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TiN METALIZING AND COATING FOR MULTI-MEGAWATT RF VACUUM WINDOWS

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Abstract

Coatings on microwave windows and high-voltage ceramics are required to eliminate secondary electron emission (SEE), which initiates multipactoring discharge causing local heating and ceramic failures due to cracking and loss of vacuum. The region surrounding the triple junction (ceramic + metal + vacuum) is the primary source of free electrons and in microwave windows and high-voltage ceramics. This region is located at the metalizing and braze joint of the ceramic support structure making the vacuum seal. On very large microwave windows typically at low frequencies, this critical region is difficult to coat by the traditional techniques of sputter coating anti-multipactoring titanium nitride or other materials. The novel processes proposed here include a means for applying and controlling the thickness of titanium nitride both in the metallizing (controlling the source) and on the surface of the window, eliminating SEE and the multipactoring discharge.

TRIPLE JUNCTION PROBLEM

High Peak RF power results in high gradients at the triple junction region of RF windows causing primary electron emission. These electrons migrate across the surface with multipacting processes and other charging effects, which create localized heating and excessive tensile stresses resulting in a window failure.

Triple Junction

The ceramic, metal, and vacuum is the triple junction and with sufficiently high RF fields is the emitter of primary electrons. During processing of HV ceramics or RF windows, the triple junction is eroded and metal vaporized onto the ceramic as shown in Fig. 1c and d. Examples of metalizing around the corner of the ceramic are shown in Fig. 1a used in the experiments discussed in Ref. [1]. It should also be noted that “Sample2” in Fig. 1a is similar to the metallization configuration used in the SLAC B-factory window of reference [2].

Up to now there has been no attempt to change the surface resistivity of the ceramic in the region of the triple junction to eliminate it. It was noted [1] that the surface of the ceramic was covered with evaporants in the region of the triple junction that was eroded from the high voltage processing as shown in Fig. 1d. At the end of the processing, the standoff voltage had increased by a factor of 10 from 10 kV to 100 kV. The only measurable attribute was the appearance of the triple junction as seen in the SEM photos of Fig. 1c and d. It was noted in [1] that the appearance of the alumina in the SEM was darker than the original as a result of the metalizing having been evaporated onto the alumina by the conditioning process. We hypothesize that this thin coating of moly-manganese (Mo-Mn) on the ceramic changes the potentials at the triple junction that exponentially reduces the emission of primary electrons and is the primary purpose of this project.

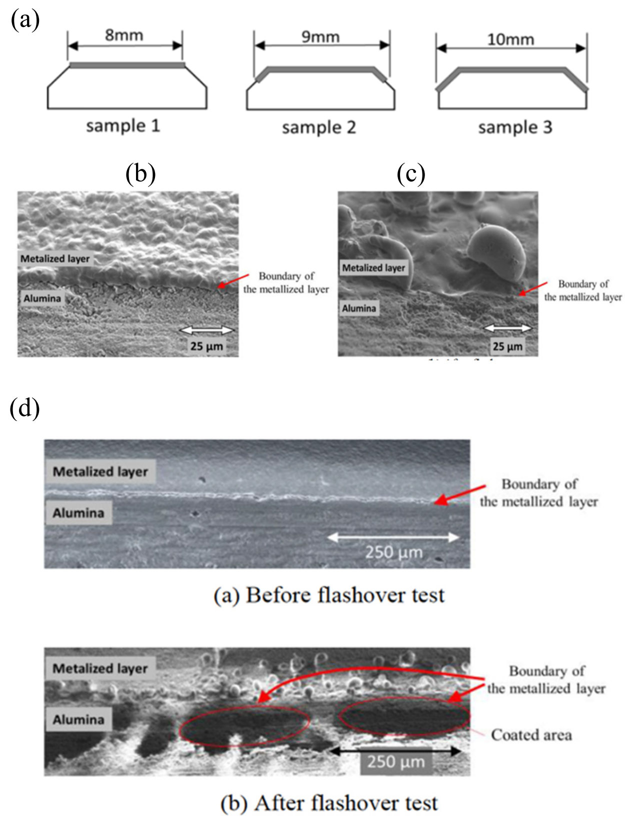

Figure 1: (a) Examples of the metalizing around a chamfer [1] (b) before processing, (c) changes to the triple junction region after high voltage processing [1], (d) Fig. 10 from Ref. [1], identifying the coated area which “eliminated” the triple junction region.

Titanium Nitride Coatings

Titanium Nitride (TiN) coatings have been used on microwave (RF) windows for over 60 years to reduce secondary electron emission [3]. A sputtering process usually applies the coating to a thickness of 10 s of nanometers. Because sputtering is a line-of-sight process, the uniformity of the coating on large round windows is peaked at the center and falls off at the edges of the window in the region of the triple junction. Special techniques need to be applied to the sputtering process to “top up” the coatings in the triple junction region. This was done on PEP-II windows by this PI and the team at SLAC to a thickness of 15Å [2]. While this process eliminated multipactor, surface charging was still a problem to be solved.

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Ion Implantation

Several researchers developed metal ion implantation processes to eliminate surface charging on high voltage ceramics in the last 10-12 years [4, 5]. This process is currently used at Thomas Jefferson National Accelerator Facility (JLAB) on high voltage ceramics and microwave windows with a surface resistivity specification 5×10^{10}-10^{15} Ω/sq.

The two processes - TiN coating and Ion Implantation - are the current standard to solving both the problem of multipactor and charging of windows, but while TiN is effective, in existing manufacturing processes it is difficult to control its uniform deposition on the ceramic surface; control of deposition thickness and adhesion of the TiN material must be repeatable and verifiable

Porosity and Metallization

While all the ceramics are sintered at high temperatures with sintering aids to maximize density to that of the pure chemistry such as aluminum oxide (Al_2O_3), theoretical density is never achieved. For example, when describing "porosity" Morgan Ceramics uses the phrase "porosity (apparent)". In fact, porosity in ceramic is composed of open and closed pores. Open pores are on the surface of the ceramic and closed pores are in the bulk of the ceramic (see Fig. 2). Because ceramics are sintered and not melted, porosity is dependent on the ceramic manufacturer's processes. As a result, every ceramic metalizing chemistry is fine tuned to a particular manufacturer's ceramic, and manufacturers of ceramic assemblies have a favorite ceramic that works well with their metalizing process.

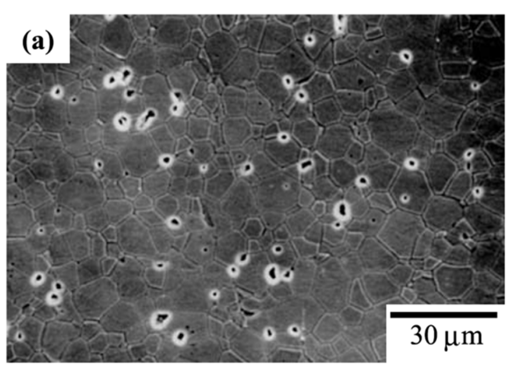
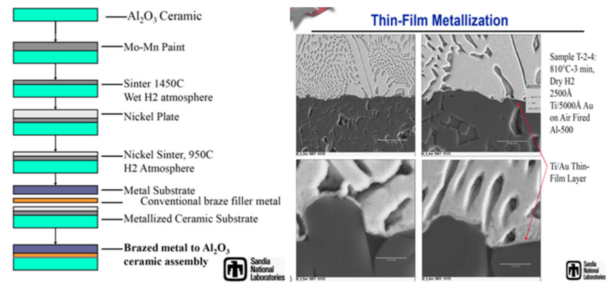


Figure 2: This example of alumina (Al_2O_3) porosity is Fig. 1.4a from Ref. [6].

The standard Mo-Mn metallizing processes, and thin film processes using Ti and Au, are shown in Fig. 3. In Fig. 3(b), both the surface roughness and porosity of alumina is identified. We will exploit this aspect in creating a novel coating for RF windows to solve three issues: 1) multipactor, 2) surface charging, and 3) brazing in the region of the triple junction. The novel coating and processes described in the technical approach section below will address all the above issues without having to change the basic RF design for a high peak power window.



(a) (b)

Figure 3: (a) The standard Mo-Mn process and (b) A thin film process using Ti and Au on AL500 Alumina achieving 12-14 ksi peel strength [7].

RF Designs and the Triple Junction

Several past approaches to hide the triple junction use the choke coax window like the primary SNS coupler as shown in Fig. 4. The triple junction is assumed to be hidden from electric fields. That is simply not the case since it is a TEM mode. Microwave designs to "hide" or eliminate the fields around the triple junction are simply not supportable. The solution is to modify the morphology and resistance at the triple junction and eliminate it.

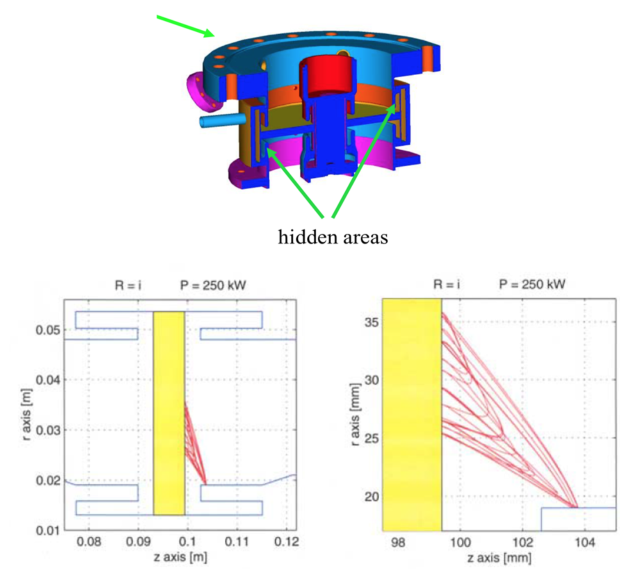


Figure 4: Coaxial choke design used at SNS [8].

Modeling the Triple Junction

Most recent examples of modeling the triple junction have pointed to the ways in which the electric field could be modified to reduce field emission [9]. In this work, the angle of the electrode and the dielectric constant of the surface of the ceramic in vacuum are considered (Fig. 5). Their results map with some elements of the findings in Ref. [1], namely in how increasing the angle and the surface characteristics next to it, described in this model by the dielectric constant, impacts the contours of the electric field in the region and changes the enhancement factor. The modeling is far from perfect and needs modifications we intend to implement. In particular, pre-breakdown current

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from the region of the triple junction, which is well documented, and how that current impacts the voltage at the triple junction will be included.

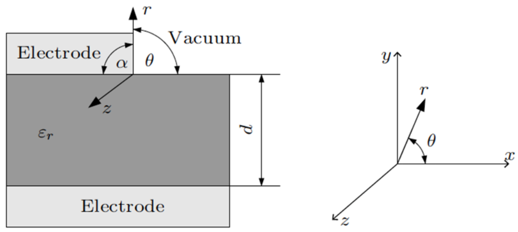

Figure 5: Modeling the triple junction with dielectric constant of the ceramic and angle of the electrode [9].

NOVEL COATING APPROACH

We will develop a single novel coating technique to eliminate the triple junction, secondary electron emission, and window charging. The window charging will be eliminated by producing a surface with a resistivity of 5×10^{10} to 10^{15} W/sq. The secondary electron emission will be eliminated by the use of TiN in the coating. The triple junction will be eliminated by coating the surface of the ceramic about 1-2 mm from the triple junction with a surface resistivity in the range of 10^1 to 10^3 W/sq.

Pre-breakdown current from the triple junction along the coated surface creates a reduction in the potential seen at the triple junction by simple IR losses. This is typically the result of conditioning as seen in the SEM photos of the condition junction of Ref. [1], but in this project, the novel coating processes will create this "conditioned" appearance. During the project, a more thorough model will also be developed of the conditioned triple junction. The RF and mechanical design of the 402.5 MHz window in WR2100 waveguide will also be documented.

Design of Experiments (DOE)

The DOE uses a matrix of variables to efficiently determine the optimum values of those variables. Those variables and the measurements required to control the results are described with the ranges used in the DOE:

1. Ceramic type will be 96-97% purity from different manufacturers, a variable.
2. The %TiN is by weight of TiN nanoparticles in the Mo-Mn base metalizing by INTA and ball milled, a variable.
3. Firing temperature ramp and hold time time (constant).
4. Firing atmosphere (constant).
5. Surface finishing grinding tool is changed for different surface roughness, a variable.
6. Surface Resistivity measurements of are made during the grinding process in various ranges 10^{10}-10^{15}, 10-1^3 and 0.
7. SEM photos of the surface verifying charge depletion (measured).
8. Peel Test of copper brazed to coupon, ksi (measured).

Mechanical Design of the Window

One RF design of the window in WR2100 waveguide shown in Fig. 6, is 12.6 in. in diameter and 0.85 in. thick. The orthogonal TE01 trapped mode is located at 432.68 MHz and the electric fields at the window parallel to the surface of the ceramic have been modeled. Further reduction of the z component in the field at the window is achieved by a radius at the corner of the waveguide and iris and will be implemented in this project.

The window will be constructed with a compression ring to eliminate tensile forces on the perimeter due to the temperature difference between the center and the edge. It is important to understand that the coating process has already been done on the window and unlike previous window designs there is no post processing of the window required.

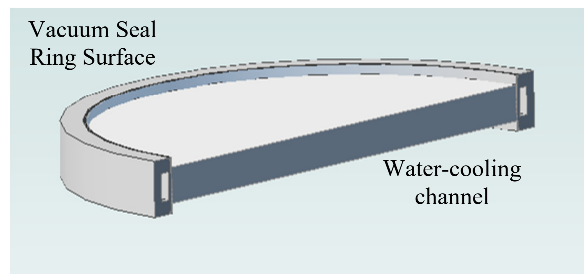

Figure 6: Conceptual elements of the mechanical design with a compression ring.

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