STATUS OF FELICHEM, A NEW IR-FEL IN CHINA*

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Abstract

FELiChEM is a new experimental facility under construction at University of Science and Technology of China (USTC), whose core device is a FEL oscillator generating middle-infrared and far-infrared laser and covering the spectral range of 2.5-200 μm. It will be a dedicated light source aiming at energy chemistry research, with the photo excitation, photo dissociation and photo detection experimental stations. We present the brief physical and technical design that delivers the required performance for this device and summarize the status of fabrication. Final assembly is scheduled for early in the next year with first light targeted for July 2017.

INTRODUCTION

In 2014, the project of "Tunable Infrared Laser for Fundamental of Energy Chemistry" (FELiChEM) was approved by the Natural Science Foundation of China. The FEL of this project is similar to the CLIO [1], FHI-FEL [2], and FELIX [3]. National Synchrotron Radiation Laboratory (NSRL) in USTC is responsible for the design, construction and commissioning of the IR-FEL apparatus. The design studies started in the beginning of 2015. Now we have finished the physical and technical design, and most of components have been ordered or are in fabrication.

The FELiChEM, as shown in Fig.1, consists of a 60 MeV accelerator with two beam transport systems that feed two oscillators and a diagnostic beamline. The energy range between 15 and 25 MeV will be covered with the first accelerator (A1) for the far-infrared FEL oscillator (40-200 μm), and the range between 25 to 60 MeV with the second accelerator (A2) for the middle-infrared FEL oscillator (2.5-50 μm).

LINAC

As shown in Fig. 1, the Linac consists of:
- a 100 keV electron gun
- a 476 MHz subharmonic standing wave pre-buncher
- a 2856 MHz fundamental frequency traveling wave buncher
- two 2856 MHz fundamental frequency traveling wave Accelerators
- set of solenoid focusing coil from the gun exit to the end of the first accelerator
- magnetic compressor (chicane)
- two beam transport systems

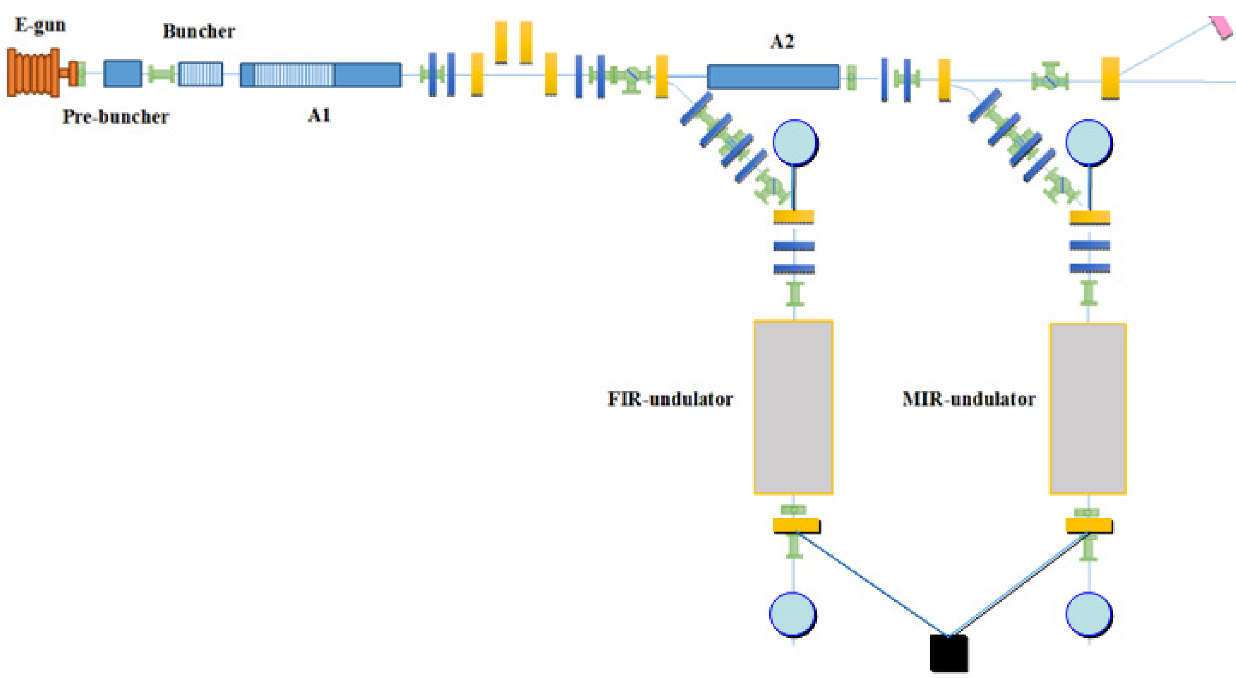

Figure 1: Schematic layout of the FELiCHEM.

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The triode gun is driven by the grid for the pulsed mode. A 476 MHz signal during 10 μs is carried to the HV deck, and a frequency divider is used to control the repetition rate of the micro bunches.

The pre-buncher will be a 20 cm long standing wave cavity operating at 476 MHz. With a gap voltage of 40 kV, the bunch length could be compressed by about 20 times in 24 cm long drift space downstream from the pre-buncher exit to the entrance of the buncher. Then a traveling wave buncher with 11 cells operating at 2856 MHz is used. With a 5 MW input power, the rms bunch length can be compressed to 4.5 ps and the beam energy is about 3.1 MeV at the exit of the buncher.

The two 2-meter accelerators with 57 cells are also operating at 2856 MHz. Because of the high average current, the beam loading effect has been considered in the accelerators. As to our design structures, when the beam current is 300 mA, one accelerator can offer about 30 MeV beam energy increase with 20 MW input power.

The magnetic chicane is designed as an optional operation condition. Its purpose is to reduce the micro-pulse length and increase the peak current of the micro bunch for the short-wavelength FEL, and for the long-wavelength FEL, it also can increase the micro-pulse length to suppress the slippage effect. The main functions of the beam transport systems are beam matching and beam energy filtering. Energy slits will be used in the dispersion section to filter out the electrons with great energy spread.

Table 1: Electron Beam Parameters of FELiChEM

Parameter	Unit	Specification	Target
Energy	MeV	15-60	15-60
Energy spread	keV	<200	<240
Emittance	mm•mrad	<15	<30
Charge	nC	1	1
Micro-pulse length	ps	2-5	2-5
Micro-pulse Repetition rate	MHz	476/n (n=1-5)	476/n (n=1-5)
Macro-pulse width	μs	1-12	5-10
Macro-pulse repetition rate	Hz	20	20

Table.1 lists the anticipated performance of the accelerator at the entrance of the undulator. The target values are those required by the FEL design for achieving the final object output radiation. Much simulation results can be found in Ref. [4]. Note that the the maximum electron beam energy is designed to be 60 MeV, mainly for enhancing the performance of radiation around 2.5 μm.

All the gun components have been ordered or are in fabrication, and will be delivered to NSRL before August, and then many tests will be carried out. Some of the accelerator components are being fabricated by ourselves, such as the pre-buncher cavity, accelerator tubes and so on. We have signed the contracts for the fabrication of the other important components, including the klystron, the modulator, the low-level RF system, the magnets, the electric power source, the vacuum system, and so on.

OSCILLATORS

FELiChEM includes two oscillators covering the spectral range of 2.5-50 μm and 40-200 μm, respectively. Each oscillator consists of two important components: undulator and optical cavity. Their basic parameters are listed in Table.2. Detailed design can be found in Ref. [5].

Table 2: Basic Parameters of FELiChEM Oscillators

parameter		Unit	specification	
			MIR	FIR
Undulator	Period	mm	46	56
	Length	m	2.3	2.24
	Min. gap	mm	16	20
	RMS K	-	0.5~3.2	0.5-3.6
	Peak field	T	0.1~0.7	0.1-0.7
Optical cavity	Length	m	5.04	5.04
	Rayleigh length	m	0.8	1.12
	Diameters of mirrors	mm	50	80
	Reflectivity	-	99%	99%
	Outcoupling hole radius	mm	0.5, 0.75 1.0, 1.5	0.5, 1.0 , 1.75

The two undulators will provide the IR users a broadly continuous wavelength tunability of larger than 300%, and with the electron beam listed in Table.1, the small-signal gain will exceed 100%. NSRL has much experience in undulator design and fabrication. We had made the first undulator in China. Now six different kinds of undulators are working in the storage of Hefei Light Source. However, because of the shortage of manpower, we will invite public bidding for the construction of the undulators for FELiChEM.

In the two oscillators, two same mirrors are used to form a symmetrical optical cavity. The undulators will be placed in the center of the optical cavities such that we have about 1.4 m space available for beam transport and diagnostic on the two sides. The IR radiation will be outcoupled from the downstream cavities, which contain multiple mirrors with different outcoupling hole sizes and mechanical conditioners for switching mirrors. In the technical design, we divide the optical cavities into four parts: mirrors, mechanical conditioners, vacuum system and control system. The mirrors are spherical with Copper base and Gold coatings. These mirrors will be ordered from a professional company soon. The mechanical conditioners and vacuum system have started fabrication in a domestic company and will be delivered to NSRL in

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the end of this year. Meanwhile, we will make the control system by ourselves. Finally, these systems will be assembled, installed and debugged in NSRL at the beginning of next year.

Table 3: Target FEL Performance of FELiChEM

Parameter	Specification
Covering spectrum	2.5 ~ 200 μm
MIR FEL oscillators	2.5 ~ 50 μm
FIR FEL oscillators	40 ~ 200 μm
Macro-pulse length	5~ 10 μs
Repetition of macro-pulse	20 Hz
Macro-pulse energy	~100 mJ
Micro-pulse length	5 ~ 10 ps
Micro-pulse energy	1 ~ 50 μJ
Bandwidth	0.3 ~ 3 %
Continuous tunability	~ 300 %

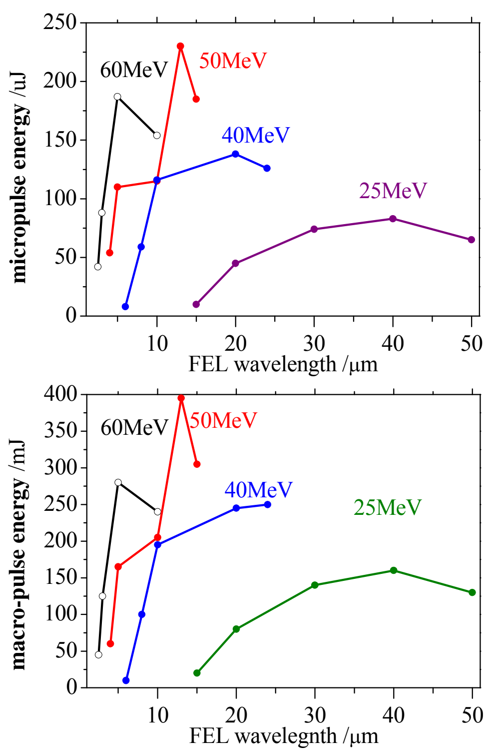

Figure 2: The MIR-FEL performance from simulation. **Top:** micro-pulse energy; **Bottom:** macro-pulse energy with the micro-bunch repetition rate of 238 MHz.

FEL PERFORMANCES

Table 3 gives the target FEL performance of FELiChEM. Based on the designed parameters, we simulated the MIR-FEL and show the saturation micro-pulse energy and the macro-pulse energy at the micro-bunch repetition rate of 238 MHz. Note that the cavity length detuning is fixed to be two radiation wavelengths. One can find that the FEL pulse energy exceeds the target by several times for most of the object wavelengths. However, in the operation, the micro-bunch repetition rate can be decreased to a lower level.

For the FIR FEL, due to the serious diffraction effect, we need to add a waveguide to reduce the diffraction loss. A planar waveguide with the height of b=10 mm is used to replace the undulator chamber. Currently we have no code to fully simulate the waveguide FEL. However, we calculated the small signal gain for the FIR-FEL as shown in Fig.3. The bottom figures are obtained by replacing the Gaussian optical beam by the fundamental waveguide mode. The waveguide enhanced the small signal gain by more than two times. In addition, according to the operation experience of CLIO and FELIX, "power gap" may appear in this waveguide FEL, and we have preliminarily considered this problem for FELiChEM.

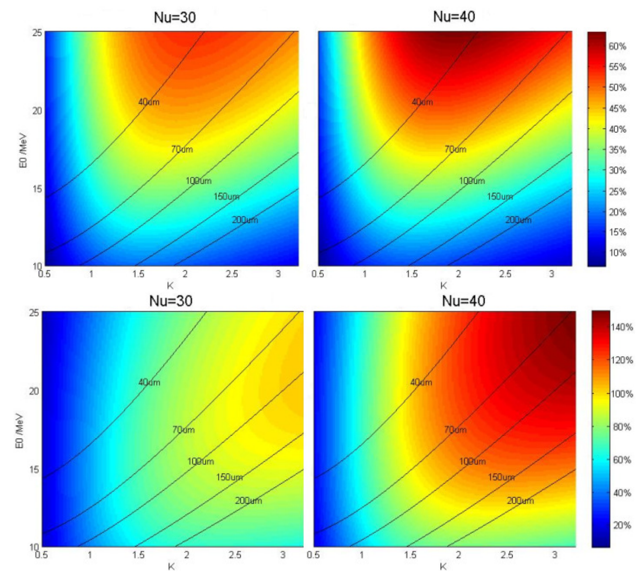

Figure 3: The small signal gain for the FIR-FEL with different undulator lengths. **Top:** with no waveguide; **Bottom:** with planar waveguide (b=10 mm).

SUMMARY

In summary, we have briefly introduced the FELiChEM project and its status. The physics and technical design of FELiChEM has been completed. The accelerator, beam transport and the oscillator components are in fabrication or being procured. The reconstruction of the facility vault in NSRL will start in July 2016 and finish in two months. Plans call for the delivery of all hardware to NSRL by the end of this Chinese year, after which assembly and commissioning will begin. First light is targeted for July 2017.

REFERENCES

[1] J. C. Bourdon, R. Belbéoch, P. Brunet *et al.*, in *Proc. EPAC'88*, p. 314.
[2] W. Schöllkopf *et al.*, in *Proc. FEL'13*, WEPSO62, pp. 657-660.
[3] P. W. van Amersfoot *et al.*, in *Proc. EPAC'88*, p. 430.
[4] He Zhigang *et al.*, in *Proc. FEL'15*, MOP010, p. 46.
[5] Li Heting *et al.*, in *Proc. FEL'15*, TUP028, p. 427.