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MANUFACTURING OF CERAMIC VACUUM CHAMBERS FOR SIRIUS ON-AXIS KICKER

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Abstract

Ceramic vacuum chambers were produced by LNLS for the Sirius kickers. Alumina tubes with an elliptical inner shape of 9.5 mm (V) x 29 mm (H) and 500 mm long were successfully manufactured by a Brazilian company. Metallic ASTM F136 titanium flanges were brazed to Nb inserts using Ag-58.5Cu-31.5Pd wt% alloy, these inserts were brazed to the ceramic using Ag-26.7Cu-4.5Ti wt% active filler metal. A titanium film was coated inside the chamber using argon plasma by RF Magnetron Sputtering technique. Samples have been investigated by Scanning Electron Microscopy (SEM) to measure film thickness along the inner section of the tube, coating morphology, chemical composition and homogeneity. The total electrical resistance of the tube was also monitored during the sputtering process to achieve the desired value (0.2 ohms/square). In this contribution, we present the results of an On-Axis kicker manufacturing process developed by LNLS.

INTRODUCTION

LNLS staff is currently engaged in the commissioning of Sirius, a new 3 GeV synchrotron light source. Among many other components, several ceramic chambers embedded in specials magnets were built. Their function is to steer an incoming particle beam onto the circular storage ring, therefore called kickers. These oblong alumina tubes must be coated with a thin metallic layer, in order to to allow the conduction of the image currents of the beam. Its final electrical resistance must be precisely controlled as not to attenuate too much the magnetic field pulses due to eddy current losses [1].

Few companies are able to manufacture such ceramic tube and LNLS worked with a Brazilian company called Engecer [2] in order to develop this ceramic component.

The objective of this work is to present a manufacturing overview of this vacuum chamber.

VACUUM CHAMBER CHARATERISTICS

Ceramic tubes with an elliptical inner shape of 9.5 mm (V) x 29 mm (H) and 500 mm long were proposed for the kicker chamber. Alumina (Al_2O_3) was best suited for this application given LNLS experience with this material on ceramic to metal brazing process over the years.

An internal tolerance of 0.4mm for the internal profile was achieved after several iterations with the manufacturer.

Vacuum Flange

The materials listed in the Table 1 were used for the flange manufacturing.

Table 1: Materials Properties

	CTE, linear (µm/m-°C) @20-1000°C	Modulus of Elasticity (GPa)	Tensile Strength, Yield (MPa)
Ti6Al4V	9,7	114	880
Niobium	8,5	103	207
Alumina 96%	8,2	-	-

Niobium demonstrated a better match for the Alumina CTE although its low yield tensile strength is not suitable for a metal gasket seal flange. So it was used as an intermediate material, and the vacuum seal flange was made with Ti6Al4V Grade 23 (ASTM F136) alloy. The complete vacuum chamber is show in Fig. 1.

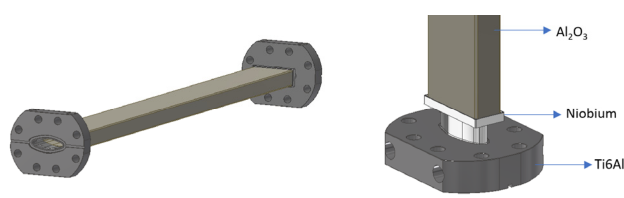

Figure 1: Kicker vacuum chamber.

VACUUM CHAMBER MANUFACTURING

Ceramic Tube

After the ceramic tube is received from the supplier, cleaning is carried and a visual analysis is performed to evaluate the internal finish, which must be homogeneous and shiny.

After cleaning, a leak test is performed to guarantee the ceramic material is vacuum tight sealed itself. Wall thickness measurement was performed with the portable thickness gauge Olympus Magna-Mike 8600, equipped with a probe's Hall Effect sensor to measure the distance between a probe tip and a target ball.

The ceramic tube goes to the Coordinate Measuring Machine (CMM) for complete measurement, and a 3D drawing file containing the ends of the tube is generated, so that the flanges can be drawn from the generated 3D point cloud.

Vacuum Flange Brazing

An initial brazing step was performed to manufacture the flanges, joining the metallic Niobium to Ti6Al4V Grade

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23 alloy with Palcusil 10 (Ag-58.5Cu-31.5Pd wt% alloy) filler metal. A leak test is performed at this step to guarantee a vacuum seal tight joint. These Nb inserts were made with excess metal left internally to subsequent machining.

The generated CMM 3D point cloud is used at this stage for the final designing and machining of the flanges. Each flange was specially designed for each end of the tube. Thus, the metallic flange copies the exact geometry of the ceramic chamber, including its local imperfections, in order to guarantee a perfect and continuous fit, without steps or gaps.

A smooth transition between the actual ceramic geometry to the ideal elliptic CAD geometry of vacuum sealing edge of the flange was also made internally, in order to perfectly match other standard Sirius components.

Metal-Ceramic Brazing

A second brazing step was performed to join the metallic flanges to the ceramic tube. Ticusil (Ag-26.7Cu-4.5Ti wt% alloy) active filler metal was used [3]. A high vacuum furnace with useful 500 mm internal diameter and 1.5 meter long for brazing the ceramic chambers on the vertical position.

After the metal-ceramic brazing, the chamber is leak tested to guarantee a vacuum sealed joint and proceeds to the next step: Ti internal coating. The complete LNLS manufacturing flow is summarized in Fig. 2.

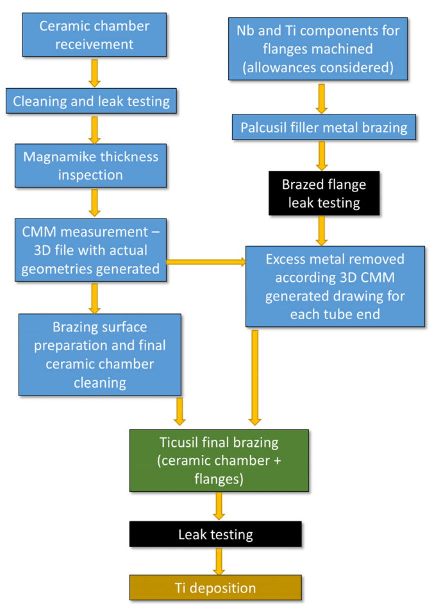

Figure 2: Manufacturing flow.

Titanium Coating

The process of cylindrical RF magnetron sputtering was used due its high efficiency and the geometry of the component to be coated. DC cylindrical magnetron sputtering was also tested.

A single 2 mm Ti wire was used as cathode even if the inner geometry is elliptical. This demonstrated not to be a problem as the interior of chambers were coated entirely and the homogeneity needed the most were at the closest points to the electron beam path. As the ceramic is not an electric conductor material, an anode was made using aluminium foil wrapped around the ceramic tube as shown in Fig. 3. This way plasma can be generated between the Ti wire cathode and the exterior aluminium foil, coating the interior of the ceramic chamber.

Electrical resistance was monitored during the sputtering with a 4-wire gauge, and this quantity was used as control parameter for the process.

The kicker chamber was cleaned and installed in the sputtering chamber. Baking was carried out at 115 °C for 24 h and a 10^{-7} mbar vacuum target pressure was achieved. Argon gas was injected at the system until 10^{-3} mbar pressure, 320 G was set at the coils and 200 W power applied to the RF system.

An overall target resistance of 1.5 Ohm was designated for the kicker tube in order to have the desired 0.2 Ohm/square value according to its dimensions.

A detailed schematic is shown in Fig. 3.

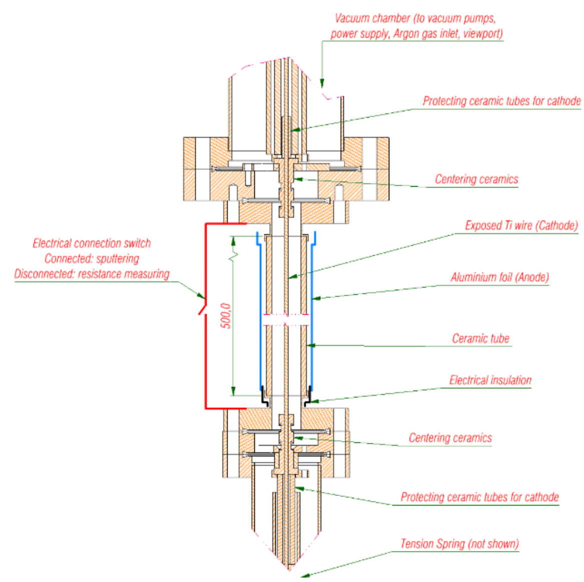

Figure 3: Ceramic chamber sputtering schematics.

After Ti sputtering, argon is inhibited and synthetic air is injected in the system to induce the film oxidation. Inducing the oxidation in-site allows to precisely measure the oxidation effect before cooling. Resistance versus time sputtering curve is show in Fig. 4 below during the sputtering step.

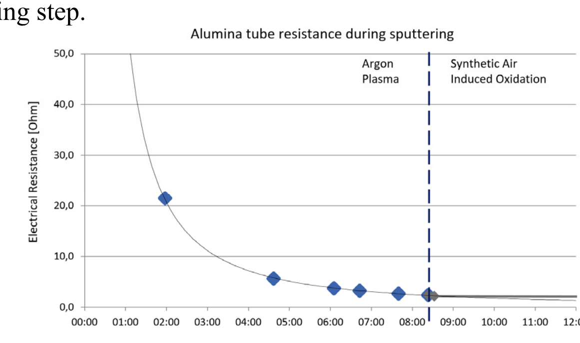

Figure 4: Chamber resistance during sputtering.

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After the resistance is stabilized due to oxidation caused by the synthetic air injection, the baking is turned off and the chamber starts to cool. Figure 5 shows the evolution of the tube resistance during these two last steps, and the correlation between the tube resistance and temperature.

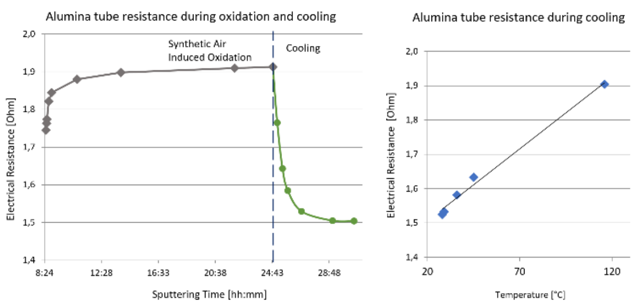

Figure 5: Ceramic chamber resistance during induced oxidation and cooling versus time (left) and ceramic chamber resistance versus temperature (right).

Taking these oxidation and cooling effects into account, it was possible to achieve the desired final resistance value of 1.5 Ohm for the kicker chamber.

FILM CHARACTERIZATION

After the deposition, sample tubes were sectioned in order to perform SEM and XPS analysis. Figure 6 shows the morphology of the obtained film through the RF magnetron sputtering and DC magnetron sputtering. A continuous and homogeneous layer over an alumina substrate with no cracks can be seen.

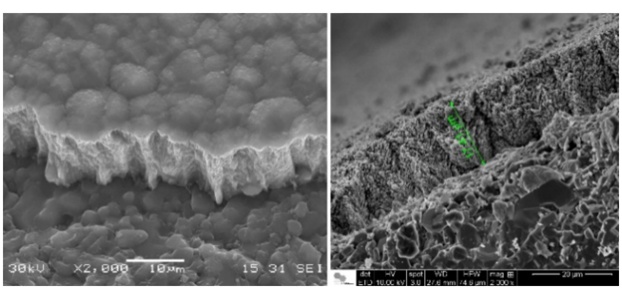

Figure 6: Ti coating morphology over alumina substrate obtained by RF magnetron sputtering (left) and Ti coating morphology over alumina substrate obtained by DC magnetron sputtering (right).

The Ti coating thickness of the DC sample measured 17.4 µm, while the RF sample measured 8 µm, although both of these sample tubes measured the same 1.2 Ohm final resistance. This indicates that a similar amount of Ti is present on both tubes, but a more porous morphology is present at the DC sample compared to the RF sample.

LNLS opted by the RF sputtering method in order to obtain a more compact morphology for the coating.

XPS analysis indicated the formation of TiO_2 and TiN possibly along with sub-oxides like TiON. Figure 7 shows the results of the XPS measurements.

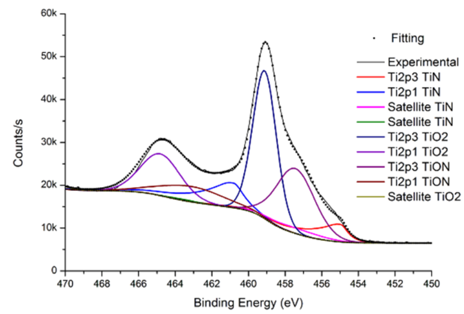

Figure 7: XPS film analysis.

In order to measure the coating homogeneity across the length of the tube, a 4-wire resistance measuring probe was used. Two wires were connected at one end of the tube, and the other 2 wires were soldered to a copper-beryllium spring loaded C-shaped terminal, to guarantee upper and bottom contact at the same time with the tube walls. Figure 8 shows the recorded measurements and no significant regions far from the linear expected behaviour were observed, indicating that the coating homogeneity was achieved across the entire length.

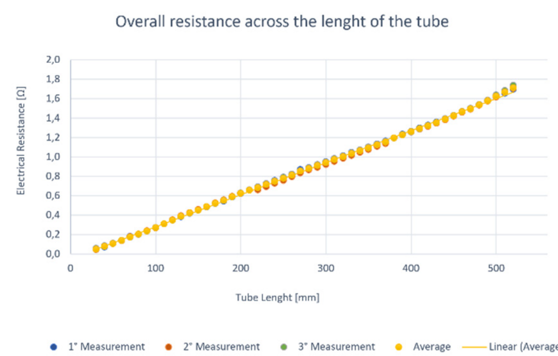

Figure 8: Overall tube resistance across the length.

CONCLUSION

The results indicate that the procedure proposed for brazing the ceramic chambers are suitable for the required parameters. Ceramic chambers were approved for ultra-high vacuum usage and meet the designed specifications of Sirius. A total of 4 tubes were produced and one is currently in operation in Sirius. Final resistance of the coated tube can be controlled if the process is well known; the film obtained covers the whole inner surface entirely and top and bottom surfaces uniformly.

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