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VOLTAGE BREAKDOWN TEST AT 473 MHZ*

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Abstract

RF breakdown test results with copper, titanium, stainless steel and SiO_2 coated copper are presented. The results show that SiO_2 coating may depress field emission.

Introduction

Voltage breakdown is one of the major factors to be considered in designing a high gradient accelerator structure. Since Kilpatrick proposed his semi-emperical criterion for rf breakdown in 1950's[1], several experiments have been conducted by various research groups. Figure 1 shows some of these results[2]-[8] and Kilpatrick's criterion curve. Obviously, these experimental data are widely dispersed and more data are needed, especially in the region of 425 - 2280 MHz.

In theoretical aspect, many models were proposed to explain dc breakdown, but few for rf breakdown. Up to now the mechanism of rf breakdown is still not clear. This fact not only limits the understanding of rf breakdown, but also affects the effort to achieve and maintain higher field gradients. More experimental information is also needed for theoretical modeling.

Motivated by the above mentioned needs, the research to be described in this paper is aimed to provide rf breakdown data at 473 MHz and to test the effect of thin films deposited onto a Cu surface, especially the possibility of SiO_2 coating to depress field emission.

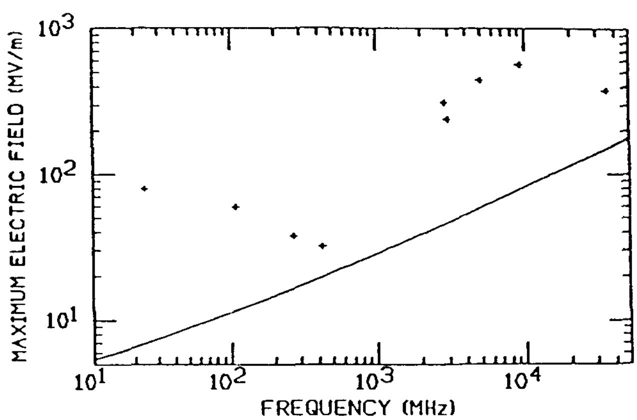

Fig.1. Experimental data and Kilpatrick criterion curve (solid line).

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Experimental Setup

The test setup is shown in Figure 2. The rf breakdown test cavity is a reentrant type resonant cavity which is in a vacuum chamber. The copper cavity consists of two demountable halves. The gap and resonant frequency can be changed easily by moving two electrodes. The electrodes are composed of two parts: body and end cap. The end caps which are made from various materials to be tested are screwed onto the bodies. A small area of each end plate of the cavity was coated with Ti to depress multipactoring. The cavity is water cooled. Table 1 shows some parameters of the cavity with different gap lengths which are results of SUPERFISH.

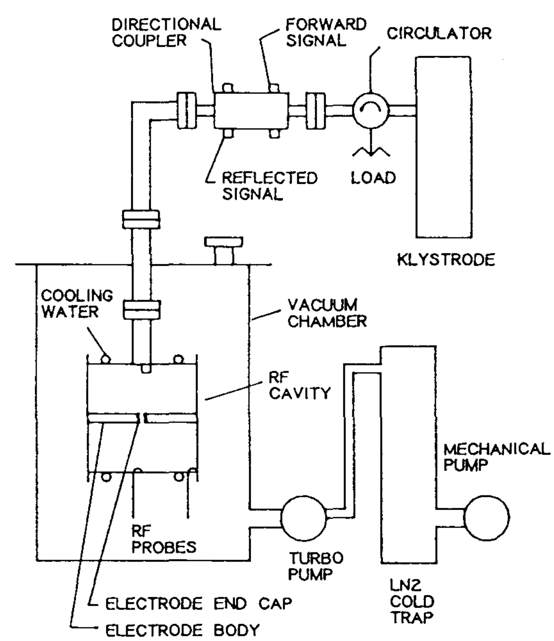

Fig.2. Experimental setup

Two rf probes are mounted at different positions to monitor rf power transmitted into the cavity. Also, the ratio of the two probes' measurements is used to detect other possible modes which may be excited at higher power levels. Seven thermocouples monitor cavity temperature at various positions.

An EIMAC 2KDW60LA klystrode was used as an rf power source providing 50 μs long pulses with a repetition rate of 100 Hz[9]. The forward and reflected power are monitored with a calibrated four port directional coupler.

The vacuum system consists of a vacuum chamber, a 500 L/sec turbo pump, a liquid nitrogen cold trap and a mechanical pump. The vacuum feedthrough for the main rf coaxial transmission line is made using a Teflon insulator and a Viton O-ring.

X-ray radiation is monitored with a Ludlum model 177 radiation detector at 2 meters away from vacuum chamber.

TABLE 1
Cavity Parameters

Gap length (mm)	1.80	1.85
Q	10997	11059
Resonant frequency (MHz)	473.512	477.138
Emax (MV/m)	57.3	55.8
Power dissipated (W)	3365	3315

Experimental Procedure

All electrode end caps were carefully polished to less than 3 μm finish and ultrosonically cleaned . Two end caps were made from Ti and two from stainless steel. Four copper end caps were coated with Ti thin films of 100 - 120 nm by sublimation. Eight copper end caps were coated with SiO_2 thin films by electron beam evaporation. The thickness of SiO_2 is 200, 300 and 400 nm. The index of SiO_2 is 1.543.

The length of the gap was measured by two methods. First, a gauge was inserted into the gap to get accurate data of gap length and the resonant frequency was measured to make a frequency-gap length curve. Second, every time after changing electrodes and retuning the cavity, the gap length was measured by calliper and checked with the frequency-gap length curve.

Before every test, the Q of the cavity, SWR and attenuation of rf probes were measured several times with an HP8753B network analyzer. During tests, the signals from the rf probes were measured with a DSA602 digitizing signal analyzer. The forward and reflected power were measured with an HP438A power meter. The maximum electric field in the cavity was determined by the expression:

$$E_{max,exp} = E_{max,theo} \left[\frac{Q_{exp} P_{exp}}{Q_{theo} P_{theo}} \right]^{1/2} \qquad (1)$$

where $E_{max,theo}$, Q_{theo} and P_{theo} are the theoretical maximum electric field, Q factor and corresponding dissipated power as calculated by SUPERFISH, and Q_{exp} and P_{exp} are experimental ones.

Experimental Results

1. Copper, Titanium and Stainless steel

The maximum field for these 3 materials can be maintained at as high as 120 MV/m, although spark spots were found on electrode surfaces after tests. Although these three materials can reach the same field level, there are differences among them. It is more difficult to maintain stable operation with copper electrodes than titanium and stainless steel. There are more and bigger spark spots on the surface of the copper than on the surface of titanium or stainless steel. The stainless steel had just one spark spot after a total of 8 hours operation. Sparks actually started at a lower electric field of 60-90 MV/m irregulaly when power was increased. The indication of such breakdown is sudden a large power reflection, an X-ray burst and a change of vacuum. Since reflected power was very high at the field level of 120 MV/m, an alternative method to measure electric field in the cavity such as X-ray measurement is needed and is planned to establish these results.

2. Ti coated copper

Ti coating did not improve performance. At the electric field of 80-90 MV/m, clear breakdown signals were observed. At such a level, whenever power was increased, the breakdown occured irregularly (every several minutes) within a pulse for 10-20 minutes. After then, high field can still be maintained for a long time. The shape of spark spots are very similar to those on the surface of pure copper. At every spark spot, the Ti film was broken.

3. SiO_2 coated copper

The purpose of dielectric coating is to isolate the microprotrusions on the metal surface from vacuum[10]. However, space charge accumulation may become a serious problem. To our knowlege, there has been no publication about testing SiO_2 coating. At this initial stage, the 400 nm SiO_2 coated copper end caps were tested . The maximum electric field used up to now is 81 MV/m. Since the SiO_2 films are only 400 nm, as a first order approximation the formula (1) is still used to estimate the maximum electric field in the cavity. Up to this level, there was neither indication of breakdown during the test nor trace of breakdown on the surface after the test. The Q of the cavity was 6915. The ratio of signals from the two rf probes was similar to that of pure copper cavity. X-rays were negligible which may indicate that SiO_2 depressed field emission. Further X-ray measurement is being planned.

Discussion

1. Although the electrodes of those three different metals can work at the electric field level of the same order of magnitude, the results show that rf breakdown and high field performance of electrodes are still related with material characteristics which may include the latent heat of fusion.

2. SiO_2 can at least survive an electric field of 81 MV/m. It may reduce field emission from the copper surface, and therefore may be applied to protect copper electrodes in high gradient rf fields.

3. Since the secondary electron emission of Ti is less than that of SiO_2, the above results imply that the secondary electron emission may not play an important role

to initiate breakdown in high gradient rf fields.

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