HIGH GRADIENT STUDIES ON UHV ROOM TEMPERATURE CAVITIES AT S-BAND FOR LINEAR COLLIDERS

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Abstract

Generation of high accelerating gradient is one of the key issues for future linear colliders, especially in a main linac, a pre-accelerator for the positron linac which is located after the positron target, and an RF gun to generate multi-bunch polarized beam. A test facility has been constructed for the systematic studies on the fundamental phenomena of high gradient UHV room temperature cavities, which consists of a 5-MW S-band klystron, an UHV system in the clean room condition, and various diagnostic instruments. A copper cavity was rinsed with pressurized ultra-pure water to reduce the dark current at high gradient. It was tested and the maximum surface field of 337 MV/m was achieved with the vacuum pressure of $2x10^{-10}$ Torr. A microscopic field enhancement factor 37 was obtained.

Introduction

Polarized electron beam with the polarization of higher than 80 % will play an important role in next generation linear colliders in the center of mass energy range of 300~500 GeV with high luminosity of 10^{33}~10^{34}/cm^2/s[1]. This is a natural expectation based on the experiences at SLC which has been operating routinely with a strained layer GaAs photocathode grown on a GaAsP sublayer[2,3] and other activities to improve the electron polarization[4,5]. The SLC source operates with an electron polarization of ~80 % at a repetition rate of 120 Hz and an accelerating DC voltage of -120 kV producing two bunches of $5x10^{10}$ electrons per pulse separated by 60 ns[6]. The important key issues to use such a photocathode device as an electron source for the routine operation are developments of Ultra High Vacuum (UHV) and high accelerating gradient technologies. The cathode life and/or quantum efficiency (QE) are affected strongly by the residual gases and dark current which is field emission electrons due to the high accelerating voltage.

The electron sources of the next generation linear colliders must produce many bunches of ~100 per pulse with bunch spacing of a several rf wavelength of the main linac instead of a single bunch in order to improve the luminosity by increasing the collision frequency. The higher accelerating voltage is also preferable to produce low emittance beam. In addition, the QE should be improved to generate many bunches since it was found that the maximum photoemitted charge is limited by the intrinsic properties of the cathode instead of by the space charge limit[6]. A high accelerating gradient rf gun was proposed as one of the candidates to realize above requirements and expecting that heavy beam loading effect in the bunching system due to multi-bunch operation is less severe[7].

The rf guns are being developed extensively by many laboratories as high brightness electron sources for linear colliders and FELs. The direction of the development is to use metallic cathode with a combination of short wavelength laser system. In such an application, the typical vacuum pressure is the order of ~10^{-10} Torr and the accelerating gradient is ~100 MV/m. In order to apply rf guns as a polarized electron source using III-V type semiconductor which is discussed previously, the vacuum pressure should be improved at least two order of magnitude and the dark current should be lowered to the level not to cause the damage to the cathode. As the first step of the development, a test facility to study high gradient S-band cavities under UHV condition has been fabricated and the first test of the rinsing technology of the copper cavity has been performed.

Test Cavity

Design of the cavity

Extensive studies on both normal- and super-conducting high gradient rf-structures and DC-guns have been carried out so far in many laboratories. The key issues to reduce the field emission current can be classified and summarized as follows: (a) quality of the base material, physical nature and distribution of its indigenous impurities, (b) surface fabrication and preparation procedure, and (c) final rinsing procedure, assembling under clean room condition[8]. Especially, a lot of work were performed to realize high gradient superconducting cavities for superconducting linear colliders, which are also available for the normalconducting rf-structures[9].

The relation between the field emission current(I_e) and the peak surface field in the structure(E_p) is given by the modified Fowler-Nordheim expression as

$$Ie/Ep^{2.5} \sim \exp(-6.53\cdot 10^{9}\cdot \phi^{1.5}/\beta\cdot Ep), \qquad (1)$$

where ϕ and β are the work function of the material and the microscopic field enhancement factor, respectively.

The standing wave cavity is designed so as to carry out the high gradient study for higher than 300 MV/m by using 5 MW klystron as described later. Fig. 1 shows the cross sectional view of the cavity. A nose cone is introduced to enhance the peak surface field. The cavity length, rf frequency, unloaded quality factor (Q_0) and the coupling coefficient of the rf input (β_{in}) are indicatid in the figure.

The peak surface field in the cavity is given as a function of the cavity rf power (P_c) as

$$Ep[MV/m] = 156.6\sqrt{Pc[MW]}, \quad (2)$$

P_c is expressed as

$$Pc = \frac{4\beta in}{(1+\beta in)^2}\left(1 - e^{-\frac{\omega}{2Q_L}t}\right)^2 \cdot Pin, \quad (3)$$

where ω ,Q_L and t are an rf angular frequency, a loaded Q and an rf pulse width.

Cavity Lenrth = 52.48mm
Frequency = 2856 MHz
Q_o = 18666
β_{in} = 1.34

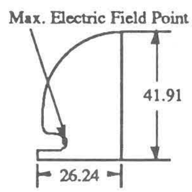

Fig. 1 Cross sectional view of the cavity
The cavity was made of OFHC copper and fabricated by the conventional method.

Rinsing procedure

The cavity was rinsed with pressurized ultra pure water. The water was sprayed radially in the cavity through the pin holes made radially to the stainless steel pipe with a diameter of 0.25" which was inserted to the cavity as shown in Fig. 2. Flanges made of polyethylene were used to seal up the cavity and fix the pipe. Drains were mounted to these flanges for tapping the water during the rinsing. The pressure of the water was ranged from 10 to 30 kg/cm^2 during the procedure and the specific resistance was kept to be higher than 17 MΩcm. After the rinsing, the water in the cavity was replaced with methanol through the filter with the mesh size of 0.2 μm which was used widely for the semiconductor farm, in order to avoid oxidation of the copper cavity. All the procedure was done in the clean room condition with class 100 and transferred to the experimental area, which was also made as a clean room of the same grade. The cavity was filled up with methanol during the transportation, which was drained just before the assembling to the experimental apparatus and evacuated immediately. All the copper gaskets for the vacuum flanges were rinsed with methanol through the filter of 0.1 μm before the usage.

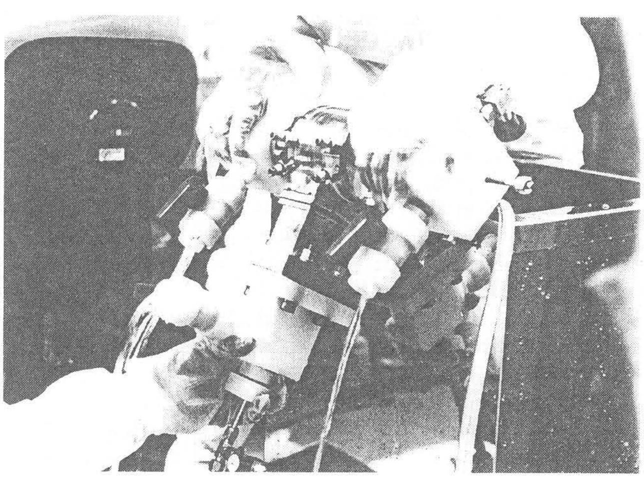

Fig. 2 Picture of the rinsing procedure with pressurized ultra-pure water.

High Gradient Experiment

Experimental apparatus and the vacuum system

A schematic drawing of the experimental apparatus is shown in Fig. 3. A 5 MW klystron is used as a power source, which feeds the cavity through a waveguide filled with SF_6 gas, an rf window to separate this waveguide to the other vacuum type waveguide. Various diagnostic systems are used to measure the dark current from the cavity such as a wall current monitor, Faraday cups (F1 and 2), an analyzer magnet, scintillation counters and survey meters. The main evacuation system is composed with a combination of ion pumps and non-evaporating getter pumps which are delivered by SAES Getters Inc. Whole the vacuum system and the cavity were baked out at 200° C for 100 hours with the exception of the rf window mentioned above. The total base pressure became 0.8x10^{-10} Torr after the baking procedure, which was monitored with B-A gauges. Partial vacuum pressure was also monitored with a residual gas analyzer (RGA). The total pressure when the RGA was turned on was 1.5x10^{-10} Torr.

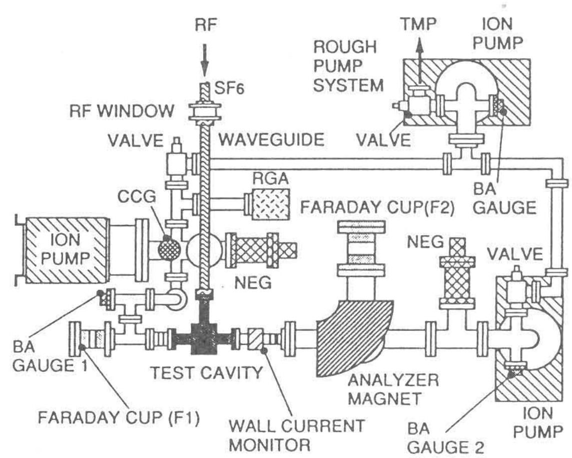

Fig.3. schematic drawing of the experimental apparatus.

rf processing

The initial stage of the rf processing was done with t=2 μs and the rf repetition rate (f_{rep}) of 10 Hz. The P_{in} could be raised up to 50 kW after 2 hours processing without any problem. Then a sudden increase of the vacuum pressure to the level of 1x10^{-8} Torr took place occasionally by every several minutes. In order to overcome such a small breakdown, the rf processing was done with the f_{rep} of 0.5 Hz carefully to avoid the permanent damage to the cavity for 10 days until P_{in} could be increased up to 0.4 MW. After that, the rf processing was done smoothly with f_{rep} of 10 Hz and P_{in} reached to 4.8 MW.

Dark current measurements

Figure 4 shows the momentum spectrum of the dark current at Ep = 297 MV/m which was measured with the magnetic analyzer. The higher end point of the spectrum corresponds to ~6MeV/c. Modified Fowler-Nordheim plots at the various stages of the rf processing are summarized in Fig. 5. The numbers (1)~(9) in the figure indicate the order of the measurements. The microscopic field enhancement factor β becomes smaller with the rf processing until the measurement (6) in which the maximum Ep = 307 MV/m. The minimum β-value of 37 was achieved at this measurement. After that, t was increased from 2 to 4 μs in order to increase Pc. The maximum Ep of 337 MV/m was achieved with this rf pulse width. An rf breakdown took place after the measurement (7) and the field emission current increased as shown in the measurement (8), then processed to (9). The experiment was terminated after the measurement (9) because of the schedule. It should be mentioned that the pressure rise when the rf power was fed to the cavity was very small as shown in Fig. 6, which was obtained at Ep=297 MV/m.

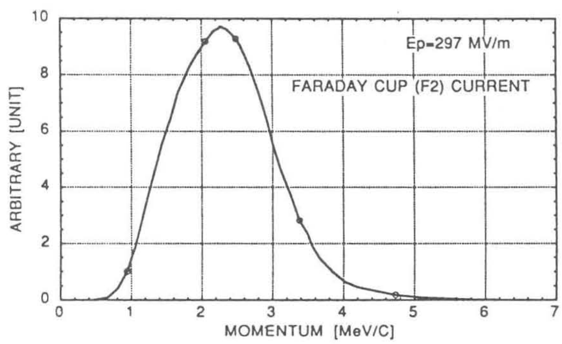

Fig. 4 The momentum spectrum of the dark current was measured at Ep = 297 MV/m with the magnetic analyzer.

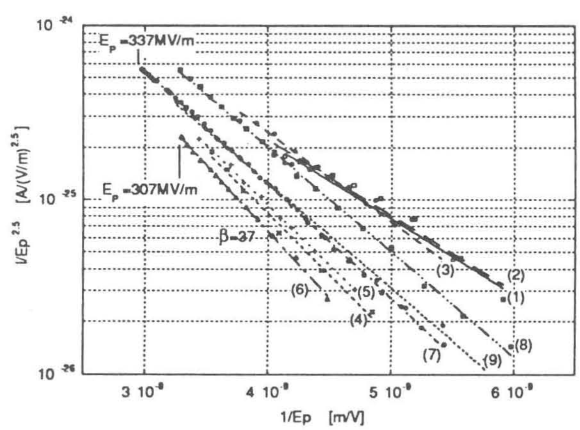

Fig. 5 Modified Fowler-Nordheim plots at the various stages of the rf processing are summarized. The park current at Ep=307MV/m in the measurement(6) was 0.4mA.

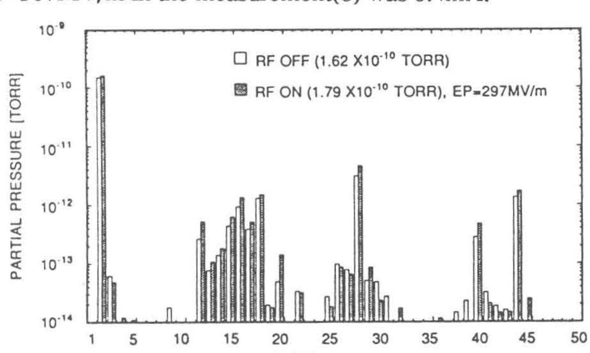

Fig. 6 Mass spectrum of residual gases when rf power is turned on aod off.

Summary

In order to realize rf-guns as polarized electron source, it is essentially important to satisfy the requirements both of UHV and high accelerating gradient, simultaneously. Especially, the dark current should be suppressed. An experimental facility to study high gradient rf cavities at S-band with UHV condition was constructed. It was shown that rinsing the cavity with a pressurized ultra pure water and assembling it in the clean room condition give promising results. The maximum surface field of 334 MV/m was achieved which was not limited by the rf breakdown but by the available rf power at the present experiment. The Fowler-Nordheim plots show the simple slope and microscopic field enhancement factor of 37 was achieved. Further improvements are expected by introducing not only the rinsing technology but also improving the material of the cavity[10].

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