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EXPERIMENTAL STUDY OF MULTIPACTOR SUPPRESSION IN DIELECTRIC MATERIALS

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Abstract

A novel coaxial resonator to investigate two-surface multipactor discharges on metal and dielectric surfaces in the gap region under vacuum conditions (~10^{-8} mbar) has been developed and tested. The resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions). A pulsed RF source delivers up to 30 W average power over a wide frequency range 650-900 MHz to the RF resonator. The incident and reflected RF signals are monitored by calibrated RF diodes. An electron probe provides temporal measurements of the multipacting electron current with respect to the RF pulses. In this paper we compare and contrast the results from the RF power tests of the alumina (97.6% Al_2O_3) and quartz samples without a coating, "the non-coated samples" and the Alumina and quartz samples with a TiN coating in order to evaluate a home made sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor. The effectiveness of this method is presented and discussed in the paper.

INTRODUCTION

A multipactor discharge is a phenomenon in which electrons impact one or more material surfaces in resonance with an alternating electric field [1]. Two main conditions must be met in order to develop a multipactor discharge between two material surfaces. First, electrons traversing the gap must impact the electrode near the time the E-field reverses the direction. Second, electrons must impact the surface with enough energy to create electron multiplication by secondary emission, i.e. δ (E) $\geq$1. The discharge is sustained by the population of electrons that remain in phase with the RF electric field. Because the discharge is sustained by secondary electrons, multipactor discharges typically occur under vacuum conditions.

Multipactor discharges are considered detrimental to RF systems in most applications. The discharges can cause vacuum window failure, limit the delivery of RF power, detune resonant cavities, damage high power RF sources, and cause a local pressure rise due to the desorption of surface gases [2]. As mentioned, multipactor (MP) is often an undesirable phenomenon, and avoidance can be critical in the operation of certain systems, it can be avoided in several ways. A general cure against multipacting is to avoid the resonant conditions by either a proper choice of the geometry of the device [3, 4] or by coating the critical areas with a material with a lower secondary yield [5,6]. This way the effect of multipacting can be significantly reduced, but very often the MP phenomenon cannot be removed. Titanium nitride (TiN) coating is used as a proven anti-multipacting coating for dielectric-loaded accelerating (DLA) structures, and RF vacuum windows. Several experimental investigations have been performed at DESY and LAL-Orsay, aimed at reducing secondary electron emission and multipactor effects by TiN layers generation on dielectric or metal surfaces [7, 8].

We propose here an experiment facility for investigating two-surface multipactor discharges on dielectric and metal surfaces. The compact apparatus consists of a RF coaxial resonator in a high vacuum system (~ 10^{-8} mbar). The RF resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions), powered with a pulsed RF source delivering up to 30W average power. These experiments were successful in identifying multipacting and allowed us the evaluation of a homemade sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor.

TiN COATING TECHNOLOGY

The presence of a dielectric window on a high power RF line has in fact a strong influence on the multipactor phenomenon, a resonant electron discharge that is strongly limiting for the RF components performances. The most important method to reduce the multipactor is to decrease the secondary emission yield of the dielectric window and the dielectric-loaded accelerating structures (DLA). Due to its low secondary electron emission coefficient, TiN thin film is used as a multipactor suppressor coating on RF ceramic coupler windows. For this purpose, a reactive DC magnetron sputtering bench has been developed at LAL-Orsay with the collaboration of the consortium Ferrara Ricerche-Italie in the frame of CARE program (Figure 1).

Within the sputtering process gas ions out of a plasma are accelerated towards a target consisting of the material to be deposited. Material is detached ('sputtered') from the target and afterwards deposited on a substrate in the vicinity. The process is realized in a closed recipient, which is pumped down to a vacuum base pressure ~ 10^{-8} mbar before deposition starts (Figure 1).

In the both sides of vacuum chamber, the machine is equipped with a 10 inch titanium disc target of high quality (grade2, minimum 99.7 % Ti). Two rotary magnet packs are placed just behind the targets to increase plasma density at their surface, and thus improve sputtering yield. Two power supplies are used to fix both target bias. A special rotating sample holder was designed to allow uniform deposition on the samples made of different materials and had different sizes and shapes. The machine allows also the RF etching of the substrate, a pretreatment step in order to remove particle contamination, as it is not possible to clean a ceramic (alumina) with solvent due to

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the high porosity of the material and the possibility of solvent trapping.

Optimal parameters for depositing TiN thin films by DC reactive magnetron sputtering were determined. X-Ray Photoelectron Spectroscopy (XPS) and X-Ray Diffraction (XRD) analysis were performed to control the compositions and the stoechiometries of the obtained films [8, 9].

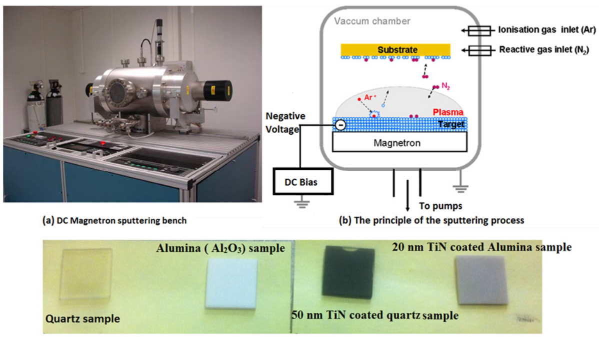

Figure 1: View of the DC Magnetron sputtering bench.

COAXIAL RESONATOR MULTIPACTOR EXPERIMENT

The RF coaxial resonator is ~ 100 mm in length with an outer diameter of ~ 60 mm (internal dimensions) [10]. The resonator's dimensions were chosen because of the available laboratory equipment. It is made out of stainless steel whose inner walls plated with copper and equipped with 4 ports: on the top, a small coaxial line penetrates the upper center electrode to provide a direct measure of the multipacting current, the bottom port for the pumping system, and two horizontal ports for RF coupling. Both RF antennas have the same coupling in order to maintain the symmetry of the central electric field. The RF antennas and diagnostics are accessed with vacuum feedthroughs. The flanges are also fabricated from stainless steel. Several pairs of center electrodes have been made from Cu, Al, and Stainless steel (S.S). One electrode sample holder made out of Cu was developed for investigating multipactor discharges on different material surfaces (Alumina ceramic (97.6% Al_2O_3), TiN coated Alumina, quartz and TiN coated quartz). The dielectric samples have the square shape with a 10 mm edge length and 1 mm thickness. The vacuum system allows low pressures of ~ 10^{-8} mbar.

A pulsed RF source delivers up to 30 W average power over a wide frequency range 650-900 MHz to the RF resonator. The pulse width and repetition rate used were 50 ms and 4Hz, respectively (20% duty cycle). The power supply is fed into a circulator which is then attached to a dual directional coupler. The forward and reflected RF powers are monitored by calibrated RF diodes (RF detectors). The electron probe is connected to an electronic circuit. A four 15 V batteries in series allow the bias of the electron probe and a current to voltage converter (1mA/V) provides temporal measurements of the multipacting electron current with respect to the RF power. Data acquisition is controlled by Visual Basic for Applications (VBA). All measured data are recorded and stored in tab delimited format which the signals can be plotted in an Excel © spread sheet. The test bench is straightforward and illustrated in Figure 2.

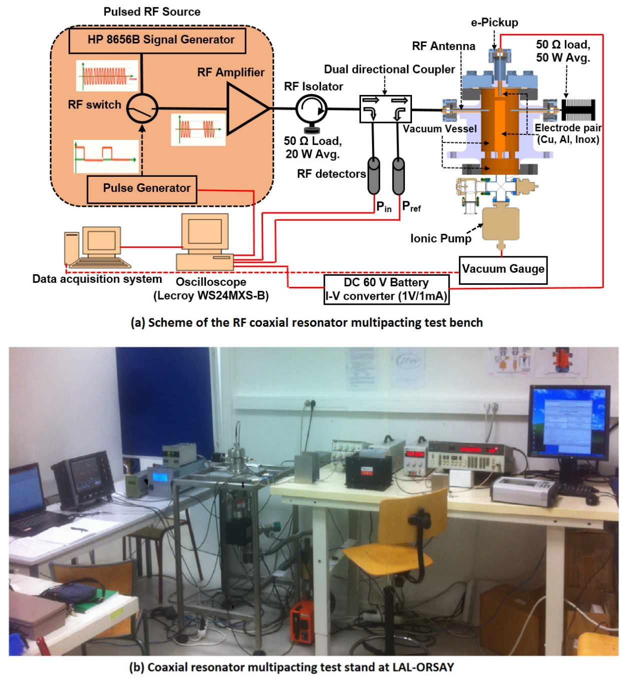

Figure 2: (a) Scheme and (b) View of the Coaxial resonator multipacting test bench.

EXPERIMENTAL RESULTS

For each measurement the electrodes are prepared for vacuum by abrasively cleaning to a moderately polished finish. They are then vacuum cleaned with alcohol before entering the vacuum vessel.

Test Procedure

After assembly of a pair of electrodes the upper conflat flange is closed and the resonator is pumped to a base pressure around 4.10^{-9} mbar through its bottom port. In order to initiate the multipactor discharge, The RF resonator is first tuned to the desired frequency. The RF source is then locked to the high-Q RF resonator. At the multipactor onset, the multipacting current, incident and reflected power and pressure variation were measured.

The S parameters' measurement were carried out with a Vector Network Analyzer (VNA). A good RF matching of the RF resonator was obtained. Main RF resonator parameters are summarized in Table 1.

Table 1: RF Resonator Parameters

Resonant frequency	742 MHz
Insertion loss (I.L)	-1.6 dB
Return Loss	-21 dB
Loaded quality factor Q_L	500
Coupling coefficient β_c	0.85

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Figure 3 shows typical scope traces for the quartz sample of the TTL signal, incident and reflected RF signals detected by the diodes, and the multipactor current provided by an electron probe.

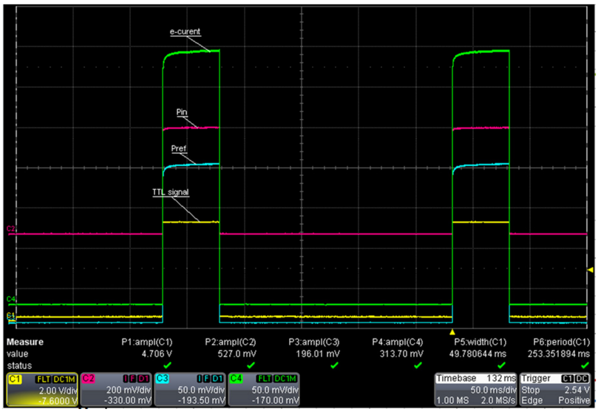

Figure 3: Typical scope traces of diode detectors and electron probe.

TiN Coating as Multipactor Suppressor

In this section we compare and contrast the results from the RF power tests of the alumina and quartz without a coating "the uncoated samples", and the TiN (20 nm) coated Alumina and TiN (50 nm) coated quartz samples in order to evaluate a home made sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor. The Alumina was chosen in this experiment because it has a high secondary emission coefficient and is commonly used in the RF vacuum windows. The quartz is used in the dielectric loaded accelerating structures. Figure 4 depicts the view of the resonator with a dielectric sample holder. The alumina and quartz samples (1 cm square sample, of height 1mm) are placed in a notch or a nick (square shaped cut) on top of one of the Cu electrodes, and the gap distance is d=6 mm.

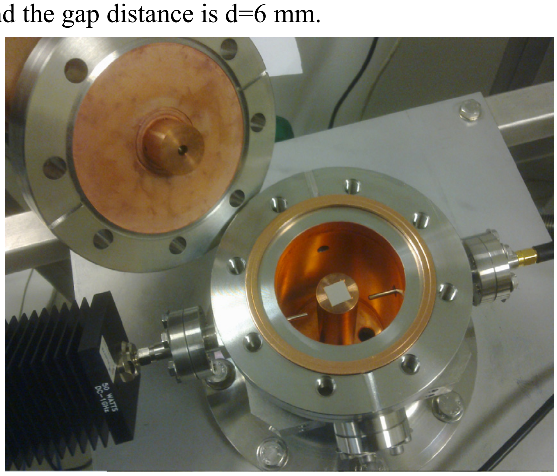

Figure 4: View of the RF coaxial resonator with a dielectric sample holder.

The electron inside the d empty gap is accelerated due to the RF electric field. The RF magnetic field in the center gap of this resonator is small as compared to the RF electric field. Occasionally the electron collides either with the top surface Cu electrode or with the bottom dielectric layer. Each collision may yield to the emission of the secondary electrons.

TiN thin layers are the most commonly used for multipactor suppression due to their low secondary emission on the one hand and good stability in RF field on the other.

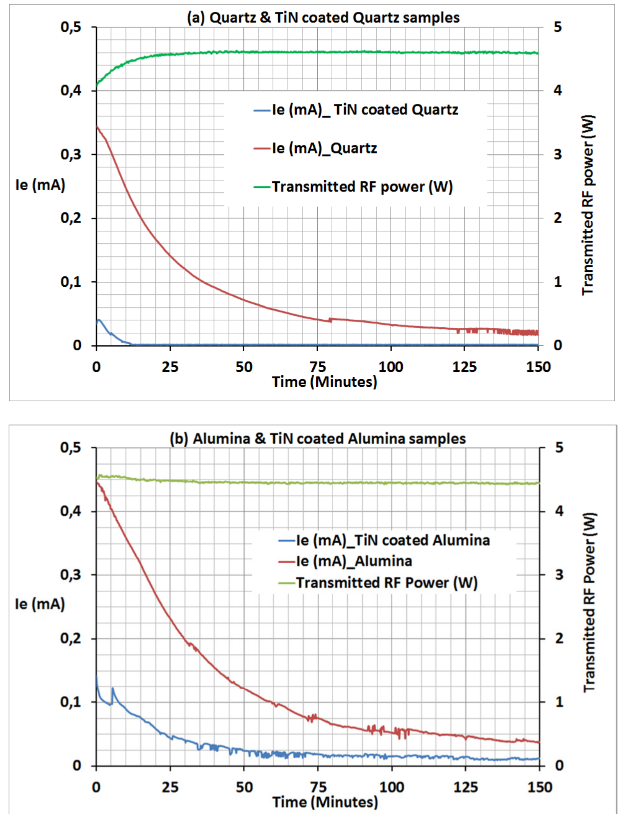

Figure 5: Multipacting current vs. time for a constant transmitted RF power (a) Quartz & TiN (50 nm) coated Quartz; (b) Alumina & TiN (20 nm) coated Alumina.

Figure 5. Shows the efficiency of the TiN coatings, a significant reduction of multipactor current and time during RF tests were reached. The RF power is set to around 4.5 W, above the MP threshold value. The multipactor times for TiN coated quartz were suppressed to 10 min whereas for uncoated quartz surface it was close to 150 min.

CONCLUSIONS

The RF coaxial resonator multipacting experiment provides a test bed for producing and studying two-surface multipactor discharges under various conditions. The apparatus is also used to explore ways to prevent, or extinguish, multipactor by techniques such as coating the dielectrics or the metals. TiN coatings with different thicknesses will be explored.

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REFERENCES

[1] R. A. Kishek, Y. Y. Lau, L. K. Ang, A. Valfells, and R. M. Gilgenbach. "Multipactor discharge on metals and dielectrics: Historical review and recent theories". Phys. Plasmas, 5(5): 2120-2126, May 1998.

[2] M. EL Khaldi, A. Gallas, W. Kaabi, P. Lepercq, C. Magueur, A. Thiebault, A. Verguet, and A. Variola,. "RF conditioning of high power input couplers for XFEL superconducting cavities". AccApp 2013, Eleventh International Topical meeting on nuclear application of accelerators, 5-8 August 2013, Bruges, Belgium.

[3] C. M. Lyneis H. A. Schwettman and J. P. Turneaure. "Elimination of electron multipacting in superconducting structures for electron accelerators". App. Phys. Let., 31(8): 541-543, October 1977.

[4] U. Klein, and D. Proch. "Multipacting in superconducting RF structures". Proceedings of the Conference of Future Possibilities for Electron Accelerators, Charlottesville, WU B 78-34, 1979.

[5] A.R. Nayaiesh, E.L. GARWIN, F.K. KING AND R.E. KIRBY. "Properties of thin anti-multipactor coatings for klystron windows". SLAC-PUB-3760, 1985.

[6] D. Proch, D. Einfeld, R. Onken, and N. Steinhauser, "Measurement of multipacting currents of metal surfaces in RF fields". WPQ24, IEEE Proceedings, PAC 95, 1776, 1996.

[7] J. Lorkiewicz, B. Dwersteg, A. Brinkmann, W.D. Moeller, D. Kostin, and M. Layalan. "Surface TiN coating of Tesla couplers at DESY as an anti multipactor remedy". The 10th Workshop on RF Superconductivity, 2001, Tsukuba, Japan.

[8] W. Kaabi H. Jenhani, A. Variola, G. Keppel, V. Palmieri . "Titanium nitride (TiN) coating as multipactor suppressor on RF coupler ceramic windows". Proceeding of the 23rd Particle Accelerator Conference 4-8 May 2009 Vancouver, British Columbia, Canada.

[9] A. Variola, W. Kaabi, H. Jenhani, P. Lepercq, G. Keppel, V. Palmieri, and F. Strada. "Titanium Nitride Coating of RF Ceramic Windows by Reactive DC Magnetron Sputtering", Proceedings of EPAC 08, June 2008, Genoa, Italy.

[10] M. El Khaldi W. Kaabi, P. Lepercq, and Y. Peinaud. "RF Coaxial Resonator for Investigating Multipactor Discharges on Metal and Dielectric Surfaces". Proceedings of LINAC14, pp.1074-1076, Aug 2014, Geneva, Switzerland.