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 2017 and developed software were released as DCore and (a new version of) HPhi. 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 2017, totally 302 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 (121)
Strongly Correlated Quantum Systems (29)
Cooperative Phenomena in Complex, Macroscopic Systems (117)

In all the three categories, most proposals involve both methodology and applications. The results of the projects are reported in 'Activity Report 2017' 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 2017, the following three invited papers are included:

"Development of open source software HΦ", Mitsuaki KAWAMURA, Takahiro MISAWA, Youhei YAMAJI, and Kazuyoshi YOSHIMI

"Monte Carlo study of Ising model with non-integer effective dimensions", Synge TODO

"Recent Extensions and Applications of Parallel Cascade Selection Molecular Dynamics Simulations”, Ryuhei HARADA and Yasuteru SHIGETA

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	12	1.2k	-	1.2k	-
B	1k	100	twice a year	62	56.9k	-	40.0k	-
C	10k	1k	twice a year	171	1433.8k	-	633.0k	-
D	10k	1k	any time	6	26.5k	-	24.5k	-
E	30k	3k	twice a year	16	474.0k	-	258.0k	-
S			twice a year	0	0	-	0	-
SCCMS				35	271.5k	-	271.5k	-
Total				302	2263.9k	-	1228.2k	-

Table 1. Research projects approved in 2017
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. There was no official System C operation in SY2017 due to system replacement.

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 Laboratory (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). Since HRC covers a wide energy and Q-range (10μeV < $\hbar\omega$ < 2eV and 0.02Å^{-1} < Q < 50Å^{-1}), it became 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 FY2016 covers wide range in magnetism and strongly correlated electrons. One of the research highlights is the observation of the magnetic excitations from two-dimensional interpenetrating Cu framework (see Fig. 1) in $Ba_2Cu_3O_4Cl_2$ [1]. Combination of position sensitive detectors in wide scattering angle and strong neutron flux in wide energy range enables the effective measurement of spin dispersion as shown in Fig. 2. The magnetic excitations were found to emerge from interpenetrating laminar sublattices of Cu_A and Cu_B spins each of which is arranged on a square-lattice. Lower energy excitations between 3 and 20meV originate from the weakly coupled Cu_B spins and closely resemble the $Sr_2Cu_3O_4Cl_2$

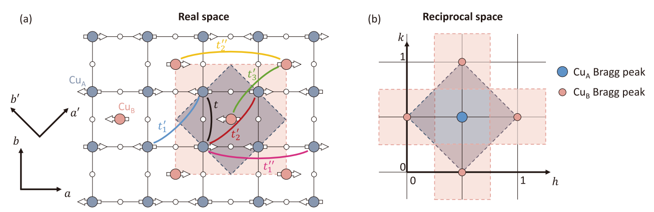

Fig. 1. (a) Depiction of the magnetic structure in $Ba_2Cu_3O_4Cl_2$. The circles filled by blue and red colors represent Cu_A and Cu_B sites, respectively. Empty circles denote intermediate O atoms. The shaded blue and red outlines represent the magnetic unit cells when Cu_A and Cu_A-Cu_B are magnetically ordered, respectively. The hopping terms between ions used in our modelling are connected by colored lines. (b) Reciprocal space of $Ba_2Cu_3O_4Cl_2$ projected onto the (h, k) plane. The shaded blue and red outlines represent the magnetic Brillouin zones of the two sublattices: Cu_A and Cu_B respectively. Bragg scattering from each sublattice is shown at the magnetic zone center.

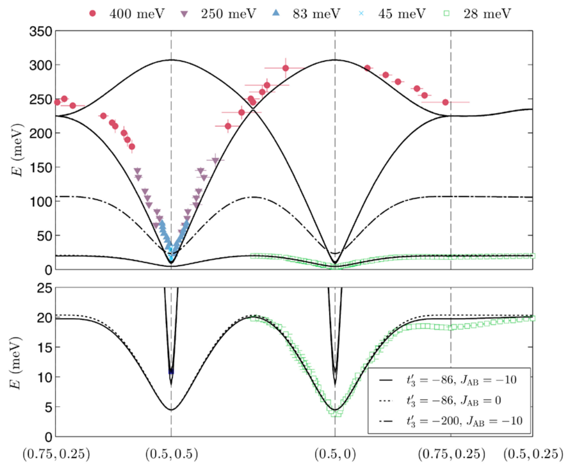

Fig. 2. Dispersion along high-symmetry directions in the 2D Brillouin zone obtained at 6 K. Extracted dispersion was obtained from TOF measurements using neutron incident energies in the 28–400meV range. The simulated spin-wave spectrum is shown for different parameters of t'_3 and J_{AB} in units of meV.

spectra [2]. In addition, the Cu_A-like excitations were truck up to 300 meV, which have not been previously studied in this family of materials. A single-band Hubbard model was characterized to characterize the spin dynamics from which an effective spin Hamiltonian was derived. A suitable parameterization of the magnetic spectrum was found using linear spin-wave theory. Careful analysis of the Cu_A and Cu_B spin-gaps provided the out-of-plane coupling, the strength of the Cu_A and Cu_B coupling as well as the exchange anisotropies. The interpenetrating Cu_B sublattice was found to be only weakly coupled to the Cu_A spins. Along the magnetic Brillouin zone boundary of weakly-coupled Cu_B spins, a significant dispersion was observed, which is argued as a quantum effect beyond linear spin wave theory.

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] P. Babkevich *et al.*, Phys. Rev. B **96**, 014410 (2017).
[2] Y. J. Kim *et al.*, Phys. Rev. B **64**, 024435 (2001).

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 985 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 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 76 in the FT of 2017.

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

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.

	Alias	Type	B_{max}	Pulse width Bore	Power source	Applications	Others
Building C Room 101-113	Electro- Magnetic Flux Compression	destructive	1000 T	μs 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	μs 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	μs 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

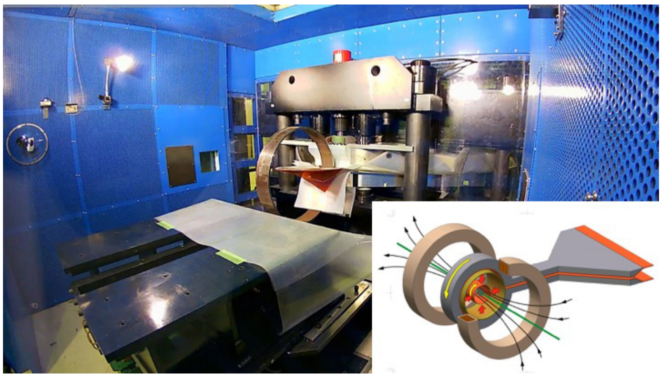

Fig. 3. (Build. C) A view of the electro-magnetic flux compression 1000 T-class megagauss generator set in side of an anti-explosive house. 1000 T project started since 2010, and finally condenser banks of 9 MJ (5 MJ + 2 MJ +2 MJ) as a main system with the 2 MJ sub bank system for the seed field have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

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 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 (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), 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. 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.

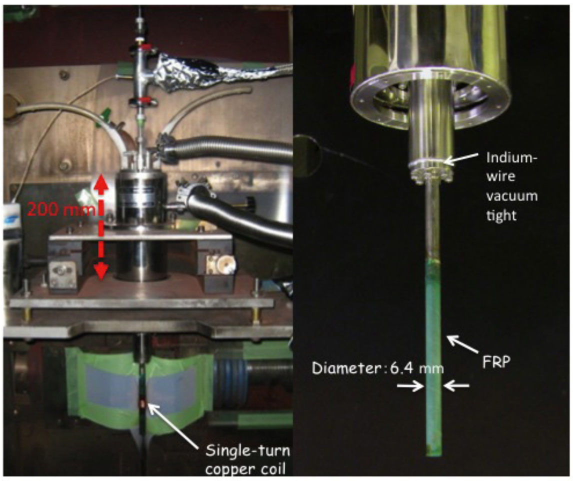

Fig. 4. Schematic picture of the H-type single-turn coil equipped with 50 kV, 200 kJ fast operating pulse power system, capable of generating 300 T within 3 mm bore coil.

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 information 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 FY2017:

- 7/11-7/12 Post-K Project Priority Issue 7 , The 2nd Annual Meeting (Koshiba Hall, Hongo, Tokyo)
- 6/7 PCoMS Matching Workshop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 6/16 Post-K Project Priority Issue 7, Sub-issue G Work shop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)

Fig. 1. Members of CCMS.

- 6/29 CCMS Hands-On, HΦ (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 7/20 CCMS Hands-On, ALPS (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 8/1 Post-K Projec Priority Issue 5, The 1st meeting (Station Conference Manseibashi, Tokyo)
- 8/28 Post-K Project Exploratory Challenge 1, Sub-Challenge D, The 3rd Tensor Network Method Study Group (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 8/30 CCMS Hands-On, mVMC (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 9/11 Post-K Project Priority Issue 7, the 3rd Forum on Academia, Industry and Government collaboration for Creation of new functional devices and high-performance materials (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 9/12 TIA-Kakehashi Poster Workshop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 10/3 CCMS Hands-On, MareriApps Live (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 10/10 RIST, The 4th Materials Workshop (Akihabara)
- 10/13 CCMS Hands-On, OpenMX(TIA)(The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 10/24 Post-K Project Priority Issue 5, The 2nd meeting (Station Conference Manseibashi, Tokyo)
- 10/26 CCMS Hands-On, xTAP (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 10/30 Post-K Project Exploratory Challenge 1, Sub-Challenge B and D, Work shop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 10/31 Post-K Project Exploratory Challenge 1, Sub-Challenge D, Work shop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 11/24 The 1st SALMON Tutorial (TIA) (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 12/4 Next QUMAT2017 (Faculty of Engineering, the University of Tokyo , Hongo, Tokyo)
- 12/5-12/6 Post-K Project Priority Issue 7, The 3rd Symposium (ISSP, Kashiwa)
- 12/20 CCMS Hands-On, RESPACK (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 12/22 Post-K Project Priority Issue 7, Sub-issue G, The 6th Work shop (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 12/26 Post-K Project Priority Issue 7, Sub-issue G, The 7th Work shop (Tokyo University of Science, Katsushika campus)
- 1/13 Post-K Project Priority Issue 7, Sub Issue E and Post-K Project Exploratory Challenge, Sub-Challenge A, The 2nd Work shop (AIST Kansai, Osaka)
- 1/26 CCMS Hands-On, OpenMX(TIA) (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 2/5-2/6 The 3rd Element Strategy Initiative, To Form Core Research Centers Symposium on the Elements Strategy Large-scale Research Facilities (Ito Hall, Hongo, Tokyo)
- 2/13 RIST, The 5th Materials Workshop (Akihabara)
- 2/20 Post-K Project Priority Issue 5, The 3rd meeting (Station Conference Manseibashi, Tokyo)
- 2/24 RIST, Mieruka Symposium (Visualization Symposium) 2018 (Nihonbashi Life Science Hub, Tokyo)
- 3/30 Post-K Project Priority Issue 7, The 2nd Positron Diffraction Work Shop (KEK, Tsukuba)
- 1/23-1/25 Innovation Camp 2018 for Computational Materials Science (Hokkaido)
- 1/26 CCMS Hands-On, OpenMX (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 2/27 PCoMS Skill-up Training (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 3/5 CCMS Hands-On, MateriApps (The University of Tokyo Kashiwa Campus Station Satellite, Kashiwa)
- 3/12-3/13 Symposium on Materials Science and Technology towards Energy-Saving Society (MASTES2018) (Takeda Hall, Hongo, 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

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

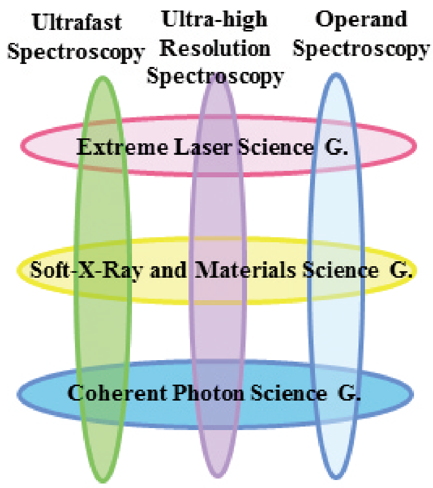

Fig. 2. Developments of advanced spectroscopy at LASOR center by three groups

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 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

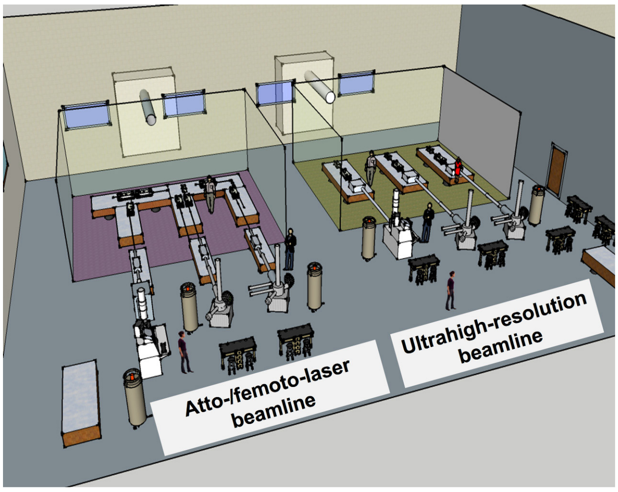

Fig. 4. Newly designed building E was constructed for new extreme VUV- and SX-lasers and new spectroscopy.

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-μeV. 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

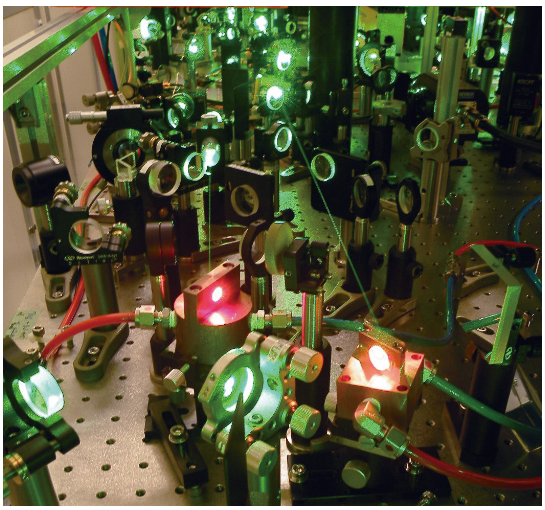

Fig. 3. Close look of a high-peak-power ultrashort-pulse laser

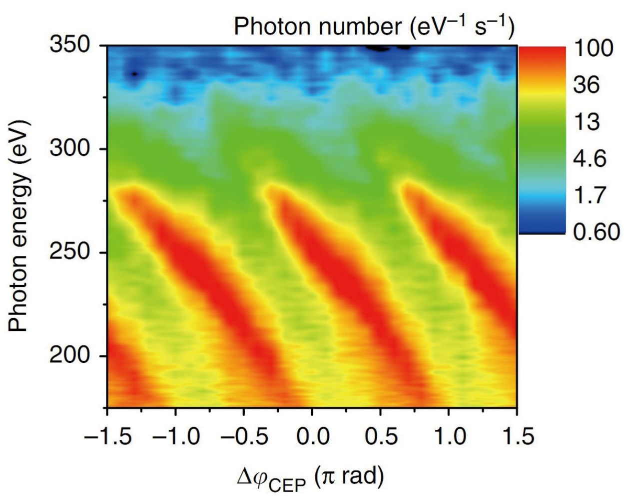

Fig. 5. Phase-dependence of high harmonic spectra in soft X rays.

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

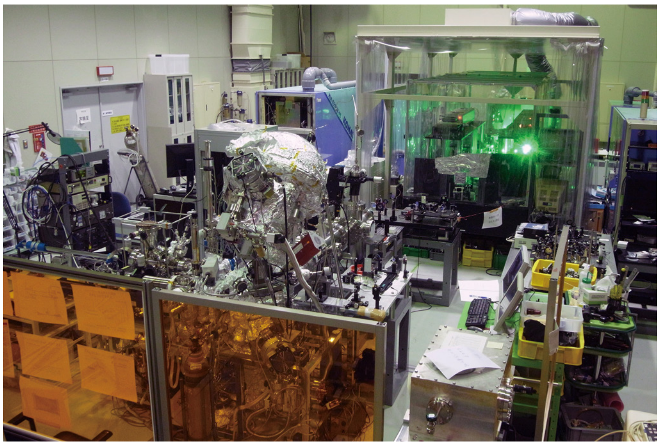

Fig. 7. Pump-probed photoemission system using 60-eV laser

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 collaborations with research groups in charge of photoemission, operand-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.

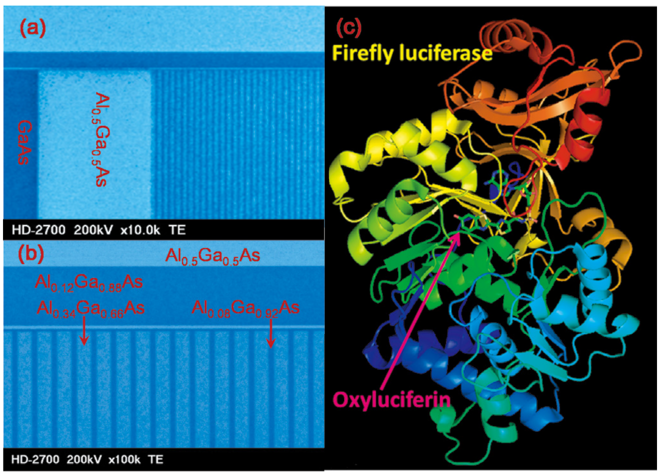

Fig. 8. Photonics devices under study: (left panel) semiconductor quantum wires and (right panel) firefly-bioluminescence system consisting of light emitter (oxyluciferin) and enzyme (luciferase)

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 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

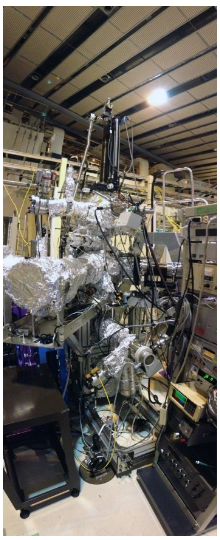

Fig. 1. TR-SX station

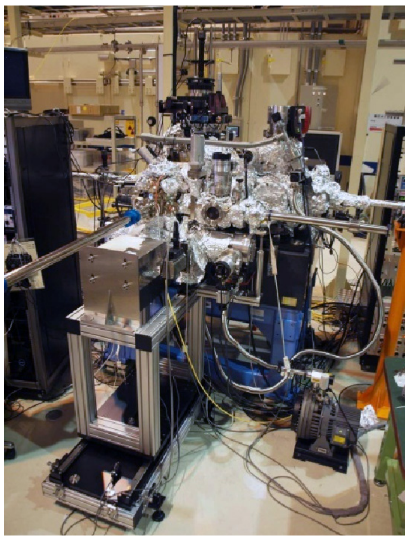

Fig. 2. 3D-nano ESCA station

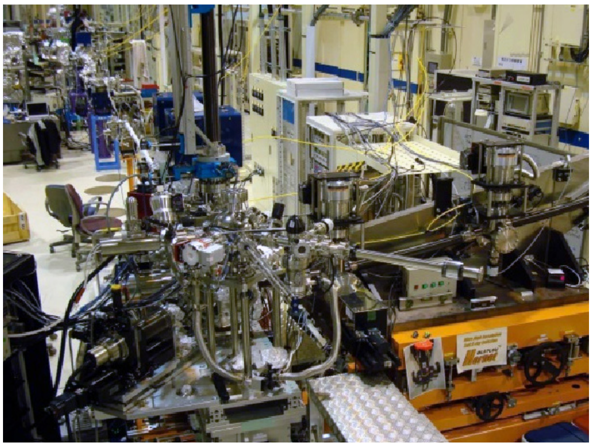

Fig. 3. Soft X-ray emission station

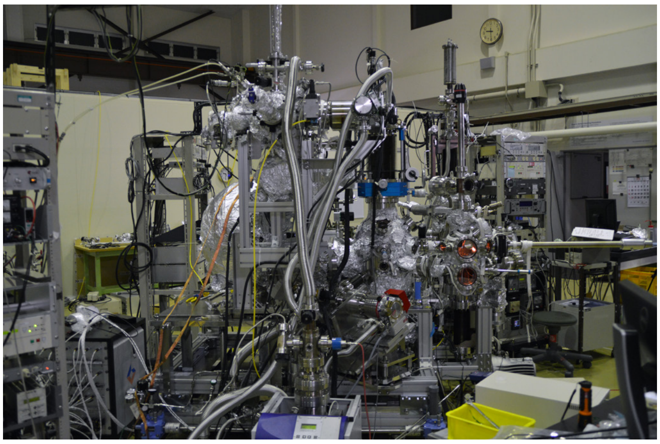

Fig. 6. Laser-SARPES system at E-building

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 soft X-ray resonant magneto-optical Kerr effect (MOKE) (Fig.4) and soft X-ray diffraction (Fig. 5), ambient pressure photoemission, 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 will enable real ambient pressure experiments in the near future. 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. Each end-station has now been opened fully to outside users. In 2015, 176 researchers made their experiments during the SPring-8 operation time of 4805 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 connected each other via 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 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 simultaneously the angle-resolved photoelectron spectroscopy with two-dimensional (energy-momentum) detection. So far, spin-dependent band structures of more than 10 materials have been studied by 4 outside groups.

Fig. 4. Soft X-ray MOKE station

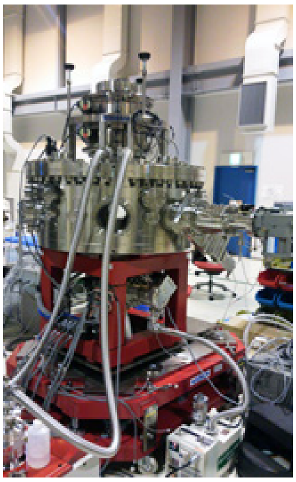

Fig. 5. Soft X-ray diffraction station