

THIN FILM COATINGS FOR SUPPRESSING ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS

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Abstract

Thin film coatings are an effective way for suppressing electron multipacting in particle accelerators. For bakeable beam pipes, the TiZrV Non Evaporable Getter (NEG) developed at CERN can provide a Secondary Electron Yield (SEY) of 1.1 after activation at 180°C (24h). The coating process was implemented in large scale to coat the long straight sections and the experimental beam pipes for the Large Hadron Collider (LHC). For non bakeable beam pipes, as those of the Super Proton Synchrotron (SPS), CERN started a campaign to develop a coating having a low SEY without need of in situ heating. Magnetron sputtered carbon thin films have shown SEY of 1 with marginal deterioration when exposed in air for months. This material is now being tested in both laboratory and accelerator environment. At CERN's SPS, tests with electron cloud monitors attached to carbon coated chambers show no degradation of the coating after two years of operation interleaved with a total of 3 months of air exposure during shutdown periods. This paper presents the SEY characteristics of both TiZrV and carbon films, the coating processes and the proposed route towards large scale production for the carbon coatings.

INTRODUCTION

Electron Multipacting (EM) is generated when secondary electrons, in resonance with an alternating electrical field, induce electron multiplication, leading to the formation of an electron cloud. In particle accelerators, this electron cloud may induce dynamic pressure rise, transverse emittance blow up, thermal load and beam losses. Among the several possible cures, the reduction of the effective maximal SEY, (δ_{\max}), of the beam pipe walls may mitigate or eliminate EM. The δ_{\max} required to avoid multipacting in a given machine depends on beam structure, the geometry of the beam pipe and the electric or magnetic fields applied.

CERN has been developing and applying coatings to reduce the SEY of technical surfaces in order to mitigate EM in its accelerators. For bakeable beam pipes, NEG coatings are a proven technology. More than 5 km of the Long Straight Sections (LSS) of the LHC are coated with a TiZrV NEG thin film, assuring a δ_{\max} of 1.1 after in situ thermal activation [1]. Furthermore, the getter properties of this coating provide a high distributed pumping speed contributing to excellent dynamic vacuum behavior.

A new challenge arrived with the upgrade of the SPS, the last accelerator in the LHC injection chain. Electron multipacting is one of the limitations in delivering the

beam for LHC to achieve its ultimate luminosity. The maximal allowed SEY is also 1.3, but NEG coatings cannot be applied since the beam pipes are embedded in the dipoles and there are no space for bakeout equipment. A thin film coating with $\delta_{\max} < 1.2$, not requiring in situ heating and robust against air venting became a desideratum. The material chosen was carbon.

If carbon coatings are chosen to mitigate electron multipacting in the SPS more than 750 beam pipes have to be coated. Two scenarios are possible: 1) coat new beam pipes and insert them in the magnets, (a very expensive and time consuming operation since the magnets have to be disassembled/assembled); 2) coat the actual beam pipes without disassemble the magnets. For scenario 1), less constraining, all the technical issues for industrial scale productions are solved. For scenario 2), the most advantageous but also the more constraining, further developments towards large scale production are still required.

NEG COATING

The TiZrV NEG coating is produced by DC magnetron sputtering from targets of Ti, Zr and V, resulting in an atomic composition of $Ti_{30}Zr_{30}V_{40}$ [2]. Since composition is not a critical parameter, it is prone for large scale production. Standard thickness is 2 μm and the low activation temperature, 180° for a period of 24h, seems to be correlated with its nano-crystalline structure (3 to 5 nm grains) [2]. The SEY of the NEG before and after activation at 250°C for 2h is plotted in figure 1.

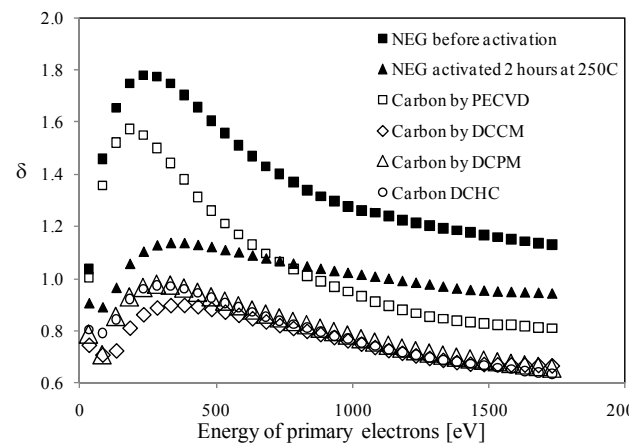


Figure 1: SEY as a function of the energy of the primary electrons for NEG, (before and after activation), and for carbon coated by different techniques.

Table 1: Parameters and characteristics of carbon coated by different techniques.

Coating technique	pressure [mbar]	Power [W/m]	T [°C]	δ_{\max} initial	δ_{\max} aged	Comments
DCCM in ECM Liner	8.0×10^{-2}	400	250	0.93	0.95	After 5 months in air
DCCM in ECM Liner	8.0×10^{-2}	400	250	0.95	0.95	After 4 months in the SPS
PECVD in ID100mm tube	2.0×10^{-1}	200	100	1.57	1.55	After 1 year in air
DCHC in MBB 40cm	1.2×10^0	360	<150	0.96	0.99	After 1 month in air
DCPM in MBB 20cm	4.0×10^{-1}	385	<150	0.96	0.98	After 3 months in air

The effect of exposure to the most common gases in ultra high vacuum systems, CO, CO₂, H₂ and H₂O was investigated by Scheuerlein et al [3] that report an increase of δ_{\max} by about 0.1 after exposure to the equivalent of 3000 L.

To coat the more than 1300 beam pipes for the LHC three DC Cylindrical Magnetron, DCCM, sputtering coating units, able to process beam pipes up to 7.5 m in length and 500 mm in diameter, were implemented at CERN (Figure 2.)

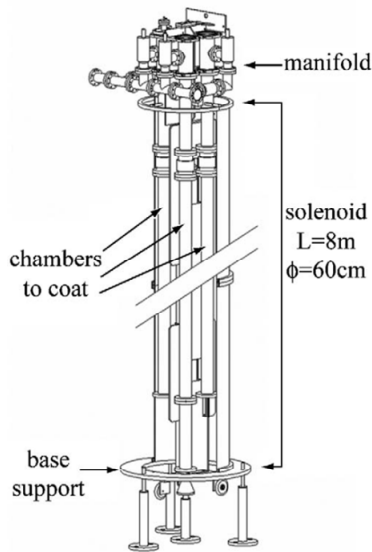


Figure 2: Drawing of the set-up for DCCM sputtering systems at CERN.

Details about the coating unit and process can be found in [2]. The coating cycle for each unit takes 2.5 working days. Operating two units in parallel allowed a maximal weekly production rate of 20 standard LSS chambers (7m long; φ80 mm, DN100CF flanged). The TiZrV thin film is now used in many particle accelerators worldwide.

CARBON COATING

Both Plasma Enhanced Chemical Vapour Deposition, PECVD, and sputtering of a graphite target were explored as coating techniques. The performance of the coatings was evaluated by SEY measurements in laboratory and electron cloud current measurements in the SPS using

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Electron Cloud Monitors (ECMs), [4, 5]. Sputtered coatings shows superior performance and several configurations are being explored to optimize the coating process and to adapt it to the different beam pipes geometries and coating scenarios.

Scenario 1: coat new beam pipes for further insertion in the magnets

New beam pipes can be coated by DCCM sputtering using the same facility used for the NEG coatings (Figure 2.). The beam pipe, without flanges, is housed in a cylindrical vacuum chamber, (Figure 3), and the target is made of two graphite rods φ13 mm (ashes content <400ppm).

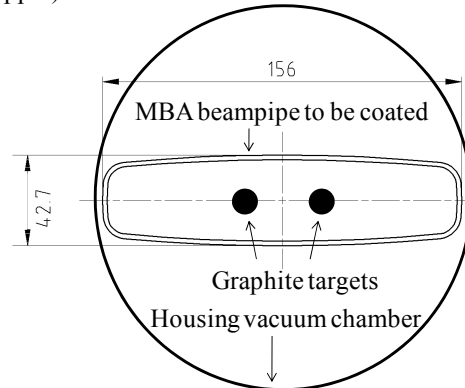


Figure 3: Set-up to coat the beam pipes of the MBA dipoles of the SPS by DCCM sputtering. A magnetic field of 180 Gauss is supplied by 8 meter solenoids.

Discharge gas is Ne and typical coating parameters are in Table 1. Four to eight hours of coating, depending on chamber's geometry, are necessary to achieve a thickness of about 400 nm. The δ_{\max} measured in laboratory is below 1.0 and we have observed a correlation with the level of contaminants in the plasma during film growth. In Figure 4 the δ_{\max} is plotted versus the hydrogen and carbon monoxide signal read by the Residual Gas Analyzer, RGA, at the end of the coating process.

The sources of contamination are the outgassing from the cathode, the beam pipe and its housing vacuum chamber. The deterioration of the δ_{\max} values (ageing) of samples wrapped in aluminium foil and stored in laboratory air for several months is negligible. Since 2008

several ECM were coated, inserted in the SPS and tested during Machine Development, (MD), runs, where they are exposed to nominal LHC beam. Electron cloud signals remain 10^{-4} below reference stainless steel ECMs even after more than two years of operation interleaved with several months of integrated air exposure [4]. Some of the ECMs were analyzed in laboratory after being tested in the SPS. No ageing or damage of the coating was observed.

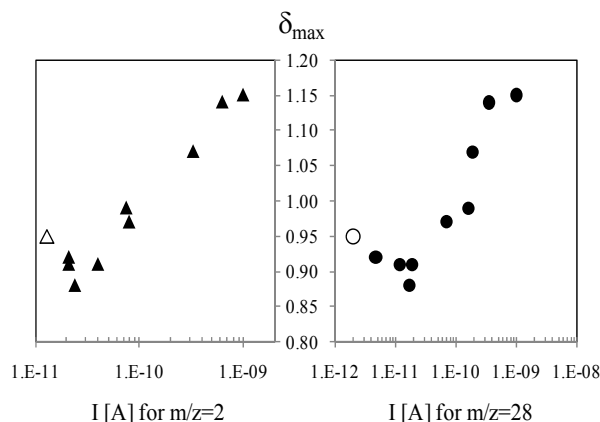


Figure 4: δ_{\max} as a function of the RGA signal for H₂ (triangles) and CO (circles) for carbon coated by DCCM. For filled markers the substrate temperature was 300°C, for the unfilled marker 200°C.

Two SPS MBB dipoles are equipped with carbon coated chambers and will be tested in the machine during 2011. As the beam pipes have to be removed/coated/re-inserted in the magnets, increasing the time and cost for the whole operation, DCCM remains a second choice solution.

Scenario 2: coat the actual beam pipes without disassemble the dipoles

PECVD coatings were produced in cylindrical vacuum chambers, with a diameter of 100 mm and 500 mm in length, using acetylene (C₂H₂) as precursor gas. In spite of the wide range of coating parameters tested, (temperature, pressure, flow rate, voltage, power), the δ_{\max} of these coatings are always about 1.5 (Figure 1), above the threshold to produce e-cloud in SPS. We believe this high yields are due to the presence of hydrogen during the film growth. As this hydrogen is inherent to the PECVD we discarded this process.

For sputtering, two different configurations are being explored: DC Planar Magnetron, DCPM, using arrays of permanent magnets, and parallel plates DC Hollow Cathode DCHC. The main constraints are the limited chambers aperture, their length, the impossibility of bakeout and the maximum allowed temperature during the coating (150°C). In DCPM, the magnetic field is assured by arrays of ring/cylindrical assemblies of SmCo permanent magnets housed in a rectangular stainless steel vacuum tight box. The graphite targets are placed on the top/bottom of the box and isolated by ceramic spacers.

The whole assembly is inserted in the centre of the beam pipe, supported on wheels and the plasma develops between the targets and the top/bottom of the vacuum chambers. A 300mm long prototype was tested so far and the SEY measured in the laboratory gave good results and slow ageing (Table 1). 2 and 7 meter long prototypes are under construction in order to coat ECMs and real size SPS dipoles. For the parallel plates DCHC configuration the target is an array of rectangular cells of graphite. The electrons are reflected by the four sides of each cell, confining the plasma. A 400 mm long prototype was successfully tested. Main difficulty is the uniformity of the discharge among cells. As δ_{\max} values and ageing were good, 2 and 7 meter prototypes are under construction in order to coat EC monitors and real size dipoles.

SUMMARY AND FUTURE WORK

NEG coatings are a proven solution to mitigate EM in bakeable beam pipes of particle accelerators. More than 5 km of the LHC are coated with TiZrV and several other machines around the world have adopted this solution. Further decrease of the activation temperature to 150°C is desirable in order to cope with the thermal restrictions of small gap magnets for future very high luminosity accelerators.

Carbon coatings enter the last phase of development and validation. In spite of being well controlled in laboratory, the ageing mechanisms are not yet fully understood and further work must be done in this direction. The influence of substrate temperature, plasma contaminants and ion bombardment during the film growth must be carefully tackled in order to optimize the coating process. The sputtering technique to coat beam pipes out of the magnets is ready for industrialization, but the implementation of this solution is compromised by the high cost of the insertion of the chambers in the magnets. So, the development of techniques to coat the chambers in the magnets became crucial. Short prototypes of DCPM and DCHC gave encouraging results but the feasibility of industrialization for 6.4 meter long magnets must be assessed before the end of 2011.

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