SOFT-X-RAY SASE-FEL PROJECT AT SPRING-8 JAPAN

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Abstract

The SPring-8 Compact SASE Source (SCSS) is a high peak-brilliance soft X-ray free electron laser project. It is the linac-based FEL dedicated machine. Combination of the high-gradient C-band accelerator and the in-vacuum short-period undulator realizes a SASE-FEL facility for soft X-ray within 100 m machine length. It has been funded in April 2001, aiming to generate first light in 2003 at VUV region, and ultimately 3.6 nm in water-window in 2005. This paper report design work SCSS.

1 SCSS PROJECT OVERVIEW

1.1 Site and Schedule

The SCSS has been funded in April 2001. It will be constructed at SPring-8 site supported by multi-laboratory collaboration including JASRI, JAERI, KEK and RIKEN. SCSS construction is scheduled to complete in 2004 and obtain FEL radiation at VUV region in 2005.

1.2 Why Do We Need Compact Machine and How?

One big problem in X-ray laser based on the SASE-FEL is its high machine cost. This is the reason why people design the X-ray FEL as a parasitic facility attached to an existing electron accelerator (LCLS uses the Two-mile Linac at SLAC), or as an integrated facility into a future large-scale machine such as TESLA linear collider. Therefore, chance to have X-ray FEL facility is quite limited and regionally localized.

However, if we can make construction cost of the X-ray FEL much lower than existing synchrotron light-sources based on the storage ring, each country or region can possess their machines in each local sides, and it will accelerate research in material science. To do this, the most important point is to make the machine size compact. The building cost will be lowered, as well as the machine itself becomes cheaper.

In the SCSS project, the following three key technologies realize the compact machine.

(1) In-vacuum short-period undulator.

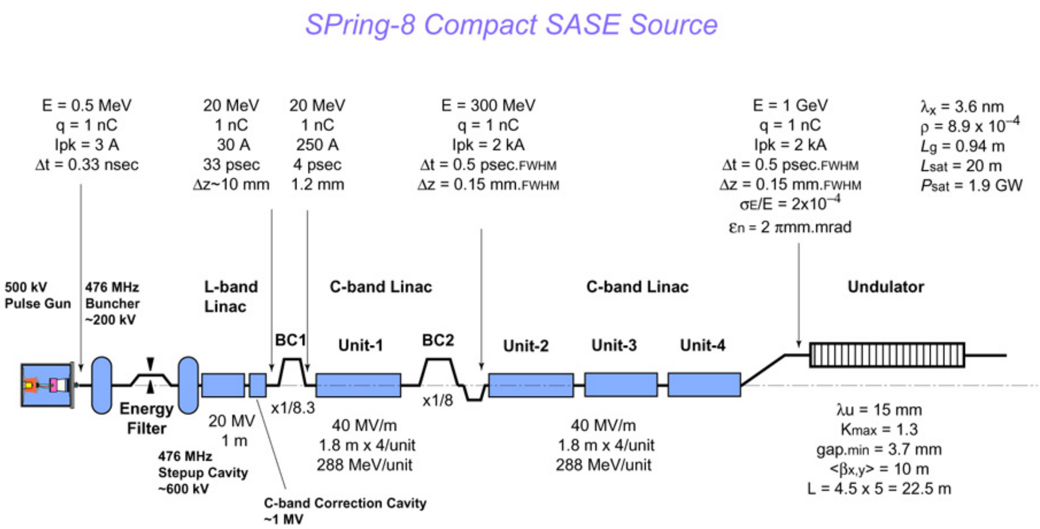


Fig.1 SCSS beam line layout. Total system length is about 80 m.

Table-1 SCSS parameters at 3.6 nm radiation wavelength.
Note that the bunch length is denoted by FWHM value.

bunch charge	Q	1	nC
normalized emittance	$\varepsilon_{nx,y}$	2	πmm.mrad
final electron energy	E	1	GeV
final rms energy spread	σ_δ	0.02	%
final FWHM bunch length	Δz	0.15	mm
	Δt	0.5	psec
peak current	I_{pk}	2	kA
undulator period	λ_u	15	mm
minimum gap	g	3.7	mm
maximum K-parameter	K	1.3	
undulator unit length	L_1	4.5	m
total undulator length		22.5	m
beta function	β	10	m
FEL parameter	ρ	8.9	x 10^{-4}
gain length	L_g	0.94	m
saturation length	L_{sat}	20	m
saturation power	P_{sat}	2.0	GW

This makes the undulator period shorter, thus the beam energy lower, as a result smaller the accelerator size. It also contributes to shorten the FEL gain length.

(2) High gradient C-band accelerator.

The accelerating gradient of 35 MV/m enables the main linac length being only 30 m to reach 1 GeV.

(3) Low emittance beam injector.

Low emittance beam injector based on thermionic single crystal CeB_6 cathode makes the FEL gain length and saturation shorter.

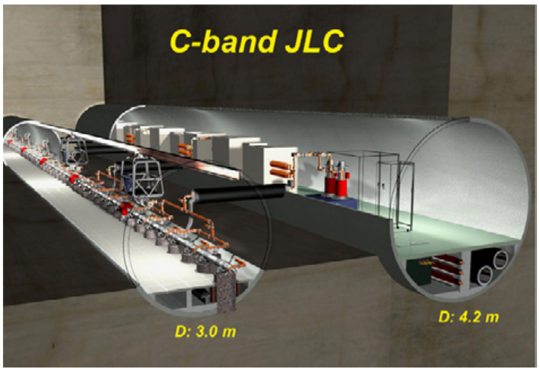


Fig. 3 C-band RF technology has been developed for 500 GeV e+e- Linear Collider project.

2 SCSS MACHINE

2.1 Machine Layout

Figure 1 shows the machine layout and Table-1 summarizes the machine parameters. SCSS consists of the low emittance electron injector, the C-band main linac, the undulator section for FEL interaction and the bunch compressors.

In order to saturate FEL at shortest wavelength in SCSS: λ_x =3.6 nm, we need a short bunch of 0.5 $psec._{FWHM}$, 2 kA, and 1 nC beam.

Note that, in this paper, we describe the bunch length in FWHM value rather than rms vale (σ_z). This is because in our system the longitudinal current profile is close to a square pulse.

2.2 Electron Injector

In the SCSS project, we chose a high-voltage pulse-gun with thermionic-cathode, instead of RF-Gun. As kwon in SASE-FEL theory, the quality of “internal” structure of bunched beam is important, such as the sliced emittance dominates the FEL gain. We believe a single crystal LaB_6 or CeB_6 cathode, whose surface becomes fairly flat in nano-meter scale after usage at high temperature, is suitable to produce such a high “internal” quality beam.

In the HV pulse gun, 3 Amp. with 300 nsec flat-top pulse beam is pulled out from a single-crystal CeB6 cathode of 3 mm diameter at 1450 deg.-C. The beam chopper cut the rising and falling parts of the pulse, then forms 2 nsec pulse. The 476 MHz pre-buncher adopts energy modulation of 400 kV peak-to-peak. The following energy filter cut the energy tail (top and bottom). After drifting 800 mm beam pipe, due to the velocity difference, electrons form a short bunch at the centre energy.

The step-up cavity and the L-band accelerator capture the single bunch and accelerate to 20 MeV, followed by the first bunch compressor (BC1).

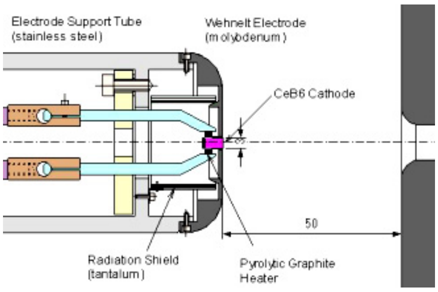


Fig. 2 Single crystal CeB_6 cathode.

2.3 Bunch Compressor BC1

In BC1, the bunch is compressed to 4 psec.$_{FWHM}$, and sent to C-band main linac. The short section of C-band accelerator right before the bunch compressor is prepared to compensate the curvature in L-band accelerator field to form linear energy slope on the bunch.

2.4 C-band Main Linac [2]

We use four units of the C-band accelerator system. Each unit is capable of accelerating beam 250 MeV, total four units provide 1 GeV beam. The C-band (5712 MHz) accelerator technology has been developed at KEK Japan as the main linac of the future 500 GeV e+e- Linear Collider project. Table-2 summarises results of the phase-I R&D on C-band during 1996~2000. The SCSS will perform a best string test of the main linac system for the Linear Collider project.

2.5 Bunch Compressor BC2

In BC2, the bunch is compressed to 0.5 psec.$_{FWHM}$. Since the coherent synchrotron radiation (CSR) effect dominates, we need careful design to minimize transverse emittance break due to CSR. We are currently working to find optimum design, including double chicane configuration.

2.6 Undulator [3]

After four units of the C-band accelerator, the beam is accelerated to 1 GeV. The bunch is accelerated not on the crest, but delayed phase to correct the residual energy slope used in BC2.

The undulator consists of five unit of 4.5 m long in-vacuum undulator, and the total active length is 22.5 m. This is longer than the estimated saturation length at the shortest wavelength. The expected saturation peak-power is about 2 GW.

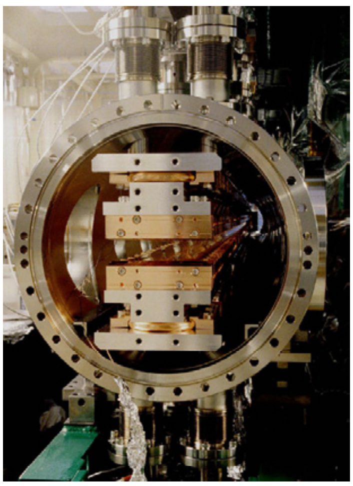


Fig. 4 Internal structure of the in-vacuum undulator.

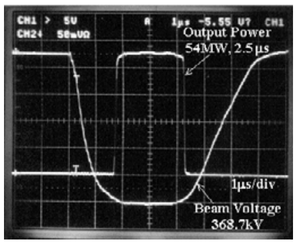
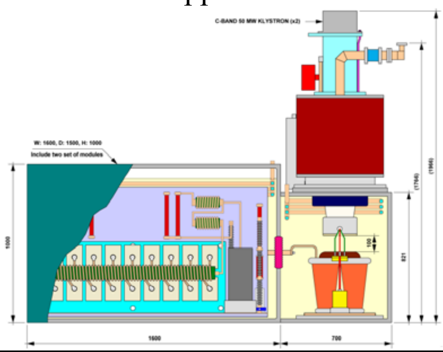
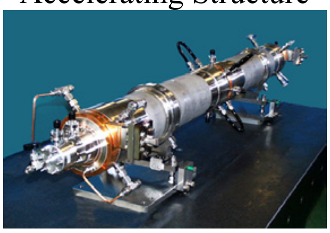
EFERENCES

[1] T. Shintake, “SPring-8 Compact SASE Source”, SPIE2001, San Diego, USA, June 2001.

[2] http:/c-band.kek.jp

[3] H. Kitamura, T. Bizen, T. Hara, X.Marechal, T. Seike and T. Tanaka, “Recent Developments of Insertion

Table-2 Phase-I R&D summary on C-band RF-system and application to SCSS.

Items	Phase-I R&D Target Achieved Results	SCSS Application (Phase-II)
Klystron 	Output 50 MW、Efficiency >45% Pulse width >2.5 μsec Pulse repetition 100 pps Focusing Power < 5 kW	Refine design details for the mass-production and reducing cost. PPM-klystron is an option.  Example of output power.
	All of No.1, 2, 3 tubes achieved 50 MW output, pulse width 2.5 μsec and 50 pps. No. 3 tube showed 47% power efficiency. Focusing power 4.6kW. Life test No.2, 3 > 5000 hours.	
Pulse Modulator Supply 	350 kV、2.5 μsec pulse generation, power efficiency >50%	Oil-filled closed design will be applied. 
	Smart Modulator, No. 1 Inverter HV power supply was firstly used in klystron modulator. Operation for klystron life-test was very successful. Power efficiency >52.4%	
RF Pulse Compressor 	Power gain >3.5、 Power efficiency >70%	Temperature stabilized design will be employed. Invar body with copper plating will provide better than one tenth phase-sensitivity on the temperature variation. High power test is scheduled in 2001.
	Cold Model Test (1997) Power Gain 3.25, Efficiency 65% Not yet performed the high-power test.	
Accelerating Structure 	Multi-bunch 1.6 nC, 80 bunch Acceleration gradient> 35 MV/m	Refine design details. Optimization for mass-production. Lowering cost. The multi-bunch option in SCSS will provide high average brightness.
	ASSET test at SLAC demonstrated damping performance of the choke-mode cavity.	
	Resolution ~ 25 nm (FFTB test) Position accuracy < 10 μm	