STATUS OF THE PHOTOCATHODE RF GUN AT TSINGHUA UNIVERSITY*

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Abstract

A photocathode RF gun system was built to develop the electron source for the Thomson scattering X-ray source at Accelerator laboratory of Tsinghua University. The system consists of a BNL/ATF type 1.6 cell S-band RF cavity, a solenoid for emittance compensation, a laser system and some simple equipments for beam diagnosis. The status of the system is introduced in this paper, and the first beam measurements of the photocathode RF gun, including the dark current, transverse beam profile, charge and quantum efficiency is also reported.

INTRODUCTION

There are growing interests in developing high brightness electron beam with low transverse emittance and high peak currents. In particular, high quality electron sources play an important role in many regions such as the 4th generation light source [1−3](including SASE and HGHG X-ray free electron laser), femto-second electron diffraction [4,5], future linear collider [6], THz coherent radiation, ultra-short X-ray source based on thomson scattering [7−10], et al. High brightness electron beam is essential for developing such kind of facilities.

At Accelerator Laboratory in Tsinghua University, an ultra-short X-ray source based on Thomson scattering between ultra-short laser beam and high brightness relativistic electron beam is proposed. High quality electron beam with high charge, low transverse emittance and short pulse length is crucial for the device. A photocathode RF gun is developed to provide the suitable electron beam for this X-ray source. The designed parameters of the gun are listed in Table 1. Recently, the system has been operated successfully with photoelectrons. In this paper, we will report the preliminary measurement results.

DESCRIPTION OF THE SYSTEM

Photocathode RF Gun

The layout of the photocanthode RF gun system is schematically illustrated in Fig.1 . It consists of an S-band RF gun , a compact single solenoid for emittance compensation, a diagnostic chamber with a pop-in YAG screen profile monitor and Faraday cup. This RF gun is similar to the traditional BNL/ATF 1.6-cell 2856MHz photocathode RF gun system[11], except for several modifications. These include removal of the insertable tuners in the full cell to reduce the risk of RF breakdown and a lengthening of the coupling hole between waveguide and the full cell to provide enough coupling of π mode. A copper cathode is used. The driven UV laser beam is injected from the optical ports mounted on the half cell with $67.5°$ angle to the cathode surface normal, and it may be increase the quantum efficiency and reduce thermal emittance by using p-polarized laser with this incidence angle[12]. The solenoid magnet is 23cm long including yoke plates directly connected with the gun at one-side. The maximum filed strength is 2.4kG at 150A. A corrector magnet is mounted inside the bore of the solenoid assembly.

The first RF conditioning of the cavity was performed in October, 2005 with a pulse width of 4 μs and a repetition rate of 10 pps. The dependence of the dark current on

Table 1: Design parameters of the photocathode RF gun system in Tsinghua University

RF Gun	
Gun type	BNL type-IV
Electric field at cathode	$\geq$ 100 MeV/m
Cathode material	Cu or Mg
Frequency	2856 MHz
Repetition rate	$<$ 50 Hz
Laser System	
Laser media	Ti:Sapphire
Wavelength	266 nm
Pulse energy in UV	$\geq$ 250 μJ
Pulse length	0.5 - 15 ps
Time jitter	$\leq$ 200 fs

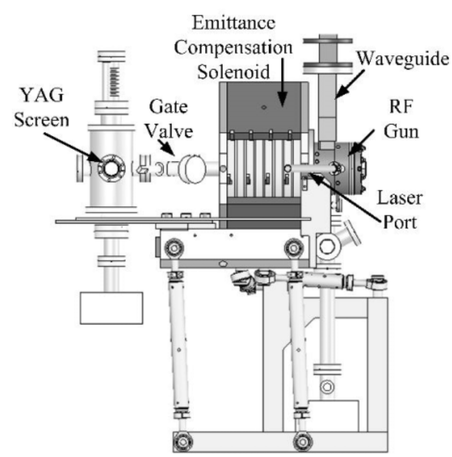

Figure 1: Layout of the photocathode RF Gun system.

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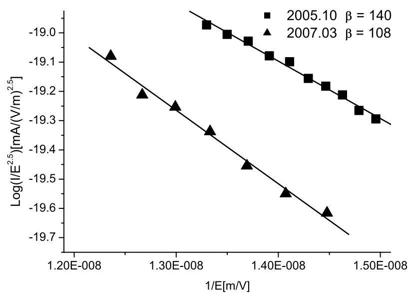

Figure 2: Fowler-Nordheim(F-N)plot for dark currents where E is the maximum gradient on the cathode and I is the Peak current.Square and triangle data are dark current with different RF conditioning time about 200 hours and 250 hours, respectively.

the field gradient was measured by using a Faraday Cup. High dark current was observed during the operation. Fig 2 shows the Fowler-Nordheim(F-N) [13] plot for the dark current. After careful conditioning of the gun for about 200 hours, the maximum input RF power is about 5.2MW, and the corresponding peak field at the cathode surface is about 80MV/m. Further increase of the input power is limited by our RF power system. The field enhancement factor β obtained from the slope of the F-N plot was about 140. In September, 2006, the cavity was conditioned to 80MV/m again. The observed dark current was dropped significantly during the conditioning process. The measured β was about 108 in March, 2007, and the RF conditioning time was about 250 hours.

Laser System

All solid state femto-second Ti:sapphire laser system, which is developed by Coherent, is used for the irradiation of cathode in rf-gun system.It include a Ti:sapphire passive mode-locked oscillator(Verdi Pumped MIRA), a regenerative amplifier(Legend), three harmonic generator, and pulse stretcher in UV. The 79.3MHz oscillator can produce 110fs FWHM pulses centered at 800nm with approximately 600mW output power. The rms time jitter between the laser and external RF is less than 200 fs. The regenerative amplifier is capable of producing 2 mJ in the IR and, after three harmonic generator, $\sim$500 μJ in the UV. The UV pulse width can be changed from several hundreds femtosecond to 15ps by the pulse stretcher. The repetition rate of the laser system in experiment is 10 Hz.

RECENT RESULTS

First photoelectrons were achieved with $\sim$ 130μJ UV(266 nm) laser on September 7, 2006, with 4.5 MW RF power fed to the gun. The corresponding peak field at the cathode surface is about 75 MV/m and the maximum energy of about 3.7 MeV is expected for the electron beam. The first beam image measured with a YAG screen is shown in Fig 4. The peak magnetic field of the solenoid is about 1.5 kG. The dark current is clearly seen on the YAG screen. The fitting of the profile with a gaussian curve indicates that the rms beam size is about 1.5 mm. The charge measured with faraday cup is about 540 pC, and the QE was calculated to be 1.8×10^{-5}. The maximum beam energy preliminarily measured with corrector magnet is about 3.4MeV at the first operation.

Figure 3: picture of laser system.

Figure 4: First photoelectrons; September 7,2006;

In photocathode RF gun, the charge is a function of the laser intensity distribution and the injected RF phase, and the photo-emission is dominated by Schottky effect with the UV light(266nm) used in the experiment. In this situation, the maximum beam charge is achieved when the laser has a launching RF phase of 90 degrees. In our experiment, measurements of charge collected by the faraday cup versus different laser injection RF phase is obtained for 4.5MW input RF power and 20 μJ laser pulse energy. The relative phase between the RF oscillator and laser pulse is changed by a phase shifter. Fig 5 shows the experimental results. During the measurement, the solenoid current is adjusted to ensure all photoelectrons are collected by the faraday cup.

We also measured the emitted photoelectrons as a function of the laser energy, as shown in Fig 6. From this measurement, it is observed that saturation of the charge occurs at laser energy about 30 μJ. The saturation can be explained by space charge effect near the cathode surface. When the

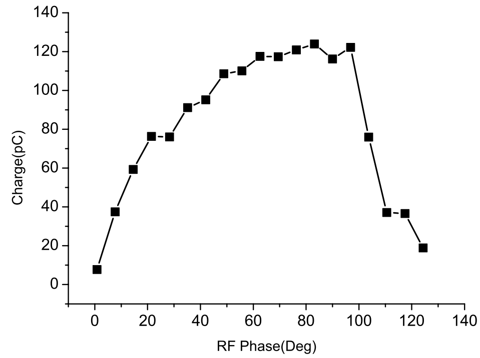

Figure 5: Photoelectron charge vs RF gun phase

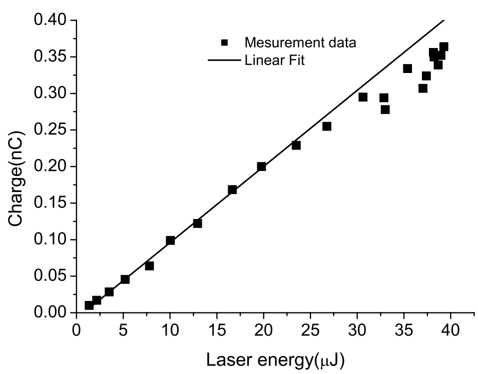

Figure 6: Charge versus laser pulse energy for the photocathode RF gun. The Max. RF field at cathode is about 75MV/m and injected RF phase is about 50^0

electrons are produced by the laser pulse, they are emitted as thin disk from the cathode. The space charge field from the electrons in the head will reduce the total field near the cathode surface and result in the saturation. Linear fits for laser energies below 30 μJ is presented, and the quantum efficiency is found to be about 7.0×10^{-5} for the specific experimental conditions.

The effect of polarization angle of laser light on charge was measured by using a $1/\lambda$ plate, as shown in Fig 7. This figure shows that sinusoidal change in charge is obtained with the laser polarization angle change and the maximum quantum efficiency is obtained at p-polarized. As D.Xiang's theory[12], it is due to the surface photoemission initiated by the presence of the normal electric field by using p-polarized laser at oblique incidence, and with this technique, the thermal emittance could be reduced by 40% for a Copper photo-cathode with atomically smooth surface.

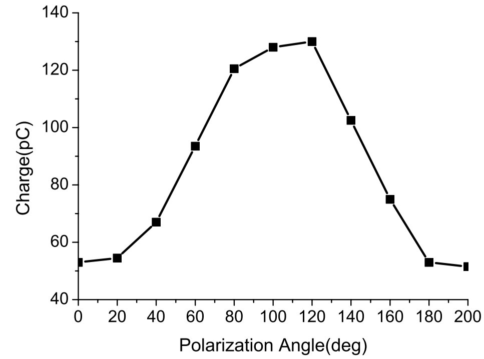

Figure 7: The charge measurement as a function of the laser polarization angle

OUTLOOK

Now, the photocathode RF gun system is updated to make it more reliable and stable. Some beam diagnostic equipments will be installed. In this summer, the characteristics of the electron beam, such as the emittance, energy spread, bunch length and timing jitter will be measured precisely. Experiment of soft X-ray generation will also be preformed using Thomson scattering between the electron beam and Nd:YAG Q-switched laser beam at different crossing angle.

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