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Ultra-low emittance *X*-band photocathode RF gun*

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Abstract In this paper, we present the simulation results of a 1.6 cell *X*-band photocathode RF gun for ultra-low emittance electron beams. It will work at 9.3 GHz. The emittance, bunch length, electron energy and energy spread at the gun exit are optimized at bunch charge of 1pC using PARMELA. Electron bunches with emittance about 0.1 mm·mrad and bunch length less than 100 fs can be obtained from this gun. A PITZ type coupler is adopted in this gun and an initial simulation by MAFIA is also given in this paper.

Key words ultra-low emittance, *X*-band RF gun, PARMELA

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1 Introduction

Ultra-short and ultra-low emittance electron bunches are strongly demanded as tools for brand new research work in biology, material, chemistry and so on. Several studies[1] have shown that photocathode RF gun can be used to generate high energy ultra-fast electron beams for electron diffraction. Because of the high electric field gradient, the space charge effects are greatly suppressed in the photocathode RF gun. Much more electrons can be got in the ultra-short electron bunch from photocathode RF gun than a DC photocathode electron gun.

The *X*-band RF gun has its advantages compared with the S-band gun[2]. It is smaller, and easier to get higher accelerating field. Therefore, an *X*-band (9.300 GHz) RF gun with a length about 3.0 cm, scaled from the 1.6 cell BNL S-band one[3] is simulated by PARMELA[4] in Section 2. A PITZ type coupler[5] is adopted in this *X*-band RF gun to avoid field asymmetries which will induce the emittance growth. An initial simulation of the RF gun with a PITZ coupler is given in Section 3.

2 Simulation of the *X*-band RF gun

The 9300 MHz *X*-band RF gun is scaled from the BNL *S*-band RF gun. It was optimized by SUPERFISH to get the electric field balance in the two cells for π mode (Fig. 1). The beam dynamics of the RF gun was simulated by PARMELA, and the simulated results were summarized in Table 1.

Table 1. The simulation parameters of the *X*-band RF gun.

gun parameters by SUPERFISH	
Freq. of π mode/MHz	9300.346
Q_0 of π mode	8889
Freq. of 0 mode/MHz	9285.725
Q_0 of π mode	9276
mode separation/MHz	14.621
input parameters for PARMELA	
bunch charge/pC	1
bunch length/fs	100
bunch radius/mm	0.5
initial emittance/(mm·mrad/mm)	0.5
injection phase/(°)	10
field at cathode/(MV/m)	100
electron bunch at gun exit	
electron energy/MeV	1.239
energy spread	$<0.3\%$
RMS bunch length/fs	71.67
normalized emittance/(mm·mrad)	0.110

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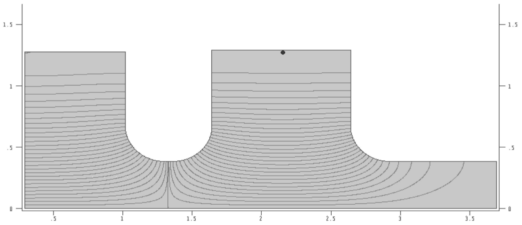

Fig. 1. The π mode electric field of the X-band photocathode RF gun.

Figures 2 and 3 give the simulated results of the energy, rms energy spread, rms bunch length and normalized emittance of electron bunches at the gun exit, for different laser phases and electric field gradients. The charge is 1 pC and the laser pulse is 100 fs, during the simulation. The electron energy decreases as the laser phase changes from 0 to 60 degrees at the electric field gradient of 80 MV/m for this gun as shown in Fig. 2(a). Meanwhile, The rms energy spread (Fig. 2(b)), the rms bunch length (Fig. 2(c)) and the normalized emittance (Fig. 2(d)) increase as the laser phase changes from 0 to 60 degrees. The higher the electric field, the higher the electron energy (Fig. 3(a)), and the rms energy spread (Fig. 3(b)), the rms bunch length (Fig. 3(c)) and the normalized emittance will be smaller. The laser phase can be chosen at the range of 0 to 30 degrees and the electric field gradient higher than 60 MV/m. The gun can work at the electron energy from 0.5 to 2 MeV, and with ultra-short bunch length, small energy spread and ultra-low emittance.

Table 1 gives the optimized parameters of the RF gun. It will work at laser phase of 10 degree and electric field of 100 MV/m. The electron energy will be around 1 MeV, the emittance 0.1 mm·mrad and the bunch length less than 100 fs, with 1 pC bunch charge.

3 Initial investigation of the RF coupling

In order to avoid field asymmetries in the gun, a PITZ type coupling structure is adopted for the X-band RF gun. Fig. 4 gives the 3D simulation of the coupler by MAFIA[6]. If critical coupling can be achieved, totally less than 1 MW input RF power is needed for 100 MeV/m gradient on axis.

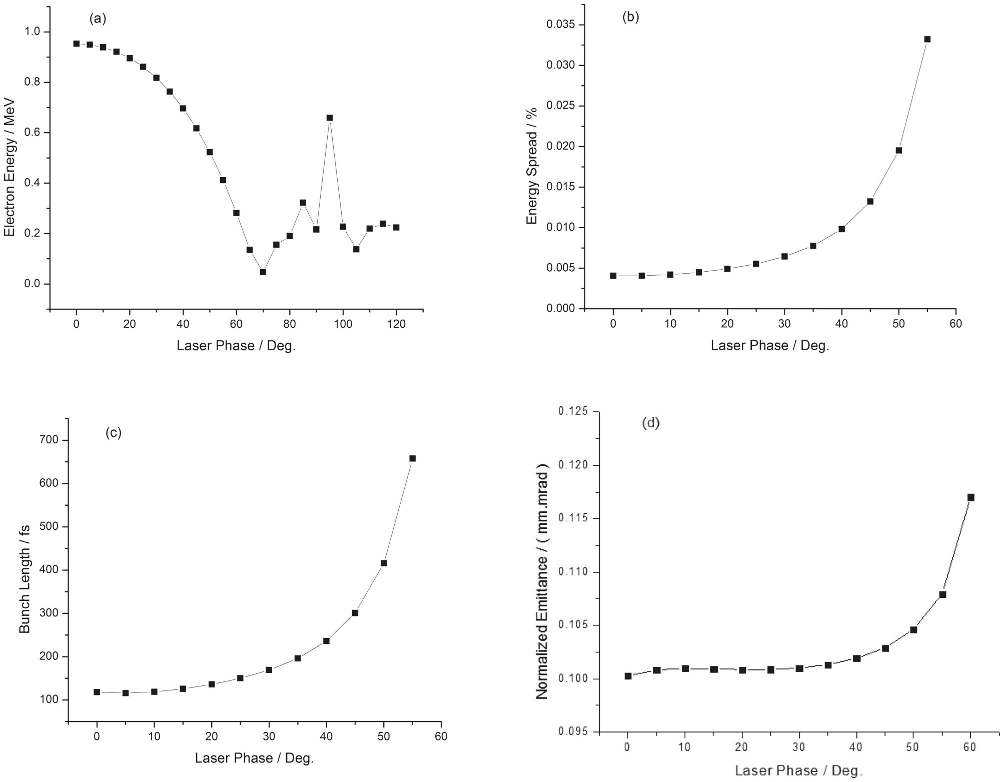

Fig. 2. The energy (a), rms energy spread (b), rms bunch length (c) and normalized emittance (d) at the gun exit for different laser phases, at one axis electric field gradient of 80 MV/m.

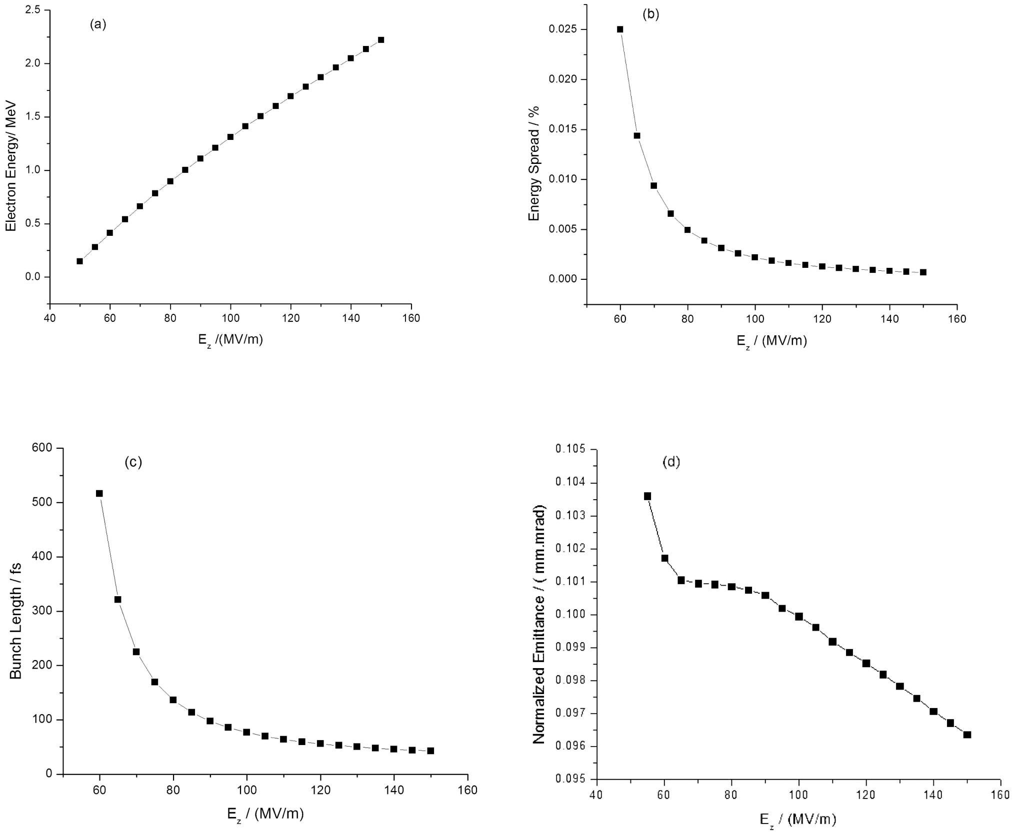

Fig. 3. The energy (a), rms energy spread (b), rms bunch length (c) and normalized emittance (d) at the gun exit for different electric field gradients Ez on axis, at laser phase of 20 degree.

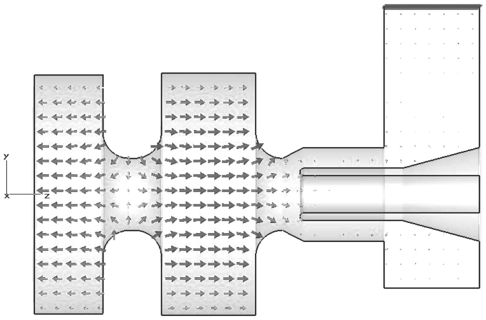

Fig. 4. The model of the PITZ type coupler.

4 Summary

A portable X-band photocathode RF gun system can be achieved using a 1 MW klystron RF power source. And the electron beam is good enough, with ultra-low emittance and ultra-short bunch length, for ultra-fast electron diffraction.

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