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Study on the W-band photocathode RF gun

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Abstract: In this paper, we continue our W-band photoinjector work. We discuss the production of a high brightness femtosecond bunch using our proposed W-band photoinjector under different parameters. The parameters of the produced bunch are the energy of 1.2 MeV, the length of 60 fs, the peak current of 90 A, the normalized emittance of 0.4 mm mrad and the energy spread of 1.9%. Finally, we present some application examples of the proposed photoinjector.

Key words: W-band, RF gun, light source

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1 Introduction

The femtosecond beam is important for accelerator-based light sources and plasma based-accelerators. A millimeter wave linac involves one of the most advanced accelerator techniques. The scaling law of an RF linac is roughly $G\sim f^{1/2}$, where G is the gradient and f is the working frequency. The accelerating gradient is in proportion to the RF frequency. The present manufacturing technique can reach the millimeter scale level. So the W-band may be a good frequency choice for an RF linac. SLAC proposed to choose the frequency of 91.392 GHz as the RF frequency, and the gradient can even reach 1 GeV/m which is the ideal value for a conventional RF linac. Actually, there have been needle gun experiments where the local gradient reached the aim of 1 GeV/m. In Ref. [1], we proposed a W-band photoinjector design scheme. In this paper, we perform a more extensive parameter study.

2 LIGA technique

We can use the LIGA technique [2] to fabricate a millimeter wave linac. LIGA is an acronym for Lithographic Galvanoformung und Abformung, which is a sequence of steps to fabricate the optical components. Deep X-ray lithography is promising for millimeter wave structure fabrication.

3 W-band photoinjector

In Ref. [1], we designed a one W-band photoinjector. In this paper, we optimize the parameters of our proposed W-band photoinjector to produce the femtosecond bunch. We scale the BNL/SLAC S-band 1.6 cell RF gun to the W-band (91.392 GHz). The main parameters of the W-band 1.6 cell RF gun cavity [1] are shown in Table 1 and Table 2.

Table 1. Main parameters of the 1.6 cell cavity.

cavity radius	1.3 mm
iris radius	0.39 mm
iris width	0.698 mm
cavity length	4.69 mm
π mode frequency	91.392 GHz
shunt impedance	267 MΩ/m
quality factor	2806

Table 2. Typical laser parameters.

wavelength	266 nm
waist	20 μm
rep	10 Hz
pulse energy	related to cathode material
pulse length	66 fs
rise/fall time	5 fs
longitudinal distribution	uniform

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There are many codes for simulating an electron gun, such as GPT [3], PARMELA [4], ASTRA [5], etc. In Ref. [1], we used PARMELA to simulate the photocathode RF gun. Here, we choose ASTRA to simulate the photoinjector. The main output parameters of our proposed W-band photoinjector are summarized in Table 3.

Table 3. Main parameters of the photoinjector.

energy	1.25 MeV
normalized emittance	0.4 mm·mrad
rms energy spread	1.9%
bunch charge	20 pC
bunch length	66 fs
peak current	90 A

The output longitudinal and transverse phase spaces are shown in Fig. 1, Fig. 2. Fig. 3 shows the transverse profile.

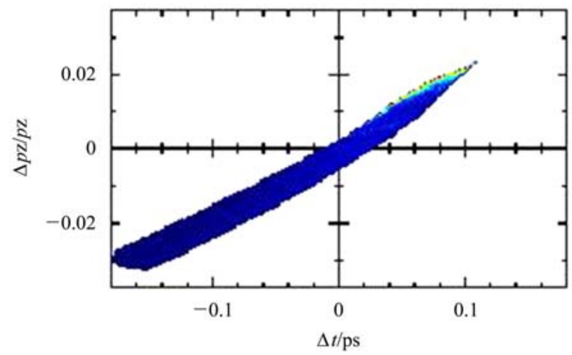

Fig. 1. The longitudinal phase space.

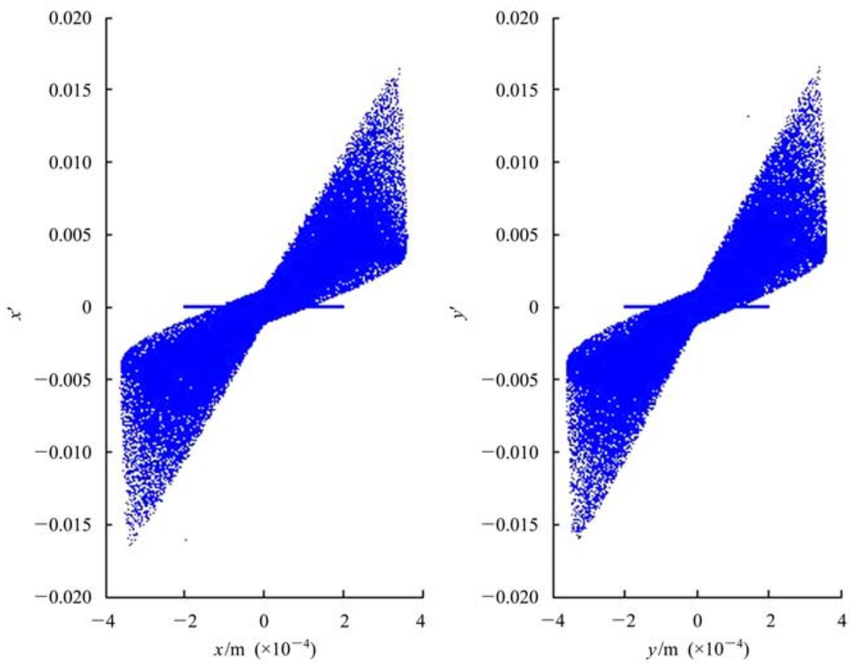

Fig. 2. The transverse phase space.

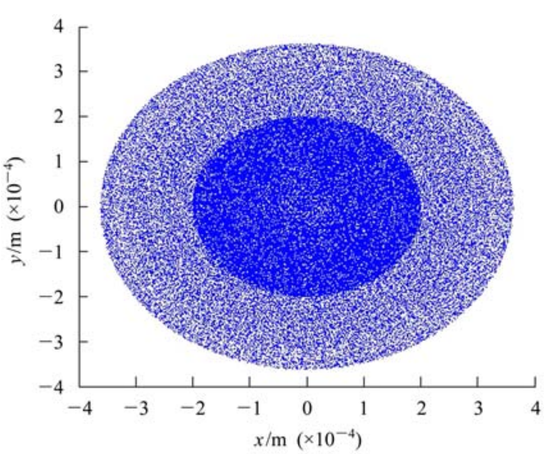

Fig. 3. The transverse profile.

4 High brightness femtosecond bunch and its application

Our proposed femtosecond beam can be used for the light source. There are many kinds of light sources, such as coherent synchrotron radiation (CSR) [6], Compton scattering and T-ray (Terahertz) FEL [6]. As Ref. [1] did, we can add some booster sections (also W-band linac section) to ramp the electron energy to tens of MeV. For example, the typical electron beam parameters are the energy of 30 MeV, the energy spread of 1% and the normalized emittance of 0.4 mm·mrad. This typical electron beam can be used to drive the CSR in the bend, Compton sacttering with a laser and T-ray FEL in the wiggler. The peak power of the CSR in the bend is much weaker than that of the T-ray FEL in the undulator. However, the CSR spectrum is wider than that of the FEL. We have done much work on the CSR and FEL in the past. In this paper, we discuss the X-ray production from laser beam Compton scattering with our proposed electron beam parameters.

The infrared laser paremeters we use are summaried in Table 4.

Table 4. Laser parameters for Compton scattering.

wavelength	15 μm
rayleigh length	32 μm
rep	10 Hz
peak power	$6.75\times10^{14}\mathrm{W/cm^2}$
pulse length	30 ps

The spectrum of the scattering photon is in a wide range. The maximum energy of the scattering photon is 10 keV.

5 Conclusion

The centimeter wave linac is a well matured technique. The S-band photoinjector has been well studied [7, 8] and is successful in many facilities. Millimeter wave linac is also a potential trend of the advanced accelerator concepts. Due to its small scale, the Wakefield effect is serious. So the beam charge should not be high, otherwise, we have to design a depressing method. Now the low charge case has been studied extensively in the FEL community and the experimental result is satisfactory.

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