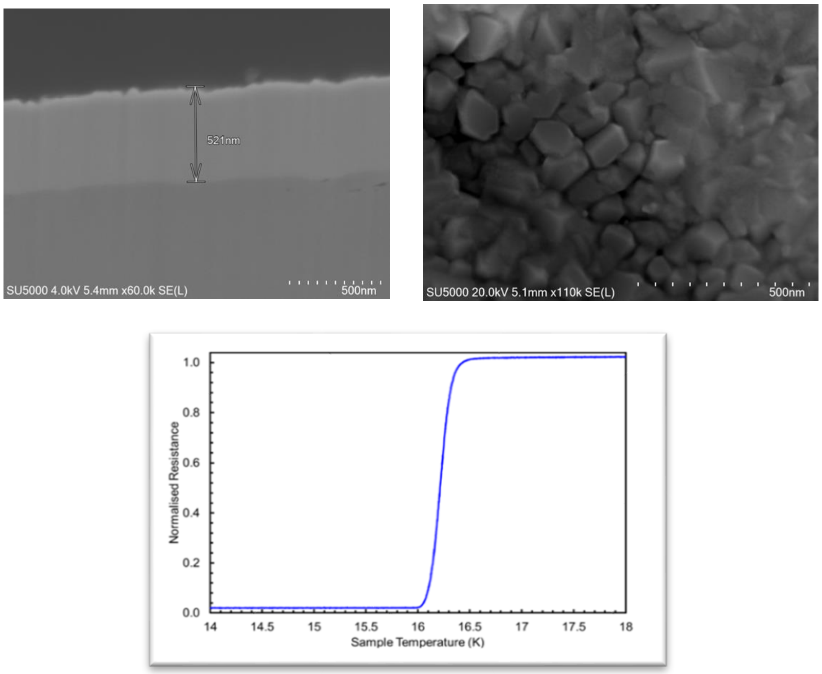


Figure 11: SEM images of Nb_3Sn deposited at 440 C on witness Cu sample placed in the cell equator: cross section (upper left) and planar (upper right) and four-point probe measurement of Nb_3Sn deposited on sapphire (bottom).

Based on these sets of results a new compact 2-inch magnetron as shown in figure 8, was designed and built in-house at Daresbury Laboratory. The major criteria were that the new magnetron had to be compact enough so as to be able to travel within the cavity, and to be able to withstand temperatures as high as 800 °C. At the same time to be able to operate for long period of time (more than 60 hours).

After cavity assembly and chamber assembly was completed, the system was backed to 150 °C for 3 days while the cavity was kept at 300 °C. After the chamber bake, the cavity temperature was increased over 12 hours to 600 °C and maintained at that 600 °C for further 12 hours.

Two thermocouples monitored the deposition temperature; one was clamped at the top flange of the Nb cavity and another floated in the middle of the cavity wall and the shielding foil. The thermocouple attached to the cavity was also used for negatively biasing the cavity.

During the deposition, the relative position of the two magnetrons with respect to each other and the cavity was changed as shown in figure 15.

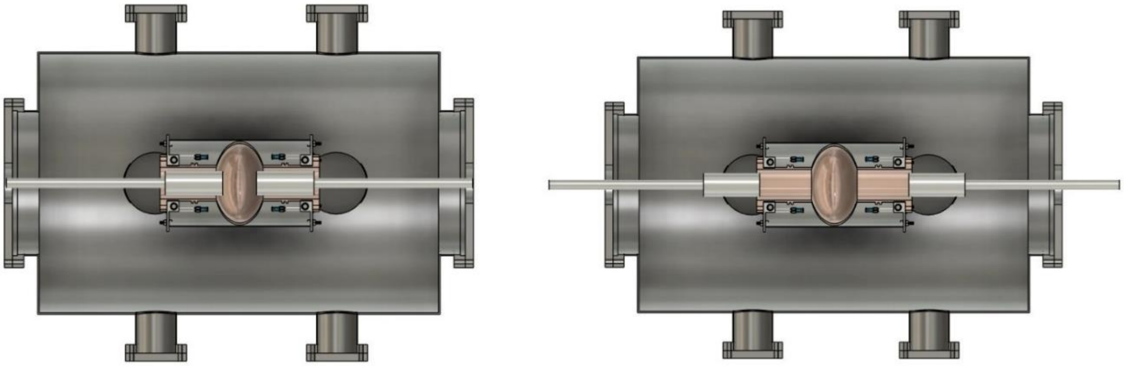


Figure 12: Relative deposition position of two magnetrons with the cavity.

The deposition parameters are listed below:

Pressure: **5.7E-3 mbar**

Temp (T) Floating: **796 °C**

Temp Cavity: **607 °C**

Gas flow: **8 SCCM**

Gas: **Kr**

Bias: **70 V**

Power: **50 W**

•322V - 0.16A magnetron 1

•337V - 0.15A magnetron 2

The deposition ran continuously for 30 hours. After the deposition all the heating was switched off and allowed the system to cool down. The first cavity visual inspection is shown in Figure 13.

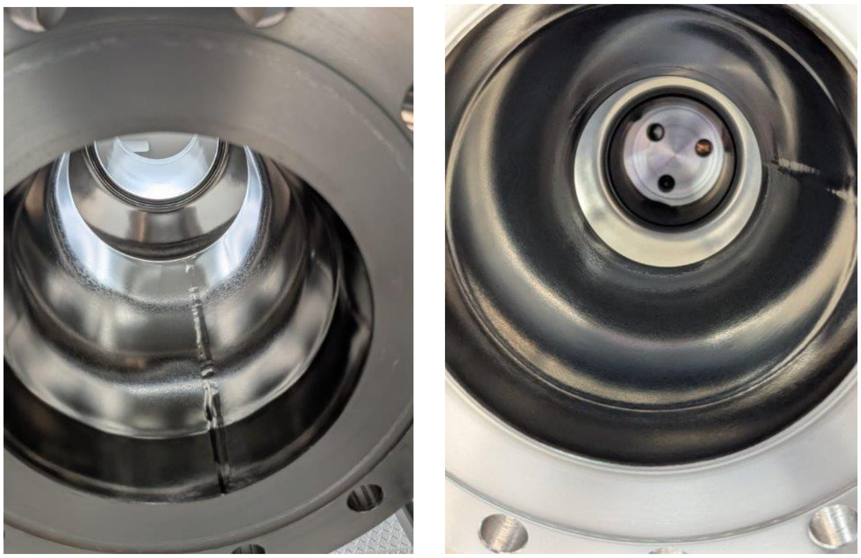


Figure 13: Top view of the cavity before (left) and after (right), deposition.

There were no noticeable differences that can be seen. The only visual difference is the slight darker grey shade of cavity appearance after deposition. The cavity was reassembled with coupler flanges and filled with dry nitrogen to 3 bar. A complete description of the coating system and cavity coating protocol is available in [15].

One of the two targets used shows areas of excessive erosion along the race-track at the end of the process (Figure 14), which have partially exposed the copper baseplate with possible contamination of the Nb_3Sn coating (to be analyzed).

Figure 14: Nb_3Sn target after the cavity coating. Along the race-track, areas where erosion has completely consumed the target are visible.

4 SRF testing

4.1. RESULTS ON QPR

The recipes for sputtering Nb_3Sn onto Cu via PVD developed in task 9.3 by INFN and UKRI were tested on planar quadrupoles (QPR) at a frequency of 400 MHz before being applied to the 1.3 GHz elliptical cavities. The QPR substrate is Nb, so as to evaluate only the effect of the Nb_3Sn coating, leaving aside for the moment the contribution of the Cu substrate. The results are reported in D9.6. For convenience, we also report them here in **Fehler! Verweisquelle konnte nicht gefunden werden.**. It can be seen that both samples at operating temperatures of 4.0 and 4.5 K have surface resistance (Rs) values below 100 nΩ up to fields of 30 mT

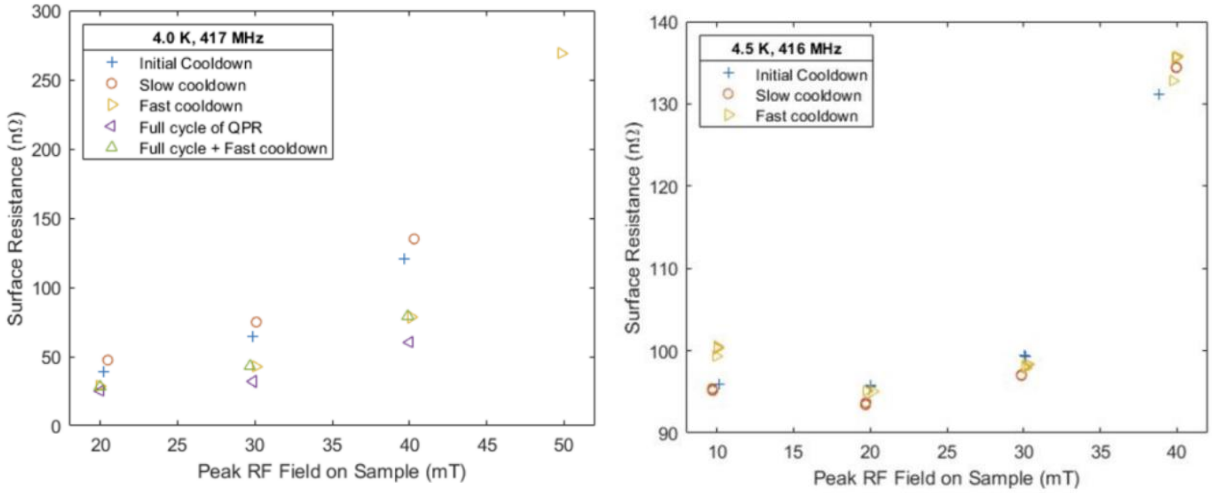


Figure 15: QPR sample surface resistance vs peak field on sample at different cooldown velocities. Left: INFN sample. Right: UKRI sample.

In particular, the INFN sample has a surface resistance is lower than that of the state-of-the-art Vapor Tin Diffusion measured under the same conditions up to 30 mT.

Two new QPRs have been deposited in INFN: one on a copper substrate to test the effect of the substrate on surface resistance (awaiting RF testing at HZB) and one deposited on an Nb bulk substrate to evaluate the reproducibility of the coating's performance. The second QPR presents performance even better than the previous one: Rs<9 nΩ at 20 mT and 4 K. If we convert Rs into quality factor and magnetic field into accelerating field (Figure 16), we can compare these results with the performance of the Nb on Cu cavities of LHC. We can see how the Nb_3Sn coating allows Quality Factors a order of magnitude higher than those of Nb to be achieved and performance that potentially overcome the requirements of FCC-ee.

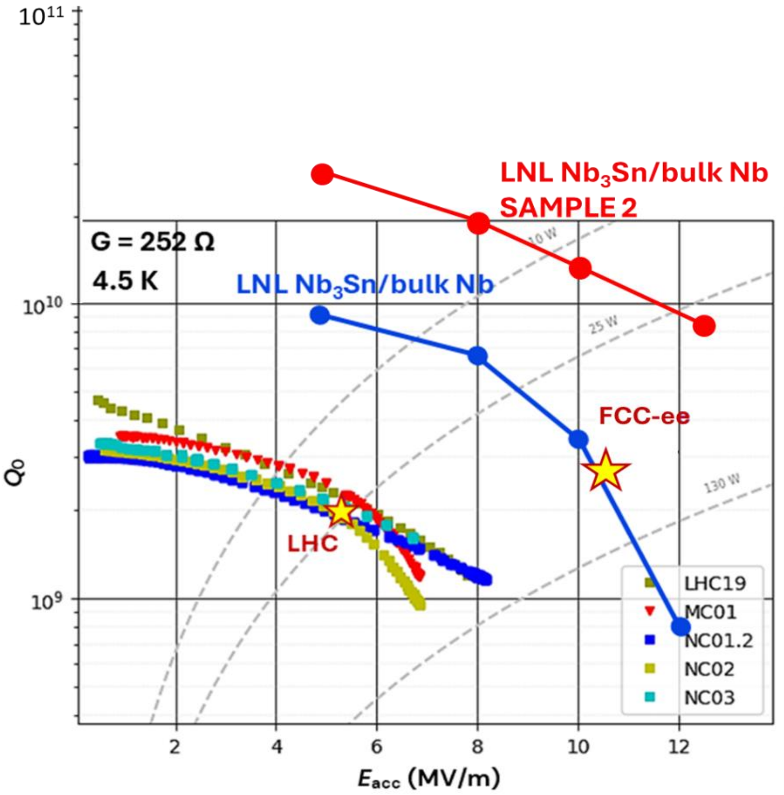


Figure 16: INFN QPR sample data converted in Q VS E_{acc} curve and compared with LHC cavities and FCC-ee 2 cell performance target [13].

4.2. RESULTS ON CAVITY

The first vertical cavity RF test was performed at HZB on a TESLA type Nb cavity from CEA sputtered with Nb_3Sn at STFC, as described in the previous chapter. For the initial characterization this cavity had been equipped with a fixed antenna aiming at an external Q value of 10E10 optimistically assuming Q values of more than 10E10 which have been demonstrated in cavities coated by liquid tin diffusion. The pickup antenna had a one order of magnitude larger Q value. Upon reception the cavity was continuously handled under clean room conditions and pumped and vented with particle-free pump stands. For extended diagnostics during cryogenic testing, the cavity was equipped with five temperature sensors arranged along the cavity axis: two at the upper beam tube, two at the lower beam tube and one at the equator. Two fluxgate sensors were mounted near the cavity equator, one pointing in axial direction (sensitive to expulsion of the dominant remnant field), and one in azimuthal direction (sensitive to fields generated by thermal currents). The top and bottom flange of the cavity were equipped with cartridge heaters in order to enable manipulation of the temperature differences along the cavity axis during the superconducting transition, see Figure 17**Fehler! Verweisquelle konnte nicht gefunden werden.**.

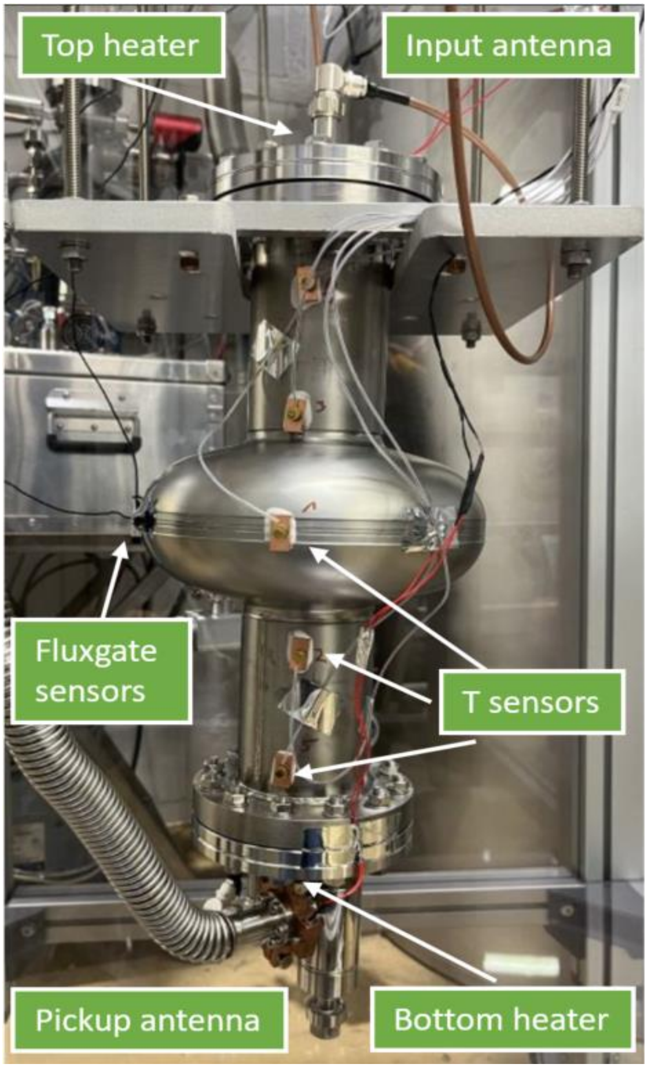


Figure 17: Labelled photo of the cavity in the insert before mounting in the cryostat

During cooldown great care was taken to keep the temperature gradient along the cavity axis small. This was done by manually adjusting the valve settings of the cryostat and was reasonably successful and no thermocurrents were recorded with the azimuthally placed sensors, see Figure 18 and Figure 19. The cavity made a first superconducting transition at 17 K. This could be clearly seen as a drop in bandwidth in S21 measurements of the antennae that were performed parallel to the cooling procedure. At the same time, since no magnetic field change was observed at the vertical sensor at 17 K either, it is reasonable to assume that 100% flux pinning of the remnant external magnetic field has occurred.

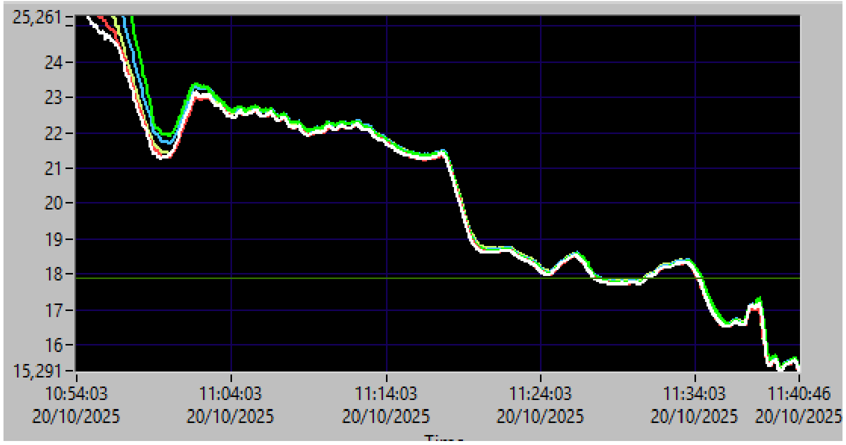


Figure 18: Temperature progression over cavity near Tc

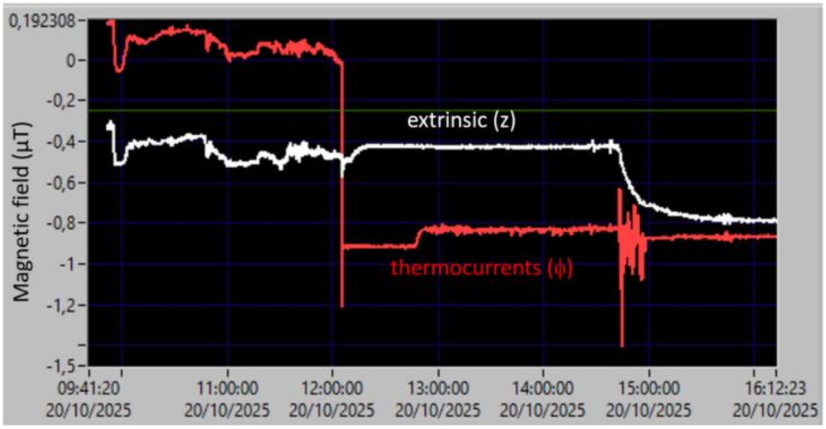


Figure 19: Magnetic field monitored at the cavity equator during initial cooldown

Once at 1.8K, it was possible to apply a field inside the cavity, but unfortunately, the stored energy was not high enough that a sufficient signal-to-noise ratio of the outgoing power signal for a successful tau or much less beta extraction could be obtained. A network analyzer based beta measurement yielded small dots in the polar plot of S11 and S22 measurements, confirming the assumption of strong undercoupling (which cannot be quantified).

It can be concluded that the loaded quality factor is dominated by Q_0, hence, no Q vs E curve was obtained. Figure 20 shows results from monitoring the S21 of the cavity during warmup. From these measurements the progression of resonant frequency and the bandwidth (3dB point) over time (where the passed time corresponds to the temperature increase) are extracted. While the Tc of the film was unusually high at 18.1 K this did not help with the RF surface resistance since the superconducting bandwidth is only two orders of magnitude higher than the normal conducting one. The reason for this poor performance despite the high Tc could be copper contamination of the film during the final preparation step. To verify this, it is intended to repeat the measurement after a cleaning step with a mixture of nitric acid and phosphoric acid which has been successfully used for bronze route samples. In parallel, we will perform an HPR on the cavity and equip it with an adjustable input coupler allowing for smaller Q values.

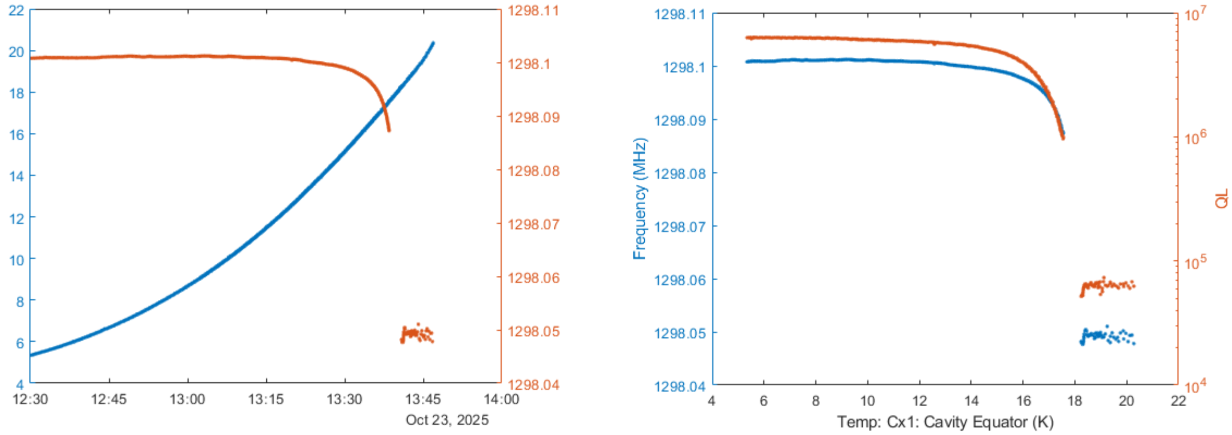


Figure 20: Left plot: Progression of frequency and cavity temperature over time during final warmup. Frequency values were obtained from a S21 measurement taken with a network analyser.
Right plot: Frequency and loaded quality factor vs temperature. QL was extracted using a Lorentzian fit.

5 Conclusions

The work carried out to achieve deliverable 9.2 has resulted in six remarkable outcomes:

1. Piccoli Srl, in collaboration with INFN, has developed a new semi-automated protocol for the manufacture of seamless Cu cavities via CNC.
2. A new surface treatment based on Plasma Electrolytic Polishing has been developed. Compared to traditional treatments, it offers removal speeds that are 10 times faster and has a lower environmental impact.
3. Two new facilities optimized for Nb_3Sn coating via PVD have been designed and built at INFN and UKRI.
4. Innovative magnetron source is under testing at INFN.
5. UKRI define a deposition protocol for 1.3 GHz cavity and coat successfully the first cavity with Nb_3Sn. The measured value of Tc ~18 K is an index of the optimal composition and phase of the Nb_3Sn coating. The cause of unexpectedly low Q is under further investigation beyond IFAST project.
6. The results obtained from QPR RF test at 400 MHz are currently state-of-the-art for Nb_3Sn films produced via PVD.

These results position the I.FAST collaboration as an international reference for the development of Nb_3Sn films on Cu and, more generally, for the development of accelerator cavities operating at 4 K.

6 References

[1] I.FAST WP9 members. (2025). First 6 GHz cavity coated and characterised. I.FAST D9.3 Deliverable Report. Zenodo. https://doi.org/10.5281/zenodo.16677760

[2] I.FAST WP9 members. (2025). Test of thin-film samples. I.FAST D9.6 Deliverable Report. Zenodo. https://doi.org/10.5281/zenodo.14905673

[3] I.FAST WP9.2 members. (2022). First seamless copper 1.3GHz cavity produced as substrate for the coating of the SC film. I.FAST MS38 Milestone Report. Zenodo. https://doi.org/10.5281/zenodo.6979934

[4] I.FAST WP9 members. (2025). 1.3 GHz Nb-coated cavity irradiated by laser in argon atmosphere and RF tested. I.FAST D9.5 Deliverable Report. Zenodo. https://doi.org/10.5281/zenodo.16419102

[5] ARIES WP15 members. (2018). Evaluation of cleaning process. ARIES D15.1 Deliverable Report. https://edms.cern.ch/document/1820617/1.0

[6] W. D. Westwood, et al.; The current-voltage characteristic of magnetron sputtering systems. *J. Appl. Phys.* 1 December 1983; 54 (12): 6841-6846. https://doi.org/10.1063/1.332006

List of Task 9.2 publications

[7] D. Dorothea et al., “Recipe Optimization and SRF Test of Cu-compatible Nb3Sn Films by DC Magnetron Sputtering from a Stoichiometric Target”. Preprint DOI: https://doi.org/10.21203/rs.3.rs-7516819/v1

[8] E. Chyhyrynets et al., “Plasma electrolytic polishing of 1.3 GHz cavities”, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[9] D. Fonnesu et al., “Influence of the Coating Parameters on the Tc of Nb_3Sn Thin Films on Copper Deposited via DC Magnetron Sputtering”, in Proc. 21th Int. Conf. RF Supercond. (SRF'23), Grand Rapids, MI, USA, Jun. 2023, pp. 92-95. doi:10.18429/JACoW-SRF2023-MOPMB013

[10] C. Pira et al., “Progress in European Thin Film Activities”, in Proc. 21th Int. Conf. RF Supercond. (SRF'23), Grand Rapids, MI, USA, Jun. 2023, pp. 607-614. doi:10.18429/JACoW-SRF2023-WECAA01

[11] N. Leicester et al., “Development of a 1.3 GHz RF research cavity for use in testing of superconducting thin films”, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[12] M. Lazzari et al., “Development of a new system for Nb_3Sn thin film deposition on 1.3 GHz cavities”, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[13] D. Fonnesu et al., “Development of Nb_3Sn coatings on copper at INFN-LNL”, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[14] C. Benjamin et al., “Optimisation of Nb_3Sn Thin Films for SRF Applications at Daresbury Laboratory”, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[15] R. Valizadeh et al., “Results of 1.3 GHz Nb cavity coated with Nb_3Sn thin film deposition by PVD magnetron sputtering, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.

[16] O.Malyshev, C. Antoine, et al., Thin-Film SRF Roadmap Report, in Proc. 22th Int. Conf. RF Supercond. (SRF'25), Tokyo, Japan, 2025.