HiSOR

ACTIVITY REPORT

2020

Hiroshima Synchrotron Radiation Center, HiSOR
Hiroshima University

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Preface

The Hiroshima Synchrotron Radiation Center was inaugurated in 1996, as part of the academic policies of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. A compact 700MeV electron-storage ring, called HiSOR (this center is often referred to as HiSOR), produces synchrotron radiation in the range of ultraviolet and soft x-ray range. The mission of HiSOR is to promote advanced research in the field of condensed matter physics including interdisciplinary fields using synchrotron radiation, as well as to develop human resources in the international research environment established inside the national university. HiSOR has been authorized as a "Joint Usage / Research Center" by the MEXT since FY2010.

In FY2020, Dr. Shiv Kumar has been appointed as an Assistant Professor to promote the high-resolution ARPES study of topological materials. Dr. Hiroshi Miyauchi from KEK has joined Prof. Katoh's group to develop vacuum systems for a compact storage ring.

Due to the COVID-19 pandemic, collaborators outside the university could not come most of the time. Therefore, we canceled the call for proposals (type G) for the 2020 period B (Sep. 1, 2020 - Mar. 31, 2021). The number of accepted proposals was reduced to 78 in total (130 proposals in FY2019), including 22 overseas proposals. Our international users could not come from early 2020 till now. Our staff members have done 16 proposals on behalf of international collaborators.

Even in the difficult situation, we have published 59 refereed papers in 2020, which exceeds the previous year's 42. About 59% of the published papers are written by international collaboration. The ratio of the top10% paper (highly cited papers in the SCI-indexed journals) becomes 13% for the period 2016-2020 (3rd mid-term objective period), indicating a quality of the published papers.

We hosted several online events; KEK-day (Dec. 19, 2020, 134 participants including 65 students from senior high schools and national technical colleges), The 34th annual joint symposium of the Japanese Society of Synchrotron Radiation Research (Jan. 8-10, 2021, 587 participants), and the 25th Hiroshima International Symposium on Synchrotron Radiation (71 participants, 11 overseas participants). To introduce our facility to junior and senior high students under the pandemic situation, we have developed content using virtual reality (VR) devices. We have sent 16 VR devices to the Hasumi Junior High in Shimane prefecture, and hold an online VR tour of the facility.

In closing, I would like to thank all the staff members for their great efforts to operate HiSOR and to maintain and advance experimental stations. I also want to thank our students and collaborators for their excellent scientific achievements, making full use of our facilities. Finally, I deeply appreciate the continued supports of Hiroshima University and the MEXT.

July 2021

Kenya Shimada

Director of Hiroshima Synchrotron Radiation Center

Table of Contents

Tabie of Contents

Preface

Current Status of HiSOR

Research Activities

—Accelerator Studies—

—Synchrotron Radiation Experiments—

Appendices

Current Status of HiSOR

Status of the HiSOR storage ring

1. Introduction

The HiSOR is a synchrotron radiation (SR) source of Hiroshima Synchrotron Radiation Center, Hiroshima University, established in 1996. It is a compact racetrack-type storage ring having 21.95 m circumference and 700MeV electron energy. It has two 180-degree normal-conducting bending magnets which generate a strong magnetic field of 2.7 T. Due to this compact configuration, the natural emittance of the electron beam is 400 nm-rad, which is rather large compared with other synchrotron light sources. It has two straight sections, where two insertion devices, a linear undulator and an APPLE-II undulator, are operational. The most outstanding advantage of the facility lies in good combination with state-of-the-art beamlines (BL's) for high-resolution photoelectron spectroscopy in the photon energy ranges between VUV and soft X-ray. Moreover, the high field bending magnets produce synchrotron radiation in wide spectral range including tender X-rays, which can be powerful probes in various research fields.

The principal parameters of HiSOR are shown in Table 1. Major parameters of these undulators are listed in Table 2. The photon energy spectra of the SR from HiSOR are shown in Figure 1.

Table 1: Main parameters of the HiSOR Storage ring.

Circumference	21.95 m
Type	Racetrack
Bending radius	0.87 m
Beam energy at Injection	150 MeV
at Storage	700 MeV
Magnetic field at Injection	0.6 T
at Storage	2.7 T
Injector	150 MeV Racetrack Microtron
Betatron tune (ν_x, ν_y)	(1.72, 1.84)
RF frequency	191.244 MHz
Harmonic number	14
RF voltage	200 kV
Stored current (nominal)	300 mA
Natural emittance	400π nmrad
Beam life time	~10 hours@200 mA
Critical wavelength	1.42 nm
Photon intensity (5 keV)	1.2×10^{11} /sec/mr^2/0.1%b.w./300mA

Table 2: Main parameters of the undulators.

Linear undulator (BL-1)	
Total length	2354.2 mm
Periodic length λu	57 mm
Periodic number	41
Pole gap	30-200 mm
Maximum magnetic field	0.41 T
Magnetic material	Nd-Fe-B (NEOMAX-44H)
Quasi-Periodic APPLE-II undulator (BL-9A,B)	
Total length	1845 mm
Periodic length λu	78 mm
Periodic number	23
Pole gap	23-200 mm
Maximum magnetic field	0.86 T (horizontal linear mode)
	0.59 T (vertical linear mode)
	0.50 T (helical mode)
Magnetic material	Nd-Fe-B (NEOMAX-46H)

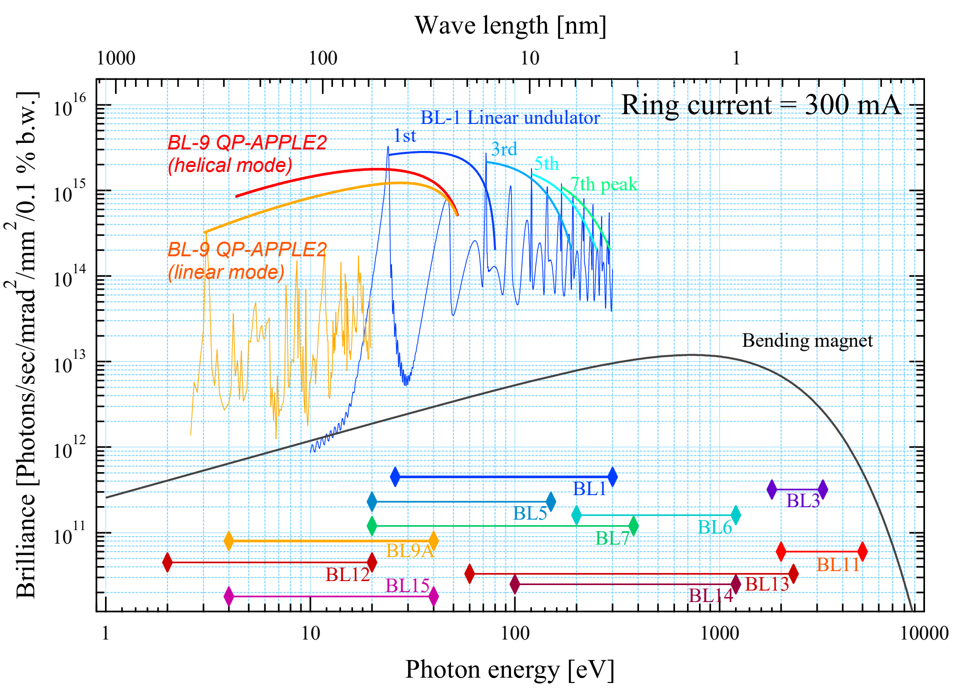

Figure 1: Photon energy spectra of the SR from HiSOR.

2. Operation status in FY 2020

The ring is operated for users from Tuesday to Friday. Figure 2 shows an example of typical users operation for one day. Beam injection for HiSOR is executed twice a day, at around 9:00 and 14:30. The beam injection is normally completed within 30 minutes. The filling beam current is about 300mA. Machine is operated for machine conditionings and studies on Monday.

Figure 3 shows monthly operation time of HiSOR storage ring in FY 2020. HiSOR regularly has a long-term shutdown period for maintenance works in every summer. However, in 2020, because the planned electricity outage was set in the middle of November, the shutdown was shifted to November. In addition, because of the COVID-19 infections, the operation was canceled in May. The total user time of FY2020 achieved 1370 hours.

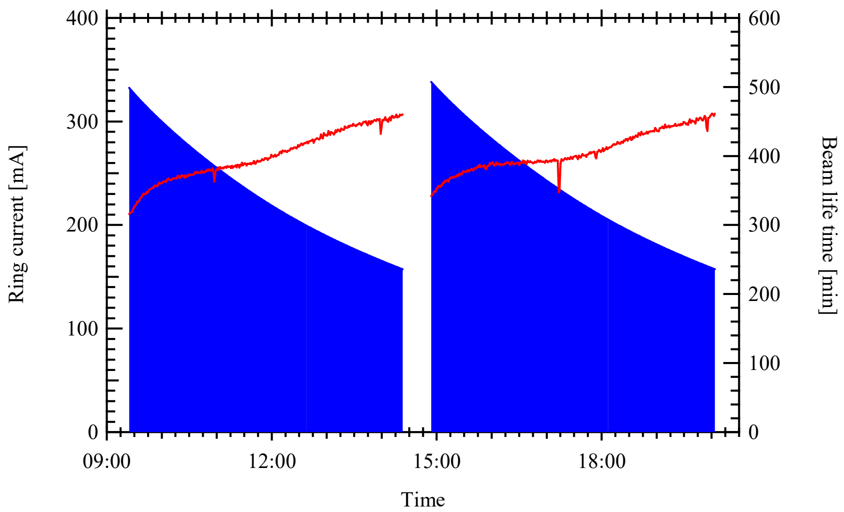

Figure 2: Typical daily operation status.

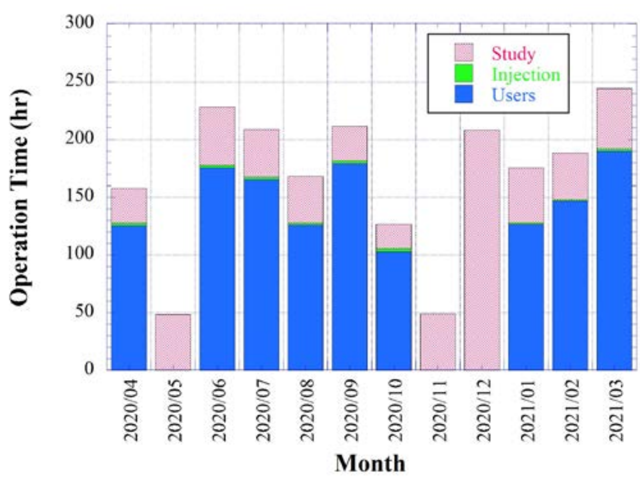

Figure 3: Monthly operation time in FY 2020.

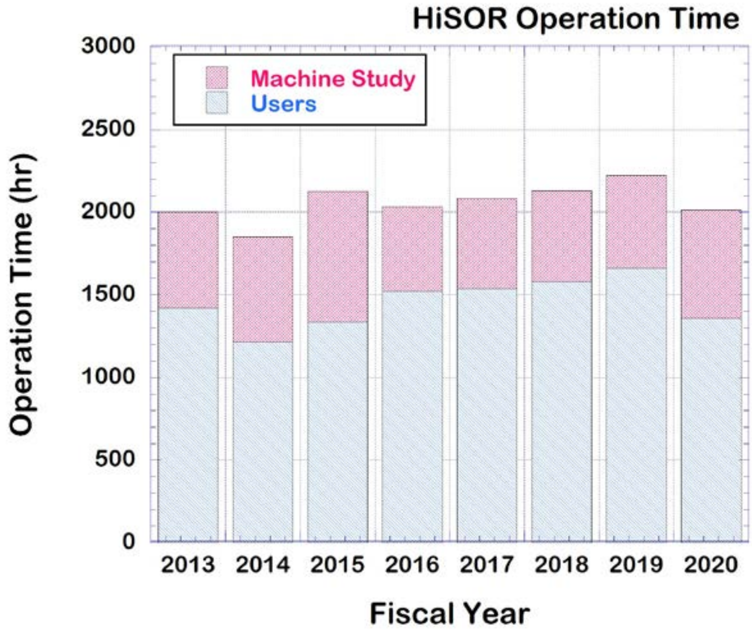

Figure 4: Operation time in FY 2013-2020.

Beamlines

A total of 13 beamlines has been constructed so far; three normal-incidence monochromators, seven grazing-incidence monochromators, two double crystal monochromators and apparatus for white beam irradiation (Fig. 1). Table 1 lists the beamlines at present together with the main subject, energy range and monochromators.

Table 1: List of Beamlines

Beamline	Source	Monochromator	Subject	Energy range (eV)	Status
BL-1	LU	GIM	Polarization dependent high-resolution ARPES	22-300	In use
BL-3	BM	DCM	Surface XAFS	1800-3200	In use
BL-4	BM		White beam irradiation		Closed
BL-5	BM	GIM	ARPES and PEEM	40-220	In use
BL-6	BM	GIM	Gas-phase photochemistry	200-1200	In use
BL-7	BM	GIM	ARPES	20-380	In use
BL-8	BM		Beam diagnosis		In use
BL-9A	HU/LU	NIM		5-35	In use
BL-9B	HU/LU	GIM	High-resolution spin-resolved ARPES	16-300	In use
BL-11	BM	DCM	XAFS	2000-5000	In use
BL-12	BM	NIM	VUV-CD of biomaterials	2-10	In use
BL-13	BM	GIM	Surface photochemistry	60-1200	In use
BL-14	BM	GIM	Soft-XMCD of nano-materials	400-1200	In use
BL-15	BM	NIM	VUV-CD of biomaterials	4-40	Closed
BL-16	BM		Beam profile monitor		In use

At present, nine beamlines BL1, BL3, BL6, B7, BL9A, BL9B, BL11, BL12, BL13 and BL14 are opened for users. Furthermore, three offline systems, resonant inverse photoemission spectrometer (RIPES), low-temperature scanning tunneling microscope (LT-STM) system, high-resolution angle-resolved photoemission spectrometer using ultraviolet laser (Laser ARPES) are in operation (Fig. 2).

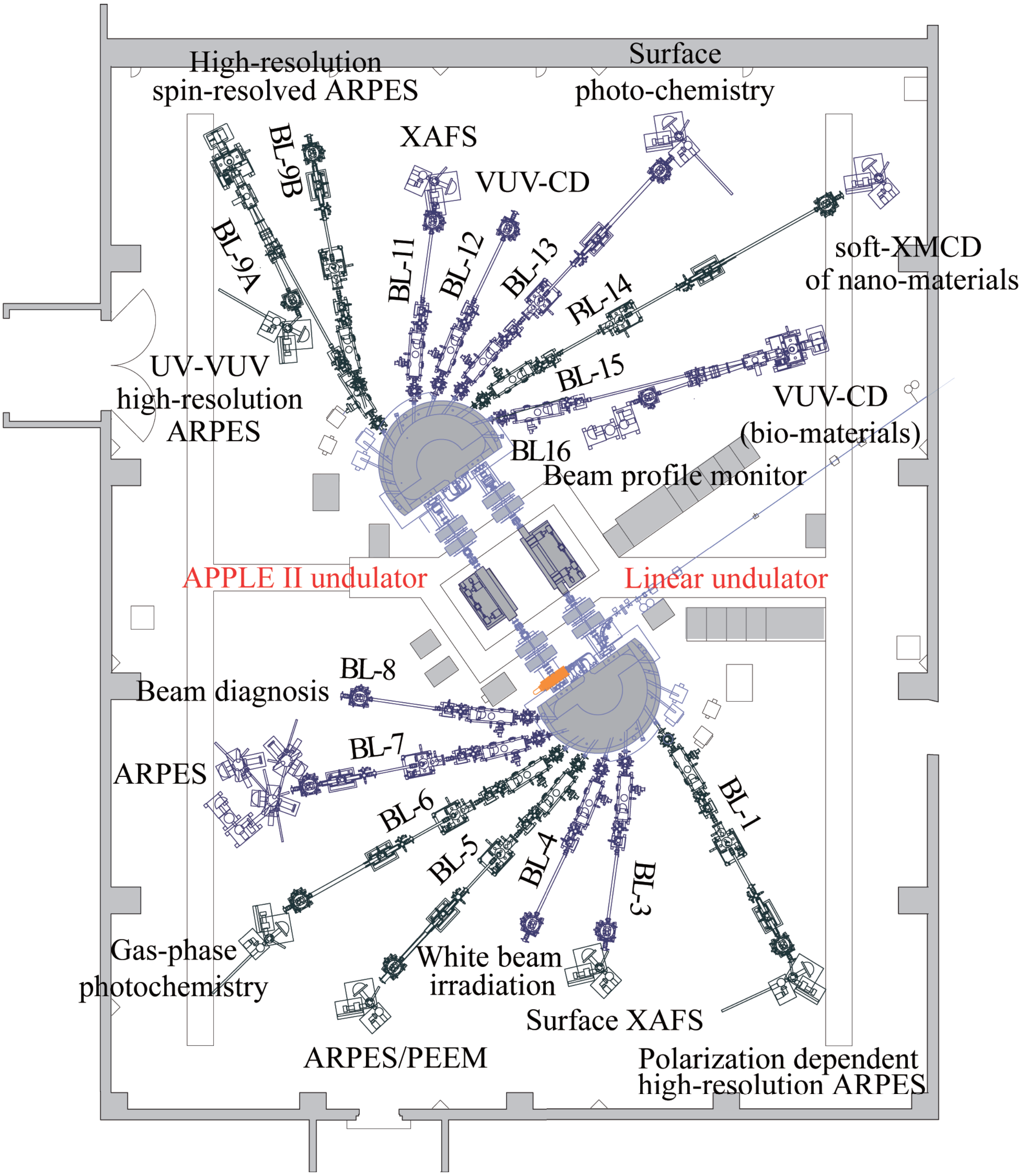

Fig. 1: Schematic view of the experimental hall.

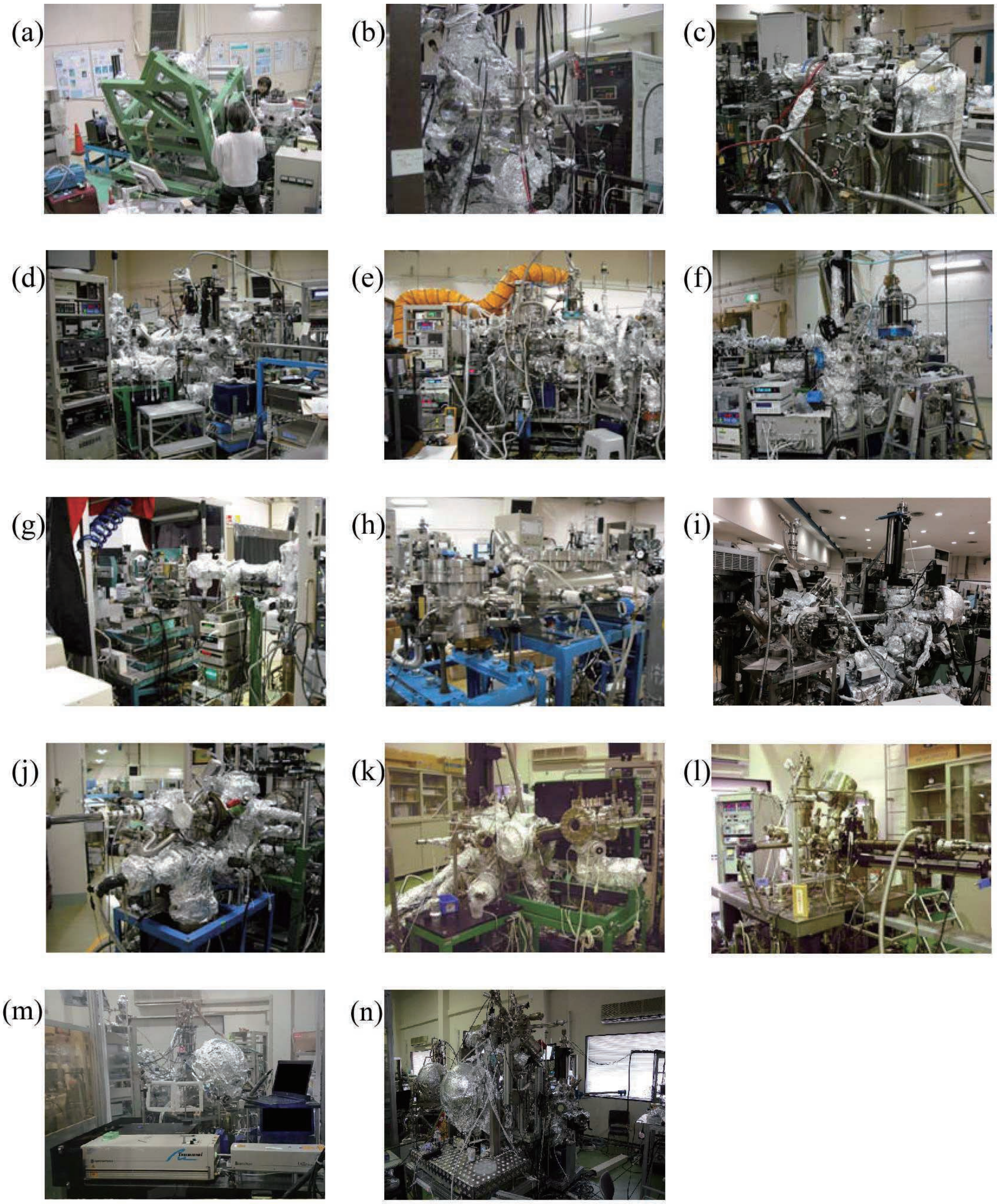

Fig. 2: Experimental stations on the beamline and offline: (a) BL-1, (b) BL-3, (c) BL-6, (d) BL-7, (e) BL-9A, (f) BL-9B, (g) BL-11, (h) BL-12, (i) BL-13, (j) BL-14, (k) RIPES (offline), (l) LT-STM (offline), (m) Laser ARPES (offline), (n) Laser spin-ARPES (offline).

Research Activities

– Accelerator Studies –

Developments of Virtual Reality Contents for Accelerator Research and Educations

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Keywords: Accelerator, Virtual Reality, Facility Tour.

The synchrotron light source, HiSOR, in Hiroshima University is compact and of low energy. The accelerator complex consists of an injector, 150 MeV microtron, and a 700 MeV storage ring. The ring has two undulators and 14 synchrotron radiation beamlines are operational. Because of its low energy, the ring is not constructed in a tunnel. Therefore, the visitors can see the accelerator and the beamlines directly. This is in contrast with large facilities, where the accelerators are in tunnels, and is beneficial to learn about the accelerators and synchrotron radiation instrumentation. Indeed, we accept many visitors, particularly from junior high schools and high schools every year. However, in 2020, because of the COVIT-19 pandemic, we could not accept their visits.

There are many examples of publishing ordinary photos and introductory videos of facilities on the WEB. However, there were only a few examples of publishing contents using virtual reality (VR), such as Material and Life Science Experimental Facility (MLF) in JPARC [1]. We think that the important factor that enhances the educational effect in facility tours is the sense of presence. When visiting large-scale research facilities like synchrotron light sources, the realism of being able to experience their scales is a major attraction. The VR technology that makes this possible will be widely used in the future. Fortunately, in recent years, the price of VR viewing devices has fallen, and it is expected that their use will expand rapidly soon.

Under such a circumstance, we started developing a VR content of HiSOR, aiming to experience producing VR contents and to seek the possible applications of the VR technologies in the accelerator research and education. We prepared an omnidirectional (360 degree) camera [2] and a tripod. We took 360 degree photographs at many places in the experimental hall of HiSOR, which would be the standing point of the audience in the VR facility tour. These photographs were combined into a VR content by using a software [3]. To determine the photograph spot, we were careful that one point could be seen from the neighboring ones (FIG. 1). Also, we were careful about keeping the height of the camera at about 170 cm from the floor, which would give a natural feeling about the line of sight. By using the software, we put some panels in the contents which explain the accelerators and the experimental apparatus. Also, we put a map at the entrance of the experimental hall.

We found that the VR contents are not only a simple alternative of real site visiting. It is capable of giving us a view which is normally impossible to see. For example, usually we cannot climb up the bending magnets of the accelerator. However, it is easy to get a view from such a place by using a omnidirectional camera (FIG. 2). We found that this is very instructive to understand how the electron beam is circulating and how the synchrotron radiation is extracted from the accelerator. In case of HiSOR, the visitors can see the accelerators directly. However, normally, high energy accelerators are constructed in a tunnel. Therefore, the visitors cannot see it directly even when they visited the facility. By using the VR technology, they can experience the facility tour to see the inside of the tunnel even when the accelerator is in operation.

As a prospect, we think that developments towards augmented reality (AR) will be the next step, in which the real pictures and computer graphics are mixed. In case of accelerator research and education, it is important to show what happens inside of the apparatus. It should be very instructive to understand the principle of accelerators and synchrotron light sources, if we could show how the electron beam is running and how the synchrotron radiation is generated and extracted.

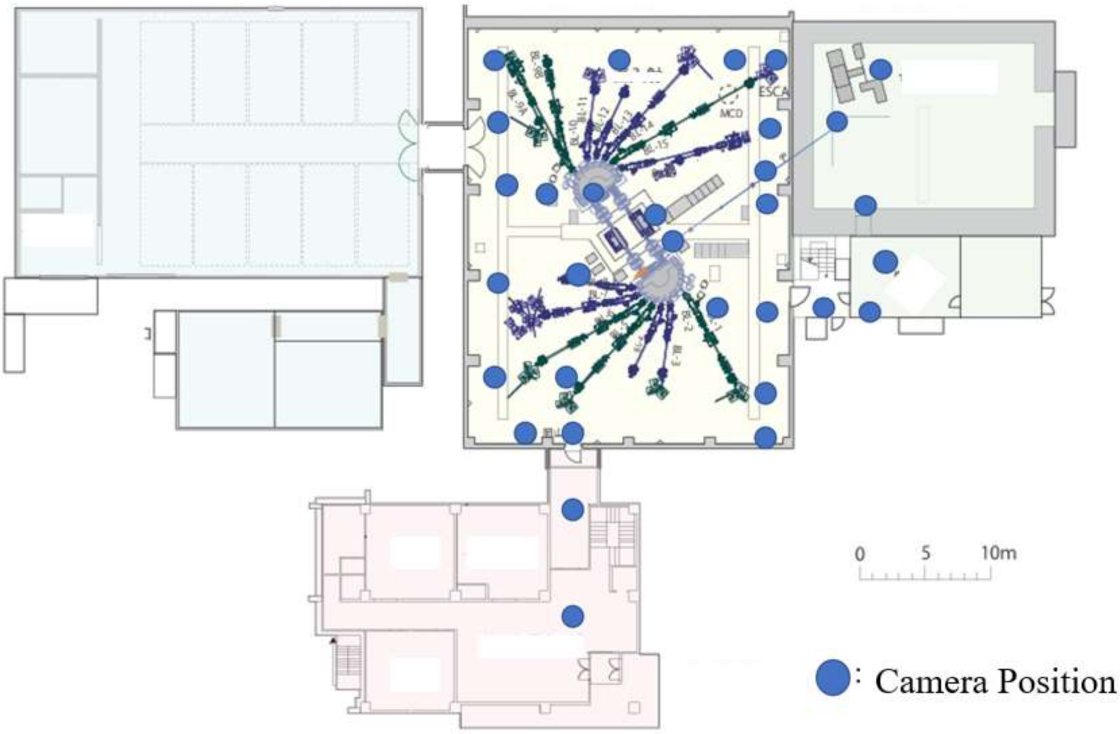

FIGURE 1. Camera positions in the facility along a route of the VR facility tour.

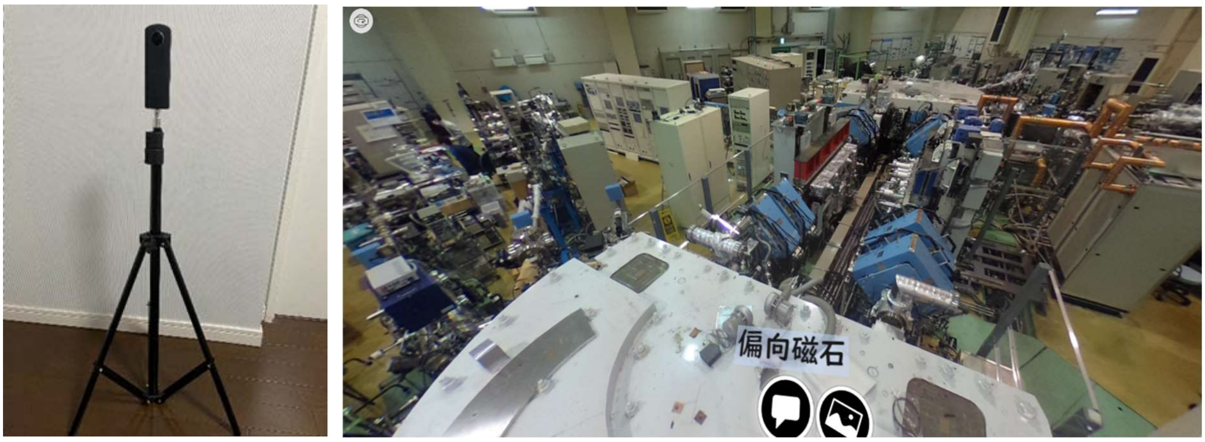

FIGURE 2. Ominidirectional Camera with tripod (left) and a view from the top of a bending magnet (right).

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Design Study on a Compact Storage Ring Light Source with Superconducting Bending Magnets

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Keywords: Storage Ring, Superconducting Magnet.

HiSOR, the synchrotron light source in Hiroshima University, is compact and low energy. It has two straight sections and is capable of producing high-intensity light in the vacuum ultraviolet region from two undulators. Moreover, two bending magnets has high field strength of 2.7 T, although they are normal conducting magnets. These magnets are capable of producing synchrotron radiation in a wide range including tender X-rays even with the low electron energy of HiSOR, which is 700MeV. Since no major modifications have been made since its construction, HiSOR is very stably operated in these years. On the other hand, after the 25 year operation since the construction, the hardware is being aged and its competitiveness in terms of light source performance are being lowered among the newly constructed light sources over the world. Some of the light sources in Japan, such as Photon Factory [1] or UVSOR [2], have been upgraded with some major modifications of hardware. SPring-8 also has an upgrade plan [3]. In case of HiSOR, it was designed and manufactured by a single company. It has a rational design without redundancy. This design concept makes it difficult to make a major modification to improve the performance or introduce new technologies to the present machine. Therefore, we have been designing a completely new ring for the future plan of the facility [4]. The design studies in the past have been focusing on achieving higher brightness in the vacuum ultraviolet range by reducing the emittance. In this study, we have investigated another direction, in which the wide spectral range up to the tender X-rays is achieved.

To produce X-rays at a low energy synchrotron light source, we have to utilize high field magnets. A superconducting magnet is most favorable. However, it had been widely considered that the operation and the maintenance of superconducting magnets are troublesome. The reason is that such devices are normally cooled by liquid helium and needs a helium refrigerator. However, in these years, in some synchrotron light sources, superconducting magnets directly cooled by refrigerators without using liquid helium [5, 6].

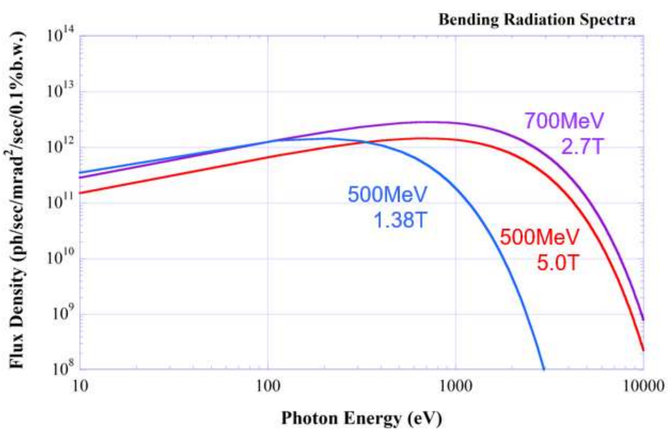

FIGURE 1. Synchrotron radiation spectra from bending magnets. That of the present HiSOR is 700MeV-2.7T. That of the new ring is 500MeV-5T (superconducting) and 500-1.38T (normal conducting).

The typical field strength of such superconducting magnets is 5T. The synchrotron radiation spectra from normal and superconducting bending magnets are compared in FIG.1. It can be seen that the 5T superconducting bending magnet in the 500MeV storage ring can cover almost similar spectral range as the bending magnets of the present HiSOR, whose electron energy is 700MeV.

Based on this result, we have designed a small racetrack-shaped ring consisting of two triple-bend cells with 180 degree bending angle for each. The bending magnet in the center of the triple-bend cell is a hybrid type that combines a superconducting and two normal conducting magnets. Here we assumed to use similar superconduncting magnet which has been stably operated at Aichi synchrotron [6]. The electron energy is reduced from the present value of 700MeV to 500MeV while ensuring the same wide bandwidth as the current high field normal conducting magnets. This electron energy reduction may be beneficial to construct the full energy injector for the future top-up operation. The ring has two long straight sections where two undulators, a septum magnet for beam injection and the RF cavity will be installed. The layout of the ring is shown in FIG. 2. The circumference is about 28m and the emittance is about 80nm. The electron energy is 500MeV.

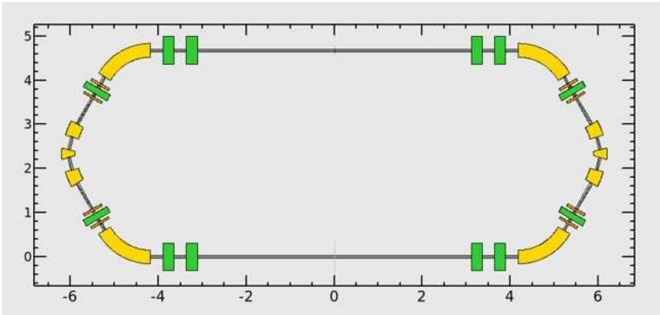

FIGURE 1. The layout of a compact storage ring with two superconducting bending magnets. The lattice consists of two triple-bend cells. The bending magnet of the center of the cells is hybrid, which consists of a superconducting bending magnet and two normal conducting bending magnets on both sides.

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