MIR-FEL Oscillator Lasing by Photocathode Operation of LaB$_6$ Thermionic Cathode in KU-FEL

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Introduction

KU-FEL = Compact MIR-FEL using thermionic RF gun

~8.4 MeV

Tunable Range: 5 – 22 µm
Peak Power: < 10 MW

4.5 cell Thermionic RF Gun

3-m Accelerator Tube 20~40 MeV

180 deg. ARC

1.8-m Undulator

5.04-m Optical Cavity

Quadrupole
45 deg. Bend
60 deg. Bend

Slit
KU-FEL Upgrade Project
Thermionic Cathode → Photocathode

Thermionic RF Gun
- Simple and Low cost
- Back-bombardment Effect
- Low bunch charge
- Good for high Ave. Power

Photocathode RF Gun
- Need Expensive ps-Laser
- No Back-bombardment
- High bunch charge
- Good for high peak Power

Our Upgrade Project
- Use same RF gun
- Use same cathode (LaB$_6$)
- Use same beamline, undulator and optical cavity
- Develop multi-bunch UV-laser for photoemission

Increase peak power of KU-FEL
**Main Component**

- Nd:YVO$_4$ Mode-locked Oscillator & **Integrated Acousto-Optic Modulator (AOM)** (89.25 MHz, 7.5 ps-FWHM) (Pulse picker)
- Beam Position Stabilizer
- Two-pass Nd:YAG Amplifier x 2
- Nonlinear Crystals (SHG & FHG)

The AOM is key component for multi-bunch UV-laser generation
Compensation of Gain Drop

W/O Compensation

Stored energy in Nd:YAG amplifier rapidly decrease when amplified micro-pulse energy is high.

⇒ High gain at the beginning of macro-pulse and low gain at the end.

The gain drop can be compensated by modulating input laser pulse by AOM.

⇒ Weak input laser pulse at the beginning of macro-pulse and strong at the end.

Multi-bunch UV-laser pulse with rectangular macro-pulse structure can be realized.
In case of e-beam repetition rate = 89.25 MHz

FEL Optical Cavity (L = 5 m, f = 29.75 MHz) ~ 3.3 m

Three independent optical pulses can be amplified.

→ Use AOM to reduce micro-pulse frequency from 89.25 to 29.75 MHz.

When macro-pulse duration is 5 μs,

89.25 MHz operation
  Micro-pulse energy : ~ 4 μJ

29.75 MHz operation
  Micro-pulse energy : ~ 20 μJ
Cathode & RF Gun

Cathode
LaB$_6$ Single Crystal
(100) Surface, 2 mmφ

RF Gun: side coupled 4.5-cell, S-band

Cathode Temperature
• Thermionic: 1700 deg. C
• Photocathode: 1100 deg. C
  ➞ Negligible thermal emission

Laser injection from 70 deg.
Polarization was adjusted to have highest QE.
The measured highest QE was ~0.01%.
Multi-bunch Photoelectron Beam Generation

@Gun Exit

@Beam Dump

- Flat top Macro-pulse generation with 4-μs macro-pulse duration.
- Bunch charge at beam dump was measured by Faraday Cup.
  - Thermionic: < 50 pC
  - Photocathode: ~ 150 pC
    - > 3 times
First Lasing with Photocathode Operation

Same condition of Undulator and FEL Optical Cavity

- e-Beam Energy: ~ 23.8 MeV
- Undulator K-value: ~ 1.1
- FEL wavelength: ~11.7 μm

Linac was adjusted to have maximum macro-pulse energy.

Micro-pulse Energy Evaluation

Thermionic Operation:

\[ \frac{13 \text{ mJ}}{(2856 \text{ MHz} \times 2 \text{ μs})} = 2 \text{ μJ} \]

Photocathode Operation

\[ \frac{0.8 \text{ mJ}}{(29.75 \text{ MHz} \times 2 \text{ μs})} = 13 \text{ μJ} \]

~ 6.5 times
Detuning Curve

Peak FEL Power [Arb. Units] vs. Relative Cavity Length [$\mu$m]

- Photocathode
- Thermionic

Wider detuning width $\Rightarrow$ Much Higher Gain
Summary

• First Lasing of KU-FEL with photocathode operation of LaB$_6$ cathode has been achieved.

• Bunch charge @undulator:
  Thermionic $<$ 50 pC $\rightarrow$ Photocathode 150 pC

• Micro-pulse Energy of FEL: 2 $\mu$J $\rightarrow$ 13 $\mu$J

• Wider detuning width imply higher gain.
Future Work

• Measurement of basic properties of FEL under the photocathode operation
  – Spectrum
  – Tunable range
  – Temporal structure

• Optimization of coupling hole of FEL optical cavity

• Apply to user experiment require higher peak power of FEL
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Thank you for your attention!