FIELD EMISSION AND HIGH VOLTAGE CLEANING OF PARTICULATE CONTAMINANTS ON EXTENDED METALLIC SURFACES

J. Tan, B. Bonin, H. Safa
C.E Saclay (DSM/DAPNIA/SEA), Gif sur Yvette, France

Abstract
The vacuum insulation properties of extended metallic surfaces depends strongly on their cleanliness. The usual technique to reduce electronic field emission from such surfaces consists in exposing them to very high electric fields during limited periods of time. This kind of processing also reduces the occurrence of vacuum breakdown. The processing of the surface is generally believed to be due to a thermo-mechanical destruction of the emitting sites, initiated by the emission itself. Comparison of the electric forces vs adherence forces which act on dust particles lying on the surface shows that the processing could also be due simply to the mechanical removal of the dust particles, with a subsequent reduction of field emission from the contaminated surface.

1. INTRODUCTION

Dust particle contaminants are known to be a dangerous enemy of all devices working under vacuum and high voltage, because they tend to promote electron field emission and, subsequently, vacuum breakdown [1,2,3]. This is of concern e.g. for vacuum gaps working in DC regime, but also for klystrons or accelerating cavities in RF regime.

Field emission from extended smooth metallic surfaces has been shown to come mainly from the particles themselves [3]. In DC regime, the conducting particles tend to emit strongly. Their emission obeys a Fowler-Nordheim law, with a field enhancement factor β of 50-200 and an effective emitting area of 10^{-13} - 10^{-17} m^2. The geometrical shape of the particle plays a very important role : the irregularly shaped particles emit more than the smooth ones [4]. For these conducting particles, the emission is probably due to a geometrical field enhancement at the particle apex. Nano-protrusions sharp enough to produce geometrical field enhancement factors as high as 50-100 have indeed been seen on active emitters under investigation with a scanning electron microscope [5]. In RF regime, metallic particles also emit, with a similar phenomenology. Whereas insulating particles do not emit in DC regime, they emit in RF, probably for non-geometrical reasons (as a plausible hint, they tend to heat up in RF). In the following, we shall restrict ourselves to conducting particles.

2. PROCESSING OF CONTAMINATED SURFACES

Experimentally, emission from conducting particles lying on a metallic surface is difficult to study because the particles tend to be blown away under the influence of the electric field. Experiments on RF processing have been made in our laboratory, using an especially designed RF cavity [6]. In this cavity, an RF electric field as high as 60 MV/m is concentrated on the hemispherical top of a removable metallic sample of area 10 mm^2. The field emission properties of the samples can be studied by direct measurement of the field-emitted current. In a dedicated series of experiments [7], the surface of several niobium samples was purposedly contaminated by a controlled amount of iron particles with a size of 10 - 50 µm.The samples were submitted to a pulsed processing with pulses of various durations between 10 µs and 10000 µs. The repetition rate of the pulses was adjusted to maintain in all cases a constant ratio : 'pulse width'/'repetition period' of 1%. The number of remaining particles was measured periodically with a scanning electron microscope, and was found to decrease steadily with increasing processing time.

As expected, the particle density decreased faster for high applied electric fields. Moreover, the cleaning was more effective for many short pulses than for a few long ones with the same processing time. Also, the biggest particles were removed more easily than the small ones.

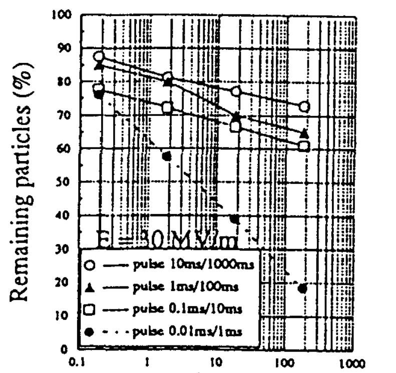

Fig. 1 Dust-cleaning efficiency as a function of processing time.

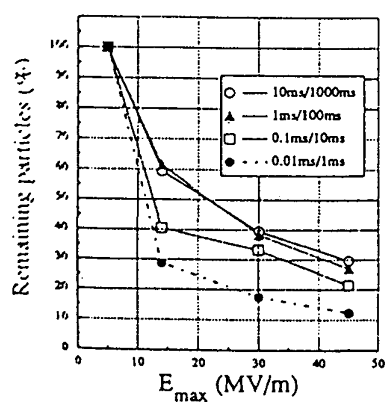

Fig. 2 Dust-cleaning efficiency as a function of the applied electric field.

These results can be interpreted if one evaluates the forces acting on the particles :

1) The electric force is of order : $F_e = \pi.\varepsilon_0.h^2.E^2$, where h is the particle height and E the macroscopic electric field on the surface. Note that the electric force between particle and substrate depends quadratically on the electric field and is always repulsive, independent of the sign of the field; Its magnitude is the same in DC and in RF regimes and is larger for bigger particles.

2) The adherence force depends on the size of the particle, and on many details like the nature and surface state of the particle and substrate. The adherence force is roughly proportional to the particle size. Its order of magnitude is given by the graph of fig.3.

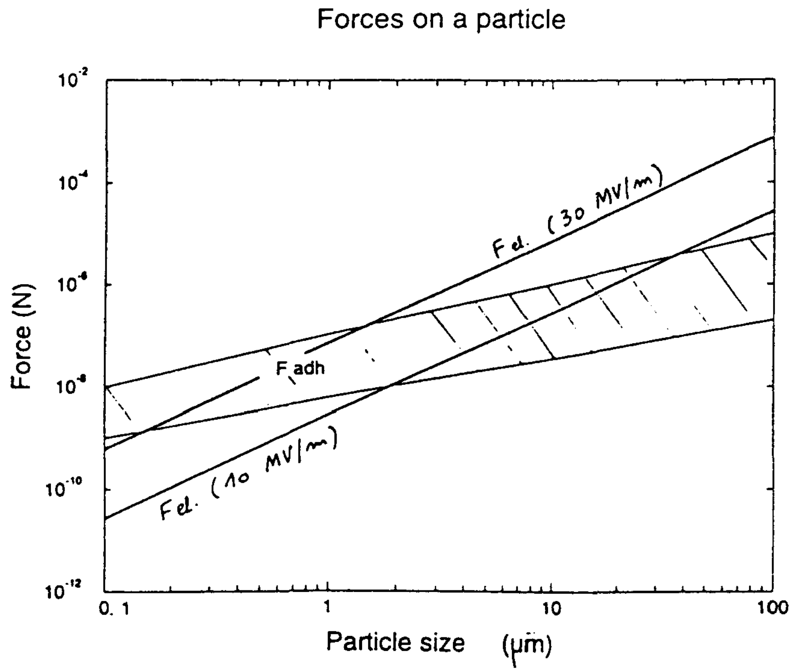

Fig. 3 Comparison between the adherence force and the electric force (for macroscopic fields of 10 MV/m and 30 MV/m) and the adherence force (hatched area). The order of magnitude of the adherence force is taken from [8-11].

It can be seen that for an electric field of 10 MV/m, the electric force exceeds the adherence force for particles larger than 10 μm. With an electric field of 30 MV/m, one can expect to remove micron sized particles. These findings are in line with the results of the present experiment. The fact that cleaning is more complete for long processing times seems to indicate a gradual decrease of the adherence force during the processing.

3. CONCLUSION

We have shown here that application of an intense RF or DC electric field is an effective way of cleaning a metallic surface from conducting particulate contaminants.

The usual technique to reduce electronic field emission from metallic surfaces consists in exposing them to very high electric fields during limited periods of time. The high voltage processing of the surface is generally believed to be due to a thermo-mechanical destruction of the emitting sites, initiated by the emission itself [12, 13]. We suggest that the processing of metallic surfaces contaminated by conducting particles could also be due simply to the mechanical removal of the particles, with a subsequent reduction of field emission from the contaminated surface.

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