

OPERATION OF THE NSRRC 2998 MHz PHOTO-CATHODE RF GUN

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Abstract

We are developing the photoinjector technology for single pass FEL research at NSRRC. The gun test facility (GTF) equipped with a 35MW, S-band high power pulse klystron as well as a 300μj, UV driver laser has been constructed for testing photocathode rf gun. Recently, a 2998 MHz, 1.6-cell photo-cathode rf gun has been fabricated in house and is being tested at the NSRRC GTF. Details of this setup will be described and the operational performance of this electron gun will be reported.

INTRODUCTION

High quality electron beams with high brightness and low emittance is required for various research fields. In particular, it is an important role in XFEL which is a source that produces high brilliance and ultrashort X-ray pulses for studying ultrafast dynamics of matter at atomic scale. Photoinjector is widely used generate high quality electron beams for developing XFEL facility, such as LCLS XFEL [1], European XFEL [2], SACLA [3] and so on. Besides, high brilliance and ultra-short electron bunches generated by photoinjector are also used in Thomson scattering [4].

The high brightness injector project at NSRRC has been carried to build up a light source for single pass FEL research. The goal of this R&D program is to build up the expertise on high quality electron beam and advanced linear accelerator technologies. Initially, a test facility for photoinjector as well as a low energy electron linac for generation of sub-hundred femtoseconds electron pulses will be setup. This low energy linac (~25 MeV) will be used for inverse Compton scattering or other novel X-ray source research. The injector system consists of a photocathode rf gun with compensation solenoid, three travelling wave rf linac structures which can accelerates electron beams up 150 MeV. The first stage of high brightness injector projector is to produce 1 nC, 10 pc electron bunches at 1 mm-mrad normalized transverse emittance by the photocathode RF gun. In the second stage, three high brightness driver linacs will be installed for short wavelength high gain FEL experiments.

PHOTOCATHODE GUN TEST SYSTEM

The test stand shown in fig.1 consists of a photocathode RF gun, a compensation solenoid, a steering magnet, a steering magnet, a insertable monitor screen, and a Faraday cup. The steering magnet is mounted on the solenoid downstream of the rf gun. Because we did not install a dipole magnet on the test stand, this steering magnet was used to estimate the energy of electron beam. The screen is composed of a 1mm thick, 1 inch in diameter YAG:Ge crystal and a polished stainless steel as

a mirror. Its position is 83 cm from the cathode. The faraday cup used for beam collection is located at the end of the beam tube. Electron beams are emitted from the gun by 266nm UV laser beams normally irradiating to the cathode.

Photocathode RF Gun

The NSRRC photocathode RF Gun is the BNL 1.6 cell Gun-IV structure [5] operating in π mode except that the operating frequency is 2998MHz. A modified design have been performed to adopt the frequency to 2998 MHz. After Brazing, the vacuum leakage test was performed. The leakage rate is lower than 5×10^{-9} mbar-liter. Fig.2 shows the resonant frequency of π mode is 2998.25MHz at woking temperature 55°C. The delta frequency of π mode and 0 mode is 3.21MHz. The unloaded Q and couple factor β of π mode is 7172 and 0.5 respectively. Because We use a copper Helicoflex Delta™ vacuum seal captive in the stainless groove in the cathode, the power loss in the stainless groove causes values of Q and β lower than the design value.

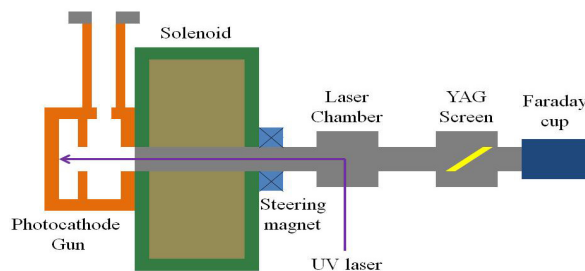


Fig. 1. A schematic drawing of the photocathode Gun test stand at NSRRC.

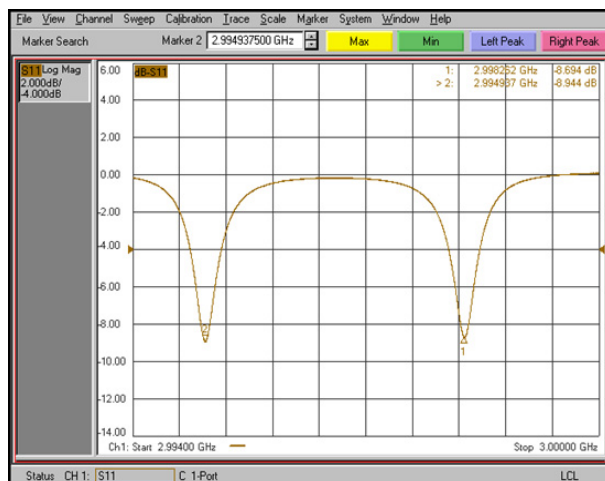


Fig. 2. Resonant frequency measurement of the photocathode RF gun.

High power microwave system

The 2998 MHz high power microwave system consists of a 35 MW, Thales TH2100A pulsed klystron which is powered by an line-type high voltage PFN. The PFN is charged resistively with a high stability high voltage power supply and has a good pulse-to-pulse stability. The measured voltage ripple from voltage divider is about 0.01% peak-to-peak in 1 μ s. A circulator and some waveguides have been pressurized with SF6 at 1.5atm to avoid gaseous breakdown. Other waveguides have been evacuated to $\sim 10^{-7}$ mbar during operation. The forward power to and reflect power from the rf gun cavity are picked up from a 60 dB dual directional coupler. And the power signals are monitored by calibrated microwave crystal detectors.

Drive Laser System

The drive laser is a state-of-the-art system from Coherent. A mode-locked oscillator generates a 800nm, 74.95MHz laser pulse train a to seed the regenerative amplifier. A Q-switch pumps the regenerative amplifier to raise the energy of the seed laser pulse great than 3.8 mJ. While IR beams from regenerative amplifier passing through THG, the third harmonic 266nm laser beams with an energy of 0.9mJ are generated. Then the UV stretcher stretches the width of UV laser beams from 1 ps to 15 ps with the output energy of 350 μ J. The 74.95 MHz signal from seed laser are locked with a signal from 2998 MHz master oscillator reduce to 1/40 by a Synchrolock system. Another signal (1 kHz) is for the Q-switch pump laser of the regenerative amplifier. Recently, because of the degradation of nonlinear crystal in THG and prisms in the UV stretcher, the output energy is 180 μ J and the beam profile is not uniform Gauss distribution. The performance of the laser system is described in another paper in this proceeding [6].

RF GUN CONDITIONING

Before illuminating the laser on the cathode, RF conditioning of the photocathode gun has been performed. In this procedure, the test system was directly pumped out by two ion pumps. While a base pressure in the gun cavity was reached 5×10^{-8} mbar, the conditioning was started with 2 μ s width and 10 Hz repetition rate rf pulses. During RF conditioning, the upper limit of vacuum was set to 5×10^{-8} mbar and the incident power has been increased slowly to avoid gaseous breakdowns in the cavity by the limiting number of arcs per hour. The RF conditioning was continued intermittently and the field gradient were reached up to 54 MV/m after a conditioning time about one hundred hours. The vacuum pressure with and without RF power decreased to 3×10^{-8} mbar and 1.6×10^{-8} mbar, respectively. In Figure 3, the red trace is the forward power to the cavity at 3.6 MW. The yellow trace represents the reflect power from the cavity. The rf gun cavity is under coupled. The dark current at this field gradient was 3 nC/bunch. The conditioning was continued until forward power exceed 4.5 MW with field gradient 58MV/m. In

this situation, RF breakdown occurred frequently. It seemed to be the maximum gradient for a stable operation of our test photocathode RF gun with unpolished surfaces inside the cavity.

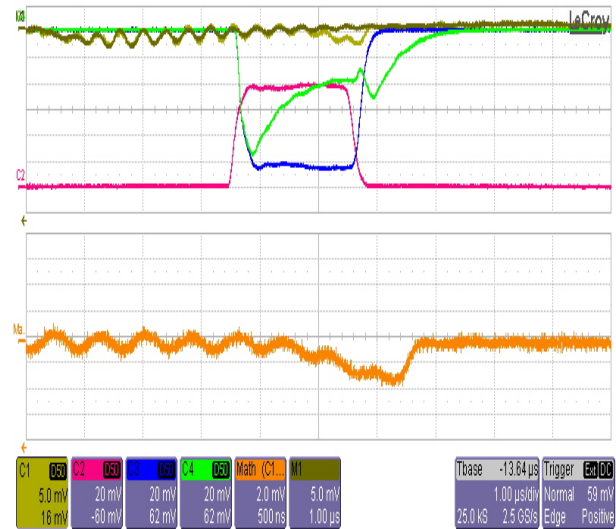


Fig. 3. Forward power (blue), reflect power (green) and dark current (orange) during rf conditioning.

After RF conditioning, the dark current was measured at different field gradients. Field emission on a surface is usually characterized using Fowler-Nordheim formula [8] analysis. The Fowler-Nordheim formula is:

$$I_{\text{peak}} = 5700 \frac{10^{4.52\Phi - 0.5} A_e (\beta_{\text{FN}} E_{\text{RF}})^{2.5}}{\Phi^{1.75}} e^{-\frac{6530\Phi^{1.5}}{\beta_{\text{FN}} E_{\text{RF}}}}$$

where A_e is the effective emitting area, Φ is work function of the material, β_{FN} is the field enhancement factor, E_{RF} is the peak RF field and I_{peak} is the peak dark current. β_{FN} can be obtained by plotting $\ln(I_{\text{peak}}/E_{\text{RF}}^{2.5})$ versus $1/E_{\text{RF}}$ as shown in Fig.4. The value of β_{FN} is 162.

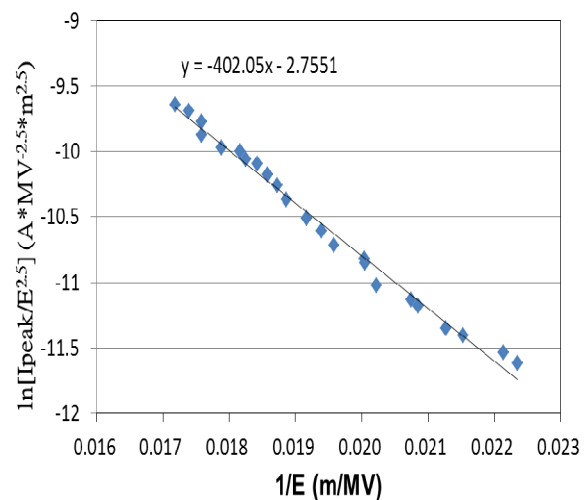


Fig. 4. Fowler-Nordheim plot for the dark current measurement.

BEAM CHARACTERISTICS

Bunch Charge Measurement

Beam current was measured by a faraday cup with which is located at 83cm from the cathode. The bunch charge was estimated by the beam current signal. In Fig.5 the bunch charge is plotted as a function of different laser injection phase. We can expect that the zero bunch charge is correspondent to the zero degree of injection phase. As a result, The maximum of bunch charge is 246 pc. The correspondent injection phase is located at about 30 degree after 50 degree. There is another small peak appears over 140 degree. This may be caused by the different electron dynamics under the low RF field 58MV/m.

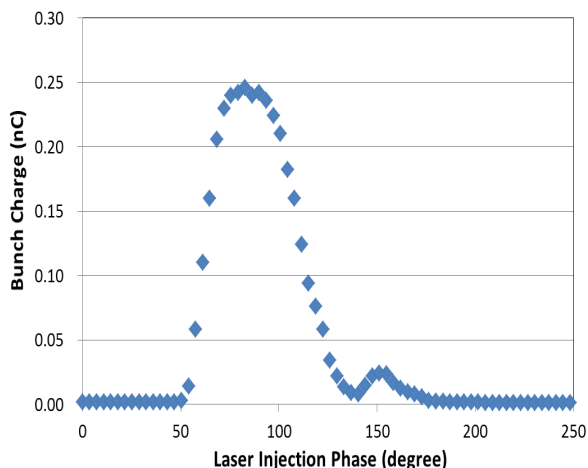


Fig. 5. Beam charge as a function of the laser injection phase.

Quantum Efficiency

The relation between the electron charge and the laser pulse energy is shown in Fig. 6. The laser injection phase set on the maximum bunch charge location. It shows that bunch charge is linear to the laser energy with. The quantum efficiency was found to be 1.5×10^{-5} .

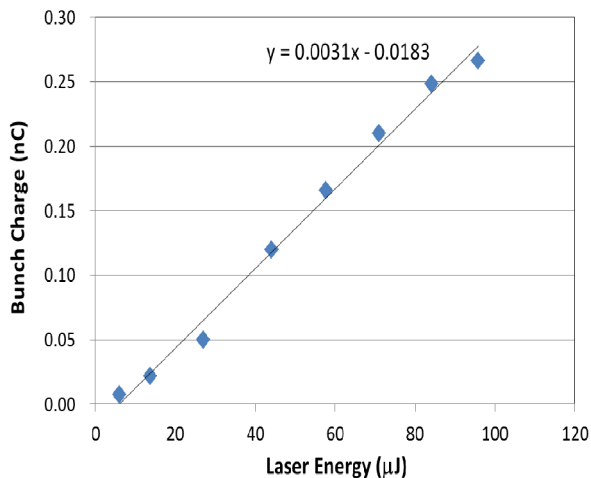


Fig. 6. Measured bunch charge versus laser pulse energy.

SUMMARY

The first operation of the photocathode rf gun has been performed in the beginning of 2013 at NSRRC. A electron bunch with 246 pc can be produced. The energy of the bunch is about 2.3 MeV estimated by using a steering magnet. In the next step, We will continue to install beam diagnostic instruments to measure characteristics of the electron bunch such as the transverse emittance and the bunch length. To achieve the field gradient large than 100MV/m the new cavities of photocathode gun machined by diamond turning will be fabricated.

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