

## DESIGN AND OPTIMIZATION OF THE ELECTRON GUN<sup>#</sup>

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### Abstract

Design of an energy-modified electron gun is of significance to do some research on the properties of Diamond-amplified cathode. Based on the design method of the Pierce electron gun, the optimum parameters of the electron gun have been obtained using the Opera-3D program. And the beam waist's position, the beam current, the beam size and the beam emittance related to the electron beam energy was investigated in this paper.

### INTRODUCTION

Electron gun is one of essential parts of electron accelerators. Nowadays, national accelerator laboratories have been studying on the high-flux photocathode injector for use of the world's most advanced accelerator, like free electron laser (FEL), energy recycle laser (ERL) and electronic cooling hadron accelerator [1,2]. Thermionic field emission is an important part among different methods to produce burst of electrons in the electron gun, like thermionic and photo electric emission. Both the design and optimization of the thermionic cathode electron gun would be discussed in this article. For the application of electron gun in the Diamond-amplified cathode [3,4], the electron beam energy must be convertible, while the beam intensity is not to be very large because of the amplification of the diamond film. In this article, design and optimization of electron gun was performed by Opera software. Electron gun was designed for production of peak current 50 mA and the electron beam energy varied from 0 to 10 keV.

### ELECTRONGUN PARAMETERS

The determination of the parameters of the electronic gun is the first step to design an electron gun meeting the experiment requirement.

Grid-control electron gun as the electron source has been confirmed to obtain steep pulse current. In addition, the beam current intensity could be controlled by the grid-control electron gun voltage. The electron gun parameters for the diamond-amplified cathode have been presented in the Table 1.

Table 1: The Electron Gun Parameters for the Diamond Amplified Cathode

Parameter	Value
Beam energy [keV]	0—10
Beam current [mA]	0.1—50
Spot size [mm]	≤1.5
Degree of vacuum [Pa]	≤2*10 <sup>-7</sup>

### DESIGN OF ELECTRON GUN

The design of gridded electron gun is composed of three parts, including cathode, anode and grid electrode design [5]. The short beam bursts could be attained in the gridded electron gun and the electron beam current could be adjusted to the grid cathode bias voltage. Commercial grid cathode is an excellent choice for the gridded electron cathode for its long service life and simple structure. Cathode dimension is decided by the cathode grid. And anode and grid electrode dimension should be designed with the experiment demand.

The grid electrode voltage is the sum of the DC voltage and the pulse voltage. When the pulse voltage on the grid electrode is relatively positive against the cathode, the beam would be extracted and focused, and when it is relatively negative, the beam emission would be restrained. The anode would help to extract the electron. Sometimes the anode hole is of certain influence to the beam defocusing. Therefore, the dimension of electron gun has been modelled and optimized by means of point depiction in the Opera-3D software.

### OPTIMIZATION OF ELECTRON GUN

The preliminary sketch of the electron gun has been presented in Fig. 1 (a). It was accomplished in the Opera software by the point depiction method according to the Pierce design method [6]. And the aperture angle is 67.5 deg. The three-dimensional model was obtained by the rotation of the preliminary sketch. And the electron beam envelope in the preliminary three-dimensional model is presented in Fig. 1 (b).

<sup>#</sup>Work supported by the National Nature Science Foundation of China under Grant Nos.11375176 and 10875118

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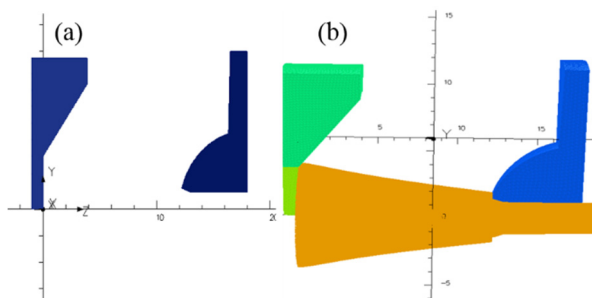


Figure 1: The preliminary sketch of the electron gun and the electron beam envelope in the preliminary model.

Obviously, some of the electron beam is blocked by the anode in the electron. And the aperture angle, the fillet radius of the focusing electrode, the distance between the anode and the cathode and the shape of the anode should be concerned in the optimization of the electron gun. The best geometry and schematic for thermionic electron gun have been presented in Fig. 2.

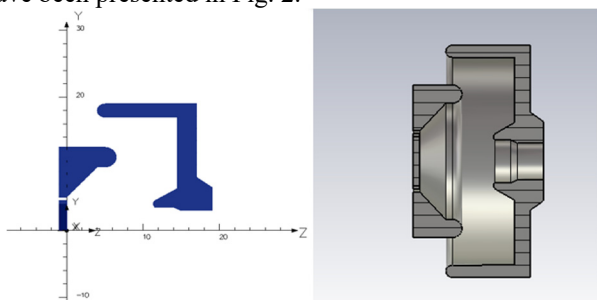


Figure 2: Geometry and schematic for thermionic electron gun.

### SIMULATION OF ELECTRON GUN

The simulation of thermionic electron gun is realized to analyse the gun performance with the Opera-3D-Pre - Processor module and the Opera-3D-Post-Processor module. While the effect of space charge has been taken into account in the Opera-3D, the electron gun simulation result would be closer to the actual situation.

The profile of electric field in the electron gun of 4.5 keV and 6.5 keV were presented in Fig. 3 (a) and Fig. 3 (b). Also, in Fig. 4 (a) and Fig. 4 (d), the electric beam envelope in the electric gun of 4.5 keV and 6.5 keV were presented.

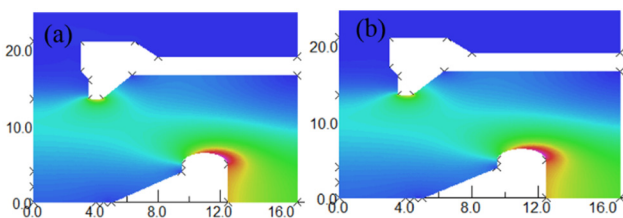


Figure 3: Electric field profile in the electron gun of 4.5 keV (a) and of 6.5 keV (b).

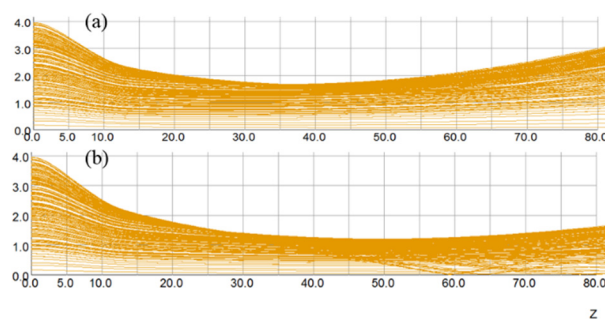


Figure 4: the electric beam envelope in the electron gun of 4.5 keV (a) and 6.5 keV (b).

The beam waist position and beam waist radius in the electron gun have also been presented in the Fig.4 (a) and Fig.4 (b). The beam waist position in the electron gun of 4.5 keV is 36 mm and the waist position of 6.5 keV is 50 mm. And the beam waist radius in the electron gun of 4.5 keV is 1.69mm. The other is 1.26 mm. The laminarity of electron gun indicates the electron beam quality in the focusing electromagnetic field and the defocusing electromagnetic field. Obviously, the laminarity in the electron gun of 4.5 keV is much better than the laminarity in the electron gun 6.5 keV, which indicates the smaller emittance in the electron gun of 4.5 keV.

And transverse phase space at electron beam waist of 4.5 keV and of 6.5 keV was represented in Fig. 5 (a) and Fig. 5 (b). The distribution of transverse phase space could be calculated by defining monitoring surface with CST code at beam waist. The particle information is also exported and depicted by the software. And the emittance could be calculated at beam waist. In Fig. 5, the emittance at beam waist of 4.5 keV is 4.63 mm·mrad and of 6.5 keV is 7.36 mm·mrad. The result is consistent well with the result about the laminarity in the electron gun of 4.5 keV and of the 6.5 keV.

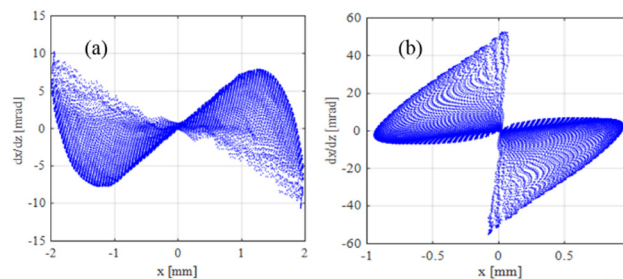


Figure 5: Transverse phase space at beam waist of 4.5 keV (a) and 6.5 keV (b).

The beam waist position, radius, current and electric field were presented in Fig. 6.

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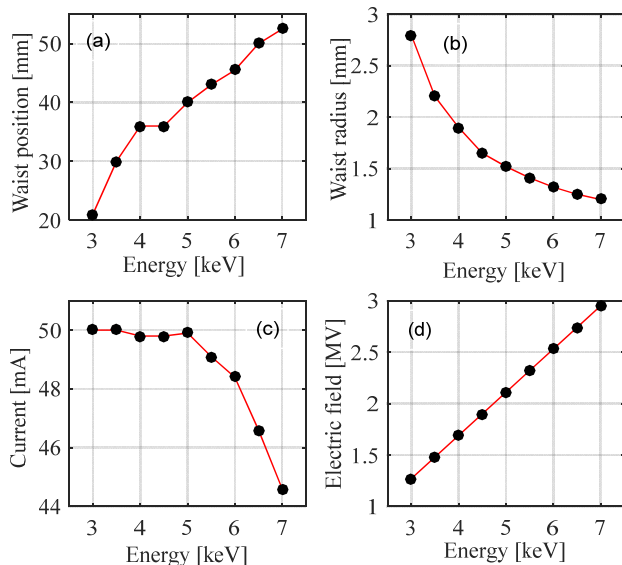


Figure 6: Opera simulations of position of bunch waist (a), current at bunch waist and current at 40 mm (b), bunch radius (c) and the highest field strength as function of bunch energy (d).

In Fig. 6 (a), while beam energy increases, the waist position changes a little, just several mm, which is under the restraints of experiment. And beam waist is going away from the cathode when beam energy increases from 3 keV to 7 keV. Obviously, compared to the high energy electron beam, the low energy beam would be much more easily focused with the bias voltage on the grid electrode and defocused because of the space charge effect. Thus the waist of low energy beam is closer to the cathode.

In Fig. 6 (b), it indicates that beam current would decrease when beam energy increases, which is caused by the degressive tendency of the laminarity. It is evitable but won't exert large influence on the result.

In Fig. 6 (c), beam waist radius decreases while electron energy varies from 3 keV to 7 keV. If beam energy is too low, the waist radius may be too large to go through anode hole. And the radius of diamond film is concluded to be about 3mm.

In Fig. 6 (d), it indicates that the electric field is linearly proportional to beam energy. Notably, the higher the beam energy, the higher the anode voltage. And so is the electric field. And it is important to figure out that electric field breakdown which is about 15 MV/m in vacuum would not happen in this gun.

## CONCLUSION

The design of electron gun is completed, which satisfies the requirement of experiment with point depiction method of the Opera-3d. And the accurate dimensions of the electron gun has been obtained by the simulation done in the software. The variation trends of waist position, beam current, waist radius and beam emittance with beam energy have been discussed with the software in the paper. And the simulation results in the software have very good agreement with experiment requirements.

## ACKNOWLEDGEMENT

The work is supported by the National Nature Science Foundation of China under Grant Nos.11375176 and 10875118.

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