STUDIES ON FIELD EMISSION IN RF CAVITIES USING AN OPTICAL DETECTION SYSTEM

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ABSTRACT

The RF cavities developed for large electron linear accelerators are still suffering from severe limitation in the operating gradient due to strong field emission. The study of the associated light emission from metallic surfaces submitted to high electric fields provides very useful data which could contribute to a further understanding of the field emission phenomena. An optical apparatus incorporating a high sensitivity video camera, a photomultiplier and associated optical devices has been constructed and successfully tested for observation and measurement of light spots in metallic samples placed in a 1.5 GHz copper cavity. An accurate calibration of the luminous detectors was accomplished. The main results obtained with different samples will be presented: light vs. electric field and radiation spectrum of the light spots.

INTRODUCTION

The first light emissions were reported by Hurley and Dooley [1][2], they observed luminous emitters on Cu cathodes submitted to DC electric field higher than 5 MV/m.This light emission was clearly correlated to electronic emission and was interpreted as an electroluminescence effect due to electrons emitted by semiconducting type impurities of the metal surface. At CERN, in a monocell superconducting cavity, light emission was also detected in a photomultiplier through a view port installed at the upper beam tube [3]. Founding their explanation on an experimental law of the light intensity as a function of the electric field, the authors related the light emission to a black body radiation of a small metal particle insulated from the cavity wall and heated by the RF field.

This present work proposes to apply this observation technique to an RF cavity and firstly to test the performances of this new diagnostic method.

The 1.5 GHz COPPER CAVITY

A 1.5 GHz copper cavity, operating at room temperature is equipped with a removable sample, which is located in the maximum electric field region. On the upper part of the cavity, a tube is mounted in which a hollow and isolated electrode allows the measurement of electrons flowing from the sample in a conical angle of 40°. The tube is ended by a sapphire window, protected from electrons bombardment by permanent magnets disposed on each side of the tube. So, simultaneously electron and light emissions can be observed.

The cavity is powered by a 5kW klystron working in pulsed mode: frequency 1 Hz, pulse length 1 to 5 ms, in order to limit the dissipation on the cavity walls. Its experimental characteristics are given on the table 1.

The sample (diameter 3 mm, height 15 mm) is screwed on the lower part of the cavity. Two copper samples and a niobium one were tested. Some had a hemispherical or a flat top, which was scratched or not with a point in order to create artificial electrons emitters.

Table 1 : Characteristics of the 1.5 GHz copper cavity

Frequency	1495 ± 5 MHz
Maximum RF power	5 kW
Maximum average power	< 50 W
Maximum peak field (300K)	> 50 MV/m
Maximum peak field (77K)	> 65 MV/m
Qo	Cu: 8600 Nb: 6000
RF pulse length	10 µs to 5 ms
Emission current	100 pA to 10 mA
Pressure	< 10^{-7} mb

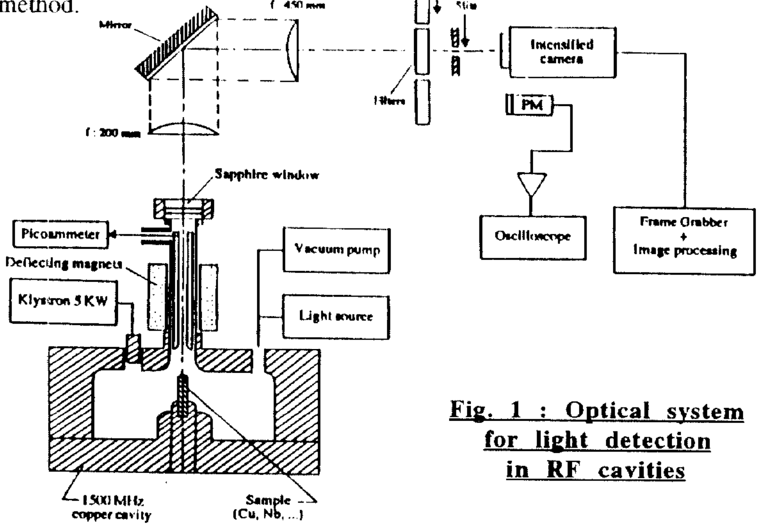

Fig. 1 : Optical system for light detection in RF cavities

THE OPTICAL DEVICE DESCRIPTION AND ITS CALIBRATION

Figure 1 shows the complete experimental setup. The optical system is consisted of a couple of lenses (magnitude of 2,25) and a mirror reflecting the sample image on an intensified camera (sensitivity of 5.10^{-4} lux, a 400-650 nm range for the 40% spectral relative response). Precise adjustment of the two lenses and light detector is obtained by DC motors remotely controlled whose overall movement precision is better than 50 µm.

The spatial resolution is about 8 µm at the sample level and about 18 µm at the camera window.

To each image pixel is associated a grey level value between 0 and 255, characterizing its luminous intensity. The energy calibration of the camera consists in the evaluation of a grey level in radiant unit. Using continous lasers providing a monochromatic coherent beam, attenuated by neutral density filters, the value of a grey level has been determinated at two different wavelengths (see table 2). The spectral curve of the conversion of a grey level has been extrapolated applying the spectral relative response given by the manufacturer specifications. The radiant sensisitivity calculated with the lowest luminous signal detectable by the camera (chosen equal to 80 grey levels distributed on a area of 12 pixels, say 324 μm^2) has been deduced.

A light detector with a larger spectral response is available on the system: it is a photomultiplier (Hamamatsu 955 with a cathode radiant sensitivity of 70 mA/W and a 40% spectral relative response of 170-700 nm). It detects either the total light coming from the sample ($8*24\ mm^2$ photocathode) or the light of a particular area of the sample (area of $450*450 \mu m^2$), when a square diaphragm of 1 mm^2 is placed in front of it. Its eanergey calibration gives a radiant sensitivity of 2.10^{-15}W at 632,8 nm, corresponding to an anode current of 1nA (see table 2).

Table 2 : Light detectors sensitivity

	Intensified camera	PM H 955
Lower detected signal	80 grey levels on 12 pixels (324 μm^2)	1nA
630 nm sensitivity	$4,5.10^{-17}$ W/grey level	(anode sensivity) $3,8.10^5$ A/W
545 nm sensitivity	3.10^{-17} W/grey level	(anode sensivity) $4,8.10^5$ A/W
630 nm radiant sensitivity	$3,6.10^{-15}$ W	$2,6.10^{-15}$ W
645 nm radiant sensitivity	$2,4.10^{-15}$ W	2.10^{-15} W
Maximum radiant sensitivity	2.10^{-15}W (450 nm)	$1,6.10^{-15}$W (400 nm)

LIGHT SPOTS OBSERVATION

During the first minutes of each experimental run, numerous luminous arcs show a vacuum unstability in the cavity. After this initial RF processing, the electric field in the cavity can be increased.

Using the intensified camera, luminous spots were observed in a electric field range of 21,06 MV/m (length pulse of 3ms) and 45,8 MV/m (length pulse of 2 ms). Some of them were so unstable that their "optical life" lasted only few RF pulses. But others emitted light during several days, say a real RF time of few minutes. Their luminous intensity could be tuned either by increasing the peak RF power in the cavity, meaning the electric field, or increasing the RF pulse length (the detector integrates the radiation signal during a longer time).

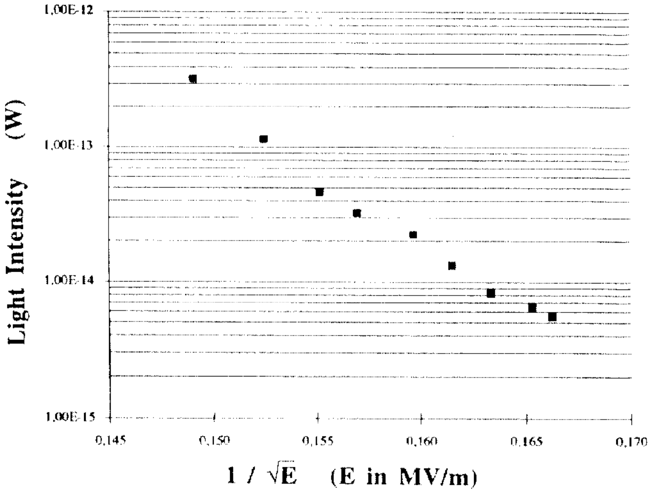

Fig.2 : Light intensity vs. electric field

Figure 2 shows the radiant power emitted by a site vs. the electric field, the luminous detector was the photomuliplier. Simultaneously, the electronic current flowing from the sample was measured and its Fowler-Nordheim curve was plotted (figure 3). The field enhancement factor β was found equal to 155 and the apparent emitting surface S equal to $1,9.10^{-13}\ m^2$. These values agree quite well with those obtained in experiments with similar cavities and samples [4].

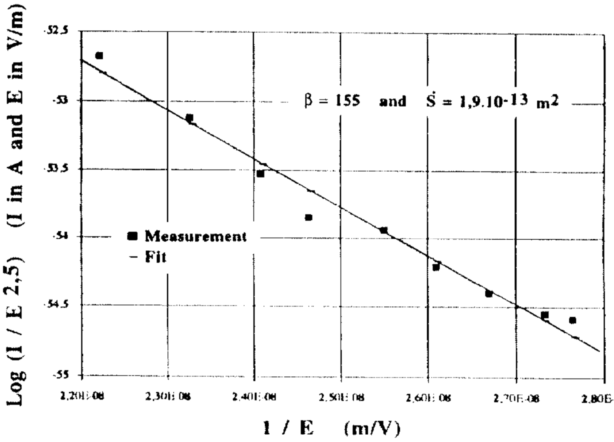

Fig.3 : Fowler-Nordheim plot measured in the cavity

LOCALIZATION OF THE LIGHT EMITTERS

At the sample level, the apparent FWHM of the light spots has been evaluated at ~ 20 µm and their radiant power has been estimated to be in the range of 10^{-13}-3.10^{-12} W.

The image examination showed that the light emitters lay in a ring around the axis of the sample, with a radius less than 1 mm, however no spots were located on a scratch. After an experimental run, the sample was taken out from the cavity and was marked at its bottom. The coordinates of the sites were calculated relative to this mark allowing us to localize these sites and its surroundings when the sample was examined with a scanning electron microscope (SEM). It was also possible to measure the DC field emission current locally by means of a polarized needle scanning the sample surface [5]. This kind of SEM examination fails to reveal a clear correlation between the light spots and electron emission sites or surface protusions.

LIGHT SPECTRA

Spectra of the radiation emitted from sufficiently stable spots were obtained using a series of high pass filters covering the 500-850 nm range in steps of 50 nm. One of them is shown in the figure 4. The power spectral density has been estimated to be in the range of 10^{-7}-10^{-5} W/m.

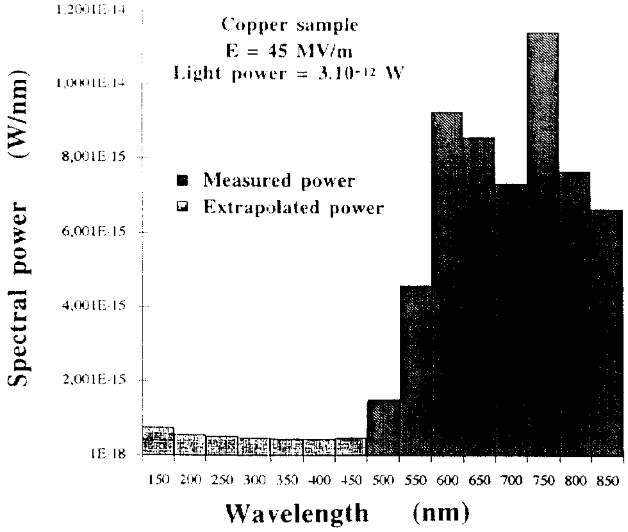

Fig.4 : Spectrum of the radiation emitted by a site and mesured with the photomultiplier.

DISCUSSION

The results presented in this paper confirm the interest of an "optical approach" to study the enhanced field emission (EFE) in RF cavities. After the first series of experiments, we can roughly state that the obtained values characterizing the luminous spots and their radiation - total power, spectral density level and the behavior vs. electric field -, are in good agreement with the results obtained in DC experimental results [1][2]. The spectral resolution of our device is not optimal (50 nm) and its improvement will allow a serious comparison with the DC experiments where some peculiar peaked structures were found.

Recently, some complementary experiments at Saclay [4], using the same type of cavity and removable samples, have shown a tight correlation between the presence of metal particles (size 1-50 µm) and EFE phenomena. Some experiments have also proved the clear influence of the geometrical shapes of the scratches. Observation of the protusions with SEM, before and after the RF test, showed geometrical aspects that could induce an enhancement factor of $\beta \sim 100$ and melted material at the apex of the protusion.

One of the main goals of the optical system was to study the radiation created by heated particles and its possible correlation with field emission sites. The spectra obtained with several sites on three different samples show some peaked structure and an important background signal with spectral distribution close to the black body radiation distribution (see figure 4). Better resolution and more statistics are needed in order to conclude on this point.

There is not yet a systematic correlation between the location of the light sites and the surface features (protusion, particles, craters,...), observed after the RF test. The accuracy in the selection of the proper area on a sample with the SEM, should be improved and also more statistics are needed.

The light response was studied with the photomultiplier and its associated diaphragm. Most of the time the light pulse was completly correlated in shape and length with the RF power signal of the cavity, which was measured with a pick-up antenna. The rise time of the light signal was estimated to be lower than 200 µs.

Thermal model calculations of a metal particle (size ~ 10 µm) lying on a metal substratum with a poor thermal contact and submitted to a RF magnetic field, show that the entire particle can reach equilibrum temperatures of ~1500K with time constants lower to 1 ms. The power levels and the spectral distribution measured in several samples could fit with these model calculations assuming that the size of the particles are smaller (<0,5 µm) or the surface emissivity of larger particles is very low.

CONCLUSION

The experimental set up will be technically improved. All events occuring in the cavity will be recorded with a video tape recorder and the experimental parameters will be stored on a PC using a Data Acquisition Board drived by the Labview software. Moreover, the accuracy of the spectral analysis will be improved with a grating separating the spectral components of the incident light, which will be measured by a 1-dimensional CCD sensor.

Now, the most important result to be clearly proved is the exact correlation between light emission sites and electron emission sites. An experiment is planned using a special superconducting cavity equipped with two different detection systems: the optical observation of the maximum electric field region of the cavity and the simultaneous and accurate X-ray mapping of electron emission sites, with a scanning arm using sensitive photodiodes.

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