Progress of Facilities

Supercomputer Center

The Supercomputer Center (SCC) is a part of the Materials Design and Characterization Laboratory (MDCL) of ISSP. Its mission is to serve the whole community of computational condensed-matter physics of Japan, providing it with high performance computing environment. In particular, the SCC selectively promotes and supports large-scale computations. For this purpose, the SCC invites proposals for supercomputer-aided research projects and hosts the Steering Committee, as mentioned below, that evaluates the proposals.

The ISSP supercomputer system consists of two subsystems: System B, which was replaced recently (Oct. 2020), is intended for larger total computational power and has more nodes with relatively loose connections whereas System C is intended for higher communication speed among nodes. System B (ohtaka) consists of 1680 CPU nodes of Dell PowerEdge C6525 and 8 FAT nodes of Dell PowerEdge R940 with total theoretical performance of 6.881 PFLOPS. System C (enaga) consists of 252 nodes of HPE SGI 8600 with 0.77 PFLOPS. Replacement of the System C is scheduled in April 2022.

In addition to the hardware administration, the SCC puts increasing effort on the software support. Since 2015, the SCC has been conducting "Project for advancement of software usability in materials science (PASUMS)". In this project, for enhancing the usability of the ISSP supercomputer system, we conduct several software-advancement activities: developing new application software that runs efficiently on the ISSP supercomputer system, adding new functions to existing codes, help releasing private codes for public use, creating/improving manuals for public codes, etc. Three target programs were selected in fiscal year 2020: (1) PHYSBO (proposal made by R. Tamura (NIMS)), (2) 2DMAT (proposal made by T. Hoshi (Tottori Univ.)), and (3) MateriApps Installer (proposal made by S. Todo (Univ. of Tokyo)). In 2021, we also started the data repository service.

All staff members of university faculties or public research institutes in Japan are invited to propose research projects (called User Program). The proposals are evaluated by the Steering Committee of SCC. Pre-reviewing is done by the Supercomputer Project Advisory Committee. In fiscal year 2020, totally 387 projects were approved including the ones under the framework of Supercomputing Consortium for Computational Materials Science (SCCMS), which specially supports FUGAKU and other major projects in computational materials science. The total points applied and approved are listed on Table. 1 below.

The research projects are roughly classified into the following three (the number of projects approved, not including SCCMS):

First-Principles Calculation of Materials Properties (189)
Strongly Correlated Quantum Systems (40)
Cooperative Phenomena in Complex, Macroscopic Systems (137)

In all the three categories, most proposals involve both methodology and applications. The results of the projects are reported in 'Activity Report 2020' of the SCC. Every year 3-4 projects are selected for "invited papers" and published at the beginning of the Activity Report. In the Activity Report 2020, the following three invited papers are included:

1. "High precision study of the Anderson transition", Tomi OHTSUKI (Sophia U.) and Keith SLEVIN (Osaka U.)
2. "Some Recent Developments in ab initio Thermodynamics of Ion Disorder in Solids", Shusuke KASAMATSU (Yamagata U.)

First semester (Apr.-Sep.)

Class	Max Points		Application	Number of Projects	Total Points			
					Applied		Approved	
	System B	System C			System B	System C	System B	System C
A	100	50	any time	8	0.8k	0.4k	0.8k	0.4k
B	500	100	twice a year	61	28.4k	4.0k	22.8k	3.9k
C	5k	1k	twice a year	115	446.5k	80.1k	239.8k	42.4k
D	10k	1k	any time	3	22.5k	2.0k	15.0k	2.0k
E	15k	3k	twice a year	9	127.4k	27.0k	88.5k	21.4k
S	–	–	twice a year	0	0	0	0	0
SCCMS				11	23.7k	4.6k	23.7k	4.6k
Total				207	649.3k	118.0k	390.6k	74.6k

Second semester (Oct.-Mar.)

Class	Max Points		Application	Number of Projects	Total Points			
					Applied		Approved	
	System B	System C			System B	System C	System B	System C
A	100	50	any time	10	1.0k	0.4k	1.0k	0.4k
B	1k	100	twice a year	57	46.6k	3.2k	22.0k	2.0k
C	8k	1k	twice a year	96	595.8k	59.0k	226.0k	22.3k
D	10k	1k	any time	0	0k	0k	0k	0k
E	25k	3k	twice a year	7	175.0k	18.0k	87.0k	8.4k
S	–	–	twice a year	0	0	0	0	0
SCCMS				10	50.0k	4.5k	50.0k	4.5k
Total				180	868.3k	85.0k	386.0k	37.5k

Table 1. Research projects approved in 2020
The maximum points allotted to the project of each class are the sum of the points for the two systems. Computation of one node for 24 hours corresponds to one point for the CPU nodes of System B and System C. The FAT nodes require four points for a 1-node 24-hours use.

3. “Large-Scale Molecular Dynamics Simulations of Karman Vortex and Sound Wave: Cavitation and Polymer Effects”, Yuta ASANO (ISSP), Hiroshi WATANABE(Keio Univ.) and Hiroshi NOGUCHI (ISSP)

Neutron Science Laboratory

The Neutron Science Laboratory (NSL) has been playing a central role in neutron scattering activities in Japan since 1961 by performing its own research programs as well as providing a strong General User Program (GUP) for the university-owned various neutron scattering spectrometers installed at the JRR-3 (20 MW) operated by Japan Atomic Energy Agency (JAEA) in Tokai, Ibaraki (Fig. 1). In 2003, the Neutron Scattering Laboratory was reorganized as the Neutron Science Laboratory to further promote the neutron science with use of the instruments in JRR-3. Under GUP supported by NSL, 12 university-group-owned spectrometers in the JRR-3 reactor are available for a wide scope of researches on material science. The submitted proposals were about 300 and the visiting users reached over 6000 person-day in FY2010. In 2009, NSL and Neutron Science Division (KENS), High Energy Accelerator Research Organization (KEK) built a chopper spectrometer, High Resolution Chopper Spectrometer, HRC, at the beam line BL12 of MLF/J-PARC (Materials and Life Science Experimental Facility, J-PARC) (Fig. 2). HRC covers wide energy transfer (100 μeV < $\hbar\omega$ < 0.5 eV) and momentum transfer (0.03 Å^{-1} < Q < 30 Å^{-1}) ranges, and therefore becomes complementary to the existing inelastic spectrometers at JRR-3. HRC has accepted general users through the J-PARC proposal system since FY2011.

Triple axis spectrometers, HRC, a four-circle diffractometer, and a high resolution powder diffractometer are utilized for a conventional solid state physics and a variety of research fields on hard-condensed matter, while in the field of soft-condensed matter science, researches are mostly carried out by using a small angle neutron scattering (SANS-U) and/or neutron spin echo (iNSE) instruments. The upgraded time-of-flight (TOF) inelastic scattering spectrometer, AGNES, is available both for hard- and soft-matter science. Our GUP has produced 2068 publications and 285 dissertations until April 30, 2021. Their lists for the last 10 years are given in Activity Report on Neutron Scattering Research which is available in ISSP and NSL web pages.

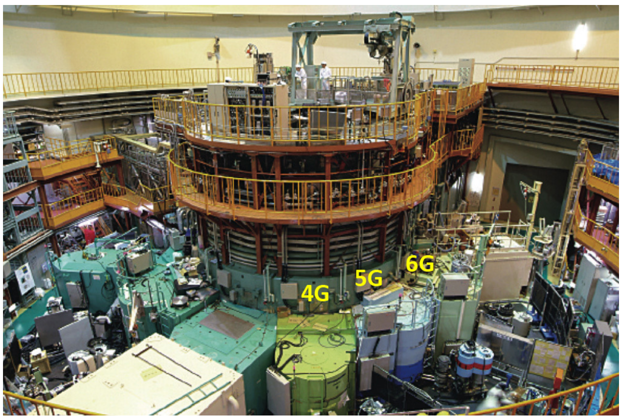

Fig. 1. Reactor hall of JRR-3. Three triple axis spectrometers are shown in the photo.

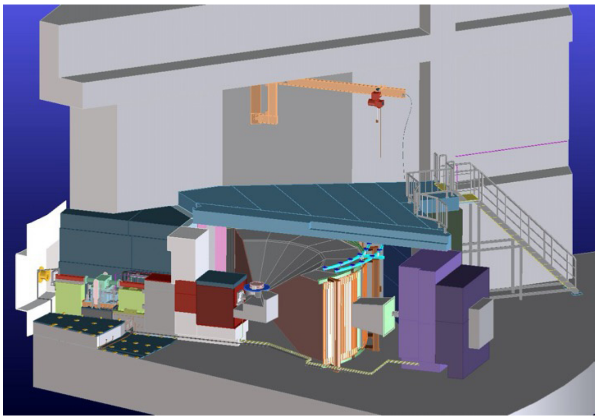

Fig. 2. Schematic view of HRC.

Since the Great East Japan Earthquake on March 11, 2011, JRR-3 had been closed mainly from safety issues. Hence, our domestic activity was only on HRC. To take up a recent research highlight, well-defined spin wave was successfully measured in the pressure-induced magneticphase in $CsFeCl_3$ [1]. Collaboration between HRC and CTAX, which is mentioned below, has clarified the hybridization of phase and amplitude modes near a quantum critical point [2]. Another progress on HRC was that a superconducting magnet up to 5 T became available. Field dependence of spin-wave spectra in 2D antiferromagnet $Ba_2MnGe_2O_7$ was measured. From FY2012 to FY2020, NSL has managed User-Program Supports for Overseas Experiments. 398 people (for 297 proposals) have performed their experiments in various foreign facilities and published 114 papers. The lists for this program are also available in Activity Report on Neutron Scattering Research mentioned above.

As for international cooperative programs, NSL operates the U.S.-Japan Cooperative Program on neutron scattering, providing further research opportunities to material scientists who utilize the neutron scattering technique for their research interests. In 2010, relocation of the U.S.-Japan triple-axis spectrometer, CTAX, was completed, and it is now open to users. NSL has another agreement with Australian Centre for Neutron Scattering (ANSTO), which was the main foreign facility for the User-Program Supports for Overseas Experiments.

It is really good news that JRR-3 has restarted in February 2021 after long shutdown and the normal GUP will come back from July 2021. During the shutdown period, we had been concentrating our efforts on upgrading the instruments and neutron beam circumstances. Specific actions taken include: the installation of focusing collimation systems, such as focusing monochromator and focusing analyzer, and material lens; and the introduction of polarization optics together with the installation of non-magnetization neutron shield. The neutron guides in the Guide Hall have also been upgraded by replacing the existing ones with super-mirror guides. These upgrades should result in increase in neutron beam flux several times. The sample environments such as cryostat and pressure cells have also been upgraded. We are looking forward to restarting science activities in JRR-3.

[1] S. Hayashida *et al*., Phys. Rev. B **97**, 140405(R) (2018).
[2] S. Hayashida *et al*., Sci. Adv. **5**, eaaw5639 (2019).

International MegaGauss Science Laboratory

The objective of this laboratory (Fig. 1) is to study the physical properties of solid-state materials (such as metals, semiconductors, insulators, superconductors, and magnetic materials) in a high magnetic field of 100 T or even higher. Such a high magnetic field can control material phases and functions. Our pulsed magnets, at moment, can generate up to 87 Tesla (T) by non-destructive manner, and up to 1200 T by destructive manner. The world record indoor magnetic field 1200 T was achieved in 2018. The laboratory is open for scientists in domestic as well as from overseas. Lots of fruitful results have come out not only from the collaborative researches but also from our in-house activities.

Fig. 1. The building C of the IMGSL.

Our interests cover the study on quantum phase transitions (QPT) induced by high magnetic fields. Field-induced QPT has been explored in various materials such as quantum spin systems, strongly correlated electron systems and other magnetic materials. One of our ultimate goals is to provide the joint-research users with a 100 T millisecond-long pulse using a non-destructive magnet, and to offer versatile high-precision physical measurements. Measurable physical quantities or properties are magneto-optical spectra, magnetization, magnetostriction, electrical transport, specific heat, nuclear magnetic resonance, and ultrasound propagation. They can be carried out with sufficiently high accuracy. Another ultimate goal is to extend the magnetic field region and discover novel phenomena happening only in extremely strong magnetic fields exceeding 100 T. Recent technical developments allow us to even measure magnetostriction and ultrasound propagation in the destructive magnetic fields over 100 T, that can directly reach potential structural changes in the ultrahigh magnetic fields. Recent discovery of magnetic field induced insulator-metal transitions of strongly correlated materials in 500 T would open new direction of the megagauss field research, namely exploration of field-induced novel phases in materials with strong interactions comparable to thermal energy of a room temperature.

A 210 MJ flywheel generator (Fig. 2), which is the world largest DC power supply (recorded in the Guinness Book of World Records) was installed in the DC flywheel generator station at our laboratory, and used as an energy source of super-long pulse magnets. The magnet technologies are intensively devoted to the quasi-steady long pulse magnet

	Alias	Type	B_{max}	Pulse width Bore	Power source	Applications	Others
Building C Room 101-113	ElectroMagnetic Flux Compression	Destructive	1200 T	3μs (100-1200T) 10 mm	5 MJ, 50 kV 2 MJ, 50 kV	Magneto-Optical Magnetization	5 K – room temperature
	Horizontal Single-turn Coil	Destructive	300 T 200 T	6μs 5 mm 10 mm	0.2 MJ, 50 kV	Magneto-Optical measurements Magnetization	5 K – room temperature
	Vertical Single-turn Coil	Destructive	300 T 200 T	8μs 5 mm 10 mm	0.2 MJ, 40 kV	Magneto-Optical Magnetization	2 K – room temperature
Building C Room 114-120	Mid-pulse Magnet	Non-destructive	60 T 70 T	40 ms 18 mm 40 ms 10 mm	0.9 MJ, 10 kV	Magneto-Optical measurements Magnetization Magneto-Transport Hall resistance Polarization Magneto-Striction Magneto-Imaging Torque Magneto- Calorimetry Heat Capacity	Independent Experiment in 5 site Lowest temperature 0.1 K
Building C Room 121	PPMS	Steady	14 T			Resistance Heat Capacity	Down to 0.3 K
	MPMS	Steady	7 T			Magnetization	
Building K	Short-Pulse Magnet	Non-destructive	87 T (2-stage pulse) 85 T	5 ms 10 mm 5 ms 18 mm	0.5 MJ, 20 kV	Magnetization Magneto-Transport	2 K – room temperature
	Long-Pulse Magnet	Non-destructive	43.5 T	1 s 30 mm	210 MJ, 2.7 kV	Resistance Magneto-Calorimetry	2 K – room temperature

Table 1. Available Pulse Magnets, Specifications

Fig. 2. Upper: The K-building for the flywheel generator (left hand side) and a long pulse magnet station (right hand side). Lower: The flywheel giant DC generator which is 350 ton in weight and 5 m high (bottom). The generator, capable of a 51 MW output power with the 210 MJ energy storage, is planned to energize the long pulse magnet generating 100 T without destruction.

(an order of 1-10 sec) energized by the giant DC power supply. The giant DC power source will also be used for the giant outer-magnet coil to realize a 100 T nondestructive magnet by inserting a conventional pulse magnet coil in its center bore. Recently, the super-long pulsed magnet has been intensively used to investigate thermal properties such as specific heat and magnetocaloric effects.

Magnetic fields exceeding 100 T can be obtained with only destruction of a magnet coil. The ultrahigh magnetic fields are obtained in a microsecond time scale. The project, financed by the ministry of education, culture, sports, science and technology aiming to generate 1000 T with the electromagnetic flux compression (EMFC) system (Fig. 3), has been completed. Our experimental techniques using the destructive magnetic fields have intensively been developed. The system which is unique to ISSP in the world scale is comprised of a power source of 5 MJ main condenser bank and 2 MJ condenser bank. Two magnet stations are constructed and both are energized from each power source. Both systems are fed with another 2 MJ condenser bank used for a seed-field coil of which magnetic flux is to be compressed. The 2 MJ EMFC system can generate 450 T. The 5 MJ system is used for generation of

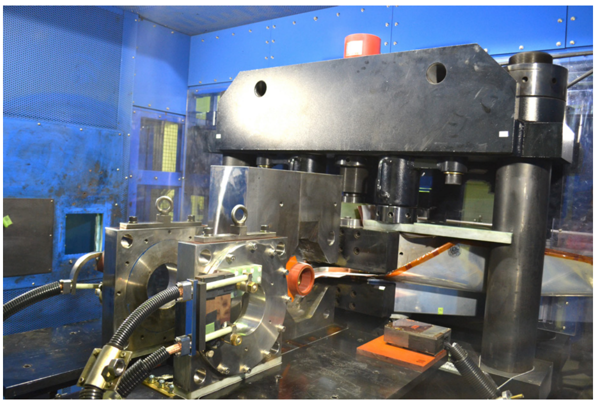

Fig. 3. A view of the coil setup of the electromagnetic flux compression inside of an anti-explosive house. The world strongest indoor magnetic field 1200 T was achieved in 2018.

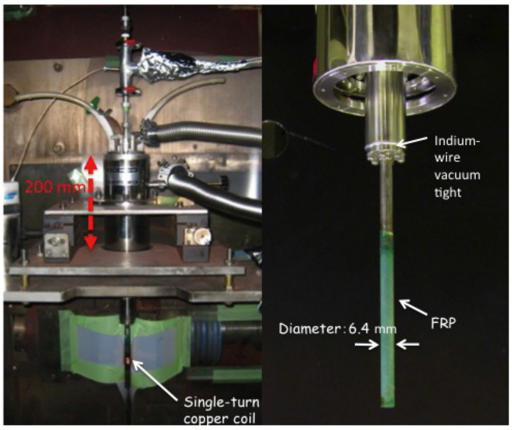

Fig. 4. Schematic picture of the V-type single-turn coil equipped with a 40 kV, 200 kJ fast capacitor bank system. The liquid-helium-bath cryostat with a plastic tail is also shown.

1000 T-class magnetic field. For the research in magnetic field range of 100 - 300 T, we have two single-turn coil (STC) systems that have a fast-capacitor bank system of 200 kJ for each. One is the horizontal type (H-type) and the other is a vertical type (V-type, Fig. 4). Various kinds of laser spectroscopy experiments such as the cyclotron resonance and the Faraday rotation are possible using the H-type STC, while a stable low temperature condition of 2 K is available for the V-type STC.

Center of Computational Materials Science

With the advancement of hardware and software technologies, large-scale numerical calculations have been making important contributions to materials science and will have even greater impact on the field in the near future. CCMS is a specialized research center established in 2011 for promoting computer-aided materials science with massively parallel computers, such as the Fugaku supercomputer, which has been recently developed in Kobe as the core of a billion-dollar national project. Activities of CCMS are divided into the following three categories: (1) highly efficient and large-scale use of the Fugaku supercomputer and its application to grand-challenge problems in computational materials science, (2) activities as the center for the community of computational condensed matter physics and materials science, and (3) computational physics research aiming to solve rare-element problems.

Fig. 1. Group photo in the CDMSI symposium

For the first category, each group in CCMS is carrying out various individual research projects in its own expertise to efficiently utilize large-scale parallel computers. For example, the Ozaki group has been developing efficient and accurate methods and software packages to extend the applicability of DFT to more realistic systems, and investigated the structural and electronic properties of various 2D materials in successful collaboration with experimental groups and industrial companies. There are other activities such as development of Tensor Network (TN) based numerical methods and Markov-chain Monte Carlo methods by the Kawashima group and the Todo group.

As for the activities in the second category, apart from major annual conferences and formal international meetings as shown in Fig. 1, the CCMS/CDMSI hosted, and also provided a series of lectures and training sessions at Kashiwa. For example, training sessions "Kashiwa Hands-On" for getting accustomed to various application programs, such as OpenMX, HΦ, mVMC, AkaiKKR, and MateriApps LIVE!, as shown in Fig. 2, have been held monthly. Each session is designed for 5-10 trainees and takes 4-5 hours. We also coordinate the use of the computational resources available to our community, and support community members through various activities such as administrating the website "MateriApps" for information on application software in computational science as shown in Fig. 3.

For the third category, the Akai team and the Fukushima group are working on the development of new permanent magnet materials. In order to meet the ever-increasing demands for new permanent magnet materials that are used for high performance permanent magnets, CCMS is theoretically investigating the various magnetic properties, such as saturation magnetization, Curie temperature, and magnetic anisotropy, of iron-based magnetic materials, including rare-earth magnet materials, $R_2(Fe,Co)_{14}B$, $R_2(Fe,Co)_{17}$, and $RFe_{11.5}Ti_{0.5}$ (R = La, Ce, … , Lu, Y) on the basis of first-principles calculations.

These activities are supported by funds for various governmental projects including Element Strategy Initiative and the Program for Promoting Researches on the Supercomputer Fugaku.

The following is the selected list of meetings organized by CCMS in recent years:

- 2019/10/8-2019/10/10 The 3rd Innovation Camp for Computational Materials Science (3rd ICCMS), Takinoyu Hotel, Yamagata.
- 2019/12/6 TIA-Kakehashi Poster Workshop 2019 The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa
- 2019/12/13 Element Strategy Initiative Advisory Council (ESIAC) 2019, TKP Garden city, Yokohama.
- 2020/2/3-2020/2/4 4th Element Strategy Symposium: New Developments in Industry-Academia Research Collaboration, Ito Hall, Tokyo.
- 2020/2/25 PCoMS Skill improvement training for graduate students & postdocs ISSP, Kashiwa.
- 2020/6/19·2020/6/23 Matching Workshop for industries & graduate students/ postdocs, Online.
- 2020/12/21-2020/12/22 Joint Research Meeting of ISSP Supercomputer Joint Use and CCMS Annual Activity Report 2020, Online.

In addition to the events listed above, we organize regular hands-on program for various application, such as Open MX and HΦ.

Fig. 2. Software in the CCMS community

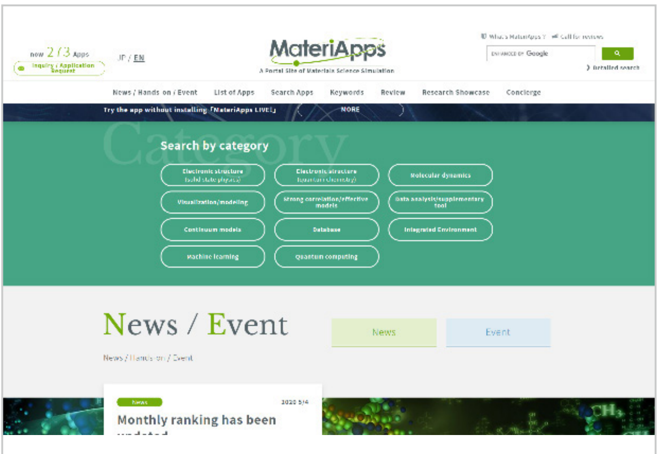

Fig. 3. MateriApps Website

Laser and Synchrotron Research Center (LASOR Center)

Laser and synchrotron research center (LASOR Center) was established in October 2012 to push the frontiers of the photon and materials science. LASOR has 10 groups in 2019, which is the biggest division in ISSP. Most of the research activities on the development of new lasers with an extreme performance and the application to materials science are studied in specially designed buildings D and E with large clean rooms and the isolated floor from the vibrations in Kashiwa Campus. On the other hand, the experiments utilizing the synchrotron radiation are performed at beamline BL07LSU in SPring-8 (Hyogo).

Fig. 1. Optical frequency comb

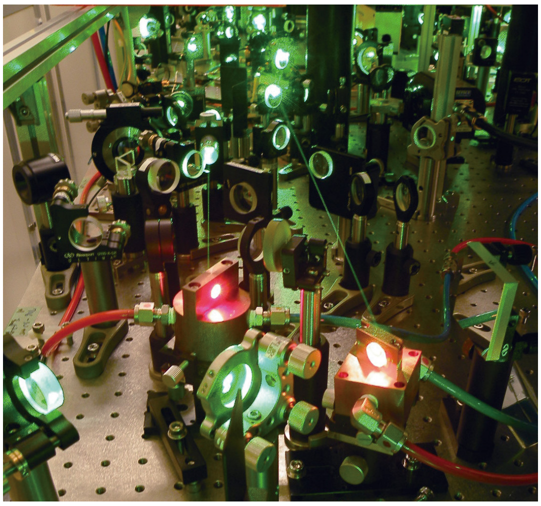

Fig. 2. Close look of a high-peak-power ultrashort-pulse laser

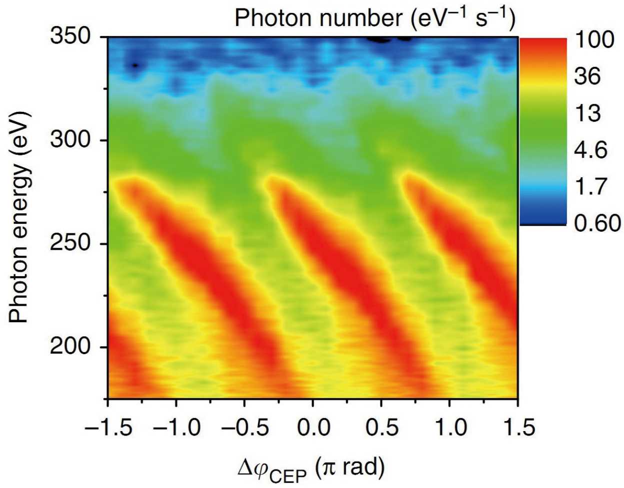

Fig. 4. Phase-dependence of high harmonic spectra in soft X rays.

The development of novel laser-based light sources in the vacuum-ultraviolet to soft-X-ray regions innovated materials investigations as represented by the highest-energy-resolution photoemission, ultrafast time-domain, and ultra-fast non-linear spectroscopies. Materials science research powered by lasers thus has entered a new era. The ultra-short and high-power lasers are more and more attractive light source for both basic science and industry. The state-of-the-art laser source and spectroscopy are intensively explored.

Another stream pursued at ISSP is the synchrotron-based research. The drastic advance in brilliance of the synchrotron radiation has also opened a new field of its own in photon science. The soft-X-ray beam-line in SPring-8 (BL07LSU) was implemented with the longest undulator in the world: The end stations illuminated by the brilliant soft-X-rays are used to output innovative achievements based on high-resolution spectroscopy data. In 2018, Japanese government has made a statement to construct a new synchrotron facility in Tohoku. LASOR has decided to subjectively contribute to this facility from the design to the operation.

Lasers and synchrotrons have developed independently; now both light sources cover a wide photon-energy range with an overlap in the vacuum-ultraviolet to soft-X-ray regions. Foreseeing their common interests in research fields and technologies, ISSP integrated the two streams, namely the extreme lasers and synchrotron radiations, into the common platform. Through the mutual interactions between the forefronts of lasers and synchrotrons, LASOR will be the center of innovations in light and materials science, with the aid of world-wide joint research and close collaborations with other divisions in ISSP such as New Materials Science, Nanoscale Science, and Condensed Matter Theory.

The mission of LASOR is to cultivate and propel the following three scientific fields:
1. Laser Science,
2. Synchrotron radiation Science,
3. Extreme Spectroscopy,

• Laser science group

We were committed to continuing to developed various state-of-the-art laser systems such as high-power solid-state or gas lasers, high-intensity lasers, ultra-short pulse lasers down to attosecond time scale (Peta Hz linewidth), ultra-stable lasers with 1-Hz linewidth, optical frequency combs, mid-infrared lasers, THz light source, and semiconductor lasers.

High-power and ultrashort pulse laser technology has progressed for this 10 years. It opened two directions of research. One is a coherent extreme ultraviolet light source realized by a high-harmonic generation (HHG) scheme. The average power of HHG became high enough to use it for a photoemission spectroscopy. The photon energies of 7 eV to 60 eV are now available. They can be either very narrow band width or ultrashort pulse. The other is an industrial science such as a laser processing. Pulse duration variable, 100-W average power, femtosecond laser is now available in LASOR for any collaborative research including companies.

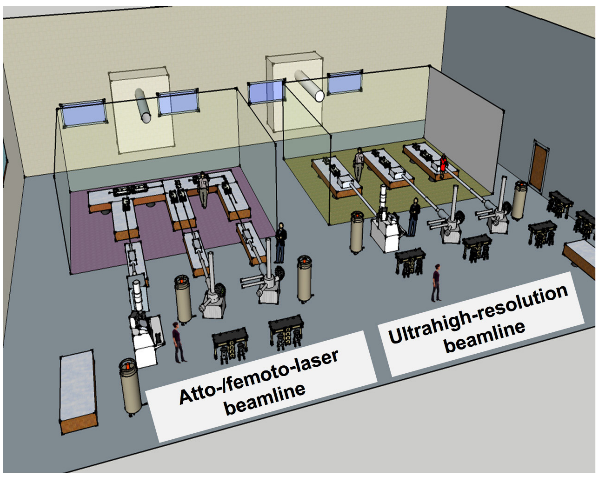

Fig. 3. Design of E building for extreme VUV- and SX-lasers and new spectroscopy.

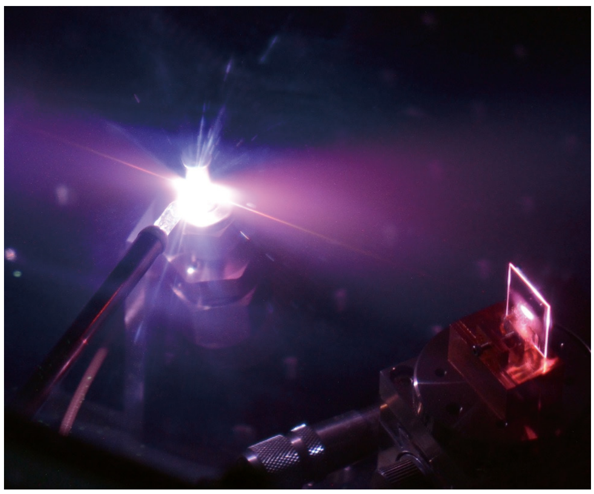

Fig. 5. 10-MHz high harmonic generation in an enhancement cavity.

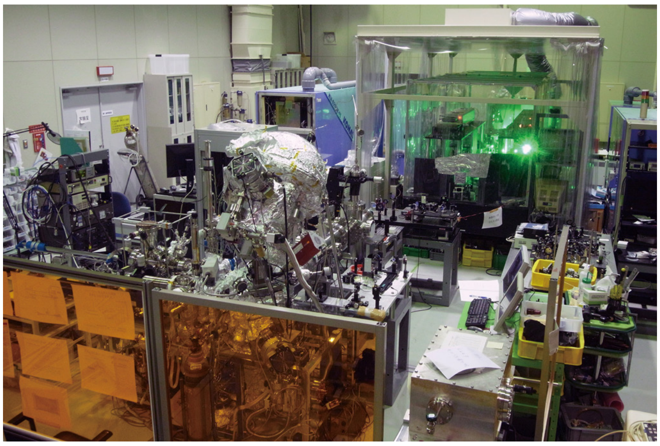

Fig. 6. Pump-probe photoemission system using 60-eV laser

We also aim to develop novel laser spectroscopy and coherent non-linear optical physics, enabled via emerging lasers and optical science/technology, and extensively study basic light-matter physics, optical materials science, and applied photonics. Such researches include ultrafast spectroscopy for excited state dynamics, terahertz magnetic-field spectroscopy for spin dynamics, quantitative micro-spectroscopy on semiconductor lasers and nano-structure photonics devices, such as quantum wire lasers, gain-switch semiconductor laser, multi-junction solar cells, and bio-luminescent systems.

• Synchrotron radiation science group

By inheriting and developing the synchrotron techniques cultivated for more than 20 years, we continuously develop world cutting-edge spectroscopies such as time-resolved photoemission/diffraction, ultrahigh resolution soft X-ray emission, 3D (depth + 2D microscopy) nano ESCA and X-ray magneto-optical effect and provide these techniques both for basic material science and for applied science, which contributes to the device applications in collaboration with outside researchers. In order to pioneer new spectroscopies for the next-generation light sources, we upgrade fast polarization switching of the undulator light source in cooperation with SPring-8. In addition, we promote frontier works on the use of X-ray free electron lasers, SACLA with high spatial and temporal coherence comparable to optical lasers in collaboration with scientists of laser light sources and spectroscopies.

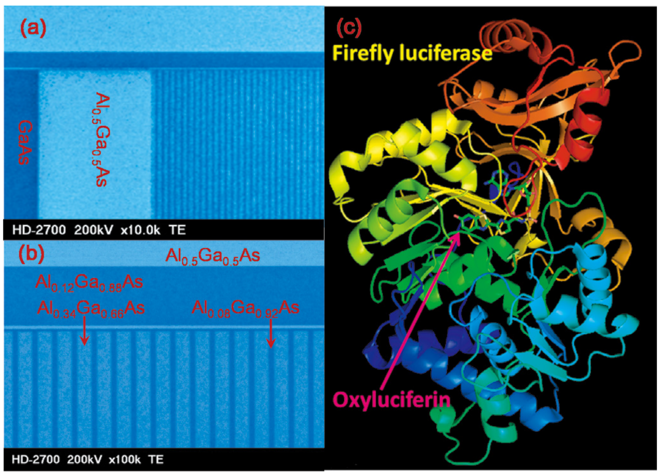

Fig. 7. Photonics devices under study: (left panel) semiconductor quantum wires and (right panel) firefly-bioluminescence system consisting of light emitter (oxyluciferin) and enzyme (luciferase)

• Extreme spectroscopy group

The advent of laser-based light sources in the soft-X-ray region is opening a new stage in the field that has been cultivated by the synchrotron radiations. One of the milestones is to develop a laser-based light source of ~7 eV for the sub-meV-resolution photoemission spectroscopy. In this five years, available photon energy became 11 eV with help of Yb-fiber laser technology. It has high photon flux (10^{14} photons/sec) with sub picosecond time resolution. Laser-based spin-resolved ARPES was realized in LASOR. This technology would open brand-new spectroscopy. High-harmonic generation based photoemission spectroscopy in the 20-60 eV region is another direction to be pursued. Time-domain spectroscopy in the femtosecond region was achieved. Combined with the picosecond time-domain spectroscopy utilizing the pulsed light delivered from synchrotrons, we investigate the electronic structures and dynamics of matter in bulk, on surface, and into the nano-scale. The ultimate objective is to expand the soft-X-ray operando methodologies by lasers. Diffractions, magneto-optical effects, and inelastic scatterings now done at synchrotrons will be performed by lasers, to access the real-time dynamics of chemical reactions and phase transitions down to the femtoseconds.

State-of-the-art laser based organism spectroscopy is a new direction in LASOR. ISSP research area is shifting from simple material and science to complex one including living body and functional material with excited state physics.

Synchrotron Radiation Laboratory

The Synchrotron Radiation Laboratory (SRL) was established in 1975 as a research division dedicated to solid state physics using synchrotron radiation (SR). Currently, SRL is composed of two research sites, the Harima branch and the E-building of the Institute for Solid State Physics.

• Brilliant soft X-ray beamline at Harima branch

In 2006, the SRL staffs have joined the Materials Research Division of the Synchrotron Radiation Research Organization (SRRO) of the University of Tokyo and they have played an essential role in constructing a new high brilliant soft X-ray beamline, BL07LSU, in SPring-8. The

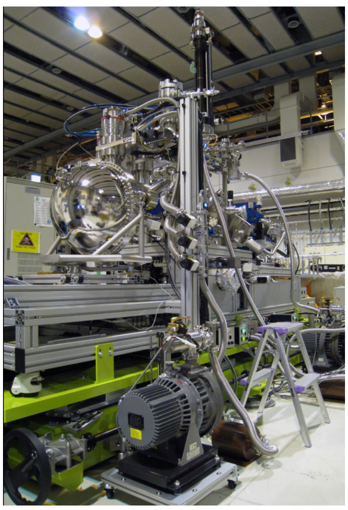

Fig. 1. Ambient pressure photoemission

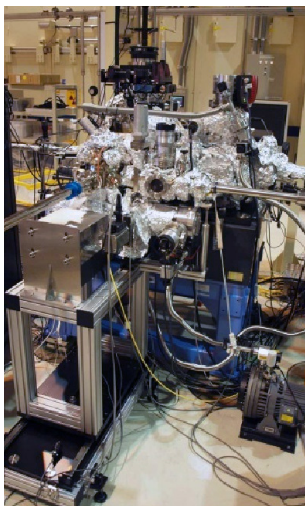

Fig. 2. 3D nano-ESCA station

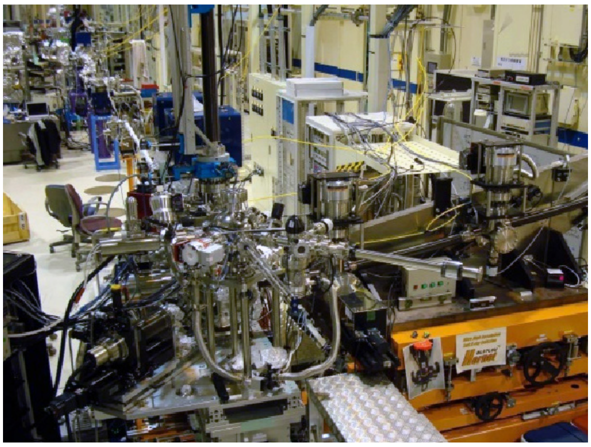

Fig. 3. Soft X-ray emission station

light source is the polarization-controlled 25-m long soft X-ray undulator with electromagnetic phase shifters that allow fast switching of the circularly (left, right) and linearly (vertical, horizontal) polarized photons.

The monochromator is equipped with a varied line-spacing plain grating, which covers the photon energy range from 250 eV to 2 keV. At the downstream of the beamline, a lot of experimental stations have been developed for frontier spectroscopy researches: three endstations, i.e. ambient pressure photoemission (Fig. 1), three-dimensional (3D) nano-ESCA (Fig. 2), high resolution soft X-ray emission spectroscopy (XES) (Fig. 3) stations are regularly maintained by the SRL staffs and open for public use, and at free-port station many novel spectroscopic tools have been developed and installed such as soft X-ray resonant magneto-optical Kerr effect (XMOKE) and so on. The beamline construction was completed in 2009 and SRL established the Harima branch laboratory in SPring-8. At SPring-8 BL07LSU, each end-station has achieved high performance:the time-resolved soft X-ray spectroscopy (TR-SX) station equipped with a two-dimensional angle-resolved time-of-flight (ARTOF) analyzer has established the laser-pump and SR-probe method with the time-resolution of 50 ps which corresponds to the SR pulse-width. This apparatus was moved to E-building in the 2020 summer to realize better temporal resolution using the fsec high harmonic laser pulse of 11 eV; the 3D nano-ESCA station reaches the spatial resolution of 70 nm; the XES station provides spectra with the energy resolution around 70 meV at 400 eV and enables real ambient pressure experiments. Soft X-ray resonant MOKE station has been developed to make novel magneto-optical experiment using fast-switching of the polarization-controlled 25-m long soft X-ray undulator. In 2020, 24 user groups made their experiments during the SPring-8 operation time. The number is slightly decreased compared with the usual annual operation because of the COVID-19 problem. The official beamtime was cut off in April and May and replaced by the beamtime in the latter half of 2020.

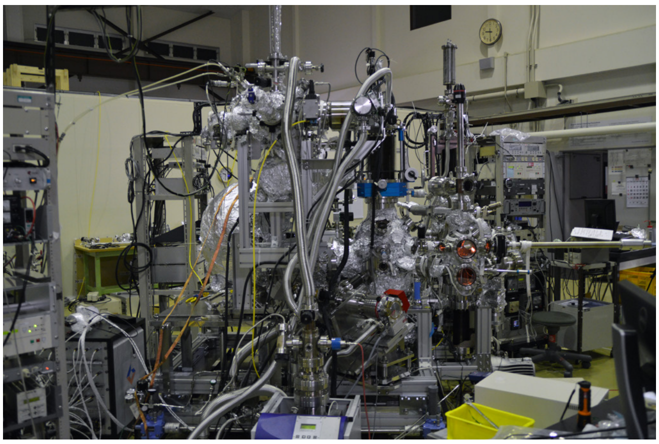

Fig. 4. Laser-SARPES system at E-building

• High-resolution Laser SARPES at E-building

High-resolution Laser Spin- and Angle-Resolved Photoemission Spectroscopy (SARPES) is a powerful technique to investigate the spin-dependent electronic states in solids. In FY2014, LASOR and SRL staffs constructed a new SARPES apparatus (Fig. 4), which was designed to provide high-energy and -angular resolutions and high efficiency of spin detection using a laser light at E-building. The achieved energy resolution of 1.7 meV in SARPES spectra is the highest in the world at present. From FY2015, the new SARPES system has been opened to outside users.

The Laser-SARPES system consists of an analysis chamber, a carousel chamber connected to a load-lock chamber, and a molecular beam epitaxy chamber, which are kept ultra-high vacuum (UHV) environment and are connected to UHV gate valves. The electrons are excited with 6.994-eV photons, yielded by 6th harmonic of a $Nd:YVO_4$ quasi-continuous wave laser with a repetition rate of 120 MHz, and 10.7 eV photons, driven by the third harmonic radiation at 347 nm of an Yb:fiber chirped pulse amplifier laser, which was developed by Kobayashi's lab in LASOR. The hemispherical electron analyzer is a custom-made Scienta Omicron DA30-L, modified for installing the spin detectors. The spectrometer is equipped with two high-efficient spin detectors associating very low energy electron diffraction are orthogonally placed each other, which allows us to analyze the three-dimensional spin polarization of electrons. At the exit of the hemispherical analyzer, a multi-channel plate and a CCD camera are also installed, which enables us to perform the angle-resolved photoelectron spectroscopy with two-dimensional (energy-momentum) detection. The laser-SARPES with 7-eV laser can provide both high-resolution spin-integrated and spin-resolved photoemission spectra in various types of solids, such as spin-orbit coupled materials and ferromagnetic materials. In addition, using the 10.7-eV makes it possible to follow their ultrafast spin dynamics in the time domain by pump-probe scheme.