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FEL-THz facility driven by a photo-cathode injector

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Abstract: Since the first lasing in March 2005 in CAEP, the FEL-THz facility has been updated, the former thermionic cathode injector has been replaced by a high brightness photo-cathode injector. The facility mainly consists of a 4.5 cells photo-cathode RF-gun injector, a hybrid undulator and the optical oscillator cavity. The parameters are as followed: number of undulator periods:44; the peak value of the undulator:0.49 T; the good aperture:6 mm; the cathode material:Cs2Te; the quadruple light was used; the width of the driving laser:12 ps; the quantum efficiency:about 1%. The commissioning of the injector has been finished; the electron energy of the injector has been measured and it is about 8 MeV with the energy spread about 1%, and the electron beam normalized emittance about 9 πmm·mrad. The charge is about 100 pC and up to 1nC per micro-pulse, the repetition rate is 54.167 MHz. The calculated wavelength of the light is about 125 micron. At present, the spontaneous emission experiment is undertaking.

Key words: Free Electron Laser; terahertz; accelerator
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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 was 115 micron, but the saturation of the FEL could not be achieved, mainly because of the low electron current and the instability of the facility. Therefore we decided to develop a high performance photo-cathode RF-gun injector. The photo-cathode RF gun injector developed from 1985[1], is easy to get the short pulse with high current and small energy spread compared with the thermionic cathode RF-gun injector, and at present, it is the standard 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, with the electron energy about 3 MeV. In order to develop the FEL-THz, the second photo-cathode RF-gun with (4+1/2) cells was studied in 2005, whose working frequency was 1.3 GHz, the electron energy was about 8 MeV, the injector worked in the pulse mode, and the macro-pulse length was 4 μs. The FEL-THz facility driven by this photo-cathode injector was built in 2006. The facility mainly included the injector, the transport beam line, the undulator, the optical cavity, the far infrared spectrum analyzer 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 were also included in the beam line. The spontaneous emission experiment is undertaking.

1 The photo-RF GUN injector

Because of the high electric field, the electron can be accelerated 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 4.5 cells 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 is illustrated in Fig.1. The SUPERFISH code was used in the design and optimization of the cavity. The distribution, the stored energy and the power

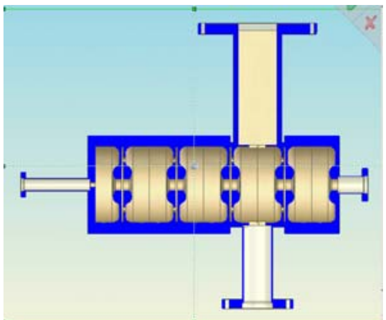

Fig.1 Schematic of the RF-gun

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dissipation of the wall were calculated. The beam dynamics was calculated by using the PARMELA code. The fundamental parameters of the RF-gun are listed in table1. The electric field on the axis was measured using network analyzer(shown in Fig.2). The energy of the injector was measured by the bending magnetic according to formula 1.

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

Where c is the speed of light, m_0 is the electron rest mass and e is the charge of the electron.

The emittance was measured using the two-screen method, the schematic of the emittance measurement is showed in Fig.3 and the emittance was calculated using formula 2 and 3. Q is the quadrupole, S_1 is the first scrren,S_2 is the second screen.

Table1 Calculated parameters of the cavity

cell number	1	2–5
frequency/MHz	1 299.95	1 299.95
stored energy/J	0.002 1	0.004 2
power dissipation/W	1 062	1 520
quality factor Q	16 710	23 346
transit time factor T	0.79	0.79
shunt impedance/(MΩ/m)	54.1	76.1
ZT2/Q/(Ω/m)	2 020	2 020

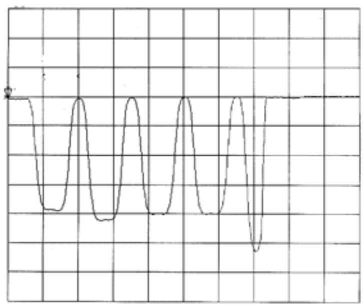

Fig.2 Electric field on the axis

$$\varepsilon = \frac{r_2 \sqrt{r_1^2 - \frac{L_1^2}{L_2^2} r_2^2}}{\left|L_2 - L_1\right|} \tag{2}$$

$$\varepsilon_n = \beta\gamma\varepsilon \tag{3}$$

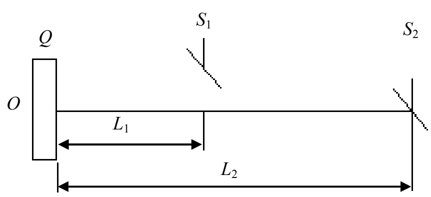

Fig.3 Schematic of the emittance measurement

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 normalized emittance, β is the ratio of the electron speed to light speed, γ is the relativistic factor. The measured normalized emittance of electron beam is about 9 πmm·mrad. The charge of the bunch measured using the integrating current transformer(ICT), is about 100 pC and up to 1 nC 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 12 ps(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 photo injector includes the mode-locked oscillator(from Time-Bandwidth), diode-pumped amplifier and FHG(fourth harmonic generation). The average power of the oscillator is 10 W, the timing jitter is 0.56 ps, the width is 11.9 ps at a repetition rate of 54.167 MHz. Micropulse energy is 3 μJ of 266 nm light. The distribution of the 266 nm light is showed in Fig.5.

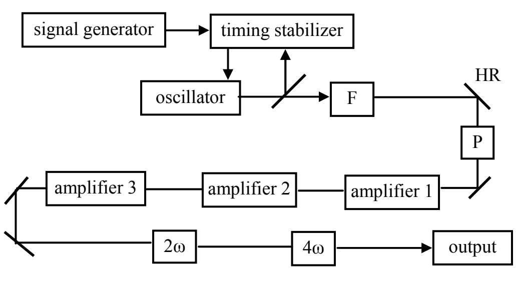

Fig.4 Cathode-driving laser system

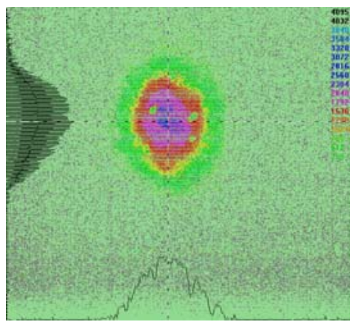

Fig.5 Distribution of the 266 nm light

2　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 θ=20°. 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 since the compressing factor is about 5, which accords well with the calculated value.

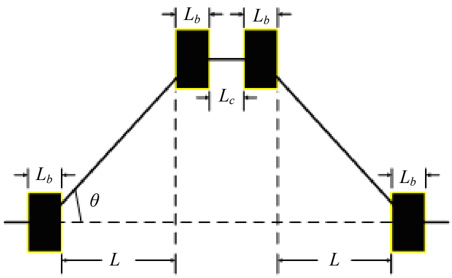

Fig.6 Schematic of the BC

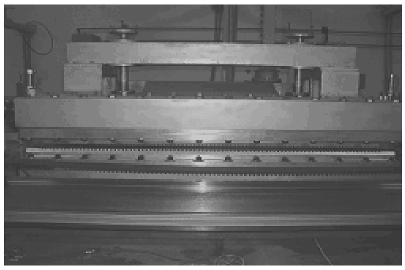
Fig.7 The undulator

3　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 and each is 32 mm long. More than 6 mm good aperture and as high as 0.49 T peak field have been achieved with a 16 mm gap(shown in Fig.7). The trace simulation for a single electron shows that the center offset is 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%.

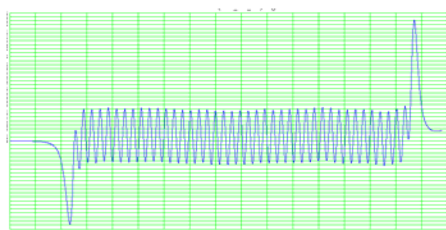
Fig.8 Simulation of the electron trajectory

4　The optical cavity

The simulation of oscillator cavity was performed by a three dimensional code[4], which includes the gain according to 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 2.767 m 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.The out coupling efficiency is 10% when the hole diameter is 1.5 mm. The curvature of the mirrors is 2.02 m. To meet this requirement that about 100 micron wavelength FEL is equipped with a narrow waveguide, the cross section of the waveguide is rectangular with 14 mm × 28 mm. The waveguide spans from the upstream mirror to the downstream mirror.

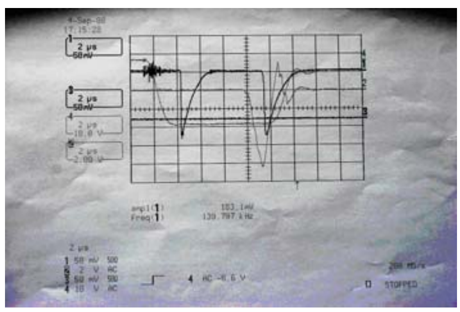
Fig.9 Spontaneous emission signal(channel 2)

5 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 that in the former facility.

6 Conclusion

We had 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. Next step we will take the stimulated emission experiment and expect to achieve the saturation.

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