THE FEL-THz FACILITY DRIVEN BY A PHOTO-CATHODE INJECTOR

Xingfan Yang[1], Ming Li[1], Weihua Li[1], Xiaojian Shu[2]

[1]Institute of Applied Electronics, CAEP, IAE, Mianyang, Sichuan, China
[2]Institute of Applied Physics and Computation Mathematics, Beijing, China

Abstract

After the first lasing in March 2005 in CAEP, the FEL-THz facility is updated ,the former thermionic cathode injector was replaced using a high brightness photo-cathode injector. The facility mainly consists of a 4.5cells photo-cathode RF-GUN injector ,a hybrid undulator and the optical oscillator cavity. Number of undulator periods is 44, the peak value of the undulator is 4900Gs ,the good aperture is 6mm .The cathode material is Cs2Te and the quadruple light is used , the width of the driving laser is 12ps , the quantum efficiency is about 1%. The commissioning of the injector is finished, the electron energy of the injector was measured and it is about 8MeV ,the energy spread is about 1% and the electron beam normalized emittance is about 9πmm.mrad. The charge is about 100pC and up to 1nC per micro-pulse , the repetition rate is 54.167MHz .The calculated wavelength of the light is about 125micron. At present ,the spontaneous emission experiment is undertaking .

INTRODUCTION

The first lasing of a thermionic RF-gun injector driving FEL-THz facility was realized in March 2005 in CAEP, the FEL light wave length is 115micron, but the saturation of the FEL can not be achieved ,mainly because of the low electron current and the instability of the facility, so we decided to develop a high performance photo-cathode RF-gun injector. The photo-cathode RF gun injector developed from 1985[1], comparing with the thermionic cathode RF-gun injector, it is easy to get the short pulse with high current and small energy spread, and at present it is the stand way to provide high brightness beam to generate high current and low emittance beam. The photo-cathode RF-gun is more adaptive to the research of FEL. We started to study the photo-cathode RF-gun in 1999, and the first one was built in 2000 ,the electron energy is about 3MeV. In order to develop the FEL-THz, the second photo-cathode RF-gun with 4+1/2cells was studied in 2005, the working frequency is 1.3GHz, the electron energy is about 8MeV, the injector works in the pulse mode, the macro-pulse length is 4μs. The FEL-THz facility driven by this photo-cathode injector was built in 2006. The facility mainly includes the injector ,the transport beam line ,the undulator ,the optical cavity ,the far infrared spectrum analyser and the detector. In order to get the high peak current ,the magnetic bunch compressor was used .The beam position monitor(BPM),the dipole bending magnet, the achromatic section and other auxiliary components are also included in the beam line. The spontaneous emission experiment is undertaking.

THE PHOTO-RF GUN INJECTOR

Because of the high electric field ,the electron can be accelerated to close to the light speed in a short range ,and the emittance growth can be reduced ,so the RF-gun is a kind of high brightness electron source[2]. The photo-RF GUN injector mainly includes the 4.5cells RF gun , the klystron microwave power source ,the photo-cathode and the driving laser. In order to reduce the emittance , the compensated solenoid was used .The structure of the rf gun illustrated in Figure 1. The SUPERFISH code was used in the design and optimised of the cavity; the distribution, the stored energy and the power dissipation of the wall were calculated. The beam dynamics was calculated by using the PARMELA code . The fundamental parameters of the RF-gun were listed in table 1.The electric field on the axis was measured using network analyser(shown in Fig.2). The energy of the injector is measured by the bending magnetic according to the formula 1.

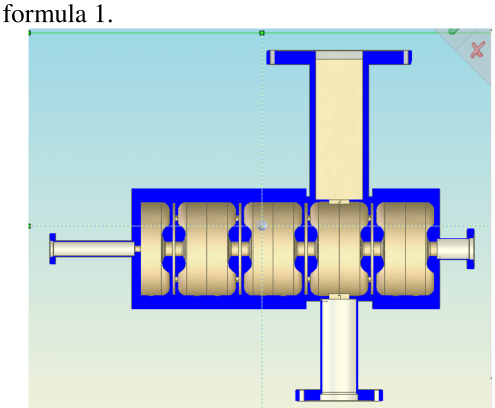

Figure 1: The schematic of the RF-gun.

Table 1: The Calculated Parameters of the Cavity

Cell number	1	2~5
Frequency/MHz	1299.95	1299.95
Stored energy/J	0.0021	0.0042
Power dissipation/W	1062	1520
Quality factor Q	16710	23346
Transit time factor T	0.79	0.79
Shunt impedance/MΩ/m	54.1	76.1
ZT2/Q/Ω/m	2020	2020

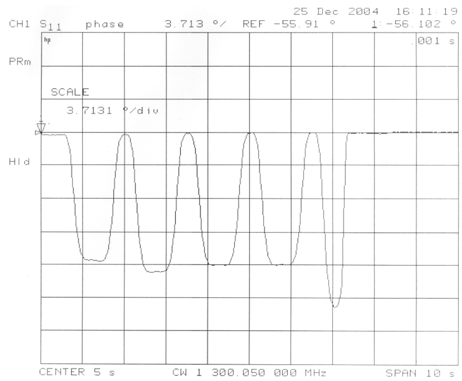

Figure 2: The electric field on the axis.

$$E = m_0 c^2 \left[\sqrt{1 + \left(\frac{eBR}{m_0 c} \right)^2} - 1 \right] \quad (1)$$

Where c is the speed of light ,m_0 is the electron rest mass and e is the charge of the electron.
The emittance is measured using the two screen method, the schematic of the emittance measurement showed in Fig.3 and the emittance is calculated using the formula 2 and 3. Q is the quadrupole , S_1 is the first scrren , S_2 is the second screen.

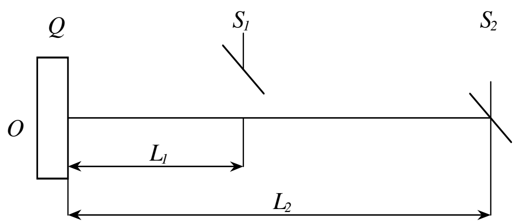

Figure 3: The schematic of the emittance measurement.

$$\varepsilon = \frac{r_2 \sqrt{r_1^2 - \frac{L_1^2}{L_2^2} r_2^2}}{|L_2 - L_1|} \quad (2)$$

$$\varepsilon_n = \beta\gamma\varepsilon \quad (3)$$

Where ε is the emittance, r_2 is the width of the beam waist on the second screen, r_1 is the width of the beam on the first screen when the beam waist on the second screen. ε_n is the nomalized emittance, β is the ratio of the electron speed over light speed, γ is the relativistic factor.The measured electron beam normalized emittance is about 9πmm.mrad.The charge of the bunch is measured using the integrating current transformer (ICT), it is about 100pC and up to 1nC per micro-pulse depending on the driving laser power. The streak camera was used to measure the pulse length before the bunch compressor, the micro-pulse length is about 12ps(FWHM).

The cathode material is Cs2Te and the quadruple light is used. The quantum efficiency is about 1%. The cathode-driving laser system(shown in Fig.4) of the RF photoinjector includes the mode-locked oscillator(from Time-Bandwidth), diode-pumned amplifier and FHG (fourth harmonic generation). The average power of the oscillator is 10W , the timing jitter is 0.56ps, the width is 11.9ps at a repetition rate 54.167MHz . Micropulse energy is 3μJ of 266nm light. The distribution of the 266nm light was showed in Fig.5.

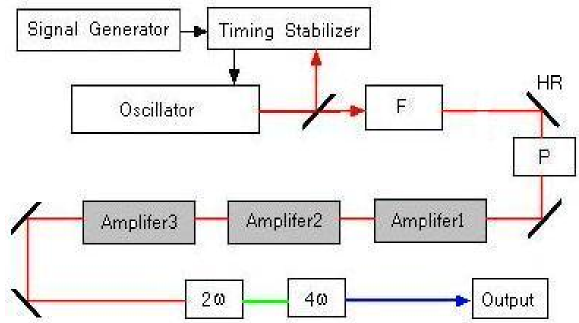

Figure 4: The cathode-driving laser system.

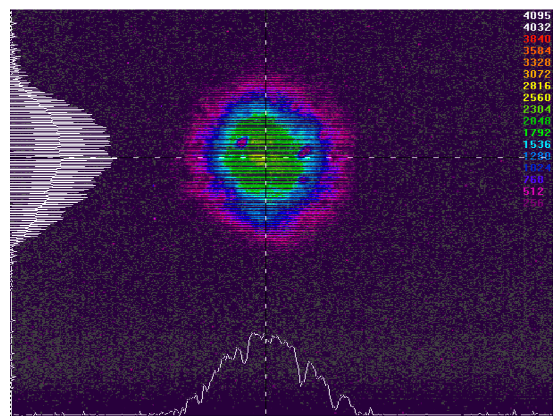

Figure 5: The distribution of the 266 nm light.

THE BUNCH COMPRESSOR

In order to provide high peak current beam for the THz-FEL at CAEP, a 4-dipole magnetic bunch compressor (BC) has been developed and the compressor is located at the gun exit where the beam energy is about 8 MeV. The schematic of the BC is shown in Fig.6. The physical length of the dipole is $L_b = 20.31$ cm, the drift distance between the first and second dipole is $L = 31.93$ cm and that between the second dipole and the third dipole is $L_c = 20$ cm. The nominal bending angle is $\theta = 20^o$ .The bunch length after the BC was determined by measuring the spectrum of coherent transition radiation (CTR) and coherent diffraction radiation (CDR) with a Martin-Puplett interferometer[3]. CTR is generated when beam strikes a metal foil and CDR is generated when beam passes through a metal aperture. The rms bunch length is found to be about 0.7 ps according the compressing factor is about 5,it is accorded well with the calculated value.

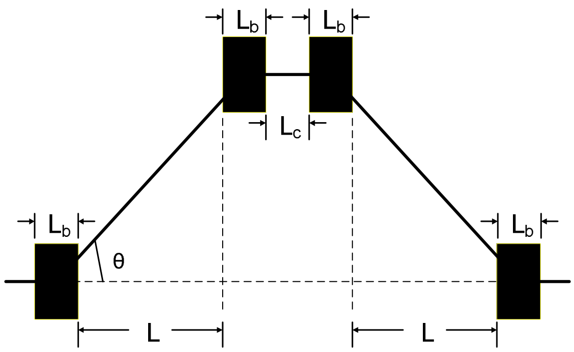

Figure 6: The schematic of the BC.

THE UNDULATOR

The undulator is one of the most important components for FEL and it is the region where the relative electron and the radiation field will interact. Its performance, such as the peak field, good field aperture etc will determine the FEL gain. A NdFeB-FeCoV hybrid undulator has been designed and built for the THz-FEL facility. The undulator consists of 44 magnet periods each 32mm long.More than 6mm good aperture and as high as 4900 Gs peak field were achieved with a 16 mm gap(shown in Fig.7). The trace simulation for a single electron showed that the center offset was less than 0.1 mm,the electron trajectory was simulated(shown in Fig.8), and the ratio of the small signal gain versus the ideal small signal gain was more than 98 percent.

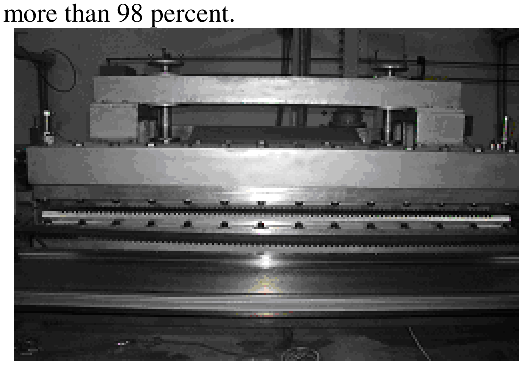

Figure 7: The undulator.

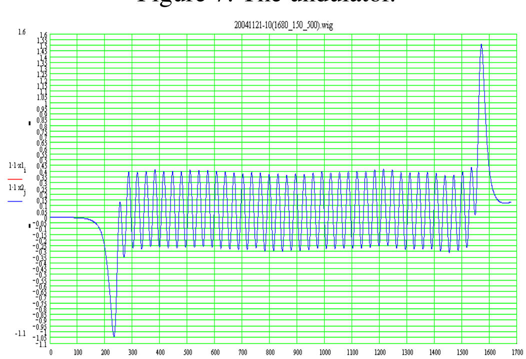

Figure 8: The simulation trajectory of the electron.

THE OPTICAL CAVITY

The simulation of oscillator cavity was done by a three dimension code[4], it includes the gain according the current ,the energy spread and the emittance , the light power rising progress in the cavity ,the optical loss, the coupling efficiency, the detuning, the sensitivity to vibration and misalignment etc .The oscillator cavity length is about 2.767m and the mirrors of the cavity can be adjusted in the optical axis direction .The mirrors are made of copper with gold coating and different out coupling holes are used ,and the out coupling efficiency is 10 percent when the hole diameter is 1.5mm.The curvature of the mirrors is 2.02m. To fulfill this requirement of about 100micron wavelength FEL is equipped with a narrow waveguide ,the cross section of the waveguide is rectangular with 14mmx28mm. The waveguide spans from the upstream mirror to the downstream mirror.

THE SPONTANEOUS EMISSION EXPERIMENT

After the commissioning of electron beam, the spontaneous emission is undertaking and the signal is obtained(shown in Fig.9) .Because of the relatively higher beam current ,the signal is stronger than the former facility.

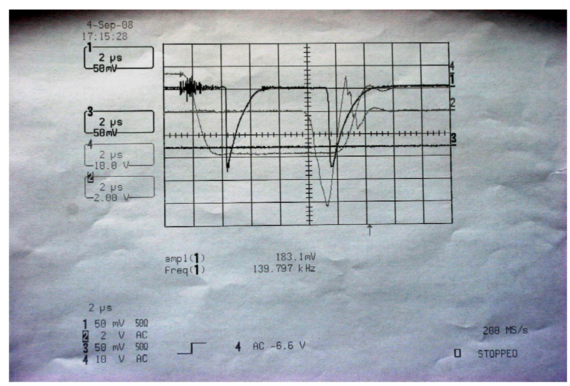

Figure 9: The spontaneous emission signal (channel 2).

CONCLUSION

We have made great efforts in the research of FIR-FEL, and obtained the stimulated emission in 2005 with the thermionic RF-gun injector driving FEL-THz facility. The photo-cathode RF-gun was developed. The next step we will taking the stimulated emission experiment and expect to achieve the saturation .

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