
RIKEN SPring-8 Center
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Greeting

Since ancient times when humans first learned how to create fire, the discovery of light sources has sparked new sciences and technologies. Harnessing fire completely differentiated mankind from other animals, leading to many different sources of light including candles, oil lamps and gas lanterns. The invention and commercialization of electric light bulbs effectively made the night shorter, resulting in significant changes to human life-styles.

X-rays, electromagnetic radiation with a much shorter wavelength than that of visible light, were discovered at the end of 19th century. Because of their high penetration capability and theoretical ability to achieve high spatial resolution, X-rays have been widely used in diverse fields of science and technology. Today, most advanced sciences and technologies are based on the fundamental understanding of materials' behaviors at the atomic or molecular level. Therefore, the use of X-rays as probes into the nano-world has become increasingly important, leading to the search for more intense X-ray sources. In this brochure, we present our progress towards new generation X-ray sources.

SPring-8 (Super Photon ring 8 GeV), located in the RIKEN Harima Institute, has been the world's brightest storage-ring-based X-ray source (3rd-generation Synchrotron Radiation source) to explore X-ray science since 1997. The RIKEN SPring-8 Center (RSC) was established in 2005 in the RIKEN Harima Institute as a photon science research complex seeking to enhance the distinct capabilities of X-ray science. In addition to promoting cutting-edge research using SPring-8, the RSC took the initiative to develop a compact SASE (Self-Amplified Spontaneous Emission) FEL (Free Electron Laser) in the hard X-ray region.

SACLA (SPring-8 Angstrom Compact free electron LAser), located in the RIKEN Harima Institute adjacent to SPring-8, is the world's first compact X-ray Free Electron Laser (XFEL) source. In June 2011, SACLA, observed the world's shortest wavelength laser light, less than 0.1 nm.

The RIKEN Harima Institute is now the only research entity in the world offering collocated XFEL (SACLA) and 3rd-generation SR (SPring-8) sources. To capitalize on this advantage, the RSC is planning other initiatives to develop new sciences and technologies that will further contribute to human progress and sustainable development.

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The RIKEN SPring-8 Center (RSC) - The Leading Photon Science Research Complex

The most important roles of the RIKEN SPring-8 Center are (i) to open up new fields in high-energy photon science related to synchrotron radiation, making SPring-8 prominent among the world's leading facilities, and (ii) to maintain this status by upgrading light sources, optics to transfer the light from the sources to end-stations, and end-station instrumentation. To achieve these goals, the RSC was established in October 2005 with the following three divisions and corresponding missions:

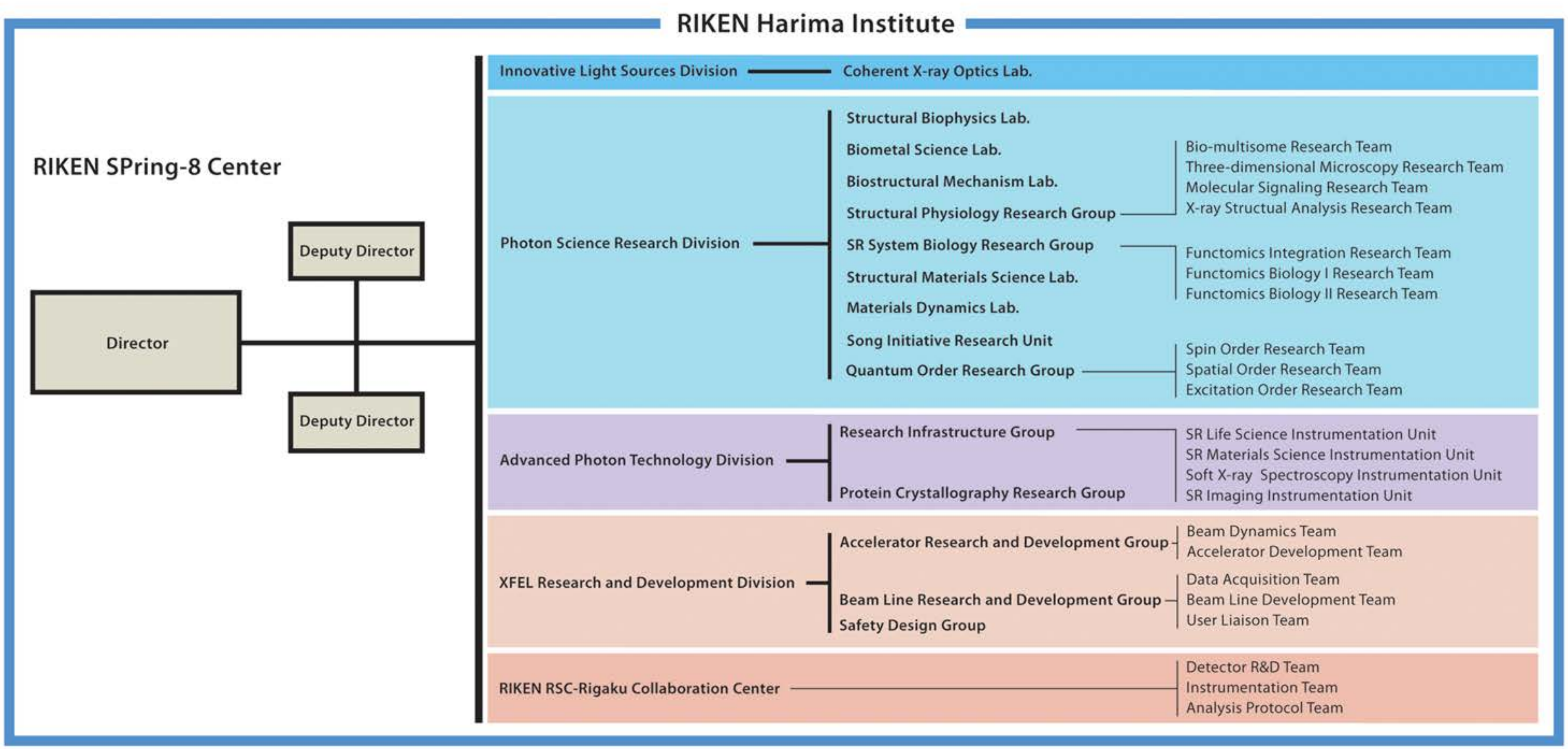
Innovative Light Sources Division:	to upgrade SPring-8 and develop next generation SR sources
Photon Science Research Division:	to explore, promote and lead research utilizing unique and advanced SR-related facilities at the RIKEN Harima site
Advanced Photon Technology Division:	to contribute to increasing recognition for SPring-8 and apply its research results in advanced uses of the SPring-8 facility

The RSC has successfully advanced SR science through a string of innovations in technologies for accelerators, insertion devices, and X-ray optics, resulting in the assembly of a Compact SASE Source that inspired the X-ray Free Electron Laser (XFEL) project. Construction of the XFEL, now known as SACLA, started in 2006 as one of Japan's five "Key Technologies of National Importance" projects to be completed in the 2010 fiscal year.

The RSC was responsible for not only the commissioning of SACLA, but also for a vast amount of cutting-edge research and development tasks. In response to this mandate, the RSC established a fourth division and mission in April 2011 to oversee SACLA-related research and development:

XFEL Research and Development Division:	to facilitate XFEL science emerging from SACLA

With both SACLA and SPring-8 located at the same RIKEN Harima site, the RSC holds a unique position in the field of high-energy photon science. The RSC has the right, as well as the obligation, to develop new scientific fields and to shift existing paradigms using the exceptional combination of these light sources. We look forward to exciting progress as scientists explore new frontiers using our facilities.



SPring-8

Super Photon ring 8 GeV

1km-long beamline
the world's longest beamline used
for RIKEN's coherent X-ray optics R&D

Osaka Mirror
an ultra high precision mirror
for X-ray nanobeams

HAXPES
advanced X-ray spectroscopy

The world's highest energy synchrotron radiation source

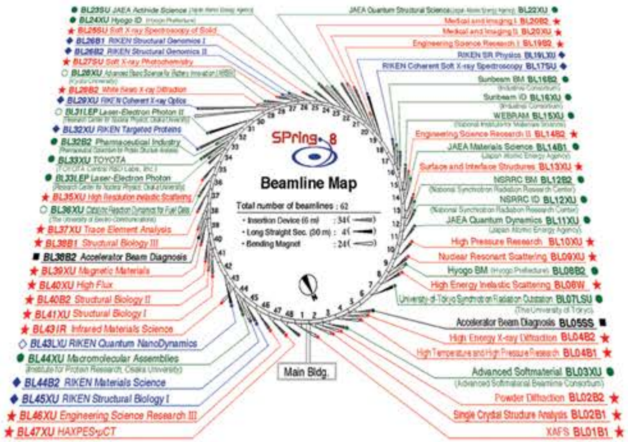
When we observe materials with light, the finest achievable resolution is determined by the wavelength of the light used for the observation. X-rays, with a thousand times shorter wavelength than visible light, are an ideal probe to explore the nano-world to attain a fundamental understanding of material behaviors at the atomic or molecular level. This type of understanding has been indispensable for a large number of contemporary sciences and technologies, leading to ever-increasing demand for much brighter X-ray sources.

SPring-8 is an electron-storage-ring-based synchrotron radiation (SR) facility with the world's highest electron energy - 8 GeV. It covers the spectral range from infrared to 300 keV X-rays. More than 50 beamlines with various types of end-station equipment serve vast areas of science and technology, ranging from pure basic science to industrial applications.

The RIKEN SPring-8 Center (RSC) currently operates its own beamlines, primarily for developing advanced utilization of SR, and collaterally, to promote its own research using SR. The RSC took the lead of applying the coherence of X-rays from an SR source by constructing two dedicated beamlines: a 30-m undulator beamline and a 1-km beamline which contributed to the creation of the Compact SASE Source concept. These beamlines were used extensively for making the world's first hard X-ray coherent diffractive imaging. They were later used for the development of high precision X-ray mirrors for nano-focusing in collaboration with Osaka University, the development of highly perfect diamond single crystals and their application to X-ray polarization optics, as well as the initial phase of development of HAXPES (HArd X-ray PhotoElectron Spectroscopy). All these developments have been transferred to other beamlines at SPring-8 and have even allowed other facilities to flourish. Quite recently, the RSC took the initiative in applying X-ray nonlinear phenomena to the super-resolved observation of electronic responses to photons. This nonlinear study will also surely spread to many other SR facilities.

SR technology has become extremely stable after years of development around the world. It is fair to say that SR is far better suited for most spectroscopic applications than SASE XFEL. The RSC operates world-class beamlines, for both soft X-ray spectroscopy and high-resolution inelastic scattering spectroscopy, which contribute to further advances in X-ray spectroscopy.

The activities of the RSC described above have contributed to maintaining SPring-8's standing around the world. The RSC expects to further strengthen SPring-8's possibility through synergetic operations with SACLA. In addition, the RSC will



The SACLA-Spring-8 Experimental Facility

One plus one will be much greater than two

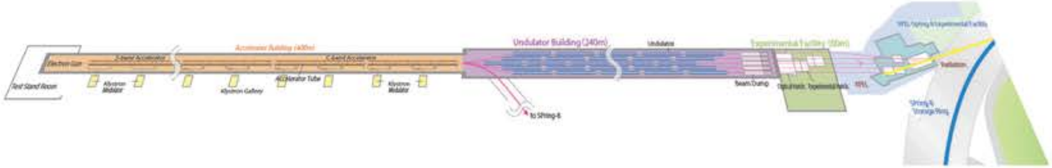
The synergetic use of two world-class facilities

The most remarkable feature of the RSC is its collocation of world-class SR and XFEL facilities at the same site. This allows a high-quality electron beam prepared for SACLA to be transported to a SPring-8 storage ring, making SPring-8 X-rays even brighter. This injection capability is essential when we consider the future SPring-8 upgrade. SACLA and SPring-8 were designed to enable X-rays from both sources to be guided onto a sample located in the SACLA-SPring-8 Experimental Facility. For the future, we envisage spectroscopy of highly charged ions produced by a flash of SACLA X-rays (using SPring-8 X-rays), or time-course observation of relaxation process of materials after the transition to instantaneous non-equilibrium states by illumination with SACLA pulses.

The high-intensity, fast-pulsed, and short-wavelength SACLA beam is suitable for observing momentary shapes and functions of individual components of systems, or smaller aggregations in systems, although irradiation of the SACLA beam would likely destroy the system under observation. The gentle SPring-8 X-rays, in contrast, can reveal the time-course behavior of a single system without interrupting or destroying that system, but the temporal and spatial resolutions are much poorer.

The combined use of SPring-8 and SACLA will provide a joint capability that exploits the advantages of each: (i) the combination of momentary data from SACLA with time-course data from SPring-8 may provide much more definitive explanations of natural processes by embedding high resolution instantaneous data into low resolution time-course data, and (ii) when high-resolution data is obtainable from crystallography using SPring-8 X-rays, single molecular dynamics or one molecule's interaction with other molecules could be reconstructed with high resolution by using only low resolution scattering data from SACLA.

The RSC will open new scientific fields through the synergistic use of these exceptional light sources, SACLA and SPring-8, allowing what is hypothesized about nature to be definitively observed.



SACLA

SPring-8 Angstrom Compact free electron LAser

The world's first compact XFEL to break the 1 Å barrier

Since we are familiar with lasers in everyday life, it is difficult to imagine what optical sciences were like before the invention of lasers. Similarly, although we have just begun exploring X-ray science, we will take X-ray lasers for granted in 50 years.

SACLA is a linear-accelerator-based XFEL built on the basis of the principle of SASE (Self-Amplified Spontaneous Emission). SACLA consists of an 8 GeV linear electron accelerator followed by in-vacuum undulators measuring 50 to 90 meters. Downstream of the linear accelerator, a dipole magnet switches the electron beam pass into five different FEL lines and a beam-transport to the SPring-8 storage ring. In the initial phase, two of the five FEL lines are equipped with in-vacuum undulators.

Discussions about construction of XFEL facilities in the US (LCLS) and Europe (Euro-XFEL) motivated us to investigate enhancing our XFEL. We decided to use in-vacuum undulators developed at SPring-8 by RIKEN researchers, instead of the conventional out-of-vacuum undulators employed by both LCLS and Euro-XFEL. An immediate consequence was that we would be able to reduce the scale of our facility to be 1/3 to 1/4 the size of LCLS or European-XFEL, because in-vacuum undulators could, in principle, allow a shorter magnetic period than out-of-vacuum undulators due to the smaller gap between magnetic poles. This was the first step for SACLA, but also the first step for a Compact SASE Source as well.

The XFEL offers unique capabilities in comparison to SPring-8: 109 times higher peak brilliance, 10-3 times shorter pulse width, and 103 times higher degree of spatial coherence. This extremely high peak brilliance could destroy a sample after illumination with only a single XFEL pulse. However, the X-ray scattering process is extremely fast, allowing the distribution of scatterers before a sample is destroyed. These completely different properties will require new methodologies for analyzing objects, including biological samples or nano-materials samples. SACLA became the world's second XFEL facility (following the LCLS) and is now the world's first compact XFEL operating below 1 Å wavelength.

XFEL technology is still in its infancy, requiring vast amounts of improvements to reach the level of maturity needed for a user facility. For this reason, the RSC manages the initial commissioning for the light source and the initial phase end-station instrumentation for SACLA, giving continuous consideration to synergetic operations and applications between SACLA and SPring-8. In other words, RIKEN's XFEL facility SACLA could be far from its final form in contrast to SPring-8. It is the RSC's responsibility to take SACLA closer to its final form, including the definition of the final form itself.

The RSC has established a new division to perform SACLA operations and to resolve most of the initial problems of SACLA.

Thermionic Electron Gun
a single CeB_6 crystal produces an ultra-low emittance electron beam

High-Gradient C-band Accelerator
an efficient enhancement of electron beam energy

Short-period In-vacuum Undulator
the shortest wavelength XFEL radiation from a moderated energy of electron beam