RF WINDOW Ti COATING CHARACTERIZATION

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Abstract

Thin titanium coatings were deposited on alumina RF windows at CERN to reduce the secondary electron emission yield. The deposition process was optimized to ensure uniform coverage of the components used in high-power RF systems. Witness samples were characterized to assess their suitability for accelerator applications. Surface resistivity was measured under controlled conditions, while the Secondary Electron Yield was evaluated to determine the effectiveness of the coating in reducing electron emission. Thickness uniformity was characterized through detailed mapping using Rutherford Backscattering Spectrometry at the Laboratori Nazionali di Legnaro, providing spatially resolved information on deposition homogeneity and confirming process reproducibility. These results provide a comprehensive overview of the properties of the titanium coatings and serve as a useful reference for optimizing surface treatments of RF windows in accelerator facilities.

INTRODUCTION

Alumina radio-frequency (RF) windows are a key component in high-power accelerator systems, owing to their excellent dielectric properties, compatibility with ultra-high vacuum (UHV) environments, and robust thermo-mechanical stability. Despite these advantages, their performance can be adversely affected under high electromagnetic field intensities, where ceramic surfaces may trigger electron multiplication phenomena such as multipactor discharge and electron loading. These effects can lead to significant limitations in RF performance and long-term component reliability [1, 2].

The occurrence of such phenomena is strongly dependent on the Secondary Electron Yield (SEY) of the material surface. Alumina is known to exhibit relatively high SEY values, making it particularly susceptible to multipactor effects. The development of effective surface treatments aimed at reducing secondary electron emission is therefore of primary importance for accelerator applications. Among the various mitigation strategies explored, the deposition of thin conductive coatings with intrinsically low SEY has emerged as a viable and effective solution, capable of mitigating multipactor while preserving acceptable RF transparency and performance [1, 3].

Titanium is considered a promising candidate for this purpose, as it combines moderate electrical conductivity, relatively low SEY, good compatibility with UHV conditions, and high chemical stability. The use of thin-film coatings also allows for the reduction of surface charging effects without significantly compromising the electromagnetic properties of the RF window [3].

Thin-film coatings have demonstrated effectiveness in reducing SEY and suppressing multipactor on ceramic substrates, with sputter-deposited films providing significant improvements on alumina surfaces. Conductive coatings have also been employed to mitigate electron cloud effects and secondary emission phenomena in RF structures [4].

In this context, the present work investigates the thickness uniformity and compositional consistency of thin titanium coatings deposited on alumina RF windows at CERN. Witness samples were characterized by means of surface resistivity measurements, Secondary Electron Yield (SEY) analysis, and Rutherford Backscattering Spectrometry (RBS) mapping at the Laboratori Nazionali di Legnaro. The objective is to assess coating uniformity, reproducibility, and overall suitability for RF accelerator applications.

COATING DEPOSITION SYSTEM

The titanium deposition on alumina (Al_2O_3) RF windows, developed at CERN, is carried out in a dedicated coating facility consisting of a cylindrical vacuum chamber with a diameter of 1.5 m and a height of 1 m. The deposition process is performed by means of DC magnetron sputtering, employing a 10-inch cathode mounted at the bottom of the chamber in a sputter-up configuration and laterally offset by approximately 300 mm with respect to the chamber axis.

The substrate, either the RF window itself or, for qualification purposes, a dedicated sample holder equipped with witness samples, is positioned along the chamber axis at a distance of approximately 350 mm from the sputtering source. A rotation system for the sample holder is integrated into the setup to enhance the uniformity of the deposited film thickness across the entire exposed surface.

For the validation of the deposition process, different substrate materials were selected (Fig. 1), depending on the specific characterization technique to be employed. Glassy carbon substrates, Structure Probe Inc. (GC_X) were used for Rutherford Backscattering Spectrometry (RBS) measurements, owing to their suitability for quantitative compositional analysis and accurate determination of thin film thickness.

For the characterization of secondary electron emission properties, sintered alumina samples (Ce_Y) were utilized, featuring a composition and surface roughness comparable to those of the operational RF windows (Ra ≈ 1.6 μm), in order to ensure a representative assessment of the SEY behaviour of the coated system.

Finally, sapphire substrates (Sa_Z) were prepared for electrical resistivity measurements; these analyses are currently ongoing.

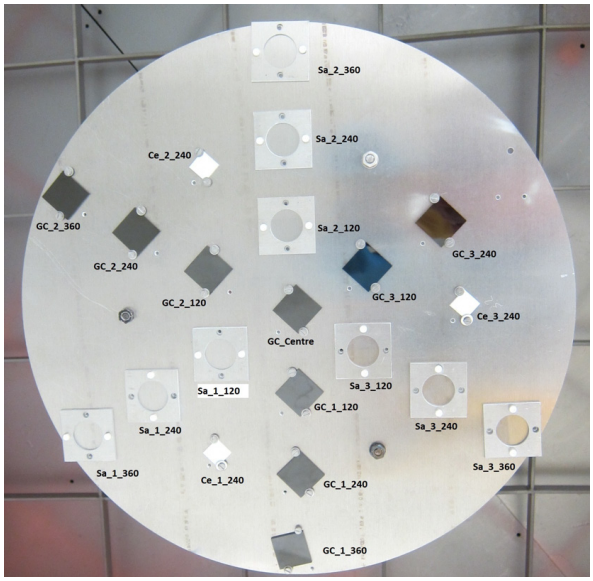

Figure 1: Arrangement of the various substrates on the sample holder, reproducing the geometry of the RF window (diameter 400 mm).

TITANIUM COATING PROCESS PARAMETERS

The deposition process was carried out using DC magnetron sputtering. The glow discharge was operated in a current-controlled regime at 0.2 A, corresponding to an average power of approximately 57 W and a discharge voltage of about 280 V. Deposition was performed in an argon atmosphere at a pressure of 7×10^{-4} mbar.

The sample holder, positioned along the chamber axis, was continuously rotated at 3 rpm in order to enhance coating thickness uniformity and minimise deposition gradients across the substrate surface. Prior to deposition, the system underwent a pump-down phase combined with a bake-out procedure at 110 °C for 12 hours, achieving a base pressure below 2×10^{-7} mbar. Vacuum conditions were continuously monitored using a Residual Gas Analyzer (RGA), operated during the evacuation phase as well as before and after each stage of the process, to ensure the absence of residual contaminants and to maintain well-controlled deposition conditions.

Real-time monitoring of the coating thickness was performed via continuous surface resistivity measurements on an alumina witness sample placed in close proximity to the sputtering source. This method provides an indirect yet reliable estimation of film growth, based on the correlation between coating thickness and surface conductivity.

The deposition process was terminated upon reaching a target sheet resistance of 11.8 MΩ/□ on the reference sample. This threshold was defined based on previous deposition campaigns, in which the relationship between electrical properties of the coating and its functional performance particularly in terms of SEY reduction and RF power absorption was established.

SEY COATING ANALYSIS

Secondary Electron Yield (SEY) measurements were carried out at CERN using an experimental setup specifically designed for the characterization of materials for accelerator applications. The employed technique is based on the measurement of the electron current emitted by the sample under irradiation with a primary electron beam of controlled energy, allowing the determination of the SEY coefficient as a function of incident electron energy.

Reference sintered alumina samples without surface treatment exhibited maximum SEY values on the order of ~9, consistent with values typically reported for oxidized ceramic surfaces used in accelerator environments.

Following the deposition of the thin titanium coating, the treated alumina witness samples showed a substantial reduction in secondary electron emission, with maximum SEY values below 2. This result indicates a high effectiveness of the coating in suppressing secondary electron emission processes.

The observed reduction can be attributed to the combined effect of the metallic character of the titanium film and the modification of surface emission properties, resulting in a decrease in both the number of emitted secondary electrons and their probability of undergoing further multiplication under resonant conditions. The measurements were performed according to established CERN procedures for SEY characterization, consistent with the methodologies developed for coated and treated surfaces.

These results confirm that thin titanium coatings are effective in significantly reducing the SEY of alumina substrates, supporting their suitability for high-power RF applications where multipactor suppression represents a critical requirement (Fig. 2).

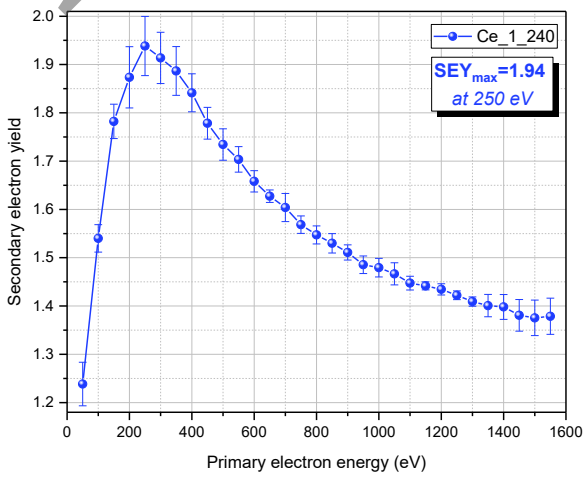

Figure 2: Secondary Electron Yield (SEY) as a function of primary electron energy for Ti-coated sintered alumina.

RBS COATING ANALYSIS

Rutherford Backscattering Spectrometry (RBS) measurements were carried out at the AN2000 facility of the Laboratori Nazionali di Legnaro (INFN) using a 1.6 MeV α-particle beam, with the aim of assessing both the thickness uniformity and the compositional properties of the deposited titanium thin films. The measurements were performed at a backscattering angle of θ = 160°, under normal beam incidence (0°), with a beam current in the range of 45–50 nA and a beam spot size of approximately 1 mm².

A total of nine samples were investigated, employing dedicated glassy carbon witness substrates to enable accurate quantitative determination of the coating thickness. For each sample, three independent RBS spectra were acquired at different positions, separated by approximately 9 mm, in order to evaluate possible lateral inhomogeneities in the film deposition. The coating thickness was then determined as the average value extracted from the three measurements, based on the measured titanium areal density (10^{15} at/cm²) and assuming the nominal bulk density of titanium. The experimental spectra were analysed using the SimNRA software [5], which allowed for consistent fitting of the scattering profiles and accurate extraction of layer thickness and composition.

The RBS spectra (Fig. 3) revealed that the deposited titanium layer is fully oxidized as a result of natural passivation upon exposure to air, with a stoichiometry consistent with TiO_2. The absence of spectral features attributable to metallic titanium confirms the complete oxidation of the coating under the investigated conditions.

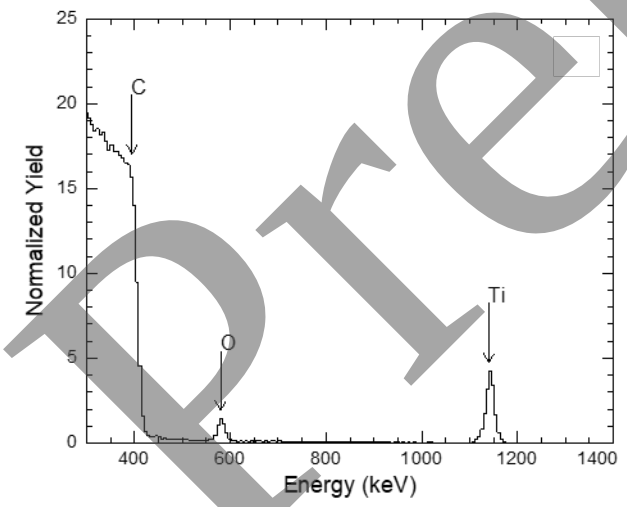

Figure 3: α-RBS spectrum of Ti coated glassy carbon

Thickness normalization was performed with respect to the titanium thickness measured on the GC_center (GCC) reference sample, and the corresponding relative thickness distributions are reported in Table 1.

Table 1: Summary of RBS Analysis

	Ti dose (10^{15} at/cm²)	Ti equivalent (nm)	*Error % Ti dose*	*Relative thickness (%)*
GCC (center)	7.3	1.28	1.2	100.0
GC_1_120	7.1	1.25	1.6	97.4
GC_1_240	7.0	1.23	1.6	96.4
GC_1_360	6.9	1.21	1.3	94.7
GC_2_120	7.2	1.27	1.3	99.2
GC_2_240	7.2	1.27	1.2	99.3
GC_2_360	7.3	1.29	1.4	100.6
GC_3_120	7.1	1.25	1.2	97.9
GC_3_240	7.1	1.24	1.3	97.2

CONCLUSION

Thin titanium coatings were successfully deposited on alumina RF windows using a DC magnetron sputtering process developed at CERN. The adopted parameters enabled a controlled and reproducible deposition, as confirmed by the characterization of witness samples.

Secondary Electron Yield (SEY) measurements showed a significant reduction, with maximum values decreasing from ~9 for untreated alumina to below 2 after coating, demonstrating the effectiveness of the titanium layer in suppressing electron emission and mitigating multipactor effects.

Rutherford Backscattering Spectrometry (RBS) analysis provided a quantitative evaluation of thickness and uniformity, indicating a homogeneous deposition with variations within a few percent.

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