

HiSOR ACTIVITY REPORT

2017

Hiroshima Synchrotron Radiation Center, HiSOR Hiroshima University

Edited by Y. Izumi

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Preface

The Hiroshima synchrotron radiation center is the only one synchrotron radiation facility attached to a national university in Japan. It was established in 1996, as part of the academic policies of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). A compact 700MeV electron-storage ring, called HiSOR (this center is often referred as HiSOR), produces synchrotron radiation in the ultraviolet and soft x-ray range. The mission of the center 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 making the most of the international research environment in this center.

In 2010, the center was authorized as a "Joint Usage / Research Center" by the MEXT. In 2016, the authorization was extended for next 6 years with the grade "A" in the term-end evaluation in 2015. To prepare for the mid-term evaluation in FY2018, we have asked assessments of the scientific achievements to the International Review Committee chaired by Prof. Ingolf Lindau (Stanford University), and assessments of the activities as the Joint Usage/Research Center to the External Review Committee chaired by Prof. Hidetoshi Fukuyama (Tokyo University of Science). The review reports clearly outlined the present status of the center, and included many constructive and helpful recommendations for our future directions.

This fiscal year, Dr. Baojie Feng joined the center as an assistant professor and actively promoted high-resolution ARPES studies on topological materials and *in situ* grown novel thin films. Prof. Andrés F. Santander-Syro from the Université de Paris-Sud stayed 6 months as a visiting professor to promote international collaborative works on the two-dimensional electron gas on oxide surfaces and some topological materials. We also hosted the international workshop on strong correlations and angle-resolved photoemission spectroscopy (CORPES17) which was held in July, 2017. 117 participants from 20 countries attended the workshop and actively discussed the latest scientific results.

In FY2017, 221 researchers including undergraduate and graduate students conducted 131 proposals including 30 proposals from outside Japan. Detailed scientific results are reported in this volume.

In closing, I would like to thank all of 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 by Hiroshima University and the MEXT.



July 2018

Kenya Shimada

Kenya Shimada Director of Hiroshima Synchrotron Radiation Center

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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 its natural emittance of 400π nmrad is rather large compared with those of the other medium to large storage rings. 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. The principal parameters of HiSOR are shown in Table 1.

Table 1: Main parai	Table 1: Main parameters of the HiSOR Storage ring.	
Circumference	21.95 m	
Туре	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 (v_x , v_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 1: Main parameters of the HiSOR Storage ring.

Fig. 1 shows an example of typical one-day operation. Beam injection for HiSOR is executed twice a day, at around 9:00 and 14:30.



Fig. 1: Typical daily operation status.

HiSOR has two 180-deg. Normal-conducting bending magnets which generate a strong magnetic field of 2.7 T. This storage ring is equipped with two insertion devices, a linear undulator and a quasi-periodic APPLE-II undulator which replaced to the previous helical undulator in summer 2012. Major parameters of these undulators are listed in Table 2. The photon energy spectra of the SR from HiSOR are shown in Fig. 2.

fulle 2. Multi parameters of the anadiators.	
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)

Table 2: Main parameters of the undulators.



Fig. 2: Photon energy spectra of the SR from HiSOR.

2. Operation status in FY 2017

Fig. 3 shows monthly operation time of HiSOR storage ring in FY 2017. HiSOR has a long term cease period to have routine inspections in summer every year. The total user time of FY2017 achieved 1519 hours. Fig. 4 shows bar graph of total operation days in each fiscal year. It shows that days for user run in FY2016 was recovered those before occurring the trouble on vacuum (see "HiSOR Activity Report 2014" in detail). Operation times of the storage ring and the Microtron from FY 2008 to FY 2017 are shown in Fig. 5.

Most remarkable thing in the maintenance of the storage ring is that we have started to replace the microwave amplifier for the accelerating cavity from that using vacuum tubes to solid-state one. Comparing with the vacuum tube, in general, the solid-state amplifier has a good stability and reproducibility for a long term operation and it has a high cost performance for the maintenance because it consists of bundling small amplifier modules. The commissioning of the solid-state amplifier was finished in early 2017 and it was used in normal operation. Therefore, the operation times of storage ring were about the same level as in the FY 2016.







Fig. 4: Operation days of HiSOR storage ring.



Fig. 5: Annual operation time of Storage ring and Microtron.

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.

Beamline	Source	Monochromator	Subject	Energy range (eV)	Status
BL-1	LU	GIM	Polarization dependent	22-300	In use
			high-resolution ARPES		
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	16-300	In use
			spin-resolved ARPES		
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	400-1200	In use
			nano-materials		
BL-15	BM	NIM	VUV-CD of biomaterials	4-40	Closed
BL-16	BM		Beam profile monitor		In use

Table 1: List of Beamlines

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 -

Construction of a Two-Photon Interferometry Measurement System for the Evaluation of the Bunch Length in the Electron Storage Ring

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Keywords: electron bunch length, two-photon interferometry.

A radio frequency (RF) accelerating cavity is installed in the storage ring, and when electrons passing through the cavity at a specific phase are well balanced between acceleration energy and emission energy as the synchrotron radiation, the storage ring can keep the electrons turning steadily inside. The group of electrons formed around the stable phase is called "bunch".

In this research, we aim to evaluate the bunch length in the storage ring of HiSOR, and have constructed a two-photon interference measurement system. We will try the two-photon interference experiment of synchrotron radiation by making the Michelson's type interferometer with prisms and mirrors. Since photomultiplier tubes are used for photon counting, a new high voltage power supply unit is fabricated and calibrated. For the sake of comparison, we also consider the electron bunch length measurement by the streak camera.

At present, an interferometer is constructed and the alignment with a He-Ne laser is performed. A schematic illustration of the interferometer is shown in the Fig.1. As the result of the alignment, we confirm the interference fringes. In the future research, it is necessary to make the two beams into parallel waves that the interference fringes are not observed. Also, since the photomultiplier tube have to work at the photon counting mode for the synchrotron radiation, it is necessary to construct a reliable shading system of stray light. After the light shielding system is constructed and the alignment of the two beams are completed, we will perform the two-photon interferometry with the synchrotron radiation.



FIGURE 1. A schematic illustration of interferometer. (a): He-Ne laser. (b): Lens. (c): Mirror. (d): Beam splitter cube. (e): Prism mirror. (f): Photomultiplier tube. (g): Linear stage.

Research Activities

- Instrumental Developments -

Ultimate spatial resolution in LASER based μ – *ARPES*

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Keywords: Angle Resolved Photoelectron Spectroscopy, Photoemission Microscopy, domain twinning

We report on the performance of the μ -LaserARPES machine, which has been recently commissioned at the Hiroshima Synchrotron Radiation Center (HiSOR) [1]. We present a summary of measurements of the twinned domain structure within the nematic phase of FeSe [2]. These measurements highlight the potential of the μ -LaserARPES method to not only produce high energy and angle resolution [3] but also profit from high spatial resolution, compared to conventional ARPES systems.

Using the combination of the focused light spot (3-5 μ m) and the precise movement of the "nano-stage" manipulator motion control, it is possible to obtain ARPES one-shot measurement on the sample surface with extremely high resolution and reproducibility in space. In Figure 1 a) such an example of a one-shot ARPES spectrum is presented. If the total intensity regardless of emission angle and kinetic energy is integrated a quasi-topographical map can be obtained (Figure 1 b). The intensity in this map is a convolution of several effects. Among which are the real topography and sample orientation, sample cleanliness and order, as well as matrix elements and local electric fields deflecting the very low energy photoelectrons. Nonetheless, this type of map was found to be able to identify regions of high spatial homogeneity on the sample for analysis. In the present case however, a more sophisticated analysis has to be performed to extract meaningful information from the current dataset.



FIGURE 1: a) Example ARPES spectrum taken at each point of the xz-mapping. Four Regions of interest are defined to correspond to the inner and outer hole pockets crossing the Fermilevel. b) Total ARPES intensity c) Using ratio of hole band intensity to judge regions of constant orientations. Only area within the dashed line is considered to be cut along Γ -point. d) Determining domain population by comparing intensity ratio from both hole pockets. Points A and B correspond to highest density of either of the twinned domains.

In particular one has to define a "quality parameter" which distinguishes regions of different sample orientation or photoelectron emission angles. This can be sufficiently done, by defining regions of interest (ROIs) as marked in Figure 1 a), and quantitatively reevaluating the previously obtained data. In the case of FeSe it is assumed based on mechanical [4] and polarization based detwinning [5] as well as tight binding calculations [6] that the two outermost bands 1R and 1L represent emission from one of the twinned domains, while the two innermost bands 2R and 2L represent contribution from the other domain. Using this assumption, regions of constant orientation are defined as having a identical 1L/1R ratio (Figure 1 c). Using this assumption regions that differ in orientation can be excluded from further analysis.

Again, using the already obtained data, we now calculate the "population density" corresponding to domain population (1R/2L ratio). This ratio is plotted (Figure 1 d) and two points (A and B) are chosen as representatives of regions with dominance of one of the two twinned domains, respectively. At this point high quality measurements of two points with high domain asymmetry can be obtained. In Figure 2 a+b) the ARPES spectrum at the two points is shown. The strong asymmetry in intensity of the outer heavy hole-like bands and the inner light hole-like band is indicative of the dominance of each of the two domains in within the illuminated area. One the other hand it is clear by the residual intensity, that neither position has a 100% domain population and that both domains always contribute to the APRES spectrum.



FIGURE 2: a) ARPES spectrum obtained at point A with outer hole pocket domain dominating. b) ARPES spectrum from point B with inner domain dominating. c) Numerical detwinning to estimate the contribution to the ARPES spectrum from the heavy hole pocket domain. d) Same as c) but for the inner light hole pocket.

Since the orientation of the sample at the two points was previously verified, it is possible to perform a "numerical detwinning" under the assumption that the ARPES spectrum of each point is created by a linear combination of identical emission from the respective domains. I.e. A = flat + h*light and B = light + k*flat. By using this assumption, we can subtract each spectrum from its pair choosing the normalization parameters h & k in such a way that the intensity in the resulting spectra does not becomes negative at any point. (flat = A - n*B and light = B - m*A). These spectra are plotted in Figure 2 c+d. While numerically extracted from the measured data at A and B the simple subtraction leads to a very pronounced effect, effectively detwinning the spectra at the Fermi level. At higher binding energies the degeneracy of the fully occupied hole bands is not lifted by the nematic phase and spectral weight remains visible in both numerical detwinnings.

In conclusion, the investigation of the domain population within the nematic phase of FeSe is a realistic example of the performance the μ -LaserARPES machine. The present study demonstrates the possibilities of combining high spatial resolution with high energy and angular resolution.

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Beam focusing and Sample-Volume Reduction Using Schwarzschild Objective at VUV-CD Spectrophotometer

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1. Introduction

At a vacuum-ultraviolet circular dichroism (VUV-CD) spectrophotometer in BL12 of HiSOR, it has been desired to reduce sample-volume with increasing the interest in rare proteins, such as human origin. A major bottleneck to hinder the achievement was large spot size of BL 12 (*ca.* 6×6 mm² at the sample position), because whole beam should pass through the sample area in CD spectroscopy. Recently, we installed a Schwarzschild objective in front of the sample position to focus incident beams and newly developed a small-volume sample-cell. As a result, we succeeded in reducing the sample volume down to 1/10. Here, we report some performances of VUV-CD spectrophotometer obtained by use of the Schwarzschild objective.

2. Beam focusing

The Schwarzschild objective (Infinite Conjugate, DUV Coated, 15X/0.28NA RefIX Objective) was purchased from Edmond Optics and installed to the CD measurement chamber (Fig. 1). The focal spot size of zeroth light was measured using a knife-edge method.



Fig. 1. (top) Top view of CD measurement chamber after installation of the Schwarzschild objective. (bottom) Schematic view of the optical components.

Figure 2 shows the focal beam profiles. Overall spot size was about $0.025 \times 0.025 \text{ mm}^2$ ($25 \times 25 \text{ µm}^2$). Since the FWHM of the beam intensities was 1.9 (H) and 2.7 (V) µm, effective spot size would be much smaller.



Fig. 2. The focal beam profiles of zeroth light at VUV-CD spectrophotometer in BL12 of HiSOR.

3. Small-volume reduction

To reduce the sample amount, new sample cell was developed. Schematic view of the sample cell is shown in Fig. 3. Sample solution was sandwiched between two grooved glasses (or grooved and flat glasses) and these glasses were covered by a stainless-steel holder. Path length can be set at about 15, 30, 60, and 75 μ m in combination with flat and/or grooved glasses of which depth is different. Sample volume encapsulated in the new cell is only 2 μ L which is 1/10 comparing to the previous cell.



Fig. 3. Schematic view of the small-volume sample cell.

4. Performance

Figure 4 shows CD spectra of myoglobin measured with and without the Schwarzschild objective. The spectra showed good agreement with each other, demonstrating that the use of the Schwarzschild objective and the reduction of sample volume does not cause the distortion in CD spectrum.



Fig. 4. CD spectra of myoglobin measured without (black) and with the Schwarzschild objective (red).

5. Conclusions

Spot size at the sample position was reduced down to 1/240 or less by using the Schwarzschild objective. Sample volume was also reduced down to 1/10. It could be reduced more when developing the smaller sample cell.