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The Hiroshima Synchrotron Radiation Center (HSRC)

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The history of HSRC is briefly sketched, going back to the early HiSOR project. The present status of this 0.7 GeV compact storage ring is described and an outline of the future of the facility is given in the context of western Japan.

Keywords: microtron; compact storage ring; beamline.

1. History

On 14 May 1997 the dedication ceremony of HSRC was held on the Higashi-Hiroshima campus, at the outcome of a 15 year long process. In 1982 a group of scientists from the Faculty of Science at Hiroshima University started a project, which they called HiSOR, for Hiroshima Synchrotron Orbital Radiation, having in mind a 1.5 GeV storage ring (Ohta, 1991). Joint research with KEK, launched in 1987, resulted in great progress in the design of this accelerator. In 1989 a chair for synchrotron radiation was created at Hiroshima University, but the facility itself was not yet approved.

In the meantime, there had been a shift of emphasis of the project, chiefly for two reasons. First, the design and construction of accelerators by industry had made great progress as a result of the development of light sources for X-ray lithography. In addition, in 1990 the SPring-8 facility, to be built in Nishi-Harima, only 210 km away from Higashi-Hiroshima, had been approved. This fact stressed the complementarity between high-energy accelerators and compact light sources and led to the conclusion that a compact synchrotron light source was more appropriate for the University than a 1.5 GeV medium-scale storage ring. This modification would result in a facility with complementary capabilities, aiming at the development of new fields opened by a compact synchrotron light source. This new concept was renamed the Hiroshima Synchrotron Radiation Center, keeping the name HiSOR for the ring itself. It was approved by the government after it had received a favourable rating from the Science Council, with funding sufficient to sustain a staff of about twelve people and to cover an output of 2880 h of light per annum.

2. Framework of the facility

The light source, the first beamlines, experimental stations and buildings were completed early in 1997, the first photons were observed shortly thereafter and useful light is expected to become available soon. An overview of the storage ring is given in Fig. 1, together with the first beamlines. In addition to sheltering the machine itself, the HSRC building, shown in Fig. 2, also provides 1500 square metres for office space (I) and 600 square metres for a preparation laboratory.

Although the scientific background of most members of the HSRC staff is solid-state or surface physics, special effort has been made in order for the HSRC to remain open to a broader field of synchrotron radiation uses, such as physical biochemists (Yamada *et al.*, 1997). Many scientists from other faculties and research centres at Hiroshima University, such as the Research Center for

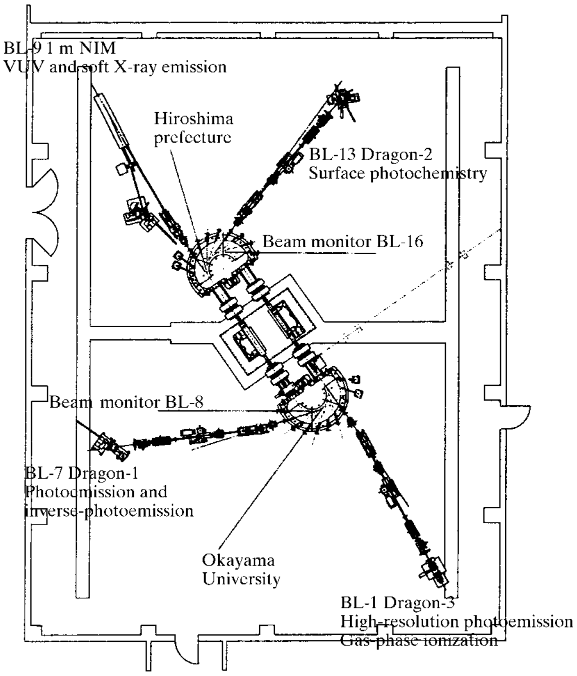

Figure 1
View of the storage ring, together with the first four beamlines. The injection channel is at the right-hand side of the figure.

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Table 1
Characteristics of HSRC microtron.

Output energy	150 MeV
Output current (peak minimum)	10 mA
Repetition rate	0.2–100 Hz
Energy dispersion	±0.1%
Magnetic field gradient (main M)	$0.14\ \mathrm{T\ m^{-1}}$
Reverse magnetic field strength	0.29 T
Energy gain per turn	6 MeV
RF frequency	2856 MHz
Wall loss (maximum)	1.5 MW
Injection energy	120 keV
Beam pulse width	0.2–2 µs
Emittance	0.5π mm mrad
Magnetic field strength (main M)	1.23 T
Pole gap (main M)	1.0 cm
Number of turns	25
Linac bore radius	1.0 cm
Electric field gradient	$15\ \mathrm{MeV\ m^{-1}}$
Beam loading (minimum)	2.0 MW

Table 2
Characteristics of HSRC storage ring.

Width of ring	3.1 m
Height of ring	1.8 m
Beam level	1.2 m
Circumference	22 m
Vacuum (no beam)	10^{-8} Pa
Energy at injection	150 MeV
Magnetic field at injection	0.6 T
Critical wavelength	1.42 nm
RF frequency	191 MHz
Harmonic number	14
Beam lifetime	>8 h at 200 mA
Photon beamports on bending sections	14 at 18° interval
Photon beamports on straight sections	2
Opening angle of beamports	20 mrad
Photon yield	1.2×10^{11} photons $\mathrm{s^{-1}\ mrad^{-2}}$ (5 keV, in 0.1% bandwidth, for 300 mA)
Length of ring	12 m
Total weight	130 ton
Orbit radius of curvature	0.87 m
Duration of injection	5 min
Vacuum (with beam)	10^{-7} Pa
Stored energy	700 MeV
Magnetic field at storage	2.7 T
Stored current (normal)	300 mA
RF voltage	220 kV
Beam emittance	0.4π mm mrad

Nanodevices and Systems and the Venture Business Laboratory, have been associated with this team. Together, these laboratories represent a manpower of about forty scientists.

The HSRC was conceived as a common facility for both research and education in the field of synchrotron radiation science. One of the primary aims is the promotion of original research by scientists and engineers from Hiroshima University and neighbouring universities and colleges, as well as cooperative research with public organizations and industry, especially local industry. Another role of the HSRC is to provide opportunities for international exchange through the promotion of cooperative research and the enrollment of foreign students.

Table 3
Parameters of insertion devices at HiSOR.

Linear undulator	
Number of periods	41
Period length (λ_u)	57 mm
Total length	2354.2 mm
Type of magnets	Nd–Fe–B (NEOMAX-44H)
Remanent field (B_r)	1.3 T
Gap distance	30–200 mm
Magnetic field	0.43 T
Helical undulator	
Number of periods	18
Period length (λ_u)	100 mm
Total length	1828.6 mm
Remanent field (B_r)	1.3 T
Polarization switching time	100 s (l⟷r)
Vertical/horizontal magnetic field	0.34/0.32 T
Type of magnets	Nd–Fe–B (NEOMAX-44H)
Gap distance	30–200 mm
Width of vertical field magnets	30 mm
Groove of vertical field magnets	11 (W) × 15 (D) mm
Width of horizontal field magnets	50 mm

3. Light source

Sumitomo Heavy Industries (SHI) developed a racetrack microtron for the injection system, based on a concept designed at the University of Wisconsin. Whereas a high repetition rate up to 100 Hz with a peak current of 10 mA is provided for the electron-beam utilization facility, injection to the storage ring will proceed at the more leisurely rate of 2 Hz. The characteristics of the microtron are listed in Table 1.

Recent progress in the manufacturing of high-field normal-conducting magnets at SHI made it possible to build a compact source with a rather short critical wavelength: the light delivered by the 2.7 T bending magnets has a critical wavelength of 1.42 nm. Were conventional magnets (1.2 T) to be used instead, an energy of 1.6 GeV would be needed to radiate the same power or 1.1 GeV to achieve the same critical wavelength. Furthermore, a

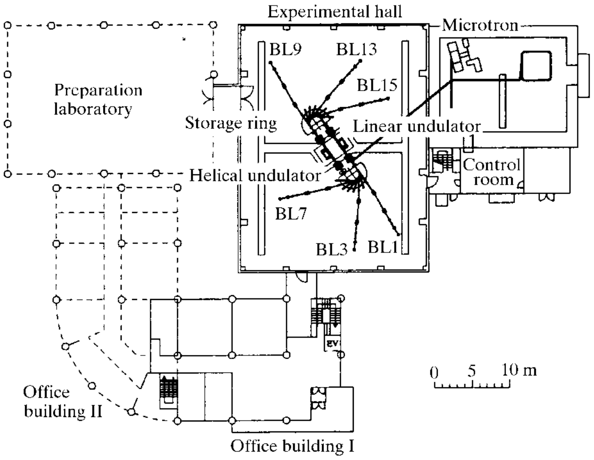

Figure 2
Layout of the laboratory. Right: microtron, small ring for parametric X-ray generation and control room. Centre: storage ring. Bottom: offices (to be completed in early 1998). Left: future plan for extension of the offices and preparation laboratory.

Table 4
Parameters of the first four monochromators.

Branch beamline (light source)	Type of monochromator R (m), $\alpha + \beta$ (°)	Grating groove density (lines mm^{-1})	Photon energy (eV)	Typical resolution ($E/\Delta E$)
BL1	Dragon-3 (grazing incidence)	2000	130–300	24000–8100
(linear undulator)	$R = 14.7$, $\alpha + \beta = 166$	1400	90–300	24000–5300
	$R = 5.9$, $\alpha + \beta = 144$	2400	26–110	59000–9500
BL7	Dragon-1 (grazing incidence)	1400	130–380	10000–3200
(bending magnet)	$R = 14.7$, $\alpha + \beta = 168.4$	700	65–190	16000–4600
	$R = 5.9$, $\alpha + \beta = 150.8$	1400	20–120	40000–5200
BL9	Normal incidence	1200	4–40	20000–2000
(helical undulator)	$R = 1$, $\alpha + \beta = 15$			
BL13	Dragon-2 (grazing incidence)	1000	340–1200	7900–2000
(bending magnet)	$R = 28.4$, $\alpha + \beta = 174$	500	170–760	7900–1500
	$R = 14.7$, $\alpha + \beta = 168.4$	700	60–300	19000–2700

protection wall around the ring is not required since the thick iron yoke of the magnets acts as a protective radiation shield. It therefore becomes possible to use the light rather close to the source and to work with higher flux densities than on more conventional rings. The photon flux from bending magnets and insertion devices is shown in Fig. 3; for comparison, we have also plotted the flux coming from bending magnets at UVSOR operated at 1.14 T and 0.75 GeV. One straight section of the ring will be occupied by a linear undulator and the other one by a helical undulator. A total of 2 × 7 beamports are available on the bending magnet. More details on the storage ring are given in Table 2.

Each of the straight sections of the ring accommodates an insertion device. The linear undulator, which can be tuned to emit radiation in the range 30–300 eV, has 41 magnetic periods, with a period length of 57 mm. The delivered intensity is three orders of magnitude higher than that from the bending magnets. The helical undulator has 18 periods with a period length of 100 mm and produces radiation with controlled ellipticity, from linear to circular, in the range 1–30 eV, according to the selected magnet array arrangement (Kimura *et al.*, 1996; Marechal *et al.*, 1995). Technical data concerning the insertion devices can be found in Table 3.

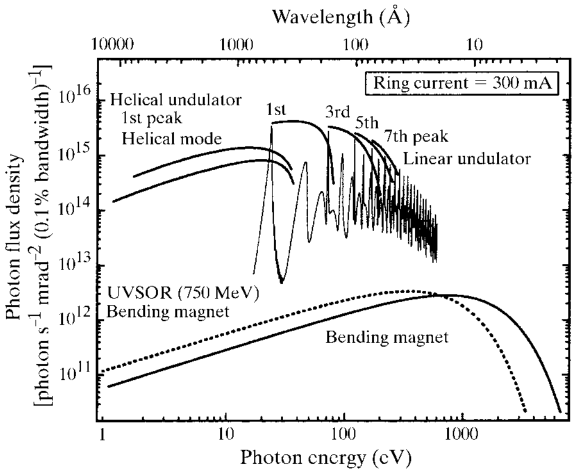

Figure 3
Density of flux at HiSOR as a function of photon energy.

Currently, electron beams of 270 mA have been accumulated at 700 MeV. The lifetime at 100 mA and 700 MeV is, unfortunately, still only 20 min due to an insufficient vacuum level. It has also been confirmed that electron beams of 30 mA and 700 MeV circulate stably when the insertion devices are operated over a wide range of gap distances.

4. Beamlines and scientific program

Four beamlines will be operational from the beginning, two on the bending magnets (BM), and one on each undulator (U) (Table 4); these beamlines consist of three Dragon-type monochromators and one normal-incidence monochromator. The next four beamlines are scheduled for the following year and include one grazing-incidence monochromator, one normal-incidence monochromator and two double-crystal monochromators.

At the beginning, the first four beamlines and the microtron will be devoted to photochemical surface reactions induced by core electron excitation (BM) (Tinone *et al.*, 1996), photoemission and inverse photoemission spectroscopies of solids (BM) (Mimura *et al.*, 1996), photoionization and ionic photofragmentation of molecules (U) (Ibuki *et al.*, 1996), high-resolution and low-temperature photoemission spectroscopy of *d,f* electron systems (U) (Shimada *et al.*, 1996), UV and soft X-ray emission spectroscopy of solids (U) (Sato *et al.*, 1997), and generation of parametric X-rays at 14.4 and 33.2 keV using relativistic electrons (Microtron) (Endo *et al.*, 1995).

The following experiments are scheduled on the next four beamlines: circular dichroism of biopolymers (BM), XAFS on solid surfaces (BM), VUV photo-absorption and fluorescence studies of molecular complexes and clusters (BM), and lattice distortion associated with phase transition of solids (BM).

The radiation from the bending magnet is devoted to experiments which require high photon flux rather than energy resolution or to experiments based on specific observation systems. On the other hand, the radiation from insertion devices is specially oriented towards experiments which need extremely high energy resolution or quite high photon flux. For some well defined projects, almost unrestricted access to the synchrotron will be provided.

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