MEASUREMENT OF MULTIPACTING CURRENTS OF METAL SURFACES IN RF FIELDS

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Abstract

Multipacting currents can absorb RF energy and produce breakdown in high power components such as couplers, windows, higher order mode absorbers, etc.. This phenomenon starts if certain resonant conditions for electron trajectories are fulfilled and if the impacted surface has a secondary yield larger than 1. There are known recipes to reduce the secondary yield by coating techniques but the success rate is often unsatisfactory. Therefore we have started systematic measurements of the RF multipacting current. We measure the multipacting current between two electrodes of a specially designed coaxial resonator. Technical surfaces (Cu, plated Cu on stainless steel, Al, stainless steel) have been investigated before and after surface treatments such as chemical cleaning, baking and Ti coating. We present data for the strength of multipacting, start current, processing time and possible reconditioning.

I. INTRODUCTION

Multipacting is a phenomenon of resonant electron multiplication:

- one electron is accelerated by the electric RF field and hits the target surface after one even (odd) number of RF half cycles as resonant condition for one (two) surface multipacting,
- the impacting electron produces more than one secondary electron.

These two conditions have to be fulfilled in order to start an electron avalanche. This electron current might result in severe limitations of the stored energy in microwave components or finally ignite a breakdown. To suppress these limitations, the resonant condition can be avoided by proper choice of geometry. Resonant conditions for a parallel plate geometry in pure electric fields can be easily predicted and thus be avoided by the right gap distance. In the case of electromagnetic fields, however, multipacting is simulated by tracking programs. In the case of complicated three dimensional RF components a simulation of electron trajectories becomes very demanding. Furthermore the RF design might not allow to change the geometry by the needed amount.

Therefore attempts are undertaken to suppress multipacting by proper coating of critical surfaces. A material for coating is chosen which has a secondary yield of smaller than or at least near by one. Different coating materials are known, for example Ti, TiN, CrO_2, etc. [1] . Those materials have been investigated by measuring the secondary yield in DC experiments on sample surfaces. RF components might have complicated geometry to be coated. The improvement also depends on coating conditions of large technical surfaces. Therefore a test resonator was developed to measure the RF multipacting current directly under various coating conditions. For fast turn around this resonator should allow a fast exchange of the multipacting electrodes and should operate at low power. In this paper the design of such a test resonator is given and first measurements on different coatings are presented.

II. DESIGN OF THE TEST RESONATOR

The resonant condition for two side multipacting in an electric field is given by:

$$E_{(n)} = \frac{4m\pi}{e} \cdot \frac{f^2 l}{(2n-1)} \tag{1}$$

n: order of multipacting (n:1,2,3,...)
f [Hz]:   frequency
l [m]:   gap distance
m [kg]: mass of electron
e [C]:   charge of electron
$E_{(n)}$ [V/m]:   resonant electric field gradient

The magnetic RF field in the center gap of a reentrant resonator is small as compared to the electric RF field. Therefore two side multipacting according to equation (1) is expected in such a resonator. The experiment prooved that multipacting actually occures at the predicted field levels. This
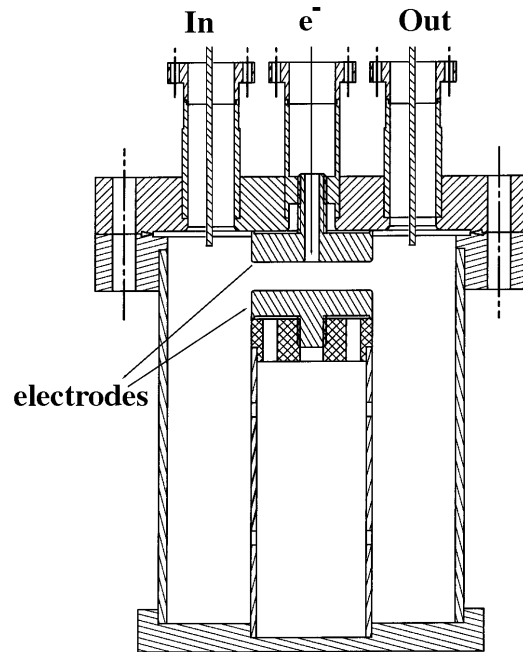

Figure 1: Test resonator

resonator has been also analysed by trajectory calculations and is discussed in [2].

A resonant frequency of 500 MHz has been chosen because of available laboratory equipment. The gap distance of 10 mm is rather large but hereby dimension tolerances by many assemblies can be neglected. Typically 10 watts of RF power is needed to reach first order multipacting. The diameter of the resonator is uncritical and was chosen according to available material.

The resonator is fabricated from copper (resonator) and stainless steel (flange) plated with copper. The two ports on the top cover are used for pumping and RF coupling. Both RF antennas have the same coupling in order to maintain the symmetry of the central electric field. A small coaxial line penetrates the upper center electrode to give a direct measure of the multipating current.

length	mm	113
outer diam.	mm	100
inner diam.	mm	42
gap distance	mm	10
resonance frequ.	MHz	500
watts/1 kV gap		5.88×10^{-3}
typ. unloaded Q		5×10^{3}

Table 1: Data of the multipacting resonator

III. MEASUREMENT PROCEDURE

After assembly of a pair of electrodes the upper Conflat flange is closed and the resonator is pumped to better 10^{-6} mbar. The generator is locked to the cavity resonance and the antennas are calibrated at low RF feld level. Then the RF power is modulated up to 20 watts with a saw-tooth generator of 0.1 Hz. The onset of multipacting current is measured and the order of multipacting is determined from the calibrated gap electric field gradient. The magnitude and the processing behavior of the mutipacting current are measured the following way:

- the RF cavity power is set to 5 watts above the onset of multipacting,
- the cavity is operated under these conditions with the generator frequency locked to the cavity,
- the multipacting current will decrease and the cavity field will increase until the electron current completely disappears. At this moment the cavity field will jump up to the undisturbed value,
- the cavity is operated for about 2 h after the first processing because sometimes multipacting will reappear.

From the above given procedure the following characteristic data are extracted:
- order of observed multipacting,
- typical decay time of multipacting current during processing,
- time needed to overcome multipacting,
- tendency of deconditioning.

IV. MEASURED RESULTS

For each measurement one pair of electrodes (= one sample) is prepared and installed. Most work has been done with Cu and stainless steel samples to calibrate the measurement equipment and to test the reproduceability of the multipacting behavior. 6 Cu samples (3 from OFHC copper, 3 from standard copper) and 4 stainless steel samples have been fabricated. After each measurement the samples were slightly chemically polished so that a new surface was prepared for the next measurement. Some Cu samples were coated with Ti (sputter technique), one sample was coated with TiN (thermal evaporation) [3]. Four stainless steel samples have been electroplated with 20 µm of Cu. Four samples (2 Cu, 2 Ti on Cu) have been stored in a plastic (PE) bag (filled with dry N_2) for one week. Table 2 summarizes the measured results. The numbers of the multipacting current and of the processing time are mean values of the individual measurements. They differ typically from measurement to measurement by 12 % (current) and 40 % (time). The value of the electric field at the onset of multipacting varies only by 7

MATERIAL	N	I [mA]	E1 [kV/m]	E2 [kV/m]	n	t [s]
Copper	18	2.92	132.1	188.4	1	2080
Copper (heated at 400°C)	2	3.52	145.8	231.4	1	1223
Cu, stored one week in PE bag	2	3.30	82.5; 139.0	108.9; 192.8	2 ; 1	>6500
Titanium on Copper	5	3.03	139.9	184.5	1	933,1
TiN on Copper	1	3.00	129.3	170.7	1	552
Titanium on Aluminum	2	2.88	141.8	183.4	1	885,5
Cu Ti, stored one week in PE bag	2	3.21	51.1; 123.6	68.1; 190.0	3 ; 1	>6500
Aluminium	7	4.30	54.7	69.4	3	>6500
Stainless Steel	18	3.37	69.3; 128.8	87.7; 147.6	2 ; 1	2781
Copper electrochemically plated on S.S.	7	3.33	132.7	183.8	1	2571

Table 2: Results of the multipacting measurements (N: number of measurements; I: multipacting current; E1, E2: electric field gradient at onset, stop of multipacting current; n: order of multipacting; t: processing time)

%. The order of multipacting is deduced from equation (1).

Figure 2 shows the typical processing behavior of Al, Cu and stainless steel samples. The multipacting current is plotted versus time under the condition of additional 5 watts RF power above the first onset of multipacting.
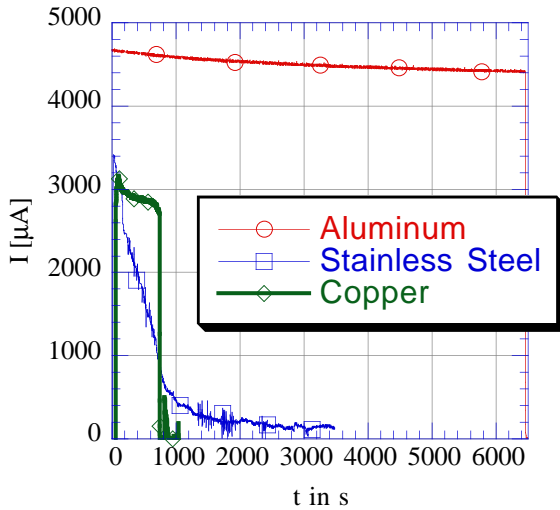

Figure 2: Multipacting current vs. time for 3 different metals

Figure 3 displays the multipacting current versus the gap voltage during processing. The multipacting current drops down so that the power being absorbed from the multipacting process decreases, too. Therefore the stored energy in the resonator and thus the electric field in the gap increase. The condition of equation (1) predicts a resonant voltage of 176 kV/m (n=1) for our geometry. The experiment shows multipacting between 150 and 210 kV/m. The width of the multipacting region is larger at lower multipacting orders. This is due to a spread of starting velocity and starting angle of the secondary electrons.
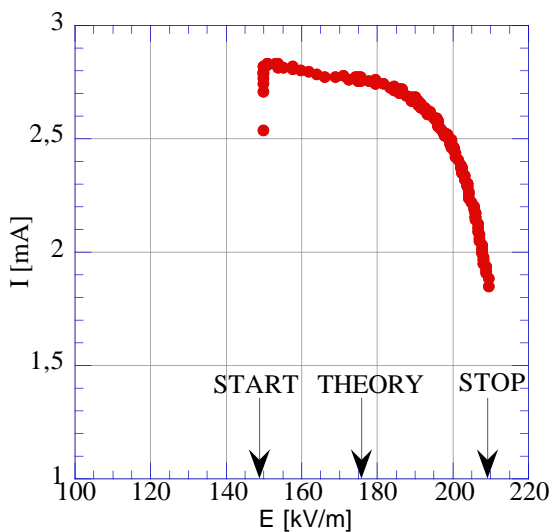

Figure 3: Multipacting current vs. electric field gradient for Titanium on Copper

V. DISCUSSION

All samples show multipacting of at least first order. They differ in magnitude of multipacting current and in processing time. Al samples show the worst behavior, as expected. They do not process within the measurement time of 6500 sec..The multipacting behavior of standard copper and OFHC copper does not differ at all. Heat treatment of 400°C, 6 hours, reduces the processing time to 60 %. Coating of Cu with Ti reduces the processing time to about 45%. A Ti coating of Al has a substantial improvement because of the strong multipacting behavior of the bare Al. After coating with Ti, samples from Cu and Al behave the same. Electroplated Cu on stainless steel is somewhat worse than pure copper before heat treatment.

One interesting result is the dramatic deterioration of Cu and Ti coated Cu samples after storage in a plastic (PE) bag. Both types of samples do not process within 6500 sec. after storage in the bag. This deterioration was also reported by another experiment [4]. The mechanism is not understood. One speculation is, that some lubricant in the PE foil penetrates to the metal surface of the sample. Nevertheless, the common practice to store or transport RF components in plastic bags should be avoided, if multipacting is of concern.

VI. ACKNOWLEDGEMENT

VII. REFERENCES

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