Progress of the SCSS Test Accelerator for XFEL/SPring-8

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SPring-8 Joint Project for XFEL
Members


from Joint Team of RIKEN and JASRI
Light Sources at SPring-8

XFEL/SPring-8
(8-GeV FEL, $\lambda=0.1$ nm)
Under Construction

SCSS Test Accelerator
(250-MeV FEL, $\lambda=50-60$ nm)

SPring-8
(8-GeV SR)

NewSUBARU
(1-GeV SR)
Outline

• Overview of the SCSS Test Accelerator

• Stable EUV-SASE for User Experiments

• Recent Topic on the SCSS Test Accelerator

• Construction Status of the XFEL Project at SPring-8
Overview of the SCSS Test Accelerator
SCSS Concept for Compact XFEL

Lower beam-energy is essential !!

1) Short-period Undulator

Radiation Wavelength
\[ \lambda = \lambda_u \left(1 + \frac{K^2}{2}\right) / 2n\gamma^2 \quad \rightarrow \text{In-vacuum Undulator} \]

2) High-gradient Linac

Higher Frequency \quad \rightarrow \text{C-band Linac (5712 MHz)}

3) Low-emittance Electron Injector

Need for short gain-length of SASE-FEL.
\[ \varepsilon = \frac{\varepsilon_n}{\beta\gamma} \quad \rightarrow \text{Single-crystal Thermionic Gun + Stable Buncher} \]

SCSS Test Accelerator

Low-emittance Thermionic Injector

- CeB$_6$ Gun ($V=500$ kV)
- Beam Deflector ($\Delta t=1$ ns)
- 238-MHz Pre-buncher ($V=200$ kV, $\phi=-110$ deg.)
- S-band APS Buncher ($V=12$ MV, $\phi=-20$ deg.)
- S-band TWA Linac ($V=38$ MV, $\phi=-25$ deg.)
- Bunch Compressor ($R_{56}=-20$ mm)
- 476-MHz Booster ($V=700$ kV, $\phi=-25$ deg.)

CeB$_6$ Cathode ($\phi=3$ mm, 1500 deg. C)

Uniform Density
Low Emittance ($0.6\pi$ mm mrad)
C-band Linac and In-vacuum Undulator

Choke-mode Structure (HOM-free)
Structure Length : 1.8 m X 4
#2 unit is operating at 37 MV/m.

Magnet Period : 15 mm
Period Number : 300 X 2
Gap : 3 mm (min.), variable
K-value : 1.5 (max.), variable
## Characteristics of Electron Beam

### Electron Beam

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>250 MeV</td>
</tr>
<tr>
<td>Charge</td>
<td>0.3 nC</td>
</tr>
<tr>
<td>Peak Current</td>
<td>300 A</td>
</tr>
<tr>
<td>Bunch Width</td>
<td>0.7 ps</td>
</tr>
<tr>
<td>Rep. Rate</td>
<td>60 pps (max.)</td>
</tr>
<tr>
<td>Initial Emittance</td>
<td>$0.6\pi$ mm mrad (90%-core)</td>
</tr>
</tbody>
</table>

### Transverse Profile

OTR monitor at C-band linac exit
EUV-SASE Saturation

Experiment

Experimental data analyzed

Normalized Emittance = $0.7\pi$ mm mrad !!


T. Tanaka
http://radiant.harima.riken.jp/simplex/index.html
Stable EUV-SASE for User Experiments
Stable EUV-SASE for User Experiments

In 2008FY, SCSS successfully delivered stable EUV-SASE light through a year.

- 11 research groups used the SCSS facility.
  - Atomic-molecular Science
  - Coherent Imaging
  - Solid-state Physics
  - Etc.
- Total Operation Time: **95-days** (840-hours)
- Downtime Rate: **4%**
- 80-days was used for improvements and R&Ds.
## Characteristics of EUV Photon Beam

### EUV Photon Beam

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>50-60 nm</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>30 μJ typical</td>
</tr>
<tr>
<td>Power Fluctuation</td>
<td>~10%</td>
</tr>
<tr>
<td>Spot Size*</td>
<td>3 mm (FWHM)</td>
</tr>
<tr>
<td>Pointing Stability*</td>
<td>5% of spot size</td>
</tr>
<tr>
<td>Averaged Spectrum Width</td>
<td>0.6% (FWHM)</td>
</tr>
</tbody>
</table>

* 10m downstream from the undulator
Stability of EUV Photon Beam

Trend Graph of Pulse Energy

Transverse Profile

Stable EUV photon beam is routinely delivered !!
Evidence of Full Spatial Coherence

EUV-SASE

Diffraction

Iris: φ10 mm

CCD image

Good Spatial Coherency !!

by courtesy of Dr. Yoshinori Nishino of RIKEN Harima Institute
Recent Topic on the SCSS Test Accelerator
Longitudinal Electron Beam Property

Shot-by-shot Electron Bunch Timing
Need for precise experiments.

Longitudinal Bunch Structure
Need for reliable commissioning.

Non-destructive and real-time measurement can be done by Electro-Optical sampling method.

Electro-optical Sampling Method

Vertical Polarization

Longitudinal Structure Encoded

Vertical Polarization

Horizontal Polarization

EO-crystal (ZnTe)

Linearly-polarized Laser

$E_T$

Electron Beam

in Vacuum Chamber
Preliminary Result at SCSS

Reconstructed EO-signal

Spatially Decoded Signal by BBO-crystal
Construction Status of the XFEL Project at SPring-8
**XFEL/SPring-8**

**Electron Beam**

<table>
<thead>
<tr>
<th>Energy</th>
<th>8 GeV</th>
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<tbody>
<tr>
<td>Peak Current</td>
<td>4.4 kA</td>
</tr>
<tr>
<td>Bunch Width</td>
<td>55 fs (FWHM)</td>
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<tr>
<td>Repetition rate</td>
<td>60 pps</td>
</tr>
</tbody>
</table>

**Photon Beam**

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>0.1 nm</th>
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<tbody>
<tr>
<td>Peak Power</td>
<td>&gt;20 GW</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>0.8 mJ/pulse</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>9 X 10^{-4}</td>
</tr>
</tbody>
</table>
Schedule

March 2009
Building construction was completed. 70% of the main rf components were fabricated.

Summer 2009
Installation of the C-band main linac will be started.

Fall 2010
Equipment installation will be finished. Rf-aging, beam commissioning.

2011~
User operation will be started.
Summary

• The SCSS test accelerator has successfully delivered stable EUV-SASE laser pulses, whose fluctuation is kept in 10% during the experimental period, for various experiments through a year.

• The experience of the machine operation is being fed back to the construction of the 8-GeV XFEL/SPring-8.

• User experiments at the XFEL/SPring-8 will be started in 2011.
Spare
Spatial Decoding

from EO-crystal
~20 ps

Laser Pulse
~150 fs

BBO-crystal

Δt

Δx
History of the XFEL Project at SPring-8

• 2000 : Concept of the SPring-8 compact SASE source.

• 2001-4: R&D of machine components.
  (Thermionic Gun, C-band Linac, In-vacuum Undulator)


• 2006 : First lasing at 49 nm at SCSS.
  : Design and construction of 8-GeV XFEL/SPring-8 started.

• 2007 : Saturation at 50-60 nm. User operation started at SCSS.

• 2008 : Building construction of XFEL/SPring-8 completed.

• 2011 : User operation (~0.1 nm) will start at XFEL/SPring-8.