THE LOW EMITTANCE PHOTOINJECTOR IN TSINGHUA UNIVERSITY*

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Abstract

A photo cathode RF gun with metal cathode is under developing in Tsinghua University. The initial emittance caused by the roughness of the cathode is studied and an analytical expression of it is given in this paper. From the roughness of the cathode we are using, the emittance caused by the roughness is about 0.3mm.mrad/mm. This paper gives the design and preparation of the RF gun system, such as the microwave measurement results. The laser system from COHERENT with pulse length 2~12ps and energy 250μJ at wavelength of 266nm is ready, and the time jitter to the RF field is less than 200fs.

INTRODUCTION

The photocathode RF gun is commonly used to get a low emittance electron bunch. There are several aspects to be considered to design a photocathode RF gun for low emittance electron beam. From the cathode, there will be initial emittance, which is very important, for it cannot be compensated. The initial emittance is from the initial kinetic energy of photoelectrons caused by the UV photons and the roughness of the surface of the cathode. The electric field gradient should be as high as possible to suppress the space charge effects. The cavity shape and rf power feed-in coupling design may cause asymmetry of the rf field and the multi-pole modes can cause the emittance growth. The performance of the laser also plays an important role. For example, the transverse and longitudinal distribution of the laser pulse will exit similar electron bunch from the cathode, and influence the space charge force in the electron bunch. The laser pulse shaping is normally used to improve the electron bunch quality. There are still some other factors influencing the emittance of a photocathode rf gun, such as the focus coil and time jitter.

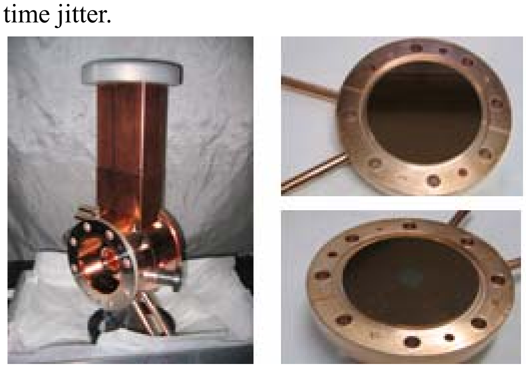

Figure 1: Pictures of the photocathode rf gun, left-up is copper and left-down is magnesium cathode.

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In Tsinghua University, a BNL/KEK/SHI type rf gun is designed, manufactured, and measured. Now the testing stand is ready and the first beam will be got these days. The pictures of the gun after wielding and the cathode are shown in figure 1.

THE INITIAL EMITTANCE FROM THE CATHODE

The initial emittance of a photocathode RF gun is from the cathode and the laser system. One part is the thermal emittance caused by the photons, and the other part is caused by the electric field on a rough surface.

Flat Metal Cathode

To analyze the thermal emittance of an idea flat metal photocathode, a model for the electron kinetic energy distribution emitted from the photocathode is presented [1]. And the average kinetic energy parallel to the cathode surface is,

$$\left\langle E_{kin,//} \right\rangle_{flat} = \frac{h\nu - \phi}{3} \tag{1}$$

A formula of the thermal emittance of an idea flat cathode is derived as shown in Eq.2. Here we assume a uniform space distribution with a radius of R.

$$\varepsilon_{n,rms,flat} = \frac{R}{2} \cdot \sqrt{\frac{h\nu - \phi}{3m_0c^2}} \tag{2}$$

The Roughness Caused Emittance

The reported measurement results of thermal emittance of copper and magnesium cathode [2,3]are significantly larger than theoretical prediction. This fact may imply that surface roughness effect may have significant contribution to the initial emittance.

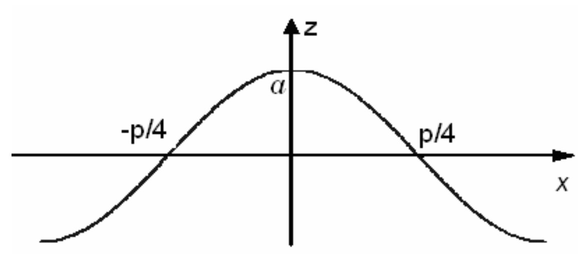

Figure 2: The model used to analyze the influence of the roughness.

We assume a simplified roughness model, as shown in figure 2. It's a one-dimensional approximation with the roughness expression as $z = a\cos(2\pi x / p)$. From the stray electric field [4] because of the micro-surface as shown in figure 2, the emittance can be given as

$$\varepsilon_{n,x,rough} = \frac{R}{2} \cdot \sqrt{\frac{\pi e a f(a_u) E_{rf} \sin\theta_{rf}}{4 m_0 c^2}} \quad . \qquad (3)$$

Where $f(a_u) = a_u - 0.59 a_u^{\ 2} + 0.023 a_u^{\ 3}$ is a correction function, which is fitting from simulation results.

We made surface profile measurements on the samples after diamond cutting or diamond polishing (figure 3). With the analytical expression (see Eq.3) in this paper, we estimated the dedication of roughness effect to the thermal emittance for our samples is about 0.3mm.mrad per mm laser radius (as shown in Table 1) .

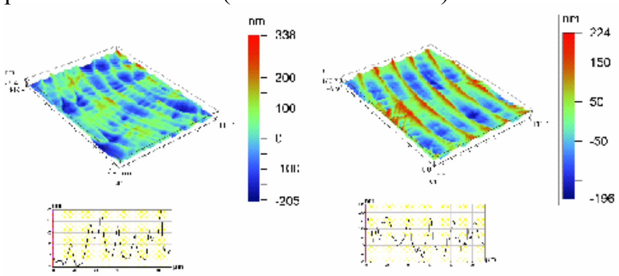

Figure 3: Copper cathode (left) and Magnesium cathode (right) cut by diamond without polishing.

Table 1: Roughness and Emittance Caused by It

Roughness period	8 µm
Roughness amplitude	70 nm
Electric field gradient	50MV/m
Emittance caused by roughness	~0.27mm.mrad/mm

MICROWAVE MEASUREMENT

The electric field distribution along the axis of this RF gun was measured and calculated using SUPERFISH. Both results are shown in figure 4.

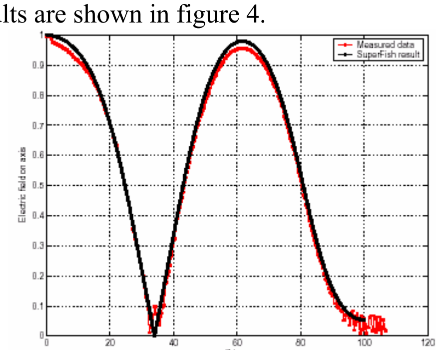

Figure 4: Measured (red) and simulation (black) results of Electric Field *Ez* along the Axis.

The detail microwave measurement results of the RF gun after welding are given in Table 2. The measured parameters are agreed well with the designed ones, which means the manufacture and welding of the RF gun are successful.

Table 2: The Microwave Specifications of the 1.6Cell RF gun at Tsinghua Univ.

	Measured	Designed
f_π-f_0 (MHz)	3.234	3.230
f_π in vacuum (MHz)	2857.37@23°C	2856.00@45°C
Q of π mode	10327	10863
β of π mode	1.19	1.28
Q of 0 mode	9503	9629
β of 0 mode	0.78	0.77

LASER SYSTEM

A Ti:sapphire laser system was bought from COHERENT, the principle sketch was given in figure 5.

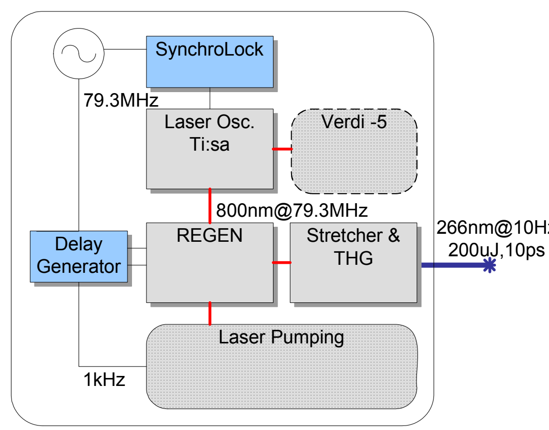

Figure 5: The diagrammatic drawing of the Laser system.

The time jitter of the laser pulse to the RF field was measured by the harmonic relative noise spectral density (see figure 6). The harmonic reference signal is obtained from Synchrolock-AP 'COMB OUT', which generates a frequency comb from fundamental reference HP8663 @79.3MHz. Measurement of 9th and 36th harmonic show a significant noise peak around 18kHz, while the fundamental measurement doesn't. This is due to the reference of fundamental measurement is directly from HP8663. In spite of the 18kHz spike, the rms timing jitter measured by means of harmonic phase noise PSD between Mira-900F and HP8663 via Synchrolock is 126±20fs.

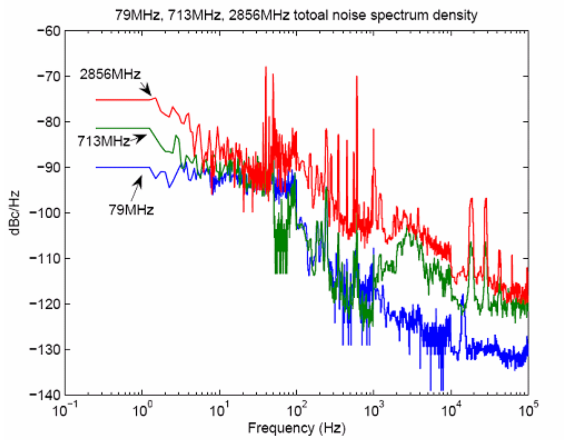

Figure 6: The measured harmonic relative noise spectral density spectra of the time jitter.

SUMMARY

Figure 7: The RF gun experimental stand.

We have done the high power processing of the RF gun. The RF power fed into the RF gun is up to 4.5MW now, which means the corresponding electric field strength on axis be 75MV/m. The RF gun experimental stand is ready, together with the laser system (see figure 7).

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