RF processing of field emitting particles

J. Tan[a)], H. Safa[b)], B. Bonin[b)], J. Jodet[c)]

a) Thomson Tubes Electroniques, 78141 Vélizy Cedex, FRANCE

b) DAPNIA / SEA, & c) INSTN / SEPEM— Centre d'Etudes de Saclay, 91191 Gif sur Yvette Cedex, FRANCE

Abstract

In this paper, we describe the results obtained from RF field emission experiments on niobium samples polluted with metallic particles. In particular, the influence of the electromagnetic field, the RF pulse length as well as the total number of pulses applied is shown. The peculiar cumulative effect found could bring some new light on the so called high peak power (HPP) processing of cavities.

1. INTRODUCTION

It is now well established that field emission (FE) on broad area electrodes or in radiofrequency (RF) cavities is generally associated with local surface defects such as scratches or contamination particles [1], [2], [3]. Many theoretical models have been developed [4], [5] in order to explain the electron tunneling through the potential barrier at the metal–vacuum interface, for field range two orders of magnitude lower than the theoretical one predicted by Fowler and Nordheim [6]. Lately, FE studies at Saclay [3] showed that the local enhancement of the field can be explained by a modified "projection model"[4] at least for two categories of emitter sites : "intrinsic" sites (i.e. whose composition contains nothing but the substrate's element, e.g. scratches), and "extrinsic" sites (meaning dust particles composed with other foreign species) [2].

Actually a great research effort among the particle accelerators community is undergone to repel FE threshold field. Dealing with scratches, those can be easily removed by means of a "heavy" chemical etching, and one may assume a surface state free of such defects after this treatment.

It had been clearly shown [7], [8] that more cleanliness during the cavity mounting steps led to significant gain for accelerating field. However, the presence of dust particles either in chemical baths or even in cleanroom atmosphere make it more difficult to avoid them on the cavity walls. One proceeds finally to surface treatments *in situ* i.e. with closed cavities.

It is generally believed that RF processing reduces FE by inactivation of emitting sites via a mechanism of thermal instability followed by a microdischarge destroying the site. This mechanism is certainly at work to reduce FE, but we would like to show that HPP processing [9] is also effective to remove mechanically dust particles from the surface, thereby reducing the total FE from the surface.

In a previous paper [10], first experimental results with dust particles obtained with the reentrant 1.5 GHz cavity were reported. Nb samples were intentionally contaminated with iron particles (20–50 μm size) and submitted to an intense pulsed field : 45 MV/m peak with repetition rate $\simeq 1\,Hz$. We noticed incidentally at that time that the number of remaining particles on the surface after applying the RF power was related to the pulse length. Long pulses led to important thermal effects i.e. melting and welding of the particles on the substrate. After treatment, the proportion of particles remaining on the surface was as follows : 75% for long pulses (τ =10 ms) as compared to 30% for short pulses (τ =100 μs). Thus one might deduce that short pulses were more likely to remove dust particles and then "clean" the surfaces. These observations were consistent with Cornell's group who showed the efficiency of HPP processing for reducing FE in accelerating cavities [9].

Following these observations, we wished to undertake a more systematic study in order to lighten the basic mechanism of "cleaning" dust particles by RF pulses. Three parameters appear to be of major importance :

1. the maximum field level on the surface E_{max},
2. the RF pulse length τ,
3. the total number of RF pulses N.

2. EXPERIMENTAL SET UP

The core of the experimental set up is a re-entrant 1.5 GHz copper cavity working at room temperature. A 5 kW klystron permits application of 50 MV/m peak field on the 10 mm^2 hemispherical top of removable niobium samples. As the cavity is not cooled, the maximum allowed RF power duty cycle is 1 %. Electrons emitted hit a current probe placed 12 mm afar from the sample collecting an *integrated intensity*. Working pressure is better than 10^{-7}mb. The full description of the apparatus, cleaning and operating procedures has been detailed in a previous paper [11].

The purpose of this work is to study the mechanism of particle removal . Thus niobium samples chemically etched are sprinkled with hundreds of iron particles (20–50 μm size) and examined using a scanning electron microscope (SEM) before mounting in the cavity.

RF duty cycle is always kept equal to 1 %. The reference number of particles is arbitrarily taken to be 100 % after an initial low RF field test ($E_{max} \leq 5$ MV/m) — so as to get rid of uncertainties due to poorly adhering particles that can get lost during transportation between the SEM and the RF cavity. After each RF test, the sample is dismounted from the cavity and observed with the SEM where the number of remaining particles on the surface is counted.

3. EFFECT OF FIELD LEVEL

It has been shown that with a pulse length τ =10 ms and at a field level of 45 MV/m, particles can melt and weld to the sample surface [10]. Therefore, the study of the behavior of particles as a function of field level should give informations about the optimum field to apply answering the following questions : i/ what is the minimum field required to remove a given particle ? ii/ what is the minimum field to cause an irreversible damage (either by welding the particles or by leaving craters on the surface)?

3.1. Experimental procedure

Four Nb samples were prepared following the procedure described in section 2.2, with different τ values for each, namely 10 ms, 1 ms, 100 μs and 10 μs.

All samples were RF processed at a low field level for 30 mn then removed for SEM observations before applying the higher RF field. Thus all samples experience *successively* 14 MV/m, 30 MV/m and 45 MV/m for 30 mn each time.

3.2. Experimental results

The results are summarized in figure 1. As one could expect, the stronger the field, the lower the number of remaining particles and consequently the more efficient is the "cleaning". More interesting is the fact that at a given field, the shorter the pulse length the better is the cleaning.

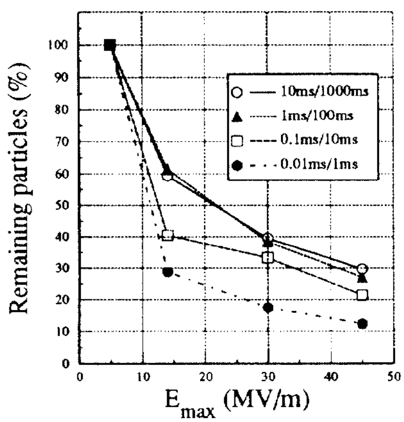

Figure 1. Effect of increasing electric field for different pulse lengths.

3.3. SEM observations

At 5 MV/m, some particles are seen to be lined up along the electric field. Almost all particles seemed in good electrical contact with the substrate as they did not charge under the SEM beam. As the field level was increased, more particles piled up. Below 30 MV/m, no craters were observed on all the samples surfaces with the exception of the sample having the longest pulse length (10 ms) where few craters (about typically 5 μm size) appeared at 30 MV/m. Craters' location was always associated with missing iron particles, and X-ray analysis revealed the presence of Fe element in craters. At 45 MV/m, the number of craters increased with τ.

3.4. FE measurements

Few reliable currents values had been obtained during RF processing. Until 14 MV/m no current signal exceeded the measurement noise (10 pA). For higher field levels, as the working duty cycle chosen was the upper limit for our experiment, microwave heating yielded an important degassing. This led to unstable positive ionization probably near the current probe which altered the current reading. At 30 MV/m the current was generally less than 4 μA whereas it increased to 15 μA at 45 MV/m.

After the last RF tests at 45 MV/m, FE measurements were performed once again at 30 MV/m : significant gain on FE was obtained as the final current did not exceed 1 μA for one sample, and 150 pA for another one.

4. TIME PROCESSING EFFECT

4.1. Experimental procedure

Four other Nb samples were prepared following the procedure described in section 2.2, with different τ values for each (10 ms, 1 ms, 100 μs and 10 μs). After one low field test, all RF tests were done keeping the field constant and equal to 30 MV/m.

We wish to observe whether the total number N of applied RF pulses can modify the number of remaining particles. In other words, is there a cumulative effect of the RF field due to the successively applied pulses and to what extent ? To do so, we apply different time durations t on the same sample, counting after each test, with the help of the SEM, the percentage of the remaining particles. As the effective RF time is $t_{eff} = C \times t$ (C is the duty cycle, here 1 %), the total number of pulses can be evaluated by $N = \frac{t_{eff}}{\tau} = \frac{C \times t}{\tau}$.

4.2. Experimental results

They first confirm the importance of the pulse length that has been already pointed out in the previous section. Short RF pulses are far more efficient than long ones. Moreover, one sees from figure 2 that there is a very strong cumulative effect (at any pulse length) which seems to show no saturation limit : the cleaning of the surface continues as long as the RF power is applied. The longer the time of exposure to RF power, the better will be the processing.

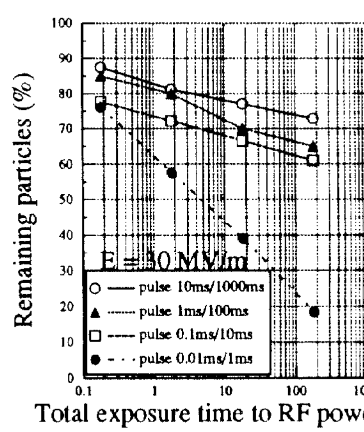

Figure 2. Effect of RF time duration for different pulse lengths.

4.3. *SEM observations*

Figures 3.a and 3.c show the samples before RF tests. In figure 3.b the first sample has undergone 18 s of RF power with a pulse length τ =10 ms, whereas the second sample is shown in figure 3.d after 5 hours of RF power at τ =10 μs. Although the field level was the same for both samples (30 MV/m), one notices that nearly all particles were still lying on the first sample while very few remained on the second one. This clearly proves the efficiency of cleaning with time using very short pulses.

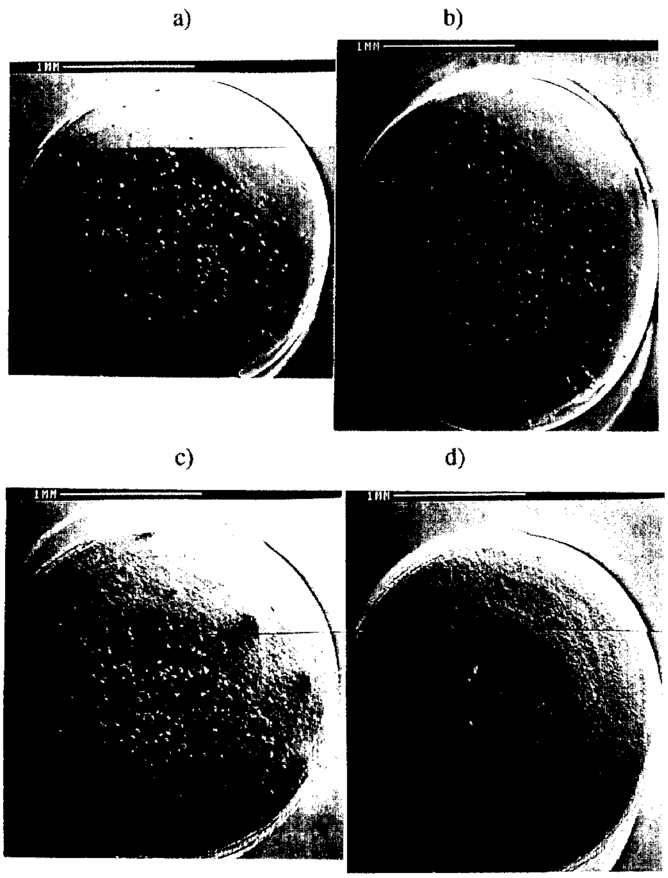

Figure 3. An effective RF processing needs short pulse length and long time : in 3b, the sample shown in 3a before test, has undergone 18s of RF power with τ=10ms. While on another sample (3c before test), 5 hours of processing with 10μs pulses at the same field have nearly clean all particles from its surface (3d after test).

It should also be noted that the surface is much more damaged (craters and molten particles) by long pulses than by short ones, even at the same field and for equal number of RF pulses.

5. DISCUSSION

A first series of experiments confirms the need for high electric field levels to throw away dust particles. Besides, they demonstrate that short RF pulses are also necessary to avoid strong thermal effects that may lead to melting and consequently welding particles onto the surface (generally the contact particle-substrate is very poor). The associated constant time may be easily evaluated and model calculations provides values close to 1 ms [12]. In that view, continuous RF processing for example is expected to be far less effective than pulsed treatments to remove particulate contaminants and to reduce FE.

The second series of experiments suggests that the removal of particulate contaminants by pulsed RF power occurs via a *cumulative mechanism*, and that many pulses of short duration are more effective than a few long ones to clean the surface. In view of this, we predict that medium power pulsed (MPP) processing should be effective to reduce FE, provided the pulse duration and the total processing time are properly chosen.

6. CONCLUSION

This work shows that pulsed RF processing can remove particulate contamination. For that purpose three conditions are required :

— A large number of pulses to obtain cumulative effect,
— Processing with short pulse lengths to avoid welding particles on the surface,
— Applying a high enough peak field to remove particulate.

These new effects contribute to the reduction of FE usually observed after application of "high peak power processing". They should be taken into account in the choice of HPP parameters, favoring (if possible) shorter pulses.

REFERENCES

[1] Niedermann Ph., Ph. D, thesis no 2197, University of Geneva (1986)

[2] Moffat D. et al., Particle Acc., 40, (1992),85–126

[3] Jimenez M. et al., J. Appl. Phys. D, 27, (1994), 1038–1045

[4] Noer R.J., Appl. Phys. A, A28, (1982) 1–24

[5] Latham R.V., IEEE Trans. Elec. Insul., EI23, no 5 (1988), 881–894

[6] Fowler R.H., Nordheim L., Proc. Roy. Soc London, A119,(1928), 173–181

[7] Proceedings of the 2nd Workshop on RF Superconductivity, Geneva, Switzerland (1984)

[8] Proceedings of the 3rd Workshop on RF Superconductivity, New York, USA (1986)

[9] J. Graber, Ph. D, Thesis, Cornell University (1993)

[10] Tan J. et al., Field emission measurements in a radiofrequency field, to be published in J. Phys. D

[11] Tan J. et al., A microwave cavity for field emission studies, to be published in J. Phys. D

[12] Junquera T. et al., Studies on field emission in RF cavities using an optical system, this conference EPAC, London, U.K. (1994)