Early Days of SACLA

March 15th, 2019
@APS, ANL

Tetsuya Ishikawa
Director
RIKEN SPring-8 Center
斉：ordered, coherent
光：light
光斉：Kwang-Je
First International Review Committee for SCSS Project

February 3, 4, 2005
Spring-8, Kouto, Harima, Japan

Won Namkung, Shin-ichi Kurokawa, Marie-Emmanuelle Couprie, John Galayda, Jochen Schneider, Jerry Hastings, Kwang-Je Kim
SCSS Review Comments

1. Summary
2. Scientific case
3. Uniqueness of projects
   1. Thermionic-gun-buncher based injector
   2. Accelerator system
   3. Undulator system
   4. Diagnostics and commissioning
   5. Synergy with Spring-8
   6. X-ray optics
4. Schedule and milestones
5. International collaboration
Summary

- SCSS is an innovative project for generation and use of intense, coherent, short pulse x-ray beams
- SCSS is a unique due to its compactness and its co-location with Spring 8, the leading third generation x-ray facility
- Spring 8 site and facility is very well-suited for this project
- Success of the SCSS will be a milestone event in the advance of technology for x-ray FEL, stimulating progress in x-ray science worldwide
- Members of the SCSS project team are well-known for their successes in innovative solutions of difficult problems
- The project schedule of the SCSS is ambitious but feasible in view of the competence of the project team and accumulated knowledge in the Spring 8 site
- The 60 nm FEL using 250-MeV accelerator is a major step toward the success of the project. We strongly recommend provision for full scientific utilization of this unique source.
- The Committee strongly recommends the prompt start of the SCSS project.
SPring-8 XFEL Status

March 16th, 2007
@NSLS, BNL

Tetsuya Ishikawa
Leader, SPring-8 XFEL Project
On behalf of the Joint XFEL Project Team
Japan launched XFEL Project

Japanese 3rd Science and Technology Basic Plan (2006-2010)
“Selection & Concentration”

273 Important R&D items
62 Strategic R&D items
5 National Key Technologies

Space Transportation
Nuclear Fuel Cycle
Next Generation X-Ray Source
Peta-Flops Computer
Earth/Ocean Observation

X-Ray Free Electron Laser was selected as one of the National Key Technologies.
“X-ray Free Electron Laser, XFEL” provides a perfectly-coherent X-rays with a miraculous intensity.

[coherence of light]

Laser Light

10 µm 1 µm 100 nm 10 nm 1 nm 1 Å

THz rays infrared rays visible rays UV rays soft X-rays X-rays hard X-rays

long wavelength (low energy) ← wavelength of light → short wavelength (high energy)
Photon Technology for 21st Century by Fusion of Two Greatest 20th Century Photon Technologies

X-Ray Technology
- Medical Diagnostic
- Foundation of Quantum Physics
- Sub-Nanometer Metrology (Diffraction)
- Metallurgy
- Organic Materials
- DNA Structure: Molecular Biol.
- Semiconductor
- Synchrotron Radiation
- Protein Structure
- Catalyst

X-Ray Free Electron Laser

Laser Technology
- Quantum Electronics
- Atom & Molecule
- Laser Metrology
- Laser Machining
- Optical Communication
- Holography
- Optical Sensor
- Optical Memory (CD/DVD)

Short Wavelength, Ultra High Brilliance, Ultra Short Pulse, High Coherence
Linac-Based Free Electron Laser
Self-Amplified Spontaneous Emission (SASE)

- e-gun
- linac
- undulator

Micro-bunching

X-Ray Laser
Self Amplified Spontaneous Emission (SASE)

Requirements for e beam

- Low Emittance
- High Density in 6D Phase Space

> nC in 0.05x0.05x0.03 mm³ volume
US and European XFEL Projects

**US**
SLAC: Stanford Linear Accelerator Center
Liniac Coherent Light Source: LCLS
- Use Existing 2 mile Liniac
- Project Cost: 315 M US$
- Size: 2 km long
- Shortest Operating Wavelength: 0.15 nm
- To Start Operation in 2009
- RF gun/Normal Conducting Liniac/Out-of-Vacuum Undulator
- 3rd Priority in DOE’s Future Facility Plan

**EU**
DESY: Deutsches Elektronen-Synchrotron
European X-Ray Free-Electron Laser
- Collaboration among 12 EU Countries + China
- Project Cost: 908M Euro
- Size: 3.4 km long
- Shortest Operating Wavelength: 0.085 nm
- To Start Operation in 2013
- RF gun/Superconducting Liniac/Out-of-Vacuum Undulator
SPring-8 Compact SASE Source (SCSS)

- SPring-8 Compact SASE Source (SCSS) is a linac-based X-ray Free Electrom Laser to emit $\lambda < 0.1$ nm radiation.

- The project was born from a discussion of how we could reduce the size of an XFEL by combining a SPring-8 in-vacuum & mini-pole undulator and a high-energy-gradient linear accelerator.

- To achieve the downsizing, we had to develop high-performance injection system, which was recently addressed by DC gun.
Compact SASE Source

Undulator Radiation

\[ \lambda_{\text{photon}} = \frac{\lambda_{\text{magnet}}}{\gamma^2} \]

\[ \gamma = \frac{E}{m_0c^2} \]

With smaller \( \lambda_{\text{magnet}} \), shorter wavelength is achievable with smaller electron beam energy \( E \).

\[ \rightarrow \text{SPring-8 In-Vacuum Undulator} \]

High gradient linear accelerator reduces the total length required for a given electron beam energy \( E \).

\[ \rightarrow \text{KEK C-Band Linac} \]
Prototype Construction

250 MeV Prototype, Total Length: 60 m, Target Wavelength: 60 nm

New Radiation Shield

Prototype FEL

Completed on 8/31/05

First Beam on 11/25/05

Lasing on 6/20/06
First Lasing at 49 nm (June 20, 2006)

Electron Beam Profile

Spectrum

FEL light

Spontaneous Undulator Emission (x500)

Charge Dependence

$E = 250$ MeV
Charge/Pulse $\leq 0.25$ nC
Emittance $\leq 2\pi$ mm$\cdot$mr
Pulse Length $\leq 2$ ps
Wavelength = 49 nm
Max. Power = 110 MW
8GeV XFEL Approved!

**Milestones**

**1st Phase Construction (2006-2010)**
Accelerator Shield, Linear Accelerator
Experimental Hall, Office Bldg,
XFEL Beam Line 1, Wide Range FEL
Bean Line 1

**Budget (2006-2010)**
Construction 290 M US$
R&D 20 M US$

**2nd Phase Construction**
5 XFEL Beam Lines, 5 Ultrashort Pulsed
Spontaneous X-Ray Beam Lines

**World-Wide Open Facility**
The same proposal-review process as SPring-8
3 Remarkable Features of XFEL producing $\lambda < 0.1$ nm X-Rays

◎ High Peak Brilliance
◎ Narrow Pulse Width
◎ High Degree of Coherence
Envisaged, Unprecedented Applications

Limitation of the current technology
- Modest Brilliance
- Modest Time Resolution
- Non-Coherent Source

XFEL
- High Brilliance
- fs Time Resolution
- Full Lateral Coherence

Atomic Resolution Cell Imaging
- Single Molecular Analysis
- Dynamics of Bio-nano Machine

Life Science

High Field Science
- Astoronomy
- Nano Dynamics
- Observation/Control of Electronic State

Nano Science/Technology

Envisaged, Unprecedented Applications
Coherent Scattering Imaging (SPring-8)

3D Rendering of GaN Nano-Dot
Application to Biological Samples (SPring-8)

*Escherichia Coli Bacteria*

![Coherent Scattering Pattern](image)

![Reconstructed Image](image)

*Human Chromosome*

![Coherent Scattering Pattern](image)

![Reconstructed Image](image)
At the 1-km-long beamline (BL29XUL) of SPring-8, the focal size in FWHM was achieved to be **48nm x 36nm (V x H)** by this manipulator.

Measured and simulated profiles are almost the same. ⇒ The mirrors alignments were carried out with the required accuracies to realize the diffraction-limited focusing.
Summary & Outlook

- Japan has launched a project to construct an X-ray Free Electron Laser (XFEL) as one of the National Key Technologies.
- SPring-8 was selected as the site of the XFEL.
- The project period is from 2006 to 2010.
- The facility will be open for the world-wide users.
- We believe the coherent X-rays from the XFEL will expand the frontier of sciences of the photons, with the photons and for the photons.

Join us to explore new science!
Happy birthday!