X-RAY FEL PROJECT AT RIKEN/SPRING-8

The steady and continuous evolution of synchrotron light sources has convinced us that they are indispensable to contemporary science and technology. A decade since the inauguration of the 3rd generation light source facilities, ESRF, APS and SPring-8 have helped solve a wide variety of mysteries in nature and a number of issues in industry. In addition, partially coherent, as well as short pulsed X-rays available have been found to be of great use; thus, motivated us to develop a new generation source which can deliver more coherent and shorter-pulsed X-rays.

It is believed that if we have X-rays FEL based on SASE principle, requests of both more coherent and shorter pulsed X-rays will be satisfied with the ultra-short pulse structure, extremely high peak power level and lateral full coherence of X-rays.

Figure 1 shows a computer image of the completed X-ray FEL machine, which will be constructed next to the existing 1 km beamline. After five years of construction, starting from the 2006 fiscal year (FY2006), we hope to start the operation of the XFEL in 2010. In the design, a low emittance electron beam will be generated by an electron gun located at the bottom-left corner, which will be accelerated to a high energy of 8 GeV by a high gradient C-band accelerator 400 m long, followed by an undulator section 80 m long, where FEL action will take place. The lased X-ray beam will be transported to the user facility, flying in free space in a vacuum pipe 100 m long, then in a beam safety shutter, an attenuator, and a monochromator, if necessary. In the first stage of the project, we will construct one undulator line and one user beamline. The rest of the beamlines will be constructed later. At the end of the C-band main linac, one branch will be connected to the booster-to-synchrotron transport line, which will directly inject an 8 GeV beam into SPring-8. It will provide a low emittance and a very short bunch beam, which will generate short X-ray pulses in the femto-second range for 100 turns before bunch spreading due to radiation damping. This type of short pulse radiation will be used to investigate the time response of materials by exciting them with a femto-second laser and then tracking the structural changes using the X-ray after the excitation.

It is believed that an X-ray FEL with wavelength shorter than 1.5 Å can only be accomplished by a scheme named SASE-FEL: self amplified spontaneous emission type free electron laser. Figure 2 shows the schematic configuration of SASE-FEL, which is quite simple: an electron source, an accelerator and an undulator. The undulator converts the kinetic energy of the electrons into X-ray radiation. In our machine design, we specially employ three key elements, a low emittance electron injector, a high gradient C-band accelerator and a short period in-vacuum undulator, which makes the system compact as compared with other projects, such as LCLS at SLAC, or XFEL at DESY.

Fig. 1. Computer image of SCSS-XFEL, (left straight facility, 700 m total length), which will provide extremely intense X-ray radiation: pulsed peak power > 1 GW, pulse length < 100 fs, repetition rate 60 pps. The designated wavelength is 1 Å at 8 GeV electron beam energy. The large circular building is the existing 8 GeV synchrotron radiation facility (500 m in diameter).

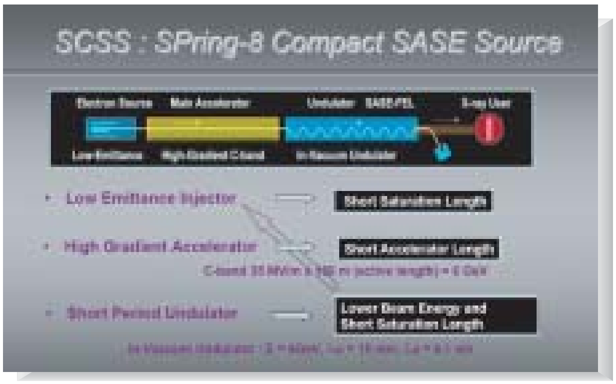

Fig. 2. Configuration of SASE-FEL and SCSS: SPring-8 Compact SASE Source concept. It is based on three key components: **(1)** low emittance electron gun, **(2)** high gradient C-band accelerator and **(3)** short period in vacuum undulator, which reduce the total length of the machine, and fit within the available site length at SPring-8.

Figure 3 shows the basic physics of FEL. It uses the radiation of electrons in free space, not orbital electrons in atoms; hence, it is named as free electron laser. In a non-FEL machine such as SPring-8 SR-ring, which is schematically indicated by the left illustration, when an electron bunch runs through the undulator, each electron generates a sinusoidal transverse electric field according to the magnetic field arrangement. It is called undulator radiation. Since the longitudinal positions of each electron are random, radiations sometimes cancel each other out, or contribute constructively, resulting in a non-coherent radiation field, which is sometimes called spontaneous radiation. The total power of spontaneous radiation is given by $P_{spt.} = N_e \cdot P_1$, where P_1 is the radiation power from a single electron, and N_e is the number of electrons. When the longitudinal positions of the electrons are aligned regularly in a radiation wavelength, all radiation fields constructively contribute; thus, the field intensity and power become extremely high, in the maximum case, $P_{coherent} = N_e^2 \cdot P_1$. Since there are 10^8~10^9 electrons in one bunch, the power gain becomes 10^5~10^8 depending on the coherent length and the degree of electron density modulation. As you may imagine, the spectral narrowing of the X-ray laser and the transverse beam confinement (parallel beam) are due to the interference effect in time and space. Thus, the X-ray power amplification is identical phenomena as the growth of density modulation in an electron beam.

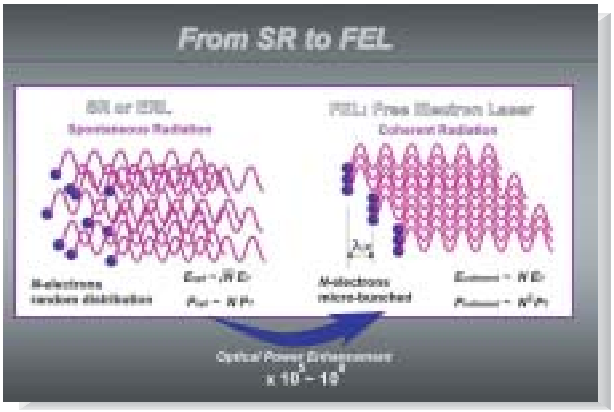

Fig. 3. What is FEL? Left-hand-side drawing shows undulator radiation of group of electrons in conventional SR and also proposed ERL. Right-hand-side is the FEL, where all electron positions are localized regularly at radiation wavelength. The peak power is enhanced drastically because of the constructive interference of all radiation.

To realize XFEL, we need a high level of technology to generate low emittance electron beam, a highly stable acceleration field, a precise beam position monitor and a stable support system for equipment. We started the R&D of those key components in FY2001. In order to check the quality of developed hardware components, and demonstrate SASE-FEL at a soft-X-ray wavelength, we constructed the "SCSS test accelerator" in the R&D facility building during FY2004~2005, as shown in Fig. 4. The designed shortest wavelength is 50 nm at the electron beam energy of 250 MeV. Right after the beam commissioning, the first spontaneous light was observed at the visible to 100 nm wavelength in November 2005. We are now debugging the hardware and control software, which is currently the most important task of the prototype, and the first lasing test at the designed wavelength is scheduled in June 2006. All experience learned from the SCSS test accelerator will be fed back into the machine design and the operation of the 8 GeV X-ray FEL. For more details, please visit our website at http://www-xfel.spring8.or.jp/.

Fig. 4. SCSS test accelerator, prototype of X-ray FEL. Construction was completed in November 2005. First lasing test at 60 nm wavelength is scheduled in June 2006.

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