FIELD EMISSION INVESTIGATION IN A SCRF CAVITY CONTAMINATED WITH ALUMINA PARTICLES

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Abstract

The presence of foreign particles contaminating the surface of SCRF cavities induces enhanced field emission which is one of the main limitation to obtain the high gradients needed for the next generation of electron accelerators. Different types of particles (metallic or dielectric) were used for contamination studies in a copper cavity at 1.5 GHz. Some relevant results of the induced field emission effects are presented in this paper. These contamination studies are now continued on superconducting surfaces on a special SCRF cavity operating at 3.6 GHz in the TM020 mode. Before contamination, the cavity was successfully tested at 1.8 K reaching a maximum surface electric field of 95 MV/m with a threshold field for electron emission of 40 MV/m.The first contamination experiments of the SRF cavity with alumina particles show unstable electron activity and an important reduction of the quality factor accompanied by strong heating of the high field area.

1. STUDIES AT ROOM TEMPERATURE

1.1 Experimental set-up

A program concerning the contamination of surfaces with foreign particles, its effect on the threshold emission field and the processing mechanisms, was started at the CEN Saclay in collaboration with the IPN Orsay. A special copper cavity was designed for field emission studies at room temperature [1]. This cavity (Figure 1) operated at 1.5 GHz is feeded by a 5 kW klystron in pulsed mode (f=1Hz, pulse length 1 to 5ms).

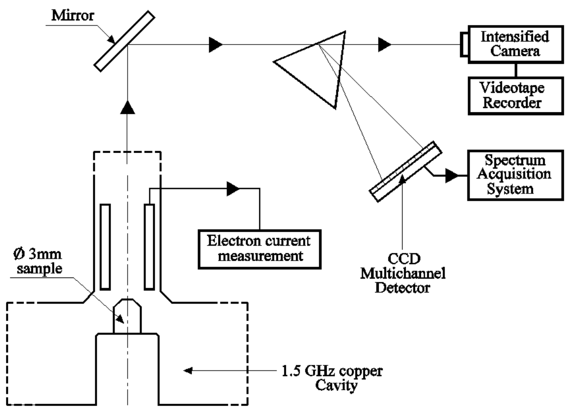

Fig. 1 : 1.5 GHz copper cavity with optical detectors

A removable sample is located in the high field region : the peak electric field (50 to 120 MV/m, for a copper sample) depends on the sample shape (∅3mm or ∅2mm).The avaiblable surface for contamination is limited to several mm^2. The measurement of the electron current with a hollow electrode, and the observation of the high field region through an optical window, allow to record simultaneously the field level, the emitted current and the luminous events. The optical detectors and the associated data acquisition system are described in the Ref. [2].

1.2 Contaminated samples

Systematic control of the samples **before contamination** confirms that the electronic emision is initiated for fields higher than 40 MV/m and the measured electron current stays in the 1nA - 100 nA range at 50 MV/m, and 10 - 100 µA at 120 MV/m. After contamination with foreign particles, the samples are mounted into the cavity before a laminar flow bench. The cavity is finally evacuated to the 10^{-7} mbar pressure range before turn the RF power on.

1.3 Experimental results with alumina particles

a) The size of particles seems to play an important role : small particles (≈1µm) are rapidly processed at high field (80 MV/m), while large particles (20 to 50 µm) show more intense electron and luminous activity starting at 10 MV/m with long processing periods.

b) The typical luminous activity of medium or large size alumina particles is well represented by the figure 2. Bright spots start to be easily detected at 10 MV/m. The density of these spots increase with the electric field and it is accompanied with explosions, and luminous tracks. During the explosive events, large current values (positive and negative) are detected. These currents persist well after the RF pulse duration. At higher fields (> 30 MV/m) the luminous areas are extended to almost the entire sample surface, new areas have appeared while the intensity of other areas has decreased. In this experiment, a maximum field of 46 MV/m was reached.

The electron current recorded during this experiment (Figure 3) shows a typical processing behaviour with highly unstable periods followed by more quite ones. Most of the time important modifications of the emitted current succeed to explosive luminous events. A very reproducible I=f(E) curve was finally obtained, starting at 1 nA @ 20 MV/m, and ending at >10 µA @ 45 MV/m. In the after-processing measurement phase, the stable luminous spots start for Epeak > 25 MV/m, with reduced density of spots, in the absence of explosions or luminous tracks, even at high field.

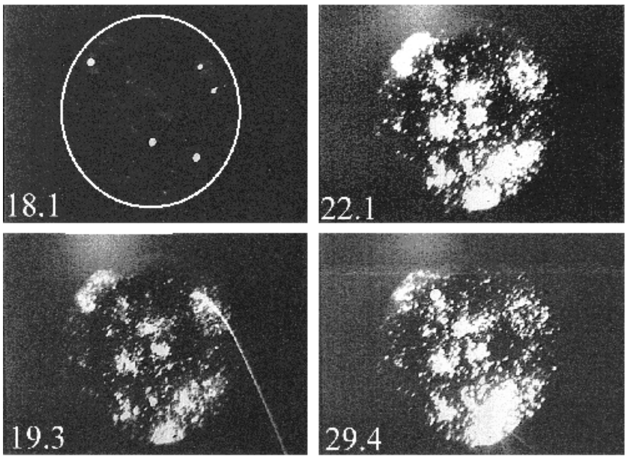

Fig. 2 : Luminous activity in a contaminated sample at different field levels (MV/m).

c) During these tests some stable luminous spots were analyzed : their luminous intensity increases with the electric field, staying in the 10^{-14} to 10^{-12} watts range. The power density spectrum of these spots have a typical triangular or gaussian shape [2] with its peak located in the 500 - 900 nm wavelength range.

d) The observation with a SEM of the sample surface after RF tests, reveals several interesting facts : an inportant number of particles of small size remains over the surface, they could be originated during the explosive events. Most of the particles presents melting effects on their surface and finally small craters (several µm diameter) are observed over the surface.

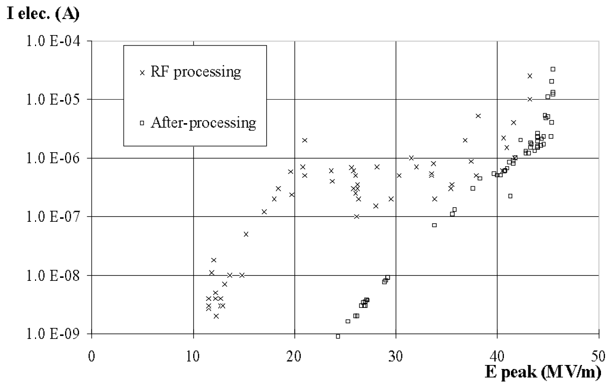

Fig. 3 : RF processing of a sample contaminated with alumina particles

1.4 Other contaminants

Some different types of particles contaminants were used with the same experimental protocol. Here we present a short summary of the more relevant results :

a) **Teflon** : the size of the particles was less than 10 µm. At high field (83 MV/m) the electron current was close to 10 µA. A reduced luminous activity was observed when compared to the alumina particles : some stable luminous spots without explosions and their spectral density shows shapes close to the alumina particles ones in the range 400 nm - 750 nm.

b) **Silica** : two sizes of particles were employed : small particles 5 to 10 µm and large particles 400 µm to 600 µm. In both cases the current was rather small reaching 200 - 300 nA at high field (43 MV/m). The luminous activity was drastically reduced in these experiments.

c) **Carbon** : graphite powder with a typical particle size of 50 µm was used in this experiment. Very high currents were obtained at intermediate field levels : > 3 mA at 32 MV/m. The emission was more stable compared to alumina particles, but the luminous activity was quite intense : explosions and stable spots were observed during the processing phase. The spectra were of two types : broad single peaked spectrum at 590 nm and two peaked spectrum at 590 nm and 700 nm.

1.5 Conclusions

a) The high electron current obtained with carbon confirms its potential threat for SCRF cavities. Less dangerous but giving strong effects are the alumina and teflon particles. The silica seems to be quite innocuous but more detailed tests are needed.

b) A clear RF processing has been observed with all the contaminants. Increasing the electric field reduces the emitted current by important factors (10 to >100) but the pre-contamination conditions are never recovered.

c) Strong heating and melting effects on both particles and metallic substrate surfaces are clearly observed by after-processing SEM examination of the samples. Very high electron current density, probably accompanied by plasma production, can explain these observations.

d) Some correlations with electroluminescence are founded in the case of stable luminous spots : the luminous intensity of the spots stays in the 10^{-12} to 10^{-14} watts range and follows a dependence with the electric field which is in well agreement with some electro-luminescence theories, and with the results obtained in D.C. experiment [3].

2. STUDIES WITH A SCRF CAVITY

A niobium SCRF cavity was specially designed for Field Emission studies (Fig. 4). When operated in the TM020 mode at 3.6 GHz, very high electric fields are obtained in the central region of the cavity bottom plate.

A small protuberance (radius 13 mm) was made in this area in order to enhance the available electric field [4].

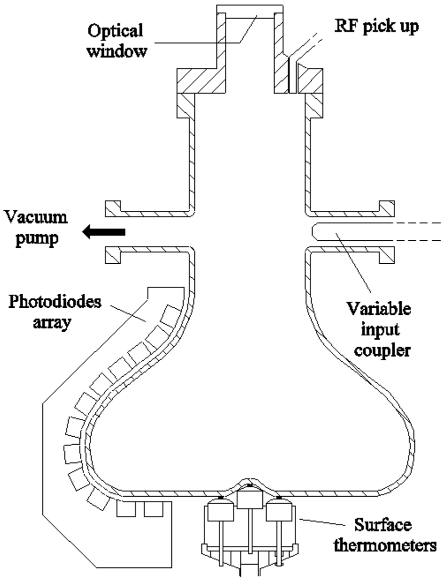

Fig. 4: Niobium cavity, 3.6 GHz (TM020 mode)

2.1 Experimental Results

Before contamination, this cavity reach a maximum surface electric field Epk,max=95 MV/m with a good quality factor at low field: Qo=5.10^9 (Fig. 5). The threshold field for electron emission was detected at 40 MV/m. In these preliminary experiments, the photodiodes array, and an energy calibrated X-ray detector, were used to verify the calculated surface electric field values.

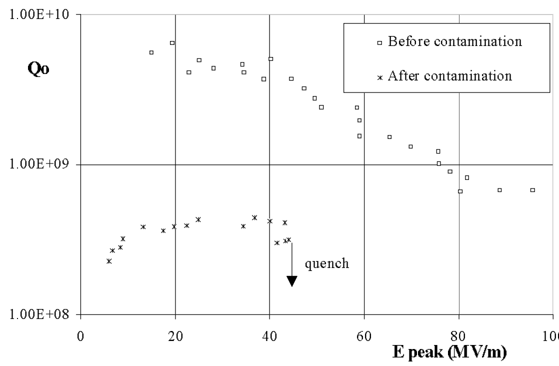

Fig. 5: RF tests of the TM020 cavity before and after contamination with alumina particles (T_{bath}=1.8 K).

A first contamination test with alumina particles was performed with a slight different arrangement of the cavity top plate: without optical window and with an axial pick-up antenna. The contamination was introduced in a clean room with a special tool which deposits alumina particles of ~15 µm in two points lying on a circle of 4 mm radius (Electric surface field ~ 0.8 Epk,max).

During the initial test at T_{bath}=4.2 K, the electron emission activity starts at low fields (>10 MV/m) and was clearly detected by the pick-up antenna and external X-ray monitor.

At T_{bath}=1.8 K, the cavity presents an important Qo degradation as compared to the pre-contamination tests, and the maximum field was limited by a quench at 40 MV/m. Field emission was detected at fields Epk,max>30 MV/m, and a strong heating in the central contaminated area. Seven surface thermometers monitor the He-side of the bottom plate: one of them is located in the cavity axis and the six others are located in a circle of 12.5 mm radius. The central thermometer detects a fast increasing temperature of the He-side surface, reaching ΔT= 0.25 K just before the quench. Some others surrounding thermometers detect also important heating (ΔT= 0.1 K). Before the contamination the measured heating for all the thermometers was lower than 70 mK in the 30 to 40 MV/m range.

More recently, a new cavity top plate was mounted including an optical window and an off-axis pick-up antenna. The first tests before contamination were perturbated by some arcing taking place at the top plate which limits the performance of the cavity and gives an important luminous background during the RF pulse. For Epk,max > 20 MV/m several stable luminous spots were observed in the high electric field area.

Nevertheless the cavity was able to handle Epk,max > 40 MV/m. A contamination test was performed and some interesting results were recorded: several stable and very intense luminous spots, located inside a circle of radius 4 mm were clearly detected in the 20 to 40 MV/m electric field range. One of them disappears at high field but no explosions or luminous tracks were observed in this test. Electron emission activity was detected by secondary electron detected by both the pick-up antenna and a X-ray detector located in the vicinity of the cryostat.

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