S-BAND PHOTOCATHODE RF GUN AT SPring-8

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Abstract

An S-band photocathode RF gun has been studied for generating a low emitttance electron beam at SPring-8. The cavity of the gun is pillbox type, and an inner wall is used as a copper cathode. The electron beam from the cathode was accelerated up to 4.1 MeV at an electric field of 175 MV/m. For emittance compensation, two solenoid magnets were used. The horizontal beam emittance measured after solenoid magnets was about 2 π mmmrad at the charge of 0.1 nC/pulse. Due to the incident angle of 66 degrees, the beam has asymmetric distribution, and the vertical emittance is larger than the horizontal one. The laser illuminating the copper cathode is the third harmonics of Ti:Sapphire laser. Although the laser profile on the cathode should be flat top shape to get very low emittance, the laser profile was deformed and far from such an ideal shape. Laser optics with a micro-lens array improved the laser shape and the beam emittance. For high quantum efficiency, a Cs_2Te cathode has been also studied. The cathode is sealed in the cartridge-type vacuum tube and four tubes can be installed in a vacuum chamber back of the cavity. Although the maximum electric field of 90 MV/m was achieved after two hours RF conditioning, the quantum efficiency decreased from 3% to 1% after the RF conditioning of 28 hours.

INTRODUCTION

The photocathode RF gun can generate a low emittance beam as it has low thermal emittance and low space charge effect. It does not require a beam bunching section normally used with a thermal cathode gun because the beam bunch length is very short typically 1-20 ps. It will be applicable to an electron source for the electron-positron collider or the SASE FEL. It will be also used as an electron source for the future industrial or medial accelerators because it is much simpler and smaller than the conventional injection system.

We have been studied an RF gun of the single cell pillbox cavity because we aimed at a high gradient field acceleration[1]. In addition, this cavity has a good symmetry and it will decrease the beam emiittance growth due to the asymmetrical RF field. The present focuses of our research are the low emittance beam generation and the high quantum efficiency cathode. For the low emittance beam generation, higher RF field was applied in the cavity and the laser was also improved to get a flat top profile. The laser and RF synchronization was carried out without PLL feedback.

For high quantum efficiency, the Cs_2Te cathode is studied. It is sealed in a glass vacuum tube at the factory. The transparent type cathode was developed as well as the reflection type cathode. As the advantage of the transparent cathode, the exactly normal angle illumination of the laser is possible and the lower thermal emittance is expected.

COPPER CATHODE GUN

RFgun cavity

The SPring-8 RF gun is a single cell cavity and has two-symmetric RF ports. The copper cathode is at the center of a cavity inner wall. One of the RF ports is for RF input and the other for RF output to a dummy load. The dummy load was added to damp the loaded Q value of the cavity, which shortens the RF filling time and might increase the maximum limit of the electric field. After RF conditioning, the maximum field gradient of 140 MV/m has been achieved for an RF pulse length of 1 μsec, and 175 MV/m for 500 nsec [2]. The symmetric structure has an advantage to generate symmetric electric field in the RF cavity, therefore the electrons emitted from the cathode are accelerated straight forward without being bent by an asymmetric electric field.

The UV laser is incident through an input window at an incident angle of 66 degrees to the cathode. Considering the low beam emittance, the other quasi-normal incident laser optics was also prepared.

Laser system and Synchronization

The laser system to illuminate the cathode is a commercial Ti:Sapphire THG laser system. The pulse frequency of the laser oscillator is set at 89.25 MHz (1/32 of the RF frequency of 2856 MHz). The output THG pulse has a pulse rate of 10Hz, wavelength of 263 nm, r.m.s.pulse length about 5ps and typical pulse energy of 200 μJ. As the UV pulse length from the THG is too short for RF gun, it is stretched with Silica glass rods.[3]

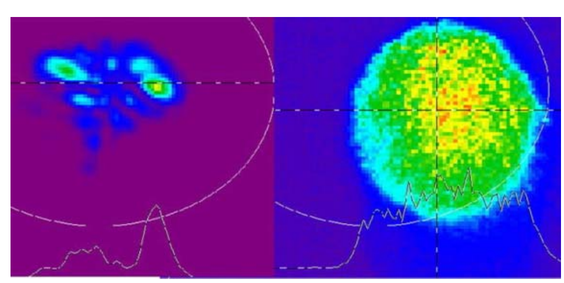

Figure 1. Profile improvement of the laser spatial profile with microlens array

To produce a low emittance beam, the laser profile was deformed into a cylindrical flat top with a microlens-array [4]. The microlens-array is a collection of small hexagonal convex microlenses with a pitch of 250 µm. The transmission rate of this optical array is about 80 % in a region of ultraviolet. The laser spatial profile without microlens-array is shown on the left hand in Fig. 1. The profile was spatially shaped by a microlens-array as a quasi-flattop profile (see on the right hand in Fig. 1).

To keep the same beam phase, the laser pulse should synchronize with the RF signal. It was realized by stabilizing the laser oscillation frequency at 89.25 MHz and the generation of the RF signal from the laser pulse of the oscillator [3]. The circuit diagram is show in figure 2. The jitter between laser pulse and the RF signal was about 1.2 ps (1σ).

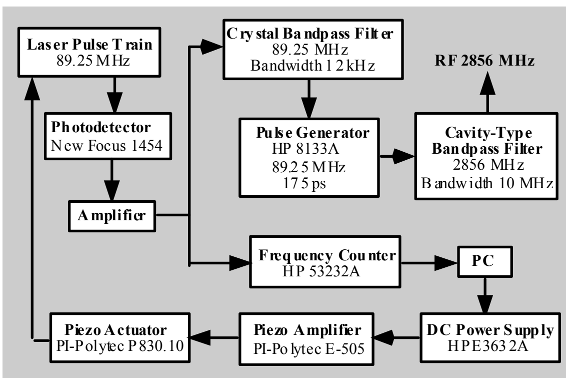

Figure 2. RF generation and frequency feedback system

Performance of RF gun

The emittance of the electron beam of 3.1 MeV was measured with double slits scanning. The maximum electric field on the cathode was fixed at 135 MV/m in the measurements. The charge of the generated electrons was

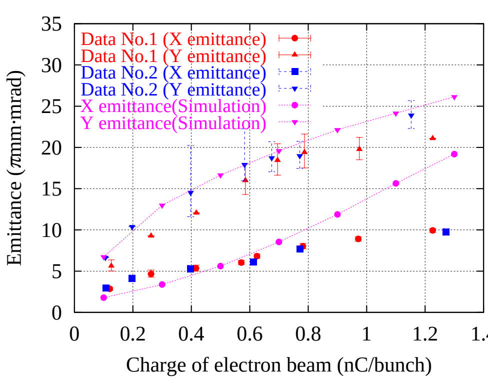

Figure 3. The Measured normalized emittance as a function of a charge per bunch.

controlled with the UV laser attenuator after the UV pulse stretcher. The charge dependence of the normalized rms emittance is shown in Fig. 3. The minimum emittance of 2.3 πmm-mrad was observed when the charge of the electrons is 0.1 nC/bunch. Due to the incident angle of 66 degrees, the beam has asymmetric distribution, and the vertical emittance is larger than the horizontal one [5].

HIGH QE CATHODE GUN

Cathode

As the copper has low Qe, it requires a high power UV laser. Such a high power laser is generally complex, unstable and difficult to use. For the stable and easy operation of the laser, high Qe cathode should be realized. As the material of the cathode, Ce_2Te has been studied as a good candidate from the point of Qe (typically several percent) and lifetime (several hundreds of hours). Because the lifetime is not still long enough, the cathode should be generally deposited after a period of operation. To avoid the deposition process, we adopt a cartridge type cathode. When the lifetime is over, the cathode can be easily exchanged.

To improve the laser injection, the transparent cathode was developed as well as the reflection cathode. As the advantage of the transparent cathode, the complete right angle illumination of the laser is possible and lower thermal emittance is expected.

The cathode cartridge is shown in photo 1. The Ce_2Te layer (50nm) is deposited on the Cr layer (30nm) on the Mo plug. It is possible to move it along the vacuum bellows. For the transparent cathode, the thin sapphire circular plate is put on the Mo plug, and Ce_2Te is deposited on the sapphire plate. Additional Cr layer as a current conductor was deposited around the cathode.

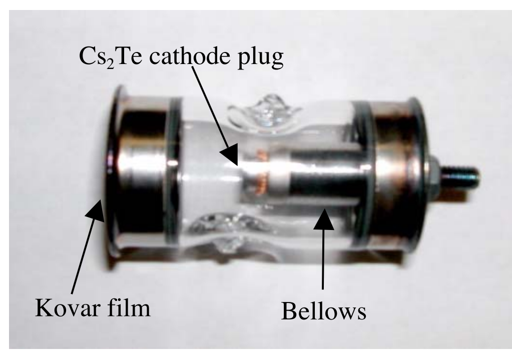

Photo 1. Cathode cartridge

As the vacuum tube cartridge is fabricated at the factory, the deposition chamber is not necessary back of the RF gun cavity. A cathode exchange system is attached to the cavity instead. Four cartridges can be kept in the cartridge holder at maximum. When the cathode plug is exchanged, a thin Kovar foil on the cartridge is teared by a pair of cutters and only the plug is inserted into the central hole of the cavity.

RF Cavity and High Power Test

A new cavity was developed for the Ce_2Te cathode. It is a modified cavity from that for the copper cathode. The main difference is the existence of a hole of 7.8 mm in diameter to insert the cathode plug. The initial RF conditioning was carried out with an OFC copper cathode plug. The electric field strength on the cathode surface at 100 MV/m was achieved after 70 hours of RF processing.

The dark current was about 1.5 times higher than that of the other copper cathode cavity.

Cathode Test

The reflection type cathode with an initial Qe of 8.3 % (measured at the factory) was tested. The RF field was increased to 90 MV/m, but due to the vacuum discharge, it took two hours of RF conditioning and the Qe decreased to 3%. Then the RF field was kept at the same level for 28 hours and the UV laser emitted. The temporal degradation of the Qe is shown in Fig. 4. The Qe decreased to about 1 % after 15 hours. The rapid Qe enhancements occurred with vacuum discharges. The damage of the surface was less than 5 % of the entire cathode region found by the EMPA observation [6]. It indicates that the degradation of Qe is not resulted from the damage on the cathode itself. The oxidation accompanying with the RF conditioning may decrease the Qe. The rapid Qe recovery may come from the removal of the oxidized surface by the vacuum discharge. The dark current was also measured and was found two times higher than that with copper cathode.

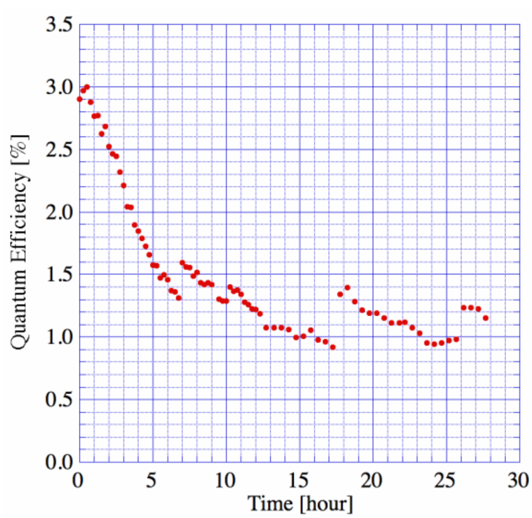

Figure 4. Temporal degradation of the Qe

The transparent cathode was also tested. The RF conditioning was not succeeded because of the continuous discharge at the cathode surface and the gap between the cathode and the hole. The Ce_2Te layer on the cathode was partially destroyed by the discharge. We are improving the structure of the cathode to avoid these discharges.

NEW TEST BENCH

For further research, a new test bench for the RF gun was constructed at SPring-8. There are two beam lines in the test bench. One beam line consists of an RF gun and a 3-m linac, and the other only an RF gun. The purpose of the former is to measure the beam emittance after accelerating electron beam with the linac. The possibility of the future beam injection to the SPring-8 linac is also considered. On the other hand, the later is for the test of the high Qe cathode or new test cavity.

A 3-m linac with the final energy at 30 MeV was added after the RF gun in the new test bench. To calculated the beam dynamics from the cathode to the end of linac, a simulation code PARMELA was used. The position of two solenoid coils and the distance between the RF gun and the linac was determined. The length from the RF gun to the linac was designed as long as possible, because the space for the optics for normal injection or the energy-analyzing magnet was indispensable. The optimized result is shown in figure 5. In spite of the long distance, the beam emittance after the linac was 2.2 πmmmrad at the beam charge of 1.0 nC. The beam emittance with a Quad scan will be measured and compared with that measured just after the RF gun.

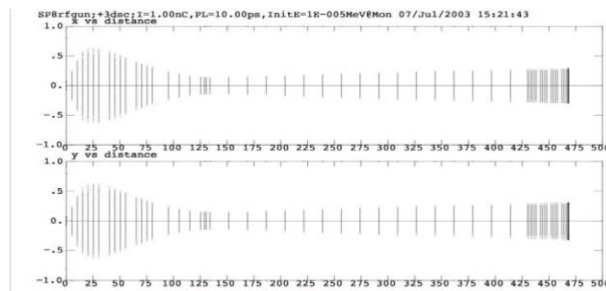

Figure 5. The beam simulation of an RF gun and a following linac with PARMELA. The laser is assumed to be normal injection to the cathode. The RFgun locates at 0 cm, two solenoids 15.4 cm and 37.4 cm, and linac starts at 120 cm and ends at 420cm.

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