Generation of two-color Free Electron Laser in Dalian Coherent Light Source

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Introduction
Overview of FEL facility

<table>
<thead>
<tr>
<th>Facility</th>
<th>VUV Length</th>
<th>Energy (GeV)</th>
<th>Budget ($)</th>
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<tbody>
<tr>
<td>Dalian</td>
<td>150m</td>
<td>0.3</td>
<td>~25 m</td>
</tr>
<tr>
<td>SXFEL</td>
<td>300m</td>
<td>1.0</td>
<td>~35 m</td>
</tr>
<tr>
<td>Fermi</td>
<td>350m</td>
<td>1.2</td>
<td>~0.18 b</td>
</tr>
<tr>
<td>FLASH</td>
<td>400m</td>
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<td>~0.3 b</td>
</tr>
<tr>
<td>Swiss-FEL</td>
<td>715m</td>
<td>5.8</td>
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<td>SACLA</td>
<td>750m</td>
<td>8.0</td>
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</tr>
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<td>PAL-XFEL</td>
<td>1.1km</td>
<td>10.0</td>
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</tr>
<tr>
<td>LCLS</td>
<td>1.5km</td>
<td>14.5</td>
<td>~0.4 b</td>
</tr>
<tr>
<td>LCLS-II</td>
<td>1.5km</td>
<td>4.0</td>
<td>~1 b</td>
</tr>
<tr>
<td>SCLF</td>
<td>3.0km</td>
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<td>European XFEL</td>
<td>3.8km</td>
<td>17.5</td>
<td>~1.5 b</td>
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Overview of FEL facility

**Construction**

SXFEL, FLASH-II, PSI-PAL-LCLSII-EuroX-SCLF

**Operation**

SDUV, DCLS, Fermi, FLASH, LCLS-SACLA

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High Gain Harmonic Generation

- Induced energy modulation at longer wavelength is changed into harmonic content after compression with a chicane.
- A selected harmonic is picked up with a succeeding undulator.


E. Allaria et al, Nature Photonics. 6 (2012) 699;
E. Allaria et al, Nature Photonics. 7 (2013) 913
Dalian VUV FEL Performance

- **Wavelength tuning range:** 50 – 180 nm
- **Pulse energy:** >100 μJ (1 mJ-Maximum)
- **Pulse duration:** 100 fs / 1 ps
- **Narrow bandwidth:** Fourier transform limited
- **Timing:** timing jitter < 100 fs
- **Frequency:** 50 / 100Hz (double pulse mode)
- **Coherence:** Longitudinal and temporal
- **Polarization:** FEL1(PMU), FEL-2(EPU)

**High brilliance/ Narrow bandwidth/ Ultra-fast/Coherence**
Current status of Dalian VUV FEL

Drive laser

Seed laser

Experiment hall

LINAC

Undulator
**SASE saturation**

**SASE gain curve**

150μJ @118nm

**SASE spectrum**

**SASE spot image**
Seed laser is 266nm, which is \(3^{\text{rd}}\) of 800nm. 88nm (\(3^{\text{rd}}\) harmonic of seed laser) is also achieved, energy is about 30\(\mu\)J.
High brilliance

DCLS Gain Curve@150nm

![Graph showing DCLS Gain Curve at 150nm wavelength with data points and different curve lines for SASE(peak), SASE(average), HGHG(peak), and HGHG(average).]
FEL wavelength tunability (50-150nm)

DCLS Spectra 50-150nm

- $\lambda_0 = 50.972\text{nm}$, FWHM = 0.021 nm
- $\lambda_0 = 59.236\text{nm}$, FWHM = 0.032 nm
- $\lambda_0 = 74.115\text{nm}$, FWHM = 0.020 nm
- $\lambda_0 = 90.321\text{nm}$, FWHM = 0.031 nm
- $\lambda_0 = 104.994\text{nm}$, FWHM = 0.055 nm
- $\lambda_0 = 118.941\text{nm}$, FWHM = 0.067 nm
- $\lambda_0 = 134.422\text{nm}$, FWHM = 0.042 nm
- $\lambda_0 = 149.287\text{nm}$, FWHM = 0.045 nm
Pulse energy fluctuation is down to 10%

- Better gun conditioning
- Feedback for LINAC power system
- Less timing jitter between e-beam and seed laser
User experiment
photodissociation dynamics of $H_2O$

Review of two-color methods

Two-color VUV FEL

60m

~1-10 ps
20ms /50Hz seed laser
Two-color VUV FEL

- Time delay of the two FEL pulses is about several picoseconds.
- FEL wavelength of the two pulses is tunable between 50 to 150 nm.

- Pump probe experiments with arbitrary OAM FEL could be realized.

• Timing jitter between the FEL and Ti:sapphire laser is about 30 fs;
• The ultrafast excited-state dynamics in isolated molecules can been studies by combining UV pump and VUV probe.

### Main Parameters of the Ti:sapphire laser

<table>
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<th>Value</th>
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<tr>
<td><strong>center wavelength</strong></td>
<td>800 nm</td>
</tr>
<tr>
<td><strong>repetition rate</strong></td>
<td></td>
</tr>
<tr>
<td>oscillator^1)</td>
<td>79.33 MHz</td>
</tr>
<tr>
<td>amplifier^2,3)</td>
<td>10-1000 Hz</td>
</tr>
<tr>
<td><strong>pulse energy</strong></td>
<td></td>
</tr>
<tr>
<td>Oscillator^4)</td>
<td>matching with the amplifier</td>
</tr>
<tr>
<td>amplifier^3)</td>
<td>≥ 10 mJ</td>
</tr>
<tr>
<td><strong>pulse energy stability^3)</strong></td>
<td>≤ 0.5% rms @800nm</td>
</tr>
<tr>
<td></td>
<td>≤ 1.5% rms @ THG</td>
</tr>
<tr>
<td><strong>pulse duration^3)</strong></td>
<td>&lt; 50 fs</td>
</tr>
<tr>
<td><strong>spatial mode quality^3)</strong></td>
<td>TEM&lt;sub&gt;00&lt;/sub&gt;, M&lt;sup&gt;2&lt;/sup&gt; &lt; 1.3</td>
</tr>
<tr>
<td><strong>beam pointing stability^3)</strong></td>
<td>&lt; 10 μrad, rms</td>
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THz and VUV-FEL

Frequency range: 0.1-3.5THz

Frequency resolution: <5GHz

Efficiency: ~0.1% (max)

Pulse energy: ~μJ level

Laser spot size: <2 mm

Thank you for your attention!