SPring-8

A New Light Source for Tomorrow

XFEL

X-ray Free Electron Laser

RIKEN

JASRI

SPring-8 Joint Project for XFEL

XFEL : A New Light Source for Tomorrow

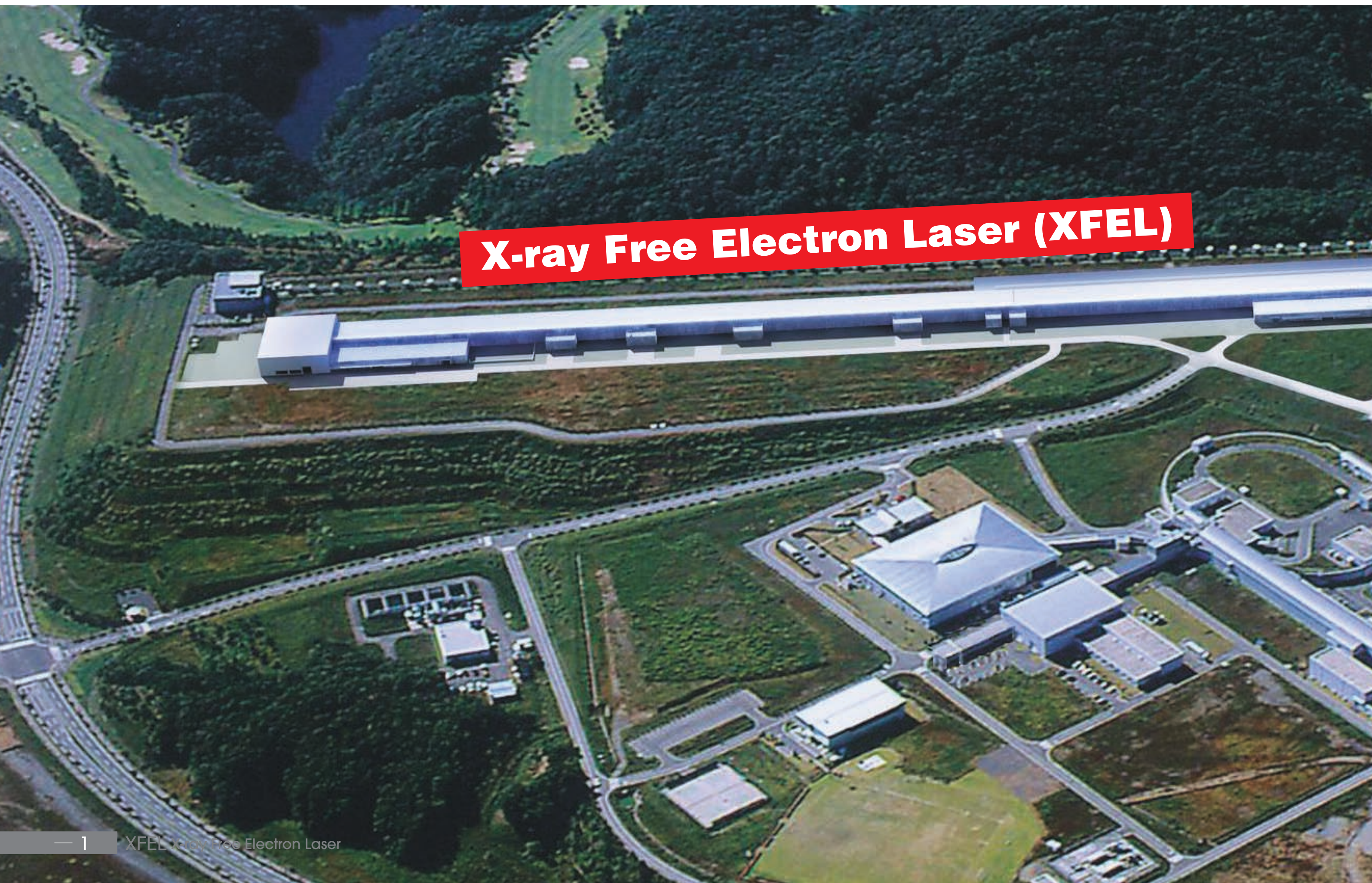
X-ray Free Electron Laser (XFEL) heralds the dawn of a new era in Science

Throughout history, the development of new optical instruments and the discovery of new light sources have given rise to great leaps forward in science. Early use of the telescope provided indisputable proof of the Copernican system; the motion picture enabled mankind to observe an instant of movement; and the microscope made it possible to see individual cells in living organisms.

In the late 19th century, scientific experiments exploited the high transmission capability of **X-rays**, leading to the development of diagnostic probes that contributed greatly to advances in medicine. Further applications using X-rays as diffraction probes enabled scientists to observe the nano-world for the first time and even to analyze DNA structures at the atomic level. More complex protein structures are currently analyzed by much stronger X-rays generated from synchrotrons such as SPring-8 (Super Photon ring-8GeV) in Japan.

The development of the **lasers** in the 20th century inspired the scientific world as it served as a completely new light source to conduct experiments. Laser disk technology eventually enabled the mass production of DVDs and CDs. Additional uses of lasers in high-speed optical communications expedited the development of the internet backbone.

After substantial advances in X-ray and laser technology, scientists began to ask for an even stronger light source to examine real images of atoms in 3 dimensions. **X-rays** combining the features of **Lasers** at the **Free Electron** state (**XFEL**) may be the most promising light source for the next generation of scientific exploration and discovery. XFEL radiation will deliver one billion times brighter and 1000 times shorter pulses than existing X-ray sources. Scientists today are only beginning to imagine the plethora of applications that will result from advancement of XFEL technology.



XFEL Project : A Key Technology for Japan

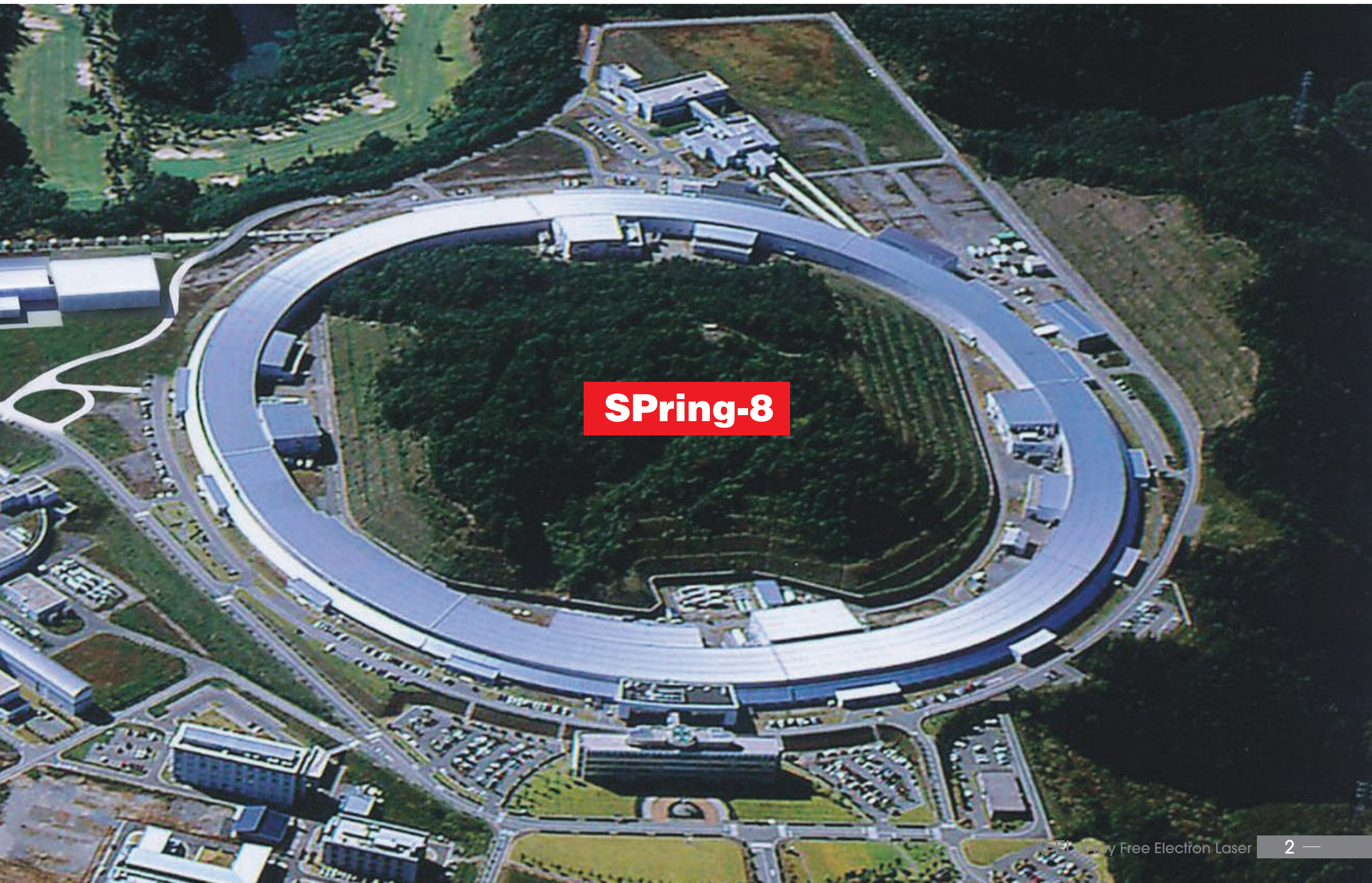
The XFEL adjacent to SPring-8 will provide great benefit to users

The X-ray Free Electron Laser Project was selected by the Japanese government as one of the Key Technologies of National Importance in 2006, and launched by RIKEN the same year. The 700 m-long 8 GeV XFEL is now under construction and will be operational in FY 2010.

The XFEL facility is built next to the SPring-8 storage ring for two fundamental reasons: First to benefit from SPring-8 numerous breakthroughs in accelerator-driven light sources technology in order to build a compact facility; Secondly for the great synergetic effect of the XFEL and SPring-8 facilities on the progress of Photon Science. For instance, laser-pumping and SR-probing techniques offer a powerful mean of investigating the atomic and chemical changes of materials, going beyond conventional atomic/molecular imaging: the intense radiation of the XFEL can excite atoms or molecules to extremely exotic states, and the whole processes of transitions can be probed afterwards by SPring-8 X-rays.

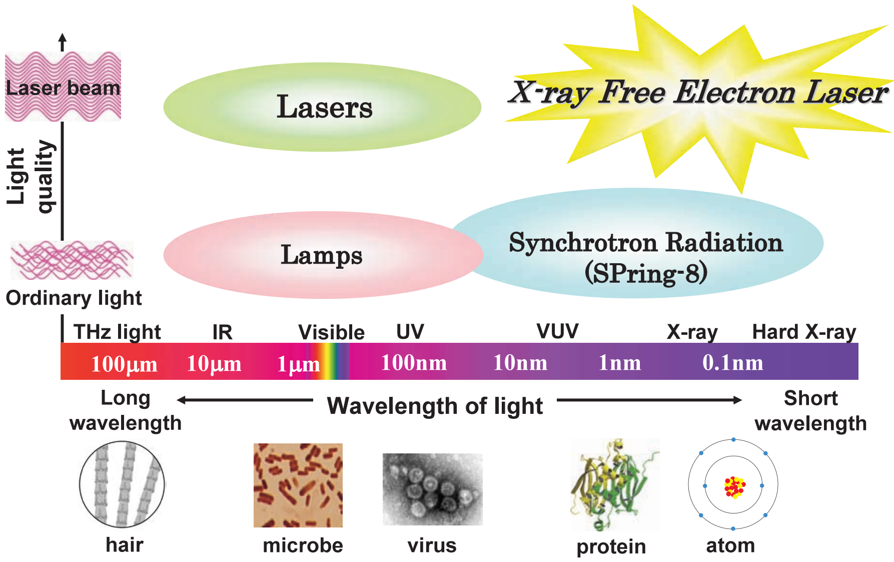
Japan's XFEL Project is led by the RIKEN-JASRI Joint Team. A 250-MeV Test Accelerator was built in 2005, and on June 20 2006, the team successfully generated VUV-laser pulses at 49 nm. This achievement marked a significant step toward the completion of Japan's X-ray FEL.

The XFEL has drawn great interest throughout the world: DESY (Deutsches Elektronen-Synchrotron, Germany) has launched the "European XFEL" Project in 2007 (completion expected in 2013), while SLAC (the Stanford Linear Accelerator Center, USA) is developing its XFEL machine, the "Linac Coherent Light Source" (LCLS), with operation planned for 2009.



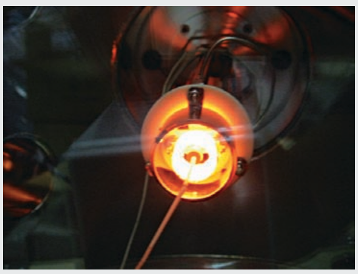
What is XFEL ?

The resolution of optical microscopes is limited by the wavelength of light. With **X-rays**, which have a wavelength 10,000 times shorter than that of visible light, atomic resolution can be achieved. Conventional X-ray sources (including **synchrotron radiation** sources) are not **coherent** (the wave field is not perfectly aligned). Laser can produce coherent light with a pair of mirrors. For X-rays, unfortunately, such mirrors cannot be used due to the low reflectivity. This limitation has motivated scientists to explore a new laser technology called **X-ray Free-Electron Laser (XFEL)**, which can work without mirrors.



Japan's Newest Technologies for Compact XFEL

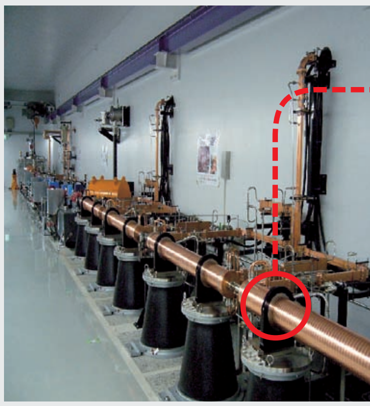
The XFEL machine is designed to be compact in order to contain the construction cost and to improve the operational stability. The compact XFEL is supported by Japan's original technologies.



CeB_6 Cathode Emitter

A high-quality electron beam is launched from a CeB_6 electron gun.

The initial conditions of the electron beam determine the final performance of XFEL radiation. SPring-8 developed a special thermionic electron gun that uses a single-crystal cerium-hexaboride (CeB_6) cathode to emit a small, collimated and stable electron beam. The beam is transported to the bunch compression system where the peak current increases up to several kilo-amperes for the XFEL generation.



The C-band increases the

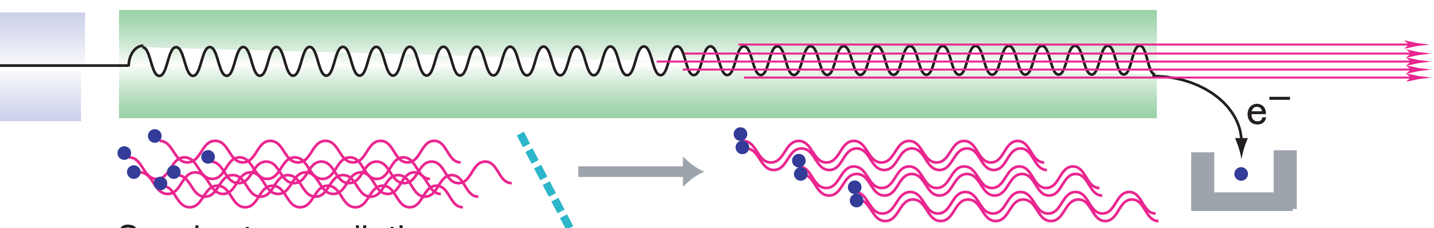
The energy of the electron beam i
linear accelerator": this accelera
SPring-8 in collaboration with KEK
acceleration gradient (35 MeV/m)
length of the accelerator. A total c
machined with sub-micron accuracy

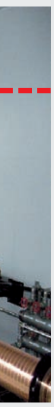
How to Generate XFEL Radiation

The source of XFEL radiation is a bunch of electrons emitted from a **linear accelerator** at a velocity close to the speed of light. This electron beam is wiggled in an array of magnets (called an **undulator**). The weak radiation initially emitted from the electron beam imprints a small density modulation on the beam itself. The modulation and the radiation grow in synergy in the undulator field. Finally the radiation energy is dramatically amplified. This process, called Self-Amplified Spontaneous Emission (**SASE**), is the basis for the generation of XFEL radiation. To generate SASE efficiently requires a small, collimated electron beam, which in turn requires a high-quality **electron gun** and a **bunch compression system**.

Design Parameters

Electron Energy	8 GeV
Electron Beam Size	40 μm
X-ray Wavelength	>0.06 nm
X-ray Peak Power	5 GW
X-ray Pulse Length	<100 fsec
X-ray Peak Brilliance	10^{33} photons/s/mm²/mrad²/0.1% b.w.

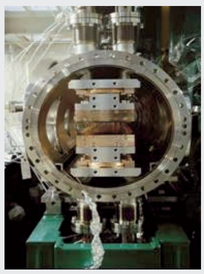




C-band
Accelerating
Structure

accelerator swiftly electron energy.

s boosted to 8 GeV by the "C-band ating structure was developed by K. Thanks to the C-band increased it is possible to reduce the total of 128 2 m accelerating structures, , will be aligned in the 400 m tunnel.



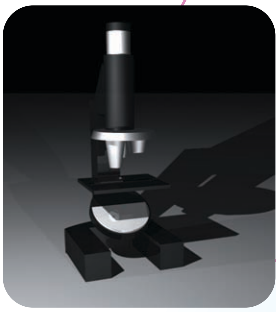
In-vacuum
Undulator

The in-vacuum undulator generates strong XFEL radiation.

The electron beam is injected into the undulator to generate XFEL radiation. The in-vacuum undulator technology, developed in SPring-8, was adopted to reach shorter wavelength radiation with a shorter magnetic period. This technology enables us to reduce the electron energy and leads to contain the total cost of construction.

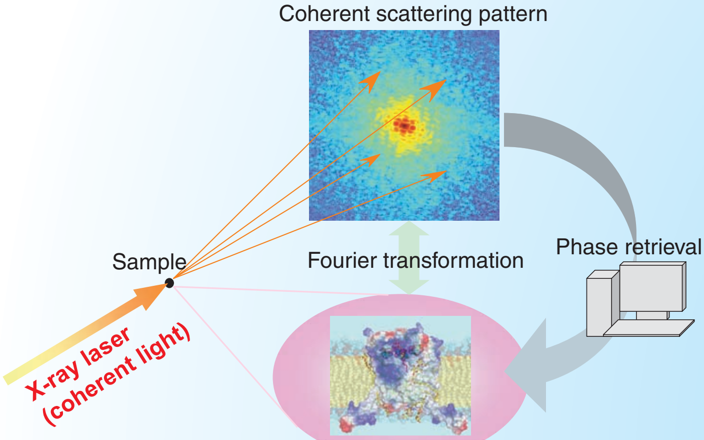
XFEL New Science and

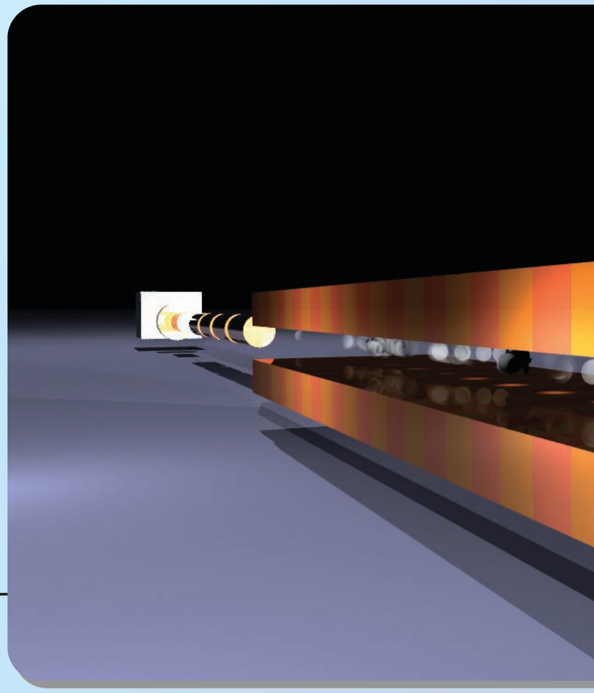
Met



Imaging Technology

Coherent X-ray imaging using XFEL is a promising technology to obtain the atomic-level resolution microscopy for various materials.

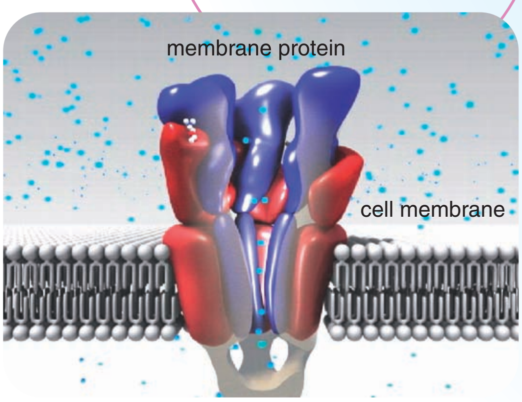


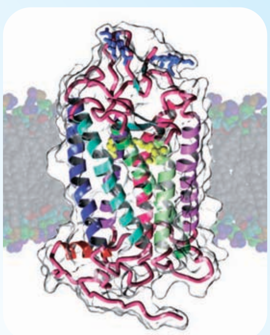


Tar

Protein Structure Analysis

Analysis of new materials leads to the generation of new functional products in biology, and pharmacy.



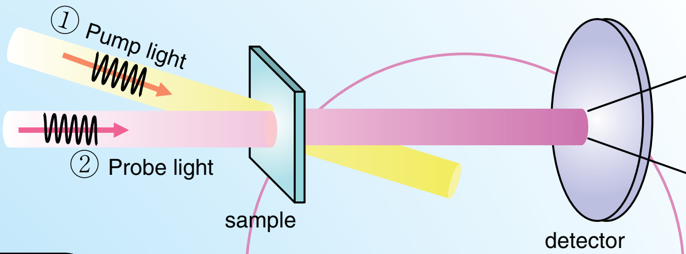


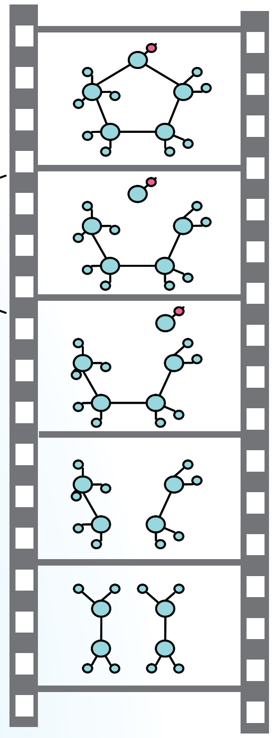
Live Cell Biology

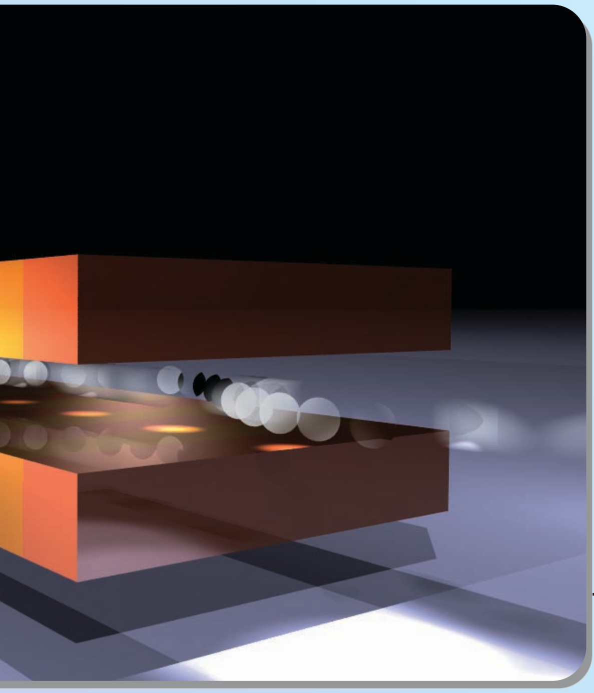
The XFEL will enable the observation of live cells: real time data acquisition will open a new way for the study of cell biology.

Technologies to Create

hods







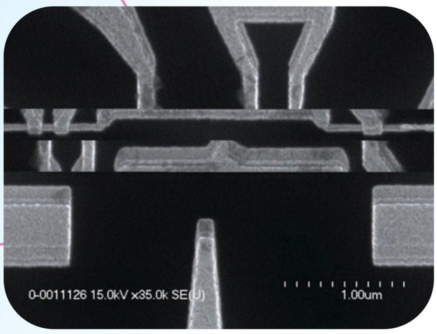
Ultra-fast Observation

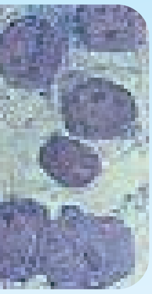
Femto-second XFEL pulses can probe the ultra-fast movement of materials.

gets

Nano Technology

The ultra-short wavelength of the XFEL will be helpful to create new functional materials.



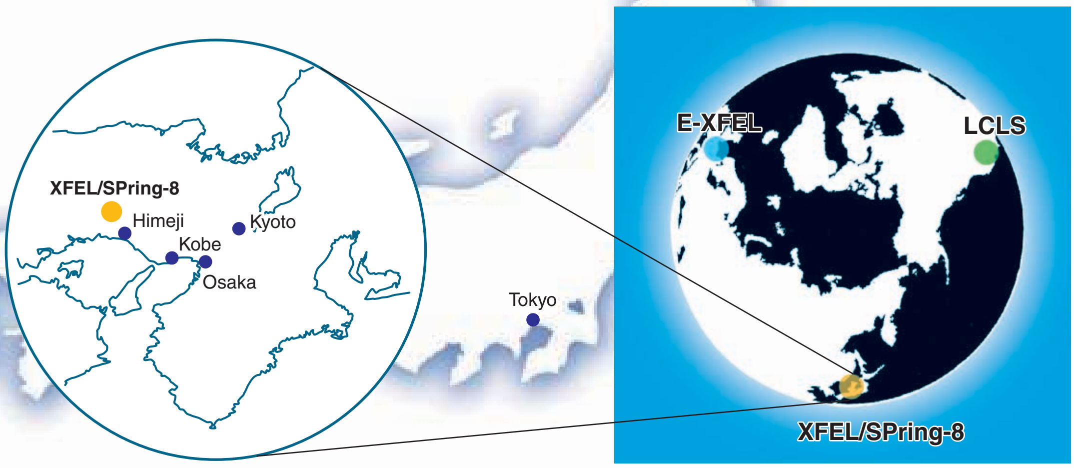


Astronomy

The ultra-high power of the XFEL enables us to investigate extreme conditions for astronomy, plasma science, and fundamental physics.

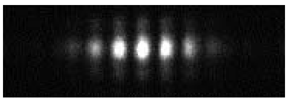
Three XFEL Projects in the World

- **XFEL/SPring-8 in Hyogo, Japan**
- E-XFEL, DESY in Hamburg, Germany
- LCLS, SLAC in California, USA

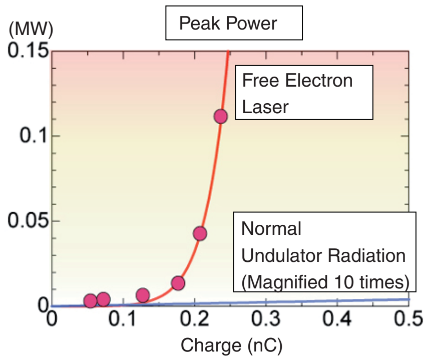


Success of First Lasing at the Test Accelerator

A light source for tomorrow is closer than ever to becoming a reality



Interference pattern by coherent light



The peak power increases exponentially with the electron charge.

The **S**Pring-8 **C**ompact **S**ASE **S**ource (**SCSS**) test accelerator was constructed to facilitate the experimental study of XFEL technology. The accelerating energy is 250 MeV (only 1/32 of the 8 GeV capacity of the XFEL machine), but all basic components are included in its design. On June 20 2006, lasing at a wavelength of 49 nm was observed. This is a remarkable milestone for the Japan's XFEL project.

SPring-8 Joint Project for XFEL
RIKEN (The Institute of Physical and Chemical Research)
JASRI (Japan Synchrotron Radiation Research Institute)

1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5148, Japan
Tel: +81-791-58-2849, Fax: +81-791-58-2862
URL: http://www.riken.jp/XFEL/ E-mail: project-xfel@riken.jp