Materials of Low Secondary Electron Emission to Prevent the Multipactor Effect in High-Power RF Devices in Space

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Abstract

Deposition methods of promising low secondary electron emission coatings such a TiN_x, CrN_x and CN_x have been studied using ion assisted electron gun evaporation in nitrogen atmosphere. Surface composition, by XPS, crystalline structure, by XRD, and morphology by SEM have been studied. Secondary electron emission coefficient has been correlated with multipactor threshold power. For each material its distinguishing physical properties and its prospect for antimultipactor coating implementation as a function of the composition of the films is obtained. TiN_x and CN_x, both obtained in crystalline phase, appear as excellent coatings to prevent multipactor.

Introduction

The multipactor effect sets one of the main limits to the working power of RF devices in space. The multipactor discharge is an electron avalanche in vacuum in resonance with the RF field and sustained by the secondary electron emission (SEE) from the surfaces exposed. This electron avalanche phenomenon appears for a determined power, frequency and electrode or wall distance and may destroy a RF equipment working in vacuum.

The main objective of this work has been to prepare and characterize coatings that delay the appearance of multipactor discharge, i.e. increase the multipactor threshold power, relating the SEE properties of the coatings with the multipactor test results. For this purpose we have selected titanium nitride, chromium nitride and carbon nitride coatings as the best coatings to prevent multipactor.

Experimental

A “Varian” system with a glass bell jar was dedicated to the deposition of the coatings. It has an ultimate vacuum of 1×10^{-8} torr and includes an electron bombardment evaporator and a 3 cm diameter ion gun (Commonwealth Scientific). Aluminium alloy blocks were used as the substrates of the coatings to be multipactor tested at ESTEC. Ion assistance consists of the Ar^+ ion bombardment with energy in the range of 100-200 eV and 0.2 mA/cm^2 ionic current, in a radius of about 5 cm, while the coating is being deposited

X-Ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) have been used to analyze the composition, morphology and structure of the coatings. Total SEE yield (σ) was measured varying the primary electron beam energy (E_p) from 20 to 2000 eV, while the sample current to ground was recorded. The sample was biased at -30 eV, to repel secondaries. We obtain the total secondary electron emission coefficient from the relation: σ = 1 – (sample current / primary current). The primary current of the electron gun was obtained by a relative calibration method, using the total secondary electron emission yield of platinum[1]. $\sigma(E_p)$ is characterised by the parameters: E_1, the first primary electron energy at which $\sigma = 1$, σ_m, the maximum yield, E_m, the primary electron energy at the maximum yield and E_2, the second primary electron energy at which $\sigma = 1$.

Multipactor threshold power was determined at ESTEC. The following parameters were used in the tests: frecuency = 5.3Ghz, pulse width = 25μs, temperature: ambient,P~10^{-6}mb.

Results and Discussion

1.- Titanium nitride coatings

Titanium nitride thin films have been used with success as anti-multipactor coatings in RF devices [2, 3, 4], due to their low SEE coefficient (σ) in vacuum conditions. However air exposure produces a so important increase of σ that these coatings can become unusable for anti-multipactor applications. A treatment that hinders this process after air exposure is needed. We have found that the argon ion assistance during deposition produces titanium nitride coatings with lower SEE coefficient even after long air exposure. In *Table 1* we compare the SEE parameters of titanium nitride coatings that have been exposed to air for a similar time, but prepared with and without ion gun assistance. The XPS quantitative analysis is also shown. Apart from the higher nitrogen incorporation to the surface of the coatings that is shown by XPS, from XRD and SEM analysis can be observed the different structure and morphology that is produced in each case. Thus, the XRD patterns in 2θ = 20º-80º of the assisted coatings, present reflections from (111) and (200) planes that are identified with TiN of cubic structure (Osbornite). This phase is not distinguished in the case of the un-assisted coatings, appearing only crystalline phases of metallic and oxide titanium. The SEM micrographs, show that the assisted coatings have a flatter surface.

This improvement of the secondary electron emission properties with the argon assistance is correlated with a spectacular increase of the multipactor threshold power from 4.2 kW to 14 kW.

Table 1 Comparison of σ_m and E_1 values and XPS quantitative analysis for titanium nitride samples deposited with and without argon ion assistance.

Ion assistance	SEE parameters		Surface composition				Air exposure (days)
	σ_m	E_1 (eV)	O	N	C	Ti	
YES	1.17	147	1.48	1.17	0.17	1.00	7
NO	1.58	53	1.40	0.81	0.76	1.00	4

2.- Chromium nitride coatings

As far as we know, the SEE characteristics of chromium nitride have not been reported in the literature. The SEE yield of the chromium nitride coatings appears as the most stable after air exposure in spite of the σ value of these coatings in vacuum is not as low as the one of the other coatings presented in this work. We have observed that the Cr_2O_3 layers that grow upon air exposure have low SEE [2]. Thus, the high increase of the nitrogen content that happen when the films are deposited with argon ion assistance, does not lead to an improvement of the SEE characteristics (see *Table 2*). As in the case of titanium nitride coatings, the assistance produces the appearance of a new crystalline phase associated with the nitride (hexagonal β-Cr_2N structure).

Multipactor results are consistent with the SEE results since the coating deposited with ion assistance showed highest multipactor threshold (9.5 kW) than the un-assisted ones (5.75 kW and 6.2 kW).

Table 2 Comparison of SEE parameters and surface composition of chromium nitride coatings obtained without and with Ar^+ assistance.

Ion assistance	SEE parameters		Surface composition				Air exposure (days)
	σ_m	E_1 (eV)	O	N	C	Cr	
YES	1.78	41	0.54	1.22	0.46	1.00	3
NO	1.71	63	1.23	0.19	0.56	1.00	3

3.- *Carbon and carbon nitride coatings*

Graphite and sp^2 hybridized amorphous carbon coatings present one of the lowest σ found in the literature[5, 6]. As far as we know, the SEE characteristics of carbon nitride have not been reported in the literature. We prepared carbon and carbon nitride coatings by evaporation of graphite in a nitrogen atmosphere with occasional argon ion assistance during deposition. The SEE characteristics and the surface compositional analysis of the films are presented in *Table 3*. The XRD patterns present peaks in the $2\theta = 10^o\text{-}80^o$, which correspond to the hexagonal and chaoite structures of carbon.

The carbon and carbon nitride coatings tested at ESTEC discharged at 7 kW. The “as-grown” non-contaminated CN surface has a value of σ_m lower than unity and therefore, no multipactor would be produced at any RF intensity. In multipactor tests, with appropriate conditioning, these low σ_m values are expected to be recovered, and consequently the multipactor effect to be suppressed. CN coating should be retained as a qualified candidate to mitigate multipactor.

Table 3 Carbon and carbon nitride coatings deposited evaporating graphite in a nitrogen atmosphere with occasional Ar^+ assistance during deposition.

Ion assistance	Substrate	SEE parameters		Surface composition				Air exposure (days)
		σ_m	E_1 (eV)	O (%)	N (%)	C (%)	Ar (%)	
YES	Al	1.30	64	3.7	22.0	73.2	1.1	4
YES	Mo/Al	1.42	52	4.5	16.2	78.2	1.1	8
NO	Mo/Al	1.23	91	4.4	-	95.6	-	2

Multipactor Test Results

In *Fig. 1* we present the multipactor threshold power obtained for the different titanium nitride, chromium nitride, carbon and carbon nitride coatings tested at ESTEC compare to that of “Alodine” (the passivating coating for Al-Cu-Mg-Mn aluminum alloys used in the aerospace industry to prevent multipactor). For the multipactor threshold power of “Alodine” we have used an average value from ESTEC data[7]. *Fig. 2* shows a reasonable correlation between E_1 and the multipactor threshold power. The scatter can be due to the time elapsed between the SEE measurements and the multipactor test.

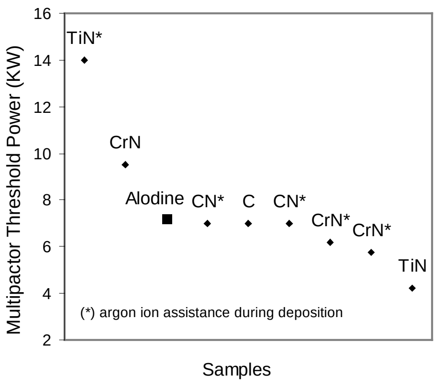

Fig. 1 Multipactor threshold power of the different coatings of this work vs. "Alodine"

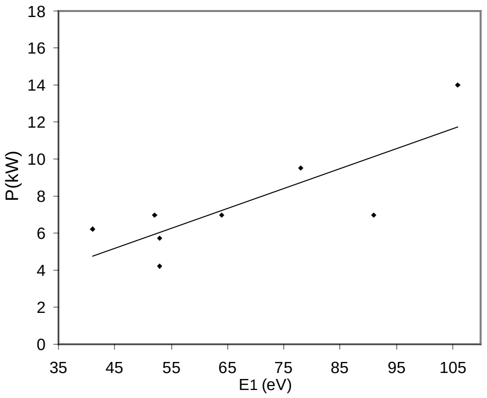

Fig. 2 Multipactor threshold power vs. E_1 at normal incidence

Conclusions

- The secondary electron emission properties dramatically depend on the composition of the monolayers closest to the surface. Contamination with O and C from the air increases drastically $\sigma(E)$ and, therefore, reduces the multipactor threshold.
- The SEM and XRD analysis have shown that roughness and structure of the surface, which are strongly affected by the ion gun assistance during deposition, have an important influence in the SEE yield.
- A high correlation has been found between the values of σ and the multipactor threshold power. The scatter in the results is explained by the time elapsed between the SEE measurements and the multipactor test.
- The multipactor tests, performed at ESTEC, showed higher multipactor threshold for some of the coatings presented in this work than for the "Alodine". The best titanium nitride discharged at 14.2 kW, the best chromium nitride discharged at 9.5 kW and for the carbon nitride coatings the multipactor threshold was around 7 kW.
- Excellent results have been reached using crystalline TiN_x coatings obtained with ion gun assistance.
- Surface passivation to avoid degradation on air exposition appears as the main objective, so that the original high electron affinity of the coating is maintained or easily restituted after a simple conditioning treatment, such as electron irradiation.

Acknowledgements

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