I.FAST

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MILESTONE REPORT

A facility for laser operation for complex 3D treatment is tested on 1.3GHz cavity

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ABSTRACT

This is Task 9.5 milestone report MS 41 A facility for laser operation for complex 3D treatment is tested on 1.3 GHz cavity.
A facility for laser operation for complex 3D treatment had been designed and built by RTU team, the operation software written by C#(C sharp) language.
Then the facility was tested for uniformity of Nd:YAG laser treatment with optical microscope and AFM.
Then, we performed a series of treatments of Nb-coated curved surfaces.
The first, the cylindrical copper tubes with Nb thin film were irradiated using the Nd:YAG laser in the chamber with an Ar gas. The irradiated samples' surface roughness (Ra)decreased by more than ten times. The cracks on the irradiated surface of samples decreased in size.

The morphology of irradiated and non-irradiated surfaces was studied by optical microscope and AFM. Irradiated the inner surface of cylindrical Nb on Cu samples by the Nd:YAG laser radiation leads to improve of adhesion and Nb surface roughness. UK Research and Innovation (UKRI), Dr. R. Valizadeh. Partner deposited Nb on Cu tubular samples. Instituto Nazionale di Fisica Nucleare

(INFN), Dr. C. Pira. Partner prepared Cu tubular samples. After laser irradiation of the sample, the roughness parameters *Ra* decreased by about an order of magnitude of 900 nm till 90 nm.

The second, the spherical RF cavity with Nb thin film on Cu substrate preparing by Dr. Reza Valizadeh from UKRI were irradiated using the Nd:YAG laser in the chamber with an Ar gas.

Irradiation of the 3D spherical part of the RF cavity by the laser shows that the deposition of Nb thin film on the Cu substrate is nonhomogeneous. Nb coating on the 2D tubular part of the RF cavity is thick, but on the 3D spheric part, it is too thin, less than 1 mk. Therefore, the 3D spheric part has not changed.

I.FAST Consortium, 2024

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

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Delivery Slip

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TABLE OF CONTENTS

Executive summary

The spherical RF cavity with Nb thin film on Cu substrate from UKRI *were irradiated using the Nd:YAG laser in the chamber with an Ar gas. Irradiation of the 3D spherical part of the RF cavity by the laser shows that the deposition of Nb thin film on the Cu substrate is nonhomogeneous. Nb coating on the 2D tubular part of the RF cavity is thick, but on the 3D spheric part, it is too thin, less than 1 µk. Therefore, the 3D spheric part has not changed.*

Irradiation of the 3D spherical part of the RF cavity by the Nd:YAG laser shows that the deposition of Nb thin film on the Cu substrate is nonhomogeneous. Therefore, it is necessary to prepare the RF cavity with homogeneous Nb deposition on Cu at low temperature and Nb thickness from 3µk to 10 µk.

1 Introduction

In superconducting RF cavities for particle accelerators, the Nb thin film coated on Cu (Nb/Cu) structure is one of the alternatives to bulk Nb RF cavities. However, R&D is required to achieve reproducible performance of Nb/Cu RF cavities, which should be comparable to bulk Nb. Since only a few µm of superconducting material is required in the RF cavity, the bulk of the RF cavity acts as a mechanical support for the structure. Therefore, one can use structural material such as Cu, which is cheaper and has higher thermal conductivity than Nb. There are three challenges associated with Cu structure coated with Nb film: (1) the Nb film adhesion, (2) the quality of Nb/Cu interface, and (3) the mechanical strength of Cu. The adhesion and the quality of the Nb/Cu interface can be improved by deposition at elevated temperatures and by using HiPIMS deposition. However, the higher temperature results in softening of Cu, which may ultimately affect the mechanical integrity of the cavity and suppress the Q-factor slope, as has been shown in [1]. As shown in our previous work [2, 3], nanosecond laser annealing of the Nb/Cu structure after Nb thin film deposition on Cu substrate allows for an increase in the grain size of Nb and improves interfacial adhesion. This allows thin film deposition at a lower temperature where the mechanical integrity of the Cu cavity is not compromised. In this process, only a thin layer of Cu is heated, so the mechanical strength of the bulk material is not affected.

2 Description of facility

2.1 Basic concept

Laser facility for irradiation inner surface of RF cavity: principal schematics and construction of Ar gas chamber

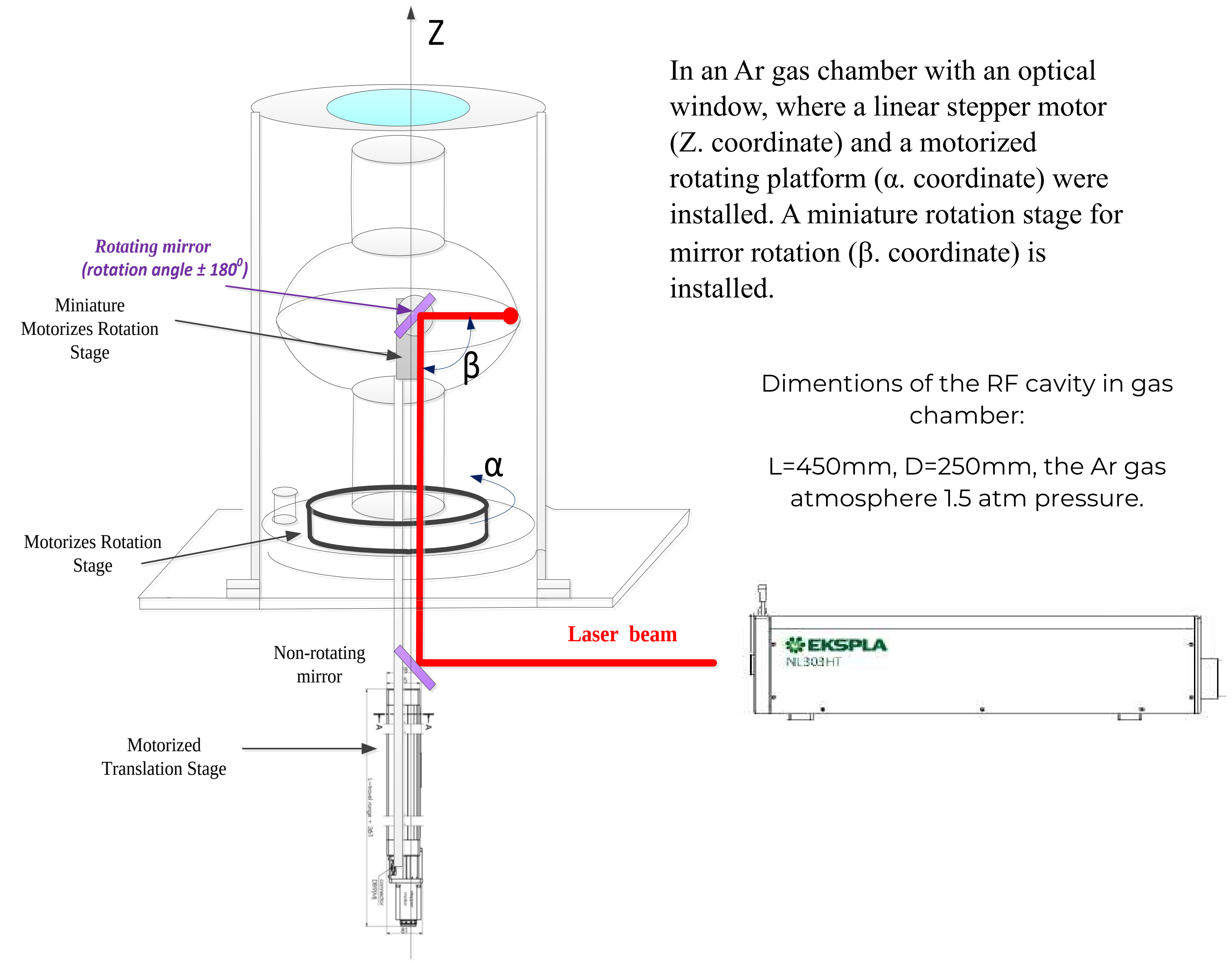

Figure 1. Principal schematics of Laser facility for irradiation inner surface of RF cavity.

2.2 Building the facility

Construction of chamber with Ar gas and Nd:YAG laser was built in the Laboratory of Semiconductor Physics, RTU, for irradiation of a tubular part of the RF cavity and both tubular and spherical parts of the RF cavity.

2.3 Software

The developed control program for laser irradiation of the RF cavity consists of two parts.
Program for irradiation of the tubular part of the RF cavity. The control is carried out on 2D coordinates: Z and α, which provide the movement of the beam along the spiral with the change of the spiral pitch or speed of rotation.
Control program for the spherical part of the RF cavity. The control is also carried out on 3D coordinates: Z, α and β. Provide rotation of the RF resonator in the horizontal plane and rotation of

the mirror in the vertical plane, which also provides the movement of the beam along the spiral inside the sphere.

2.4 TESTING THE OPERATION WITH A NB COATED SAMPLE

2.4.1 Test with a tubular part of the cavity

Initial tests were performed with a simple tubular sample. Tubular sample with dimeter of 800 mm and length of 200 mm were coated with 10 µm thick Nb film at UKRI/STFC and shipped to RTU.

Figure 2 shows these samples installed at the facility with tubular sample, mirror and rotation stage.

Figure 3 shows these samples after laser treatment at the facility. Photos of nonirradiated surface (upper image) and irradiated by Nb:YAG laser (I_{max} and I_{min} intensities of the laser beam, under and upper bands correspondently) of tubular part of inner surface of RF cavity (under image). After laser irradiation, the roughness parameters *Ra* decreased by about an order of magnitude from 900 nm to 90 nm. The mechanical properties also increase: after laser irradiation at I_{max}, the hardness increases by 50%. It can be seen that the optical properties of the Nb/Cu structure depend on the laser intensity: the reflection index (R) of the unirradiated surface is 30% and R=95% at I max, and R=87% at I min. This indirect dependence can be used for nondestructive control of the mechanical properties of the RF resonator, such as hardness and adhesion.

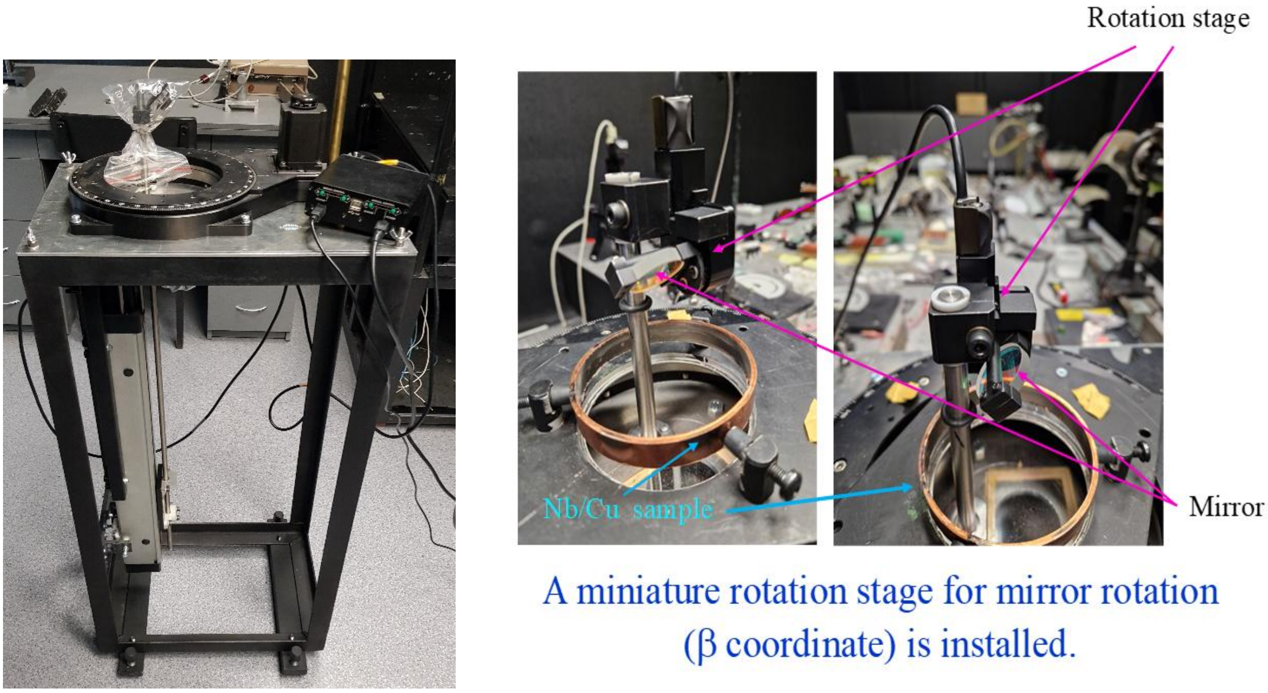

Figure 2. Photos of construction of Ar gas chamber with a tubular part of RF cavity.

Nonirradiated surface

Irradiated surface:

I_{min}=40 MW/cm^2

I_{max}=50 MW/cm^2

Figure 3. Photos of nonirradiated surface (upper image) and irradiated by Nb:YAG laser of tubular part of inner surface of RF cavity (under image). After laser irradiation, the roughness parameters Ra decreased by about an order of magnitude from 900 nm to 90 nm.

2.4.2 Test with a spherical part of the RF cavity

Figure 4 shows the first 1.3 GHz Nb coated cavity installed at the facility for laser treatment. This sample does not have a top tubular part; however, this is sufficient for testing a capability of laser treatment facility.

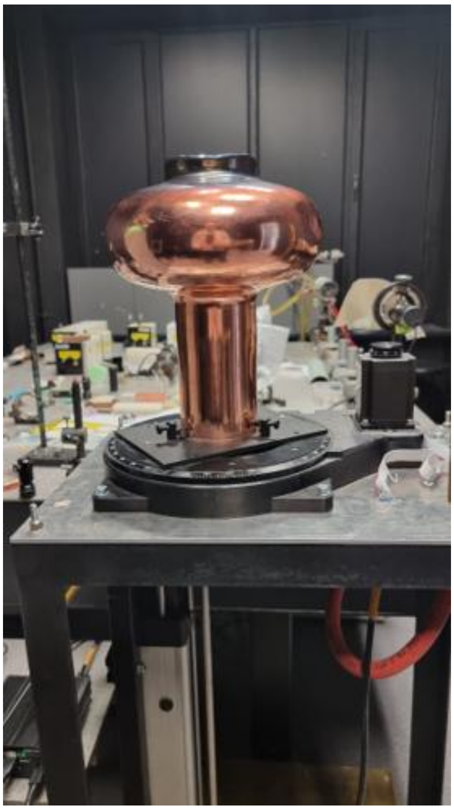

Figure 4. Photo of construction of Ar gas chamber with controlling 3D coordinates for laser treatment of the RF 1.3 GHz cavity with Nb thin film in the inner surface.

Figure 5. Photo of inside part of RF cavity after irradiation by Nd:YAG laser

Irradiation of the 3D spheric part of RF cavity by the laser shows that the deposition of Nb thin film on the Cu substrate is nonhomogeneous (see Fig. 5) – Nb coating on the 2D tubular part of the RF cavity is thick, but on the 3D spheric part is too thin. Evidence of this statement is the red collar of the 3D part of the RF cavity. It means that the thickness of Nb is less than 1 µm. The software for the control of β coordinates is developing. It is coordinated with the previous software for α and Z coordinates

3 Future plans / Conclusion / relation to other IFAST work

The facility for Laser treatment of RF 1.3 GHz cavity in Ar atmosphere has been built at RTU. The facility has been tested with optical microscope, AFM, measurement hardness and adhesion of Nb on Cu for 2D samples. It demonstrates that after the laser irradiation, the roughness parameters *Ra* decreased by about an order of magnitude from 900 nm to 90 nm. The mechanical properties also increase: after laser irradiation at I max, the hardness increases by 50%. It can be seen that the optical properties of the Nb/Cu structure depend on the laser intensity: the reflection index of the unirradiated surface (R) is 30% and R=95% at I max, and R=87% at I min.

This leads to the conclusion that Task 9.5 Milestone 41 has been met.

In the following months RTU team will continue laser processing of the RF cavity with homogeneous Nb deposition on Cu substrate.

We have shown that the optical properties of the Nb/Cu structure depend on the laser intensity: the reflection index (R) of the unirradiated surface is 30% and R=95% at I max, and R=87% at I min. This indirect dependence can be used for nondestructive control of the mechanical properties of the RF resonator, such as hardness and adhesion.

As soon as Task 9.2 partners provide Task 9.5 with another cavity (-ies), the laser treatment will be performed and the cavity will be sent to WP9 partners for the RF test.

4 References

[1] Yang Y. et al.(2020) Study on laser annealing of niobium films deposited on copper for RF superconducting cavities, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Vol. A964, pp.1- 8, 163803.

[2] Medvids A. et al., (2020) Improvement of Nb/Cu adhesion and increase of Nb crystal size by laser radiation, *Appl. Surf. Sci*, vol. 525, pp. 146528-146532.

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