# THE RESEARCH OF FIR-FEL IN CAEP

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*Abstract*

The research of FIR-FEL has been undertaken about 10 years in CAEP (China Academy of Engineering Physics) and first lasing at center wavelength 115 µm was observed in March 2005. The facility consists of RF-gun, alpha magnet, L-band SW accelerator, beam transport line, wiggler, optical cavity and measurement system. At present, a high brightness photo cathode RF-gun is commissioning, the cathode material is Cs2Te and the quadruple light is used. This injector will be used in the FIR-FEL project in the second half of this year. In this paper, the design consideration, the system layout and experiment results are introduced.

## INTRODUCTION

The research work of FIR-FEL was started in 1997 in CAEP. In 1999 the 30MeV RF SW electron linac was built, the linac consists three accelerating sections, the resonant frequency is about 1.3GHz, a 1+1/2cell thermionic RF-gun was used as the injector. When doing the FIR-FEL, only the first accelerating section(ACC1) was used, the electron energy is about 6.5MeV~7MeV. The FIR-FEL facility consists of RF-gun, alpha magnet, ACC1, beam transport line, wiggler, optical cavity and measurement system (shown in Fig.1). Based on this facility the first lasing was observed in March 2005 and the center wavelength was 115 µm. As one important direction of FEL the high average power FEL was proposed. Two key technology of high average power FEL are the high brightness photo-cathode injector and the SRF ERL. The high brightness photo-cathode RF-gun injector was studied in our Lab in 1999 and the first photo-cathode injector with 2+1/2cell was operated in 2000.In order to study the SRF technology, cooperative with the Peking University, we built a superconducting cavity. This cavity includes a single cell (the frequency is 1.3GHz). This cavity was tested in our Lab in 2000, the energy gain is about 0.6MeV.

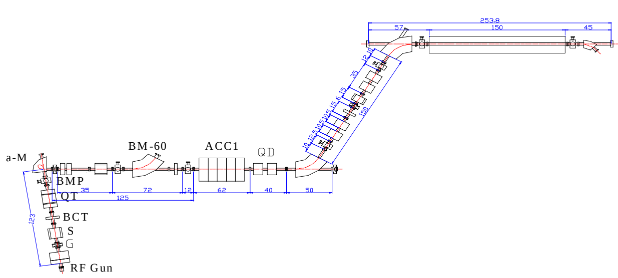


Fig.1: the schematic of the FIR-FEL facility.

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## THERMIONIC CATHODE RF GUN INJECTOR

The study of FEL needs the high brightness electron beam with small energy spread. The beam quality is mainly determined by the injector. The development of high-brightness electron sources has been a challenging project for many years. RF gun is one kind of high brightness electron source which developed for the purpose of FEL research in 1984[1]. It has high electric field. The electron was accelerated to the light speed in a short distance, so the space charge effect has been reduced efficiently and easy to get the small emittance. There are two kinds of RF guns, one is the thermionic cathode RF-gun, the other is photo-cathode RF gun. The work of thermionic RF gun in our Lab is introduced in this section and the photo-cathode RF gun will be introduced in the next section. The advantages of thermionic cathode RF gun are the simple construction, operating reliability and low cost, it acts as an important role in the research of FEL especially at the beginning and it has been studied in detail. We built thermionic RF-gun as the injector for the 30MeV linac. The drawback of this kind of injector is the relative larger energy spread aroused by the wide capture phase and electron back bombardment. In order to decrease the electron back bombardment and obtain good quality electron beam, several guns with different structure have been built and experimented in our Lab. The SUPERFISH and PARMELA codes were used for the accelerating structure design. The ring cathode RF gun was tested also, but the experiment result was not good. Finally the 1+1/4cell gun was selected (shown in Fig.2), the electric field on the axis was measured using network analyser (shown in Fig.3). It was built in 2004(shown in Fig.4), the cathode material is LaB6, the diameter is 5mm and the electron energy of this injector is about 1.5MeV. Using this injector, the FIR-FEL stimulated emission was observed.

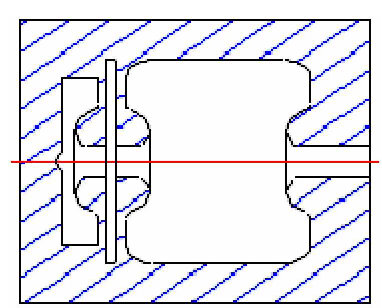

Fig.2: the schematic of the thermionic cathode injector.

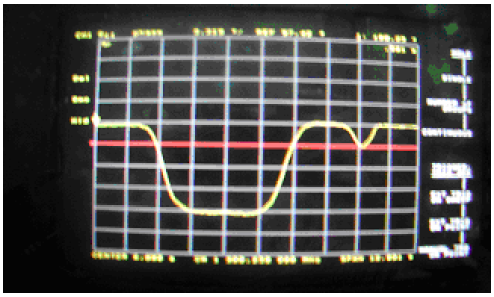

Fig.3: the electric field on the axis.

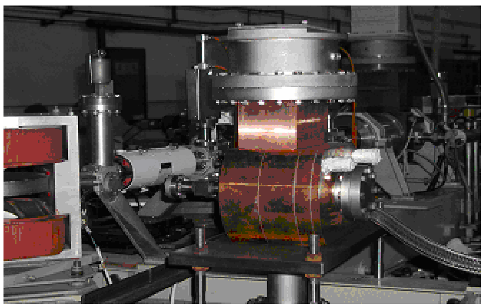

Fig.4: the thermionic cathode injector.

## PHOTO-CATHODE RF GUN INJECTOR

The photo-cathode RF gun injector developed from 1985[2], comparing with the thermionic cathode RF-gun injector, the photo-cathode RF-gun is more adaptive to the research of FEL, it is easy to get the short pulse with high current and small energy spread. 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 3μm~8μm FEL, the second photo-cathode RF-gun with 4+1/2cell was studied in 2004(schematic was shown in Fig.5, the frequency is 1.3GHz), so the total electron energy(including the injector and three accelerating sections) is about 37MeV. The electric field on the axis was measured using network analyser (shown in Fig.6). It was built in 2005(shown in Fig.7), the focusing solenoid and compensated solenoid were used. This injector is commissioning at present.

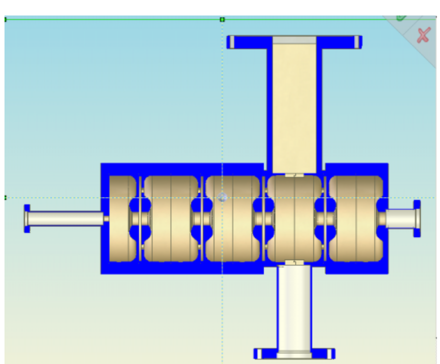

Fig.5: the schematic of the photo-cathode injector.

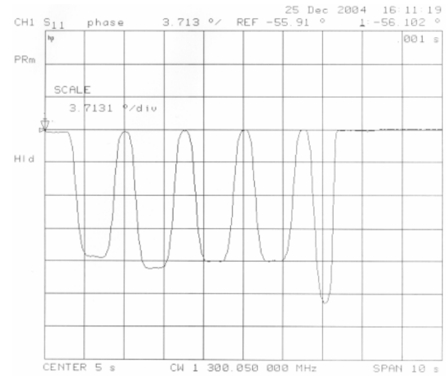

Fig.6: the electric field on the axis.

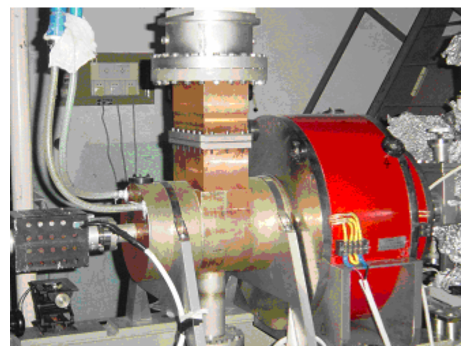

Fig.7: the 4+1/2cell photo-cathode injector.

The cathode material is $Cs_2Te$ and the quadruple light is used. The quantum efficiency is about 1%, the electron energy is 7MeV. The cathode-driving laser system(shown in Fig.8) of the RF photoinjector include 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 energies is 3μJ of 266nm light.

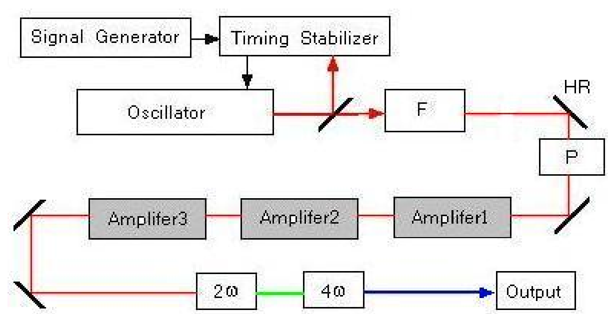


Fig.8: Optical Schematic of the cathode-driving laser system F, the Flady isolator.P, pockel .HR, high reflector.

## THE WIGGLER

The Wiggler is one of the most important components for FEL and it is the region where the relative electron and the radiation field will interact. It's performance, such as the peak field, good field aperture etc. will determine the FEL gain when we calculate the relative electron performance. A NdFeB-FeCoV hybrid wiggler has been designed and built for CFEL. More than 10mm good aperture and as high as 3235 Gs peak field were achieved with a 18 mm gap (shown in Fig.9). 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.10), and the ratio of the small signal gain versus the ideal small signal gain was more than 98 percent. Recently, we've observed the resonance light in the 115 um FIR-FEL experimental study which used this wiggler.

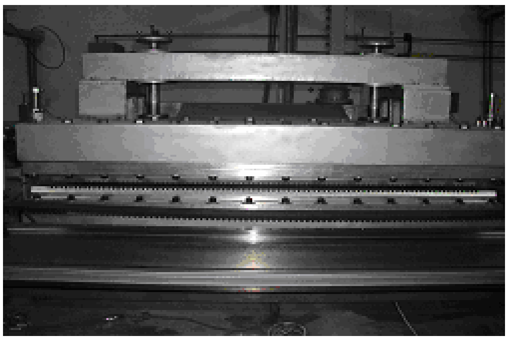

Fig.9: the wiggler.

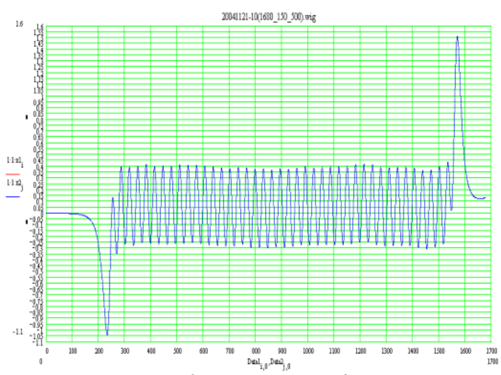

Fig.10: simulation trajectory of the electron in the wiggler.

## THE STUDY OF SRF TECHNOLOGY

In order to get the high average FEL power, the high average electron beam power should be provided first, and the machine should be operated in the CW condition thus the SRF is required. SRF ERL technology is the practical way to obtain the high average power FEL and proved by JLAB[3]. Cooperate with the Peking University, we built a facility to study the SRF technology, (shown in Fig.11), at this facility the 2+1/2cell photo-cathode injector was used. The high average power FEL was proposed and we will begin to build the SRF ERL machine in the next years.

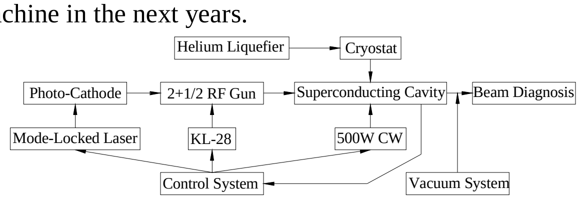


Fig.11: the schematic of the SRF test facility.

## THE FIR FEL EXPERIMENT

The parameters of the FIR-FEL facility is shown in table 1.The macro-pulse current is measured by BCT and the beam currents are measured at the different position of the beam line, shown in Fig.12. The width of the micro-pulse is measured by the streak camera. The microwave power of the injector and ACC1 are provided by a klystron with 10MW. The stimulated signal is obtained in the March 2005, shown in Fig.13 and the spectrum of the stimulated signal is measured using grating analyser, shown in Fig.14, the center of the spectrum is 115μm, the width of spectrum is about 1%.

Table 1: parameters of the FIR-FEL facility

| | |
|---|---|
| Energy 6.5MeV | Normalized emittance 20πmm·mrad |
| Macro-pulse current 130mA | Number of wiggler periods 44 |
| Macro-pulse width 4μs | Period length 32mm |
| Micro-pulse current 4A | Wiggler gap 18mm |
| Micro-pulse width 25ps | Magnetic field 3250Gs |
| Energy spread 1% | Optical cavity length 2536mm |

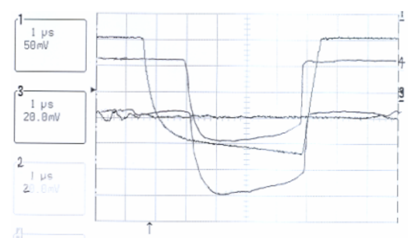

Fig.12: the beam current at the different position on the beam line, measured with BCT.

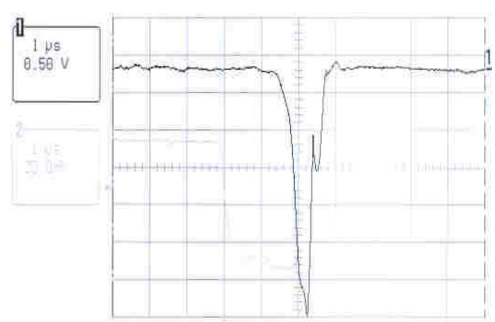


Fig.13: the FEL stimulated emission signal.

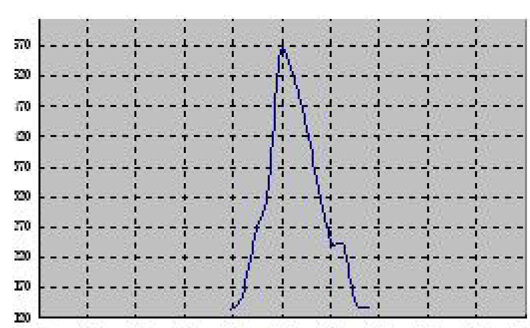

Fig.14: the spectrum of the stimulated signal.

## CONCLUSION

We have made great efforts in the research of FIR-FEL, and obtained the stimulated emission in 2005. The thermionic-cathode and photo-cathode RF gun injectors have been built. The high power FEL project was proposed and a single cell superconducting facility was built and tested. The next step we will build the SRF energy recovery Linac.

## REFERENCES

[1] A. Westenshop, J.M.J. Madey, "Microwave Electron Gun", Laser and Particle Beam, 1984, 2(2), p223.

[2] C.H. Lee etc IEEE Trans Nucl Sci NS-225 1985, p3045.

[3] S. Benson, D. Douglas, M. Shinn, etc, "High Power Lasing in the IR Upgrade FEL at JEFFERSON LAB" Proceeding of FEL2004, p229-232.