SURFACE TiN COATING OF TESLA COUPLERS AT DESY AS AN ANTIMULTIPACTOR REMEDY

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Abstract

A development project was carried out at DESY, aimed at reducing secondary electron emission and multipactor effects in TESLA couplers by TiN layers generation on surfaces which were not protected in this way previously. Thin TiN films on ceramic or metallic surfaces were produced by deposition from Ti vapor in low pressure ammonia. Selection of processing parameters and their effect on multipactor suppression in RF field have been studied using a multipactor test resonator at DESY. Appropriate values of deposition rate, substrate temperature, final layer thickness and chemical conversion procedure were selected. A significant reduction of multipactor time during RF tests was reached due to surface coating. Chemical analysis of TiN layers on both ceramic and metallic substrates has been performed using SIMS method. TiN coating of more than 80 wave guide and cylindrical RF windows were performed for TTF2, TTF3 and TTF4 versions of TESLA couplers. Surface processing of flat wave guide windows for TTF2 resulted in significant reduction of multipactor effects and improvement of power transmission. Their good performance remained unchanged after 24-hour exposition to air. TiN coating of all vacuum-facing surfaces of TTF2 coupler led to reduction of the indispensable RF conditioning time from typically 3 days down to 4-6 hours.

1 INTRODUCTION

The performance of RF power elements of couplers is often limited by field emission or multipactoring. The latter is started if certain resonance conditions are satisfied for trajectories of electrons striking surfaces of bigger than 1 secondary electron yield. Multipacting currents absorb a substantial part of RF power, lead to inhomogeneous heating, thermal stresses and, particularly in ceramic windows, to cracking.

Together with careful design of coupler and window geometry, aimed at avoiding resonance conditions, secondary electron emission of vacuum-facing surfaces is reduced by applying thin layers of materials with low secondary electron yield. The most used coating is TiN, preferred for its stability in RF field. Apart from variety of sputtering methods, evaporation technique is used for TiN layers generation. Good results were reached using titanium vapor deposition in a reactive atmosphere of low pressure ammonia. The vapor is usually released by sublimation from electrically heated titanium filament. Using this method multipactor phenomena were successfully eliminated from RFQ accelerator at LANL [1] and ceramic coupler windows at FERMILAB [2].

In response to multipactor problems connected with TESLA couplers performance, sublimation technique was implemented and developed at DESY in the years 1999-2001. Along with TiN coating of several types of ceramic coupler windows, TiN deposition on all the vacuum-exposed TTF2 coupler surfaces has been done.

2 COATING SETUP AND OPERATION

A temporary TiN coating apparatus consists of a cylindrical stainless vacuum vessel of 20 cm diameter and about 80 cm tall, equipped with ports for power supply and diagnostic feedthroughs, quartz windows and gas inlets. It is connected to a pumping system based on a turbopump of 500 l/s pumping speed.

The titanium vapor source (filaments) is made of 99.8% purity titanium wires, 1 mm in diameter. They are typically used as horizontal loops or vertical lines. Each RF element to be coated requires a specific filament geometry, shields and deposition sequence. A more detailed description of the sublimation setups used for each component is given in a separate report [3].

In course of a typical surface processing, vacuum-clean RF components and the sublimation setup are placed in the vessel and the system is pumped out. At a basic pressure of less than 10^{-5} mbar filaments are heated up and kept at ca. 1000 ^{o}C for 15 to 30 min. In case of ceramic components coating, the substrate temperature attains about 150 ^{o}C. Ammonia is admitted into the vessel. The ammonia pressure is kept typically at 10^{-3} mbar (for filament-substrate distance 3 - 7 cm) while the vacuum system is being pumped. The titanium coating process is started by heating the filament to ca. 1400 – 1500 ^{o}C. The coating lasts roughly 30 - 150 s, depending on sublimation rate and filament - substrate distance.

The Ti -> TiN conversion in the layer is reached after

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closing the valve between the vessel and the pumping unit and raising the ammonia pressure to several hundred mbar. This "afterprocessing" step lasts typically from 10 hours up to some days. The chemical conversion degree of the titanium layer depends on the substrate temperature during deposition.

3 MULTIPACTOR SUPPRESSION ON TiN-COATED SAMPLES, FILM RESITIVITY

The impact of TiN coating on multipactor suppression in RF field was studied using a test resonator at DESY. The device enables a direct measurement of RF multipactor current between two flat electrodes installed in a specially designed coaxial resonator [4]. The resonance condition for two-surface multipactoring is reached at a frequency of 0.5 GHz. The cavity is operated at a power of 5 W above the onset of multipactoring. During the test the multipactor current drops steadily and the RF electric field in the cavity increases until the electron current fully disappears. For each measurement a new pair of surface-coated electrodes is mounted. The time needed to overcome multipactoring is taken as a figure of merit of the coating procedure.

Ten pairs of aluminum or copper electrodes were titanium coated in ammonia and studied in the test resonator. In parallel, ceramic plates were surface treated in the same way. The resistivity of the layers deposited on these samples was on-line measured. The deposition rate was 9 nm/min and the final layer thickness – between 4 and 40 nm. During some tests the vacuum vessel temperature of 150 ^{o}C was reached by resistive heating. Chemical conversion of the layer was performed after deposition at an ammonia pressure between 150 and 700 mbar. Selected, representative results are given in Table 1.

RF performance of the layers of thickness between 7 and 15 nm , reached in a single coating operation, proved to be most promising. The corresponding multipactor times were confined to 5 – 12 min, whereas for a pure (non-coated) copper surface it was close to 50 min and for pure aluminum it's practically unlimited. Heating up the vessel had no significant impact on multipactor time. A 4 nm thick layer was too thin to suppress secondary emission effectively (multipactor time equal 50 min).

The chemical composition of a 8 nm thick layer on a copper electrode was tested using SIMS method [5]. It indicated the proportion between titanium and nitrogen atomic content close to 1: 0.8, with oxygen admixture of below 20%. For more detailed data XPS tests of TiN layers on ceramic substrates are now underway.

Most ceramic samples coated together with RF electrodes showed yellowish or gray-yellowish color after exposition to air. The resistivity of layers grew up from typically 10 – 50 kOhm/sq to roughly 1 MOhm/sq as a result of afterprocessing in ammonia. After exposing to air it grew further to tenths or hundreds of MOhm/sq for 13 – 15 nm and to GOhm/sq values for 7 nm thick layers. In most cases cooling the coated samples in liquid nitrogen to 70 K raised further their surface resistance by a factor of 10 - 20. This effect is likely to reduce cryogenic loses in cold (70 K) coupler windows.

4 TiN COATING OF COUPLERPOWER ELEMENTS

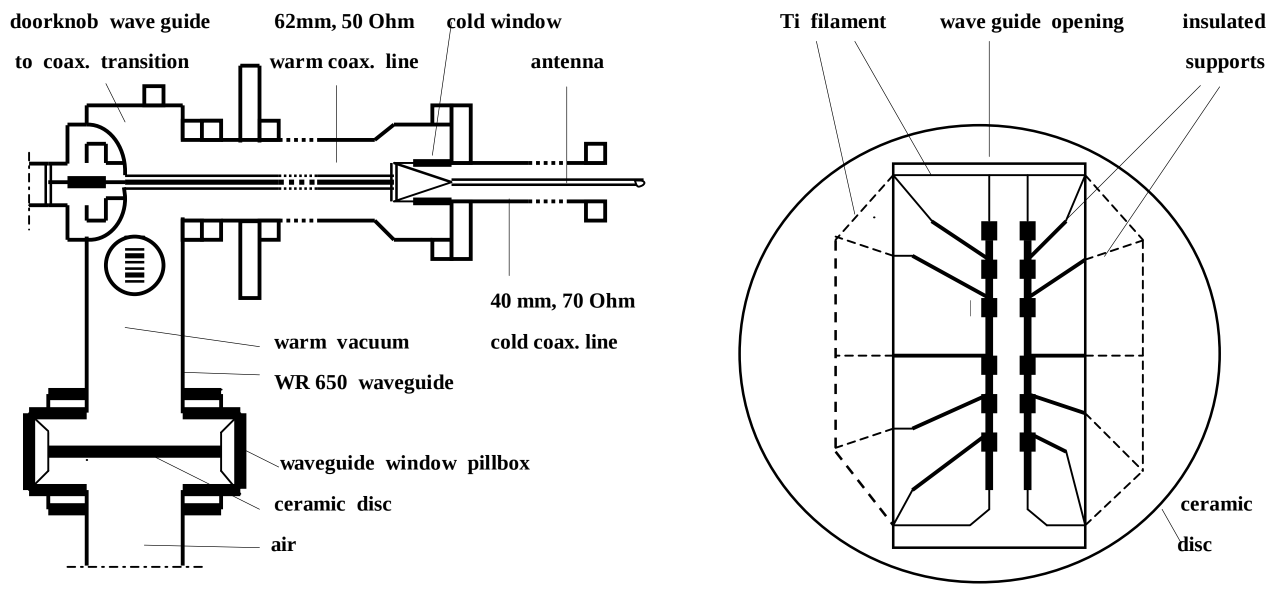
4.1 Coating of TTF2 Wave Guide Windows

The planar wave guide window of the TTF2 input coupler is in contact with atmospheric air on one side and warm vacuum on the other (Figure 1a). It consists of an alumina disc (21.2 cm in diameter, 1 cm thick), mounted in a stainless, pillbox-type container. The peak transmitted power is close to 1 MW at a pulse length of 1.3 ms and repetition rate equal several Hz. Lower than needed power transmission, accompanied by electron and light emission, was due to multipactoring originated on the vacuum side of the ceramic disc. With the TE10 waveguide transmission mode the multipactor is likely to originate at the disc periphery.

An effective TiN coating must reach a sufficient thickness (above 5 nm) at the disc rim and in the area inside the pillbox, where the normal to the disc surface RF electric field component attains maximum. The layer thickness in the disc center is not crucial since the electric field is predominantly tangent to the ceramic surface in this area. In order to deliver a sufficient amount of titanium to the disc periphery the filament had to be mounted inside the pillbox. It had a form of a loop with extreme dimensions equal 16 and 14.5 cm, installed

Table 1: Test results from DESY coaxial resonator and resisitivities of surface layers on ceramic samples

Substrate Material	Vessel temperature	Final layer Thickness	Afterprocessing: NH3 pressure, time	Multipactor time	Surface layer resistivity on ceramic plates after 4-weeks exposition to air	
					at 300 K	at 70 K
copper	Clean surface before coating			3000 s		
aluminum	clean surface before coating			>6500 s		
aluminum	150 ^{o}C	15 nm	300 mbar, 2 days	800 s	55 MOhm/sq	1 GOhm/sq
aluminum	150 ^{o}C	7 nm	250 mbar, 2 days	650 s	3 GOhm/sq	200 GOhm/sq
aluminum	25 ^{o}C	7 nm	700 mbar, 1 day	700 s	24 GOhm/sq	300 GOhm/sq
aluminum	150 ^{o}C	4 nm	200 mbar, 1 day	3000 s		



(a) (b)

Figure 1: Simplified schematic view of TTF2 coupler (a) and titanium sublimation setup inside the wave guide window (b).

horizontally on an insulated support, 25 mm from the disc surface (Figure 1b). With the installed sublimation setup each window to be coated was connected to a pumping unit and underwent normal deposition procedure (see 2). Due to possible thermal stresses, however, discs of the wave guide windows were not preheated to above 100°C before deposition. Computation and preliminary measurement of the layer distribution confirmed that the area with the highest layer thickness overlaps largely with the area of high normal electric field component. Practically reached thickness values ranged from 10 – 15 nm in the region directly below the wire and 6 - 8 nm at the disc rim to ca. 3 nm in the center.

Twenty one wave guide windows of the TTF2 coupler have been TiN coated. A number of them were checked using a special RF test-stand at DESY and some other were installed directly in couplers. The impact of the coating on the windows RF performance is summarized below:

- The necessary processing time has been reduced from several to one day.
- Proper power transmission has been reached (no light or electron emission).
- RF performance remained unchanged after a previous 1-day exposition to air.
- Due to the layer thinness in the central part of the disc no power losses on the ceramic surface were observed.

4.2 Coating of Cylindrical Windows for TTF3 and TTF4 Couplers

TTF2 and TTF3 couplers contain the same cylindrical cold windows permanently connected to electrically coupling antenna (Figure 1a) [6]. Unlike TTF2, the TTF3 coupler, instead of a wave guide window, contains a cylindrical warm window in the half height wave guide to coax. transition. The inner surface of the window is exposed to warm vacuum whereas the outer one - to air. Both windows consist of alumina ring equipped with two short, 1 mm thick copper rings on both ends. The copper rings are used to braze the window to the external conductor of a coaxial transmission line.

More than twenty cylindrical windows of each sort for TTF3 were TiN coated at DESY. The cold (70 K) windows got all-surface coverage whereas the warm ones - only on the inner side. In addition, ten windows of each kind were coated for newly constructed (at LAL, Orsay, France) TTF4 couplers with 80 mm cold coax. line.

The windows were processed successively in two operations: coating of their end surfaces and coating of their cylindrical surfaces. The general scheme of the sublimation setup for end surfaces coating is given in Figure 2a. Two titanium wire loops of a diameter identical to that of the copper collar are suspended above the upper and below the bottom collar of the window at a distance equal 50 – 60 mm. A coating setup for 3 windows was used, composed of four titanium wire loops connected in series and powered from a single dc power supply (Figure 2a). Cylindrical surfaces were coated using a device with 7 (9) vertical filaments for TTF3 (TTF4) coupler windows (Figure 2b). Three to six windows were piled up in a vertical stake. One of the wires was stretched along the axis of the stake whereas the remaining six (eight for TTF4 windows) were arranged 8 cm off the stake axis. The average thickness of the surface TiN films on different widows ranged between 8 and 11 nm.

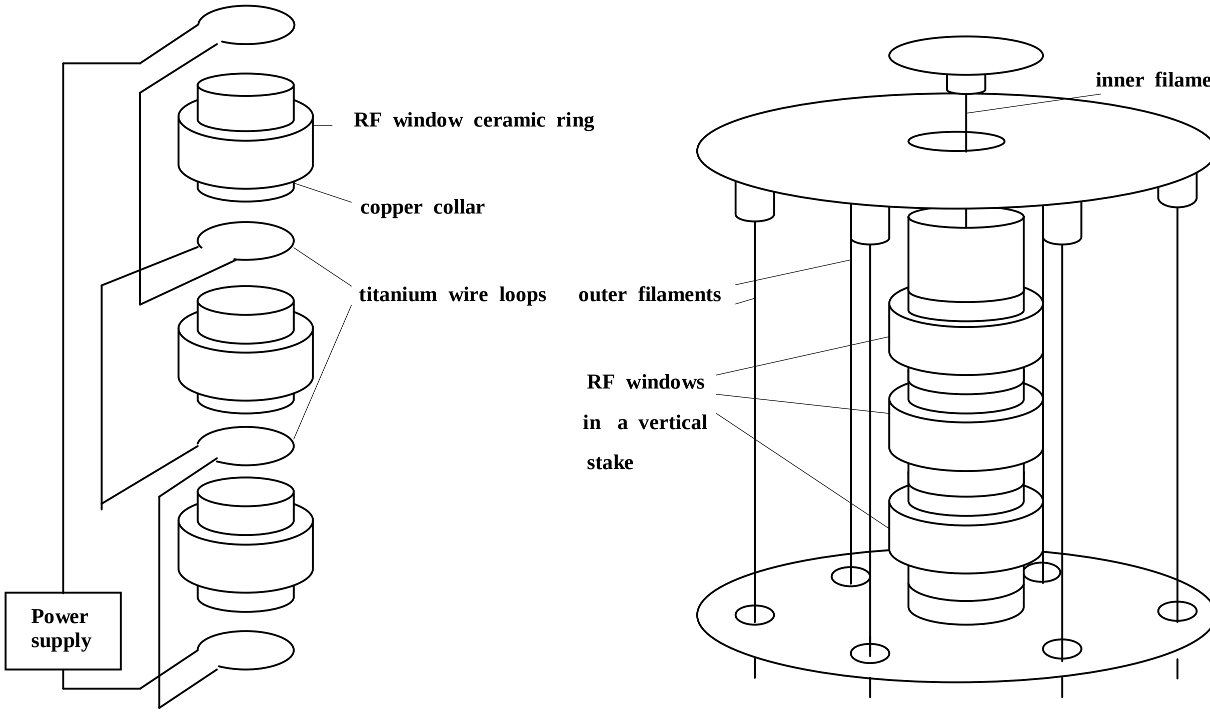


Figure 2: Schematic view of sublimation arrangements for TiN coating of end surfaces (a) and cylindrical surfaces (b) of TTF3 and TTF4 coupler windows.

Two pairs of warm and cold windows were installed in TTF3 couplers. The warm windows heated up to 75 °C during operation, which corresponds to RF power losses of 2W, at RF power load somewhat exceeding the design values. The problem was solved by installing an air-cooling system. For more details concerning TTF3 conditioning results see [7]. Since the resistivity of the surface layers were well in GOhm/sq region it seems unlikely that the power losses were due to their residual conductance. No significant cryogenic losses were observed in the 70 K region of the coupler. The assembly of TTF4 couplers is currently underway.

4.3 Whole Surface TiN Coverage of TTF2 Coupler

Initiation of multipactor modes in real RF transmission systems is not fully predictable. Due to a large area exposed to warm vacuum in TTF2 coupler, it is justified to protect it by TiN covering of all vacuum-facing surfaces. Apart form ceramic windows four main components of the coupler (the doorknob wave guide, inner and outer electrodes of the warm coax. and complete cold coaxial line – see Figure 1a) were separately surface-treated using different filament systems. A complete account on these activities is given in [3]. Like in the case of ceramic components, titanium layer was partially converted to TiN in ammonia. Except non-accessible areas (like bellows ect.) the estimated Ti layer thickness varied form 10 to 25 nm.

The sublimation setup for cold coaxial line was composed of eight vertical filaments supported on insulated titanium rods, inserted between the antenna and the outer conductor. Full coverage with titanium of the inner surfaces was reached. The short filament – substrate distance (<1 cm), however, resulted in a visible lack of the layer homogeneity in some areas.

RF check of the coupler showed a very short processing time (5 hours) needed to reach 1 MW stable power regime at a pulse length of 0.02 ms and repetition rate equal 2 Hz. Without the protective layer this time amounts to roughly 3 days and after argon processing drops down to typically 16 h [6]. After extending the power load up to 1.8 MW, however, electron emission started in a strictly localized area of the antenna surface, at a pulse length of 0.8 ms. It could not be suppressed by further processing. The antenna is to be replaced by a new one and the coating procedure will be repeated. A detailed account on RF processing of TTF2 coupler is given in [7].

5 CONCLUDING REMARKS

A sublimation TiN-coating technique has been used for antimultipactor protection of TESLA couplers. A significant improvement was achieved as to RF performance of TTF2 wave guide windows.

Also the complete TiN coverage of the coupler resulted in a strong reduction of the conditioning time necessary to reach the designed working regime. Nevertheless, the subsequent RF power overload led to a permanent electron activity in cold coax. in TTF2. Since the warm parts of TTF2 coupler behaved correctly during the RF tests we want to change only the antenna together with the cold window.

6 ACKNOWLEDGMENT

Thanks are due to all the colleagues who contributed to the construction and development of the existing TiN coating apparatus at DESY and to RF tests.

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