

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 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 is SGI ICE XA / UV hybrid system that consists of FAT nodes with large memory, CPU nodes based on Intel Xeon, and ACC node enhanced by GPGPU accelerator. Its theoretical performance is 2.6 PFLOPS. System C is HPE SGI 8600 with 0.77 PFLOPS.

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". In this project, for enhancing the usability of the ISSP supercomputer system, we perform some software-advancement activity such as 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, writing/improving manuals for public codes. Two target programs were selected in fiscal year 2018 and developed software were released as DSQSS (proposal made by A. Masaki (RIKEN)) and RESPACK (proposal made by K. Nakamura (Kyutech)). The SCC is also providing a service for porting users' software to General Purpose GPUs

(GPGPU).

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 2018, totally 283 projects were approved. The total points applied and approved are listed on Table. 1 below. Additionally, we supported post-K and other computational materials science projects through Supercomputing Consortium for Computational Materials Science (SCCMS).

The research projects are roughly classified into the following three (the number of projects approved):

First-Principles Calculation of Materials Properties (131)
Strongly Correlated Quantum Systems (33)
Cooperative Phenomena in Complex, Macroscopic Systems (119)

In all the three categories, most proposals involve both methodology and applications. The results of the projects are reported in 'Activity Report 2018' 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 2018, the following three invited papers are included:

"Development of Open-Source Software mVMC and its Applications", Takahiro Misawa, Yuichi Motoyama, and Kota Ido (ISSP, U. Tokyo)

"First-Principles Studies on Anomalous Electron and Spin Transport Properties in Non-Trivial Spin Textures", Fumiyuki ISHII (Kanazawa U.)

"Coarse-Grained Force Field for Lipid Domain Formation Simulations", Sangjae Seo, and Wataru Shinoda (Nagoya U.)

Class	Max Points		Application	Number of Projects	Total Points			
	System B	System C			Applied		Approved	
					System B	System C	System B	System C
A	100	50	any time	20	2.0k	1.0k	2.0k	1.0k
B	1k	100	twice a year	70	64.2k	3.5k	42.6k	2.9k
C	10k	1k	twice a year	168	1395.3k	77.2k	620.0k	62.0k
D	10k	1k	any time	8	42.3k	3.0k	30.0k	2.5k
E	30k	3k	twice a year	17	490.0k	46.0k	279.5k	39.8k
S			twice a year	0	0	0	0	0
SCCMS				25	235.5k	19.1k	235.5k	19.1k
Total				308	2229.3k	149.7k	1209.6k	127.3k

Table 1. Research projects approved in 2018

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 points for the CPU nodes of System B and System C. The FAT and ACC nodes require four and two points for a 1-node 24-hours use, respectively.

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 for the university-owned various neutron scattering spectrometers installed at the JRR-3 (20MW) operated by Japan Atomic Energy Agency (JAEA) in Tokai. 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 the General User Program supported by NSL, 14 university-group-owned spectrometers in the JRR-3 reactor are available for a wide scope of researches on material science, and proposals close to 300 are submitted each year, and the number of visiting users under this program reaches over 6000 person-day/year. 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). HRC covers a wide energy and Q-range ($10\mu\text{eV} < \hbar\omega < 2\text{eV}$ and $0.02\text{\AA}^{-1} < Q < 50\text{\AA}^{-1}$), and therefore becomes complementary to the existing inelastic spectrometers at JRR-3. HRC started to accept general users through the J-PARC proposal system in FY2011.

Triple axis spectrometers, HRC, 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 the small angle neutron scattering (SANS-U) and/or neutron spin echo (iNSE) instruments. The upgraded time-of-flight (TOF) inelastic scattering spectrometer, AGNES, is also available through the ISSP-NSL user program.

Scientific outputs from HRC in FY2018 covers wide range in magnetism and strongly correlated electrons. One of the research highlights is the study on quantum phase transition in the singlet-ground-state antiferromagnet CsFeCl_3 [1]. Even though the HRC spectrometer is designed for inelastic neutron scattering measurement, the use of white beam allows us to measure Laue spots. Temperature evolution of the Laue spot at $\mathbf{q} = (1/3, 1/3, 0)$ at 1.4 GPa in Fig. 1(a) evidences the existence of the pressure-induced magnetic Bragg peak at the \mathbf{q} in CsFeCl_3 . Combination of further measurements using a neutron diffractometer ZEBRA and magnetic structure analysis reveals a 120° structure with a propagation vector of $\mathbf{k}_{\text{mag}} = (1/3, 1/3, 0)$. The estimated critical exponent of the order parameter suggests that CsFeCl_3 belongs to the universality class of $U(1)\times Z_2$

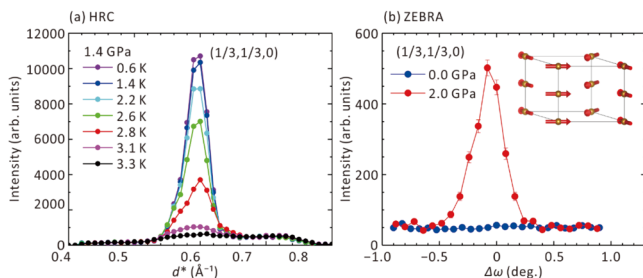


Fig. 1. (a) Temperature dependence of magnetic Bragg peak measured at HRC spectrometer. (b) Neutron diffraction profiles at 0.0 and 2.0 GPa measured at ZEBRA spectrometer. The inset exhibits the determined magnetic structure.

symmetry which is expected to realize the chiral liquid state.

Technical progress of HRC spectrometer was the development of high pressure environment. Cylinder-type cell made of CuBe alloy was designed by Prof. Uwatoko. The volume for the sample space is 5 mm in diameter and 20 mm in length. The maximum pressure is 1.4 GPa. The measurement was performed on 0.4g of CsFeCl_3 sample. 1 K cryostat was used to achieve 0.7 K, and the power of the J-PARC operation was 400 kW. Well-defined spin wave was successfully measured in the pressure-induced magnetic phase in CsFeCl_3 .

The NSL also 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.

<https://neutrons.ornl.gov/ctax>

[1] S. Hayashida et al., Phys. Rev. B 97, 140405(R) (2018).

International MegaGauss Science Laboratory

The objective of this laboratory (Fig. 1) is to study the physical properties of solid-state materials (such as semiconductors, magnetic materials, metals, insulators, superconducting materials) under ultra-high magnetic field conditions. Such a high magnetic field is also used for controlling the new material phase and functions. Our pulse magnets, at moment, can generate up to 87 Tesla (T) by non-destructive manner, and from 100 T up to 1200 T (the world strongest as an in-door record) by destructive methods. The laboratory is opened for scientists both from Japan and from overseas, especially from Asian countries, and many fruitful results are expected to come out not only from collaborative research but also from our in-house activities. One of our ultimate goals is to provide the scientific users as our joint research with magnets capable of a 100 T, millisecond long pulses in a non-destructive mode, and to offer versatile physical precision measurements. The available measuring techniques now involve magneto-optical measurements, cyclotron resonance, spin resonance, magnetization, and transport measurements. Recently, specific heat and calorimetric measurements are also possible to carry out with sufficiently high accuracy.

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



Fig. 1. Signboard at the entrance of the IMGSL.

magnetic materials. Non-destructive strong pulse magnets are expected to provide us with reliable and precise solid state physics measurements. The number of collaborative groups for the research is almost 56 in the FT of 2018.

A 210 MJ flywheel generator (Fig. 2), which is the world largest DC power supply (recorded in the Guinness Book of World Records) has been installed in the DC flywheel gener-



Fig. 2. The building for the flywheel generator (left hand side) and a long pulse magnet station (right hand side). The flywheel giant DC generator 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.

ator 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 (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.

Magnetic fields exceeding 100 T can only be obtained with destruction of a magnet coil, where ultra-high 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

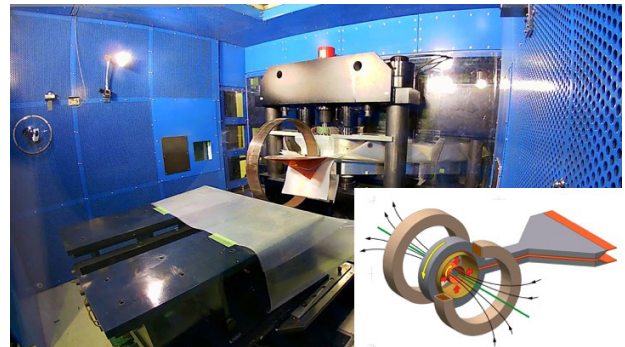


Fig. 3. (Build. C) A view of the electro-magnetic flux compression 1000-T-class megagauss generator set in side of an anti-explosive house. 1000 T project started since 2010, and finally condenser banks of 9 MJ (5 MJ + 2 MJ + 2 MJ) as a main system with the 2 MJ sub bank system for the seed field have been installed, and settled in the year of 2014.

	Alias	Type	B _{max}	Pulse width Bore	Power source	Applications	Others
Building C Room 101-113	Electro- Magnetic Flux Compression	destructive	1200 T	μ s 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	μ s 5 mm 10 mm	0.2 MJ, 50 kV	Magneto-Optical measurements Magnetization	5 K – 400 K
	Vertical Single-Turn Coil	destructive	300 T 200 T	μ s 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 State	14 T			Resistance Heat Capacity	Down to 0.3 K
	MPMS	Steady State	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

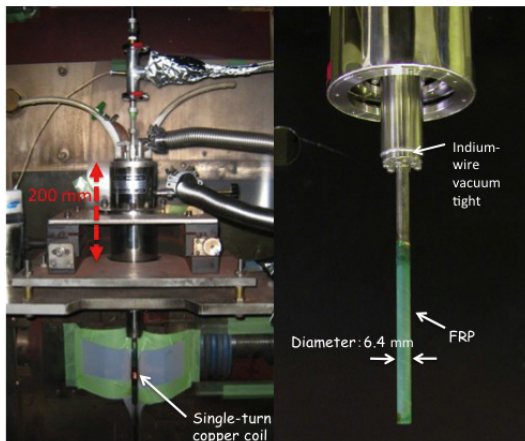


Fig. 4. Schematic picture of the H-type single-turn coil equipped with 50 kV, 200 kJ fast operating pulse power system, capable of generating 300 T within 3 mm bore coil.

(Fig. 3), has been proceeded. 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 is currently under the process for optimizing several mechanical and electrical parameters such as dimensions of coils and liners. And so far, generation of 450 T was successfully done using 1.6 MJ energy. The 5 MJ EMFC system is under conditioning the main gap switches by finely tuning control parameters. And so far, generation of 1200 T was successfully done using 3.2 MJ energy. As an easy access to the megagauss science and technology, we have the single-turn coil (STC) system capable of generating the fields of up to 300 T by a fast-capacitor of 200 kJ. We have two STC systems, one is a horizontal type (H-type, Fig. 4) and the other is a vertical type (V-type). Various kinds of laser spectroscopy experiments such as the cyclotron resonance and the Faraday rotation are possible using the H-type STC.

Center of Computational Materials Science

The goal of the materials science is to understand and predict properties of complicated physical systems with a vast number of degrees of freedom. Since such problems cannot be solved with bare hands, it is quite natural to use computers in materials science. In fact, computer-aided science has been providing answers to many problems ranging from the most fundamental ones to the ones with direct industrial applications. In the recent trends of the hardware developments, however, the growth of computer power is mainly due to the growth in the number of the units. This fact poses a very challenging problem before us --- how can we parallelize computing tasks? In order to solve this problem in an organized way, we 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 infor-



Fig. 1. Members of CCMS.

mation on application software in computational science. These activities are supported by funds for various governmental projects in which CCMS is involved. In particular, we are acting as the headquarters of Priority Area 7 of MEXT FLAGSHIP2020 Project (so-called "post-K computer project"). In addition to this, CCMS is involved in Priority Area 5 and Pioneering Area (CBSM2) of FLAGSHIP2020 project, Element Strategy Initiative, and Professional Development Consortium for Computational Materials Scientists (PCoMS).

The following is the selected list of meetings organized by CCMS in FY2018:

- 4/2-4/3 Joint Research Meeting of ISSP Supercomputer Joint Use and CCMS Annual Activity Report 2018 ISSP, Kashiwa
- 5/10 PCoMS Matching Workshop for industries & graduate students/postdocs The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa
- 7/2-7/12 The International Summer Workshop 2018 on First Principles Electronic Structure Calculations(ISS2018) ISSP, Kashiwa
- 7/19-7/20 Post-K Project Priority Issue 7, The 3rd Annual Meeting Koshiba-Hall, Hongo, Tokyo
- 10/2-10/4 The 2nd Innovation Camp for Computational Materials Science (2nd ICCMS) The Kaike Seaside Hotel, Tottori
- 10/19 Post-K Project Exploratory Challenge 1, Sub-Challenge D, Workshop KOIL, Kashiwa
- 12/3 TIA-Takehashi Poster Workshop 2018 The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa
- 12/17-12/18 Post-K Project Priority Issue 7, The 4th Symposium ISSP, Kashiwa
- 2/4 PCoMS Skill improvement training for graduate students & postdocs ISSP, Kashiwa
- 3/5 The visualization Symposium 2019 Akihabara UDX theater, Tokyo

Laser and Synchrotron Research Center (LASOR Center)

Laser and Synchrotron Research (LASOR) Center started from October, 2012. LASOR Center aims to promote material sciences using advanced photon technologies at ISSP by combining the "Synchrotron Radiation Laboratory" and "Advanced Spectroscopy Group". These two groups have long histories since 1980's and have kept strong leaderships in each photon science fields for a long time in the world. In the past several decades, the synchrotron-

based and laser-based photon sciences have made remarkable progresses independently. However, recent progresses in both fields make it feasible to merge the synchrotron-based and laser based technologies to develop a new direction of photon and materials sciences. In the LASOR Center, extreme laser technologies such as ultrashort-pulse generation, ultraprecise control of optical pulses in the frequency domain, and high power laser sources for the generation of coherent VUV and SX light are intensively under development. The cutting edge soft X-ray beamline is also developed at the synchrotron facility SPring-8.

LASOR center aims three major spectroscopic methods [ultrafast, ultra-high resolution, and operand spectroscopy] by three groups [extreme laser science group, soft-X-ray spectroscopy and materials science group, and coherent photon science group], as illustrated in Fig. 2. Under this framework, various advanced spectroscopy, such as ultra-high resolution photoemission, time-resolved, spin-resolved spectroscopy, diffraction, light scattering, imaging, microscopy and fluorescence spectroscopy are in progress by employing new coherent light sources based on laser and synchrotron technologies that cover a wide spectral range from X-ray to terahertz. In LASOR Center, a variety of materials sciences for semiconductors, strongly-correlated materials, molecular materials, surface and interfaces, and bio-materials are studied using advanced light sources and advanced spectroscopy. Another important aim of LASOR Center is the synergy of photon and materials sciences.

Most of the research activities on the extreme laser development and their applications to materials science are performed in the ISSP buildings D and E at Kashiwa

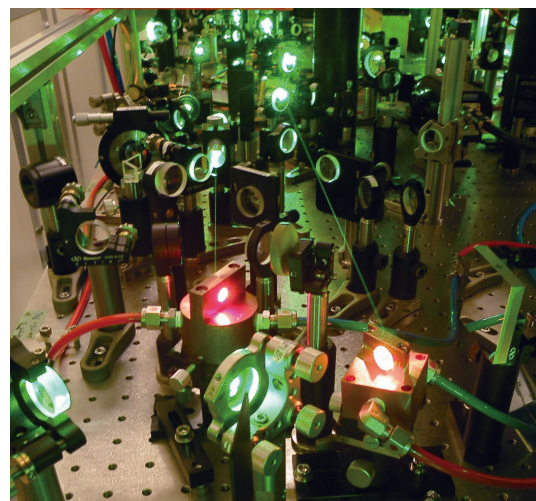


Fig. 3. Close look of a high-peak-power ultrashort-pulse laser

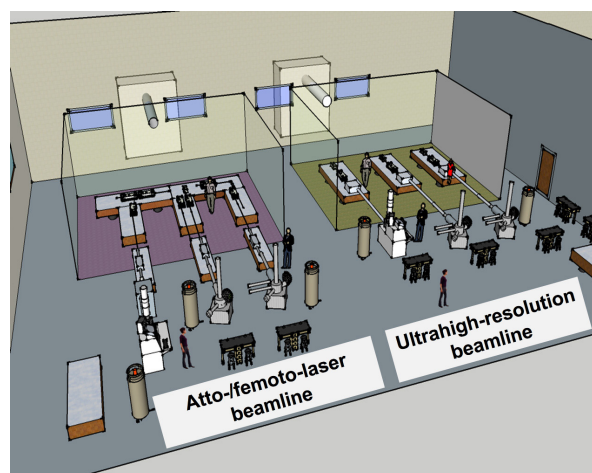


Fig. 4. Newly designed building E was constructed for new extreme VUV- and SX-lasers and new spectroscopy.



Fig. 1. Open ceremony of LASOR center on October 2012.

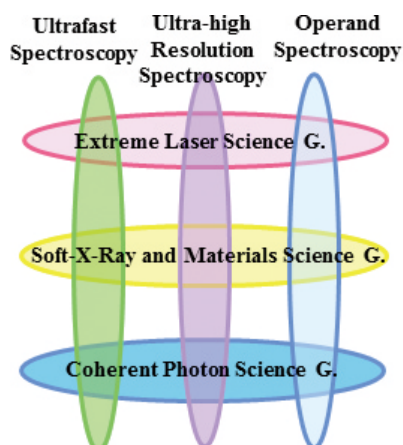


Fig. 2. Developments of advanced spectroscopy at LASOR center by three groups

Campus where large clean rooms and the vibration-isolated floor are installed. On the other hand, the experiments utilizing the advanced synchrotron source are performed at a beamline BL07LSU in SPring-8 (Hyogo).

- Extreme Laser Science Group

The advancement of ultrashort-pulse laser technologies in the past decade has transformed the laser development at ISSP into three major directions, (i) towards ultrashort in the time domain, (ii) ultra high resolution in the spectral domain, and (iii) the extension of the spectral range, with extreme controllability of the laser sources. For ultrafast spectroscopy, we have developed carrier-envelope phase stable intense infrared light source that can produce sub-two cycle optical pulses for high harmonic and attosecond pulse generation. So far we observed coherent soft-X-ray radiation extending to a photon energy of ~ 330 eV. The simulation predicts the soft-X-ray field consists of single isolated attosecond pulses. For ultra-high resolution spectroscopy, fiber-laser-based light sources are intensively developed for producing EUV pulses for high resolution and time-resolved photoemission spectroscopy as well as extending the frequency comb to ultraviolet or infrared for various applications. The spectral range of intense optical pulses are being extended from visible to IR, MIR and THz ranges. Various types of high-repetition-rate ultrastable light sources are developed for laser-based ultrahigh resolution photoemission spectroscopy, high-average-power EUV generation in an enhancement cavity, and frequency comb spectroscopy

for atomic physics, astronomical application, and frequency standards.

• Soft-X-ray and Materials Science Group

Recently, VUV and SX lasers have progressed very rapidly. They become very powerful for the materials science using the cutting-edge VUV and SX spectroscopy. Especially, angle resolved photoemission spectroscopy (ARPES) is very powerful to know the solid state properties. Laser has excellent properties, such as coherence, monochromaticity, polarization, ultra-short pulse, high intensity, and so on. By using monochromatic laser light, the resolution of ARPES becomes about 70- μ eV. The materials science with sub-meV resolution-ARPES is improved drastically by using high resolution laser. For example, superconducting gap anisotropy of the superconductors and Fermiology of the strongly correlated materials are studied very well. On the other hand, using pulsed laser light, the time-resolved photoemission in fs region becomes powerful to know the relaxation process of photo-excited states of the materials. Furthermore, by using CW laser with circular polarization in VUV region, the photoelectron microscopy (PEEM) is developed. The spatial resolution of nm resolution is very powerful for the study of nanomagnetic materials.

• Coherent Photon Science Group

The coherent-photon science group has main interests in exploring a variety of coherent phenomena and non-equilibrium properties of excited states in condensed matters, in

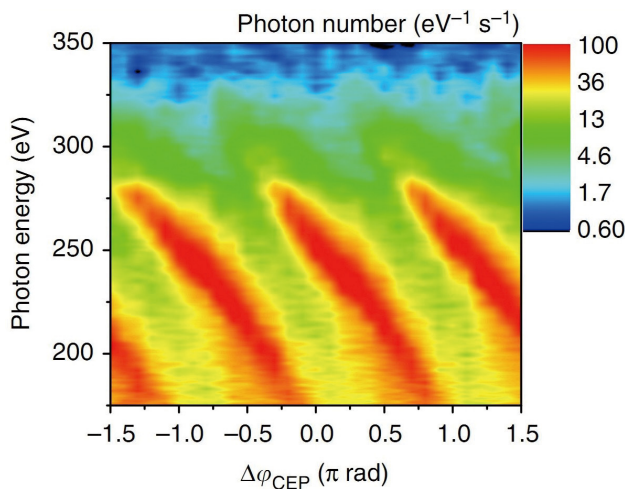


Fig. 5. Phase-dependence of high harmonic spectra in soft X rays.

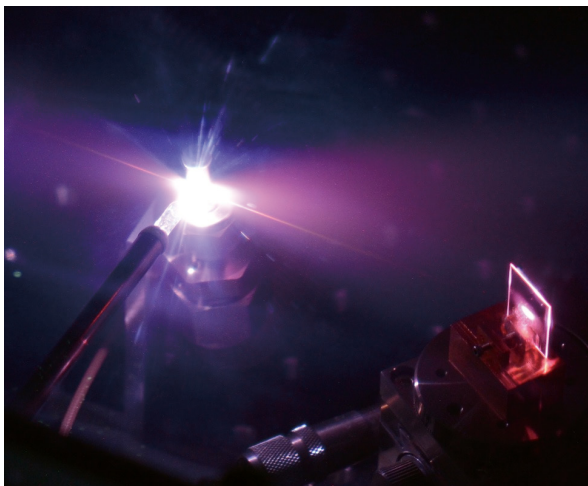


Fig. 6. 10-MHz high harmonic generation in an enhancement cavity.

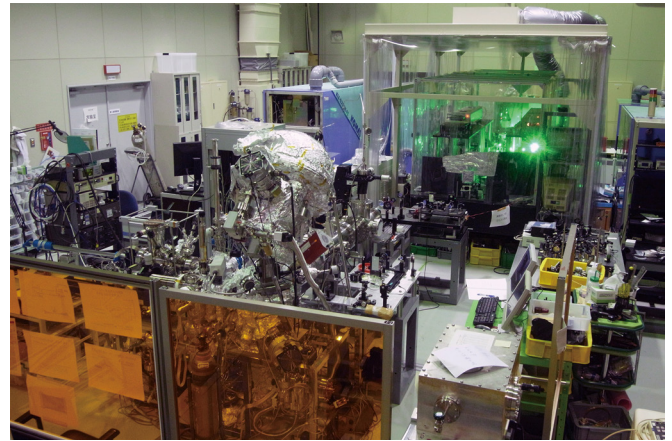


Fig. 7. Pump-probed photoemission system using 60-eV laser

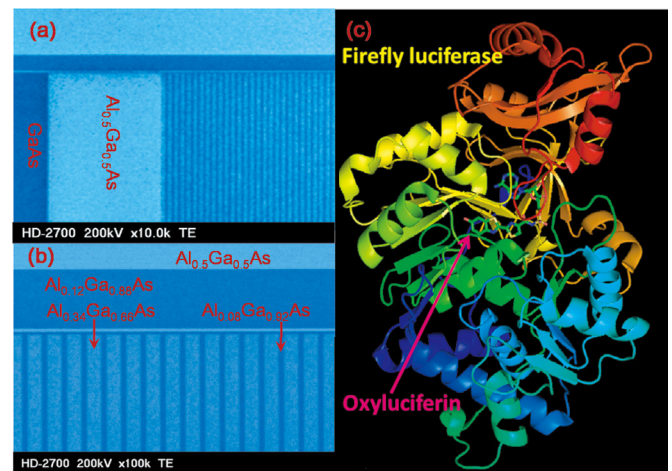


Fig. 8. Photonics devices under study: (left panel) semiconductor quantum wires and (right panel) firefly-bioluminescence system consisting of light emitter (oxyluciferin) and enzyme (luciferase)

collaborations with research groups in charge of photoemission, operant-spectroscopy and extreme laser science. This group covers a wide range of materials, from semiconductors, ferroelectrics, antiferromagnets, and superconductors to biomaterials. Various ultrafast optics technologies such as femtosecond luminescence, terahertz spectroscopy, and pump-and-probe transmission/reflection spectroscopy are applied to studies on dynamics of photo-excited carriers and photo-induced phase transitions. Coherent control of matters using phase-locked strong terahertz or mid-infrared pulse is extensively studied. Advanced photonics devices are intensively studied, such as quantum nano-structure lasers with novel low-dimensional gain physics, low-power light-standard LEDs, very efficient multi-junction tandem solar cells for satellite use, and wonderful bio-/chemi-luminescent systems for wide bio-technology applications.

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

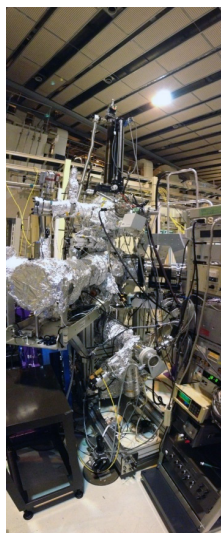


Fig. 1. TR-SX station

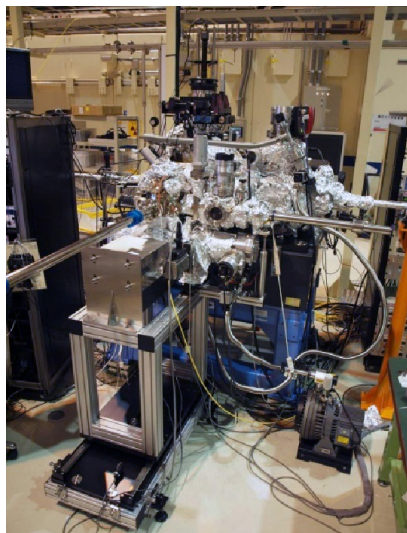


Fig. 2. 3D-nano ESCA station



Fig. 4. Ambient pressure photoemission

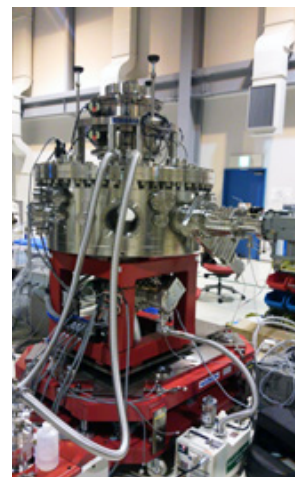


Fig. 5. Soft X-ray diffraction station

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 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: five endstations, i.e. time-resolved soft X-ray spectroscopy (TR-SX) equipped with a two-dimensional angle-resolved time-of-flight (ARTOF) analyzer (Fig. 1), three-dimensional (3D) nano-ESCA station equipped with the Scienta R-3000 analyzer (Fig. 2), high resolution soft X-ray emission spectroscopy (XES) stations (Fig. 3) 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 ambient pressure photoemission (Fig. 4) and soft X-ray diffraction (Fig. 5) which are also open for public use from 2018, and soft X-ray resonant magneto-optical Kerr effect (MOKE), two dimensional photoelectron diffraction 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 TR-SX station have established the laser-

pump and SR-probe method with the time-resolution of 50 ps which corresponds to the SR pulse-width; 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 enabled 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. The soft X-ray diffraction station has been fully constructed and the time-resolved measurement is available by using lasers at the TR-SX station. In 2018, 242 researchers made their experiments during the SPring-8 operation time of 4608 hours.

- High-resolution Laser SARPES at E-building

Spin- and angle-resolved photoelectron spectroscopy (SARPES) is a powerful technique to investigate the spin-dependent electronic states in solids. In FY 2014, Laser and Synchrotron Research Center (LASOR) SRL constructed a new SARPES apparatus (Fig. 6), which was designed to provide high-energy and -angular resolutions and high efficiency of spin detection using a laser light instead of the synchrotron radiation in Institute for Solid State Physics. The achieved energy resolution of 1.7 meV in SARPES spectra is the highest in the world at present. From FY 2015, 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

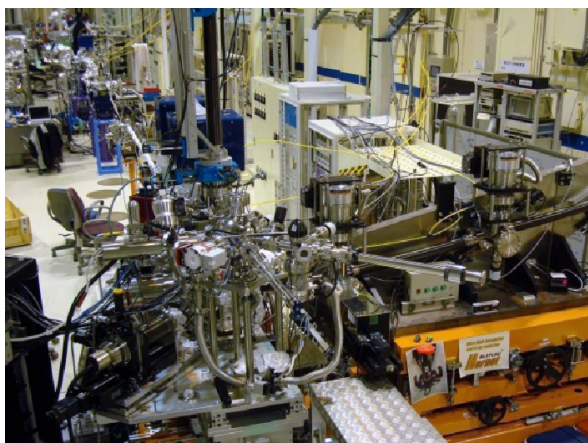


Fig. 3. Soft X-ray emission station

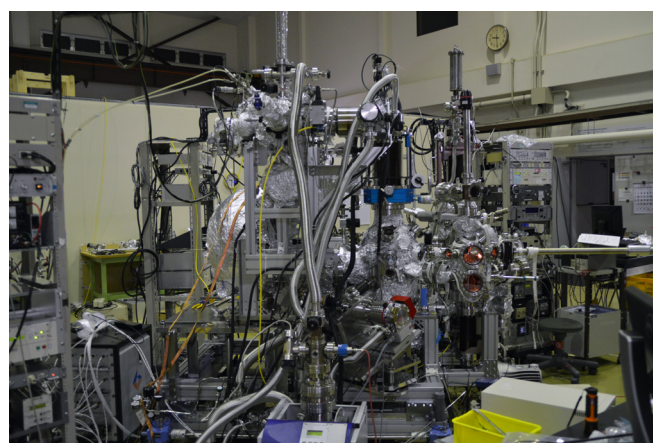


Fig. 6. Laser-SARPES system at E-building

connected each other via UHV gate valves. The electrons are excited with 6.994-eV photons, yielded by 6th harmonic of a Nd:YVO₄ quasi-continuous wave laser with repetition rate of 120 MHz. The hemispherical electron analyzer is a custom-made ScientaOmicron 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 machine 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.