RF BREAKDOWN TEST OF SiO_2 COATED COPPER ELECTRODES *

D.Sun, P.Datte, W.W.MacKay and F.R.Huson
Texas Accelerator Center†, 4802 Research Forest Drive,
The Woodlands, TX 77381

Abstract

RF breakdown test results with copper and SiO_2 coated copper are presented. The results show that SiO_2 coating can withstand an rf field as high as 100 MV/m at 471 MHz without sparking and depress the field emission.

Introduction

For high gradient accelerators, rf voltage breakdown is one of the major factors which impose the limits on the maximum field gradient. Since Kilpatrick proposed his semi-empirical criterion for rf breakdown limit in the 1950's [1], several experiments have been conducted to test the rf breakdown limit at various frequencies. But up to now the mechanism of rf breakdown still remains unclear. Different metals were tried to increase the breakdown limit, but there is no substantial increase. The surface coating of rf cavities was proposed to be a possible way to increase the breakdown limit far above the electron multipactoring limit [2][3].

Field emission is another detrimental factor for operation of high gradient accelerators, since it can induce breakdown, consume extra rf power, cause wakefields and possible excitation of unwanted modes of oscillation in the accelerating structures. So the research on how to depress the field emission for high gradient accelerating structures is needed.

In this paper we report our research on the possibility of SiO_2 coating of copper electrodes. Our interest is to investigate what improvement could be made in the depression of the field emission and increase of maximum field gradient by SiO_2 coating.

Experiment Setup

The test setup is shown in Figure 1. A reentrant type resonant cavity is used which consists of two demountable halves and two movable electrodes. 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 to be tested are screwed onto the bodies. A small area of each end plate of the cavity was coated with titanium to depress possible multipactoring. The cavity is partially water cooled.

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 the cavity's temperature at various positions.

An x-ray spectrometer is set up for the measurement of maximum rf field and field emission in the gap. This x-ray spectrometer consists of a NaI detector, a LeCroy 3001 multichannel analyzer, a LeCroy 4608C discriminator, an HP 5314A universal counter and an IBM PC.

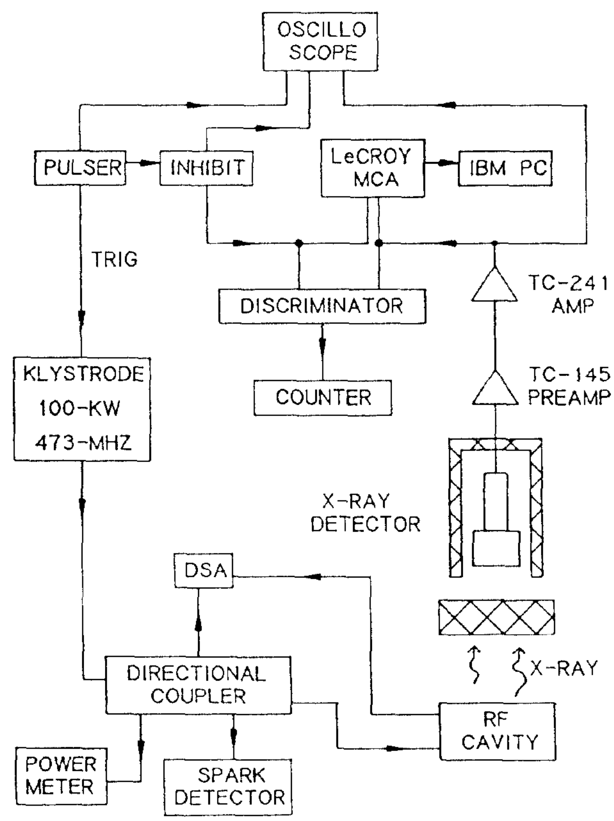

Figure 1. Experiment Setup.

An EIMAC 2KDW60LA klystrode is used as an rf power source providing 8-50 μs long pulses with a repetition rate of 10-100 Hz [4]. The forward and reflected powers are monitored with a calibrated four port directional coupler, a Tektronix 602A digital signal analyzer and an HP 408A power meter. Also the reflected signal is sent to a spark rate counter.

The rf cavity is in a high vacuum chamber which is

*Work supported in part by the SSC

0-7803-0135-8/91$01.00 ©IEEE

pumped by 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 with a Teflon insulator and a Viton O-ring.

Experimental Procedure

The pure electrode end caps were made of OFHC copper. They were carefully polished to less than 3 μm finish and ultrosonically cleaned. After cleaning, several copper end caps were coated with SiO_2 thin films by electron beam evaporation. The thickness of SiO_2 is 400 nm. The refractive index of SiO_2 is 1.543. Before and after each test the Q and SWR of the cavity and attenuation of rf loops were measured several times with an HP8753B network analyzer. The x-ray spectrometer was calibrated with gamma ray standards (^{133}Ba, ^{57}Co, ^{137}Cs, and ^{22}Na). To compare the field emission, we measured the x-ray intensity at several field levels with both pure copper and SiO_2 coated copper electrodes. The rf frequency was 471 MHz. The rf pulse length was 8 μs, and the repetition rate was 100 Hz. All tests were done after the vacuum chamber was pumped to less than 3×10^{-7} torr.

The maximum electric field in the cavity was determined by two methods: pick up loop and x-ray spectrum. The pick up loop method determines the maximum electric field by the expression:

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

where $E_{\mathrm{max,theo}}$, 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 the experimental values.

Since the real field distribution and oscillation modes at high electric field can be different from either those measured at low field level or those calculated by SUPERFISH, it is necessary to employ another method to ensure the accurate determination of the real maximum electric field in the gap. The x-ray measurement is used to determine the maximum energy obtained by the field emitted electrons. The high energy end of the x-ray spectrum (Bremsstrahlung) corresponds to the amplitude of the rf voltage in the gap. The maximum electric field is determined by deviding the voltage amplitude with gap length.

The total intensity of the x-rays can be used to determine the current density of the field emitted electrons by the following expression:

$$I = CjZV^m \qquad (2)$$

where I is the total intensity of the x-ray, C and m are constants, Z is the atomic number of the electrode material, j is the electron current and V is the voltage between electrodes. The x-ray intensity can be determined by the spectrum if the other parameters are fixed.

Experimental Results

1. Breakdown limit

The breakdown started at a field level of 97-100 MV/m with the SiO_2 coated electrodes. This sample was first tested up to 81 MV/m [5]. After the first test, the cavity was opened and the electrode surfaces were visually checked. There was no trace of sparking. Afterward the samples were kept in the ordinary atmosphere for seven months and were tested again. The samples showed good repeatability until the first spark occurred at 97-100 MV/m. After the spark occurred, the signals from x-ray spectrometer were heavily piled up, which indicated a dramatic increase of field emission. After the cavity was opened, there were two small pits seen on the electrode surfaces, similar to those of pure copper electrodes. Except for those two pits, the SiO_2 film remained undamaged. As we previously reported [5], with pure copper electrodes, the sparks started at a electric field of about 60 MV/m. The maximum field of pure copper electrodes can be maintained at a level of 120 MV/m after a long time careful conditioning, but there are a lot of spark traces left on the surfaces after tests.

2. Field emission

Figure 2 shows the x-ray spectrum from SiO_2 coated copper and the pure copper electrodes at an rf field of 42.5 MV/m. The pure copper electrodes had been conditioned and operated at various field levels up to 120 MV/m for a long time. The x-ray spectrum was taken after operations of more than 100 hours. In order to avoid pileup of the x-ray signals, we had to increase the shielding of the x-ray detector with increase of rf field, but at each field level, the same shielding was used for both pure and SiO_2 coated copper electrodes. Table 1 lists the total counts of x-ray signals normalized by the total effective counting time at three different rf field levels. The data shows that the total normalized x-ray counts of the pure copper sample is about 20 times more than that of SiO_2 coated copper.

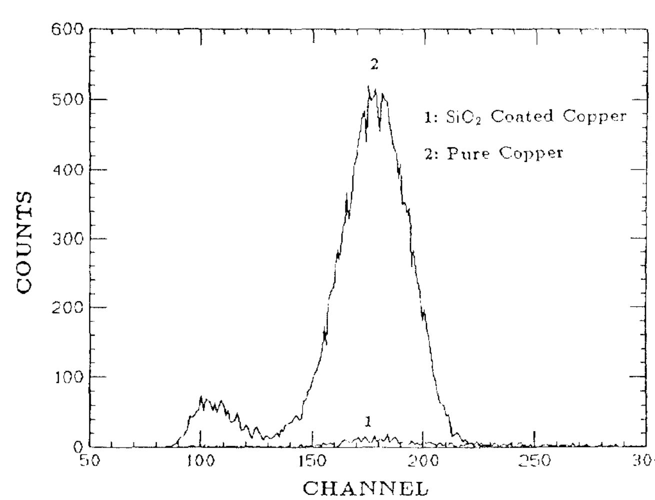

Figure 2. X-ray spectrum at rf field of 42.5 MV/m

TABLE 1
Normalized Total Count

rf field (MV/m)	total counts per second		ratio
	pure Cu	SiO_2 coated Cu	
42.5	2120	104	20.4
67.5	3643	148	24.6
85	4488	86	52.2

Conclusion

1. The above reported results show that the SiO_2 coating can increase the rf breakdown starting level up to 97-100 MV/m. The Kilpatrick limit at 471 MHz is 20 MV/m. This means that SiO_2 coating may provide a method for keeping the electrode surface free of damage during high field gradient operation.

2. The SiO_2 coating can reduce the field emission. Compared with the pure copper electrodes which were used for more than 100 hours, the total normalized counts of the x-ray signals can be decreased up to 20 times. This could improve operation of accelerators at high field gradient by reducing the dark current.

References

† TAC at HARC is a consortium of Rice University, Texas A&M University, the University of Texas, Prairie View A&M University, Sam Houston State University and the Baylor College of Medicine MR Center.

1. W. P. Kilpatrick, "Criterion for Vacuum Sparking Designed to Include Both rf and dc," Review of Scientific Instruments, **28** (10), 824 (1957).
2. W. Peter, "Vacuum Breakdown and Surface Coating of rf Cavities," J. Appl. Phys. **56** (5), 1546 (1984).
3. B. Hoeneisen, Internal Report No.2, Instituto de Fisica Universidad de Guanajuato, 1987.
4. W. W. MacKay, *et al.*, "Operation of a 473MHz Pulsed Klystrode Power Source," Proceedings of the 1990 Linear Accelerator Conference, Albuquerque, New Mexico, September 1990, pp. 186.
5. D. Sun, *et al.*, "Voltage Breakdown Test At 473 MHz," Proceedings of the 1990 Linear Accelerator Conference, Albuquerque, New Mexico, September 1990, pp. 216.