I.FAST

Innovation Fostering in Accelerator Science and Technology

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MILESTONE REPORT

First seamless copper 1.3GHz cavity produced as substrate for the coating of the SC film

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ABSTRACT

This Report is related to achieving I.FAST Milestone 38 (First seamless copper 1.3GHz cavity produced as substrate for the coating of the SC film).

The accelerating cavities used in this project will be of the elliptical seamless type made with spinning technology, developed by Enzo Palmieri.

INFN, in collaboration with Piccoli Srl, aims to improve the quality of 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.

This report presents the results obtained in the development phase of the 1.3 GHz elliptical seamless cavity manufacturing technology and the realization of the first seamless cavity obtained with a CNC lathe and which will be used as a substrate for the coating of superconducting films.

Thus, the I.FAST Milestone 38 has been achieved.

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

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Delivery Slip

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1. Introduction

The innovative thin-film cavities to be developed in iFAST WP9 will be made by depositing an alternative superconducting Nb film on a copper substrate.

The quality of the substrate is of key importance, indeed, it influences the final performance of the cavities [1]. In particular, better performances of seamless cavities over EBW has been observed many times in thin films cavities (ALPI at INFN [2], HIE-ISOLDE at CERN [3], R&D programs at CERN [4]).

The accelerating cavities used in this project will be of the elliptical seamless type made with spinning technology, developed by Enzo Palmieri in 1993[5].

INFN, in collaboration with Piccoli Srl, aims to improve the quality of production, in particular the reproducibility, by using numerically controlled machines instead of traditional semi-automatic lathes. The motivation for this development lies in the fact that currently the process of producing seamless cavities via spinning is dependent on the sensitivity and experience of the operator, which heavily influences the quality of the inner cavity surface as well as the dimensionality.

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.

The fabrication of the first cavity was the final result of an R&D study that can be divided into 3 parts:

1. move cavity forming process from semi-automatic to fully automatic using CNC machine;
2. study annealing temperature;
3. improve forming process.

The first goal was to adapt the production process of seamless cavities to CNC lathes. This step was accomplished by developing 4 different programs that starting from a copper disk, through 4 different dies lead to the production of the elliptical cavity. All spinning tests were performed at Piccoli Srl, under the supervision of INFN.

The annealing study was first conducted on small samples to evaluate the possibility of lowering the standard annealing temperature of 500 °C used by Piccoli Srl. The aim is to maintain the mechanical properties achieved with an annealing of 500 °C, but reducing the grain size, which ensures better machinability of the material. The second part of the study turned to work on cavities. To standardize the results, two identical OFE copper plates were started from which eighteen cavity simulacra were obtained and used to develop the spinning process using numerically controlled machines and test the effect of intermediate and final annealing. Samples were obtained cutting the cavities and were characterized at INFN and the University of Padua. All annealing processes were carried out at INFN's UHV furnace.

Having demonstrated the possibility of obtaining a complete cavity with the optimized parameters, it was then investigated whether the process could be further improved.

Figure 1: 1.3 GHz seamless copper cavities produced in this work to optimize the CNC program, study the effect of different annealing temperatures and the reproducibility of the process.

2. CNC Machine program optimization

The process was divided into 4 steps, using 4 different molds. The CNC program of each production STEP was written by manually performing the first spinning and having the machine record the parameters used (rotation speed, tool used, tool feed, force applied in the various stages of the spinning process). The program was then gradually optimized with several tests in which certain parameters were changed from time to time until the disk and subsequent passes were fully formed. The tests for software development were carried out with 33 mm diameter and 3 mm thick commercial copper discs, hardness 55 VH (the same shape and mechanical characteristics as the OFE copper used for the fabrication of the accelerating cavities and in the following annealing tests). The set-up used can be seen in Figure 2.

In these tests, to reduce copper consumption we opted for a starting disk of only 33 mm, which would allow us to produce the first cut-off and the cell, which is the most critical part of the process, where defects are concentrated and where cracks can be created. The second cut-off can be achieved by simply increasing the diameter of the initial disk.

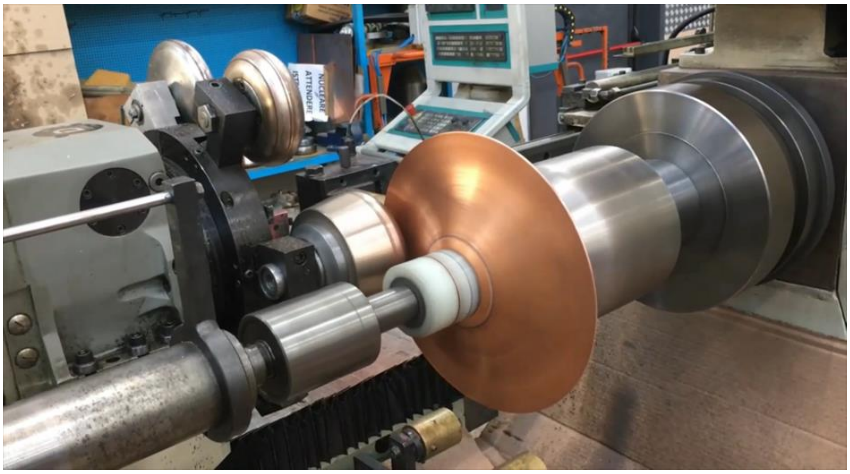

Figure 2: Initial stage of forming via CNC spinning of an elliptical cavity seamless 1.3 GHz. Shown is the CNC lathe used with the various tools available, and the starting copper disk being pressed against the first steel mold to form the cone from which the cavity will then be formed in subsequent steps.

In Figure 3 you can see the different production steps of the seamless cavities obtained via CNC spinning and the perfectly formed cavity cell in the last step on the right.

With these tests, the possibility of using CNC machines to produce seamless cavities was demonstrated for the first time, and in particular the possibility of obtaining the elliptical seamless cell even without intermediate annealing.

Figure 3: The 4 steps required for the fabrication of elliptical seamless cavities via CNC. In the first two steps (starting from the left), one-piece steel molds are used, while for the following two, Teflon sector molds are used. An intermediate annealing can be done between step 3 and 4 to relax the material and reduce the risk of cracking when closing the second part of the cell.

3. Annealing Temperature Study

3.1 Small samples annealing test

The spinnability of a copper disk is strongly dependent on its mechanical properties, particularly hardness and grain size. To form the elliptical cavities, , Piccoli Srl traditionally uses OFE copper plates with hardness 55 HV, obtained by annealing heat treatment in a UHV furnace at LNLs. The standard annealing treatment involves 2 h at 500 °C, and follows the temperature profile in Figure 4.

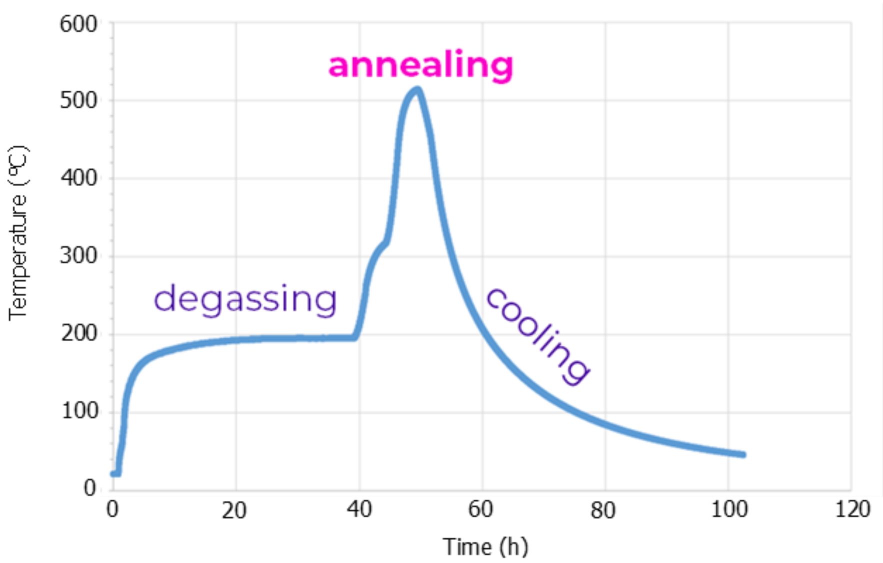

Figure 4: Annealing temperature profile of UHV furnace for OFE copper disks used at LNL. Before the annealing process, samples degas at 200 °C for 40 hours.

The possibility of reducing the annealing temperature was investigated in order to decrease the grain size and thus increase the machinability of the material. The effect of temperature was then evaluated in terms of hardness and stress-strain. Three different annealing temperatures were tested: 500, 400 and 350 °C. Tests were carried out on small samples processed on a UHV chamber at LNL and then characterized at the University of Padua. The results are shown in the figures below. The hardness in Figure 6, the characteristic stress strain in Figure 7, while the micrographs obtained by optical microscope are visible in Figure 5.

The results obtained show that no substantial differences in stress strain behaviour and material hardness are obtained between 400 and 500 °C. However, by raising the temperature to 350 °C, the hardness is still optimal, but the ultimate strength is reduced. The average crystalline grain size, on the other hand, decreases slightly from 500 °C to lower temperatures.

In subsequent productions therefore, the annealing temperature will be raised to 400 °C, so that there will be an improvement in spinnability.

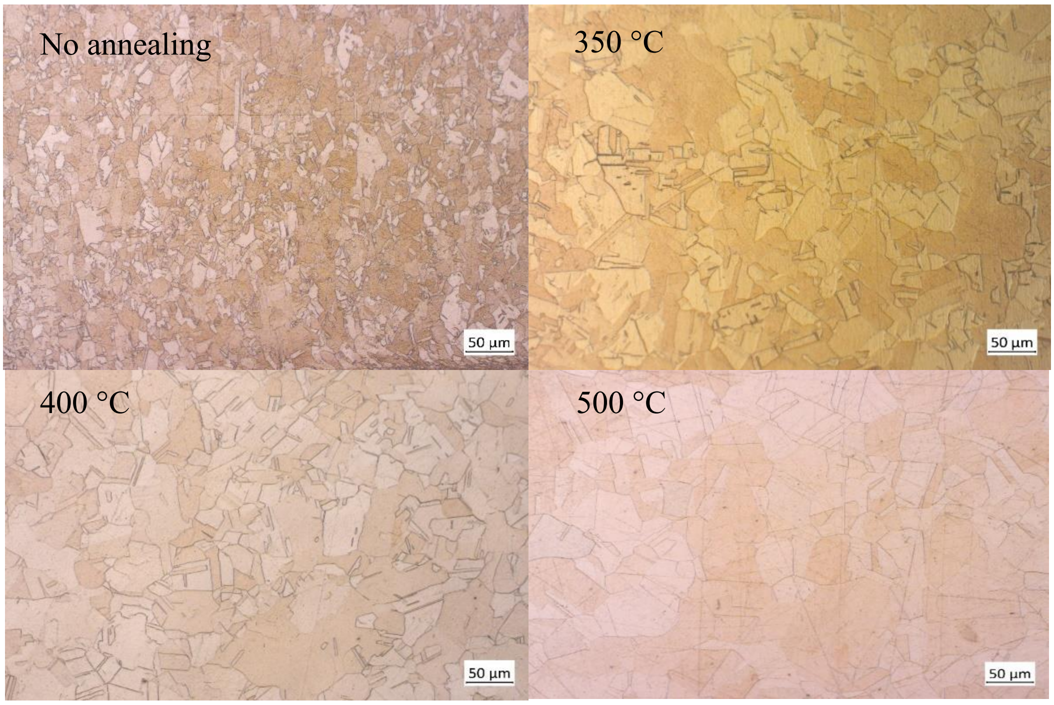

Figure 5: Optical microscopies of copper surfaces at different annealing temperatures. Microstructural analysis showed grain enlargement in all annealed samples compared to the untreated sample. The samples with 350 and 400°C annealing exhibited no pronounced grain size differences, while the sample annealed at 500°C, on the other hand, showed a significantly larger grain size than the previous ones

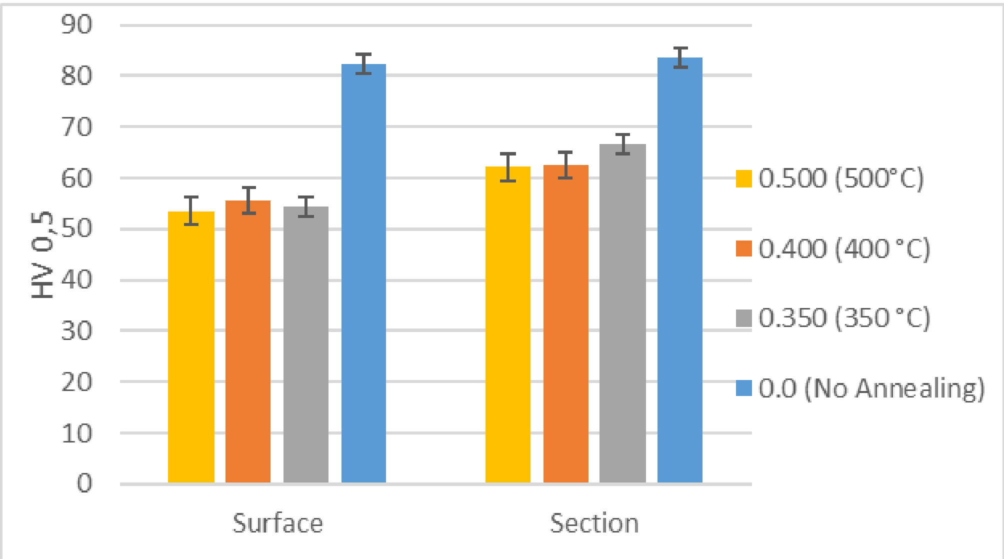

Figure 6: Microhardness as a function of annealing temperature, measured on the sample surface and section. The surface measurements, show that the hardness decreases from 82 HV to 54 $\pm$ 2 HV already at 350 °C and remains constant even by raising the annealing T to 500 °C.

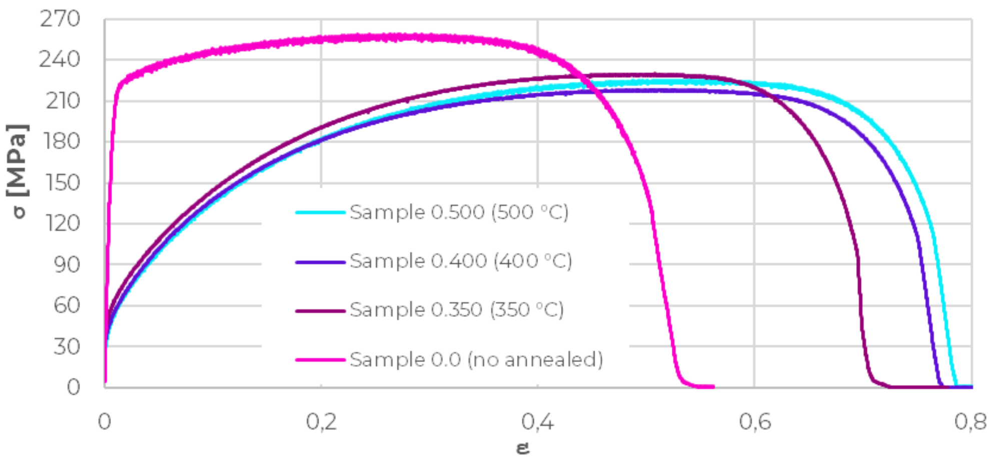

Figure 7: Stress strain curves as a function of annealing temperature. Annealing temperature of 400 and 500 °C produced a similar behaviour, while lower annealing temperature reduced the ultimate strength.

3.2 Intermediate Annealing Test

The second part of the study turned to work on cavities. To standardize the results, two identical OFHC copper plates were started from which 18 cavities simulacra were obtained and used to develop the spinning process using numerically controlled machines, test the effect of intermediate and final annealing and the reproducibility of the process.

The study is still ongoing, but we can already report some preliminary data. Specifically, 3 cavities were made with 3 different annealing routes, in accordance with Table 1, to highlight any advantages given by intermediate annealing between step 3 and step 4 production (Figure 3). For each cavity produced, two samples were cut and extracted from the first and second half-cells and characterized in terms of hardness (see Figure 8).

Table 1 Cavities Annealing treatments history

Cavity	**Annealing treatments history**		
	disk	Intermediate	Final
1.1 no annealing	500 °C	-	-
2.1 intermediate	500 °C	500 °C	-
3.1 final annealing	500 °C	-	400 °C

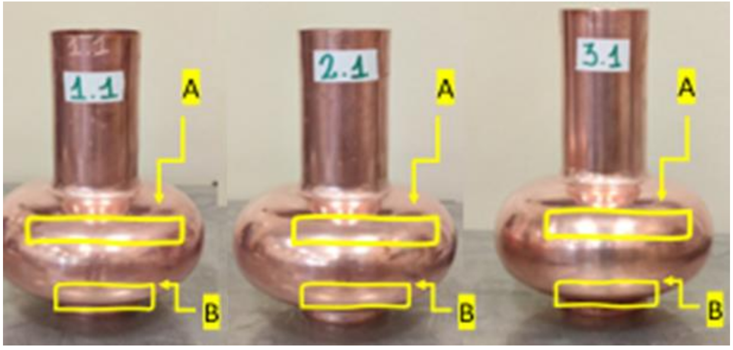

Figure 8: Cavities used in this study. Shown in yellow are zones A and B, the first and second half-cells, respectively, from which the characterized samples were extracted.

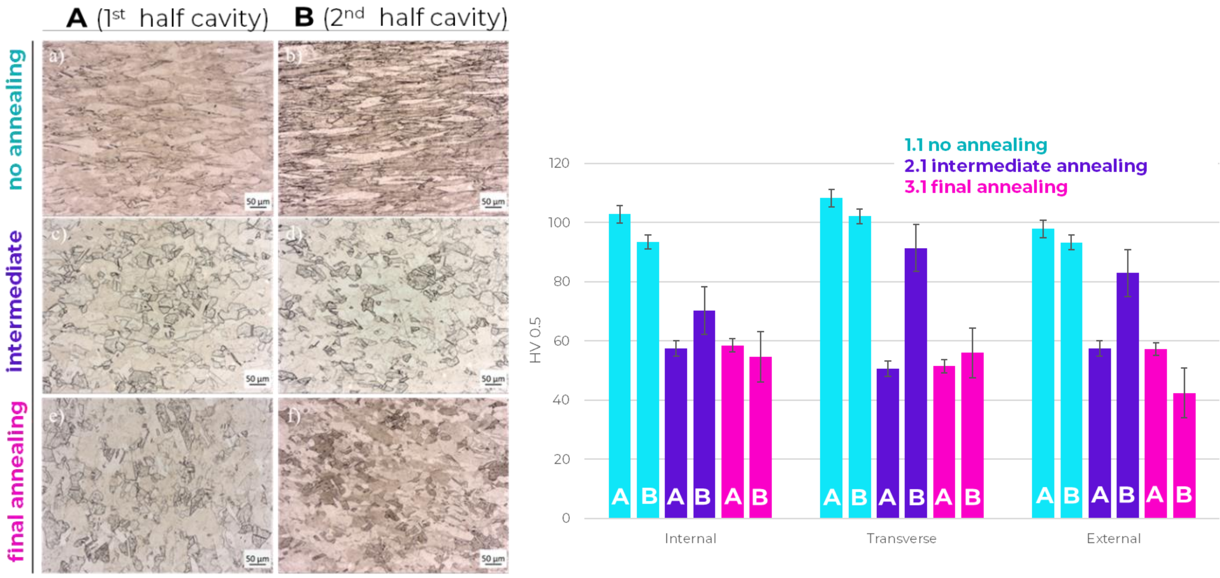

Figure 9: Optical microscopies (on the left) and microhardness values (on the right) for samples extracted from cavities described in Table 1 and Figure 8. optical microscopy shows that annealing at 500 and 400 °C, in addition to reducing hardness back to initial levels, is also effective in removing the directionality of crystalline grains induced by the spinning process.

From the results in Figure 9, it can be seen that in a cavity made without any annealing, the cold work applied leads to twice the hardness value over the entire cell. With intermediate annealing, we see that the first half-cell, which is no longer being worked, returns to hardness values similar to those of the starting plate. The second half-cell, instead, remains at hardness values up to 30 percent lower than in an annealing-free process, confirming the operator's feelings of better workability and reducing the risk of producing cracks and defects.

Indeed, from inspection of the inner surface it can be seen how in the cavity obtained without annealing, at the height of the iris of the second half-cell, there are defects directed orthogonally to the spinning direction, which with further cold work would have originated cracks. In contrast, these defects are not present in the cavity with intermediate annealing. Clearly this behaviour needs to be confirmed with a measurement campaign carried out on more cavities to rule out the possibility that this is a random episode.

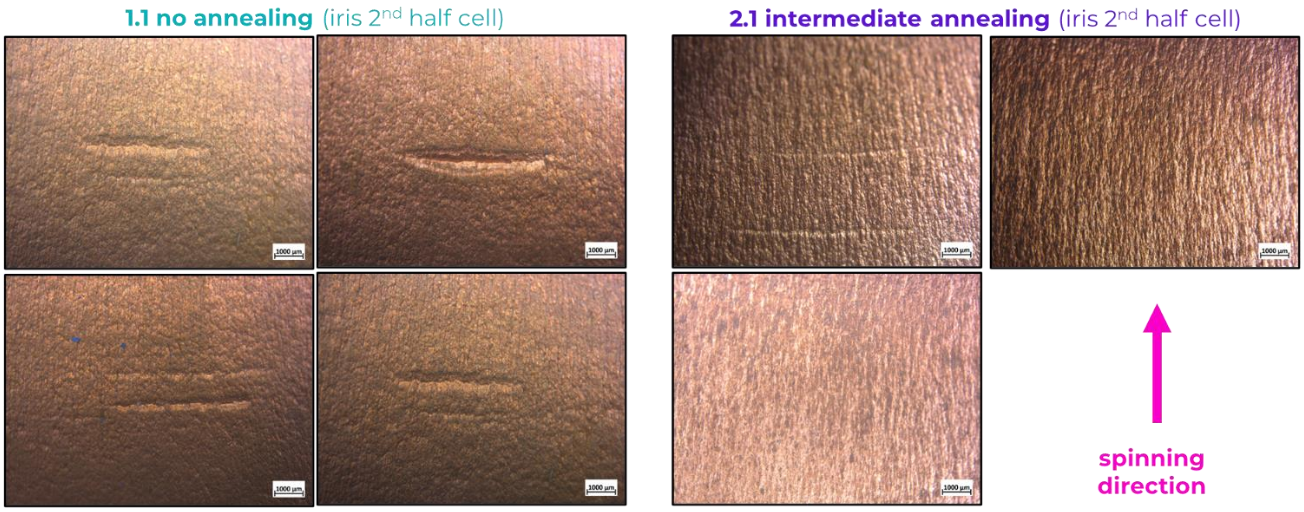

Figure 10: On the left, cavity 1.1 made without intermediate annealing has deep defects orthogonal to the spinning direction, which are not present in cavity 2.1 made with intermediate annealing at 500 °C.

4. First complete seamless cavity produced

The CNC program developed for manufacturing the test cavities was adapted to 45-mm-diameter disks to also realize the second cut-off, which was not realized in the test cavities. Piccoli's operator holding the first complete seamless cavity made with CNC lathe can be seen in Figure 11. The cavity was made with the standard parameters, i.e., 500 °C disk annealing and no intermediate annealing. It will be used as a reference for subsequent cavities where instead the annealing temperature will be lowered to 400 °C. The protocol has not been fully defined, yet, and future studies will define if to introduce the intermediate annealing in cavity production.

In addition to the complete cavity, currently at INFN, other substrates produced during the development of the seamless spinning technology were sent to partners STFC and University of Siegen and will be used for the first coating tests of superconducting films in the elliptical geometry of the 1.3 GHz cavities.

Thus, the I.FAST Milestone 38 (First seamless copper 1.3GHz cavity produced as substrate for the coating of the SC film) has been achieved.

Figure 11: Franco Telatin holding the first complete copper 1.3 GHz seamless cavity made in the iFAST project.

5. Process improvements/Future plans

In addition to intermediate annealing, it is thought to be possible to reduce material stress and thus improve internal surface quality by introducing a preliminary deep drawing step, just as it was done for 400 MHz seamless cavities [6]. The mold has already been made by Piccoli and the first cavities will be produced by the end of the year. A metrological measurement campaign is also planned to evaluate the reproducibility of the seamless process via CNC and compliance with the nominal cavity dimensions.

6. References

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