KU-FEL Facility

Status Report

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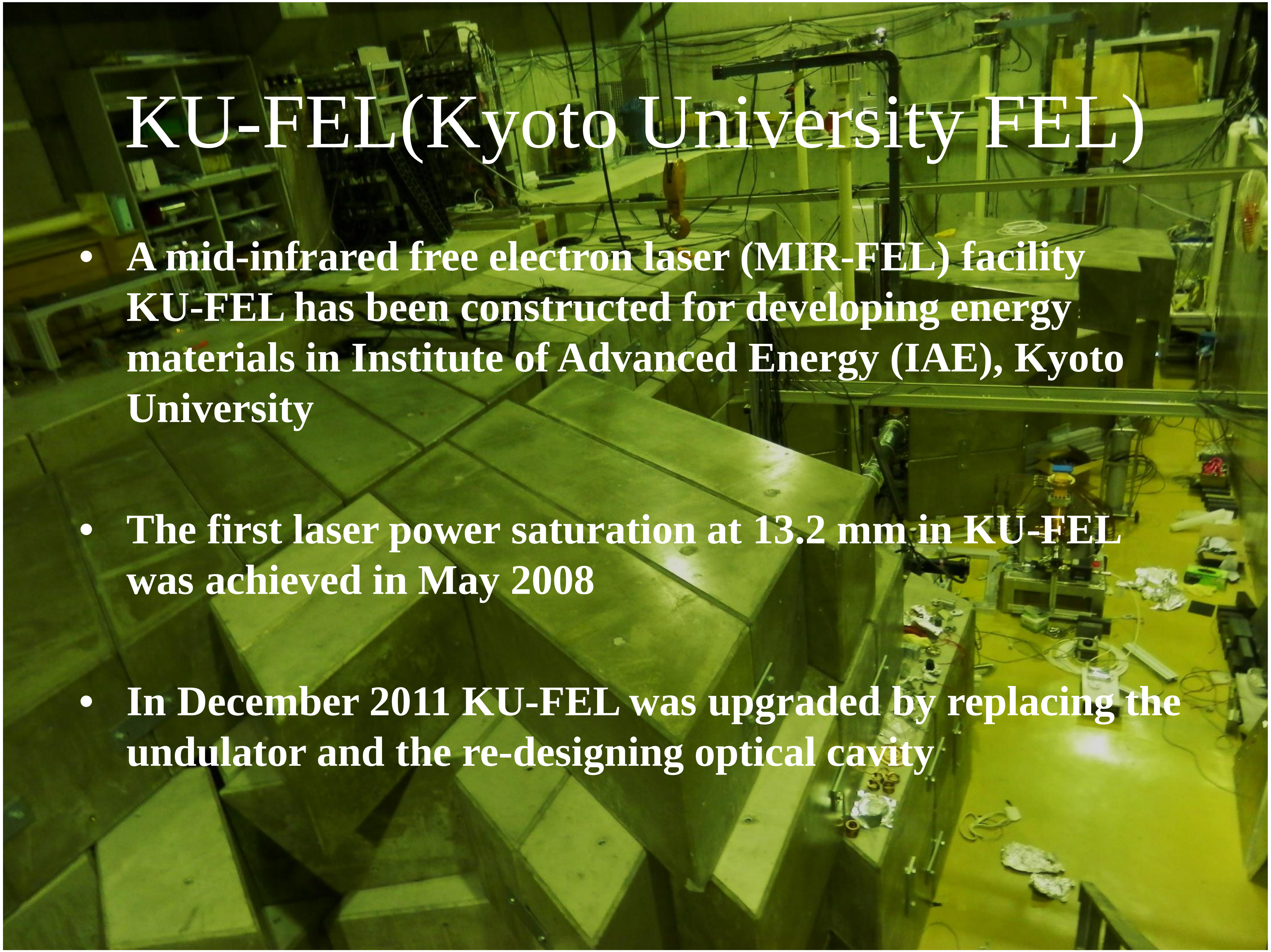
KU-FEL(Kyoto University FEL)



- **A mid-infrared free electron laser (MIR-FEL) facility KU-FEL has been constructed for developing energy materials in Institute of Advanced Energy (IAE), Kyoto University**

- **The first laser power saturation at 13.2 mm in KU-FEL was achieved in May 2008**

- **In December 2011 KU-FEL was upgraded by replacing the undulator and the re-designing optical cavity**

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- Application
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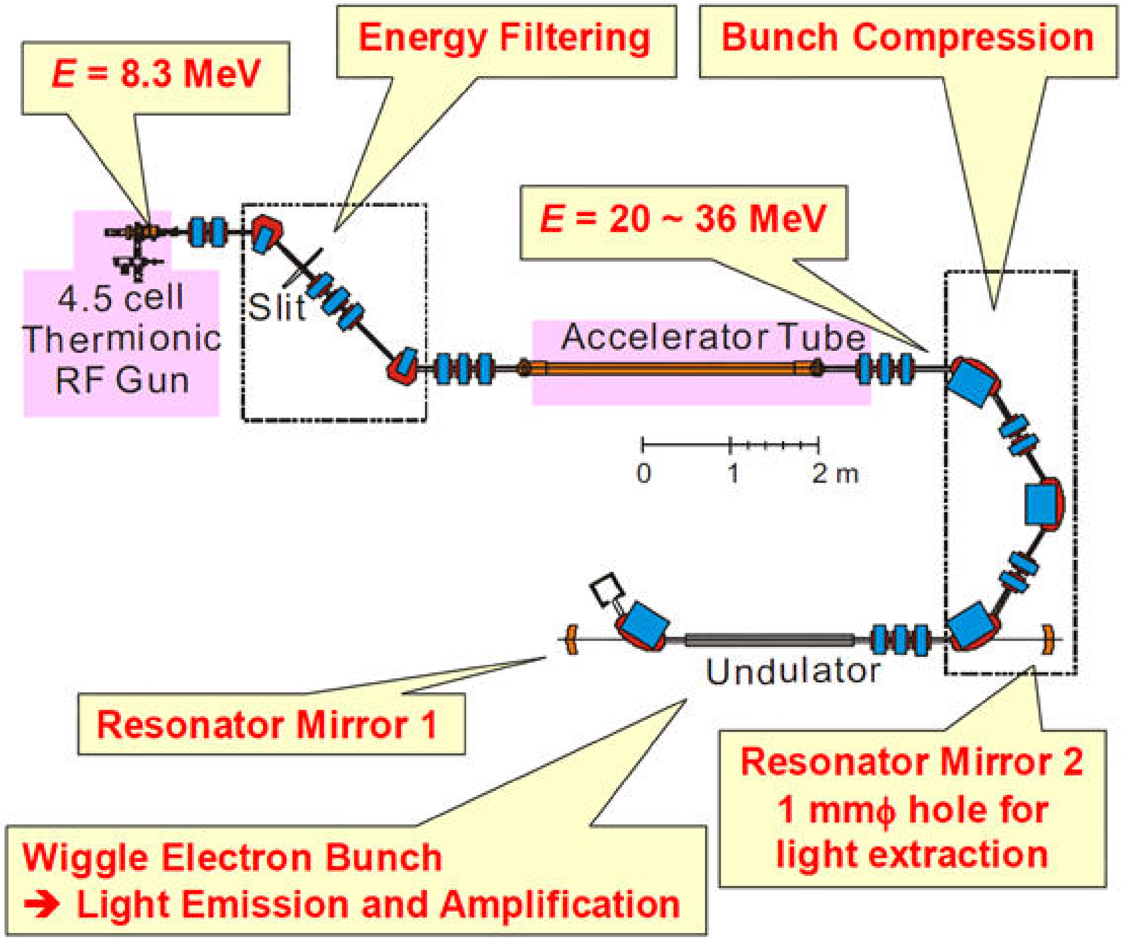
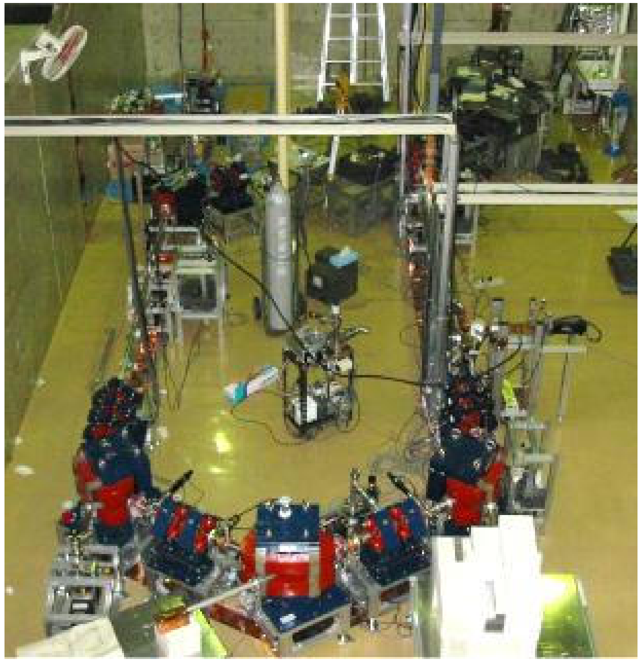
KU-FEL Structure

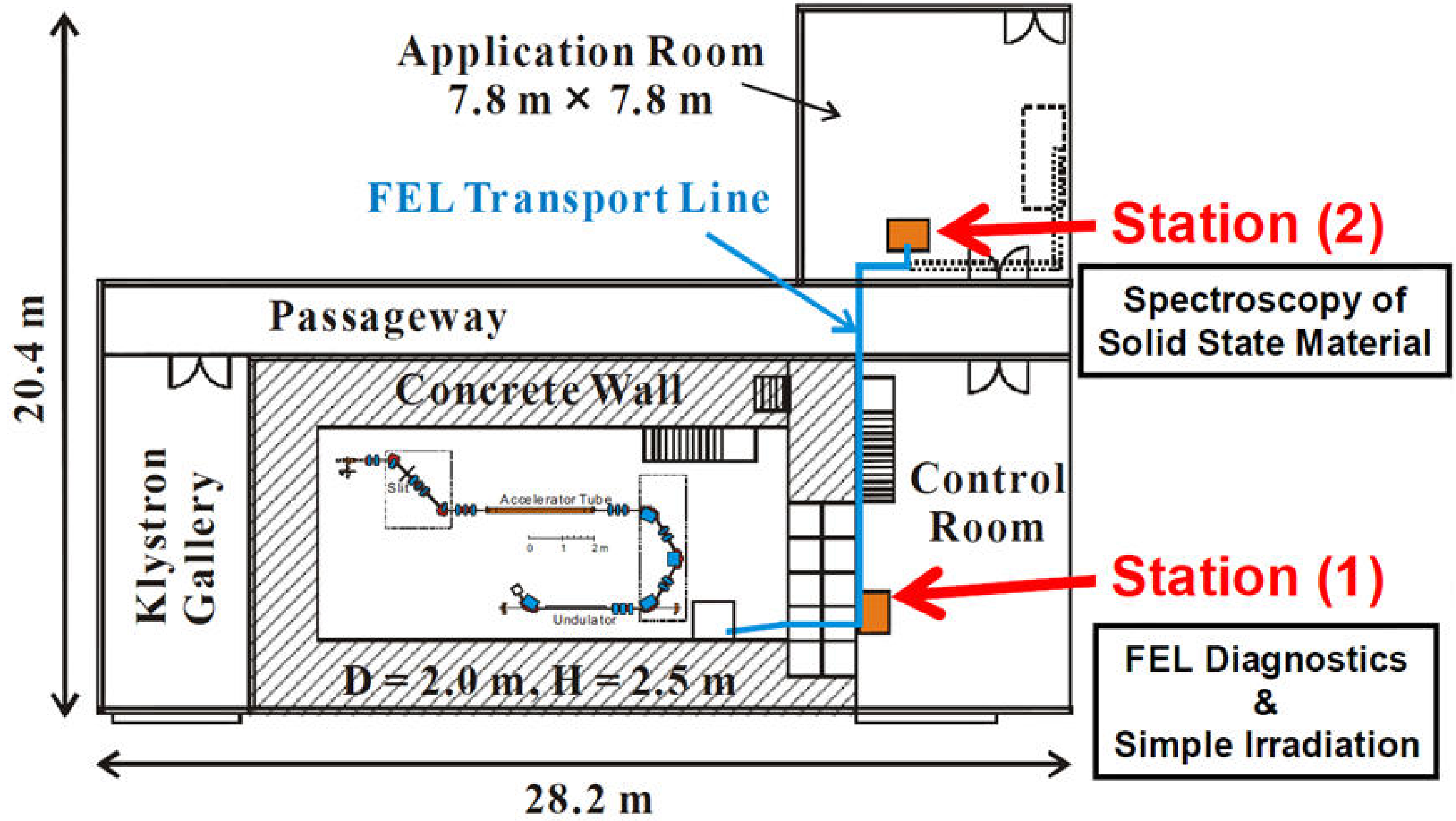


Mid Infrared Oscillator type FEL



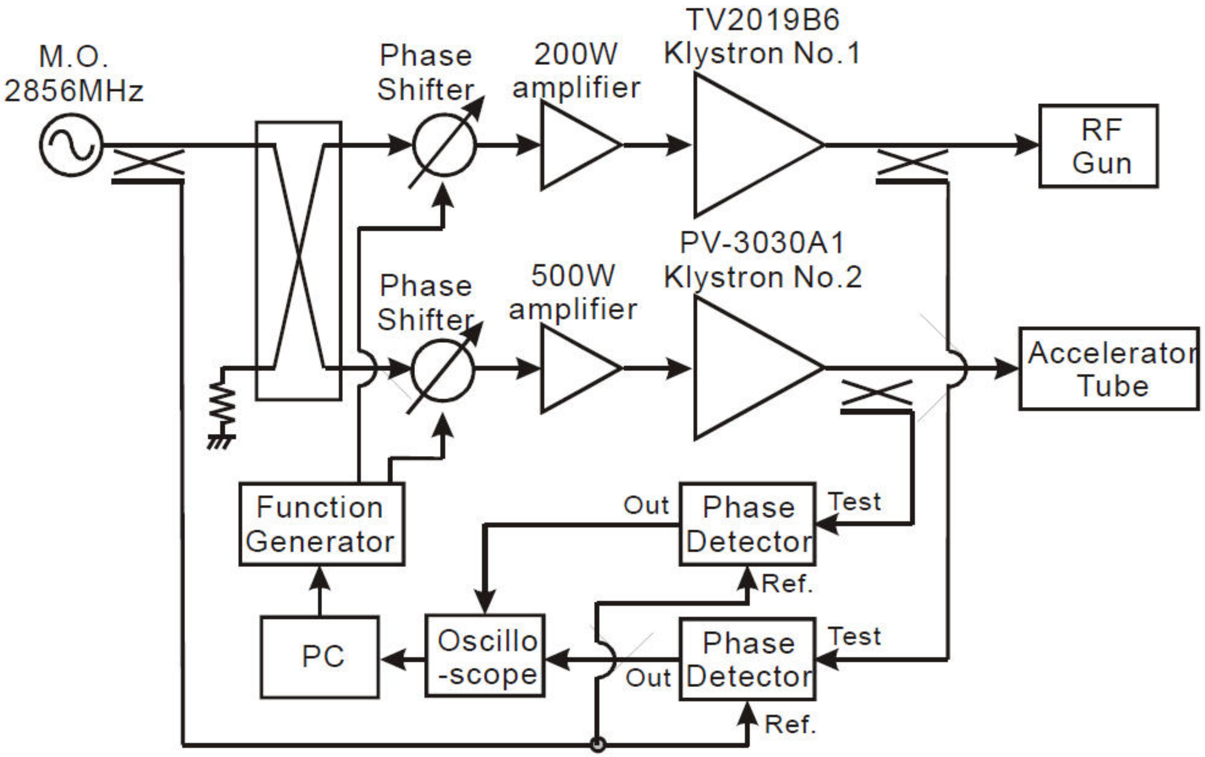
FEL Hall

Two user stations are ready for use.

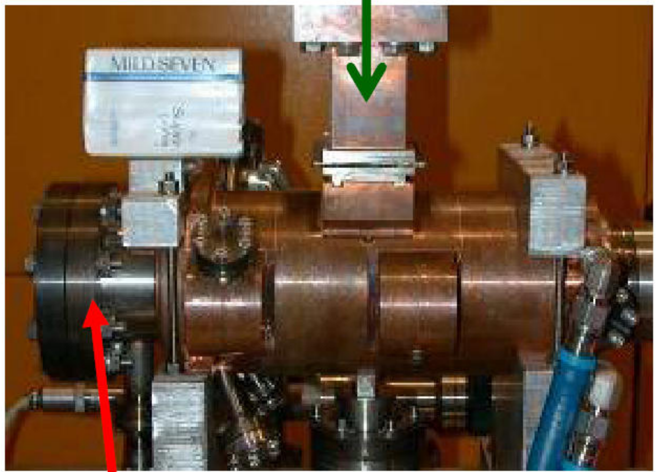


Schematic Diagram of RF-System in KU-FEL

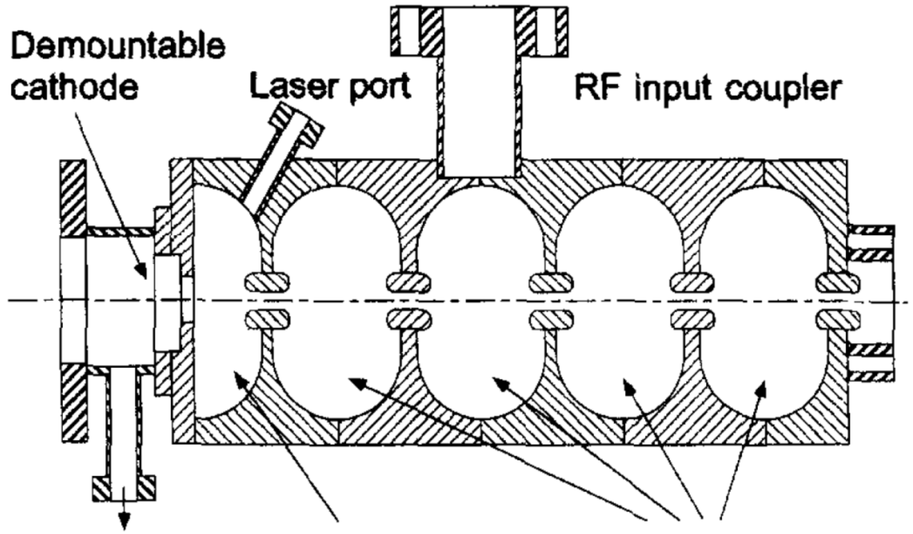
There are two different Klystrons used to supply RF-gun(10MW) and Accelerator(20MW). RF system including two voltagecontrolled phase shifters to measure and compensate the phase shift.



RF Gun



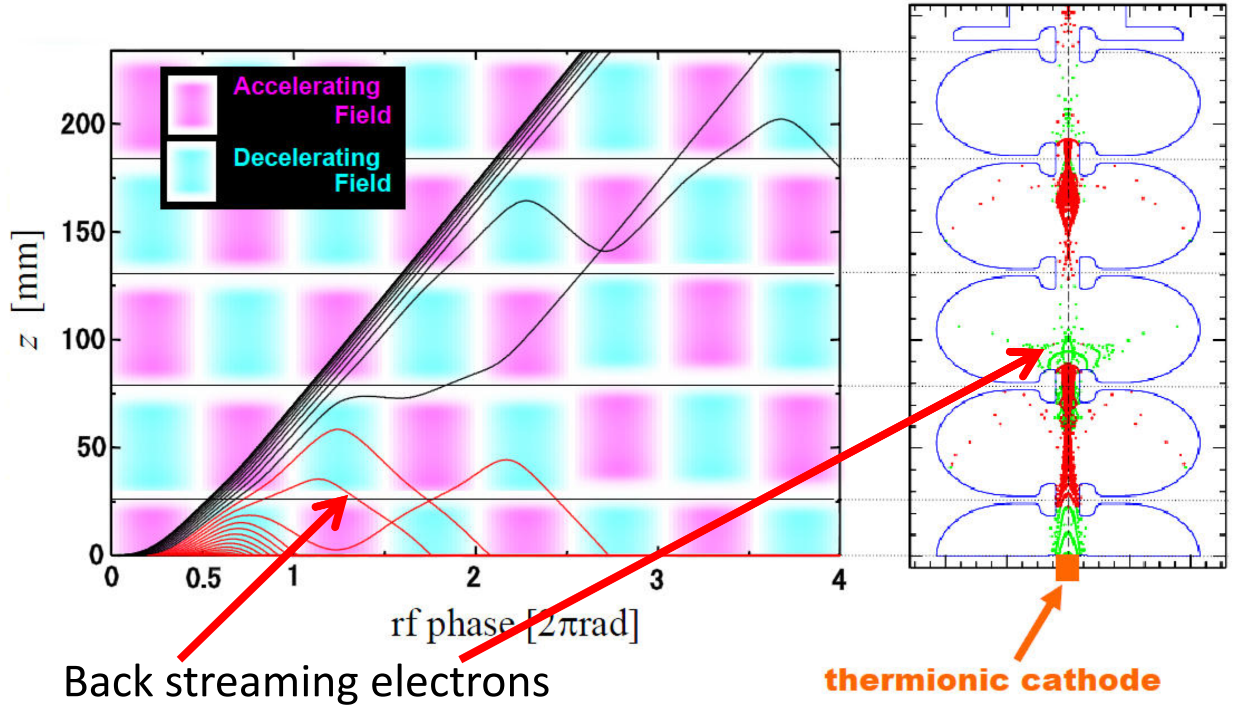
4,5 cell thermionic RF gun for IR FEL generation



The electron beam is produced by a LaB6 thermionic cathode of 2 mm diameter.
A transverse magnetic field of about 10 G on the cathode surface is applied to divert backstreaming electrons

Back Bombardement Effect

- BB effect: some electrons are “drifting” into the decccelerating rf-phase, which accelerates them back to the cathode. The back streaming electrons hit the cathode and increase its temperature
- 1-D simulation of back streaming electrons for 4.5 cell thermionic rf gun



Ramping Current

Back streaming electrons heat the cathode

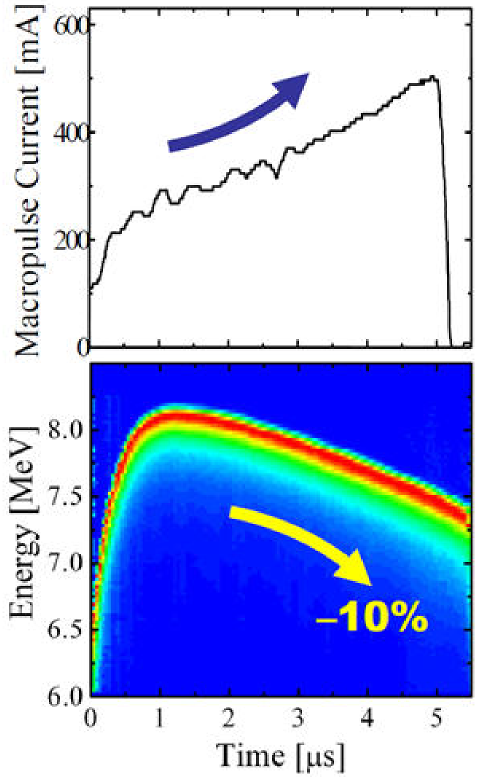
Surface temperature rises

Beam current increases

Beam loading increases

Beam Energy decreases

Macropulse duaration decreases



Beamloading Compensating Methods

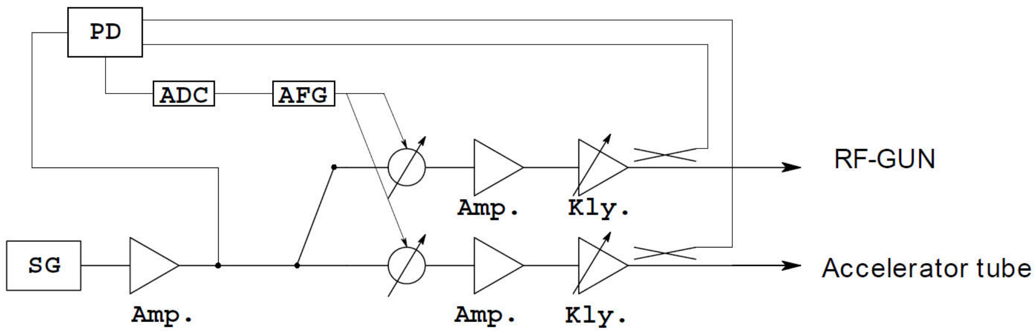
- The FEL saturation is achieved after application of measures to mitigate the beam loading increase due to BBE (back bombardement effect)

- *Amplitude modulation method*

In order to stabilize the electron beam energy amplitude-modulated RF pulses are applied to the RF gun and accelerator. This method causes phase shift, which is compensated by electrical phase shifters

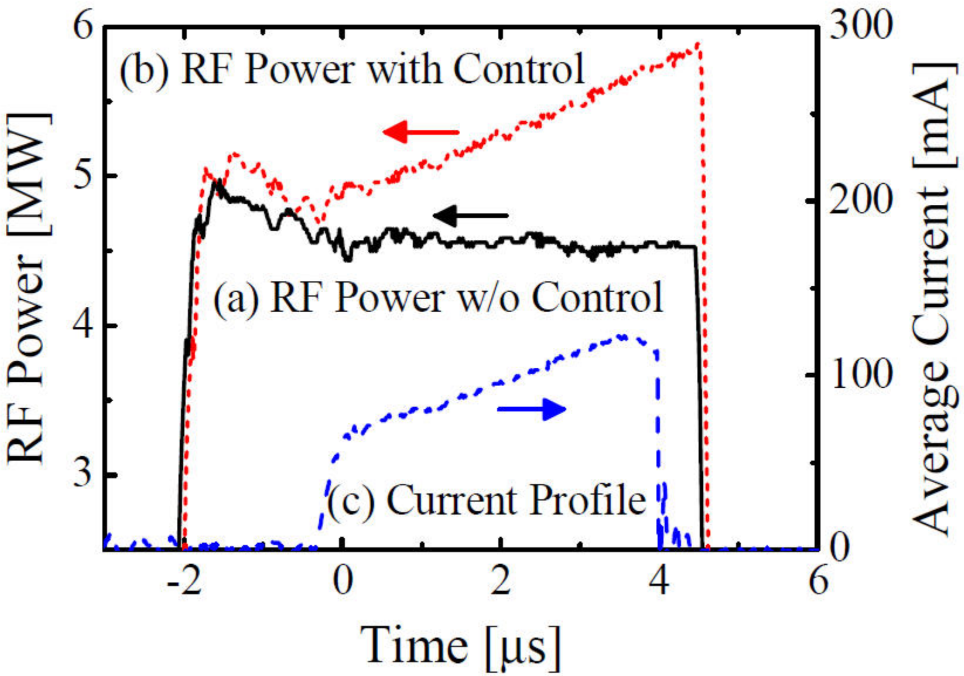
Cavity detuning method

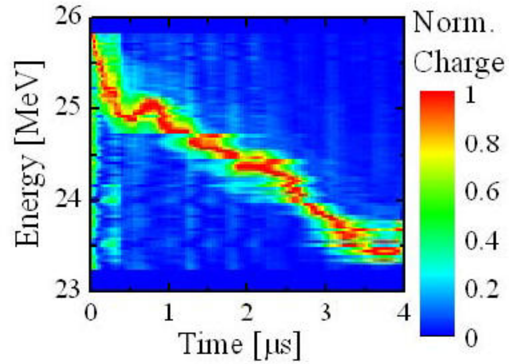
In order to increase the gain the RF power is applied to the electron gun with slightly higher frequency (290 kHz) than the resonance



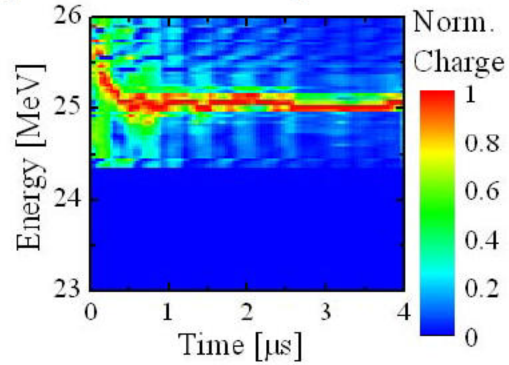
Amplitude Modulation Method

Modification of RF amplitude compensates for energy drop of electron beam





(a) Energy evolution without amplitude control

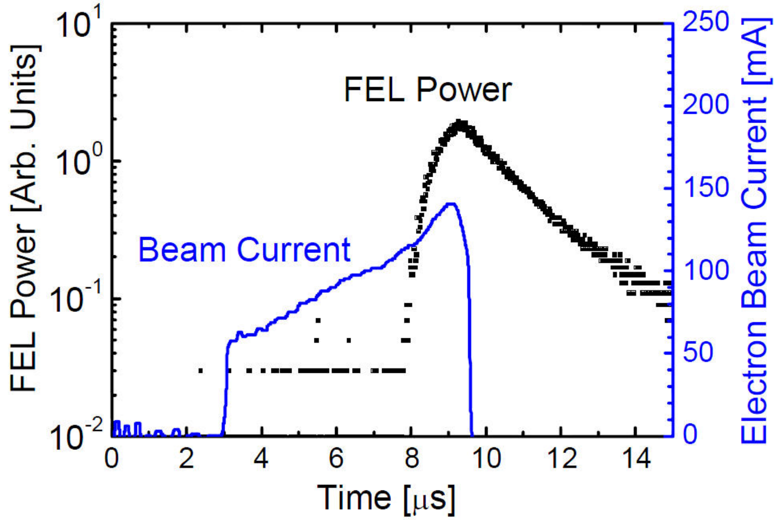


(b) Energy evolution with amplitude control

Electron Beam Properties

The Back Bombardement Effect causes additional heating of the cathode material, which increases the current with time. The ramping current limits the FEL pulse duration.

Electron beam properties of KU-FEL	
Energy Spread (FWHM)	~3 %
Peak Current	~40 A
Normalized Emittance (x and y)	3.5, 12 π mm-mrad
Macro-pulse Duration	7.2 μs
Ramping current due to BB effect	
Macropulse current	~100 mA
Bunch Length (FWHM)	2.0 ps



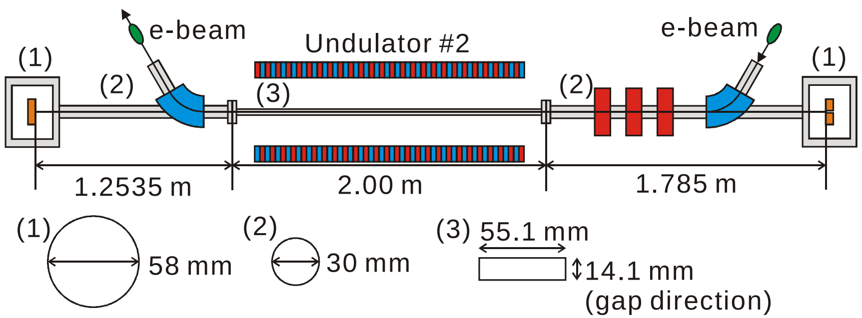
Undulator and Cavity

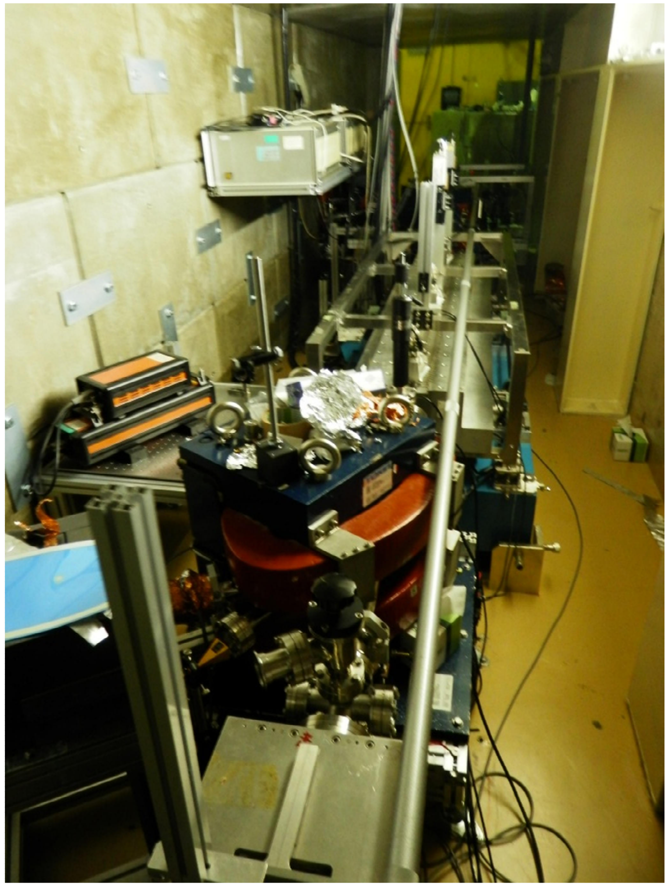
Parameters undulator which had already been used for ERL-FEL in JAEA.

Undulator #2 (from Dec. 2011)	
Structure	Hybrid
Period length	33 mm
Number of periods	52
Maximum K-value	1.05*
Minimum Gap	20 mm*

*with present vacuum chamber. Mechanical limit of the minimum gap is 15 mm. Then K-value will be higher than 1.5.

Geometry of the undulator and cavity mirrors.

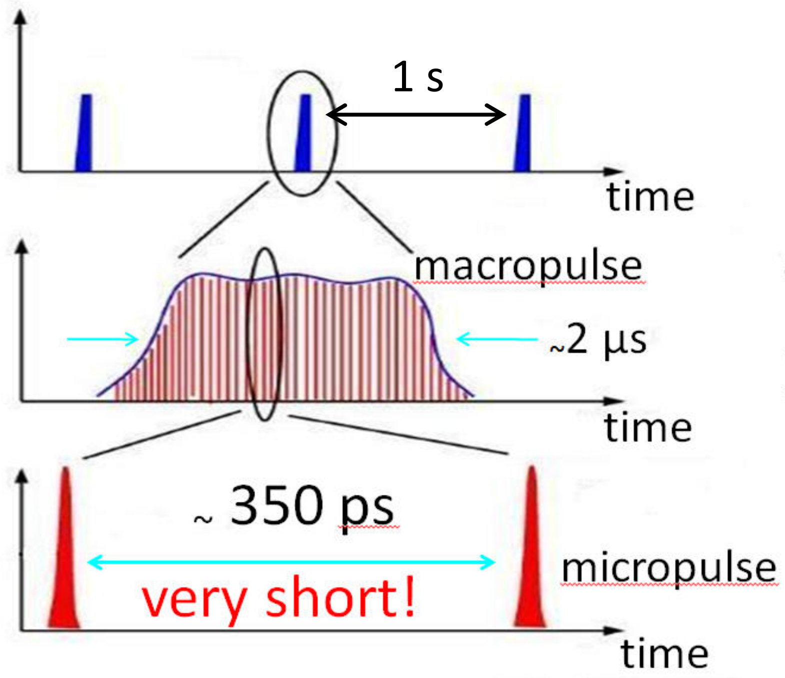




FEL Parameters

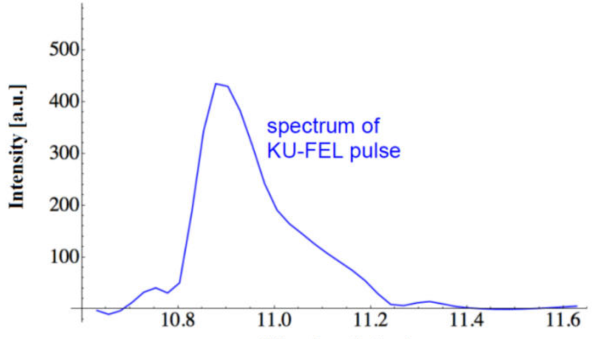
FEL radiation consists of macro-pulse and micro-pulse corresponding to electron beam structure. The macro-pulse is released with 1 Hz repetition rate. Each micro-pulse contains 5700 micropulses

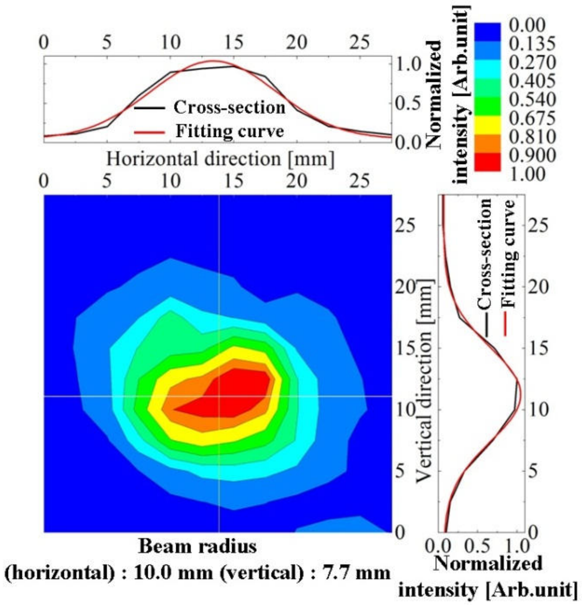
Mid infrared oscillator FEL	
Wavelength range	5 – 14.5 μm
Peak power	~4 MW
Macro-pulse duration	~ 2 μs (@10μm)
Macro-pulse energy	1 – 15 mJ (max.@ 10 μm)
Macro-pulse power	5 kW
Micro-pulse energy	0.5-2.5 μJ
Micro-pulse duration	< 0.66 ps @ 12 μm

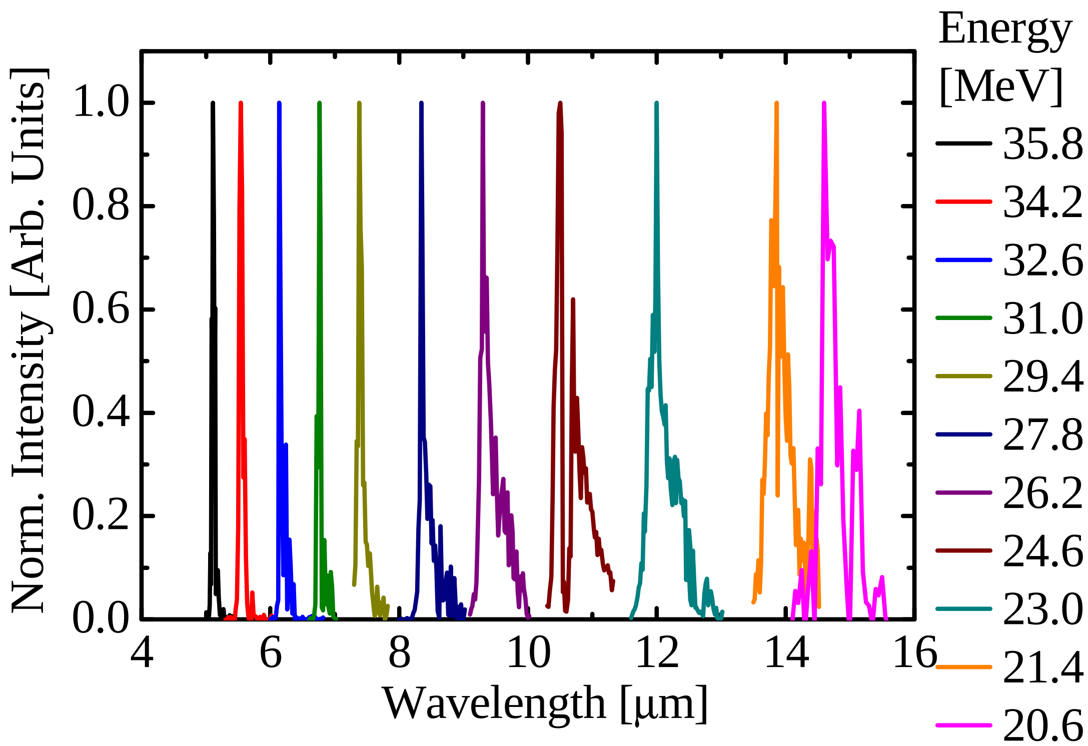


FEL Spectral Characteristics

The wavenumber of FEL is adjusted by changing e-beam energy
Present Tunable Range : 650 – 2000 cm-1 : 5 – 14.5 μm







Application for Material Science

Main Project: Investigation of the relation between lattice vibration (phonon) and electronic structure by wide gap semiconductors (SiC, TiO2). We use photo luminescence spectroscopy in combination with selective phonon excitation by MIR-FEL.

Si-C:	12.6 μm
Si-H:	11.2 μm
Si-N:	10.4 μm
Si-O:	9.8 μm
……	

Selective Phonon Excitation

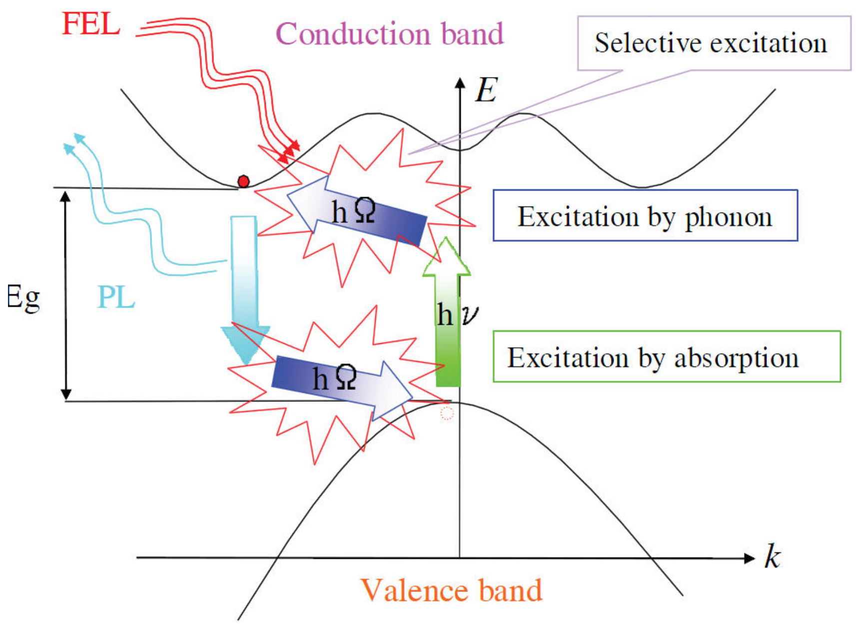
MIR-FEL(KU-FEL)
for selective phonon excitation

+

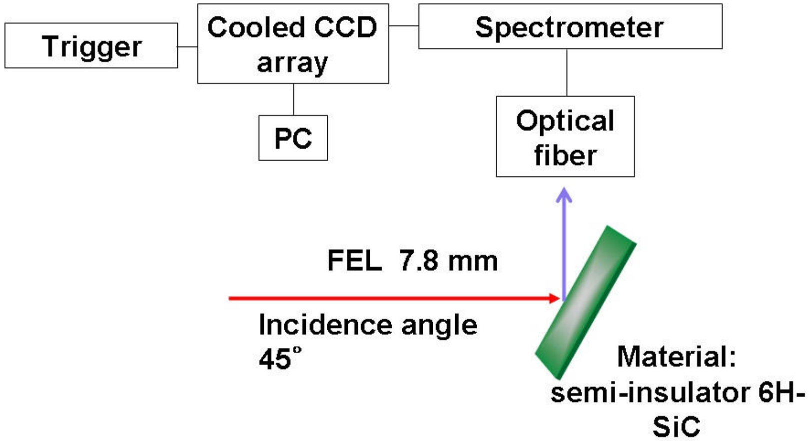
Photoluminescence (PL) measurement system
for observation of electronic structure

↓

Analysis the relation between
a specific phonon mode and electronic structure

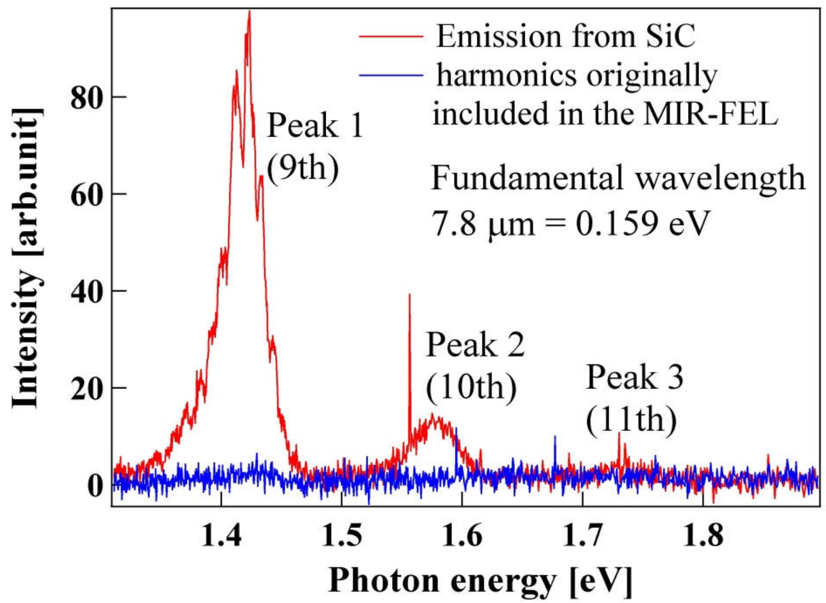


Application for HHG Investigation



Measurement condition

Wavelength	7.8 μm (0.159 eV) 8.6 μm (0.144 eV)
Macro-pulse power	4 mJ
Macro-pulse width	2 μs
Repetation rate	1 Hz

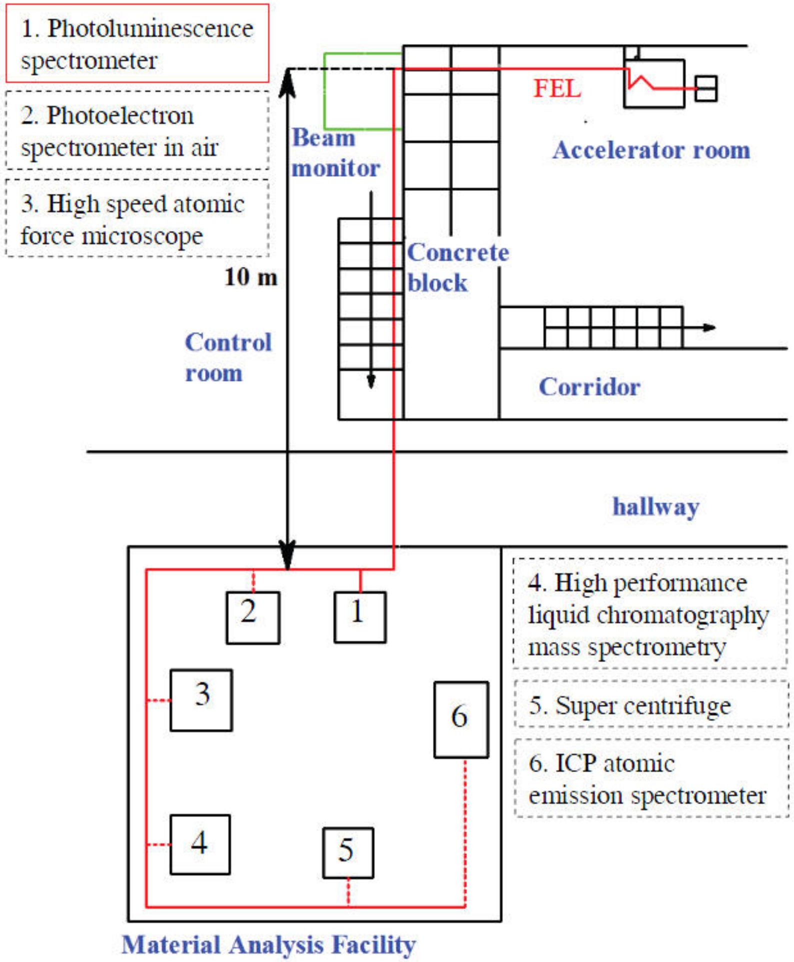


Further Development of Measurement system

The FEL radiation will be provided to 6 different experimental systems:

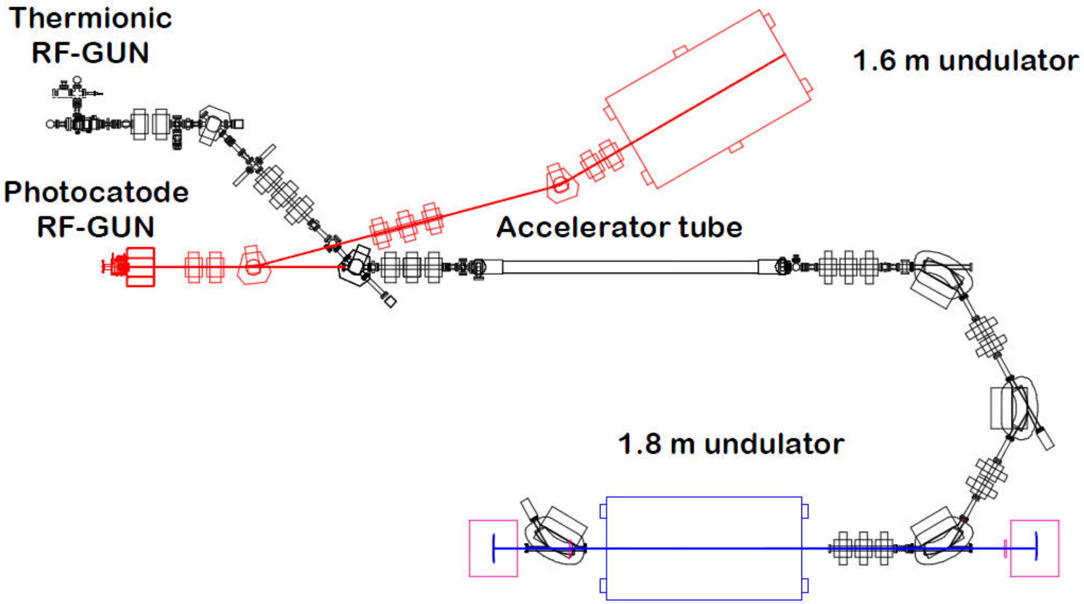
- *Photoluminescence (PL) spectrometer(already present)*
- *Photoelectron spectrometer in air*
- *High speed atomic force microscope*
- *High performance liquid chromatography mass spectrometry*
- *Super centrifuge*
- *ICP atomic emission spectrometer*

The measurement systems will be applied for investigation of candidate materials for electrode of solar cells, a next generation materials for power devices, and photocatalytic mater.



Further Development
Facility Construction

- **Beam stability improvement**: Currently a beam position and energy stabilization is under development. This system uses amplitude information from the BPMs and a bunch phase stabilization system
- **Electron beam improvement-** The thermionic RF gun shall be modified to triode type in order to mitigate the electron back bombardment effect
- **THz FEL amplifier -** A new construction for a THz FEL amplifier is planned



Summary

- MIR FEL facility in Kyoto University is now ready for use
- Tunable Range : 650 – 2000 cm-1 (5 – 14.5 μm)
- Electron beam feedback control system is under development
- Photocathode system will be installed
- PL spectroscopy system with MIR-FEL is ready for
  phonon-electron interaction study in semiconductors.
  Other user stations are under construction

KU-FEL Group

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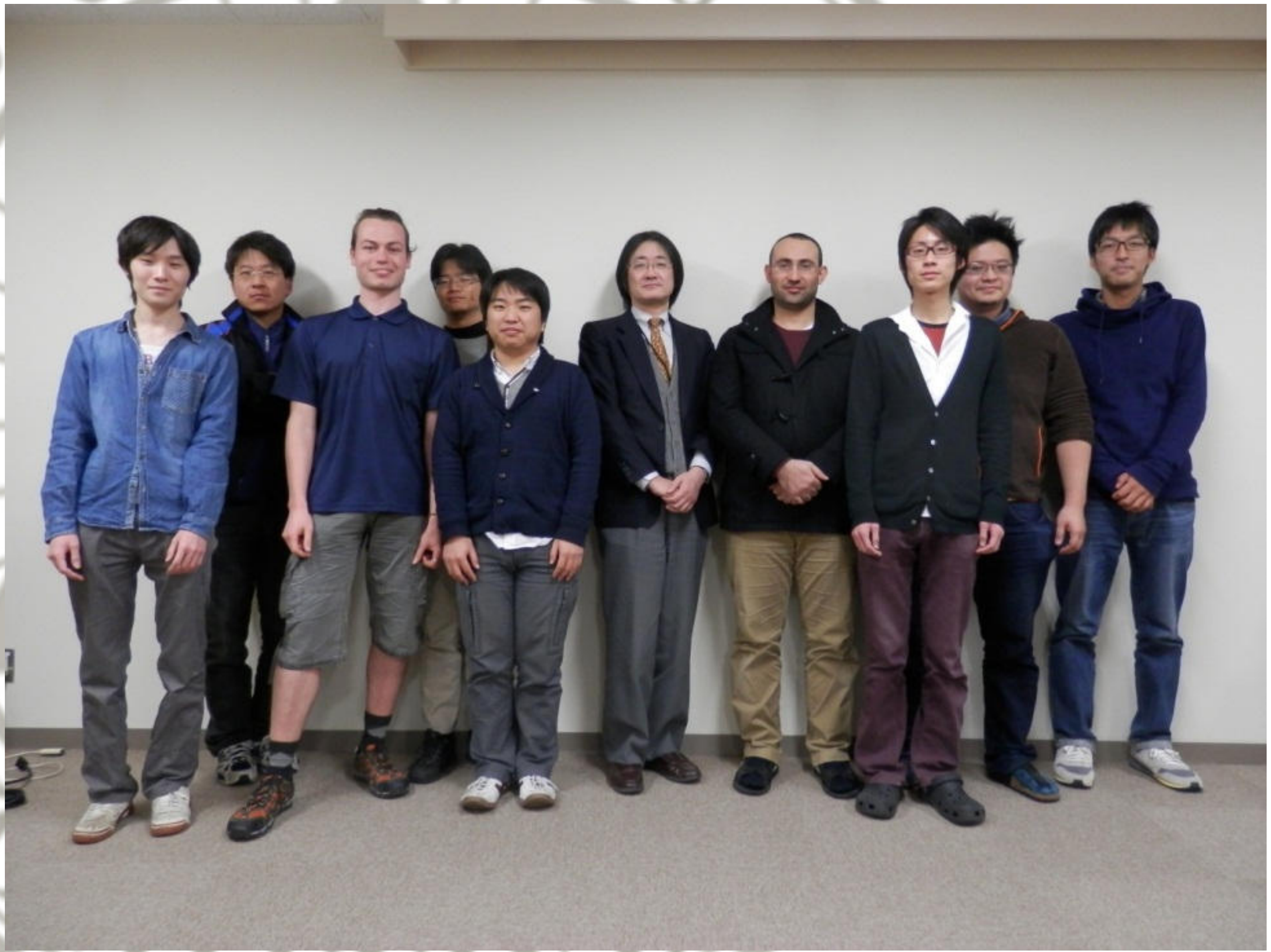
*Kyohei Yoshida**
*Marie Shibata**
*Kensuke Okumura**

*not in picture



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ご清聴ありがとうございました

(Danke für Ihre Aufmerksamkeit)

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