

# STUDY OF LUMINOUS SPOTS OBSERVED ON METALLIC SURFACES SUBJECTED TO HIGH RF FIELDS

T. Junquera, S. Maïssa, M. Fouaidy, A. Le Goff, IPN (CNRS - IN2P3) 91406 ORSAY cedex, France  
B. Bonin, M. Luong, H. Safa, J. Tan, CEA - DAPNIA - SEA, 91191 GIF-SUR-YVETTE cedex, France

## Abstract

The performance of high gradient superconducting RF cavities for electron accelerators is mainly limited by field emission. Major improvements have been recently obtained using different surface conditioning techniques confirming the involvement of metallic particles in field emission enhancement. In this paper we present the results obtained with an optical apparatus attached to an RF copper cavity equipped with a removable sample which is subjected to high RF fields ( $E_{pk} > 40$  MV/m). Stable light spots are observed on the sample surface and their intensities and optical spectra are measured as a function of the surface electric field. The total emitted current is simultaneously measured by an isolated hollow electrode facing the sample. Particles of different types were deliberately sprinkled over the sample surface and the luminous features are studied. Light intensity, spectral power density and evolution of the luminous sites provide useful information for understanding the field emission phenomena and the conditioning effects.

## I. INTRODUCTION

In this paper we report on the development and experimental work performed with an optical apparatus attached to an RF cavity. A detailed description of this device and some preliminary results were presented in previous papers [1] [2]. The initial goal was to develop a diagnostic tool able to localize and characterize the light spots which are observed on the surface of cavities submitted to high electric fields. This effect has been observed in DC experiments [3] and sometimes an intense luminous activity has been reported in RF cavities with heavy field emission.

## II. EXPERIMENTAL SET UP

### a) Cavity

A simple copper cavity has been proposed by the Saclay Group [4] [5] for studying the RF field emission on removable samples. Field emission from metallic surfaces at room temperature is practically the same as from those at liquid helium temperatures. A simple cavity with a removable sample, operating at room temperature offers fast turn around and low operating costs. The work concerning deliberately contamination with metallic particles was presented in references [4] [5] [6]. An identical cavity was slightly modified to simultaneously observe the top of the sample through an optical window and collect the electron current with a hollow electrode was developed [1] [2]. Two types of samples were used in

the present study [Fig.1]: #1 giving  $E_{max} = 60$  MV/m and #2 giving  $E_{max} = 100$  MV/m (for 5 kW peak input power). These are the electric fields on the top of the samples which can be maintained for pulse lengths in the range of 10  $\mu$ s to 5 ms with a duty cycle of 1 %. The field obtained with #1 samples was calibrated using a X-ray detector and the field with #2 samples was calculated with means of a computational code.

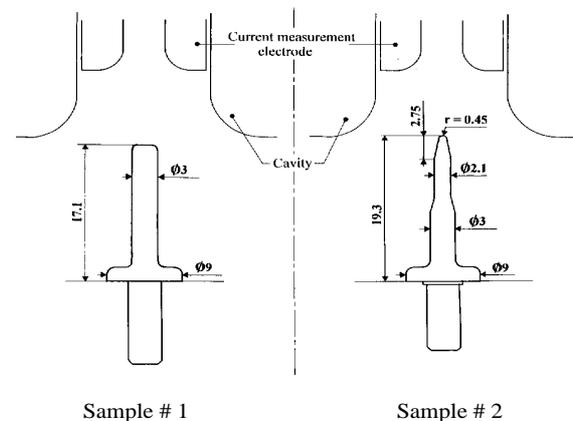


Fig. 1 : Sample geometry (all dimensions in mm)

### b) Optical detectors

A simplified scheme is given in Figure 2. The intensified camera has a sensitivity of  $5 \times 10^{-4}$  lux in the wavelength range of 400 - 650 nm (at 40 % of maximum relative response). A detailed description is given in Ref. [2]. During the first tests a series of high-pass filters was used for a rough evaluation of the spectral power density with a resolution of 50 nm. The spectral analysis system was recently improved. A pair of crossed slits (50  $\mu$ m) was inserted in the optical path. While the slits are moved to select the light emanating from just one spot. A prism is then positioned on the optical path and the dispersed light analysed by a cooled CCD multichannel sensor (Hamamatsu C5809 model).

This two dimensional CCD array (64 vertical x 512 horizontal) integrates the incoming light during the exposure phase. At the end of this time, the photocharges of individual pixels are accumulated, first along the vertical axis (binning phase) and then sequentially transferred to a readout stage. A sample and hold circuit delivers a low impedance video signal which is digitized by an oscilloscope. This signal is processed by a PC computer program which displays the power density spectrum for each exposure phase.

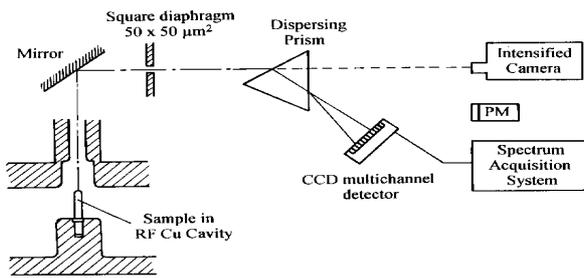


Fig 2 : Optical detectors

Due to the wavelength dependence of the refractive index of the prism, the wavelength range covered by each CCD channel varies from channel to channel : 1nm/channel at 400 nm, 10 nm/channel at 1100 nm (1 channel corresponds to 64 vertical pixels). The CCD sensitivity and channel calibration were performed with different near-monochromatic light sources (laser diode, LED, narrow band filters) [Fig. 3].

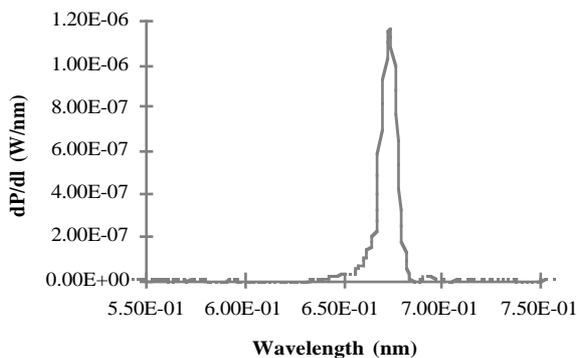


Fig. 3: Calibration spectrum obtained with a 670 nm laser diode

Our calibration of power sensitivity was within  $\sim 7\%$  of the manufacturer's values : a spot with luminous intensity of  $10^{-14}$  W is detectable by this means. The correspondance between wavelength and channel numbers was accomplished with  $\pm 1$  channel error by using an interpolation method between the monochromatic wavelength values.

### III. RESULTS

Samples were prepared using a technique which is now established [4]. Particles are sprinkled on the top of a clean sample placed over the cold vapors of an  $\text{LN}_2$  bath. The particles stick to the moistened surface and after drying remain well adhered (for samples prepared in this manner, the particles remain attached during sample mounting in the cavity and the majority remain attached even with the application of electrostatic fields). The samples are mounted in the cavity on a laminar flow bench. The prepared cavity is then evacuated and the experiment starts when the pressure reaches the range of  $10^{-7}$  mbar. The past efforts of the GECS group were concentrated on

field emission from metallic particles and surface scratches [4, 5, 6]. In this paper we focus on observations made on samples contaminated with dielectric ( $\text{Al}_2\text{O}_3$ ) particles.

Two sizes of alumina particles have been studied : large particles (50 -  $\mu\text{m}$ ) and small particles ( $\sim 1\mu\text{m}$ ). On examination of the samples in the SEM, it was found that the smaller particles tended to agglomerate into larger clusters, but there were many individual particles as well.

#### Large particles

A copper sample (type # 1) contaminated with alumina particles was submitted to RF pulses of 4 ms (1 Hz repetition rate). Luminescent spots were clearly observed starting at a field of 5 MV/m. Increasing the field up to 30 MV/m leads to a higher density of spots on the top of the sample and a higher luminous power [Fig. 4]. The electron current was very unstable (500  $\mu\text{A}$  at 10 MV/m).

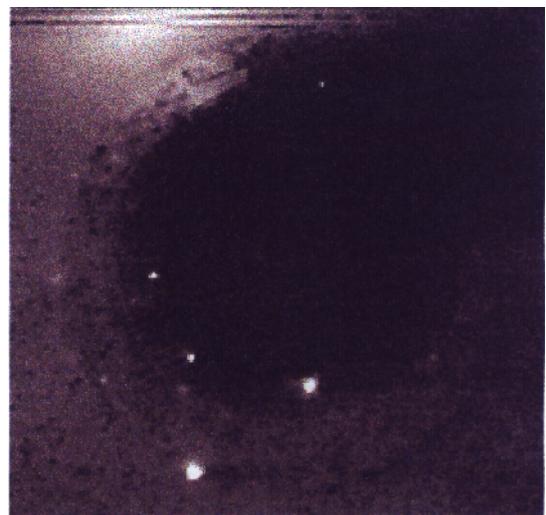


Fig. 4: large alumina particles at  $E = 8$  MV/m

Above this field level luminous tracks were observed, sometimes following straight trajectories, other times curved [Fig. 5].

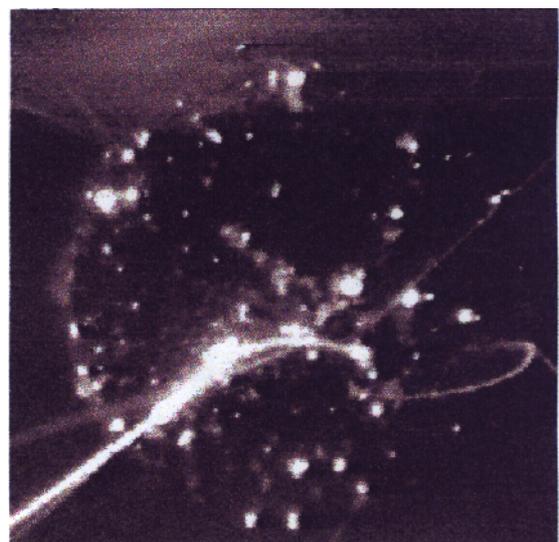


Fig. 5: large alumina particles at  $E = 20$  MV/m

These tracks appear to be originated from the light spots and are accompanied with an increase of the vacuum pressure, higher electron current and important disturbances in the frequency tuning of the cavity. After several RF pulses the electron current and luminous effects stabilize, but each time the RF power level is increased it triggers a new spectacular pattern of light tracks and sometimes "explosion-like" luminous effects. Eventually a field level of 40 MV/m was reached and a more stable emission phase was obtained. At this point the RF power was turned off and the cavity vacuum allowed to recover. The cavity behaved very differently during the next experiment. The current was quite stable and found to be roughly Fowler-Nordheim in nature. Luminous activity did not start until 20 MV/m. Several individual spots were measured with the spectral analysis system. Each spot showed a spectrum [Fig. 6] with same shape but with a different spectral density peak value and wavelength (ranging from 600 nm to 800 nm). One spot was studied between 30 - 40 MV/m; it was found that the peak wavelength did not change as the field level was increased. This study took several hours and during this time some of the light spots remained quite stable

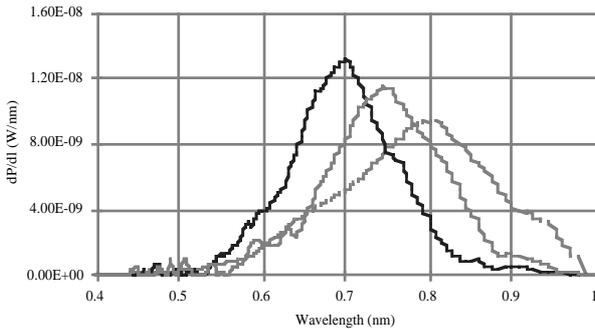


Fig. 6 : Three different light spots

Afterwards, the sample was examined in a SEM. Melted features were found on alumina particles with diameters on the order of 10  $\mu\text{m}$ . Small clusters of smaller particles ( $\sim 5\mu\text{m}$  in diameter) coated the sample surface and some craters were also identified in their vicinity.

#### Small particles

In this experiment a niobium sample of type #2 was used which gave more stable operating conditions. The electron current was quite low (15  $\mu\text{A}$  at 80 MV/m) and unstable during the first few minutes. Small luminous spots [Fig. 7] were observed which remain visible just for 1 or 2 RF pulses (100  $\mu\text{s}$  long, 5 Hz repetition rate, estimated field 80 MV/m). After this conditioning period the pulse length was increased to 2 ms (1.2 Hz repetition rate). This time, no light spots were visible on the top of the sample and the electron current stayed stable ( $I_e \cong 2 \mu\text{A}$  at 80 MV/m). Examination in the SEM showed a large number of small craters (1 or 2  $\mu\text{m}$ ) in the area where the light spots had been visible. No trace of initial particles was founded over the surface. The short life and instability of the light

spots made the spectral measurement very difficult in this experiment.



Fig. 7 : Small alumina particles at E = 80 MV/m

## IV. DISCUSSION

These experiments show that dielectric particles interact strongly with the RF fields in the cavity. They emit light and may be responsible for the observed electron current. There is also a clear dependence on the particle size.

The unstable behavior during the conditioning phase is accentuated for the larger particles which produce higher currents and more intense light spots. The light spectra show some similarity to those observed in alumina waveguide windows [7]. Some luminous features observed in the experiment with large particles have been also observed in DC experiments [3] : same order of magnitude of the luminous power in a light spot ( $10^{-12}\text{W}$ ), spectral power density in the range 600 nm - 800 nm and peak wavelength not dependent on the electric field.

Let us consider the RF heating of these particles. The power density absorbed by a dielectric is given by  $P(\text{W}/\text{m}^3) = 1/2 \epsilon_0 \epsilon_r \omega E^2 \tan\delta/2$ . For alumina ( $\epsilon_r = 10$ ,  $\tan\delta = 10^{-3}$ ) in a field of 50 MV/M at 1.5 GHz, we find  $P \sim 10^{12}\text{W}/\text{m}^3$ . The temperature increase of a particle of any size can be calculated using the specific heat ( $C_p \cong 756 \text{ J}/\text{kg}\cdot\text{K}$ ) and density 3970  $\text{kg}/\text{m}^3$ ) of alumina. The time constant  $\tau$ , to reach this temperature is proportional to the contact thermal resistance,  $R_{th}$  and to the total heat capacity  $C$  of the particle. From SEM measurements, a value of  $R_{th} \geq 10^7 \text{ K}/\text{W}$  has been determined giving time constants in the range 10  $\mu\text{sec}$  - 100 msec.

## V. REFERENCES

- [1] T. Junquera, A. Le Goff, B. Bonin, H. Safa, J. Tan : "6th Workshop on RF Superconductivity" (Newport News, Oct. 1993) CEBAF report, p. 1014,
- [2] T. Junquera, S. Maïssa, M. Fouaidy, A. Le Goff, B. Bonin, H. Safa, J. Tan : Proc. EPAC 94 (London 1994), p. 2203,
- [3] R. Hurley, P. Dooley, J. Phys. D : Appl. Phys. 10 (1977) L 195,
- [4] J. Tan, H. Safa, B. Bonin, J.M. Tessier : J. Phys. D : Appl. Phys. 27 (1994) 2644,
- [5] J. Tan, H. Safa, B. Bonin, M. Jimenez : J. Phys. D : Appl. Phys. 27 (1994) 2654,
- [6] J. Tan, H. Safa, B. Bonin, J. Jodet : Proc. EPAC 94 (London 1994),[7] S. Michizono, Y. Saito, S. Yamaguchi, S. Anami, N. Matuda, A. Kinbara, Proc. XVth ISDEIV, Darmstadt (1992), p. 614.
- [7] S. Michizono, Y. Saito, S. Yamaguchi, S. Anami, N. Matuda, A. Kinbara. Proc. XVth ISDEIV, Darmstadt (1992), p. 614.