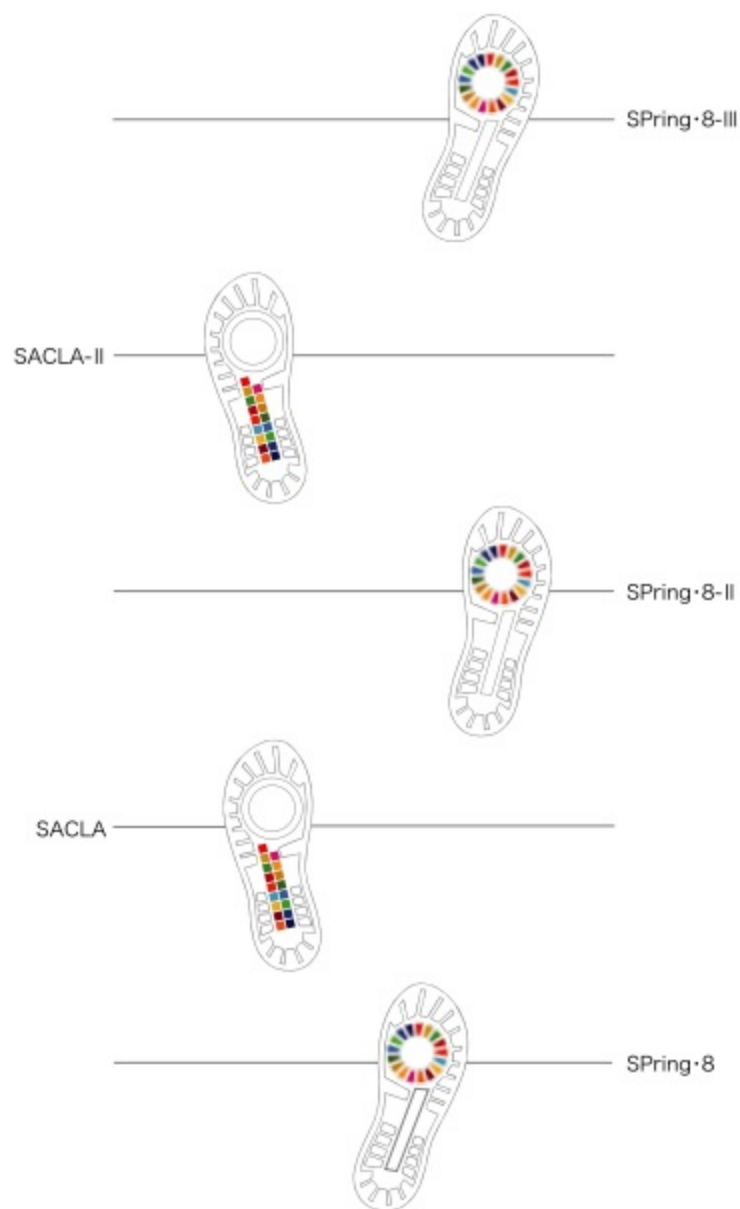




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Issued: September 2022 RIKEN 2022-036

Spring-8 toward a sustainable future 2022

RIKEN SPring-8 Center



SPring-8
 toward a sustainable future
2022



List of Research by Field

Life Science & Medicine

Life Science

Drug Discovery

Medicine & Health Care

Materials & Devices

Metal Material

Non-metal Material

Magnetic Materials

Semiconductors & Electronics

Crystal Structure & Molecular Structure

Environment, Life & Society

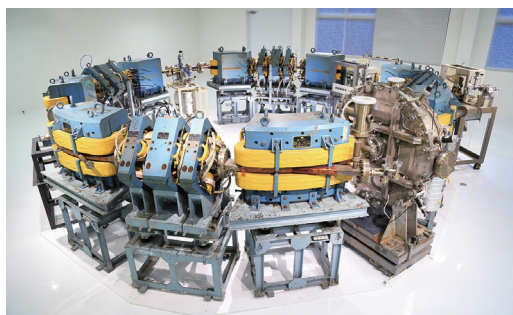
Living

Environment

Energy

Quality Control & Production Process

Earth & Planetary



Life Science

- 1-1 Quantum physics helps destroy cancer cells
- 1-2 Discovery of bird fossils from a new genus and species; The most primitive in Early Cretaceous birds
- 2-1 The budding mechanisms of parainfluenza viruses from infected cells
- 2-2 To improve biofuel production using animal cellulases
- 3-1 Expectations for accelerating drug screening
- 3-2 Expectations for accelerating cyclic peptide drug discovery
- 4-1 Survival strategy of pathogenic bacteria by detoxification
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- 5-1 Visualization of the intracellular localization of fatty acids and changes in lipid metabolism
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- 6-1 How two enzymes produce right-hand- and left-hand-type molecules
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Drug Discovery

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- 23-1 Successful removal of oxygen vacancies from metal oxide catalyst surfaces
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Preface

This booklet, "SPring-8 Toward a Sustainable Future," organizes the results of SPring-8 and SACLA by field and links them with the Sustainable Development Goals (SDGs) established by the United Nations.

The first edition was published in 2020 and has progressed to the third edition published in April 2021. Fortunately, strong reader support and demand have motivated us to move forward with a new edition incorporating the latest findings. The SDGs were not well known globally when we were preparing the first edition. Voices called for the SDGs to be disseminated through textbooks and school education. Now, we feel that the world is finally catching up with awareness.

Last August, SPring-8/SACLA issued a Green Facility Declaration in line with the Japanese government's 2050 Carbon Neutral Declaration and Green Innovation Strategy.

SPring-8 and SACLA are implementing Sustainable Development Goals (SDGs) toward 2030. They support and facilitate industry, government, and academia research and development to achieve carbon neutrality by 2050. The declaration states our commitment to supporting these activities more strongly than before and continuing to strive to reduce energy consumption in the facilities further. Industry-government-academia collaboration supports our efforts toward achieving the SDGs and improving sustainability.

This booklet can serve as a guide to reporting our efforts and progress. We believe that the update of this booklet should be an ongoing activity and have decided to include the year on the cover for clarity. We hope that the readers continue to find value in this booklet.

September 2022 In issuing the revised
Director
RIKEN SPring-8 Center

石川 裕也



SPring-8's Activities Supporting the SDGs



ELIMINATION OF POVERTY

Contributes to the development of materials and devices that enable people to connect with each other and work anywhere around the world



ZERO HUNGER

Clarifies how our body takes in nutrients, and contributes to the development of functional foods



GOOD HEALTH AND WELL-BEING

Clarifies the structures and functions of proteins applicable for pharmaceutical research and combating disease



QUALITY EDUCATION

Addresses current problems, and describes them in common language that anyone can understand



GENDER EQUALITY

Reduces gender discrepancies by advancing and popularizing science



CLEAN WATER AND SANITATION

Reveals the mechanisms causing various types of pollution



AFFORDABLE AND CLEAN ENERGY

Contributes to the development of energy-saving and compact devices



DECENT WORK AND ECONOMIC GROWTH

Develops technology that promotes efficient production



INDUSTRY, INNOVATION AND INFRASTRUCTURE

Explores new materials and phenomena, and provides guidelines for industrial applications



REDUCED INEQUALITY

Contributes to the creation of materials and devices for all people, anywhere in the world



SUSTAINABLE CITIES AND COMMUNITIES

Contributes to the development of robust, light and restorable housing materials



RESPONSIBLE CONSUMPTION AND PRODUCTION

Investigates the destruction mechanisms of materials and provides guidelines for incorporating the eventual breakdown of materials in their designs



CLIMATE ACTION

Investigates how the states of materials change depending on temperature and humidity, and contributes to the development of disaster-resistant materials



LIFE BELOW WATER

Researches the effects of marine pollution on materials



LIFE ON LAND

Clarifies the mechanisms of photosynthesis, discovers techniques for artificial photosynthesis, and contributes to forest protection



PEACE, JUSTICE AND STRONG INSTITUTIONS

Contributes to forensic investigations

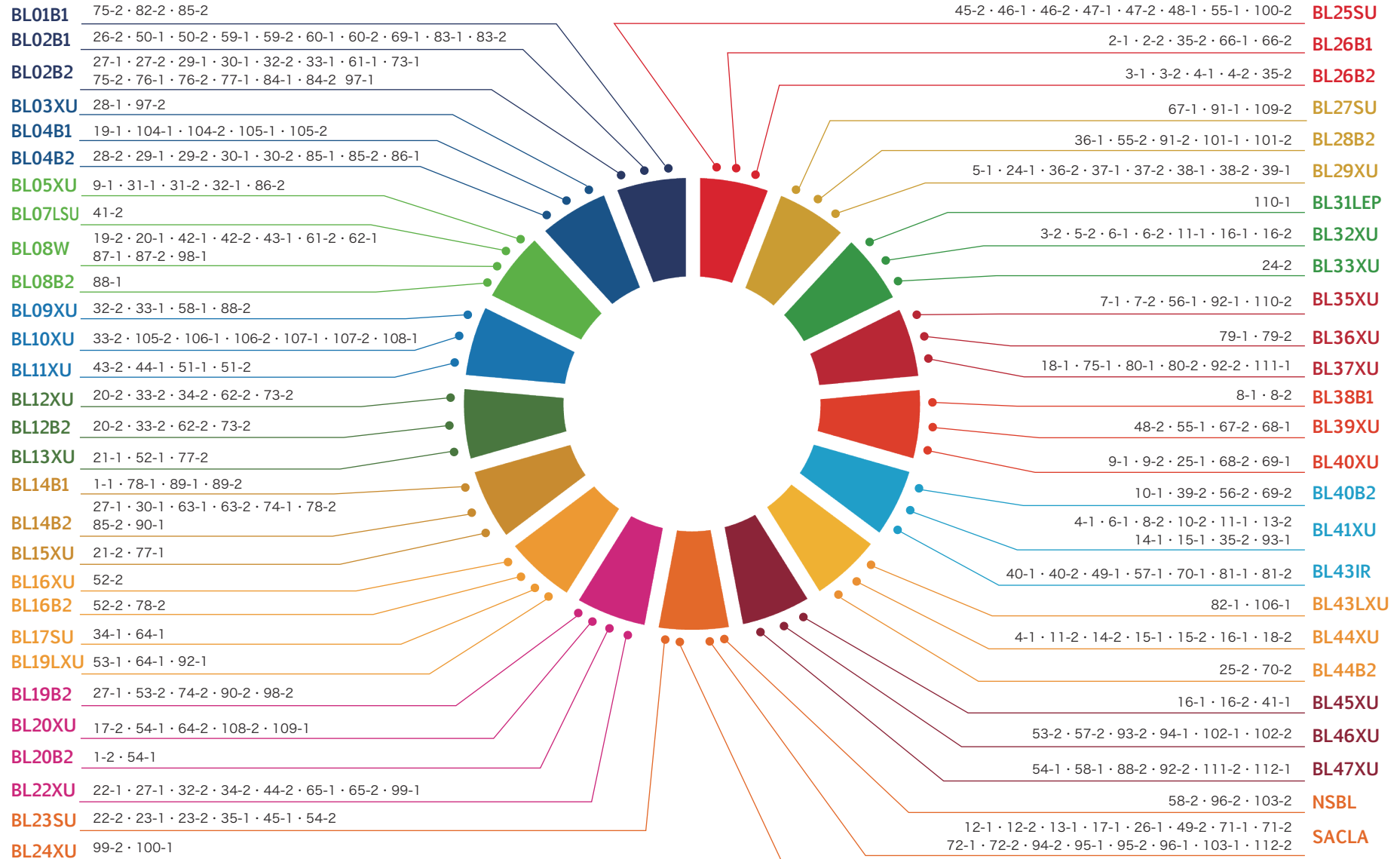


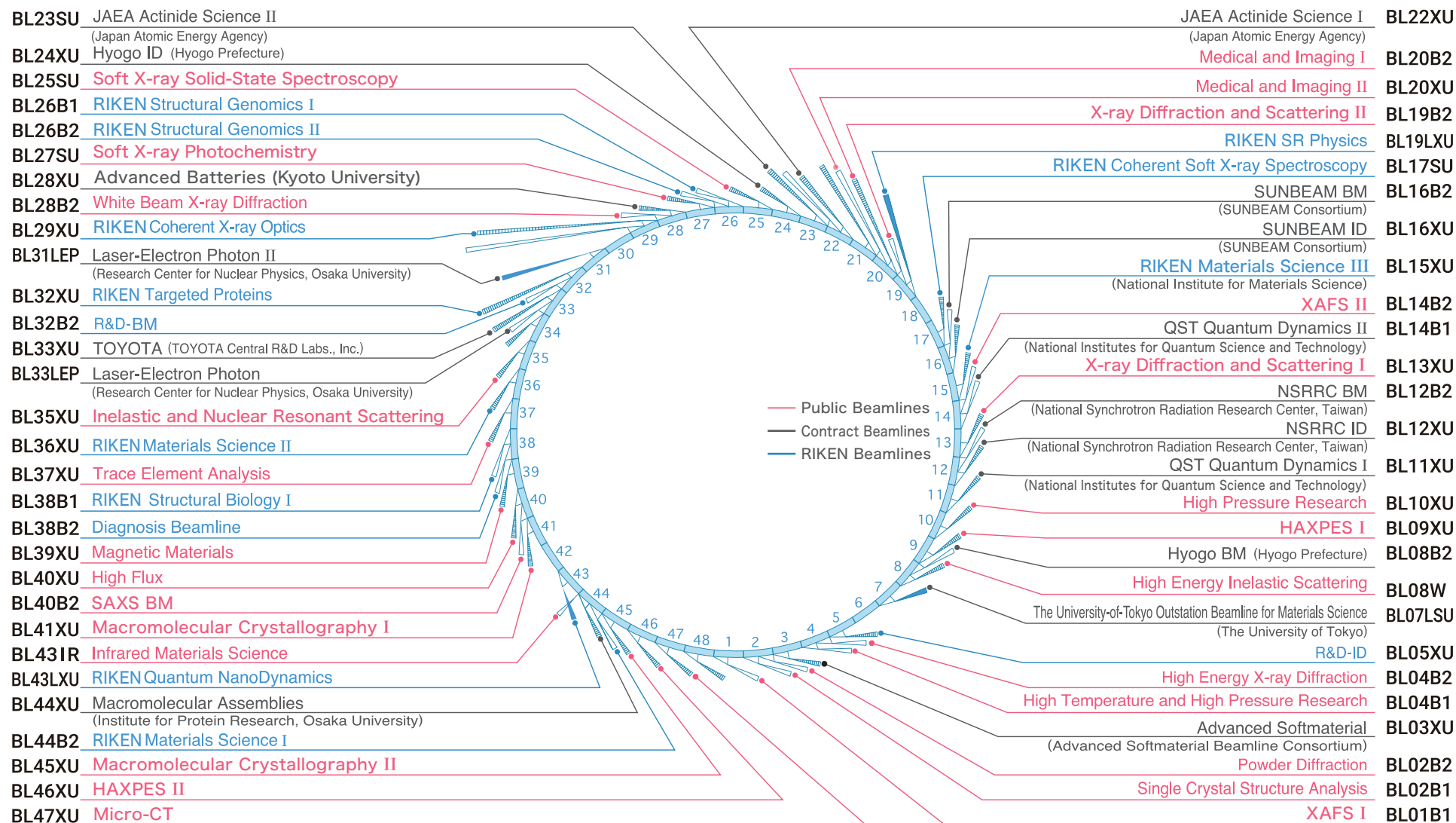
PARTNERSHIPS FOR GOALS

Promotes scientific research in collaboration with synchrotron facilities around the world



Contents by Beamlines





Notes for beamline abbreviations

XU (Hard X-rays by undulators) Hard X-rays with high brilliance that are generated by in-vacuum undulators
 SU (Soft X-rays by undulators) Soft X-rays that are generated by undulators with a long magnetic period
 B1/B2 (Bending Magnets) Broadband X-rays that are generated by bending magnets

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- 27-2 New semiconducting material "Boron Monosulfide Sheet (BS Sheet)"
- 28-1 To elucidate the curing mechanism of highly heat-resistant epoxy resins
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- 29-2 Structure in densified silica glass: Characterizing order within disorder
- 30-1 Success in synthesizing coordination polymer glass
- 30-2 To optimize synthesis of lead-free piezoelectric ceramics
- 31-1 To develop materials for future life
- 31-2 Restoring the 3D structure of fibrous material from its X-ray diffraction pattern
- 32-1 To control toughness and suppleness at the molecular level
- 32-2 To develop materials that shrink when heated
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- 34-2 To develop novel negative thermal expansion materials
- 35-1 Testing graphene protection against fast oxygen
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- 36-1 To develop new tire materials with superior wear resistance
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- 37-1 To understand the heterogeneity of molecular motion, which holds the key to the glassy state
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- 38-1 New developments in single-shot coherent diffractive imaging
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- 39-1 X-ray nanoprobe scanner
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- 43-1 Visualizing the electronic state responsible for high-temperature superconductivity
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- 44-1 Electronic states against expectations
- 44-2 Tolerance of spin-Seebeck thermoelectricity against irradiation by swift heavy ions
- 45-1 To fabricate novel magnetic topological heterostructures
- 45-2 Guidelines for lifetime resistance to heat and corrosion in magnetic properties of Sm-Co magnets
- 46-1 To develop power-saving spintronics devices
- 46-2 Successful imaging of an HDD write head in operation with an accuracy of 10 billionth of a second
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- 47-2 To develop devices with new functionality
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- 48-2 To visualize the atomic arrangements of disordered alloys
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- 49-2 Ultrafast magnetic control

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- 50-1 To fabricate a supramolecular coil with a current response to magnetism
- 50-2 To develop high-performance organic semiconductors exhibiting anomalous structural phase transition behaviors
- 51-1 *In-situ* observation of GaN growth on a graphene surface
- 51-2 Anomalous lattice deformation in GaN/SiC (0001)
- 52-1 To improve device performance by strain control
- 52-2 To develop and adopt LEDs with higher efficacy and increased energy savings
- 53-1 To understand novel devices using hidden orders
- 53-2 High-performance nanosheet materials created at air/liquid interfaces
- 54-1 *In-situ* observation of die-attach solder joints that are cyclically energized
- 54-2 Exploring how semiconductors become ferromagnets
- 55-1 To develop clean & high-performance electronic devices: Snap-shooting of the onset of device operation
- 55-2 Next-generation semiconductor materials that bring about an energy-saving society
- 56-1 Unveiling the origin of low thermal conductivity
- 56-2 Design guidelines for efficient charge transport in thin film devices
- 57-1 Understanding the pressure response of an exotic "excitonic semiconductor"
- 57-2 To apply porous material coatings to plastic surfaces
- 58-1 Direct observation of "skewed electronic band structure" induced by electric polarization in ferroelectric materials
- 58-2 Next-generation semiconductor nanofabrication technology (EUV&BEUV lithography) made accessible to the world

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- 59-1 Observation of equilateral triangle molecules in solid materials
- 59-2 To develop one-dimensional charge transfer complexes with infinite anion chains
- 60-1 To develop flexible metal-organic structures
- 60-2 Precise electron density level analysis of functional materials
- 61-1 Ceramics showing excellent stretching in every direction
- 61-2 To develop novel nano-sheet materials with controllable conductivity
- 62-1 To observe photo-induced structural changes in perovskites
- 62-2 To understand the chemistry in high-efficient catalysts and solvents
- 63-1 Mechanism of forming porous materials (metal-organic frameworks)
- 63-2 To develop a new catalyst to convert CO₂ into methanol
- 64-1 Attosecond "stopwatch" utilizing the change in the PCI effect due to fluorescence emission
- 64-2 Probing surface morphology using X-ray imaging techniques
- 65-1 Barium titanate particle size control
- 65-2 3D imaging of a single nano-crystal
- 66-1 World's first nitrogen-doped nanotube molecules!
- 66-2 Moiré than meets the eye; Researchers make carbon nanotube patterns called moirés for materials
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- 70-2 Estimating the life of structural materials based on their chemical bonds
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- 73-2 Contract renewal for Taiwanese beamlines at SPring-8
- 74-1 To observe ice inside frozen food
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- 77-1 Multi-element nano-alloy exhaust gas purifying catalyst beyond Rh
- 77-2 To develop eco-friendly electronic devices
- 78-1 Waste pork bones turned into an adsorbent for toxic metals
- 78-2 To develop the Tungsten recycling process
- 79-1 Realizing high performance and high durability fuel cell electrode catalysts
- 79-2 X-ray photoelectron spectra measurements of fuel cells during operation
- 80-1 First application of transition edge sensor (TES) detector to fluorescence XAFS and environmental analysis
- 80-2 Genetic processes and environmental behaviors of Cs-bearing microparticles (CsMP) emitted by an atomic power plant accident
- 81-1 To develop new types of CO₂ adsorption materials aiming at construction of a carbon neutral society
- 81-2 To obtain a real picture of the lipids covering the body of an insect
- 82-1 The controversial meso-scale dynamics of liquid water

Energy

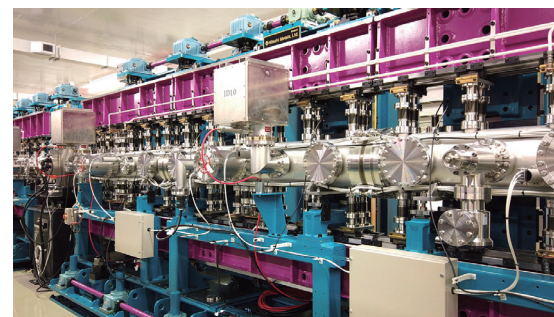
- 82-2 To promote higher-performance CO₂ hydrogenation catalysts
- 83-1 To synthesize a new porous material that decomposes water and generates hydrogen by light irradiation
- 83-2 Controlling large-amplitude atomic vibrations by pressure, leading to performance enhancement of thermoelectric materials
- 84-1 New oxide material that can be multi-cooled by a magnetic field and pressure
- 84-2 Precise control of electronic structure doubles thermoelectric performance
- 85-1 Producing hydrogen from water and sunlight using red rust
- 85-2 Successful development of nanospace design for electrode materials
- 86-1 Mixed crystalline/amorphous structures in battery cathodes
- 86-2 The hydration process of membrane electrolytes of fuel cells
- 87-1 To observe the self-organized pattern of electrode reactions in Li batteries during charging
- 87-2 To visualize the redox orbital of anion in an Li-rich cathode material
- 88-1 To develop safe rechargeable batteries
- 88-2 Creating solar cells with new power generation mechanisms
- 89-1 Hydrogen storage by earth-abundant metals
- 89-2 Synthesis of hydrides from alloys that were thought not to be hydrogenated
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- 91-1 Revealing lattice oxygen stability in battery cathode active materials
- 91-2 To develop new processes for solar-grade silicon
- 92-1 Effective information to design artificial enzymes
- 92-2 To elucidate the thermoelectric performance originating from changes in structure and electronic state
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- 93-2 To develop high-efficiency technology for organic photovoltaics
- 94-1 New molecular design for high-performance semiconducting polymers
- 94-2 Sub-micrometer focusing system for a soft X-ray free-electron laser
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- 95-2 Shortening X-ray pulse duration
- 96-1 Recording molecular movies with high spatial and temporal resolutions
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- 97-2 Aiming to reduce production costs from the correlation between fiber structure, physical properties, and manufacturing conditions
- 98-1 To visualize the Li ion during the charge and discharge processes
- 98-2 To fabricate high-performance structural materials
- 99-1 To advance welding technology
- 99-2 To visualize the internal structural changes of devices and materials at work
- 100-1 Automotive coating with both high-durability and aesthetic effects
- 100-2 To establish highly efficient soft X-ray (SX) nano-focusing techniques
- 101-1 One millisecond X-ray CT with multi-beam imaging
- 101-2 To develop local stress evaluation technology for metallic materials
- 102-1 Improved safety of metal structural materials
- 102-2 Improvement of Li ion battery performance
- 103-1 To develop new materials and manufacturing technologies
- 103-2 To create a system and develop components with new functionalities

Earth & Planetary

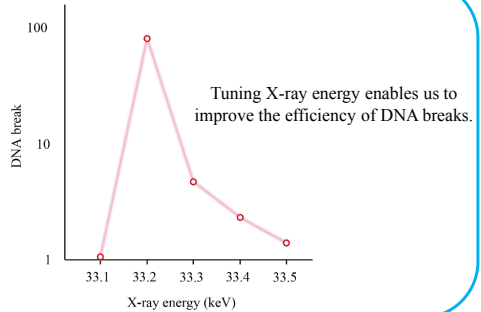
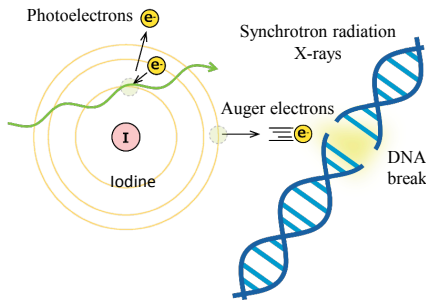
- 104-1 Origin of the 660 km seismic velocity discontinuity in the Earth's mantle
- 104-2 Succeeded in reproducing a magma ocean
- 105-1 Successful measurement of the sound velocity of Mars core material
- 105-2 New hydrous minerals that may exist in the depths of supergiant planets
- 106-1 To understand the chemical composition of the Earth's core
- 106-2 To understand how water is transported to the Earth's core
- 107-1 Large amount of hydrogen in the Earth's core
- 107-2 Clarifying the structure of the Earth's inner core; Is the Earth's inner core a mixture of two types of iron alloys?
- 108-1 Loss of the Martian magnetic field and evaporation of oceans
- 108-2 To analyze Ryugu asteroid particles obtained by the Hayabusa2 spacecraft
- 109-1 To discover the nature of unknown materials
- 109-2 Detection of nitrogen(N)-bearing organics from early Martian samples
- 110-1 World of quarks explored by high-energy γ rays (Laser-Electron Photons)
- 110-2 To understand what is deep inside the earth
- 111-1 What happened after the meteoroid impacted at the K-Pg boundary?
- 111-2 Discovery of "Fossil Ice" in a primitive meteorite
- 112-1 Discovery of CO₂ enriched fluid in a meteorite
- 112-2 Interpreting the history of the solar system



BL14B1

Quantum physics helps destroy cancer cells

- Irradiated monochromatic X-rays onto the tissue to prompt iodine to release electrons, which then caused double-strand breaks in the nuclear DNA, triggering cell death
- To develop new radiation therapy techniques



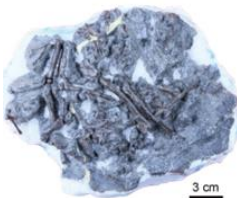
Reference: Y. Higashi *et al.*, *Sci. Rep.*, **11**, 14192 (2021)

BL20B2

Discovery of bird fossils from a new genus and species; The most primitive in Early Cretaceous birds

- Using high-energy micro-CT, analysis was performed on bird fossils from Katsuyama, Fukui, Japan, which has features never before seen in other bird fossils (Named "*Fukuapteryx prima*")
- The phylogenetic relationship between *Fukuapteryx prima* and other bird fossils revealed that *Fukuapteryx prima* is the most primitive bird from the Early Cretaceous period

Skeletal production form of *Fukuapteryx prima* and its schematic diagram.



3D skeletal and life restoration of *Fukuapteryx prima*



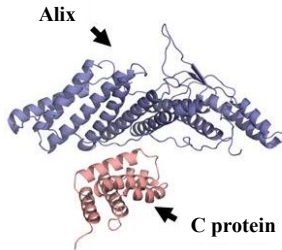
Image credit: Masamori Yoshida.

Japanese fossils contribute to the understandings on the evolution and ecology of primitive birds

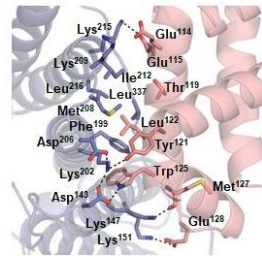


Reference: T. Imai *et al.*, *Commun. Biol.*, **2**, 399 (2019)

- The budding mechanisms of parainfluenza viruses from infected cells
 - The complex structure of the viral C protein and the Alix host factor, associated with acute respiratory infection, has been identified
 - The mechanism by which the virus buds from infected animal cells was clarified
→ Targeting the C protein will lead to the development of antiviral drugs



Structure of the C-terminal region of the C protein of Sendai virus in complex with the N-terminal region of Alix.

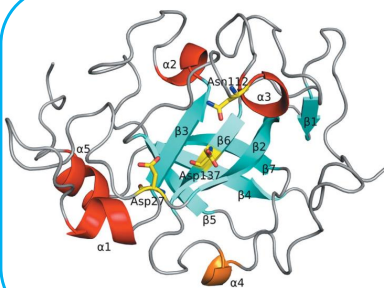


Binding mode between C protein and Alix; replacement of the 125th tryptophan of C protein with leucine resulted in no binding to Alix.

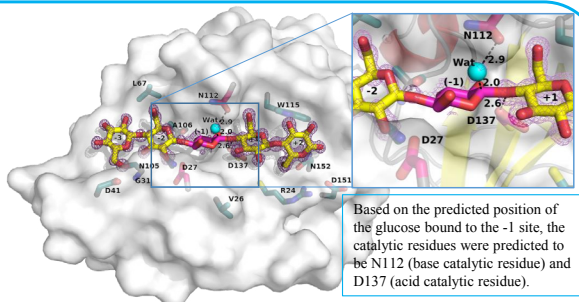


Reference: K. Oda *et al.*, *J Virol.*, **95**, 81521 (2021)

- To improve biofuel production using animal cellulase
 - The crystal structure of cellulase (EG27II) derived from a snail has been determined at 1.0 Å resolution for the first time
 - The catalytic residues were estimated from the complex structure with cellobiose
→ In addition to cellulases from microorganisms, animal cellulases could be used for bioethanol production



Overall structure of EG27II



Structure of cellobiose (+2/+1 and -2/-3 sites) bound to cleft

Based on the predicted position of the glucose bound to the -1 site, the catalytic residues were predicted to be N112 (base catalytic residue) and D137 (acid catalytic residue).

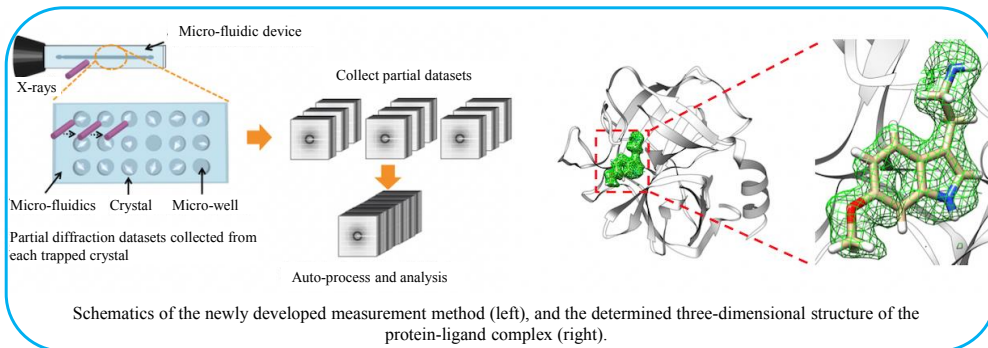


Reference: T. Nomura *et al.*, *Acta Cryst.*, **D75**, 426-436 (2019)

BL26B2

Expectations for accelerating drug screening

- Developed a new method to easily analyze the protein structure close to physiological conditions
- Semi-automated measurement of protein-ligand complex structures with only simple pipetting
- Expected to speed up the search for drug candidate compounds in pharmaceutical companies, etc.

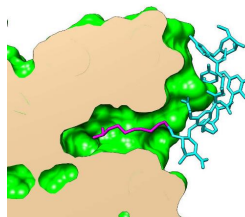
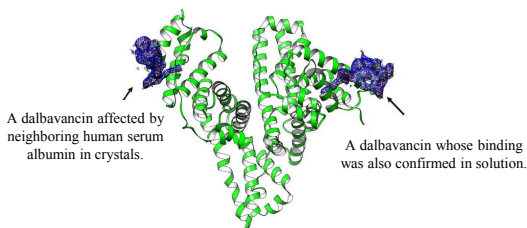


Reference: M. Maeki *et al.*, *Chem. Sci.*, **11**, 9072-9087 (2020)

BL26B2
BL32XU

Expectations for accelerating cyclic peptide drug discovery

- The crystal structure of the complex of dalbavancin, a cyclic peptide drug, and human serum albumin, a plasma protein, were clarified
- The crystal structure and solution state analysis elucidated the binding state in solution
- Expected to contribute to the optimization of cyclic peptide pharmaceuticals



(Left) Structure of the complex of the dalbavancin and human serum albumin revealed by crystal structure analysis.
(Right) Cross-sectional view of the enlarged dalbavancin binding site

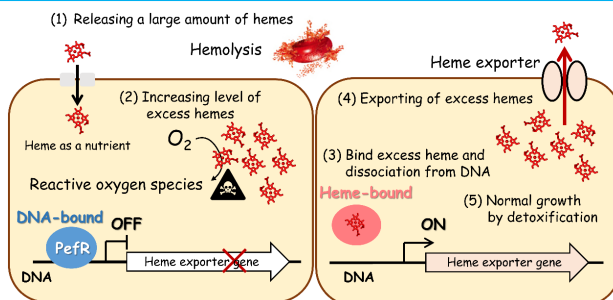


Reference: S. Ito *et al.*, *J. Med. Chem.*, **13**, 14045-14053 (2020)

BL26B2
BL41XU
BL44XU

Survival strategy of pathogenic bacteria by detoxification

- Structure determination of the heme-responsive sensor protein, which controls intracellular concentrations of heme acquired from animal host blood
 - Revealed the detoxification mechanism for the survival of pathogenic bacteria
- To develop new antimicrobial agents



Physiological function of the heme-responsive sensor protein PefR in *Streptococcus agalactiae*

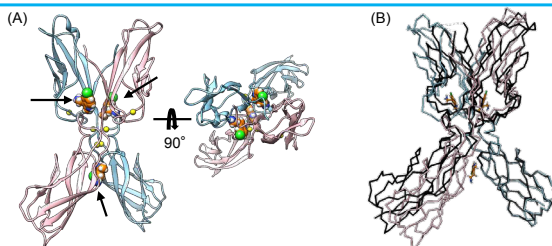


Reference: M. Nishinaga *et al.*, *Communications.Biology*, **4**, Article no. 467 (2021)

BL26B2

Acceleration of the development of anti-metastatic drugs

- Small molecules that regulate P-cadherin, a cancer-related protein, were identified
 - Crystallography of the targeted protein provided the mechanism of action
- High contribution to the development of anti-metastatic drugs targeting P-cadherin



(A) Crystal structure of P-cadherin in complex with small molecules. The black arrows show the binding positions.

(B) Superposition of the structures of P-cadherin with or without compounds. Compared with the structure without compounds (black), the compounds-bound P-cadherin had a drastic structural change, which gave a reasonable explanation for the inhibition of protein function.



Reference: A. Senoo *et al.*, *Communications Biology*, **4**, 1041 (2021)

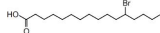
BL29XU

Visualization of the intracellular localization of fatty acids and changes in lipid metabolism

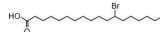
- One-element label fatty acids and fluorescent X-ray microscopy have enabled the world's first high-resolution imaging of intracellular lipids
 - Intracellular lipids can be observed with organelle-level resolution
- To develop research related to various phenomenon, diseases, and their treatments

Schematic views of the Br-labeled fatty acids

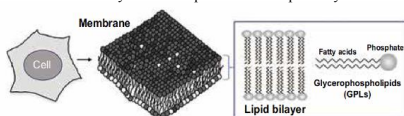
Br palmitic acid (Br-PA) (Br-16:0)



Br stearic acid (Br-SA) (Br-18:0)



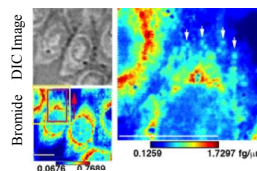
Schematics of fatty acids incorporated in the lipid bilayer of cells.



Scanning X-ray fluorescence microscopy to reveal single-element labeling of fatty acids



Scanning fluorescent X-ray microscopy measurement



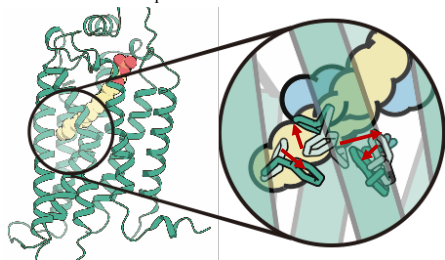
Reference : M. Shimura *et al.*, *FASEB, J.*, **30**, 4149 (2016)

BL32XU

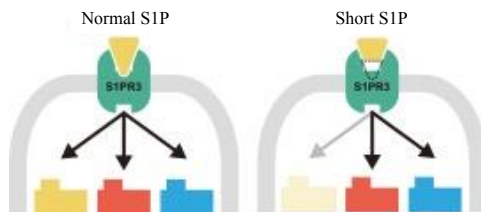
Elucidating a new activation mechanism of lipid receptors

- The structure of the lipid receptor, which regulates immune and vascular systems, was determined with its endogenous ligand SIP
 - SIP activates the receptor by straightening its lipid chain
 - With short SIP binding, SIP receptors transmit unbalanced signals
- To develop new drugs

SIP receptor structure and SIP-induced conformational changes



SIP (yellow) activates receptors by straightening its lipid chain

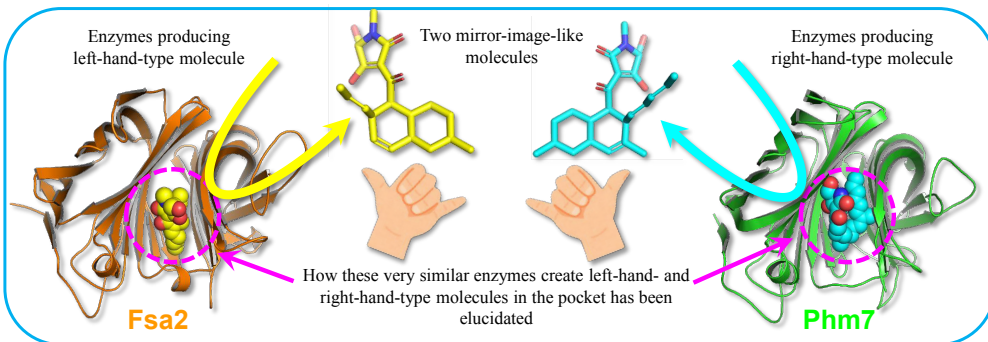


Regulating the length of SIP can bias the signal conveyed by SIP receptors



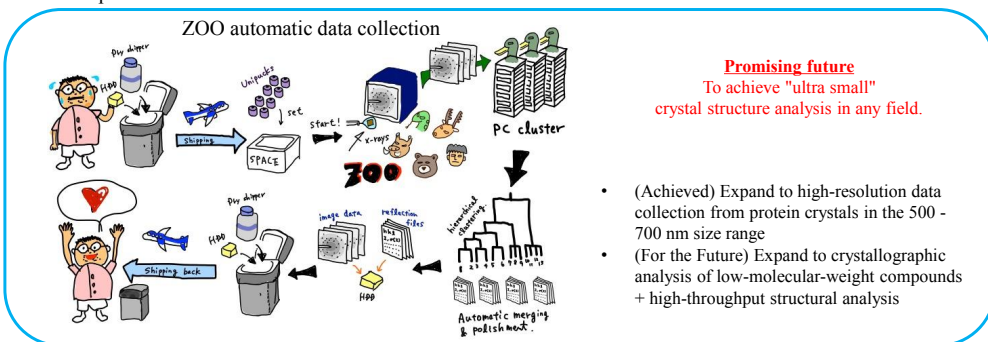
Reference : S. Maeda *et al.*, *Sci. Adv.*, **7**, eabf5325 (2021)

- How two enzymes produce right-hand- and left-hand-type molecules
 - Crystal structures of two very similar enzymes, Phm7 and Fsa2, which produce right-hand- and left-hand-type molecules, were determined
 - The mechanism of how Phm7 and Fsa2 produce right-hand- and left-hand-type molecules based on molecular simulations was elucidated based on the crystal structures
- To design enzymes that produce compounds with complex structures



Reference: Fujiyama and Kato *et al.*, *Angew. Chem. Int. Ed.*, **60**, 22401 (2021)

- Structure analysis from submicron crystals by automatic measurements
 - The ZOO system is a fully automated data collection system for protein crystallography
 - Using intense $1\ \mu\text{m}$ sized X-rays enables successful structure evaluation of protein crystals smaller than $1\ \mu\text{m}$ ($\sim 500\ \text{nm}$ at $2.5\ \text{\AA}$ resolution)
- To apply not only to protein crystals but also to crystals of low-molecular-weight compounds

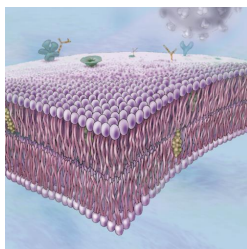


BL35XU

■ Better understanding of properties of biomembranes essential for biological activity

- Developed a new method to measure viscosity of 2D model membranes
- Determined the relaxation times of a membrane by neutron and X-ray spectroscopy
- Clarified the relationship between the membrane property and molecular movements in the membrane

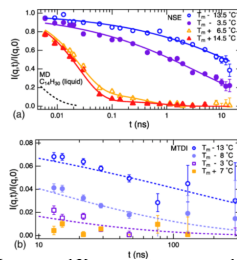
→ Potential applications for developing novel drugs or controlling membrane functions



Biological membranes essential for life



Two relaxation processes in a lipid membrane identified by the present study



Neutron and X-ray spectroscopy enabled access to lipid molecular dynamics spanning more than four orders of magnitude in time



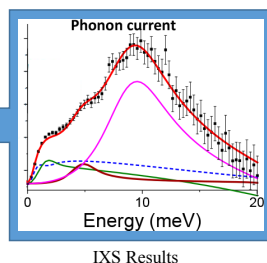
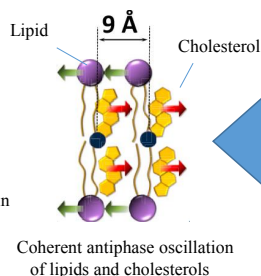
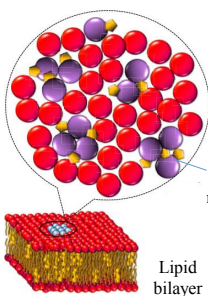
Reference: M. Nagao *et al.*, *Phys. Rev. Lett.*, **127**, 078102 (2021)
M. Nagao, *Spring-8 News*, **106** (2021)

BL35XU

■ To understand the motion in plasma membranes

- Lipids in a bilayer form transient nanoscopic substructures in the liquid-ordered phase
- The ordered lipids and cholesterol move in anti-phase

→ Results to understand the liquid-liquid phase separation and related diseases



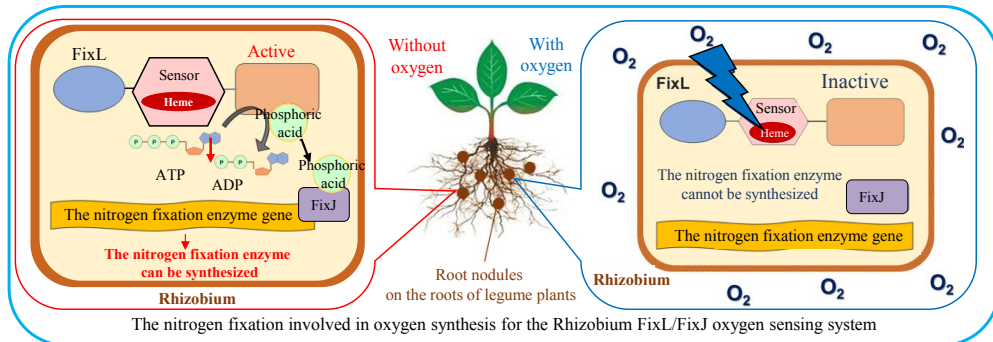
Reference: D. Soloviov *et al.*, *Proc. Natl. Acad. Sci. USA*, **117**, 4749 (2020)

BL38B1

■ To elucidate the whole picture of proteins that supply nitrogen to plants

- To investigate the important reaction of Rhizobium, which attaches to the roots of legumes such as soybeans and peas, to convert the nitrogen in the air into ammonia
- For the first time, we analyzed the entire picture of the proteins (FixL and FixJ), which make it easier for Rhizobium to sense the oxygen concentration in the soil and supply nitrogen to plants

→ To improve crop productivity by elucidating the mechanisms of nitrogen supply to plants



Reference: G. S. A. Wright *et al.*, *Science Signaling*, **11**, eaaq0825 (2018)

BL38B1
BL41XU

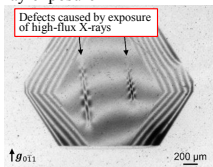
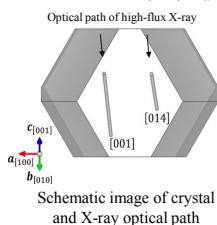
■ New insights into protein crystal defects by X-ray exposure

- First observation of the defect formation process in protein crystals by X-ray exposure
- The defects can be controlled by changing X-ray dose rate and combining with previous theories

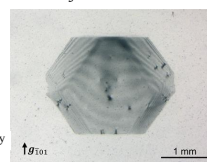
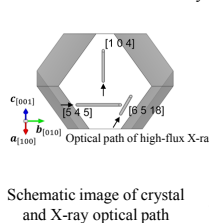
→ To realize efficient, effective, and accurate protein crystallography

Differences in defect formation between different high-flux X-ray exposure methods

For normal X-ray exposure



When the X-ray dose is adjusted



The lower dose per unit time prevents the formation of defects in the crystal even if the total dose is the same.



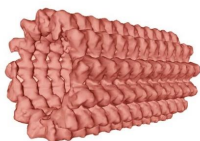
Reference: R. Suzuki *et al.*, *Acta Crystallogr. D.*, **78**, 196-203 (2022)

To elucidate the structural changes of microtubules

- Subtle structural changes were detected in microtubules, a component of cytoskeletons
 - Determined that the spacing between the protein and microtubule changes slightly depending on the type of nucleotide to which they bind
- To search for drugs that bind to microtubules, which can lead to the development of novel anti-cancer drugs

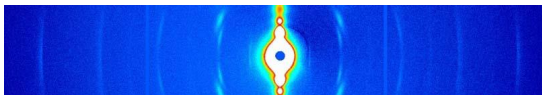
BL40XU
BL05XU

Structure of microtubule

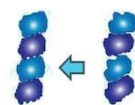


Foster *et al.*, *J. Cell Biol.* (2022)

Precision X-ray diffraction pattern recorded from microtubule



structural change of microtubule



straight curved

Unlike electron microscopy, X-ray diffraction can precisely measure the interval of tubulin, the constituent of microtubules, in real time. By using this feature, very subtle structural changes are detected in tubulin upon binding to drugs.



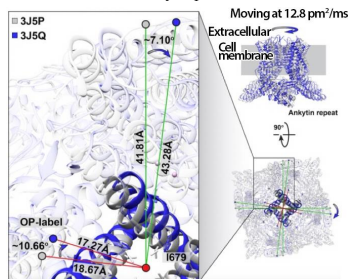
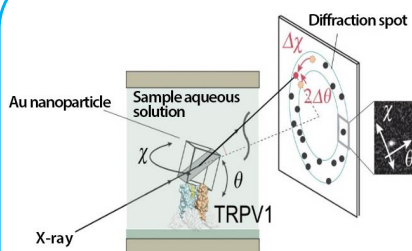
Reference: Estévez-Gallego *et al.*, *eLIFE*, **9**, e50155 (2020)

High-speed motion detection of channel proteins that sense heat and pain

- Real-time observation of intramolecular motion of transient receptor potential (TRP) channels
 - The TRP channels bind to capsaicin, a component of hot peppers, and send signals through their clockwise twisting motion
- To understand the mechanisms of pain perception and develop pain relief

BL40XU

Detecting the torsional motion of TRPV1 molecules when activated by capsaicin



TRPV1 motion was measured by tracking the motion of diffraction spots from gold nanocrystals that were labelled on the extracellular side of TRPV1

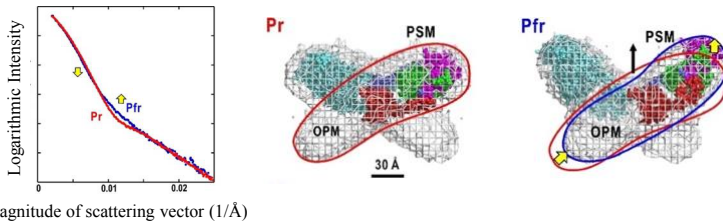


Reference: S. Fujimura *et al.*, *J. Phys. Chem. B*, **124**, 11617 (2020)

Red spectrum induced structural changes in phytochrome A

- Phytochrome A is a plant photoreceptor that regulates the response to red/far-red light
- Elucidation of structural changes in the phytochrome A produced by red light, contributing to plant germination
- Expected to open a new direction in designed optogenetics by clarifying the role of phytochrome molecules

Scattering profile of phytochrome A and structural models for Pr- and Pfr-types



Phytochrome A is composed of a photo-sensory module (PSM) and an output module (OPM), and causes a photoreaction between Pr- and Pfr- types to the red spectrum. PSM and OPM bend while moving slightly to the right.

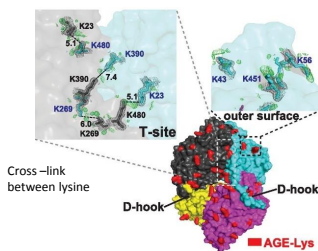


Reference: M. Oide & M. Nakasako, *Sci. Rep.*, **11**, 2827 (2021)

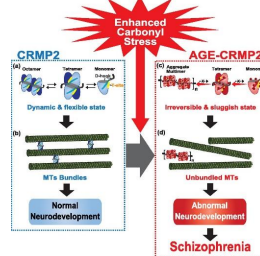
Revealed the molecular mechanism of schizophrenia under oxidative stress

- Revealed the carbonylated structure of CRMP2 of schizophrenia iPS Cells
- Revealed irreversible multimer formation of CRMP2 induced by oxidative stress
- The cross-link formation impairs the function of CRMP2 to bundle microtubules, resulting in abnormal neurodevelopment
- Drug discovery for schizophrenia targeting carbonylated CRMP2

Structure of CRMP2 involved in neurite outgrowth



Formation of cross-links induced by oxidative stress



Loss of function to bundle microtubules by carbonylation

Figures are reproduced from *Life Science Alliance*, **2**, e201900478 following CC-BY license



Reference: M. Toyoshima and X. Jiang *et al.*, *Life Science Alliance*, **2**, e201900478 (2019)

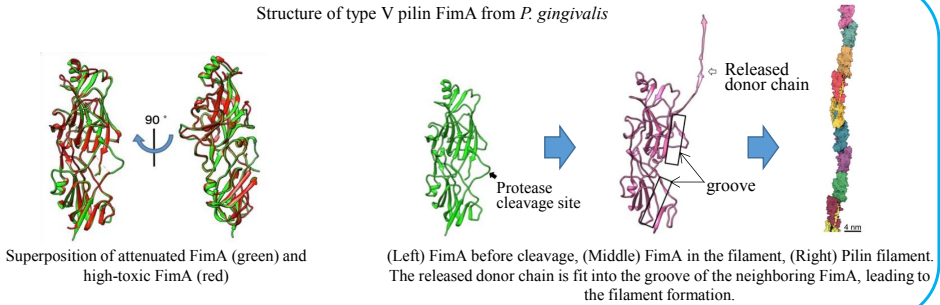
BL32XU
BL41XU

Structure of type V pilin and mechanisms of pili formation

- The structure of FimA, a type V pilin, from *P. gingivalis*, a major etiological agent of periodontal diseases, was determined
- Release of the donor chain of FimA by protease cleavage triggers the formation of filaments

→ To develop antibacterial drugs targeting pilin filament

Structure of type V pilin FimA from *P. gingivalis*



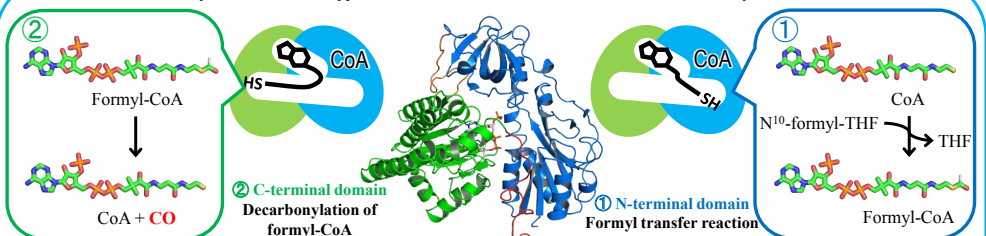
Reference: S. Shibata *et al.*, *Nat. Microbiology*, **5**, 830 (2020)

BL44XU

Molecular mechanism of carbon monoxide synthesis *in vivo*

- Determined the structure of HypX, responsible for carbon monoxide biosynthesis in the maturation of NiFe-hydrogenase
 - Revealed a novel function for coenzyme A (CoA), which acts as a key molecule in carbon monoxide biosynthesis
- Expected to be applied to efficient production of hydrogenase, which is responsible for hydrogen energy production

Crystal structure of HypX and its molecular mechanism of carbon monoxide synthesis



Crystal structure of HypX revealed that CoA strongly binds to the cavity in HypX. Mutation analysis, MD simulation and other experiments supported conformational changes of CoA in the cavity of HypX, and supports the reaction mechanism (①→②).

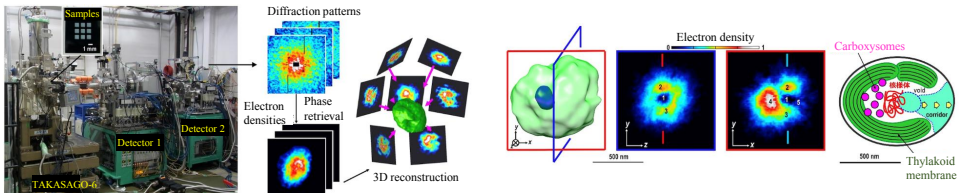


Reference: N. Muraki *et al.*, *Commun. Biol.*, **2**, 385 (2019)

To visualize 3D cell structures

- Three dimensional structures of cyanobacteria cells were successfully visualized by X-ray diffraction imaging using ultrashort XFEL pulses
 - Characteristic structures common among the cells were found
- To develop non-invasive X-ray imaging

Three dimensional structure analysis of cyanobacteria using X-ray diffraction imaging.



An averaged 3D electron-density map was successfully reconstructed from ~300 diffraction patterns with a resolution of tens of nanometers.

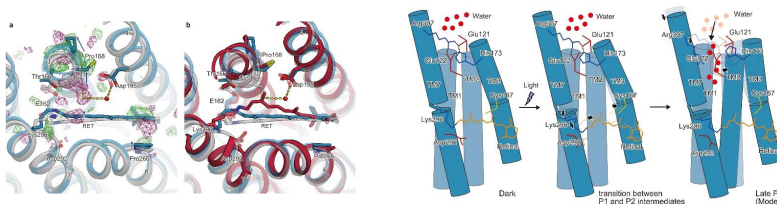


Reference: A. Kobayashi *et al.*, *Sci. Rep.*, **11**, 3877 (2021)

Fast light-driven dynamics in channelrhodopsin

- Serial femtosecond crystallography (SFX) revealed fast structural changes in photoactivated channelrhodopsin
 - Better understanding of a molecular mechanism of light-driven cation transport
- To develop novel optogenetic tools

Structural changes in channelrhodopsin after photo-excitation



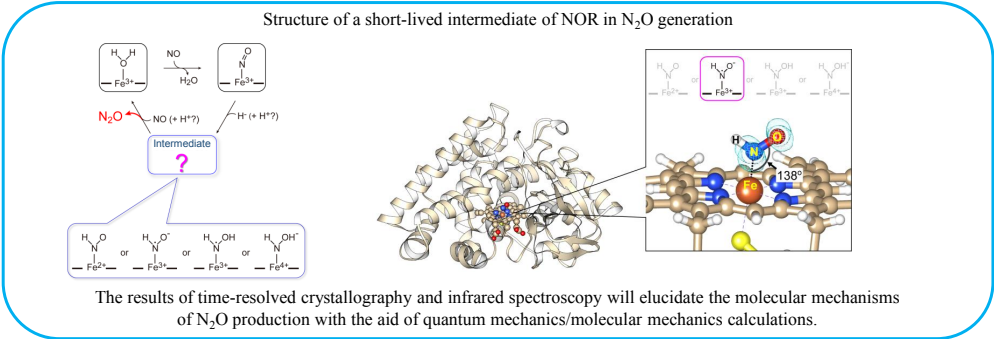
Early conformational changes revealed by time-resolved SFX will lead to the elucidation of the mechanism of optical-signal transportation in channelrhodopsin.



Reference: K. Oda *et al.*, *eLife*, **10**, e62389 (2021)



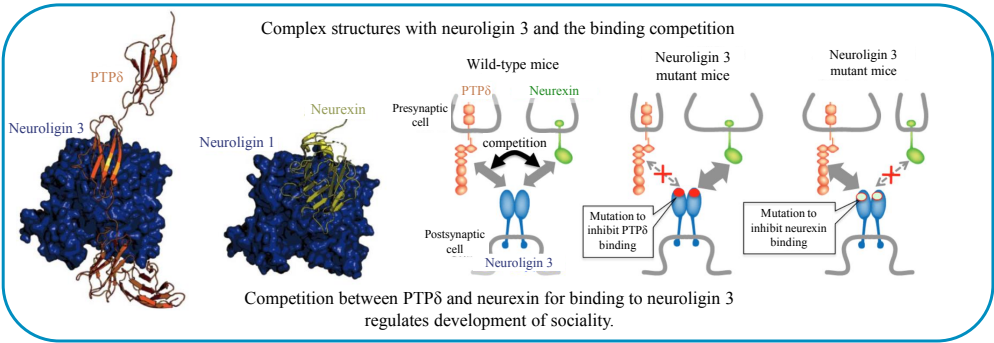
- Atomic-resolution structures of reaction intermediates in enzymes
 - High-resolution structure analysis of nitric oxide reductase (NOR), which is an enzyme used to produce nitrous oxide (N₂O), a greenhouse gas, in microorganisms
 - A mechanism of N₂O production from nitric oxide (NO) was revealed
 - To develop research for reducing greenhouse gas emissions



Reference: T. Nomura *et al.*,
Proc. Proc. Natl. Acad. Sci. USA, **118**, e2101481118 (2021)



- Non-canonical pathways for regulating the development of sociality
 - Crystal structure of neuroligin 3-PTPδ revealed the splicing-dependent interaction mode of PTPδ and the competition mechanism with neuroligin 3-neurexin interaction
 - Structure-guided mutagenesis helped to clarify that a balanced synapse formation by competitive binding to neuroligin 3 is important for development of sociality
 - Potential therapeutic target for autism spectrum disorder

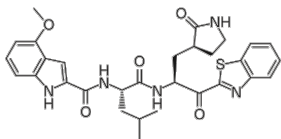


Reference: T. Yoshida *et al.*, *Nat. Commun.*, **12**, 1848 (2021)

BL41XU

- Structure of the main protease of SARS-CoV-2 in complex with GRL-2420^{5h}
 - Developed a new inhibitor for the main protease of SARS-CoV-2 (M^{pro})
 - Reveled the interactions between M^{pro} and the inhibitor by crystal structure analysis
- Through redesign and synthesis of new compounds based on the findings of this study, new compounds with a 100- to 200-fold increase in antiviral activity have now been achieved, paving the way for the clinical development of safe, orally available drugs for the treatment of novel coronavirus infections

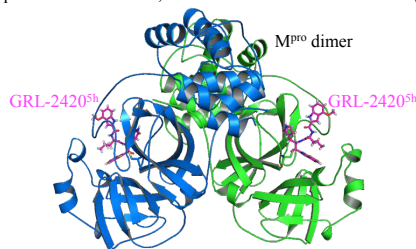
The structure of M^{pro} of SARS-CoV-2 in complex with an inhibitor, GRL-2420^{5h}



GRL-2420^{5h}, a new inhibitor for M^{pro}



Crystals of SARS-CoV-2 M^{pro}



Structure of M^{pro} in complex with GRL-2420^{5h}

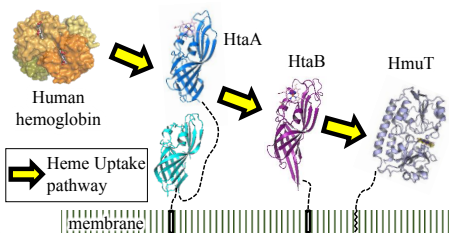


Reference : S. Hattori, H Hayashi, K Hasegawa *et al.*, *Nat. Commun.*, **12**, 668 (2021)

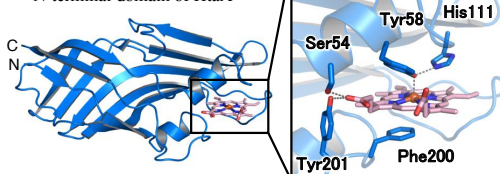
BL44XU

- Molecular mechanisms of the iron uptake system in pathogenic bacteria
 - Determined the first crystal structures of HtaA/HtaB, novel heme binding/transport proteins in the heme uptake system in *Corynebacterium glutamicum*
 - Elucidation of the molecular mechanism of heme transfer among these proteins is proposed based on the spectroscopic and structural analyses
- Expected to develop novel antibacterial drugs for *Corynebacterium*, including *C. diphtheriae*

Heme uptake pathway and crystal structures of HtaA/HtaB in *Corynebacteria*



N-terminal domain of HtaA



Reference : N. Muraki *et al.*, *Chem. Commun.*, **55**, 13864 (2019)

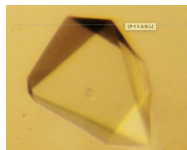
BL41XU
BL44XU

To elucidate the molecular mechanism by which anti-obesity drugs inhibit the pathogenic factor of *Staphylococcus aureus*

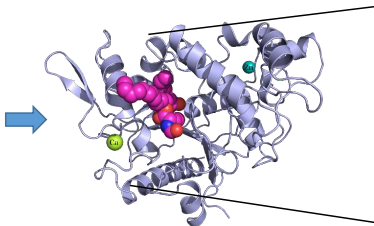
- Crystal structures of *Staphylococcus aureus* lipase (SAL) without/with its inhibitor, orlistat, were determined
- The results showed that the anti-obesity drug, orlistat, inhibits SAL 200 times more than the other SAL inhibitors and the molecular mechanism of its inhibition was analyzed

→ To provide structure-based information on the production of potent anti-SAL drugs and lipase inhibitors and understanding how orlistat can be repositioned to treat bacterial diseases

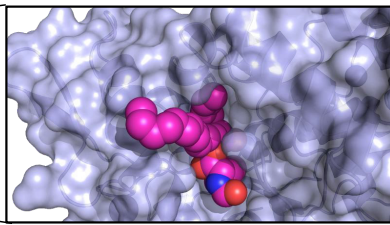
Crystal structure of SAL complexed with orlistat



Crystal of SAL-orlistat complex



Atomic structure of SAL complexed with orlistat



Structure of orlistat bound to the active site of SAL



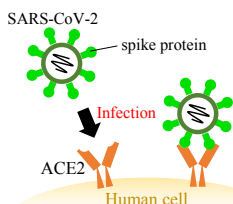
Reference: K. Kitadokoro *et al.*, *Sci. Rep.*, **10**, 5469 (2020)

BL44XU

To develop engineered ACE2 to neutralize SARS-CoV-2

- Developed an ACE2 receptor mutant that showed high affinity to the SARS-CoV-2 spike protein
 - High affinity modified ACE2 is a promising strategy to neutralize SARS-CoV-2
 - The crystal structure of the receptor binding domain (RBD) of the SARS-CoV-2 spike protein and the high affinity modified ACE2 receptor was determined
- Structural basis for affinity enhancement by mutagenesis

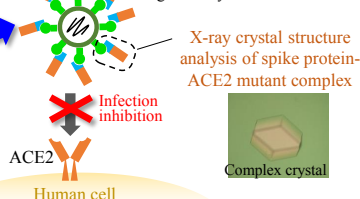
Strategy to inhibit SARS-CoV-2 infection by high-affinity modified ACE2



Development of high affinity ACE2 by random mutation



Neutralizing SARS-CoV-2 by high affinity modified ACE2



Crystal structure of the SARS-CoV-2 spike RBD in complex with the high-affinity modified ACE2 was determined at 3.2-Å resolution, revealing the affinity enhancement mechanism by mutated residues in the modified ACE2

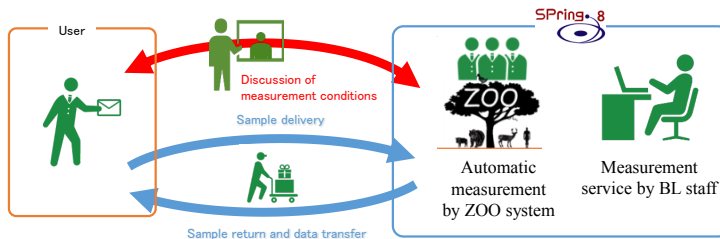


Reference: Y. Higuchi, *et al.*, *Nat. Commun.*, DOI: 10.1038/s41467-021-24013-y (2021)

BL32XU
BL44XU
BL45XU

- Support for research related to novel coronavirus infections
 - We supported drug discovery-related research using the protein crystallography beamline to rapidly overcome novel coronavirus infections
 - Automatic measurements and measurement services enabled experiments without the need to visit SPring-8

Research support performed at SPring-8 Protein Crystallography Beamlines



X-ray diffraction experiments of protein crystals were performed by sending frozen samples to SPring-8 and with automated measurement/measurement services we support drug discovery-related research.

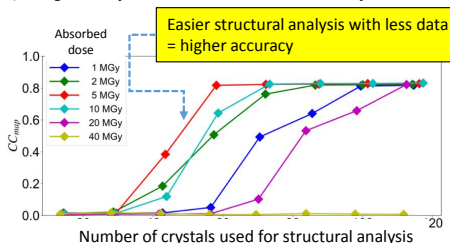
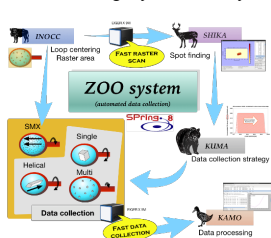


Reference: G. Ueno, *et al.*, *J Synchrotron Radiat.* **12**, 380-384 (2005)
K. Hirata, *et al.*, *Acta Cryst.*, **D75**, 138-150 (2019)

BL45XU
BL32XU

- Suggestion of optimum small-wedge synchrotron crystallography (SWSX) data collection conditions
 - Radiation damage to crystals caused by X-rays is a major problem for achieving high precision data acquisition
 - Experimental evaluation of the optimum X-ray dose to microcrystals
 - Proposed guidelines for optimal SWSX data collection conditions

Small-wedge synchrotron crystallography (SWSX) using the fully automated measurement ZOO system



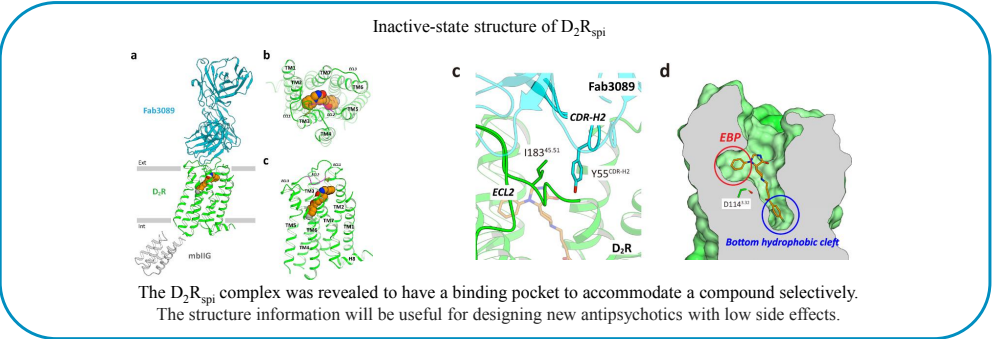
For protein microcrystals, the absorbed dose is about 5 megagray (MGy, 1 MGy is about 1 million gray).
→ The most efficient and accurate data collection is possible.



Reference: Baba, S. *et al.*, *J Synchrotron Radiat.*, **28**, 1284-1295 (2021)



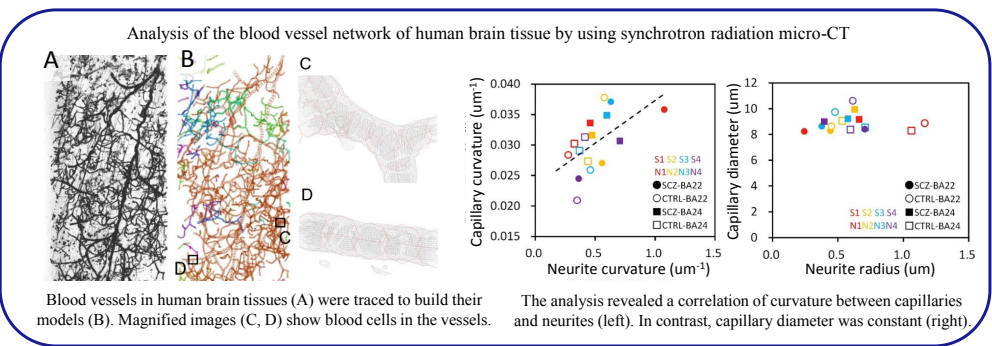
- Structure analysis of drug target protein
 - To reveal the structure of dopamine D₂ receptors in complexes with the antipsychotic drug spiperone (D₂R_{spi})
 - The structure was found to differ substantially from other inactive-state structures with different inverse agonists
- To develop novel antipsychotics with improved safety and efficacy



Reference: D. Im *et al.*, *Nat. Commun.*, **11**, 6442 (2020)



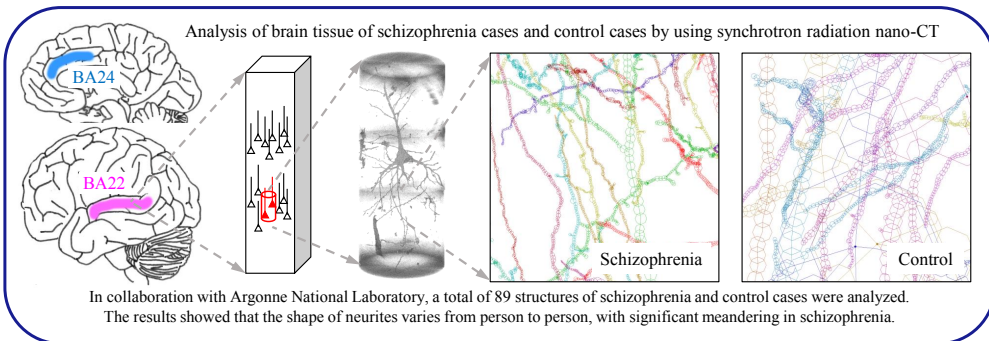
- The structural relationship of cerebral blood vessels and neurons
 - Schizophrenia brain tissues and control cases were visualized with micro-CT
 - Analysis of 3D structures of the human brain tissues revealed a correlation of curvature between brain capillaries and neurites
- This suggests an imbalance in brain metabolism in schizophrenia that shows tissue atrophy in some areas of the brain



Reference: R. Saiga *et al.*, *Scientific Reports*, **11**, 11768 (2021)

BL37XU

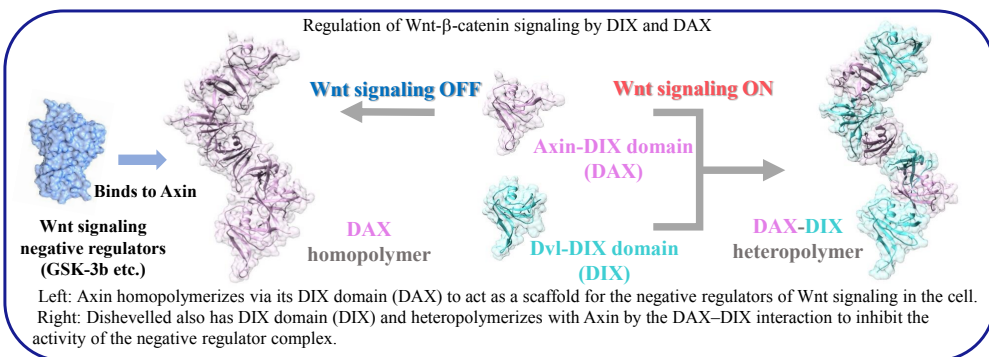
- Nano-CT revealed structural changes of neurons in schizophrenia
 - Nanometer-scale 3D structures of human brain neurons were visualized by using synchrotron radiation nano-CT
 - Geometric analysis of the neuron images indicated that neurite curvature differs between individuals and becomes extraordinary in schizophrenia
- This finding should lead to the development of a new treatment for schizophrenia



Reference: R. Mizutani *et al.*, *Transl. Psychiatry*, **11**, 49 (2021)

BL44XU

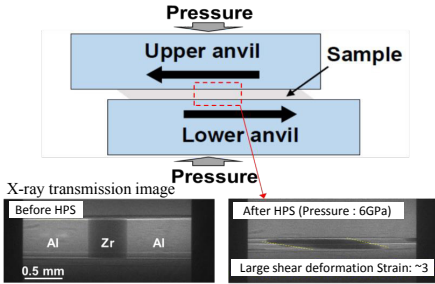
- Structural basis of the regulation mechanism of Wnt- β -catenin signaling by Dishevelled-DIX and Axin-DIX (DAX) domains
 - The results revealed that the interaction between Dishevelled and Axin through their DIX domains is crucial for up-regulating the Wnt- β -catenin signaling pathway, which regulates embryonic development and tissue homeostasis
- Expected to develop novel anti-cancer drugs targeting the DAX-DIX interaction



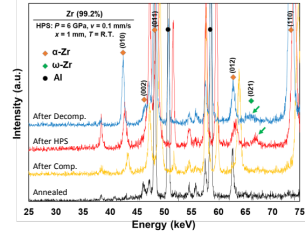
Reference: K. Yamanishi *et al.*, *Sci. Signal.*, **12**, eaaw5505 (2019)

- Real-time observation of the machining process
 - Large strain was introduced into the sample using a high-pressure sliding device
 - The observation of strain and annealing during deformation processing is now possible, enabling optimization of the high-temperature, high-pressure machining process
- To develop hard metal and ceramic materials through microstructure control by large strain processing

Material deformation behavior during High-Pressure Slide machining (HPS)



$\alpha \rightarrow \omega$ phase transformation behavior of pure zirconium



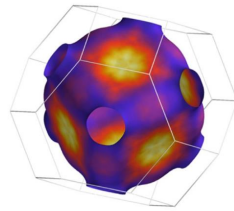
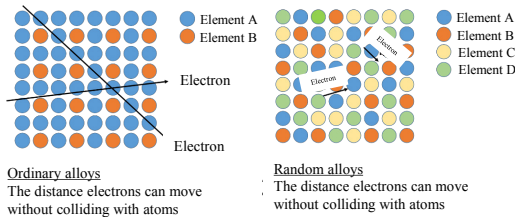
Acceleration of phase transformation by strain introduction



Reference: Z. Horita *et al.*, *Mater. Trans.*, **62**, 167 (2021)

- Successful observation of the fermi surface in maximally disordered alloys
 - Extreme fermi surfaces were observed in the maximally disordered alloy, equiatomic $\text{Ni}_{0.25}\text{Fe}_{0.25}\text{Co}_{0.25}\text{Cr}_{0.25}$
 - In the high-entropy alloy, the distance that electrons can travel without colliding with atoms is extremely short, on the scale of atomic distances
- To provide new clues to understand the behavior of electrons in strongly correlated materials

Extreme fermi surface smearing in a maximally disordered alloy



Electrons in NiFeCoCr disordered alloys can barely move farther than the interatomic distance.

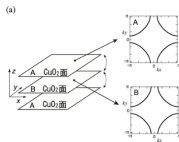


Reference: H. C. Roberts *et al.*, *Phys. Rev. Lett.* **124**, 046402 (2020)

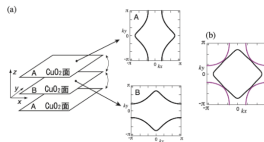
Overthrowing the established theory of high-Tc cuprate superconductors

- An electron in cuprate superconductors differ from the established theory for “two-dimensional motion”, thus we found that the electron is a superposition of one-dimensional motion
- To elucidate the origin of why copper oxides become superconductive at high temperatures

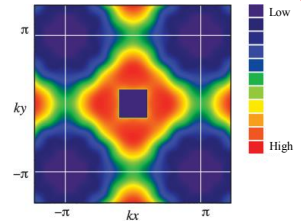
Fermi surface in the electron nematic liquid crystal state



Two-dimensional Fermi surface



Fermi surface in the electron nematic liquid crystal state



Electron momentum density

The observation of the fermi surface in the electron nematic liquid overthrew the established theory.



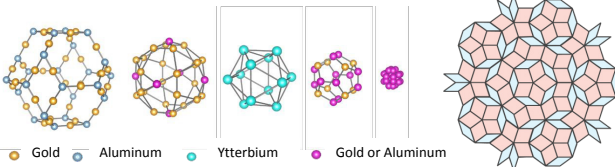
Reference: H. Yamase *et al.*, *Nat. Commun.* **12**, 2223 (2021)

New function of icosahedral clusters

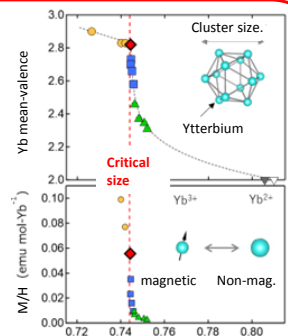
- Investigated the electronic/magnetic properties of quasicrystal Ytterbium atoms in icosahedral clusters
- Found that the magnetic susceptibility is greatly ($\times 30$) enhanced or suppressed by a slight expansion/compression (of $\sim 10^{-11}$ meters) of the icosahedral clusters
- Possible application to the development of new nanotechnology materials

Structure and electronic/magnetic properties of Gold (Au)-Aluminum (Al)-Ytterbium (Yb) quasicrystals

Quasicrystals : clusters (left panels) are locating on quasi-periodic lattices (middle)



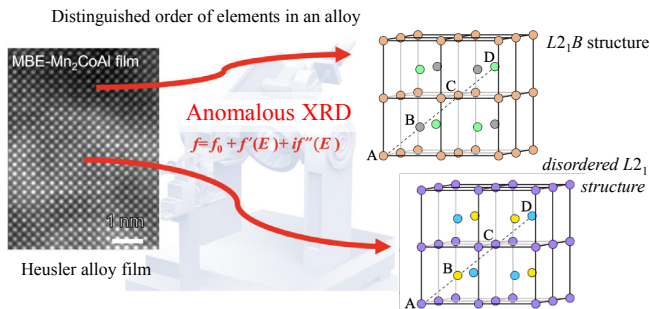
Various quasicrystals consisting of clusters of different sizes were synthesized. We have found the critical size of the cluster at which the property of ytterbium atoms drastically changes (right panel)



Reference: K. Imura *et al.*, *Sci. Rep.* **10**, 17116 (2020)

To develop ordered alloy thin-films with novel functionalities

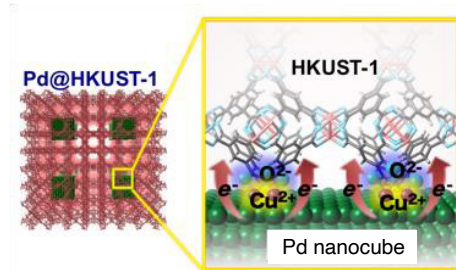
- The structural orders in Heusler alloy films were revealed on the atomic scale using synchrotron X-ray diffraction
- Expected to be applied to spintronics, thermoelectronics, shape memory, and more



Reference: K. Kudo *et al.*, *Phys. Rev. B*, **103**, 104427 (2021)
 H. Tajiri *et al.*, *Acta Mater.*, **235**, 118063 (2022)

To elucidate the reason behind hydrogen storage capability improvements

- The valence bands of palladium nanocubes covered with HKUST-1 and the charge transfer from the palladium nanocubes to HKUST-1 were investigated
- It was found that the charge transfer from the palladium nanocubes to HKUST-1 is the reason for the improvement of hydrogen storage capabilities
- To promote the development of novel hybrid materials



Mechanism of hydrogen storage

Charge transfer from the palladium nanocubes to HKUST-1
 ↓
 Improve hydrogen storage capability

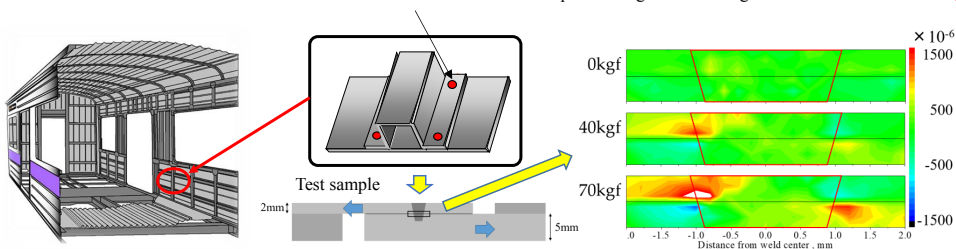
Novel principle for the development of hybrid materials



Reference: Y. Chen *et al.*, *Commun. Chem.* **1**, 61 (2018)

- To apply structural soundness evaluations for new processing technology development
 - Succeeded in non-destructive measurement of internal strain distribution near the welds in a steel material subjected to laser spot welding under tensile loading
 - By promoting evaluation using conventional finite element analysis and its improvements, strength prediction in unknown materials and new processing techniques can be expected

Evaluation of the strain distribution around the laser spot welding under loading

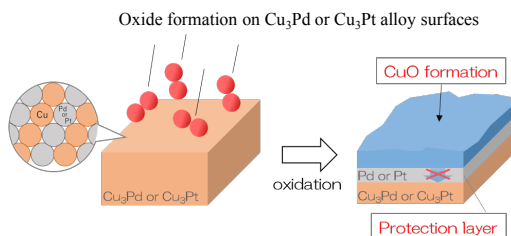
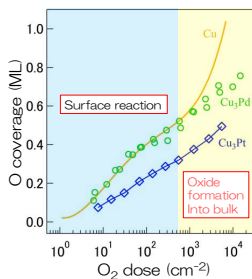


The strain distribution was measured while focusing on the internal local strain near the welded interface, and as a result the strain distribution was obtained in almost the same range calculated using finite element analysis.



Reference: T. Shobu *et al.*, *Quantum Beam Sci.* 5, 17 (2021)

- Alloying to control surface reactions
 - SXPES revealed the reaction of fast oxygen molecules on copper alloy surfaces
 - Alloying can suppress the oxidation of metal deeper into bulk materials
 - The types of oxides formed on surfaces are controllable by alloying and fast molecules
 - To develop oxidation-resistant materials and low-cost oxide catalysts



Oxide formation in bulk materials is suppressed for alloyed pure copper (left). The layer of the alloy prevents oxidation further into the bulk material and causes production of CuO , which is more oxidized than Cu_2O , which forms on pure copper (right).

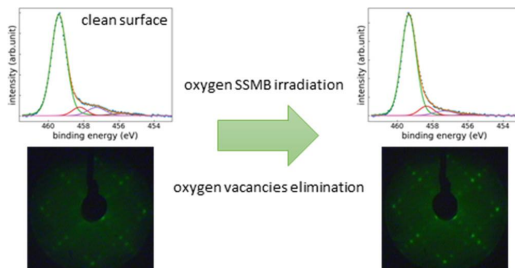
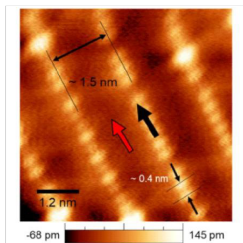


Reference: Y. Tsuda *et al.*, *Sci. Rep.*, 11, 3906 (2021)

Successful removal of oxygen vacancies from metal oxide catalyst surfaces

- Fast oxygen molecules can eliminate oxygen vacancies from the surface of TiO_2 , a well-known photocatalyst
- New method for controlling vacancies to realize highly efficient catalysts

Vacancies on anatase $\text{TiO}_2(001)-(1 \times 4)$



Oxygen molecules with high translational energy eliminate vacancies without breaking the surface structure.

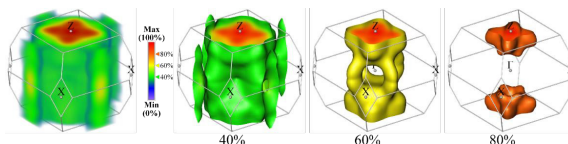
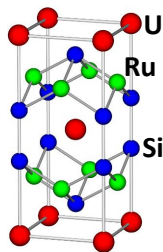


Reference : D. Katsube *et al.*, *Langmuir* **37**, 12313 (2021)

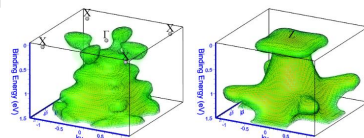
Revealing the three-dimensional electronic structures of materials

- The steric electronic structure of the superconductor URu_2Si_2 has been analyzed
- The U 5f electrons that induce superconductivity have a three-dimensional electronic structure and electron correlation effects
- To apply to other materials to elucidate the origin of their physical properties

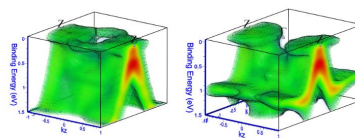
Crystal structure of URu_2Si_2



In-plane band structures



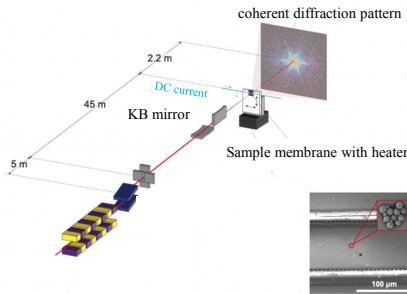
Out-of-plane band structures



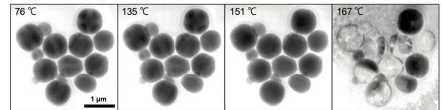
Reference : S. Fujimori *et al.*, *Electronic Structure*, **3**, 024008 (2021)

- To understand phase changes and melting of alloys during heating
 - To observe the melting and disappearance of phase interfaces inside of alloy particles due to heating with a scanning coherent diffractive imaging microscope
 - To image the working state of practical materials to improve their functionality

Conceptual diagram of the sample observation microscope during heating



Structural changes of Sn-Bi alloy particles during the heating and melting processes.

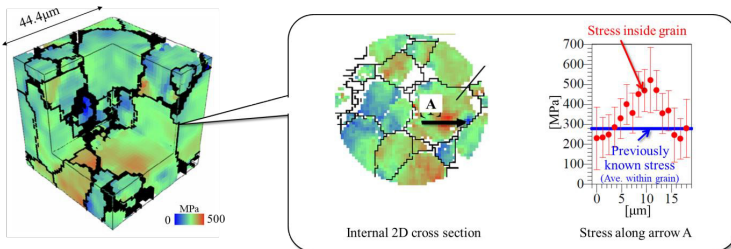


The eutectic structure inside of the Sn-Bi alloy changes from a uniform single crystal at 151 °C to melted at 167 °C.

Reference: N. Ishiguro *et al.*, *Microscopy and Microanalysis*, **26**, 5, 878 (2020)

- To improve component reliability and manufacturing processes
 - The world's first successful nondestructive measurement of 3D distributions of stresses "inside" crystal grains of metallic materials
 - Measurement of local stresses much higher than previously known average stresses
 - To contribute to identifying weak points inside components and to develop prediction simulations

Measured 3D stress distribution in deformed steel



The world's first demonstration showing large local stresses inside grains even under applied loads smaller than rupture stress levels (330 MPa)

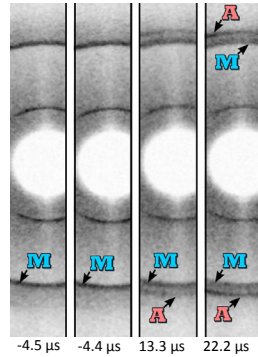
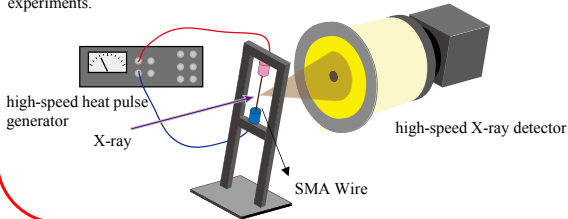
Reference: Y. Hayashi *et al.*, *Science*, **366**, 1492-1496 (2019)

■ Visualization of martensitic transformations in shape memory alloys

- Microsecond-scale microstructural changes in a shape-memory alloy wire have been visualized by applying thermal pulses to the wire and using high-speed time-resolved X-ray diffraction
- The results are expected to be used for the development of novel materials, and powerful high-rate shape memory alloy actuators

Actual measurements of the speed of martensitic transformations in shape memory alloys

Martensitic transformation is a rapid phase transformation between solid atomic arrangements and serves as a fundamental deformation mechanism in shape memory alloys. We investigated "how fast the martensitic transformation occurs" by applying thermal pulses to a shape memory alloy and performing high-speed time-resolved X-ray diffraction experiments.



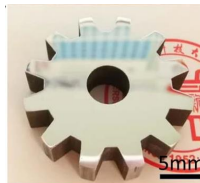
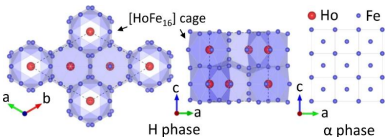
Reference: A. Dana *et al.*, *J. Alloys. Compounds*, **856**, 157968 (2021)
A. Dana *et al.*, *Shape Memory and Superelasticity*, **7**, 333 (2021)

■ To develop tough and reasonable metallic materials with zero thermal expansion (ZTH)

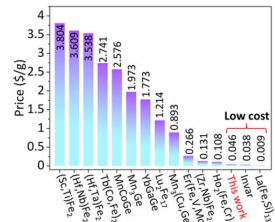
- Fe containing a small amount of Ho becomes a tough ZTH material
- Synchrotron, neutron and electron beams can reveal the mechanisms
- To develop tough and reasonable ZTH materials

Crystal structure of the HoFe alloy

A trial ZTH material



Comparison in cost



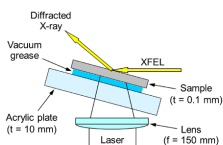
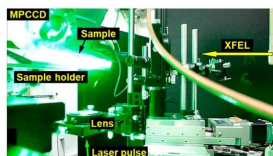
A new strategy makes it possible to develop a tough and reasonable ZTH Fe alloy, which contains 4% Ho.



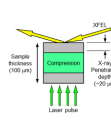
Reference: C. Yu *et al.*, *Nat. Commun.*, **12**, 4701 (2021)

- To visualize fast structural dynamics in metallic materials
 - Dynamic responses of an aluminum alloy to laser irradiation was investigated by time-resolved X-ray diffraction for a better understanding of the mechanism of laser shock peening, which enhances the durability of metallic materials
 - To develop metallic materials with higher durability

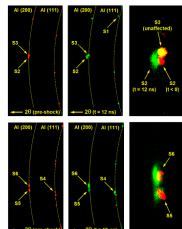
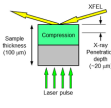
Ultrafast X-ray diffraction of laser-irradiated aluminum alloys



@12 ns



@16 ns



Structure changes were observed after laser irradiation under the conditions simulating the laser shot peening.



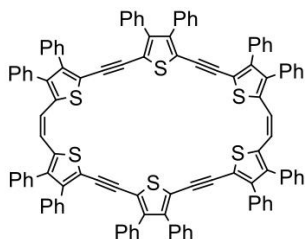
Reference: Y. Sano *et al.*, *Metals*, **10**, 1490 (2020)

Non-metal Material

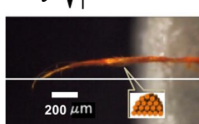
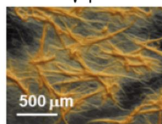
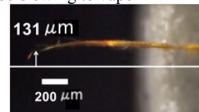
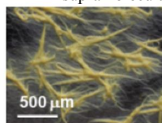
Single Crystal Diffraction

- To develop supramolecular actuators driven by vapor
 - Cyclic thiophene hexamer with phenyl groups were synthesized, and supramolecular fibers were fabricated
 - Reversible transformation/motion was achieved by vapor alone without using a power or heat source
 - To develop an actuator based on a novel principle driven solely by vapor

Synthesized cyclic thiophene hexamer molecule



Discoloration and deformation of supramolecular fibers owing to vapor



dry ⇄ acetone vapor



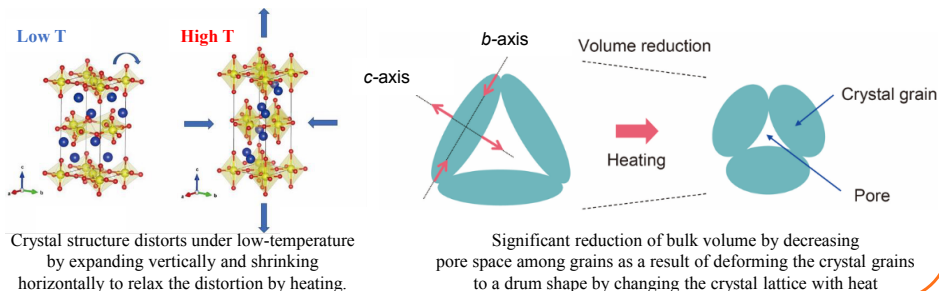
Reference: M. Iyoda *et al.*, *J. Am. Chem. Soc.*, **142**, 13662 (2020)

BL02B2
BL14B2
BL19B2
BL22XU

■ New giant heat-shrink material

- The mechanisms of new giant heat-shrink materials have been revealed via crystal structure analysis
 - This interesting characteristic was found to be due to the distortions of crystal structure and the reduction of voids between crystal grains during heating
- Applications: Precision instruments, optical communication, manufacturing of semiconductors, structural materials

Mechanism of negative thermal expansion caused by change in crystal structure and material texture of layered ruthenates



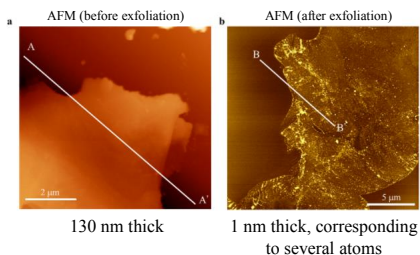
Reference: L. Hu *et al.*, *Chem. Mater.*, **33**, 7665 (2021)

BL02B2

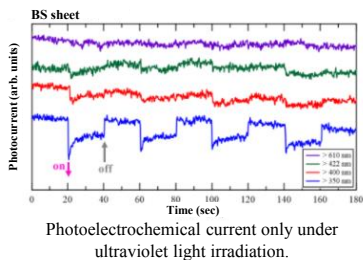
■ New semiconducting material “Boron Monosulfide Sheet (BS Sheet)”

- Succeeded in synthesizing rhombohedral BS, and high purity (over 99.2 %) was confirmed by synchrotron X-ray diffraction
 - First production of BS sheet which had been theoretically predicted to exhibit excellent thermoelectric and hydrogen storage properties
- Applications: Thermoelectric materials, H₂ storage, photocatalysts, batteries, optical sensors

Atomic force microscopy (AFM) of rhombohedral BS (left) and exfoliated BS sheet (right)



Photoelectrochemical current response under light on and off conditions

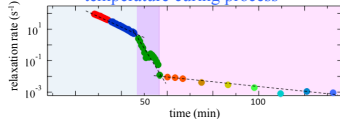


Reference: H. Kusaka *et al.*, *J. Mater. Chem. A*, **9**, 24631 (2021)

- To elucidate the curing mechanism of highly heat-resistant epoxy resins
 - Heterogeneous fluctuations that occur during the curing process of epoxy resins were evaluated on the molecular scale and it was discovered that the heterogeneity of fluctuations differ greatly depending with the curing temperature
- Important findings for improving the efficiency of epoxy resin curing conditions

Dynamics slowing down during the curing process were observed.

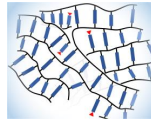
Time variation of relaxation rate during low temperature curing process



Chemical bonding reactions proceed in three stages.

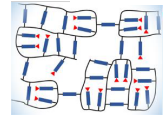
When cured slowly at low temperatures first and then at high temperatures, a homogeneous, high-density network is formed. However, when cured at high temperature from the beginning, a heterogeneous and low-density network is formed.

Schematic diagram of the molecular structure



Slow curing resin in low temperature and high temperature process

High-density network



Fast curing resin at high temperature only

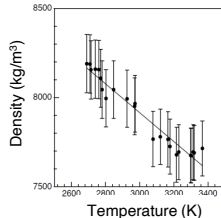
Low-density network



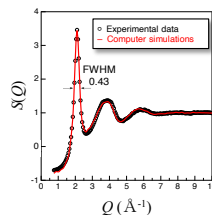
Reference: T. Hoshino *et al.*, *Scientific Reports*, 9767 (2021)

- Nonglass-forming oxide liquid with the formation of distorted tetraclusters
 - Synergetic collaboration of density measurements from the International Space Station (ISS), synchrotron X-ray diffraction, and computer simulations revealed the structure of high-temperature liquid Er_2O_3
 - The structure of liquid Er_2O_3 comprises distorted OEr_4 tetraclusters in nearly linear arrangements and the homology is similar to the crystalline phase

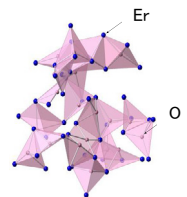
ELF (electrostatic levitation furnace) at the ISS-KIBO and measured density data for liquid Er_2O_3 (<https://iss.jaxa.jp/kiboexp/equipment/pm/elf/>)



High energy X-ray diffraction data for liquid Er_2O_3 (2923 K)



Visualized OEr_4 tetracluster network in liquid Er_2O_3



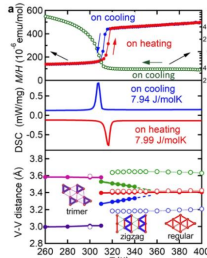
Structural feature of nonglass-forming liquid was successfully obtained → Helpful for the design of new glass materials



Reference: C. Koyama *et al.*, *NPG Asia Mater.*, 12, 43 (2020)

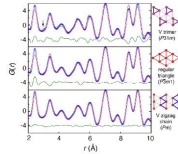
■ Lattice dynamics of a characteristic soft viscous crystal in inorganic crystals

- Discovery of a new type of lattice disorder modulation structure
 - The zigzag chain is a characteristic of "soft viscous crystals", a kind of soft matter, with these results leading to the discovery of "inorganic soft viscous crystals"
- Pioneering new avenues for the development of new functional materials

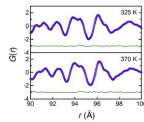


Temperature dependence of physical properties of LiVS₂ crystals

- (1) Unlike the periodic modulation structure, which appears in the low-temperature phase, this appears above 320 K.
- (2) Disorder on the macroscopic scale and broad coherence on the mesoscopic scale.
- (3) The disordered modulation structure of the lattice appears with dynamics on the slow time scale of seconds.



Local Structure Analysis of LiVS₂ Crystals by PDF Method



In disordered modulation structures Vanadium forms zigzag chains (Zigzag chain structures reproduce PDF data)

Zigzag chain dynamics is a characteristic of "soft viscous crystals," a type of soft matter
→ Realization of "inorganic soft viscous crystals"

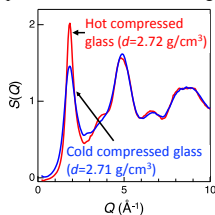


Reference: N. Katayama *et al.*, *npj Quantum Materials*, **6**, 16 (2021)

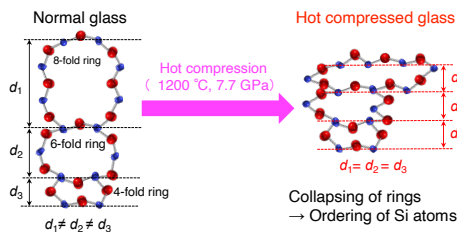
■ Structure in densified silica glass: Characterizing order within disorder

- A densified silica glass was synthesized by heated compression at 1200 °C and 7.7 GPa, and identified as the most ordered glass by X-ray diffraction measurements
- The dynamics of glasses are influenced not only by the density but also the structure
- The structural order in the most ordered glass is formed by aligning Si atoms with the collapsing ring structure along Si-O bonds

High energy X-ray diffraction patterns for densified silica glass



The scheme of the structural ordering of silica glass



Glass structure can be manipulated by controlling temperature and pressure.



Reference: Y. Onodera *et al.*, *NPG Asia Mater.*, **12**, 85 (2020)

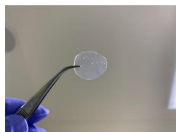
BL02B2
BL04B2
BL14B2

Success in synthesizing coordination polymer glass

- Preparing electrolytes for automotive fuel cells using coordination polymer glass
- Coordination polymer glass is soft and has high performance at 120° C without humidification

→ Expected to apply electrolyte material to automotive fuel cells

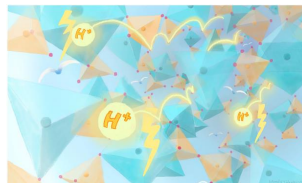
Previous materials cannot function as electrolytes in fuel cells unless they are sufficiently hydrated.



Coordination polymer glass is prepared by introducing metal ions into protic ionic liquids

A coordination polymer glass that works as an electrolyte without humidification is prepared by adding metallic zinc ions, Zn^{2+} , to an ionic liquid (left) of phosphoric acid, H_2PO_4^- , which has many hydrogen ions (protons).

Structural analysis using synchrotron radiation X-rays revealed that metal ions and phosphoric acid form a large network, and that the dynamic movement of this network leads to a mechanism in which only hydrogen ions conduct.



The molecular structure of the new polymer glass facilitated the movement of protons (H^+) across it under dry conditions at 120°C. (© Minkyu Takamiya/Kyoto University iCeMS)



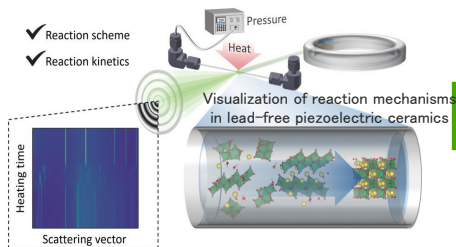
Reference: T. Ogawa *et al.*, *Chem. Sci.*, **11**, 5175 (2020)

BL04B2

To optimize synthesis of lead-free piezoelectric ceramics

- To understand hydrothermal synthesis effects such as temperature, time, the effect of NaOH concentration on the reaction rate, reaction mechanisms, product crystal size and structure of the products

→ To accelerate the development of lead-free piezoelectric ceramic materials by controlling synthesis conditions



Observation of reaction mechanisms of lead-free piezoelectric ceramics at various temperatures and times

Toward the commercial application of lead-free piezoelectric ceramics comparable to the performance of commonly used lead zirconate titanate



Reference: M. Einarsrud *et al.*, *Inorg. Chem.*, **60**, 7632 (2021)

■ To develop materials for future life

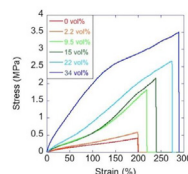
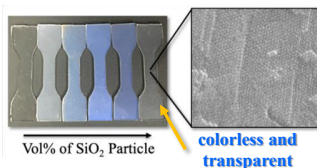
- With reference to transparent biological tissues, it was found that dispersing high concentrations of fine particles with uniform particle size in bridged polymers resulted in colorless transparency and high toughness
- It is expected to become a useful material for highly advanced medicine, wearable displays, and soft robots

Transparent and tough elastomer based on the microstructure of the cornea



Corneal structure applied to composite elastomers

Optical properties vary with particle concentration.



High elongation and high elastic modulus

In the cornea, the ordered structure of collagen fibers makes it colorless and transparent, and its complexation with gel tissue makes it highly tough. By designing materials based on the microstructure, a colorless, transparent, high-toughness composite material was created.



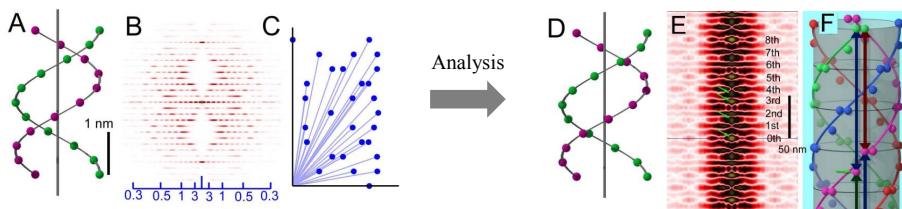
Reference: Y. Takeoka *et al.*, *ACS Materials Letters*, **4**, 325 (2020)

■ Restoring the 3D structure of fibrous material from its X-ray diffraction pattern

- Developed a method to restore the non-rotationally averaged 3D structure of a fibrous material from its rotationally averaged X-ray diffraction pattern
 - Applicable to a wide range of fibrous materials, ranging from DNA and myofilaments in the body to synthetic polymer filaments
- Useful in studies of life sciences and development of novel synthetic filaments

Calculation procedure

Application to myosin filament in muscle

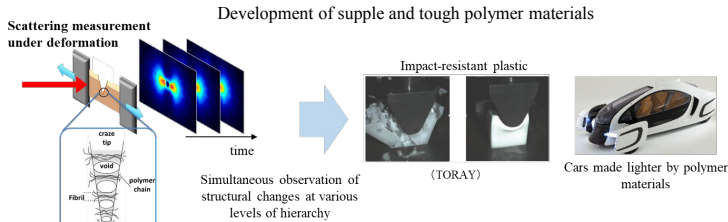


(A) Model of DNA double helix, (B) Its diffraction pattern, (C) Patterson function calculated from B, (D) 3D structure restored from C, (E) Patterson function recorded from real myosin filaments, (F) 3D structure restored from E.



Reference: H. Iwamoto, *IUCrJ*, **8**, 544 (2021)

- To control toughness and suppleness at the molecular level
 - Research on the fragility of polymers at the molecular level
 - Detailed analysis of structural changes on various spatial scales caused by deformation and fracture
- To develop products that combine toughness and flexibility with the lightweight properties of polymers

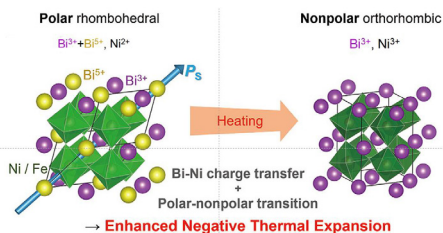


By analyzing changes in the hierarchical structure of polymer materials under various modes of deformation, the fracture and fatigue mechanisms were clarified and new materials were developed. Various automobile parts were replaced with polymeric materials from metallic materials, resulting in a 40% weight reduction.

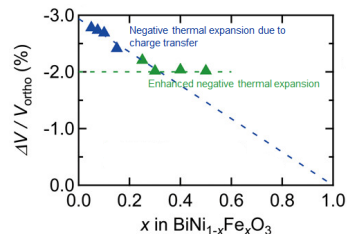


ImPACT HP (<https://www.jst.go.jp/impact/shinayaka/index.html>)

- To develop materials that shrink when heated
 - Negative thermal expansion properties are enhanced by two simultaneous mechanisms: Intermetallic charge transfer and a polar-nonpolar transition
- To design guidelines for thermal expansion control materials for precise positioning



HAXPES and PDF analysis revealed that $\text{BiNi}_{0.7}\text{Fe}_{0.3}\text{O}_3$ has $\text{Bi}^{3+}/\text{Bi}^{5+}$ and Ni^{2+} valence states and polar structure at low temperatures.



The charge transfer between Bi^{5+} and Ni^{2+} and the polar-nonpolar transition occur simultaneously, which enhance the negative thermal expansion



Reference: T. Nishikubo *et al.*, *J. Am. Chem. Soc.*, **141**, 19397 (2019)

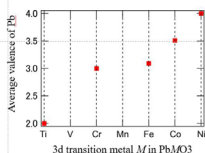
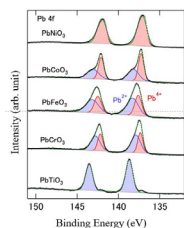
BL02B2
BL09XU

■ To elucidate the novel charge distribution of lead ferrite

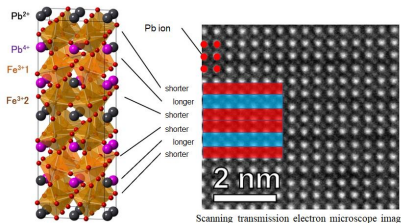
- Perovskite-type lead iron oxide (PbFeO_3) has a unique charge distribution such as $\text{Pb}^{2+}_{0.5}\text{Pb}^{4+}_{0.5}\text{Fe}^{3+}\text{O}_3$

→ To develop new negative thermal expansion materials

Charge distribution and crystal structure of lead iron oxide (PbFeO_3)



Average valence of Pb ions determined by HAXPES
 Pb^{2+} and Pb^{4+} exist at 1:1, indicating that the average valence is trivalent



Characteristic crystal structure with alternating one layer of only Pb^{2+} and two layers of Pb^{2+} and Pb^{4+} in a 1:3 ratio



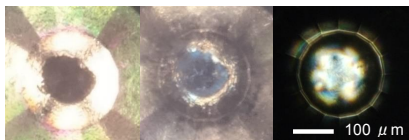
Reference: X. Ye *et al.*, *Nat. Commun.*, **12**, 1917 (2021)

BL12XU
BL12B2
BL10XU

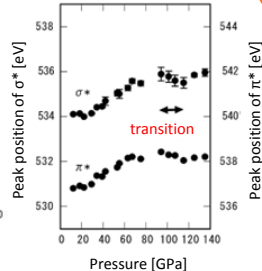
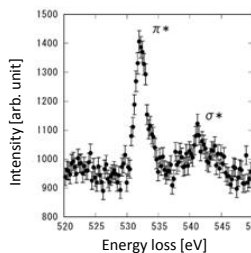
■ To observe the electronic structure of Oxygen during the insulator-to-metal transition under high pressure

- Observed the electronic structure change in oxygen across the insulator-to-metal transition due to pressure
 - Successfully detected signals from a tiny sample at very high pressure (> 1 Mbar)
- To apply the operand measurements and the imaging of the chemical status of low-Z samples to novel materials

Optical images and the change of the electronic structure of oxygen at high pressures



27 GPa 55 GPa 110 GPa (1.1 Mbar)



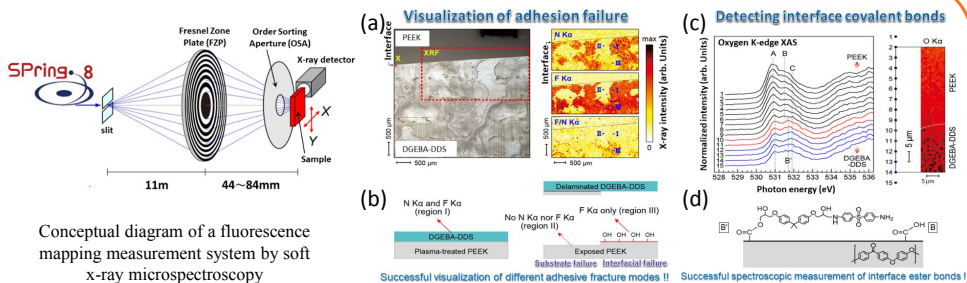
The red shift (lower energy shift) due to the insulator-to-metal transition was observed. The sample was as small as 0.1 mm in diameter and 0.01 mm in thickness during the transition.



Reference: H. Fukui *et al.*, *Proc. Nat. Acad. Sci.*, **116**, 21385 (2019)

To establish theories for adhesive interfaces

- To observe the adhesive interface between thermoplastic resin and thermosetting epoxy adhesive
 - Successful visualization of different adhesive fracture modes by microspectroscopy
 - Successful observation of traces suggesting the formation of interface ester bonds
- Expectation for feedback on material design for improved innovative bonding technology

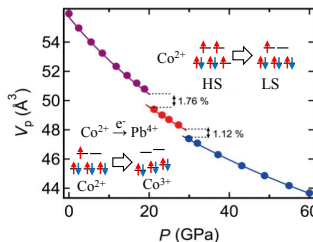
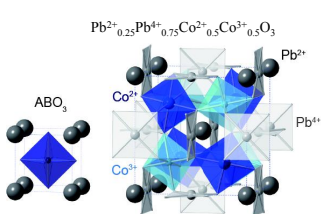


Reference: H. Yamane *et al.*, *Commun. Mater.*, **2**, 63 (2021)

To develop novel negative thermal expansion materials

- Sequential spin-state transition and intermetallic charge transfer were found first by applying pressure in perovskite oxide PbCoO_3 with peculiar charge distributions
 - Discontinuous volume reductions were observed at these transitions
- To develop novel negative thermal expansion materials by enabling these transitions during heating at ambient pressure through chemical substitution

Crystal structure and charge distribution of PbCoO_3 at ambient conditions and pressure variation of the unit cell volume



The high-spin (HS) state of Co^{2+} transforms into the low-spin (LS) state by pressurization up to 15 GPa.

With a further increase of pressure up to 30 GPa, the charge transfer from Co^{2+} to Pb^{4+} occurs, and the charge distribution finally changes into $\text{Pb}^{2+}_{0.5}\text{Pb}^{4+}_{0.5}\text{Co}^{3+}_{0.5}\text{O}_3$.

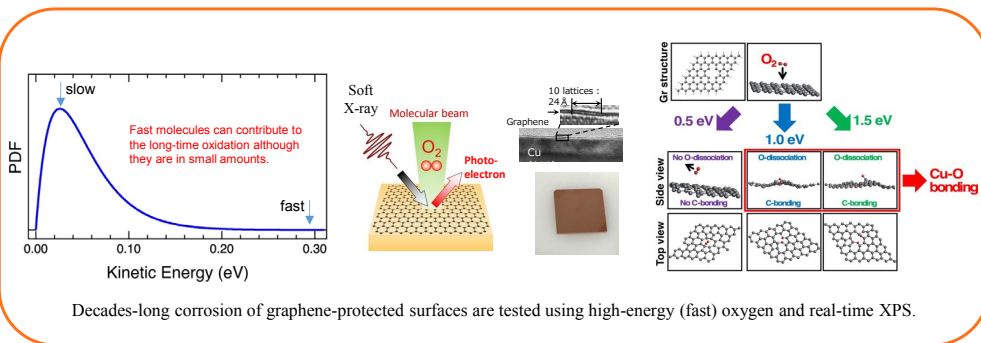
Volume reductions occur at these transitions due to the shrinkage of the ionic radius of Co both in the HS to the LS transition of Co^{2+} and Co^{2+} to Co^{3+} transition.



Reference : Z. Liu *et al.*, *J. Am. Chem. Soc.*, **142**, 5731 (2020)

■ Testing graphene protection against fast oxygen

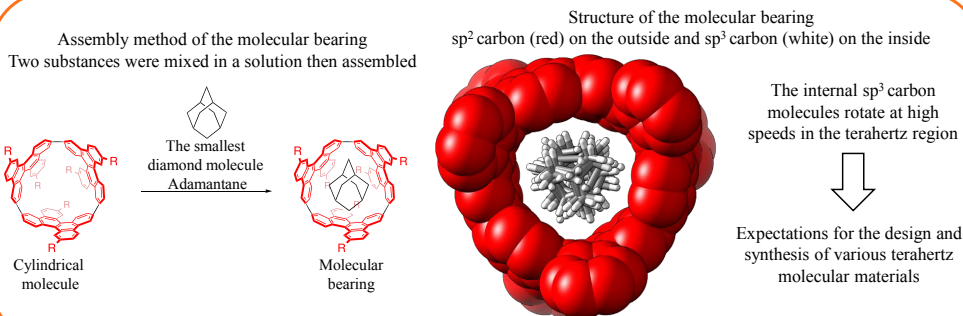
- Fast oxygen molecules can nondestructively permeate through graphene
 - The permeation occurs at defect sites of graphene
 - Decades-long corrosion can be tested using fast oxygen
- To apply to protective graphene coatings that prevent food and material degradation



Reference : S. Ogawa *et al.*, *J. Phys. Chem. Lett.*, **11**, 9159 (2020)

■ To fabricate molecular bearings with terahertz frequencies

- For the first time, a single molecule molecular bearing has been synthesized by combining sp^2 carbon from carbon nanotubes and sp^3 carbon from nanodiamonds
 - The diamond molecule inside rotates at high speeds, with a rotational frequency in the terahertz region
- To apply Beyond 5G/6G next-generation information and communication infrastructures

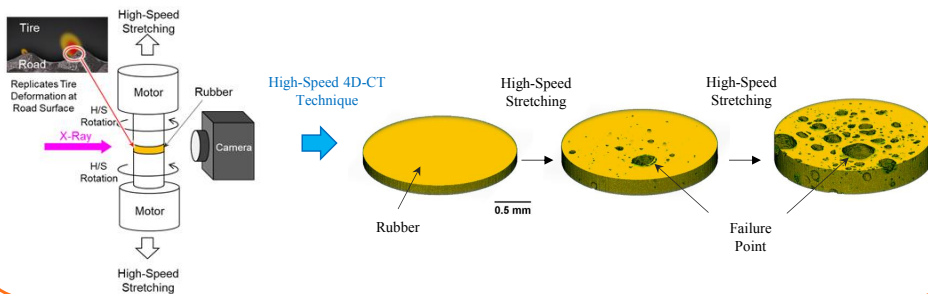


Reference: T. Matsuno *et al.*, *Nat. Comm.*, **12**, 5062 (2021)

BL28B2

- To develop new tire materials with superior wear resistance
 - Succeeded in observing the rubber failure phenomena with 10 ms temporal resolution
 - This advancement allows for continuous, high-speed observation of rubber failure phenomena in three dimensions and under conditions that better approximate the state of tire rubber during actual wear

Schematic of high-speed 4D-CT imaging system & resulting 3D image of rubber failure in progress.



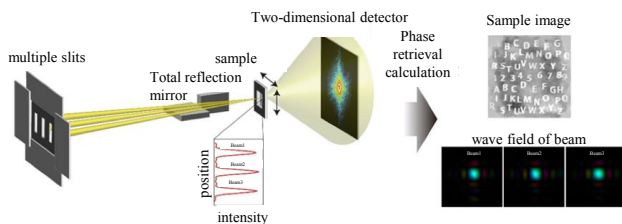
Sumitomo Rubber Industries, Ltd.

Reference: R. Mashita *et al.*, *J. Synchrotron Radiat.*, **28**, 322 (2021)

BL29XU

- Large field-of-view scanning coherent diffractive imaging microscope with multibeam X-ray irradiation
 - To develop techniques to simultaneously acquire images of multiple sample regions, expand the observation field of view, or shorten the measurement times
 - To apply to imaging advanced functional materials

Schematic diagram and observation outcomes of a scanning coherent diffractive imaging microscope using multiple slits



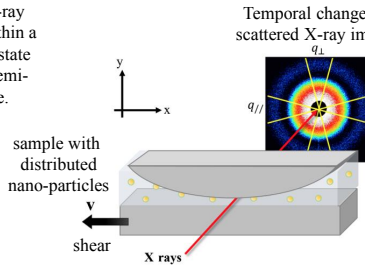
Compared to conventional measurements using a single X-ray beam, a wider observational field of view was obtained while using the same measurement time.

Reference: M. Hirose *et al.*, *Optics Express*, **28**, 2, 1216 (2020)

- To understand the heterogeneity of molecular motion, which holds the key to the glassy state
 - The properties of the glassy state show for the first time that heterogeneity can be eliminated by applying a displacement stress (shear) determined by the heterogeneity due to areas with different rates of molecular motion
 - Expected to contribute to the development of materials durable against friction and stress

Conceptual diagram of the experiment to examine the state of glass

Fine particles that cause X-ray scattering were dispersed within a polyvinyl acetate in a glass state then injected between the semi-cylinder and the substrate.



The substrate was moved at a constant speed to apply a displacement stress (shear). The solution was then irradiated with coherent X-rays and the motion of the particles were analyzed from the changes in the scattered image.



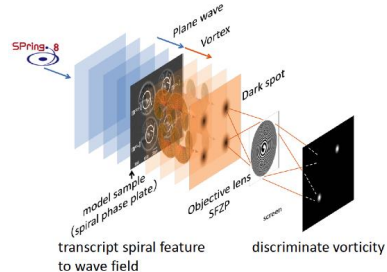
Reference: T. Hoshino *et al.*, *Phys. Rev. Lett.*, **124**, 1118004 (2020)

- X-ray microscope for identifying the orientation of helical structures within an object
 - Succeeded in creating an optical vortex by passing X-rays through an object with a spiral structure
 - The orientation of the helical structure can be identified by the X-ray microscope, which uses an imaging lens with spiral properties
 - To determine the spiral dislocation in functional material crystal samples

The relationship between the number of turns of the optical vortex beam and the surrounding intensity distribution

	typical laser	vortex	vortex
equal phase plane			
winding number	0	+1	-1
intensity and orbital angular momentum			
	bright@center	dark@center	dark@center

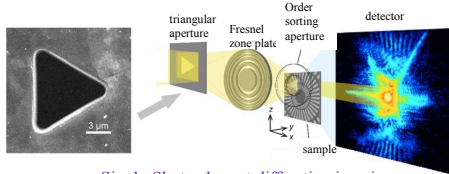
Schematic diagram of the X-ray microscope that identifies the orientation of helical structures.



Reference: Y. Kohmura *et al.*, *Optics Express*, **28**, 16, 24115 (2020)

- New developments in single-shot coherent diffractive imaging
 - By limiting the sample exposure area to a triangle, it is possible to reproduce an object from a single diffraction image, increasingly simplifying image reconstruction calculations
 - To apply to dynamic imaging for samples such as soft materials

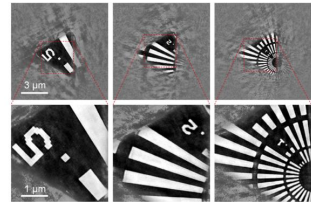
Conceptual diagram of single-shot coherent diffractive imaging



Single-Shot coherent diffractive imaging
(Conventional) Can observe only isolated objects smaller than the exposure area.

(This technique) Can observe a large area of the sample by irradiating only a limited area, like a triangle, with X-rays.

Image obtained from single-shot coherent diffractive imaging



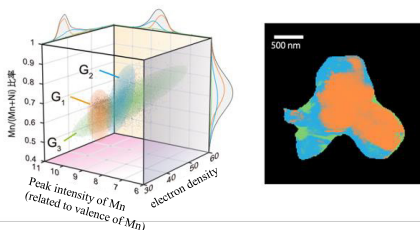
Succeeded in reconstructing a sample image with a spatial resolution of 17 nm from a single diffraction intensity pattern.



Reference: J. KANG *et al.*, *Optics Express*, **29**, 2, 1441 (2021)

- Succeeded in high-definition visualization of the inside of battery material particles
 - The scanning coherent diffractive imaging microscope revealed a non-uniform distribution of composition and chemical states in lithium battery positive electrode particles
 - To apply to nanostructure/chemical state analysis for various functional materials

Results determining the classification and distribution of composition and chemical states in lithium battery positive electrode particles.



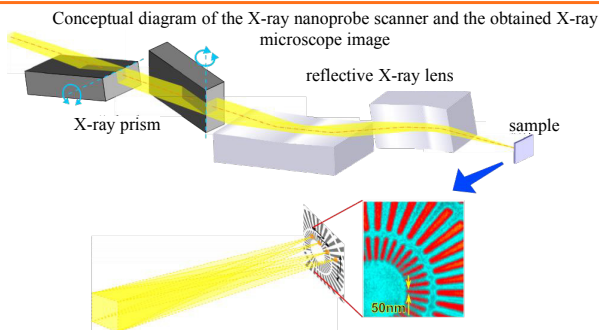
Analysis of the correlation between the composition and chemical state parameters revealed that regular (G1), irregular (G2), and impure phases (G3), can be grouped. G1 tended to be distributed in the center of the particle, with the others on the outer circumference.



Reference: H. Uematsu *et al.*, *J. Phys. Chem. Lett.*, **12**, 24, 5781 (2021)

X-ray nanoprobe scanner

- To develop a method to scan a focused nanoprobe without moving the sample
 - To achieve scan accuracy that is orders of magnitude finer than conventional methods
- The scan accuracy of the scanning X-ray microscope is approaching 1 nm

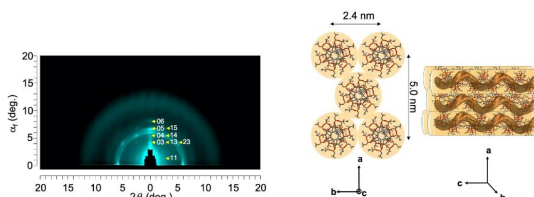


Reference: J. Yamada *et al.*, *IUCrJ*, **8**, 5, 713 (2021)

To obtain chiral silica using achiral stereoregular polymer

- The helical conformation of polymer could be achieved by mixing isotactic poly-methacrylate-functionalized POSS and a chiral dopant
 - The chiral silica compound with exclusive optical activity was produced after removing the chiral dopant at high temperature
- Expected to contribute to drug development that requires chiral synthesis and separation

GIWAXD image and helical molecular model of the polymer



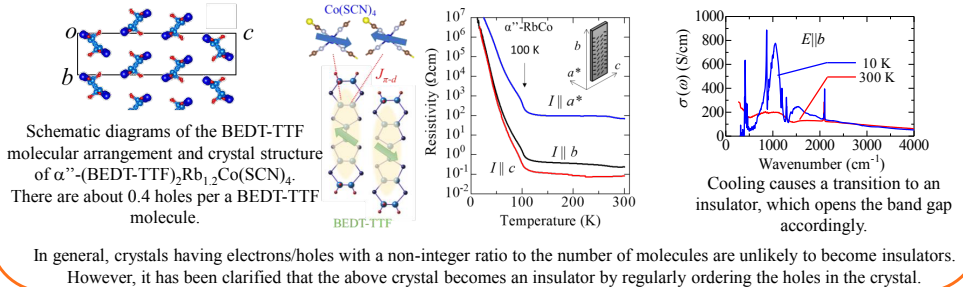
It was revealed by the GIWAXD that during the chiral synthesis process the sample has a helical structure.



Reference: K. Manabe *et al.*, *JACS-Au.*, **1**, 375-379 (2021)

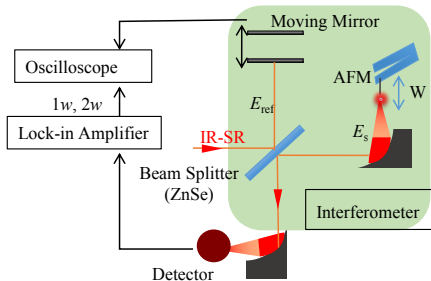
- To obtain organic electronic materials with new functionality
 - A molecular crystal was found whose holes per molecule are about 0.4, which display a metal-insulator transition, with the properties then clarified by infrared spectroscopy
 - It was discovered that the magnetic phase may appear at low temperatures
- By elucidating the conduction mechanisms, it will be possible to design new electronic devices and magnetic materials

Organic crystals whose conductivity vary with temperature

Reference: S. Iguchi *et al.*, *J. Phys. Soc. Jpn.* **90**, 074701 (2021)

- Nanometer-order spatial-resolution in the infrared region smaller than the wavelength
 - To develop infrared spectroscopy for nanometer-order micro-samples and micro-range infrared spectroscopy
- Aiming to elucidate chemical compositions, bonding states, and electronic states with high spatial resolution

Schematic Illustration of the optical path



The near-field spectrometer consists of an AFM system which brings the probe close to the sample and a spectrometer for measuring the infrared spectrum.

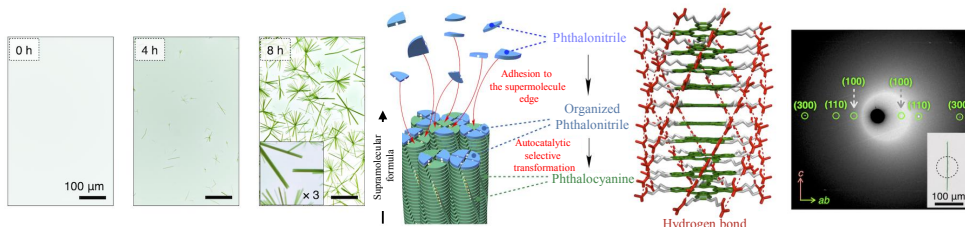
Reference: Y. Ikemoto *et al.*, *Jpn. J. Appl. Phys.* **54**, 082402 (2015)

BL45XU

Successful synthesis of precise polymers with low environmental impact

- By only heating the phthalonitrile molecules, solvent-free phthalocyanine supermolecule polymers are synthesized with low environmental impact
- Phthalocyanine molecules are obtained by autocatalytic function with high yields over 80%
- Metal phthalocyanine can be produced with coexisting metal salts
- Block copolymers can also be produced from phthalocyanine and metal phthalocyanine

Solvent-free advancement of autocatalytic supermolecule polymerization



Phthalocyanine is one-dimensionally linked through hydrogen bonds of amides. This facilitates the reductive cyclization reaction from phthalonitrile to phthalocyanine.



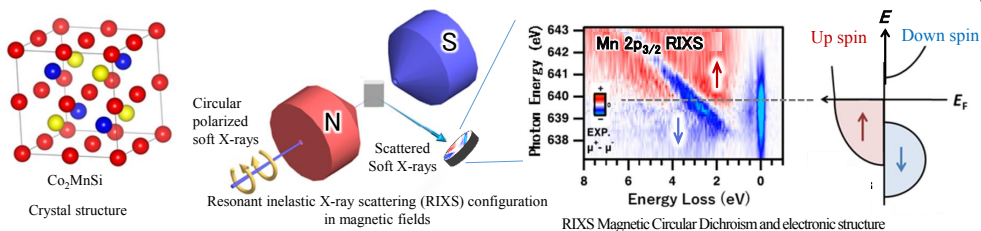
Reference: Z. Chen *et al.*, *Nat. Mater.*, DOI:10.1038/s41563-021-01122-z (2021)

BL07LSU

Developing material exploration measurement methods for Society 5.0

- *In-situ* observation of spin-polarized electron structures in device-operating environments within a magnetic field
 - Demonstrating unique halfmetallic electronic structures for spintronics
- Spintronics material research is accelerating and will be used in future energy-saving products

Observation of electronic states of halfmetallic ferromagnets in a magnetic field



First direct detection of electron spin components, the source of magnetism, in the electronic structure of spintronics materials simulating device-operating environments.

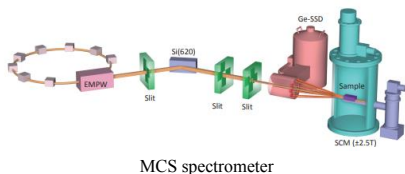


Reference: H. Fujiwara *et al.*, *Sci. Rep.* **11**, 18654 (2021)

Bayesian spectroscopy successfully reduced the magnetic Compton measurement time

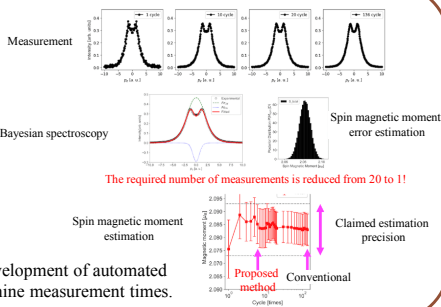
- By applying the recently developed analysis method Bayesian Spectroscopy, the magnetic Compton scattering measurement time can reduce to one twentieth of the original time
 - The measurement, which previously took about one day, can be done in about one hour
- Research and development of magnetic materials by magnetic Compton scattering

Accelerating measurement by integrating data-driven science



MCS spectrometer

It is expected that the data science will play an important role in the development of automated measurement systems, as computers will be able to automatically determine measurement times.

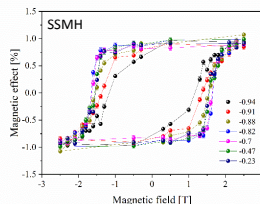
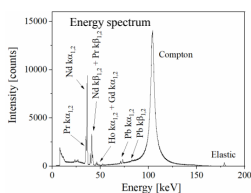


Reference: Y. Yokoyama *et al.*, *J. Phys. Soc. Jpn.* **90**, 094802 (2021)

Observation of magnetic state in magnets

- To develop methods to observe the magnetic state inside magnets
- Observation of the degradation of coercivity at the surface because of the mechanical treatment, and the degradation of coercivity inside of the magnet because of the demagnetizing field

Depth dependence of spin-specific magnetic hysteresis



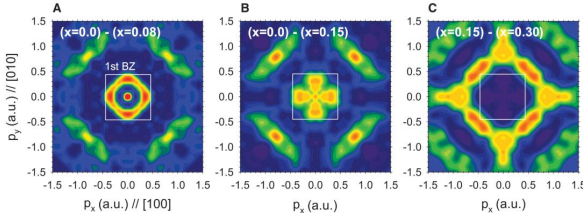
The surface mechanical treatment of the Nd-Fe-B sintered magnets decrease the coercivity in the surface region with a thickness of 120 nm. In the internal region of this magnet, the coercivity decreases because of the demagnetizing field.



Reference: N. Tsuji *et al.*, *Appl. Phys. Lett.* **116**, 182402 (2020)

- Visualizing the electronic state responsible for high-temperature superconductivity
 - Succeeded in visualizing the electronic state inducing high-temperature superconductivity in high T_c superconducting cuprate
 - The change in the hole state was observed from the electron momentum density distribution
- To elucidate the mechanisms of superconducting cuprate

The change of electron momentum density distribution due to hole-doping



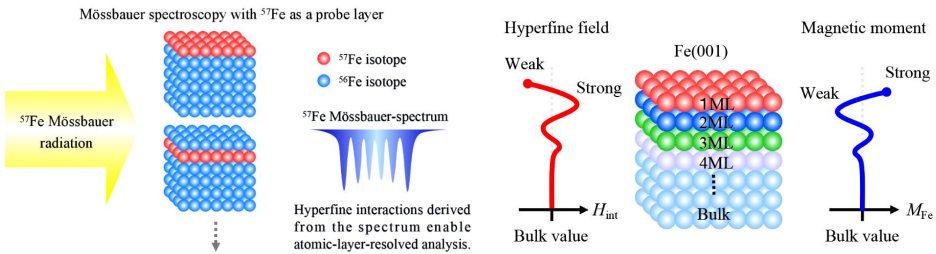
We revealed that the electron momentum density changes significantly in the under-doped and over-doped regions



Reference: Y. Sakurai *et al.*, *Science*, **332**, 6030 (2011)

- To develop higher performance magnetic and spintronics materials
 - Direct observation of magnetic Friedel oscillation at the Fe (001) surface by synchrotron based atomic-layer-resolved magnetic structure analysis
 - Predicted 40 years ago, magnetic Friedel oscillations were finally observed in the layers beneath an iron surface
- To develop advanced magnetic and spintronics devices

Iron surface magnetism observed by atomic-layer-resolved synchrotron Mössbauer spectroscopy.



Layer-by-layer magnetic study is realized by changing the embedding position of the ^{57}Fe monolayer in the thin film.

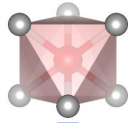
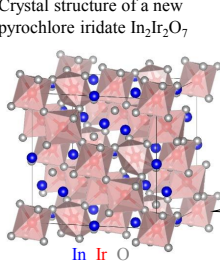


Reference: T. Mitsui *et al.*, *PRL* **125**, 236806 (2020)

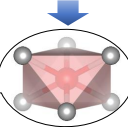
Electronic states against expectations

- 5d electronic states in a new pyrochlore iridate were unveiled
- Isotropic 5d electrons were found to situate in the distorted lattice
- This characteristic of the 5d electron can yield novel physical properties in new 5d transition-metal compounds

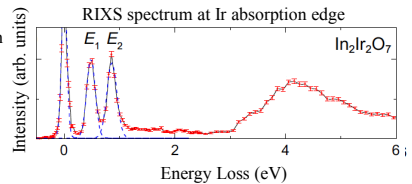
Crystal structure of a new pyrochlore iridate $\text{In}_2\text{Ir}_2\text{O}_7$



Regular IrO_6 octahedron without distortion



Distorted IrO_6 octahedron in $\text{In}_2\text{Ir}_2\text{O}_7$



In $\text{In}_2\text{Ir}_2\text{O}_7$, separation between E_1 and E_2 in the spectrum is smaller than the other pyrochlore iridates, indicating that 5d electronic states are more isotropic despite the larger distortion of IrO_6 octahedron.

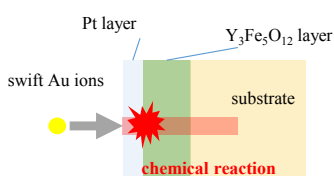


Reference: A. Krajewska *et al.*, *Phys. Rev. B*, **101**, 121101(R) (2020)

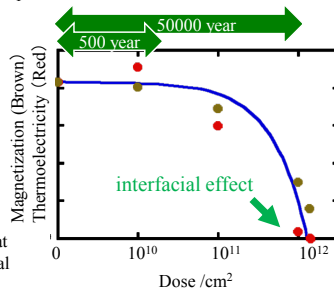
Tolerance of spin-Seebeck thermoelectricity against irradiation by swift heavy ions

- $\text{Pt/Y}_3\text{Fe}_5\text{O}_{12}$ devices have a very high radiation tolerance to swift heavy ions
- The origin of the deterioration is likely to be the chemical reactions at the interface
- To develop new technologies for the safe and effective utilization of waste heat from spent nuclear fuels in the radiation environment

Irradiation of Au ions and the service life of the spin-Seebeck thermoelectric device



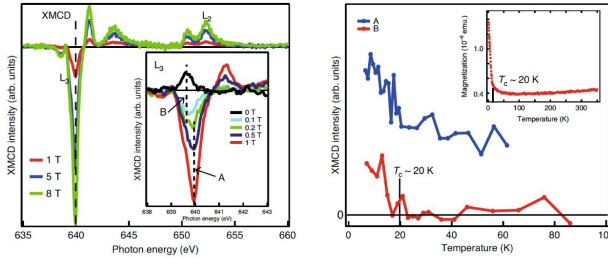
The performance of $\text{Pt/Y}_3\text{Fe}_5\text{O}_{12}$ devices would be constant for several hundred years even if the spent nuclear fuel is used as a heat source. The origin of the degradation is suggested to be the chemical reaction at the interface of the device from HAXPES results.



Reference: S. Okayasu *et al.*, *J. Appl. Phys.* **128**, 083902 (2020)

- To fabricate novel magnetic topological heterostructures
 - $\text{Mn}_4\text{Bi}_2\text{Te}_7/\text{Bi}_2\text{Te}_3$ heterostructures in which the Mn atoms are embedded in the topological insulator Bi_2Te_3 were fabricated, and the magnetic property was revealed by soft X-ray magnetic circular dichroism (XMCD)
 - This novel heterostructure is potentially important for the realization of quantized anomalous Hall effects with high working temperatures

Magnetic-field and temperature dependent XMCD spectra at Mn $L_{2,3}$ edge



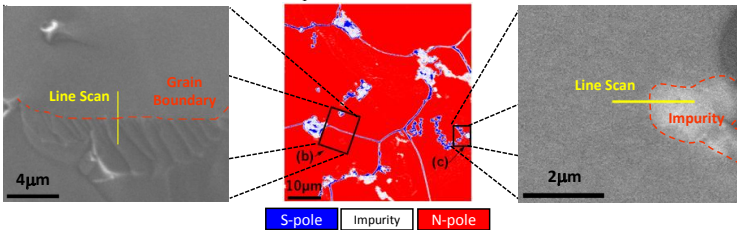
There are two distinct Mn components (A and B). The Curie temperature of B is ~20 K, while A shows a paramagnetic behavior.



Reference : T. Hirahara *et al.*, *Nat. Commun.*, **11**, 4821 (2020)

- Guidelines for lifetime resistance to heat and corrosion in magnetic properties of Sm-Co magnets
 - Real-space identification of magnetically weak positions of Sm-Co magnets under external magnetic fields

The relationship between magnetic reversal process (red to blue), microstructure, and composition distributions.



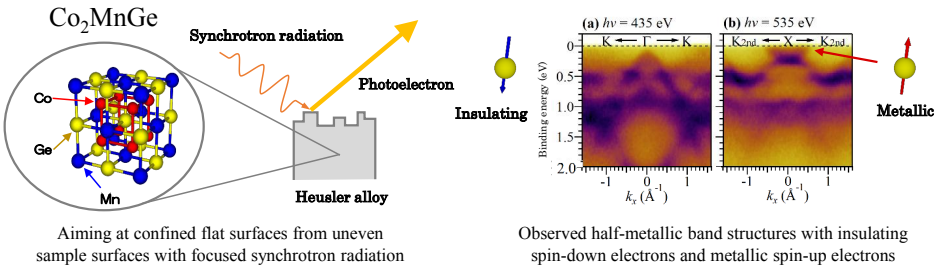
Reversal of the external magnetic field preferentially reverses the magnetization of the grain boundary (left) and impurity (right). Reforming of magnet grain boundaries and reduction of impurities are key to improving magnetic properties.



Reference : Y. Matsuura *et al.*, *Appl. Phys. Lett.* **117**, 022409 (2020)

- To develop power-saving spintronics devices
 - Directly observed the three-dimensional band structures of the Heusler alloy Co_2MnGe
 - First analysis of half-metallicity in Co_2MnGe
- Guidelines for developing innovative spintronics devices with low-power consumption

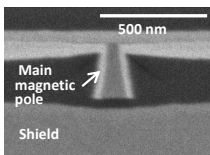
Observation of three-dimensional band structures by angle-resolved photoemission spectroscopy



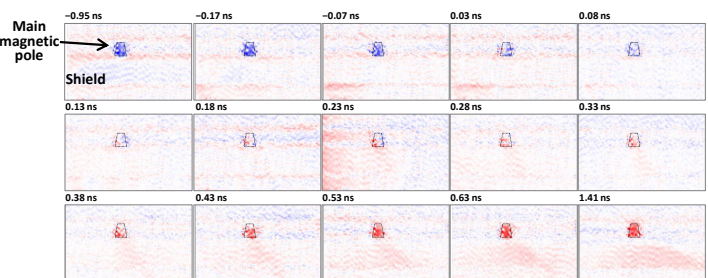
Reference: T. Kono *et al.*, *Phys. Rev. Lett.*, **125**, 216403 (2020)

- Successful imaging of an HDD write head in operation with an accuracy of 10 billionth of a second
 - High-speed magnetization reversal of the magnetic material on the write head was captured
- To contribute to further increasing HDD capacity and energy conservation

SEM image of the HDD write head



The time dependence of the direction of magnetization was obtained by X-ray magnetic circular dichroism measurements.



※Red and blue in the figure correspond to vertically upward and downward magnetization, respectively.

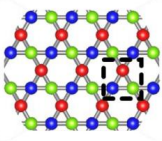


Reference: H. Suto *et al.*, *J Appl. Phys.* **128**, 133903 (2020)

■ Novel theoretical prediction of magneto-optical responses

- To simulate a magneto-optical response of antiferromagnetic states in Kagome lattice materials
- Universal interpretation of XMCD response for antiferromagnets
- To contribute to research and development of new materials utilizing antiferromagnetic states

Antiferromagnetic state in a Kagome lattice.
Classifiable by spin (arrow) chirality.



Plus chirality



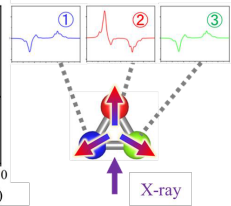
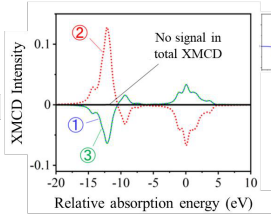
Minus chirality



It has been thought that there is no XMCD response in antiferromagnetism because the spins cancel each other



Found that XMCD signal is obtained only with minus chirality

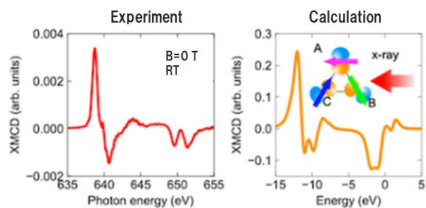
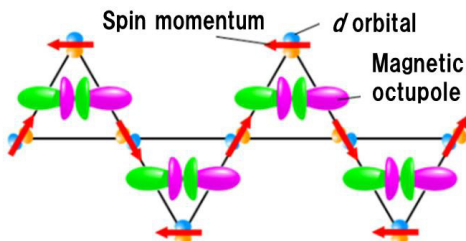


Reference: N. Sasabe *et al.*, *Phys. Rev. Lett.*, **126**, 157402 (2021)

■ To develop devices with new functionality

- Magnetic octupoles were observed in Mn_3Sn with high thermoelectric effect
- The XMCD proved effective in observing magnetic octupoles
- To contribute to the development of spintronic devices and thermoelectric materials with magnetic octupoles

Magnetic octupole induced in Mn_3Sn



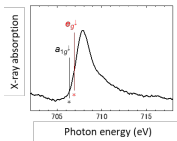
Induced magnetic octupole is confirmed with comparison between experimental spectra and calculations assuming magnetic octupole state.



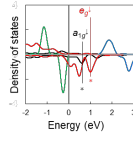
Reference: M. Kimata *et al.*, *Nat. Commun.*, **10**, 1038 (2021)

- First steps toward integrated quantum computing using molecules
 - First demonstration that electron spin can be transferred to an organic molecule by electric current
 - Organic magnetic materials have longer coherence than metallic magnetic materials
- Expected to be applied to quantum computing circuits

Iron(II) phthalocyanine on platinum wires



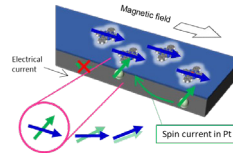
Experimental results



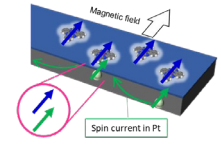
Calculation of the density of state

The spin of the iron(II) phthalocyanine molecule is retained after device processing

Electrical resistance changes depending on the direction of the external magnetic field



[When organic molecules spin and currents are orthogonal]
Passing of spins occurs
→ additional electrical resistance

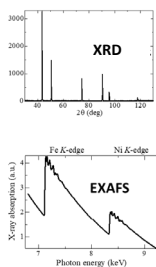


[When the spin and current of an organic molecule are parallel]
Spin remains unchanged



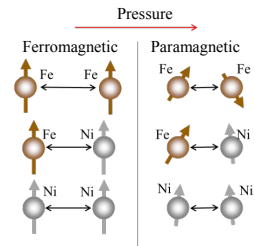
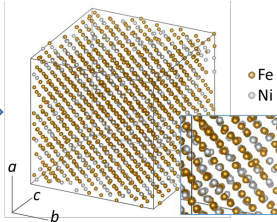
Reference: H. Gamou *et al.*, *Nano Lett.* 20,1,75-80 (2020)

- To visualize the atomic arrangements of disordered alloys
 - To understand element-selective visualization of the atomic arrangements in Fe-Ni disordered alloys
 - Interpreting the zero-thermal expansion of Fe₆₅Ni₃₅ ferromagnetic Invar alloys as the elongation/shrinkage of Fe-Fe pairs
- Guidelines for producing materials with good thermal and magnetic elastic properties



Reverse Monte Carlo calculations

Atomic arrangements of disordered alloys



Elongation/Shrinkage of Fe-Fe pairs in the Fe₆₅Ni₃₅ disordered alloy was investigated by reverse Monte Carlo calculations using complementary data sets of extended x-ray absorption fine structure (EXAFS) and X-ray diffraction (XRD).

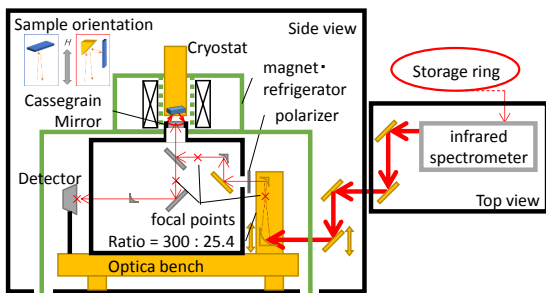


Reference: N. Ishimatsu *et al.*, *Phys. Rev. B*, **103**, L220102 (2021)

Wideband infrared micro-spectroscopy in high fields and low temperatures

- To investigate magnetic-field effects on materials using low-energy infrared light
- To elucidate the electromagnetic cross-correlations and off-diagonal responses of materials which have been actively studied in recent years: multiferroics, strongly correlated electron systems, topological insulators, Dirac electron systems, quantum Hall systems, etc.

Improving performance by redesigning the magneto-optical infrared micro-spectroscopy station



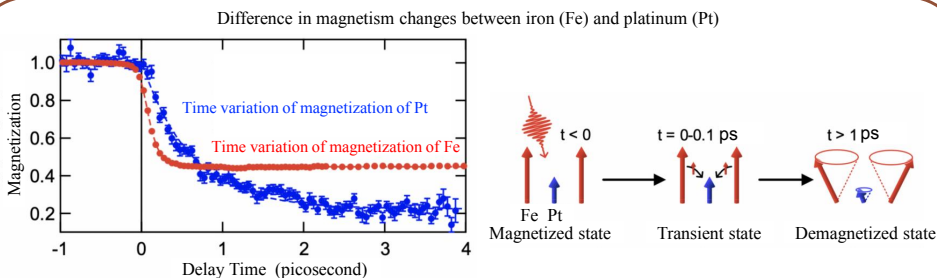
- A stable optical system was constructed by installing the microscope on an optical bench instead of a vibration-free stand.
- The adjustment performance of the two-stage light focusing system have been improved. As a result, easy operation is possible with small areas and strong intensities on the sample, and wide bandwidths of infrared light.
- The cryostat has been upgraded, thus low-temperature experiments with less helium consumption have become possible.



Reference: S. Iguchi *et al.*, *Spring-8 Sci. Res. Rep.* **8**, 88 (2020)

Ultrafast magnetic control

- Ultrafast laser-induced magnetism changes were observed in an iron-platinum alloy
- The speed of the changes were revealed to differ between iron and platinum sites for the first time
- To develop ultrafast opto-magnetic memory devices



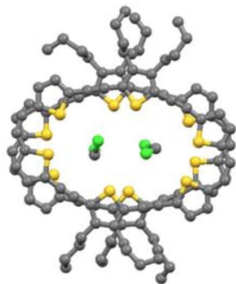
In the transient state after laser irradiation, the magnetic state of Pt changes slower than that of Fe.



Reference: K. Yamamoto *et al.*, *New J. Phys.*, **21**, 123010 (2019)

- To fabricate a supramolecular coil with a current response to magnetism
 - Successful construction of nanostructures of giant thiophene cyclic molecules
 - Double-donut-shaped giant molecules exhibit cyclic current in magnetic fields
- Significant contributions to the development of molecular electronics technology based on organic molecules

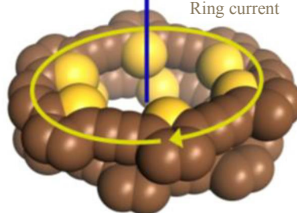
Giant thiophene cyclic molecule



Ring current is produced by external magnetic field.

External magnetic field

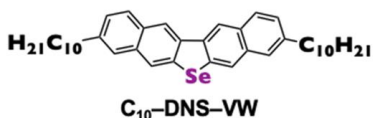
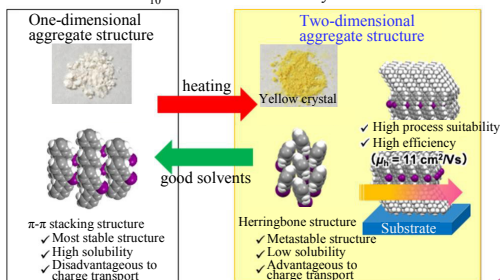
Ring current



Reference: T. Okamoto *et al.*, *J. Am. Chem. Soc.*, **142**, 14974 (2020)

- To develop high-performance organic semiconductors exhibiting anomalous structural phase transition behaviors
 - High-performance organic semiconductor C_{10} -DNS-VW with high-process suitability was developed
 - The unique phase transition behavior of the crystalline phases leads to high-solubility and semiconductor performance
- Making great strides in the practical application of key devices for the near-future IoT society

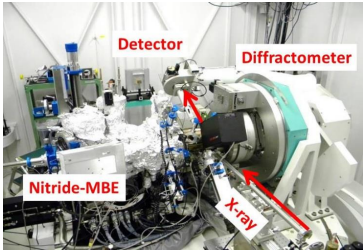
Selenium-bridged V-shaped semiconductor molecules

Characteristics of the organic semiconductor C_{10} -DNS-VW in this study

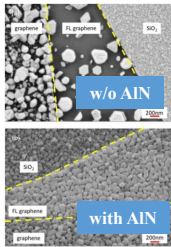
Reference: T. Okamoto *et al.*, *J. Am. Chem. Soc.*, **142**, 14974 (2020)

BL11XU

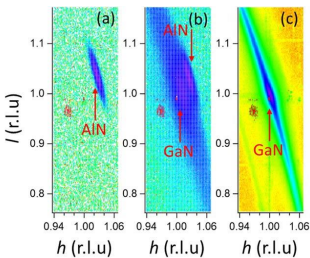
- *In-situ* observation of GaN growth on a graphene surface
- The effect of the AlN buffer layer on the quality of the GaN film was studied for application of flexible optoelectronics devices
 - *In-situ* XRD reciprocal space mapping (RSM) during GaN growth was measured using an MBE-XRD system
- We found that the AlN buffer is effective in enhancing the lateral growth of the GaN film



Molecular Beam Epitaxy/X-ray Diffractometer (MBE-XRD system)



GaN growth on graphene



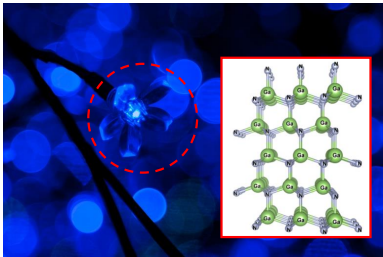
Reference: S. Fuke *et al.*, *Jpn. J. Appl. Phys.* **59**, 070902 (2020)

BL11XU

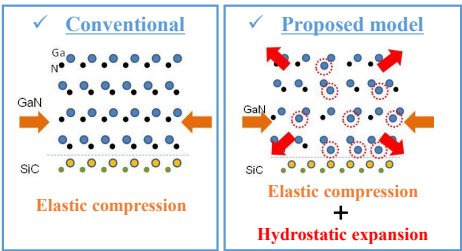
- Anomalous lattice deformation in GaN/SiC (0001)
- Initial growth properties of the GaN are crucial for all optoelectronic devices composed of GaN-based materials (LED, laser diodes, and high-power transistors)
 - The evolution of the lattice parameters during the growth of the GaN layer was measured by *in-situ* XRD
- The observed lattice deformation indicates that the control of interstitial defects in the initial growth is important for fabricating GaN-based devices

Application of gallium nitride (GaN)

Initial GaN growth analysis by *in-situ* XRD



Blue LED and GaN crystal structure



Proposed lattice deformation model (elastic compression incorporated with hydrostatic expansion due to interstitials)

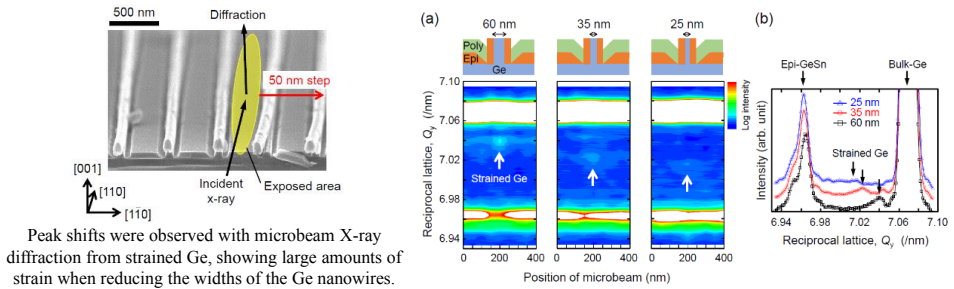


Reference: T. Sasaki *et al.*, *Appl. Phys. Lett.* **108**, 012102 (2016)

To improve device performance by strain control

- The microscopic local stress and strain in the Ge/Ge_{1-x}Sn_x heterostructures were investigated using synchrotron microdiffraction
- Materials with high hole mobility required for p-type MOSFET channel can be developed with strain control

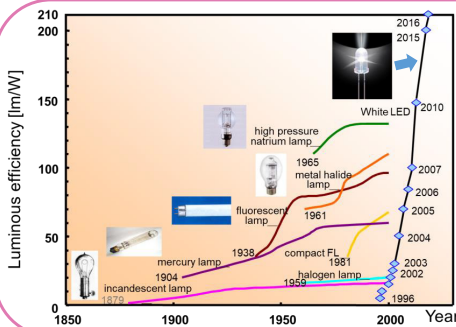
Lattice strains depend on the width of germanium nanowires



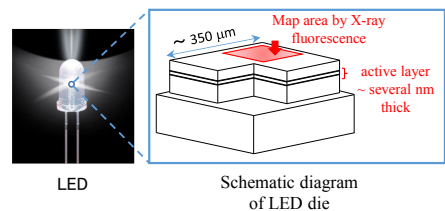
Reference: S. Ike *et al.*, *Appl. Phys. Lett.*, **106**, 182104 (2015)

To develop and adopt LEDs with higher efficacy and increased energy savings

- Visualized minute compositional changes in the active layer of LEDs
- Confirmed the correlation between optical characteristics and composition distribution
- Proved it is necessary to control the fluctuation of compositions with nano-micro scale



Efficiency of white LEDs and schematic diagram

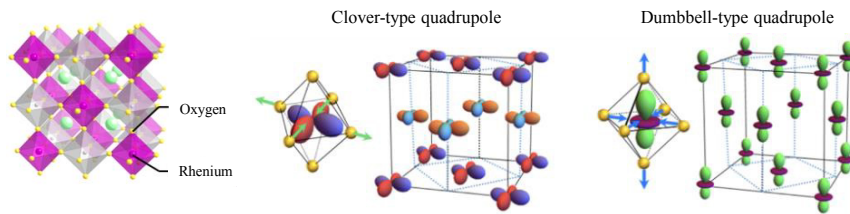


Reference: A. Sakaki, *et al.*, *Scientific Reports*, **9**, 3733 (2019)

To understand novel devices using hidden orders

- The first observation of multipolar order at low temperatures in a compound including rhenium, which is a transition metal with high atomic number, was observed
- To design devices with new operation mechanisms based on the unique nature of electrons, i.e., multipole

Schematic view of the order of the charge distribution on a Re atom



Observation of oxygen positional shift as small as about one part per trillion meters reveals Clover-type and Dumbbell-type quadrupole orders.

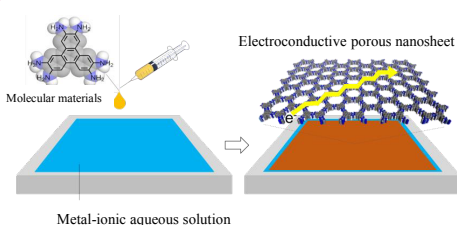


Reference: D. Hirai *et al.*, *Phys. Rev. Res.*, **2**, 022063(R) (2020)

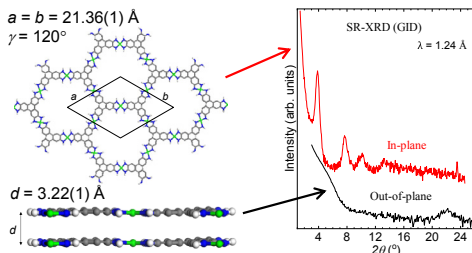
High-performance nanosheet materials created at air/liquid interfaces

- By dropping material solution on a liquid surface an electroconductive porous ultra-thin sheet can be synthesized
- High-performance nanomaterials can be manufactured by this energy-saving process under ambient temperature and pressure
- To apply to downsizing and increasing the functionality of sensors and batteries

Fabrication of nanosheets on water surface



3D nanostructure and orientation revealed by SR-XRD



Focused on the phenomenon that a uniform and large area oil film is formed on the water surface.

Creating a conductive functional material with advanced 3D nanostructures by devising the combination of materials and synthetic conditions.

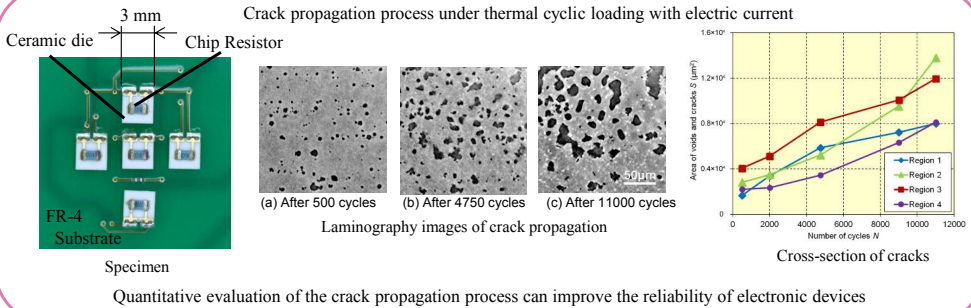


Reference: T. Ohata, R. Makiura *et al.*, *ACS Appl. Mater. Interfaces*, **13**, 54570 (2021)

BL20XU
BL20B2
BL47XU

In-situ observation of die-attach solder joints that are cyclically energized

- Die-attach solder joints on an electronic board were successfully observed under energized conditions with X-ray laminography
- The thermal crack propagation process could be observed quantitatively under the thermal cyclic loading with electric current



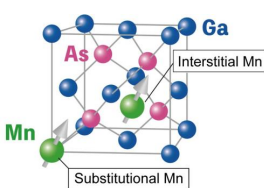
Reference: H. Tsuritani *et al.*, *Proc. of InterPACK2017*, IPACK2017-74177 (2017)

Exploring how semiconductors become ferromagnets

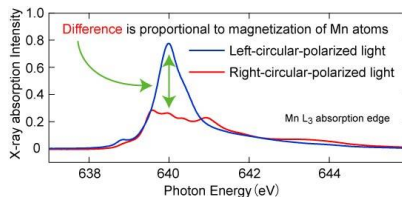
- Atomic-level observations of magnetic ordering processes in ferromagnetic semiconductors promises a candidate material for spintronics
- Ferromagnetism is developed by the overlap of locally spin-aligned regions
→ Insight for its practical use as a spintronics device

BL23SU

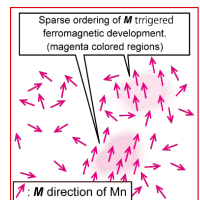
Manganese-doped gallium arsenide ($\text{Ga}_{1-x}\text{Mn}_x\text{As}$)



Study of the magnetic state of only Ga-substituted Mn



Temperature and magnetic-field dependent investigation of the difference between two kinds of X-ray absorption spectra (X-ray MCD)



Ferromagnetism is developed by the overlapping of local ferromagnetic regions.



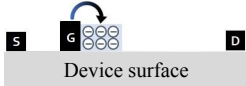
Reference: Y. Takeda *et al.*, *J. Appl. Phys.*, **128**, 213902 (2020)

BL25SU
BL39XU

- To develop clean & high-performance electronic devices:
Snap-shooting of the onset of device operation
 - Temporal-variations in a device's electronic state were directly observed by XAFS and XMCD with a time-resolution of ~ 60 picoseconds
 - The capability of time-resolved analysis of micro-devices with a resolving power of ~ 100 nm has been demonstrated

<Time-resolved imaging of surface electron trapping (SET) in GaN-HEMT power device>

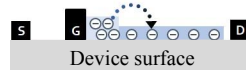
Pico $\sim$ nanoseconds
after application of gate (G) – drain (D) voltage



Strong SET concentrated near G



Micro $\sim$ milliseconds



SET pervaded toward D

In order to unveil the mechanisms of current-collapse phenomenon, which hinders efficient operation of GaN-HEMT, an actual GaN-HEMT device under operation was observed in a time-resolved manner.

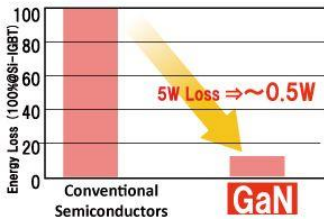
- The SET process was traced through time-resolved XAFS spectra at the Ga L_3 -edge and it was revealed that immediately after the voltage application, the strong SET took place near the gate electrode.



Reference : K. Omika *et al.*, Appl. Phys. Lett. **117** 171605 (2020)

BL28B2

- Next-generation semiconductor materials that bring about an energy-saving society
 - Evaluation by X-ray topography of "gallium nitride (GaN)" single crystals with high energy conversion efficiency
 - This result can provide a technical guideline for the stable production of higher quality GaN single crystals



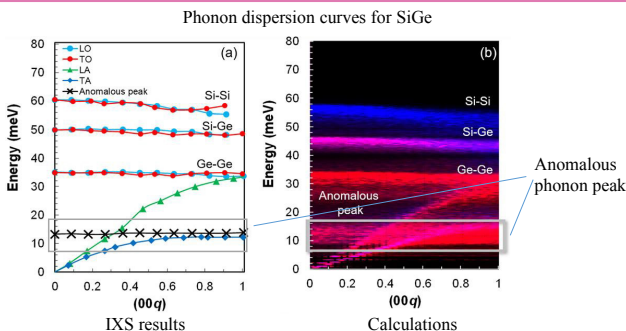
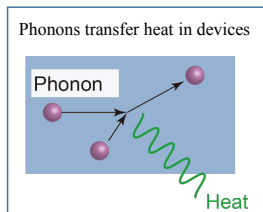
Referenced from Japan Science and Technology Agency
<https://www.jst.go.jp/sdgs/practices/p040.html>



Reference : J. Kim *et al.*, Phys. Rev. Applied, **11**, 024072 (2019)

Unveiling the origin of low thermal conductivity

- The phonon structure of SiGe, a thermoelectric material, was investigated
 - An anomalous phonon peak was observed, which does not appear in the pristine materials, Si and Ge
 - The anomalous peak is the origin of the low thermal conductivity of SiGe
- To be used for finding high-efficient thermoelectric materials for devices

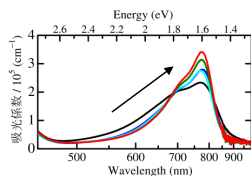


Reference : R. Yokogawa *et al.*, *Appl. Phys. Lett.*, **116**, 242104 (2020)

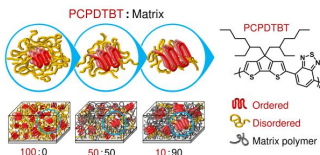
Design guidelines for efficient charge transport in thin film devices

- Investigation of the cause of charge transport capacity for blend polymer films, which are essential for the development of organic electronic devices
 - Light absorption of narrow band gap polymer (PCPDTBT) have shifted to low energy
 - The ordering of conjugated polymer chains in nanometer scale (10^{-9} m) was improved
- Guidelines for the development of blend thin films that maintain high-charge transportability

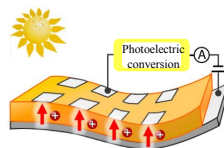
To create high-performance electronic devices with polymer blend thin films



The light absorption characteristics of PCPDTBT



Improvement of short-range order of PCPDTBT



To apply the development of high-efficiency polymers e.g. solar cell



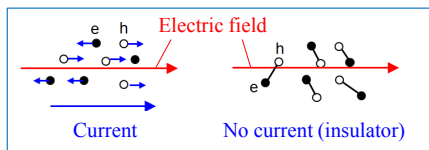
Reference : A.T. Hidayat *et al.*, *Macromolecules*, **53**, 6630 (2020)

BL43IR

Understanding the pressure response of an exotic “excitonic semiconductor”

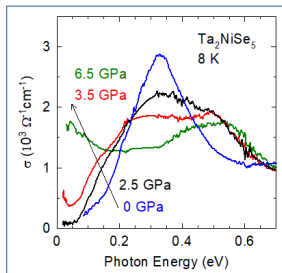
- Pressure response of an “excitonic insulator”, which is insulating due to the spontaneous formation of bound states (excitons) by electrons and holes which would carry current if not forming excitons
 - Pressure evolution of the characteristic energy gap has been determined
- Possible future applications for unique electronic materials

An “excitonic insulator” is obtained when electrons and holes form excitons.



Current and metallic conduction result (above left) if electrons (e) and holes (h) are free, but an insulator results (above right) if electrons and holes form bound states (excitons) which are electrically neutral.

Pressure response of the energy gap



Pressure response of the optical conductivity of excitonic insulator candidate Ta_2NiSe_5 . The energy gap is suppressed with increasing external pressure.



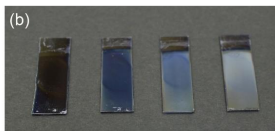
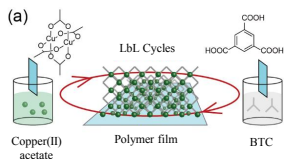
Reference: K. Matsubayashi *et al.*, *J. Phys. Soc. Jpn.*, **90**, 074706 (2021)

BL46XU

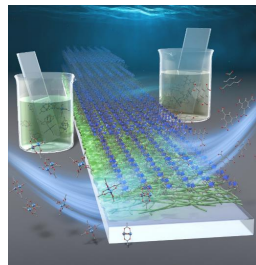
To apply porous material coatings to plastic surfaces

- Successful growth of metal-organic structure (MOF) thin films on the surface of general-purpose polymer materials such as acrylic resin
- MOF thin films can be produced by an extremely simple method of immersing a substrate alternately in two different solutions at room temperature and in air
- Expected to have a ripple effect on the development of functional materials

(a) Schematic diagram of the preparation method and (b) substrates coated with MOF thin film



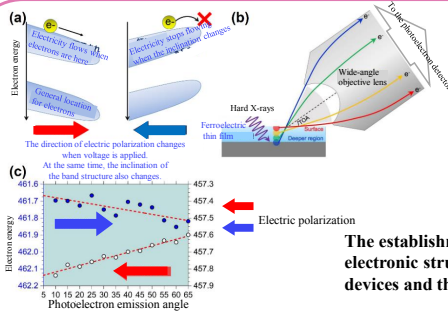
The MOF thin films can be prepared by a very simple method: Soak polymer plates alternately in two kinds of MOF solutions.
The obtained MOF thin film have a uniform thickness.



Reference: H. Ohara, *et al.*, *ACS Appl. Mater. Interfaces*, **12**, 50784 (2020)

BL09XU
(BL47XU)

- Direct observation of “skewed electronic band structure” induced by electric polarization in ferroelectric materials
 - First observation of a skewed band structure in BaTiO₃ using angle-resolved hard X-ray photoelectron spectroscopy (HAXPES) with an on-site developed wide-acceptance electrostatic lens
 - Succeeded in precision synthesis of BaTiO₃ thin-film with single polarization domain
 - To develop high-speed and high-capacity nonvolatile memory (FeRAM) and artificial synapses based on ferroelectric materials



Ferroelectrics, which are a key material for capacitors used in smartphones and other devices, have been thought to have “skewed electronic structure”, but it had never actually been observed

The skewed electronic structure in BaTiO₃ was successfully observed for the first time in the world with an angle-resolved HAXPES experiment at BL47XU

The establishment of an experimental method to investigate the skewed electronic structure is expected to advance the development of frontier electronic devices and the study of artificial synapses using ferroelectric materials



Reference: N. Oshime *et al.*, *Scientific Reports*, **10**, 10702 (2020)

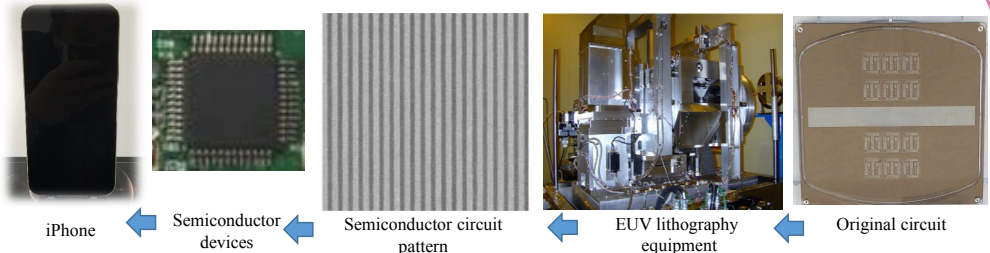
Semiconductors & Electronics

Methodology

- Next-generation semiconductor nanofabrication technology (EUV&BEUV lithography) made accessible to the world
 - Succeeded in reducing the width of a semiconductor circuit line to 1/5000 the diameter of a human hair, to enable the technology for smartphones after 5G and 6G
 - To develop ultra high-integration (terabytes), high-speed (1000 times), low-power consumption (1/10), and low-manufacturing cost (1/100 to 1/1000 every 5 years) semiconductor circuits that can operate at room temperature

NewSUBARU
BL03
BL09
BL10

EUV Lithography Technology



EUV lithography technology, which has been in development at the University of Hyogo since 1996, has been applied to the mass-production of 5 nm generation logic semiconductor devices in smartphones since 2020.

Further nanofabrication is required to develop *Beyond EUV* lithography technology.



Reference: T. Watanabe *et al.*, *Proc. SPIE*, **11908**, 11908U (2021)
T. Watanabe *et al.*, *J. Photopolym. Sci. Technol.*, **34**, 105 (2021)
T. Watanabe *et al.*, *Jpn. J. Appl. Phys.*, **36**, 7597 (1997)

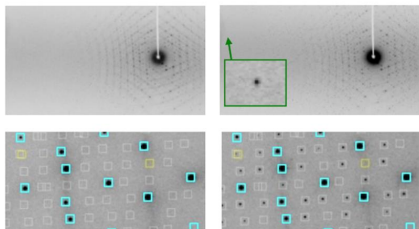
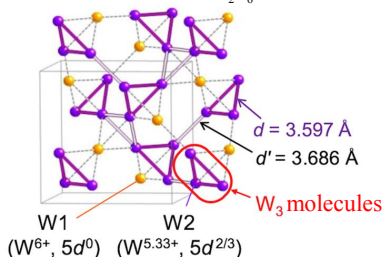
■ Observation of equilateral triangle molecules in solid materials

- To achieve the "Anderson Condition," a difficult problem in physics that had remained unsolved for more than half a century
 - The properties of electrons were successfully manipulated to create new regular structures of atoms and electrons
- Realizing new regular structures of electrons and self-organization phenomena

Single crystal X-ray diffraction image of CsW_2O_6

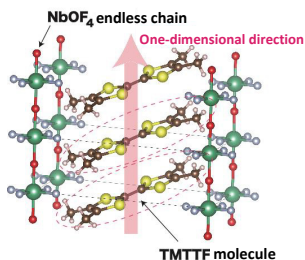
250 K (-23 °C)

100 K (-173 °C)

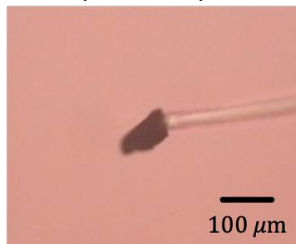
-58 °C or lower, the arrangement of W atoms in CsW_2O_6 Reference: Y. Okamoto *et al.*, *Nat. Commun.*, **11**, 3144 (2020)

■ To develop one-dimensional charge transfer complexes with infinite anion chains

- The phenomena have been revealed that rigid infinite anion chains suppress crystal lattice deformation
- Material development through new material design incorporating rigid infinite anion chains

Crystal structure of one-dimensional charge transfer complex (TMTTF)(NbOF_4) with infinite anion chain

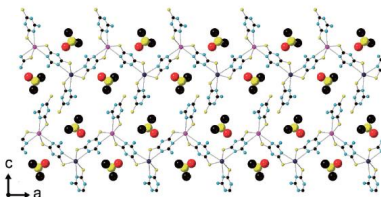
Example of a sample used for synchrotron radiation X-ray structural analysis measurements

Reference: T. Nakamura *et al.*, *Inorg. Chem.*, **60**, 5206 (2021)

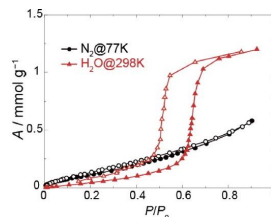
To develop flexible metal-organic structures

- Metal-organic structures that can incorporate water molecules and DMSO molecules were successfully developed
 - It was found that incorporating molecules changes the crystal structure
- Expected to be applied to various applications such as sensors and catalysts

Crystal structure of KGF-2, a metal-organic structure incorporating DMSO molecules



Adsorption isotherms of nitrogen (black circles) at 77 K and water (red triangles) at 298 K



※ Filled symbols indicate adsorption, blank symbols indicate desorption

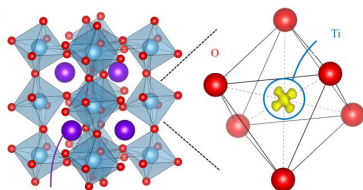


Reference: Y. Kamakura *et al.*, *Chem. Lett.*, **50**, 1053 (2021)

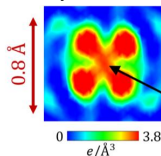
Precise electron density level analysis of functional materials

- Direct observation of the spatial distribution of electrons with a resolution of approximately one hundred billion parts per two meters (0.2 angstroms)
 - Electron density analysis by the core-difference Fourier synthesis (CDFS) method using synchrotron radiation X-ray diffraction
- This method is expected to expand the study of electron orbitals in a wide range of applications

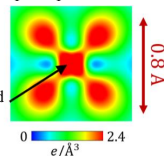
Experimental observation of the distribution of electrons as predicted by quantum mechanics



Electron distribution obtained by this method



Electron distribution obtained by first-principles calculations



High-precision measurements using synchrotron radiation and an electron density analysis method based on the CDFS method enabled us to extract the valence electron density distribution without assuming a quantum mechanical or informatics model.

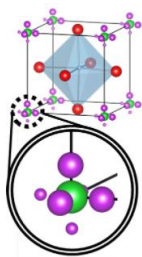


Reference: S. Kitou *et al.*, *Phys. Rev. Research*, **2**, 033503 (2020)

■ Ceramics showing excellent stretching in every direction

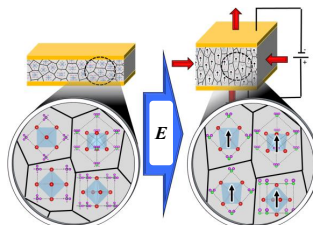
- Synchrotron X-ray diffraction revealed that the mechanism of functional expression of ceramic materials exhibit excellent piezoelectric and ferroelectric responses in spite of having a pseudo-cubic structure
- Possibility to function as high-performance ferroelectric and piezoelectric materials by degree of structural disorder controlled by the electric field

Structural disorder of Bi ion



Schematic illustration of electric field response of ceramic grains

Randomly oriented
microscopic ceramic
grains



Bi ions gather
toward the direction
of electric field

Stretching in
response to the
electric field

The new concept of controlling structural disorder by electric field is expected to lead to the development of ferroelectric and piezoelectric materials with better performance.



Reference: Y. Kuroiwa *et al.*, *Commun. Mater.* **1**, 1-8 (2020)

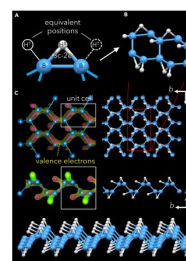
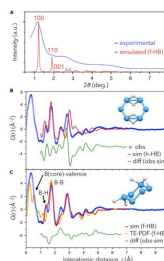
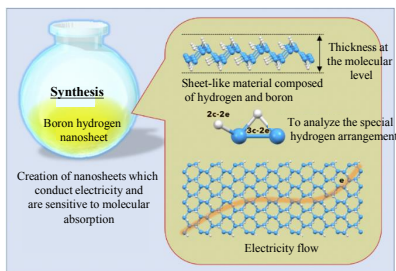
Crystal Structure & Molecular Structure

Pair Distribution Function

■ To develop novel nano-sheet materials with controllable conductivity

- Novel nano-sheet materials composed of boron and hydrogen exhibit a significant change in conductivity due to a special arrangement of hydrogen atoms
- To apply to wearable electronics and sensors with new mechanisms

Chemically synthesized hydrogen borides



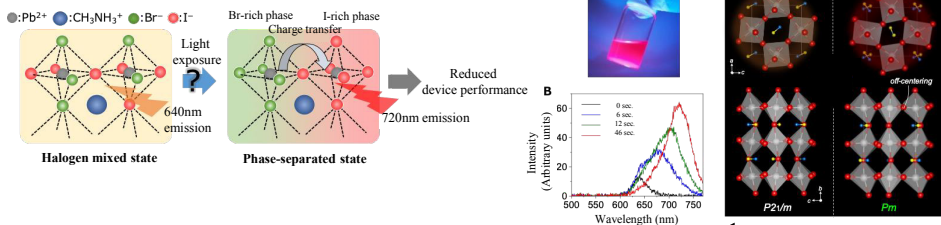
The special arrangement of hydrogen atoms enable the adsorption of organic molecules, and the conductivity of the material is significantly changed



Reference: S. Tominaka *et al.*, *Chem.* **6**, 406-418 (2020)

- To observe photo-induced structural changes in perovskites
 - For perovskites containing halide ions, the changes in luminescent properties are caused by changes in the crystal structure at the sub-Å level
 - The structural changes can be suppressed by inactivating lattice defects on the crystal surface
- To develop novel device applications controlled by light

Emission behavior of halogen mixed organic-inorganic perovskites and a model for photo induced structural changes



The structural changes can be suppressed by inactivating lattice defects on the crystal surface.

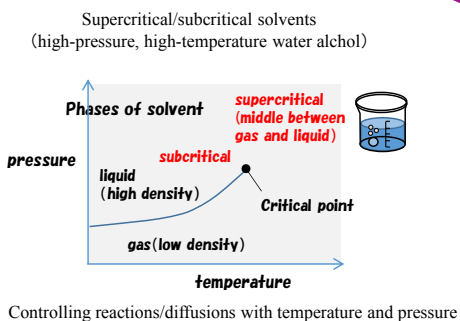
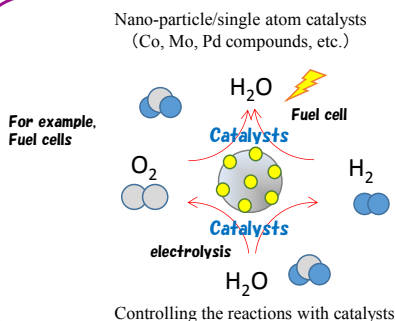


Reference: S. Tominaka *et al.*, *ACS Energy Lett.* **6**, 11, 3858-3863 (2021)

Crystal Structure & Molecular Structure

Inelastic Scattering / Nuclear Resonance Scattering

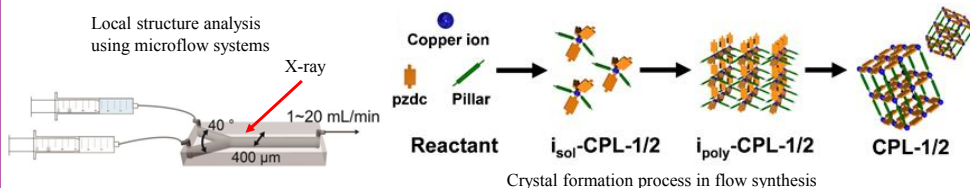
- To understand the chemistry in high-efficient catalysts and solvents
 - Catalysts: To speed up chemical reactions, core technology for electrolysis and fuel cells
 - Solvents: To solve low-solubility materials, useful for extraction or decomposition of necessary/unnecessary ingredients
- Key for the efficiency enhancement is to determine the chemical status at the active site



■ Mechanism of forming porous materials (metal-organic frameworks)

- The structure at the initial stage of the reaction was elucidated by developing the local structure analysis that combines XAFS and microflow systems
- Analyzing the role of each ligand in crystal formation of metal-organic frameworks using microfluidic systems will lead to the development of adsorbents, catalysts, and battery materials using new porous materials

Crystal formation process immediately after the start of the reaction in the flow synthesis of metal-organic frameworks



It was clarified that the crystal formation process proceeds in three stages and the two types of ligands used as raw materials have contradictory functions of promoting and suppressing crystal formation, respectively.

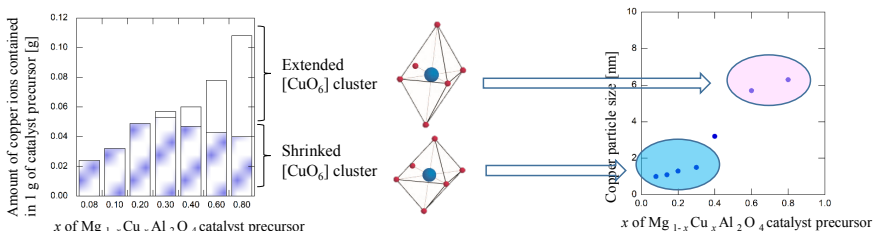


Reference : Y. Tanaka *et al.*, *Chemistry A European Journal*, **26**, 8889 (2020)

■ To develop a new catalyst to convert CO_2 into methanol

- Succeeded in miniaturizing copper particles by focusing on the coordination structure of copper ions in the process of forming copper nanoparticles
- Control the particle size of copper nanoparticles
- Developed a catalyst that converts CO_2 into methanol with high efficiency

Differences in copper nanoparticle size due to differences in the amount of copper ions in the catalyst precursor

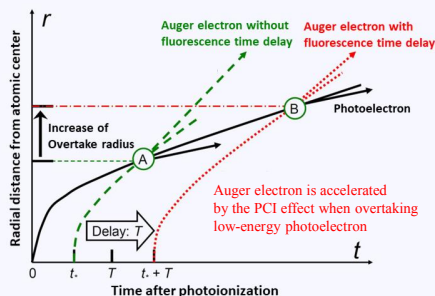
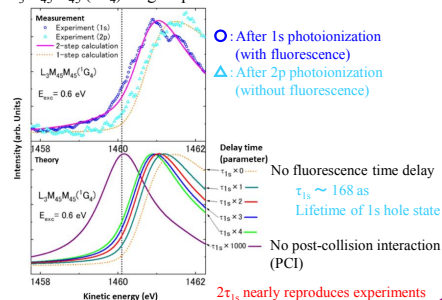


The difference in the amount of copper ions contained in the catalyst precursor make it possible to form copper nanoparticles of 2 nm or less



Reference : S. Tada *et al.*, *ACS Catal.*, **10**, 15186 (2020)

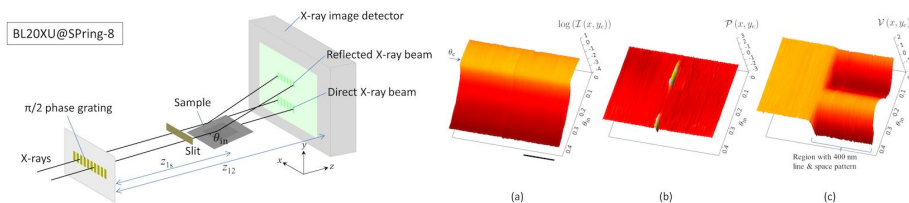
- Attosecond “stopwatch” utilizing the change in the PCI effect due to fluorescence emission
- To demonstrate a method to pursue electronic structure dynamics on an attosecond time scale
- Observation of differences in PCI effects between K-shell and L₃-subshell ionization
- Succeeded in measuring the lifetime of inner-shell vacancies on a time scale of 100 attoseconds

L₃M₄₅M₄₅ (¹G₄) Auger spectra

Reference: S.Kosugi *et al.*, *Phys. Rev. Lett.*, **124**, 183001 (2020)

- Probing surface morphology using X-ray imaging techniques
- Combining X-ray reflectivity with X-ray grating interferometry, quantitative acquisition of nm-order structural information, which is much higher than the spatial resolution of imaging detectors, has been successfully achieved
- Visualization of surface structural information with a wide FOV on the order of mm
- Various applications expected, such as precision evaluation of optical elements

Vertical and horizontal position information of sample surface is measured by reflectance and grating interferometry



(a) The glancing-angle dependence of X-ray reflectivity, (b) the wavefront distortion of the reflected X-rays, and (c) the visibility contrast due to the pattern formed on the sample surface can be obtained. From this information, structural parameters of the sample surface can be quantitatively determined.



Reference: W. Yashiro *et al.*, *Scientific Reports*, **9**, 14120 (2019)

BL22XU

Barium titanate particle size control

- For the synthesis of barium titanate nanoparticles, it is important to control the particle size of titanium oxide, which is a raw material
 - The internal structure of the particle was clarified by X-ray PDF and electron tomography
- To obtain new guidelines for material designs

Visualized nanoparticles with synchrotron radiation PDF analysis and electron tomography

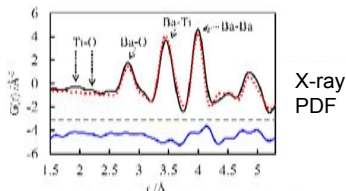


Figure 1. PDF analysis of the XRD pattern obtained by means of high-energy synchrotron X-rays of BaTiO₃ nanocubes.

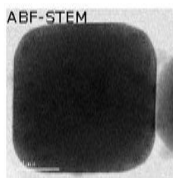


Figure 2. Observation of a BaTiO₃ nanocube in the direction of [001] incidence.

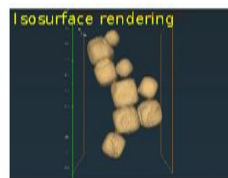


Figure 3. Electron tomography of BaTiO₃ nanocubes.

Taking advantage of the characteristics of synchrotron radiation and electron microscopy, it was found that 100 nm-sized barium titanate nanoparticles have a ferroelectric structure and a dense internal structure without voids.



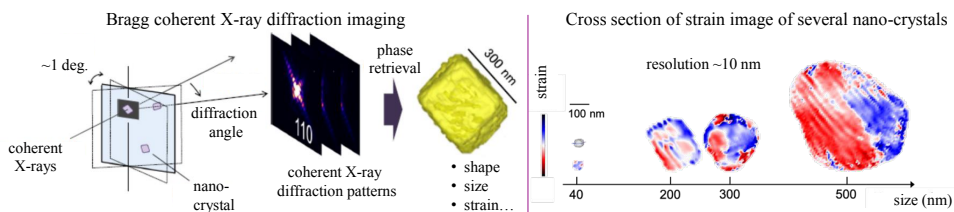
Reference : K. Nakashima *et al.*, *ACS Omega*, 6, 32517 (2021)

BL22XU

3D imaging of a single nano-crystal

- A Bragg coherent X-ray diffraction imaging apparatus has been installed for the first time in Japan and it has enabled the visualization of 40 nm to 500 nm nano-crystals
- To elucidate the size effects intrinsic to nano-crystals
- To observe nano-crystals installed in devices

3D imaging of the whole structure of nano-crystals *i.e.*, shape, size, domain, strain, etc.



3D imaging of single nano-crystals having a wide variety of sizes from 40 nm to 500 nm and shapes which can be determined by using the coherent X-rays at the synchrotron radiation light sources.

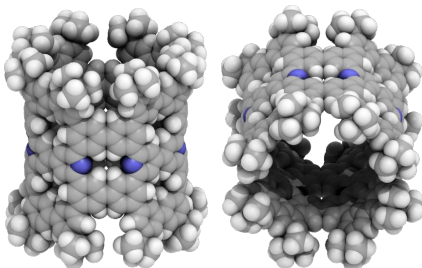


Reference: N. Oshime *et al.*, *Jpn. J. Appl. Phys.* 60, SFFA07 (2021)

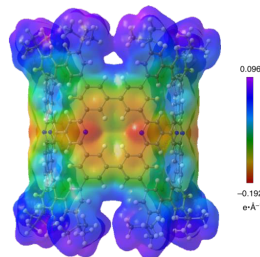
BL26B1

World's first nitrogen-doped nanotube molecules!

- Nanotubes with embedded nitrogen atoms were chemically synthesized
 - Nitrogen doping, previously uncontrollable, has been realized with complete control
 - It was found that nitrogen doping makes it easier for nitrogen to receive electrons, and as a result, nanotubes can easily become n-type semiconductors
- Expected to accelerate development of nitrogen-doped nanocarbon materials



Structure of a nitrogen-doped nanotube molecule (left: side view, right: bottom view). Nitrogen atoms are in blue.



Changes in electronic state due to lone pair. Red and blue areas indicate high and low electron density, respectively.

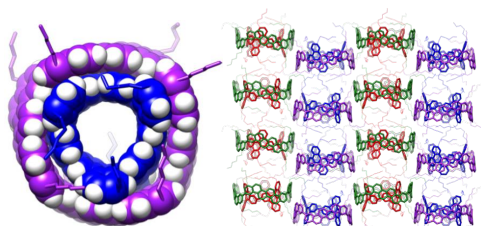
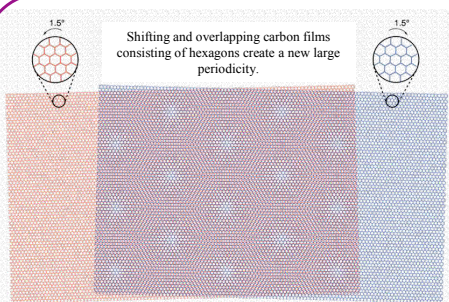


References: (1) K. Ikemoto *et al.*, *Nat Commun.*, **11**, 807 (2020)
(2) <https://go.nature.com/3N36oD4>

BL26B1

Moiré than meets the eye; Researchers make carbon nanotube patterns called moirés for materials

- Nanocarbon molecule Moiré caused by shifting and overlapping carbon films created for the first time in the world
- It was found that a specific bilayer structure can be selectively obtained among several possible combinations of displaced structures



Molecular moiré.
The crystal structure of
a carbon bilayer.

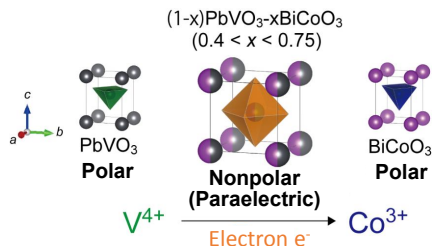
Packing of molecular moiré
in crystals



Reference: T. Matsuno *et al.*, *Nat. Commun.*, **12**, 1575 (2021)

■ Controlling a polar structure by an inter-metallic charge transfer

- An inter-metallic charge transfer creates a polar-to-nonpolar crystal structure change in $(1-x)\text{PbVO}_3 - x\text{BiCoO}_3$ solid solutions
- New insights into the development of ferroelectric/piezoelectric materials and negative thermal expansion materials



The X-ray absorption measurements reveals that the crystal structure changes stem from a self-doping effect induced by inter-metallic charge transfer between V and Co ions on the *B*-site ($\text{V}^{4+} + \text{Co}^{3+} \rightarrow \text{V}^{5+} + \text{Co}^{2+}$).

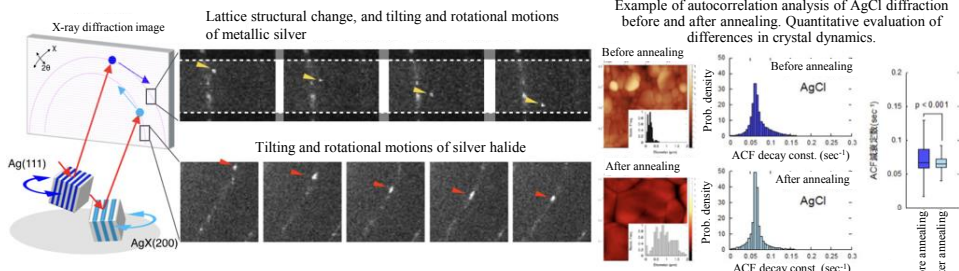


Reference: H. Yamamoto *et al.*, *Chem. Mater.*, 32, 6892-6897 (2020)

■ Successful tracking of crystal lattice motion with picometer precision

- Captured tilting and rotational motion of silver halide during photochemical reactions and changes in metallic silver lattice structure
- Detected structural changes of a single microcrystal by heat annealing on an atomic (picometer) scale
- To apply to improve functional efficiency and durability to the development of functional materials

X-ray diffraction movie of silver halide thin film and silver microcrystals formed by X-ray irradiation of the film



To understand 「Diffracted X-ray Blinking (DXB)」 to characterize local structural dynamics in polycrystalline materials.

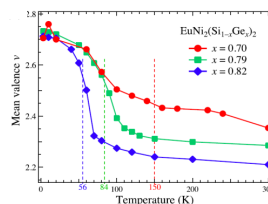
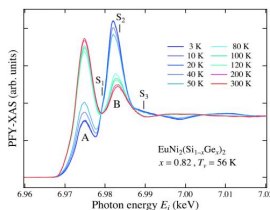
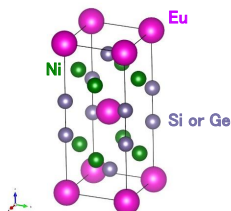


Reference: M. Kuramochi *et al.*, *Sci. Reports*, 11, 4097 (2021)

To develop materials with new functions

- To control material functions by controlling elemental composition ratios
 - Successful valence estimation with high-accuracy by high-energy resolution measurements
- To design new functional materials with high-performance and high-quality by precise control of elemental composition ratios

Difference in physical properties due to difference in elemental composition ratio



Focusing on the differences in physical properties depending on the elemental composition ratio of materials with the same crystal structure, the origin of the valence change of the target elements were elucidated by measuring the temperature dependence of the valence change with high-energy resolution and high-precision.



Reference: R. Shimokasa *et al.*, *Rad. Phys. Chem.*, **175**, 108150 (2020)

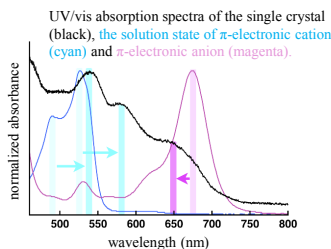
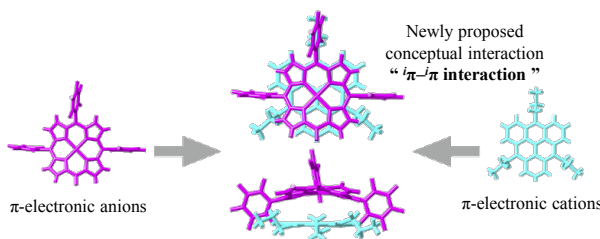
Crystal Structure & Molecular Structure

Single Crystal Diffraction

Development for advanced photocatalysts and photoconducting materials

- Porphyrin-based π -electronic anions were synthesized and formed ion-pairing assemblies with π -electronic cations
 - The theoretical calculations revealed that the absorption spectra of the stacked ion pairs were correlated with the assembling modes
- π -Electronic ion pairs, which have the characteristic assembling mode and properties, will be applied to develop advanced photocatalysts and photoconducting materials

Stacked structure and absorption spectra of π -electronic ion pair



The large change in the UV/vis spectrum profile of single crystal state is highly correlated with the assembling mode.



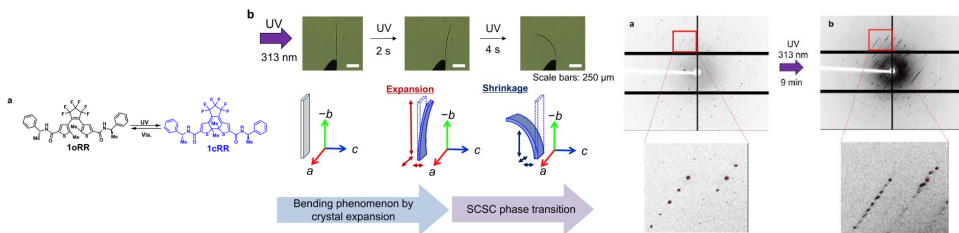
Reference: Y. Sasano *et al.*, *Chem. Sci.*, **12**, 9645 (2021)

BL02B1
BL40XU

■ Development of a fast-response soft robot using single crystal phase transition

- The response of photo-induced bending of a diarylethene crystal was enhanced by a martensitic-like single-crystal-to-single-crystal phase transition
 - The molecular motion was traced by single crystal structure analysis
- This phase transition is a new mechanism to realize fast-response soft robots using photo-induced bending of photochromic crystals

Martensitic-like photo-induced single-crystal-to-single-crystal phase transition of a diarylethene crystal



Martensitic-like phase transition plays an important role for the fast motion during bending.
This phase transition is a new mechanism to achieve fast-response soft-robots.

Figure courtesy of Ryukoku Univ.

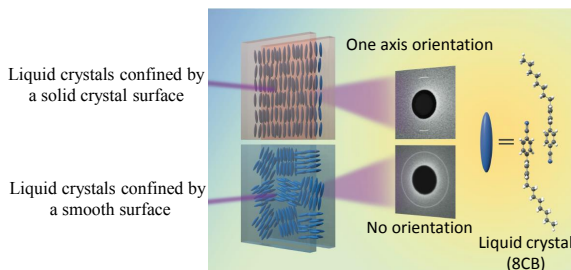
Reference: A. Fujimoto *et al.*, *Chem. Sci.*, **11**, 12307-12315 (2020)

BL40B2

■ Surface force and shear effects of liquid crystal molecules in nano-space

- Investigation of how liquid confined in nano-space differs from sizable volumes
 - Analysis of the molecular arrangement and the shear effect on different surfaces for liquid crystals (8CB) confined to a 2 nm space
- To elucidate the properties of molecules when confined, such as friction in micro-space, nano-/micro devices, and nano-molding

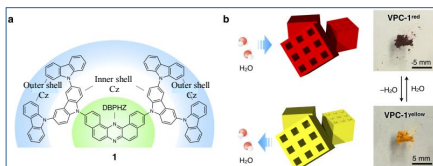
The structure of liquid crystals enclosed in nano-space using different surfaces

Reference: M. Mizukami *et al.*, *Phys. Chem. Chem. Phys.*, **23**, 131 (2021)

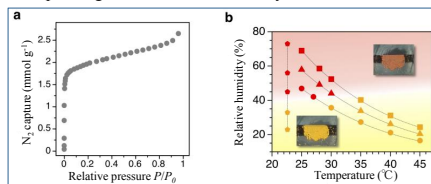
■ Sigmoidally hydrochromic porous molecular crystals

- An aromatic dendrimer self-assembles into a molecular crystal featuring micro-pores that preferentially capture guest H_2O
- Detailed spectroscopic measurements revealed that, upon adsorption of H_2O , the color of the crystal changes from yellow to red reversibly and abruptly, meanwhile, the peripheral dendrons of the constituent monomer rotate simultaneously

Porous Van der Waals crystals that change color depending on the ambient humidity



(a) Molecular structure (b) Schematic illustrations and photographs of the crystalline powder



N_2 adsorption isotherm profile and a phase diagram

A porous crystal is assembled from discrete molecules that aggregate with each other via weak Van der Waals interactions. The crystal exhibits a vivid and abrupt color change in response to humidity. The associated rotational motion of the dendron is identified by spectroscopy and computational simulations.



Reference: H. Yamagishi *et al.*, *Commun. Chem.*, **3**, 118 (2020)

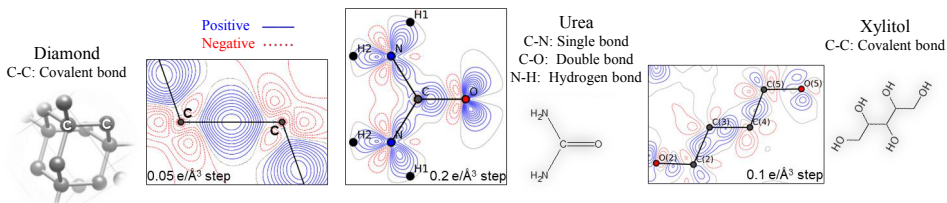
Crystal Structure & Molecular Structure

Powder Diffraction

■ Estimating the life of structural materials based on their chemical bonds

- Valence electrons of polycrystals were visualized in the form of actual materials
 - Visualization of valence electrons needed single crystals, which differed from the formed actual materials
- Chemical bonds would make it possible to see how structural materials and pharmaceuticals function

Valence electron density maps obtained from polycrystals



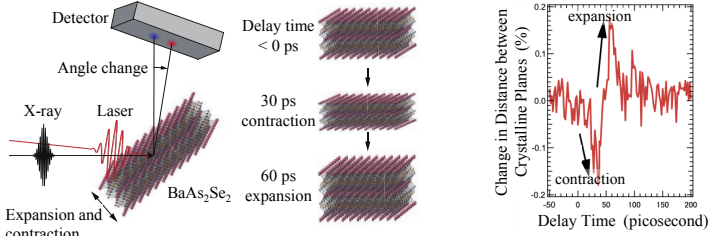
Visualized chemical bond: covalent bond between C-C atoms in diamond; single bond between C-N atoms, double bond between C-O atoms, and hydrogen bond between N-H atoms in urea; and covalent bond between C-C atoms in xylitol



Reference: B. Svane *et al.*, *Acta Cryst. A*, **77**, 85 (2021)

- To understand ultrafast changes in crystal structures
 - Ultrafast laser-induced structure changes were observed in an iron-based superconductor crystal (BaFe_2As_2)
 - A new method was demonstrated for manipulating the crystal and electronic structures of superconductors
- To develop new ultrafast switching devices and quantum information equipment

Ultrafast light-driven changes in the crystal structures of the iron-based superconductor (BaFe_2As_2)



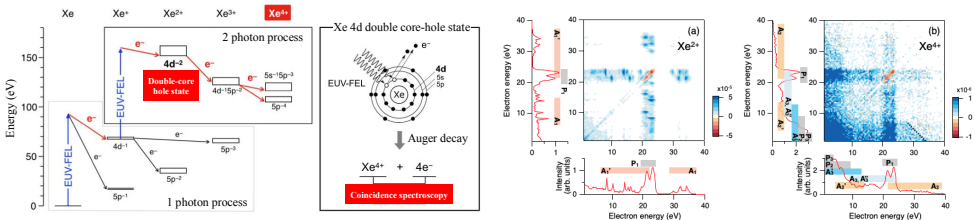
The superconductor crystal contracts once within a few tens of picoseconds after laser irradiation and then expands.



Reference: T. Suzuki *et al.*, *Phys. Rev. Research*, **3**, 033222 (2021)

- Nonlinear multiple ionization via double core-hole states
 - The multielectron-ion coincidence spectroscopy enables the detection of weak, high-order signals, which reflect local chemical environments around atomic sites
 - The electron- Xe^{4+} coincidence spectra show characteristic features associated with two-photon absorption to the $4d^{-2}$ double core-hole state
- To develop analytical methods of local chemical environments

Energy diagram of Xe^{2+} and electron-electron correlation maps for Xe^{2+} and Xe^{4+}



Electron-electron correlation maps for (a) Xe^{2+} and (b) Xe^{4+} obtained by the triple covariance analysis. The sharp Auger peaks observed in (a) almost disappear in (b), and the electron signal due to the double core-hole state appears.

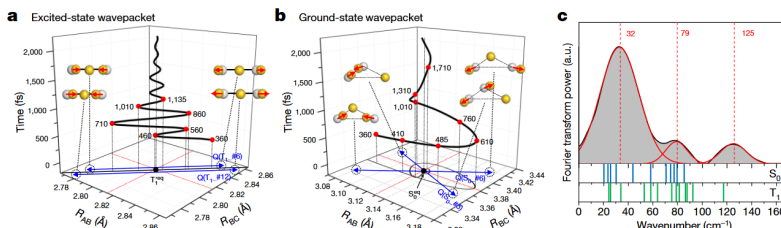


Reference: M. Fushitani *et al.*, *Phys. Rev. Lett.*, **124**, 193201 (2020)

Direct observation of bond formation mediated by molecular vibration

- A new measurement method has been developed to visualize the mechanisms of photochemical reactions
- Atomic-scale spatial resolution and 100-femtosecond time resolution were achieved
- By understanding various photochemical reactions such as those in photosynthesis, efficient methods for controlling and utilizing the reactions can be developed

"Vibration mediated bond formation" and changes in molecular structure at the initial stage of reaction



The measurement method with the atomic-scale spatial and femtosecond temporal resolution enabled visualization of fast reaction processes of the gold trimer complex $[\text{Au}(\text{CN})_2]_3$.



Reference: J. G. Kim, *et al.*, *Nature* **582**, 520 (2020)

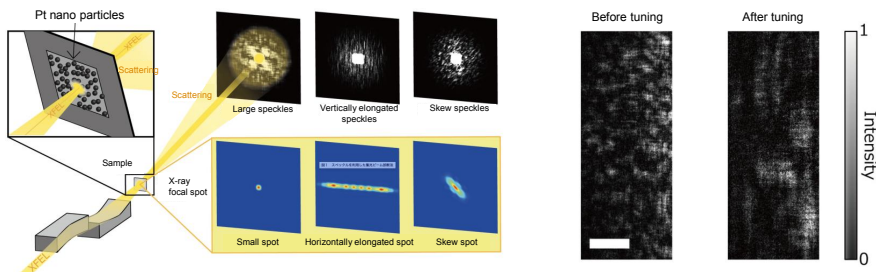
Crystal Structure & Molecular Structure

X-ray Imaging

Precise characterization of nano-focused X-ray laser profiles

- Spatial profiles of X-ray laser beams focused down to 6 nm were precisely characterized by analyzing grainy structures ('speckles') in coherent X-ray scattering patterns
- Shot-to-shot characterization of X-ray nano-beam profiles were achieved
- To discover exotic phenomena with well-defined ultra-intense X-ray lasers

Schematic of nano-beam characterization using coherent speckles



Smaller X-ray beam generates larger speckles. Single-shot characterization of the X-ray laser profiles demonstrated that the focal spot size (speckle size) was reduced (increased) after optics tuning.



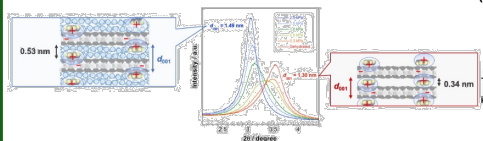
Reference: T. Inoue *et al.*, *J. Synchrotron. Rad.*, **27**, 883 (2020)

BL02B2

■ Direct observation of the “Decaf” process on clay minerals

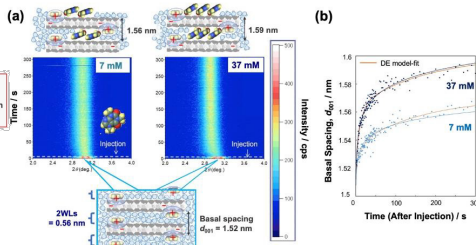
- Direct observation of the caffeine adsorption process on clay minerals in water by synchrotron X-ray diffraction
 - Revealed the importance of the breaking up process of the micro water molecular layer to absorb large amounts of organic molecules
- Expected to be applied to adsorbents for removing toxic substances from water (e.g. caffeine in tea)

Synchrotron X-ray diffraction patterns of clay minerals in a humidity-controlled environment



Adsorption of water molecules opens the interlayer. The diffraction peak shifts to the left by increasing the interlayer distance.

Time-resolved X-ray diffraction observation (in seconds) of the increase in interlayer distance for clay minerals in water by adding caffeine



Reference: T. Okada *et al.*, *Langmuir* 37(35), 10469-10480 (2021)

BL12XU
BL12B2

■ Contract renewal for Taiwanese beamlines at SPring-8

- National Synchrotron Radiation Research Center (NSRRC, Taiwan) built the Taiwan beamlines, BL12XU and BL12B2, at SPring-8 in 2000
 - The contract was renewed in Jun 2020 by NSRRC, RIKEN, and the Japan Synchrotron Radiation Research Center
- Strong corroboration between Taiwan and Japan to achieve SDGs

Signing ceremony



Remote ceremony was organized in Jun 2020

Taiwanese Synchrotron Facility



Smaller ring (Top, left) is 1.5- eV Taiwan Light Source (TLS).
Larger ring (Center) is 3 GeV Taiwan Photon Source (TPS).



Kobe Shimbun on 1st July 2020

To observe ice inside frozen food

- Freeze storage can greatly extend the expiration date of food
- Problems with the deterioration of frozen foods, which depend on the freezing conditions, were investigated
- Ices in frozen foods that contribute to their deterioration were successfully observed

Development of the capability to observe frozen foods by X-ray CT

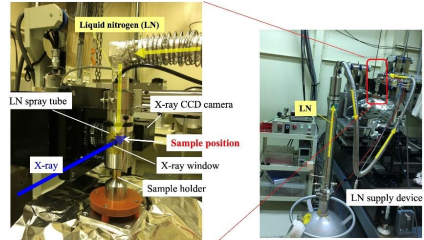


<http://www.japantuna.net/press34> <http://www.oil.or.jp/info/79/page02.html>

Technical development issues

Suppressing damage to food materials (meat, fish, etc.) due to ice coarsening

Ices in frozen foods could be observed by keeping foods frozen and using high-intensity monochromatic X-rays.



<http://www.jasri.jp/business/gijutsusienn/Industrial/in025.html>

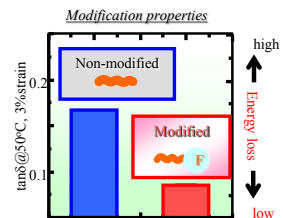


Reference: M. Sato *et al.*, *Japan Journal of Food Engineering*, 17, 83 (2016)

To develop tire rubber material with low rolling resistance

- Dispersion of the filler used as a reinforcing material in the rubber composition was evaluated using SAXS/USAXS equipment that covers a wide q range at BL19B2
- To develop and innovate fuel-efficient tires with less environmental impact

How to achieve both tire grip and low energy loss (low rolling resistance)?



The relationship between the modification properties of rubber and energy loss was clarified by investigating the aggregated state and size of the filler using SAXS/USAXS.



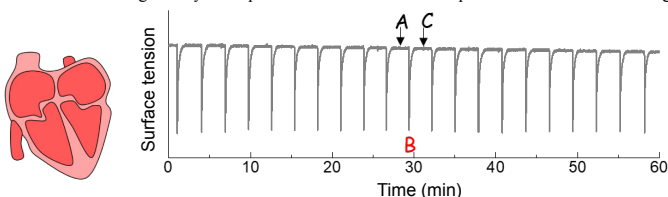
Reference: JSR Corp.

BL37XU

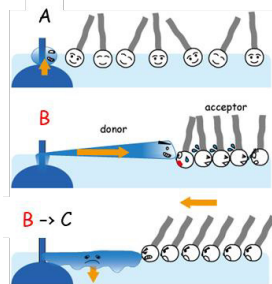
To observe the rhythmic motion of molecules by Marangoni convection

- Succeeded in observing "Marangoni convection" at the molecular level
 - Molecules periodically push back the Marangoni convection
- To understand the mechanism of rhythm generation that controls biological activities such as heartbeats

Understanding the rhythmic phenomenon of life from the periodic motion of non-living matter



It has been repeatedly observed that lipid molecules at the air-water interface become regularly oriented normal to the surface at every onset of the Marangoni convective flow. This can be regarded as a self-driven engine, and may assist understanding of the mechanisms of rhythm generation that control biological activities such as heartbeats.



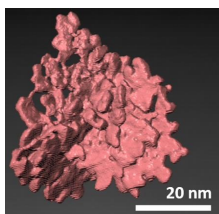
Reference: Y.F. Yano *et al.*, *J. Phys. Chem. Lett.* **11**, 6330–6336 (2020)

BL01B1
BL02B2

To realize highly efficient water electrolysis systems

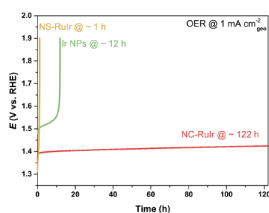
- Synthesized Ruthenium–Iridium nanosized-coral (RuIr-NC) are coral-like structures consisting of highly crystalline nanosheets with hcp solid-solution structures
 - The performance is better than that of conventional water electrolysis catalysts
- To popularize water electrolysis systems using a catalyst which is cheaper, highly active and highly durable

Ru–Ir nanosized-coral

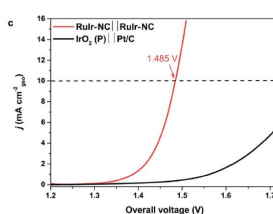


Ruthenium(Ru)–Iridium(Ir) nanocatalyst

High catalytic durability



High catalytic activity



Focusing on the fact that the surface structure strongly affects the catalytic reaction, we synthesized a highly crystalline catalyst. To popularize water electrolysis systems by mainly using ruthenium, which is cheaper than iridium

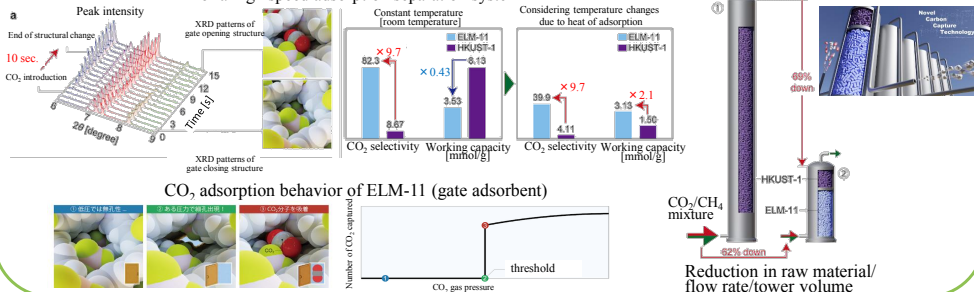


Reference: D. Wu *et al.*, *Nat. Commun.*, **12**, 1145 (2021)

New-generation CO₂ gas separation system using gate-type adsorbents

- To develop a novel CO₂ separation system using new materials (gated adsorbents)
 - High efficiency and energy conservation of CO₂ adsorption and separation recovery
 - Applicable to exhaust gas treatment of CO₂ emission such as thermal power plants
- Expected for the development of adsorbents with better performance

Evaluation of CO₂ separation characteristics and examination of applications for a high speed adsorption separation system

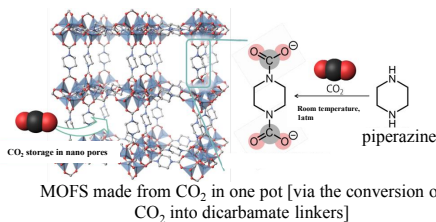


Reference: S. Hiraide *et al.*, *Nat. Commun.* **11**, 3867 (2020)

Successful conversion of CO₂ into porous materials at ambient temperature and pressure

- Development of a synthesis method of porous metal complexes (PCP/MOF) through reactions of CO₂ with organic molecules and metal ions
- A new approach to a carbon neutral society

Crystal structure of PCP/MOF from CO₂ at ambient temperature and pressure



Large-scale synthesis of PCP/MOF generated by CO₂

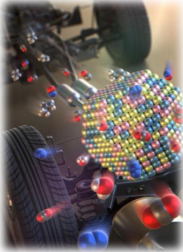


Reference: K. Kadota *et al.*, *J. Am. Chem. Soc.* **143**(40), 16750-16757 (2021)

BL02B2
BL15XU

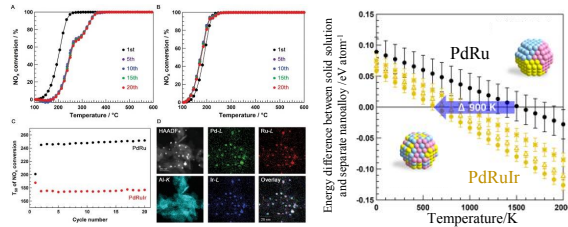
Multi-element nano-alloy exhaust gas purifying catalyst beyond Rh

- Development of various nano-alloys with high-temperature stability by adding a third element to PdRu
 - Performance potential beyond Rh to be used as automotive exhaust gas purification catalysts
 - Less expensive, highly active, and highly durable catalysts for exhaust gas purification
- To develop new materials by designing multi-element configuration entropy materials



PdRuM solid solution nano-alloy exhaust gas purification catalyst

Three-way catalytic cycle test of PdRuR nano alloy catalyst and PdRu



The new multi-element nano-alloys are more active and durable to exhaust gas purification reactions at high temperatures compared to Rh and PdRu.



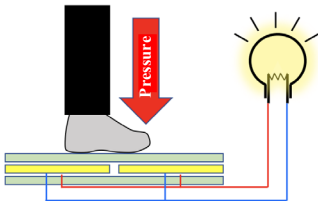
Reference: K. Kusada *et al. Adv. Mater.*, **33**, 2005206 (2021)

BL13XU

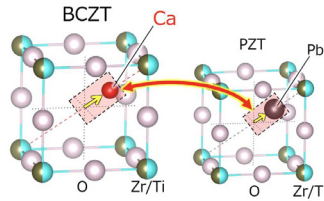
To develop eco-friendly electronic devices

- Key factor in the performance of lead-free piezoelectric materials was identified using X-ray holography
- Calcium could play a similar role to lead used in existing piezoelectric materials

Piezoelectric materials used in walking power generation



Similar displacement of Ca with Pb



Using calcium, which has good biocompatibility, as an alternative to lead opens the way to develop eco-friendly piezoelectric materials



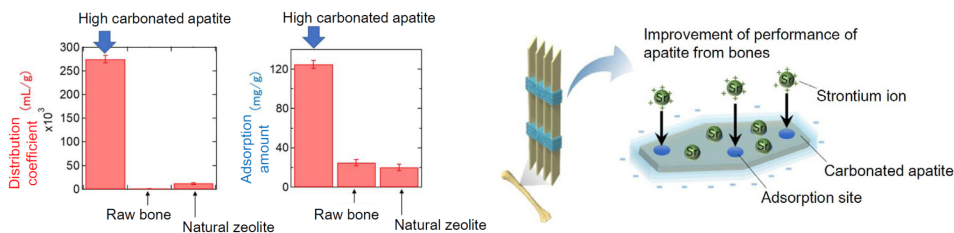
Reference: Y. Yamamoto *et al., Appl. Phys. Lett.*, 052905 (2022)

BL14B1

Waste pork bones turned into an adsorbent for toxic metals

- Development of low-cost and high-performance metal adsorbent technology using food waste was achieved
 - Immersing discarded pork bones in an aqueous sodium bicarbonate solution produces high carbonated apatite, which adsorbs strontium ions 20-times more than natural zeolite
- New application of common food waste for environmental decontamination materials

Strontium adsorption performance of the high carbonated apatite



Synchrotron radiation experiment revealed that the high carbonated apatite has many strontium adsorption sites. The high carbonated apatite shows better performance for strontium adsorption than natural zeolite.

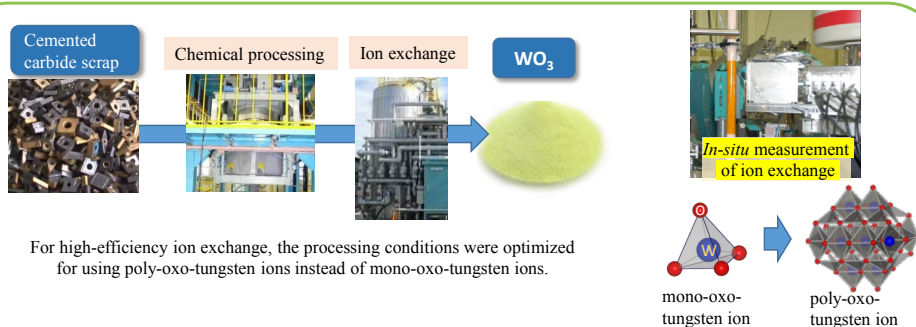


Reference: Y. Sekine *et al.*, *J. Environ. Chem. Eng.*, **9**, 105114 (2021)

BL14B2
BL16B2

To develop the Tungsten recycling process

- The ion exchange process was optimized and a high-efficiency recycling process was developed
- To shorten the development period of resource-saving technology

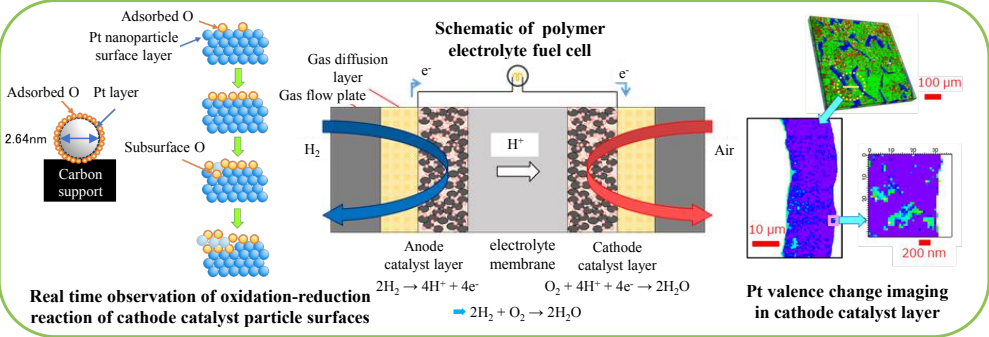


SUNBEAM • Sumitomo Electric Industries Ltd.

Reference: J. Iihara, *JSSRR*, **27**, 253 (2014)

- Realizing high performance and high durability fuel cell electrode catalysts
 - Construction of the world's highest performance time/spatial/energy resolved XAFS measurement system
 - Operando analysis of the complex interior of the fuel cell was performed
 - To provide information for the design of next generation fuel cell electrode catalysts

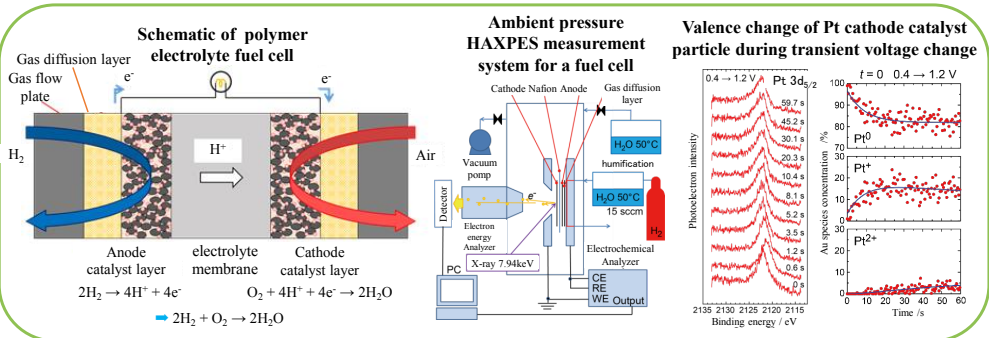
BL36XU



Reference: K. Higashi *et al.*, *PCCP.*, **20**, 18919 (2020)

- X-ray photoelectron spectra measurements of fuel cells during operation
 - The world's first X-ray photoelectron spectra under real ambient pressure was successfully obtained
 - The electric potential inside the fuel cell as well as the decomposition of electrode catalyst particles during catalyst poisoning were successfully measured
 - Novel powerful analysis tools for fuel cell and catalyst materials

BL36XU

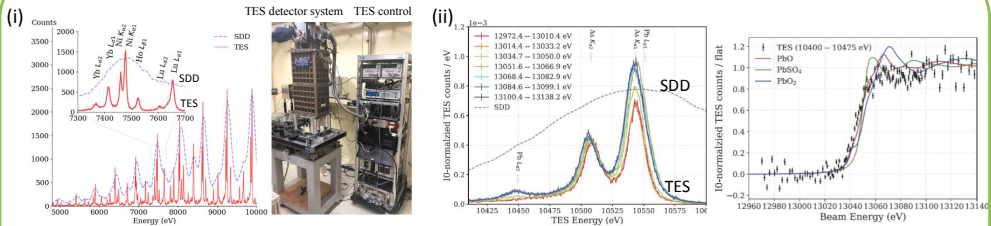


Reference: T. Nakamura *et al.*, *J. Phys. Chem. C*, **124**, 17520 (2020)

First application of transition edge sensor (TES) detector to fluorescence XAFS and environmental analysis

- TES with 30 times energy-resolution compared with SDD was first applied to fluorescence XAFS, which enable analysis of trace elements in environmental samples
 - TES-fluorescence XAFS were applied to As and Pb (typically toxic elements) and Fe in aerosols (important for climate change)
- Future application to high-energy resolution fluorescence detection (HERFD)-XANES

Fluorescence XAFS with TES is a powerful tool for trace element analysis and HERFD-XANES for the future



XRF spectrum of 61-element doped standard silica glass detected by TES, showing much better energy-resolution compared with conventional silicon drift detector (SDD)

Lead (Pb) L_{III}-edge XAFS analysis for a sample containing both arsenic (As) and Pb, which cannot be measured by SDD due to proximity to their fluorescent X-rays.

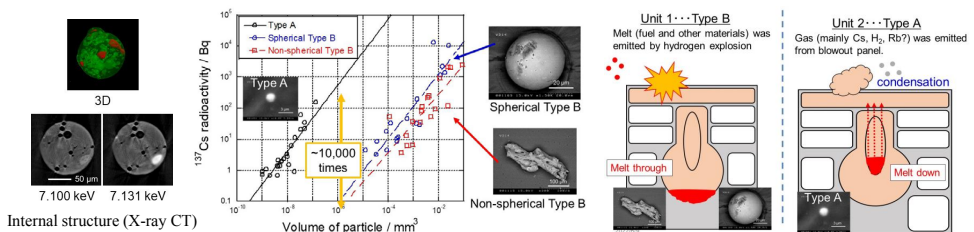


Reference: S. Yamada *et al.*, *Rev. Sci. Instrum.*, **92**, 013103 (2021)

Genetic processes and environmental behaviors of Cs-bearing microparticles (CsMP) emitted by an atomic power plant accident

- Internal structure and elemental ratio were determined by X-ray microscopy
 - Systematic understanding of genetic processes of CsMP based on multiple analyses
- Understanding internal conditions of the reactor during the accident, the formation processes of CsMP, and the relationship with the distribution into the environment

Genetic processes and environmental behaviors of CsMP emitted by an atomic power plant accident



Two types of CsMPs were identified in this study: (i) spherical silica (SiO₂) particles that incorporated volatile elements including ¹³⁷Cs in the reactor; (ii) irregular shaped particles produced by the cooling of melted materials in the reactor.



Reference: H. Miura *et al.*, *Sci. Rep.*, **10**, 11421 (2020)

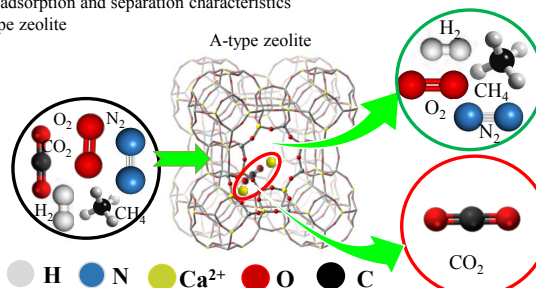
BL431R

To develop new types of CO₂ adsorption materials aiming at construction of a carbon neutral society

- Previously unobserved high-performance CO₂ adsorption in A-type zeolite at room temperature has been visualized, opening doors to applications in air purification

→ Expected to contribute to solving environmental problems and also for use of this material in a wide variety of application including industrial fields

Unprecedented adsorption and separation characteristics evoked by A-type zeolite



We have succeeded in trapping CO₂ selectively and efficiently even at room temperature, and in the lower pressure region by utilizing A-type zeolite made up by elements such as Si, Al, and Ca which exist in large quantities in the earth's crust. The CO₂ molecule adsorbed is simultaneously pinned by two kinds of Ca²⁺ ions exchanged in respective sites comprising 8- and 6-membered rings flanked side by side. The adsorbed volume of CO₂ was the largest values among those so far found for other zeolites, as well as those for other materials, except materials with the basic nature under similar conditions. This material also exhibits excellent separation nature for CO₂ in a mixture of gases containing N₂, O₂, CO₂, CH₄, and H₂.



Reference: A. Oda *et al.*, *J. Mater. Chem. A.*, **9**, 7531 (2021)

BL431R

To obtain a real picture of the lipids covering the body of an insect

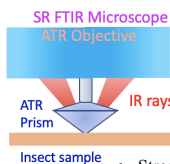
- The first visualization of a two-dimensional distribution of "cuticular lipids", which cover an insect body, and contribute to various functions (e.g., preventing water evaporation and foreign substance invasion, and communication between insects)

- Accumulated information on the distribution and aggregation state of cuticular lipids

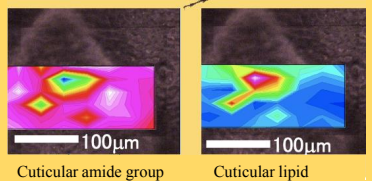
→ Clues to the mechanistic understanding of insect body surface functions

Composition distribution at the outermost cuticle of a male adult two-spotted cricket

Visualization of lipid distributions on the forewing surface by micro-infrared ATR spectroscopy



Two-spotted cricket's forewing



Two-spotted crickets show that
·lipid layer thickness change drastically, and
·solid-liquid phase separation of lipids occur.

American cockroaches show the same features.

These findings suggest the followings.



Many insects would show uneven cuticular lipid distribution and have subsequently position-dependent physiological functions on the body surface.

- Strong IR absorption of lipids appear at specific locations.
- Exoskeleton absorption becomes weaker in those areas.



Reference: F. Kaneko *et al.*, *J. Phys. Chem. B.*, **125**, 9757 (2021)

BL43LXU

The controversial meso-scale dynamics of liquid water

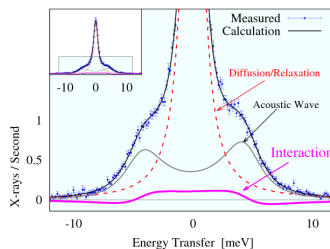
- Collective dynamics of water on a nanometer (nm) length scale were observed with unprecedented resolution (less than one-milli-electron-volt)
 - The “new” mode scientists had previously seen was explained as a result of interactions between molecular diffusion and sound waves
- More precise understanding of meso-scale dynamics in liquids

High-resolution inelastic X-ray scattering spectrometer



One must properly include mode interactions to make accurate models of dynamics in liquids

Interactions of acoustic and quasi-elastic modes in liquid water



Reference: D. Ishikawa and A. Q. R. Baron, *J. Phys. Soc. Jpn.* **90**, 083602 (2021)

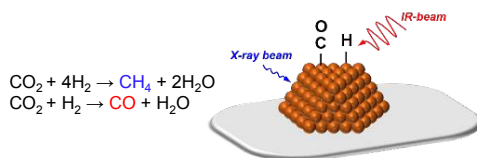
Energy

X-ray Absorption & Emission Spectroscopy

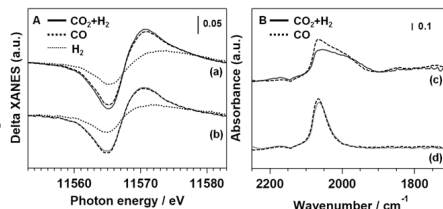
To promote higher-performance CO₂ hydrogenation catalysts

- Measurements of the adsorption ratio of CO and H on the surface of Pt were obtained, which significantly affects the product selectivity
 - Developed a quantitative evaluation method for adsorbed species on the Pt surface by simultaneous measurements of XAFS and IR
- To provide design guidelines for the development of high performance CO₂ hydrogenation catalysts

BL01B1



Adsorption ratio of CO and H on Pt surfaces greatly affects product selectivity.



In the catalyst for CH₄ production, it was found that H species were adsorbed on the Pt surface in addition to CO species.

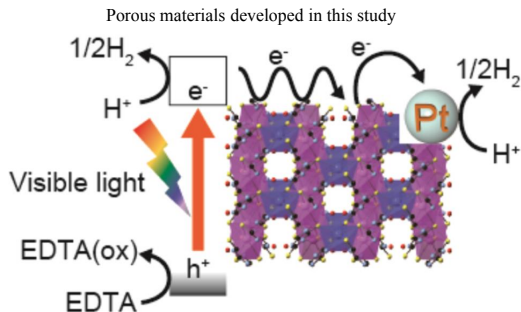


Reference: S. Kikkawa *et al.*, *Chem. Cat. Chem.*, **14**, e202101723 (2022)

■ To synthesize a new porous material that decomposes water and generates hydrogen by light irradiation

- Successful synthesis of metal-organic structures containing sulfur, which had been known to be difficult to synthesize
- This new material has shown catalytic properties to break down water and generate hydrogen under light irradiation

→ Leading to the development of MOFs that will become excellent catalysts or semiconductor materials



Water molecules can be captured in the myriad of holes contained within.

The skeleton is made up of sulfur, lead, and organic molecules, and the network has been shown to conduct electric current.



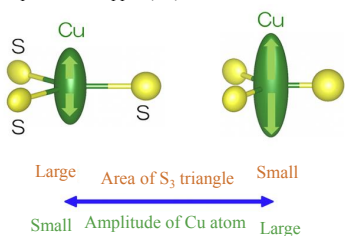
Reference: Y. Kamakura *et al.*, *J. Am. Chem. Soc.*, **142**, 27 (2020)

■ Controlling large-amplitude atomic vibrations by pressure, leading to performance enhancement of thermoelectric materials

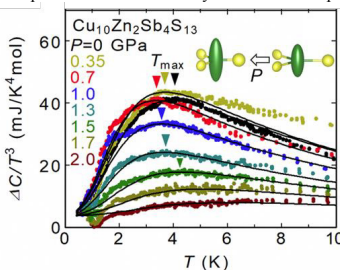
- The origin of large-amplitude atomic vibrations, which lead to high performance thermoelectric materials, was analyzed
- Pressurization enhances large-amplitude atomic vibrations in the thermoelectric conversion material tetrahedrite

→ Paving the way for higher efficiency in thermoelectric conversion

Relationship between the area of S_3 triangles and the amplitude of copper (Cu) atoms in tetrahedrite



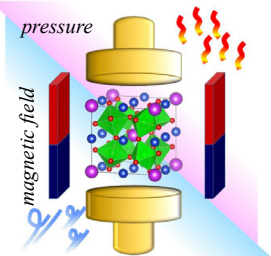
Temperature dependence of C/T^3 , specific heat C divided by the cube of temperature



Reference: K. Umeo *et al.*, *Phys. Rev. B*, **102**, 100302 (2020)

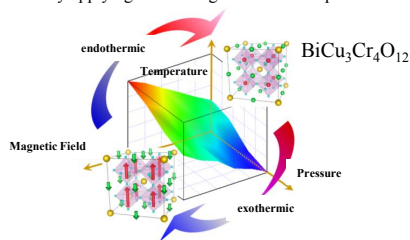
- New oxide material that can be multi-cooled by a magnetic field and pressure
 - Demonstrated a highly efficient heat control solid material with large multiple caloric effects
 - Charge transition at the ferrimagnetic transition temperature proved by synchrotron powder X-ray diffraction techniques
- To develop a new thermal control system using multiple external fields

Heat control by magnetic field / pressure



Efficient heat control by multiple methods

Change of phase transition temperature by applying both a magnetic field and pressure



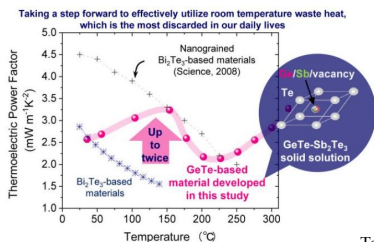
Expand control of thermal properties with different order parameters (magnetic field/pressure)



Reference: Y. Kosugi *et al.*, *Sci. Rep.* **11**, 12682 (2021)

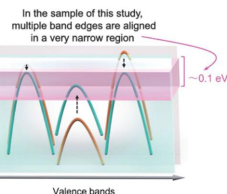
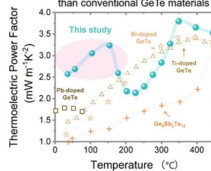
- Precise control of electronic structure doubles thermoelectric performance
 - Up to twice the performance of existing room temperature thermoelectric materials
 - Performance improvement of conventional GeTe-based material by precise control of electronic structure
- Expected to be applied to energy harvesting technology that contributes to IoT society in the near future

Temperature dependence of thermoelectric power factor



(left) Temperature dependence of thermoelectric power factor of the GeTe solid solution and conventional GeTe materials
(right) Schematic diagram of the band convergence

Higher performance in the low temperature range (near room temperature) than conventional GeTe materials



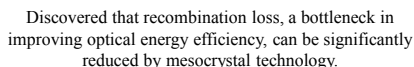
To contribute to an energy-saving society as an effective energy utilization technology and to realize the IoT



Reference: T. Oku *et al.*, *Mater. Today. Phys.* **20**, 100484 (2021)

BL04B2

- Hematite is one of the most promising photocatalytic materials that is abundant in nature and can absorb a wide range of visible light.



Further improvement of the efficiency of hematite mesocrystal photocatalytic electrodes and their application to devices, and at the same time, application of mesocrystal technology to other photocatalytic materials.

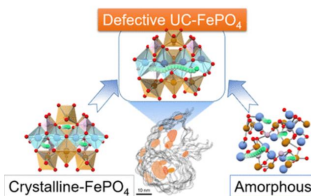
→Early realization of solar photovoltaic hydrogen production systems



Reference: Z. Zhang *et al.*, *Nat. Commun.*, **10**, 4832 (2019)

BL01B1
BL04B2
BL14B2

- An FePO₄ electrode composited with carbon has been found to be capable of **several hours of charging and discharging even at near room temperatures**



Demonstrated the effectiveness of nanospace-based material design in promoting slow ionic behavior that is difficult to overcome with conventional technology.

Continue to improve the performance of materials and contribute to societal implementation

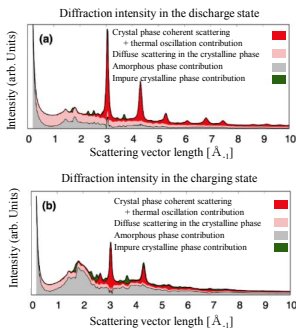


Reference: Y. Orikasa *et al.*, *Chem. Mater.*, **32**, 1011 (2020)

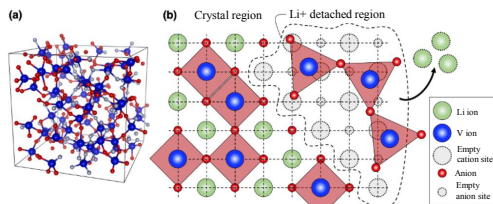
Mixed crystalline/amorphous structures in battery cathodes

- Discovered that repeated charging and discharging eliminates the atomic arrangement disorder, resulting in a decrease in battery capacity
- To improve battery capacity and durability and understand the charge-discharge mechanisms to improve the development of rechargeable batteries

PDF analysis separates crystalline and amorphous phases



The structure of the amorphous phase formed during the charging process was analyzed.



To elucidate the relationship between structural changes caused by repeated charging and discharging and the decline of battery capacity.

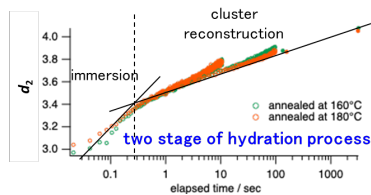
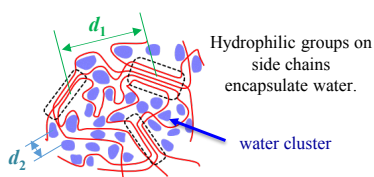


Reference: S. Hiroi *et al.*, *Chem. Mater.*, **33**, 5943 (2021)

The hydration process of membrane electrolytes of fuel cells

- The mechanisms of electrolyte membrane swelling and shrinkage were investigated
- It was found that the hydration process of the electrolyte membrane occurs in two stages: Initial immersion and cluster reconstruction.

Hydration processes in perfluorinated electrolyte membranes over a wide range of time scales (10^{-2} - 10^3 s)



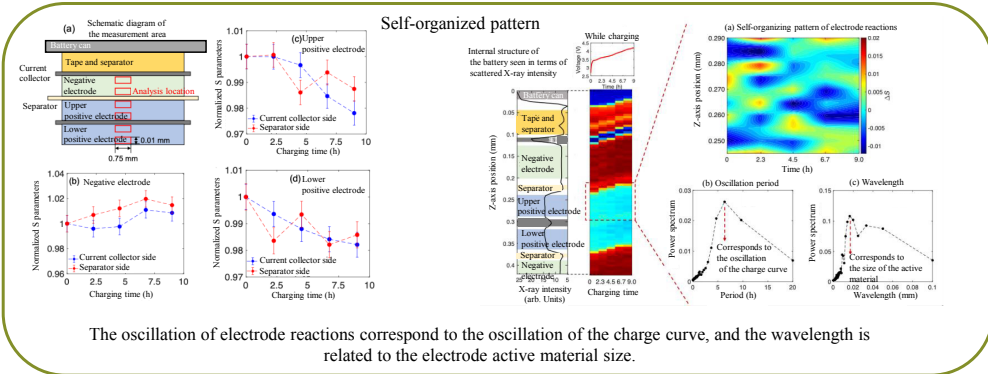
Changes in the distance between water clusters were studied immediately after the electrolyte membrane was immersed in water. It was found that water immersion into the membrane occurred in a few hundred milliseconds, followed by restructuring of the cluster structure.



Reference: S. Fujinami *et al.*, *Polymer*, **180**, 121699 (2019)

BL08W

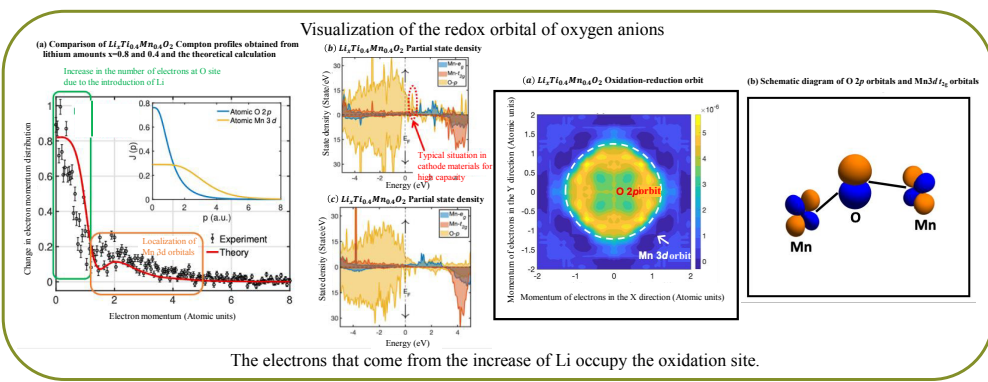
- To observe the self-organized pattern of electrode reactions in Li batteries during charging
 - Successful observation of the self-organized pattern of electrode reactions in the positive electrode of a cylindrical Li ion battery during charging
 - To solve the problem of non-uniform lithium reaction distributions in the electrode caused by large electrodes



Reference: K. Suzuki *et al.*, *Aool. Phys. Lett.* **118**, 161902 (2021)

BL08W

- To visualize the redox orbital of anion in a Li-rich cathode material
 - Revealed the electronic structure of an Li-rich cathode material
 - To visualize the redox orbital of anion in a Li-rich cathode material
 - As a new method to evaluate the electronic states of anions, it is expected to contribute to the development of cathode materials



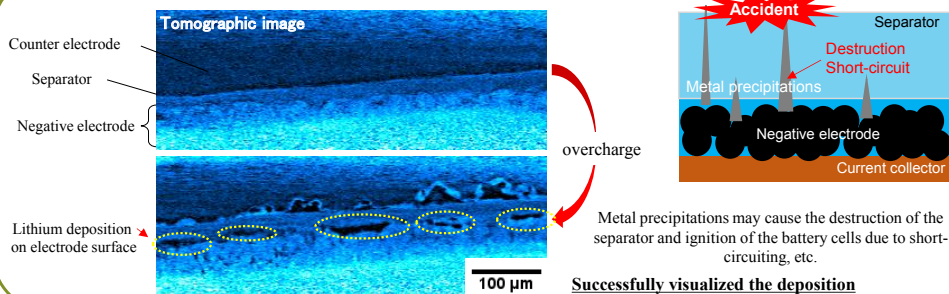
Reference: H. Hafiz *et al.*, *Nature.* **594**, 213-216 (2021)

BL08B2

To develop safe rechargeable batteries

- *Operando* X-ray CT of lithium-ion rechargeable batteries was performed for visualizing metal precipitations (such as lithium dendrites) on the negative electrode during overcharging
- Lithium deposition on the electrode is a critical issues for the safety of battery cells
→ The understanding of the deposition behavior of the lithium is important for the development of safe lithium-ion rechargeable batteries

Results of *Operando* X-ray CT during overcharging



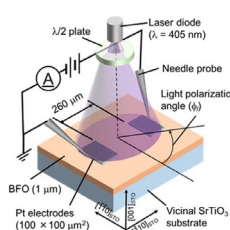
Kobelco Research Institute, Inc.

BL09XU
(BL47XU)

Creating solar cells with new power generation mechanisms

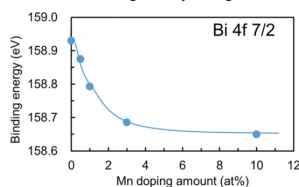
- Discovered a dramatic increase in photovoltage generation in BiFeO₃ thin films with the small amount of Mn doping due to the bulk photovoltaic effect
- Photovoltage enhancement mechanisms were elucidated using synchrotron radiation experiments including hard X-ray photoelectron spectroscopy (HAXPES)
→ To develop new solar cells with the potential to have superior performance compared to conventional p-n junction solar cells

Mn-doped BiFeO₃ irradiated with blue-violet laser light dramatically improves the photovoltage generation.



Generated voltage:
852 V @ -193 °C
(Approximately **1,700 times higher** than that of 0.5V by conventional Si solar cells)

The mechanism of photovoltage enhancement was investigated by using HAXPES.



Bi 4f binding energy is decreased with an increase in the amount of Mn doping.

→ Experimental evidence that the Fermi level, the maximum energy of electrons, is lowered by Mn doping

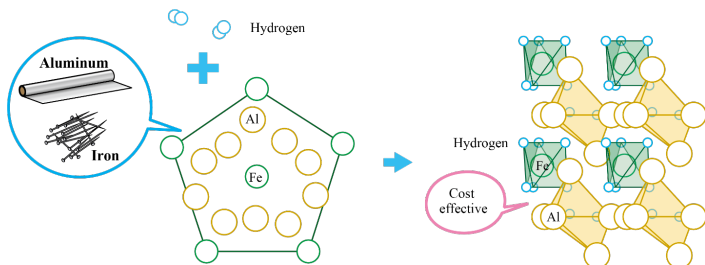


Reference: S. Nakashima *et al.*, *Scientific Reports* **10**, 15108 (2020)

BL14B1

Hydrogen storage by earth-abundant metals

- Based on the new concept of “combining metals with low hydrogen affinity”, hydrogen was stored in aluminum and iron alloys, which are abundant, without including rare metals
- Dramatically expanding the scope of material exploration and leading to realize practical hydrogen storage materials without rare metals



This was made possible by the new concept of combining aluminum and iron, two metals that do not react easily with hydrogen.



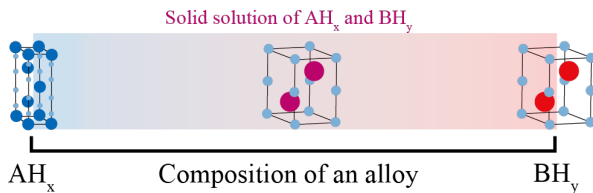
Reference: H. Saitoh *et al.*, *Mater. Des.*, **208**, 109953 (2021)

BL14B1

Synthesis of hydrides from alloys that were thought not to be hydrogenated

- Hydrides consisting of metals with low hydrogen affinities have been synthesized, although synthesizing such a hydride was considered difficult
- Hydrogenation mechanism of such an alloy were clarified
- Guidelines for developing hydrogen storage materials containing metals with low hydrogen affinities

Hydrides consisting solely of metals with low hydrogen affinities tend to be a mixture of hydrides of individual constituent elements.



- For metals A and B with low hydrogen affinities, each metal was not hydrogenated near ambient pressure, but forms hydrides AH_x and BH_y under high pressure.
- We found that alloy hydrides tend to be pseudo-binary hydrides of AH_x and BH_y .

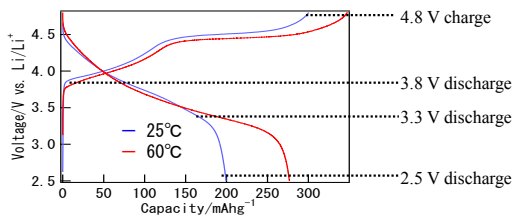
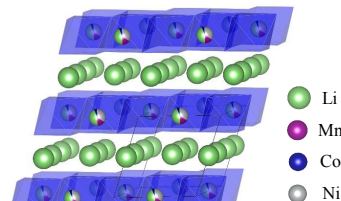


Reference: R. Utsumi *et al.*, *J. Alloys Compds*, **893**, 162300 (2021)

Redox of high-capacity cathode materials in charge/discharge processes

- Redox reactions of transition metals in $\text{Li}_2\text{MnO}_3\text{-Li}(\text{Mn}_{1/3}\text{Ni}_{1/3}\text{Co}_{1/3})\text{O}_2$ solid solutions during charge and discharge processes were revealed
- The effect of operating temperature on the charge/discharge mechanisms were clarified
→ Optimization of metal composition, considering operating temperature

Crystal structure and charge/discharge curves of $\text{Li}_2\text{MnO}_3\text{-Li}(\text{Mn}_{1/3}\text{Ni}_{1/3}\text{Co}_{1/3})\text{O}_2$ solid solution



The electric capacity depends on the operating temperature due to a difference in the redox reaction. Especially, a material with a high Co content can show high-capacity at elevated temperatures, since Co is active electrically at higher temperature ranges.

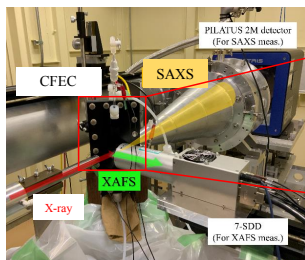
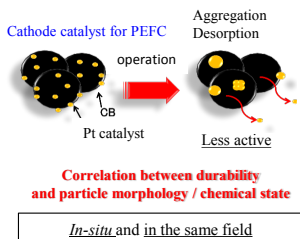


Reference: Y. Idemoto *et al.*, *J. Power Sources*, **378**, 198 (2018)

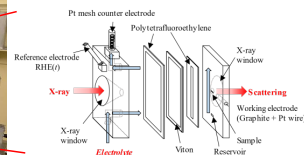
To develop *in-situ* measurement systems for clarifying the degradation processes of polymer electrolyte fuel cell (PEFC) catalysts

- *In-situ* A-SAXS, XAFS, and electrochemical measurements in the same analytical field can be performed simultaneously to reveal the correlation between the degradation of PEFC catalysts and particle morphology/chemical state
→ Further improvement in the durability of catalysts

In-situ SAXS/XAFS measurement system combined with electrochemical flow cell for SR experiment



Channel flow electrode cell (CFEC)



Applicable to samples with a small amount of catalyst concentration.

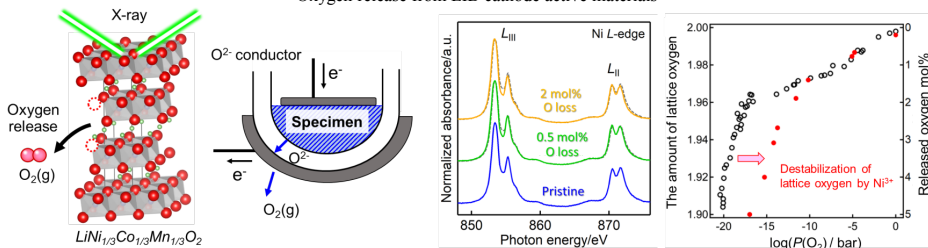


Reference: T. Watanabe *et al.*, *ECS. Transactions*, **98**, 477 (2020)

Revealing lattice oxygen stability in battery cathode active materials

- The methodology to investigate lattice oxygen stability was developed and by this evaluation it was revealed that high valent Ni promotes oxygen release
- Guidelines for reliable cathode active materials were proposed
- This understanding contributes to the development of advanced high energy density and robust batteries

Oxygen release from LIB cathode active materials



The first experimental evidence that high valent Ni degrades the stability of lattice oxygen was provided by the combination of coulometric titration and X-ray absorption spectroscopy.

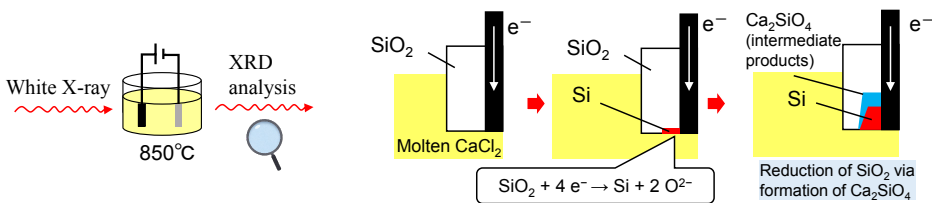


Reference: X. Hou *et al.*, *Adv. Energy Mater.*, **11**, 2101005 (2021)

To develop new processes for solar-grade silicon

- A new process using direct electrolytic reduction of SiO_2 in molten salt has been developed as an alternative to the conventional Siemens process for the production of solar-grade silicon
- In-situ* XRD analysis of reactions in molten salt elucidates a reaction mechanism, without cooling, rinsing, or air exposure

In-situ X-ray diffraction study of the electrochemical reduction of SiO_2 in molten CaCl_2



The O^{2-} ion diffusivity affects the formation of intermediate products.



Reference: Y. Katasho *et al.*, *Electrochem. Commun.* **115**, 106740 (2020)

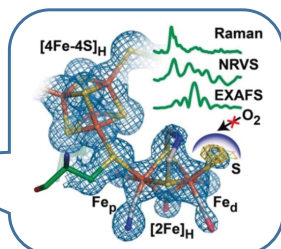
BL35XU
BL19LXU

Effective information to design artificial enzymes

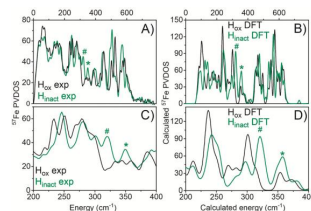
- Hydrogenase, an enzyme that catalyzes hydrogen, was analyzed by various methods
- How O_2 stable state is realized has been elucidated at the molecular level
- To understand high efficiency enzymes to realize a clean hydrogen society



Hydrogenase,
an enzyme that catalyzes hydrogen



Elucidated the molecular structure of the
active center: Sulfur blocks oxygen attack.



PVDOS derived from nuclear inelastic
scattering spectra and its simulation



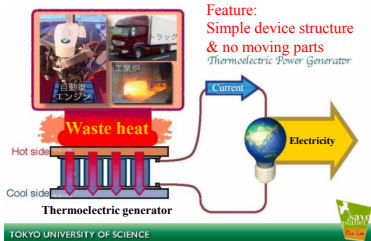
Reference: P. Rodriguez - Maciá *et al.*, *Angew. Chemie Int. Ed.*, **59**, 16786 (2020)

BL37XU
BL47XU

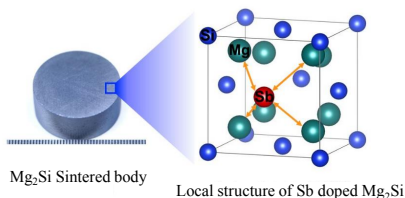
To elucidate the thermoelectric performance originating from changes in structure and electronic state

- To analyze the antimony (Sb)-doped magnesium silicide (Mg_2Si), a next-generation thermoelectric material
- Clarified the electronic state and structural changes that are the origin of thermoelectric properties
- To perform efficient and environmentally friendly energy conversion of unused heat

Functional manifestation mechanisms of thermoelectric power generation materials



Overview of the Thermoelectric Generator Module;
Thermoelectric elements have a simple device structure and no moving parts, resulting in a long service life and eliminating the need for maintenance work



Local structure of Mg_2Si with Sb;
The substitution of Sb into the Si site widens the interatomic distance of the first proximity atom (Mg) by about 5.5%.



Reference: T. Kadono *et al.*, *Appl. Phys. Lett.*, **117**, 143901 (2020)

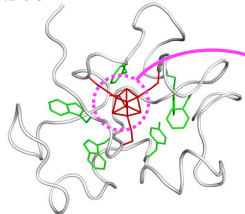
BL41XU

■ Ultra high-resolution structure analysis of HiPIP involved in photosynthesis

- Determined the structure of high-potential iron-sulfur protein (HiPIP) at 0.48 Å resolution
 - Observed the density of 3d electrons of iron and 3p electrons of sulfur as well as hydrogen atoms important for protein function
 - Revealed the electron storage mechanisms of HiPIP
- To elucidate electron transfer mechanisms in photosynthesis and respiration of living organisms

Ultra high-resolution structure of HiPIP

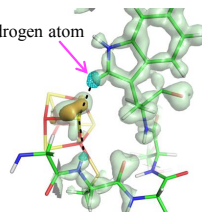
Structure of HiPIP



iron-sulfur cluster

Density of 3d electron of iron and 3p electron of sulfur

Hydrogen atom



Electron density of amino acids near the iron-sulfur cluster

Accurate atomic coordinates obtained by ultra high-resolution structure analysis and observation of valence electrons visualized by charge density analysis revealed the electron storage mechanisms of HiPIP.



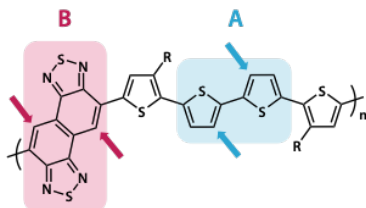
Reference: Y. Hirano *et al.*, Nature, **534**, 281 (2016)

BL46XU

■ To develop high-efficiency technology for organic photovoltaics

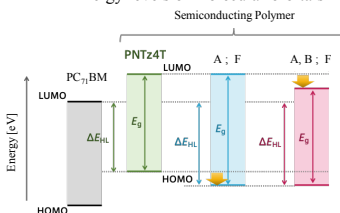
- Succeeded in increasing the efficiency of organic photovoltaics (OPV) by developing new semiconducting polymers with fluorine atoms
- Elucidated the influence of the fluorine introduction position on semiconducting polymer properties and solar cell performance
- One step toward practical application of low-cost, next-generation solar cells

Chemical structure of PNTz4T and the position of fluorine



Successfully introduced fluorine at position B in addition to position A

Energy levels of molecular orbitals



The conversion efficiency was improved by controlling the molecular orbital energy level.

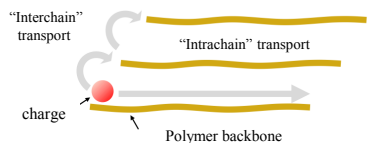


Reference: M. Saito, *et al.*, Adv. Energy Mater., **10**, 1903278 (2020)

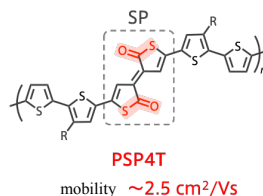
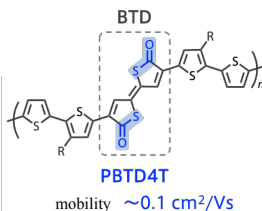
New molecular design for high-performance semiconducting polymers

- Determined that π -electrons are highly spread along the polymer main chain by recombining the chemical structure
- Successfully improved the charge transport in the polymer main chain, resulting in a significant increase in the charge mobility of polymer semiconductors
- More than 20 times improvement in semiconductor performance

Intra- and inter-chain charge transport paths in polymer semiconductors



Chemical structures of PBTD4T and PSP4T



By recombining the chemical structure, the charge transport properties within the polymer main chain were improved more than 20-fold.

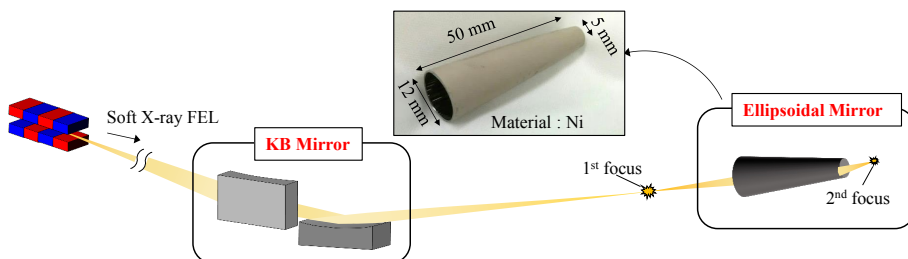


Reference: T. Mikie, *et al.*, *Chem. Mater.* **33**, 8183 (2021)

Sub-micrometer focusing system for a soft X-ray free-electron laser

- A hybrid focusing system combining an ellipsoidal mirror and a Kirkpatrick-Baez (KB) mirror was developed
 - An intense soft X-ray field is generated without enhancing the output power of the light source
- Saving energy in free-electron laser facilities

A hybrid focusing system for a soft X-ray free-electron laser (FEL)



The two-stage focusing system, which combines a KB mirror system (large acceptance) with an ellipsoidal mirror (large numerical aperture), produces a sub-micrometer spot of the soft X-ray FEL.

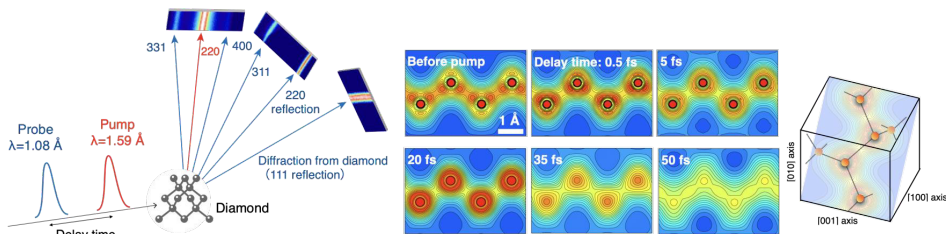


Reference: H. Motoyama *et al.*, *J. Synchrotron Rad.*, **26**, 1406 (2019)

Short pulse duration can outrun radiation damage

- Time-resolved observation of X-ray interactions with matter revealed delayed onset of the X-ray induced structural changes
- Evidence for the feasibility of damage-free X-ray structure determination using ultrafast X-ray pulses, such as those from SACLA

Electron-density distribution in diamond after irradiation with an XFEL pulse



An X-ray pump-probe experiment revealed that electron density distribution in diamond does not change considerably until 5 fs after irradiation with an XFEL pulse.

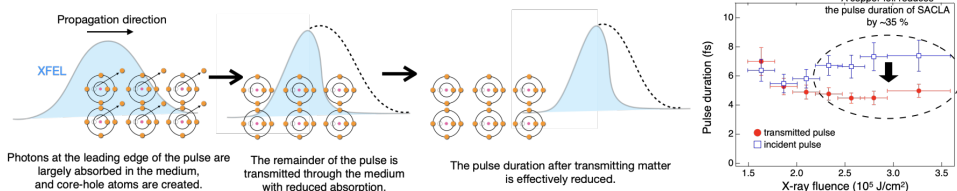


Reference: I. Inoue *et al.*, *Phys. Rev. Lett.* **126**, 117403 (2021)

Shortening X-ray pulse duration

- An optical technique using atoms with core-hole vacancies has been developed to reduce the pulse duration of X-ray free-electron lasers
- This achievement serves as a stepping stone for extending nonlinear optical technologies to the hard X-ray region

Pulse shortening using core-hole atoms in a $10 \text{ }\mu\text{m}$ thick copper foil



X-ray-induced changes in transmittance of the copper foil lead to the reduction of SACLA's pulse duration by 35%.

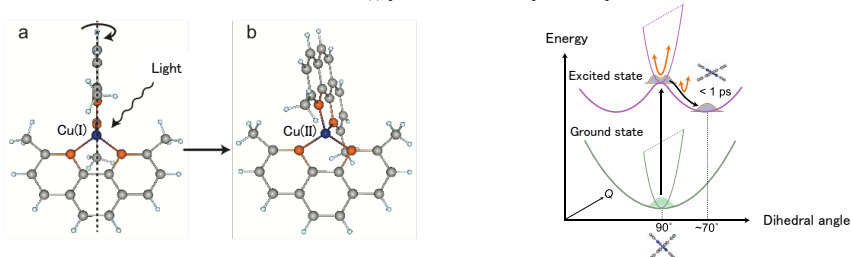


Reference: I. Inoue *et al.*, *Phys. Rev. Lett.* **127**, 163903 (2021)

Recording molecular movies with high spatial and temporal resolutions

- Vibrational motion in a photoexcited Cu(I)-phenanthroline complex was tracked with sub-angstrom resolution by using femtosecond time-resolved X-ray spectroscopy
- Better understanding of photochemical reactions can lead to the development of novel photocatalysts including those for artificial photosynthesis systems

Structural distortion of a Cu(I)-phenanthroline complex after photoexcitation



By using XFEL pulses with a femtosecond duration, the vibrational motion associated with the photo-induced structural distortion was probed with sub-angstrom resolution.

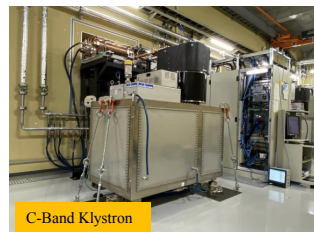
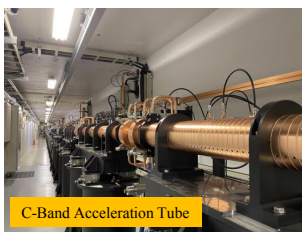
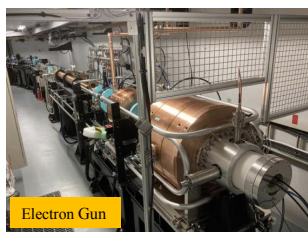


Reference: T. Katayama *et al.*, *Nat. Commun.*, **10**, 3606 (2019)

Commencement of the operation of a 1.0 GeV electron beam injector exclusively for NewSUBARU

- Designed and constructed a compact, low-cost linear electron accelerator (with the cooperation of the SPring-8 accelerator team)
- Succeeded with a low-emittance, short-pulse electron beam in stable operation
- Increased the current in the NewSUBARU electron storage ring (300→350 mA)
- To verify the equipment operation for the Tohoku 3 GeV light source

The 1.0 GeV linear electron accelerator used for the NewSUBARU electron storage ring



It has become possible to stably inject a high-quality electron beam into the NewSUBARU accelerator ring at any time, improving the performance of the light source accelerator and achieving flexible operation.



Reference:

- [1] T. Inagaki *et al.*, *IPAC2021*, **WEPAB039** (2021)
- [2] S. Hashimoto *et al.*, *Particle Accelerator Society of Japan TUOB03* (2021)
- [3] T. Inagaki *et al.*, *Phys. Rev. ST Accel. Beams* **17**, 080702 (2014)
- [4] T. Asaka *et al.*, *Phys. Rev. Accel. Beams* **23**, 063401 (2020)

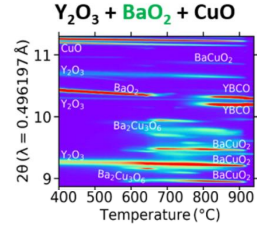
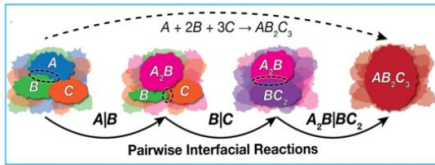
- Visualization and computational modeling of synthesis processes
 - Visualization of synthesis processes of high-Tc superconducting oxides by synchrotron powder X-ray diffraction, electron microscopy, and first-principles calculation
 - Computational modeling to understand the driving force of the reaction
- Efficient design of synthetic reaction processes of functional materials by understanding the synthetic process

Investigation of solid-state reactions of the high-Tc superconductor YBCO

Direct observation by synchrotron XRD

RT

940 °C



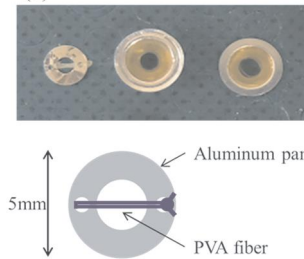
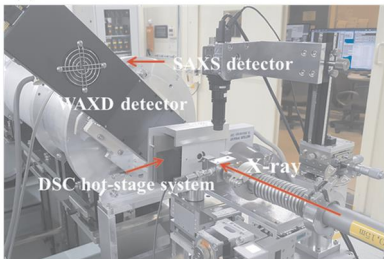
Logical design of synthetic reaction processes of various functional materials with complex compositions



Reference: A. Miura *et al.*, *Adv. Mater.* **33**, 2100312 (2021)

- Aiming to reduce production costs from the correlation between fiber structure, physical properties, and manufacturing conditions
 - *In-situ* measurements of thermal analysis, crystal structure evaluation, and nanostructure evaluation are possible while suppressing heat shrinkage of fibers
 - Under constant length constraint conditions, the melting behavior differs depending on the fiber manufacturing conditions
- To apply production processing conditions

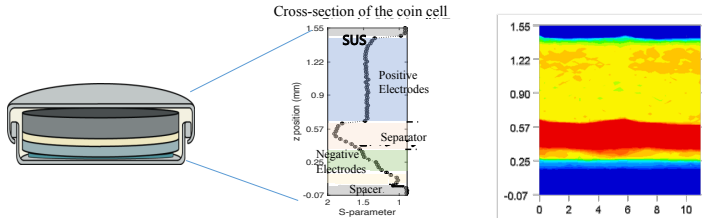
Pictures of DSC / SAXS / WAXS simultaneous measurements under constant length constraint conditions of fiber samples



Reference: *FSBL research reports* 16 (2019)

- To visualize the Li ion during the charge and discharge processes
 - The changes of Li ions during the charge and discharge process of a commercial Li ion coin cell were observed nondestructively
 - The cause of battery degradation was elucidated

The Li density distribution change during charge and discharge processes.



S-parameter, which quantifies the shape of the Compton profile, visualizes the changes of Li ions during the charge and discharge processes.



Reference: K. Suzuki *et al.*, *J. Synchrotron. Radiat.*, **24**, 1006 (2017)

- To fabricate high-performance structural materials
 - Changes in polycrystalline structures of metals for structural materials during deformation that governs their mechanical properties were quantitatively evaluated
 - Key knowledge for the realization of high-performance structural materials

In-situ observations revealed the relationship between deformation of metallic materials and changes in dislocation density in the crystal structure.

Dislocation density during tensile deformation of fine-grained pure Al

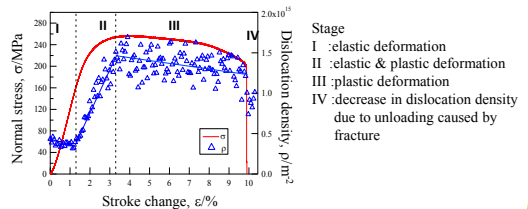


<https://www.x-ray-netto.co.jp/business/press.html>

Preventing the destruction of structural materials



<http://www.mf-fuji.jp/products/bar-bar.htm>



Microscopic changes in crystal structure can be quantitatively evaluated as well as macroscopic deformation behaviors.



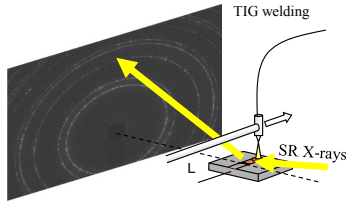
Reference: H. Adachi *et al.*, *Journal of the Japan Institute of Light Metals*, **64** (10), 463-469 (2014)

To advance welding technology

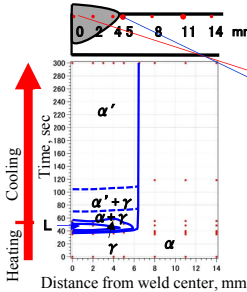
- Succeeded in observing time changes for structure stress after TIG welding at 50 fps
 - It was revealed that stress is formed after the structure stabilizes during cooling
- Stress control by advancing welding conditions

Experiment environment

Measure the time change of the diffraction ring during welding with an area detector

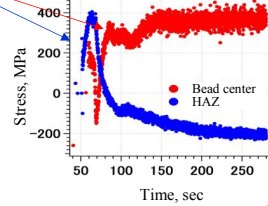


Structure



Stress

Tensile stress is generated in the bead center and compressive stress is generated around the heat affect zone (HAZ) under cooling.



Reference: A. Tsuji *et al.*, *JMSM*, 65 (9), (2016)

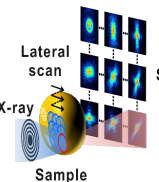
To visualize the internal structural changes of devices and materials at work

- Lensless dynamic nanoimaging methods are developed to visualize local nano-dynamics in samples too thick for electron beams
 - The method, termed multiple-shot coherent diffraction imaging (CDI), is capable of achieving temporal resolutions of 10 – 100 ms, ~100 times faster than ptychographic CDI
- To investigate nano-structural changes and deteriorations inside devices at work.

Two complementary lensless nanoimages: 3D visualization via ptychography and 2D dynamic imaging via multiple-shot CDI.

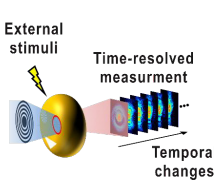
Ptychography

Wide field-of-view, 3D

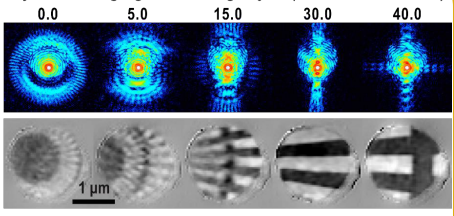


Multiple-shot CDI

Dynamic imaging, 2D



Dynamic imaging of a moving object (Siemens star chart)



Multiple-shot CDI enables video reconstruction of the real-space dynamics from time-resolved coherent diffraction patterns. Ptychographic CT (static, 3D) and multiple-shot CDI (dynamic, 2D) can be switched by changing the measurement scheme.



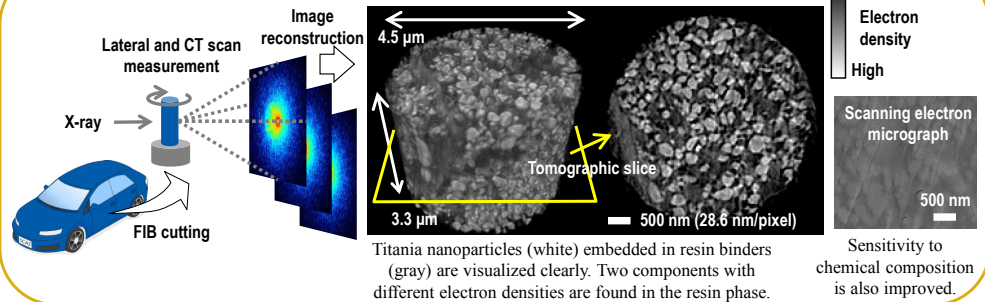
Reference: Y. Takayama *et al.*, *Commun. Phys.*, 4, 48 (2021)

BL24XU

■ Automotive coating with both high-durability and aesthetic effects

- Automotive coating film with nanoscale pigment particles are three-dimensionally visualized via an advanced nano-CT technique, called ptychographic CT
- High spatial-resolution and quantitative contrast beyond the conventional techniques
- To understand the structural basis of the function and deterioration processes to fabricate an automotive coating film with both high-durability and aesthetic effects

Three-dimensional structure of automotive coating film visualized via ptychographic CT.



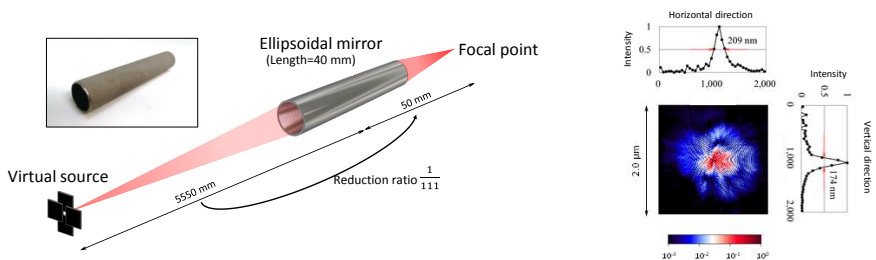
Reference: S. Suehiro *et al.*, *JCOT*, **56**, 204-210 (2021)

BL25SU

■ To establish highly efficient soft X-ray (SX) nano-focusing techniques

- Developed a new ellipsoidal SX focusing mirror
- Succeeded in highly efficient SX focusing
- Contributing to the performance improvement of the SX analysis methods such as photoelectron spectroscopy, absorption spectroscopy and imaging

SX focusing system and focusing profile by the ellipsoidal mirror

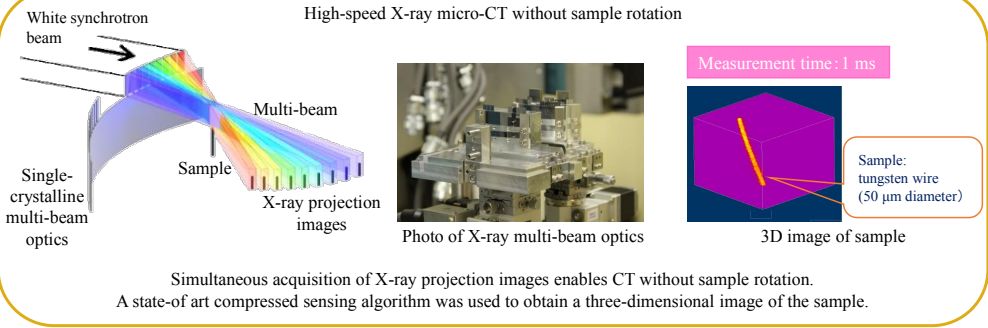


Reference: Y. Takeo, *et al.*, *App. Phys. Lett.*, **116**, 121102 (2020)

BL28B2

■ One millisecond X-ray CT with multi-beam imaging

- The world's first successful proof-of-concept demonstration of X-ray CT with millisecond temporal-resolution was achieved without rotating the sample, which conventionally required rotating the sample at ultrahigh speed to obtain projected images from multiple angles
- To apply to fluid samples, living organisms, rotating machine tools, etc.

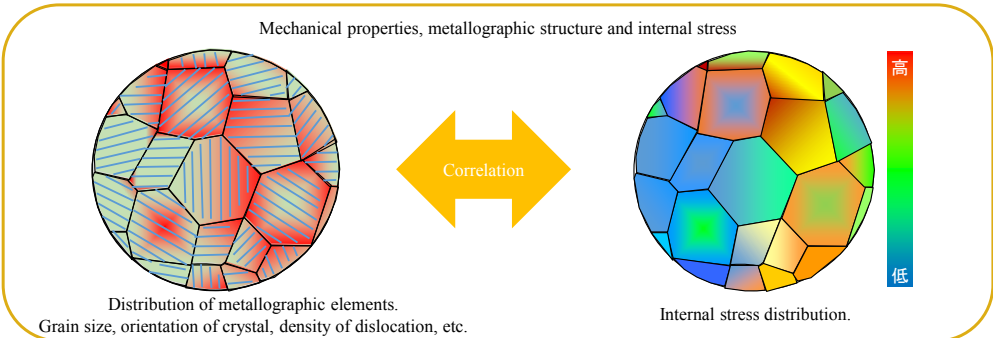


Reference: W. Voegeli et al., *Optica*, 7, 514 (2020)

BL28B2

■ To develop local stress evaluation technology for metallic materials

- In order to understand the mechanisms of the mechanical properties of metallic materials, the correlation between metallographic structure and internal stress distributions were evaluated
- New information on the internal stress distribution guides the improvement of functionality of metallic structural materials

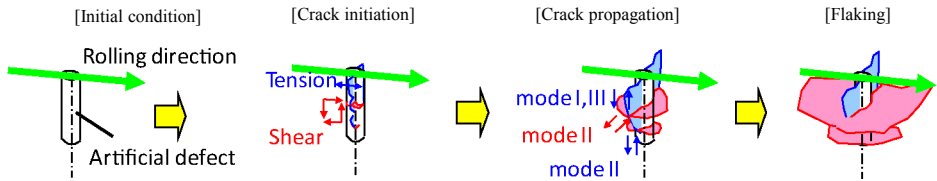


Reference: K. Kajiwara et al., *ISIJ International*, 53, 165 (2013)

Improved safety of metal structural materials

- The effect of defect shape on rolling contact fatigue (RCF) crack initiation and propagation in high-strength steel was clarified by X-ray Imaging
- Guidelines for improving the safety of metal materials have been obtained

Process of RCF crack initiation and propagation.

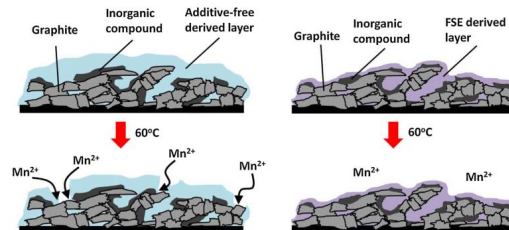


Reference: T. Makino *et al.*, *International Journal of Fatigue*, **92**, 507 (2016)

Improvement of Li ion battery performance

- The mechanisms of degradation of the negative electrode were clarified by chemical state analysis at the solid electrolyte/electrode interface
- Guidelines for high performance Li ion batteries

Graphite electrodes before and after elevated temperature storage or cycling



The charge/discharge capacity retention during high temperature cycling was successfully improved.



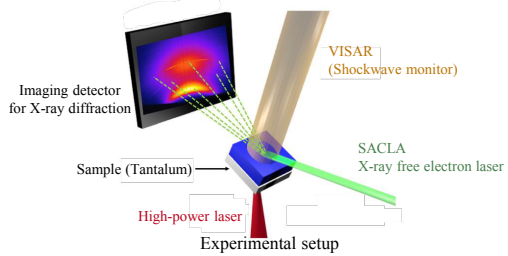
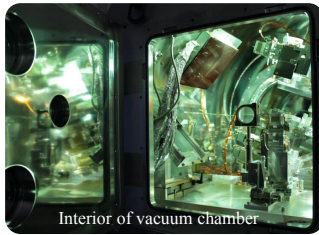
Reference: K. Yamagiwa *et al.*, *Electrochimica. Acta.*, **160**, 247 (2015)

To develop new materials and manufacturing technologies

- Metallic materials in a liquid phase have been directly observed with XFEL under extreme states excited by a high-power optical laser
- Internal negative pressure of the liquid metal reached above 5 GPa during the shock release

→ Beneficial for developing new materials and manufacturing technologies

Experiments of ultra-high-pressure environments using high-power nanosecond laser and XFEL



Behavior of melted tantalum was observed under an ultra high-pressure environment produced by high-power laser irradiation.



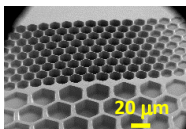
Reference: K. Katagiri *et al.*, *Phys. Rev. Lett.*, **126**, 175503 (2021)

To create a system and develop components with new functionalities

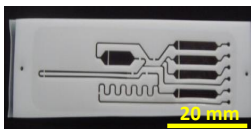
- X-ray microfabrication enables large-area, deep-etching, cross-sectional mirror surface processing

→ To contribute to the creation of next-generation functional systems and devices such as microchemical systems, X-ray optical elements, THz waveguides, and more

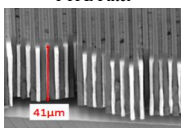
Examples of structures that can be created with X-ray microfabrication



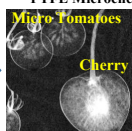
PTFE Filter



PTFE Microchemical Chip



Talbot interferometric
Diffraction grating

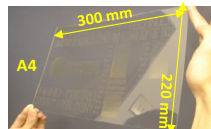


X-ray photo

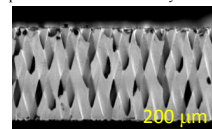


Stereoscopic control
panel

To realize new functions and create high-performance devices and systems



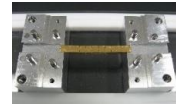
A4 size microfabrication
(Example of processing an acrylic plate)



3D Micro Mixer



Bend waveguide



Bandpass Filter

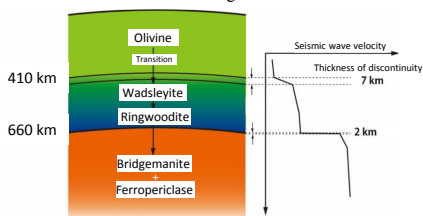


Reference: H. Kido *et al.*, *Microsystem Technol.* **19**, 301 (2013)
Y. Ukita *et al.*, *Microsyst Technol.* **16**, 1495 (2010)
A. Yamaguchi *et al.*, *Appl. Phys. Lett.* **108**, 051610 (2016)

■ Origin of the 660 km seismic velocity discontinuity in the Earth's mantle

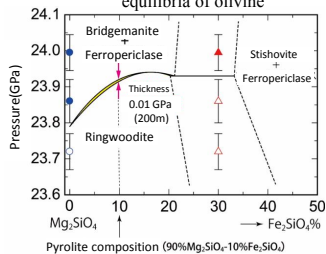
- Precise determination of high-pressure phase transition conditions for olivine
- Significantly improved the accuracy of pressure determination and succeeded in determining a very narrow phase transition pressure range of 0.01 GPa
- Comparison with seismic observations clearly suggests that a phase transition of the olivine component 660 km discontinuity

Width of seismic discontinuities in the mantle and their origin



Previous studies have been less accurate in determining experimental pressure

Precise determination of high-pressure phase equilibria of olivine



Agreement with olivine phase transitions and seismic observations

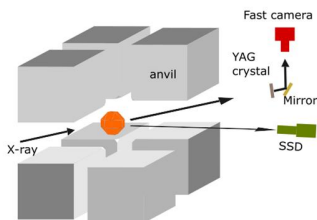


Reference: T. Ishii *et al.*, *Nat. Geosci.*, **12**, 869 (2019)

■ Succeeded in reproducing a magma ocean

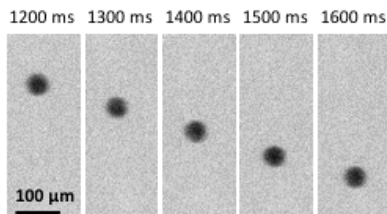
- Developed a semiconductor diamond heater and succeeded in determining the viscosity of magma materials under ultra-high temperatures and pressures
- Cooling and solidification processes of magma oceans based on viscosity data
- Suggests that the lower mantle was formed by deposition from magma oceans

High -P and -T experimental setup



Semiconductor diamond heaters are useful for both X-ray imaging and high-temperature generation

Falling rhenium sphere through the molten sample



Viscosity of lava material is derived from the velocity of a falling sphere



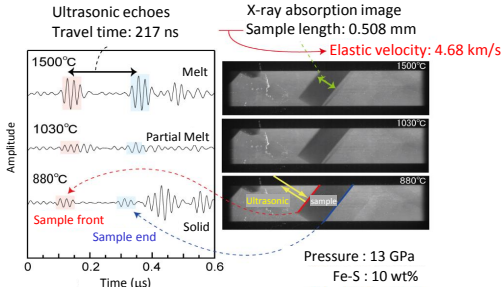
Reference: L. Xie *et al.*, *Nat. Commun.*, **11**, 548 (2020)

BL04B1

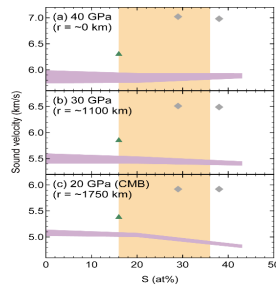
Successful measurement of the sound velocity of Mars core material

- The world's first precise measurement of sound velocity in liquid iron-sulfur alloy
- Direct comparison with seismic data from NASA's Mars Interior Exploration Project is now possible to contribute to understanding the formation processes of Mars and the origin of its moons through JAXA's exploration

Precise measurement of elastic velocity using ultrasonic echoes and X-ray images



Seismic velocity variation in the Martian core as a function of Sulfur concentration



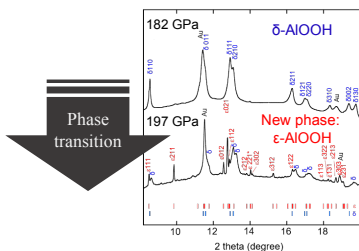
Reference: K. Nishida *et al.*, *Nat. Commun.*, **11**, 1954 (2020)

BL04B1
BL10XU

New hydrous minerals that may exist in the depths of supergiant planets

- The crystal structure of aluminum hydroxide (AlOOH) was found to change (phase transition) at 190 GPa
- Aluminum hydroxide was found to continue storing water even under ultra high-pressure
- Providing new insights into the water cycle and internal structure of icy planets and extrasolar super Earths

The mechanism of the water cycle have a significant impact on planetary evolution.



Crystal structure of a new hydrous mineral ϵ -AlOOH, newly emerged under ultra high-pressure.

Experiments using high-brilliance synchrotron radiation X-rays at SPring-8 in combination with a laser-heated diamond anvil cell/multi-anvil press, coupled with first-principles calculations, have revealed a new hydrous mineral structure.

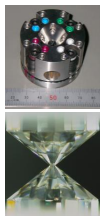


Reference: M. Nishi *et al.*, *J. Geophys. Res.*, **124**(10), 10231-10239 (2019)
M. Nishi *et al.*, *Icarus*, **338**, 113539 (2020)

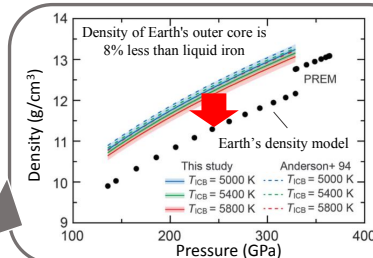
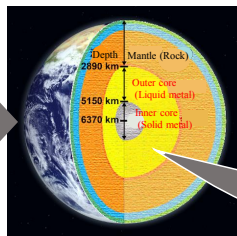
- To understand the chemical composition of the Earth's core
 - The world's first successful precise measurement of the density of liquid iron under extreme conditions almost equivalent to the outer core of the earth
 - Strong constraints can be placed on the chemical composition of the outer core
- Results represent a major step toward unraveling a 70-year mystery in earth science

There were no examples of precise measurements of the density of liquid pure iron under high-pressure equivalent to the outer core.

Compact high-pressure apparatus using diamonds



Reproduction of the Earth's core at SPring-8



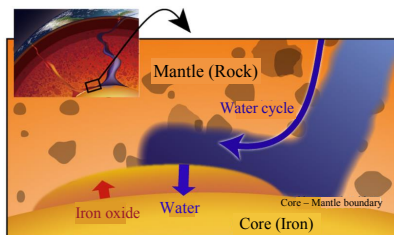
Succeeded in determining the precise density of liquid metals under high-pressure using a new analysis method that is completely different from conventional methods.



Reference: Y. Kuwayama *et al.*, *Phys. Rev. Lett.*, **124**, 165701 (2020)

- To understand how water is transported to the Earth's core
 - Successful observation of chemical reactions between water and metallic iron under extreme conditions corresponding to the Earth's core-mantle boundary
 - Found that the surface of the Earth's core may be covered with a layer of rusted iron
- Provides new insight into the question "Where does surface water subducted deep underground from the plate end up?" which has been actively debated for many years

The key to a complete understanding of the cycles of water, matter, and energy on Earth



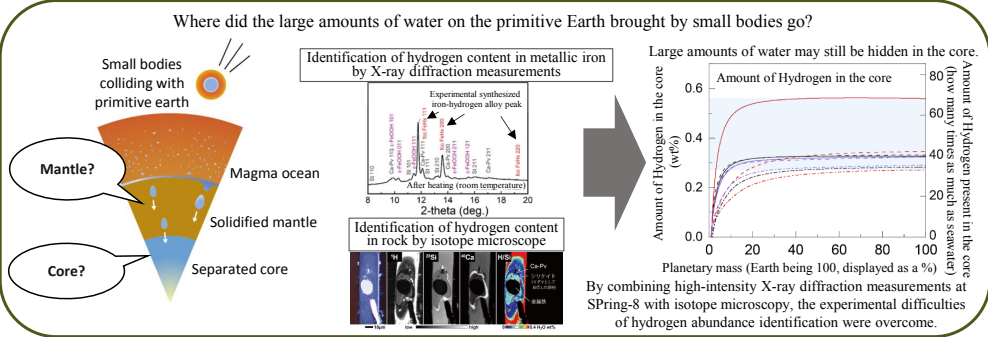
Time change of the chemical reaction of metallic iron + water → iron oxide + iron hydride was observed by combining laser heating + high-pressure apparatus using diamond + high-intensity X-ray diffraction measurement at SPring-8.



Reference: M. Nishi *et al.*, *Geophys. Res. Lett.*, **47(19)**, (2020)



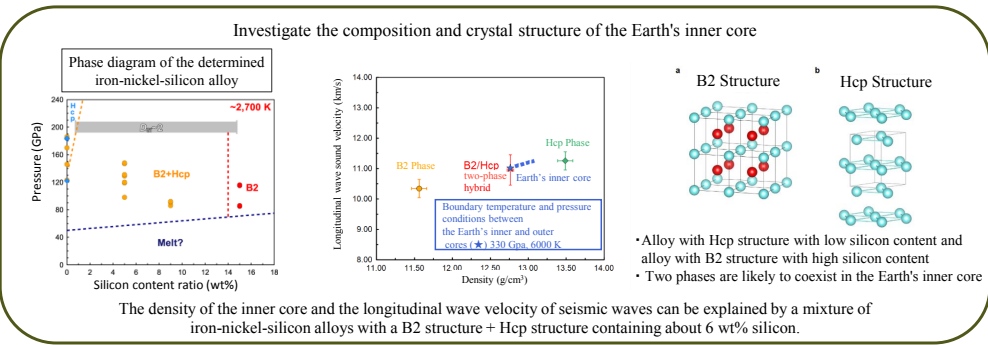
- Large amount of hydrogen in the Earth's core
 - By reproducing the conditions of magma oceans during the Earth's formation period via ultra high-pressure experiments, the hydrogen partitioning between the core and the molten mantle has been revealed
 - Strongly constrained the chemical composition of the core and found that the primitive earth may have contained 50 times as much water as the oceans
- Significant contribution to our understanding of the origins of the oceans and the Earth



Reference: S. Tagawa *et al.*, *Nat. Commun.*, **12**(1), 1-8 (2021)



- Clarifying the structure of the Earth's inner core; Is the Earth's inner core a mixture of two types of iron alloys?
- Crystal structure and phase relations of iron-nickel-silicon alloys have been obtained via high pressure and temperature experiments corresponding to the Earth's core
- The Earth's inner core may be constructed from a two-phase mixture of iron–nickel–silicon alloys, and it should provide new insights into seismology



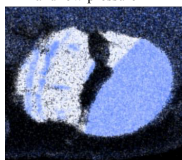
Reference: D. Ikuta *et al.*, *Commun Earth Environ.*, **2**(1), 1-10 (2021)

Loss of the Martian magnetic field and evaporation of oceans

- Successful melting experiments of iron-sulfur-hydrogen alloys under high-temperature and high-pressure conditions comparable to those in the Martian and Earth cores
 - Clarification that the behavior of iron-sulfur-hydrogen alloys varies depending on temperature conditions
- Elucidating the mystery of the loss of the Martian magnetic field and the evaporation of the oceans

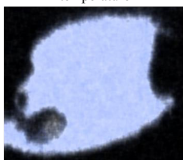
Elemental mapping of cross section of samples

Example of a typical sample where the liquid separates into sulfur-rich (right) and sulfur-poor (left) regions at low-temperature and low-pressure

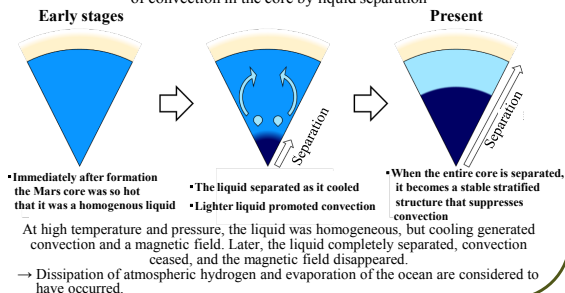


Fe S 5 μm

Typical sample with homogeneous distribution of sulfur and no liquid separation at high-pressure and high-temperature



Schematic diagram of the enhancement and suppression of convection in the core by liquid separation

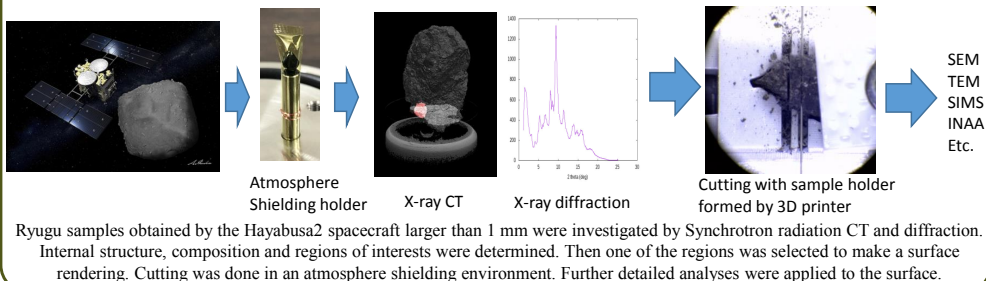


Reference: S. Yokoo *et al.*, *Nat. Comm.*, **13**, 644 (2022)

To analyze Ryugu asteroid particles obtained by the Hayabusa2 spacecraft

- Nondestructive, three-dimensional observations of Ryugu particles were conducted to obtain detailed structure and mineralogical compositions
- The results showed that Ryugu particles have similar characteristics of CI chondrites, which show heavy aqueous alteration and contain abundant organics

Analytical flow of Hayabusa2 returned samples (images of simulant meteorites)



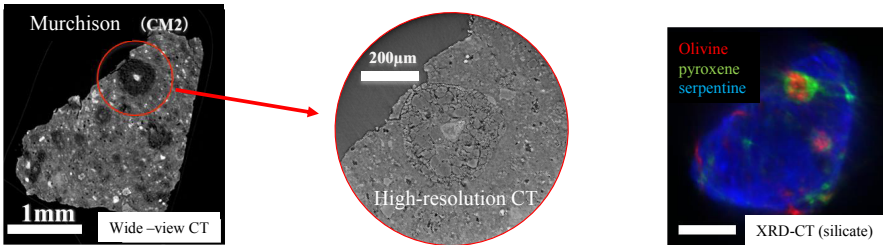
Reference: in preparation

BL20XU

To discover the nature of unknown materials

- Distribution of hydrous and anhydrous minerals, graphite, and diamonds in meteoritic materials can be observed
- The method was applied to Hayabusa2 returned samples which contain abundant hydrous minerals and organics

Comprehensive CT system (multi-scale CT + XRD + Phase contrast CT)



It is difficult to distinguish mineral phases by general X-ray tomography with absorption contrast. Using XRD-CT which is a combination of CT and XRD, distribution of hydrous (serpentine) and anhydrous (other) minerals can be observed.



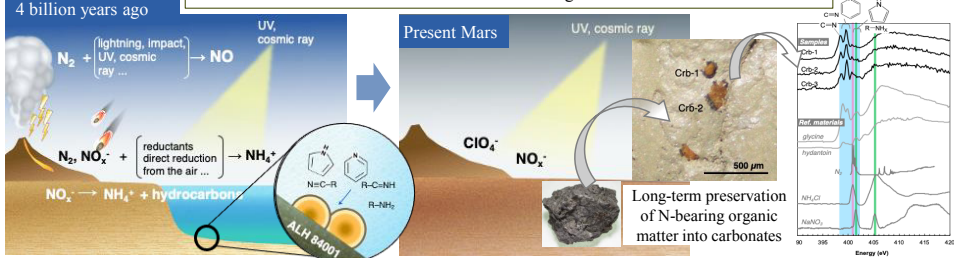
Reference: M. Uesugi *et al.*, 2019 *LPICo* 2157.6280U (2019)

BL27SU

Detection of nitrogen(N)-bearing organics from early Martian samples

- 4-Billion-year-old carbonates in the Martian meteorite ALH 84001 contained N-bearing organic compounds that most likely originated from early Mars
 - In contrast, these carbonates did not contain nitrates, common salts found on the presently oxidized Mars
- Early Mars had a wetter and less oxidized environment with various organic matter

Evolution of the Martian surface environment: Insights from the meteorite ALH84001



Nitrogen XAFS measurements revealed the presence of N-bearing organic matter in the ALH 84001 carbonates.

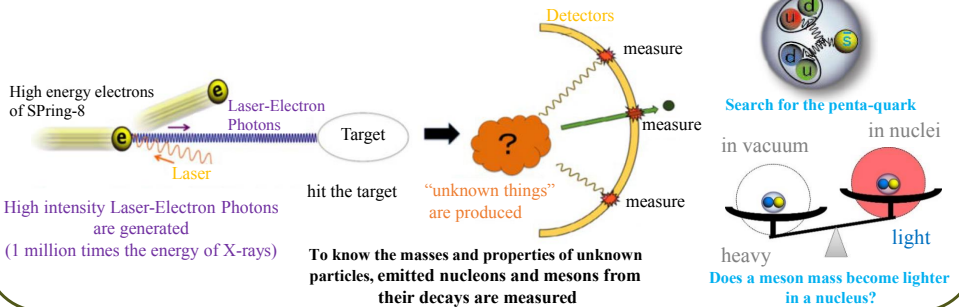


Reference: M. Koike *et al.*, *Nat. Commun.*, **11**, 1988 (2020)

World of quarks explored by high-energy γ rays (Laser-Electron Photons)

- A large detector system was created to search for new kinds of exotic particles consisting of tiny particles called quarks
- Using Laser-Electron Photons, mesons in nuclei were produced and the nuclear bound state of η' mesons were investigated, giving the upper limit of their production rate
- To establish the existence and properties of new particles, and explore the origin of mass

“Watch” the smallest world with Laser-Electron Photons



Reference: N. Tomida *et al.*, *Phys. Rev. Lett.*, **124**, 202501 (2020)
S.Y. Ryu, *AIP. Conf. Proc.*, **2249**, 030024 (2020)

To understand what is deep inside the earth

- Experiments estimated the sound velocity of hexagonal close-packed (hcp) iron under high-temperature and high-pressure, which simulates the inside of the Earth
- The results indicate the possibility of existence of H, S, and Si at the inner core

The inside of the Earth (inner and outer cores) is dominantly made of iron.



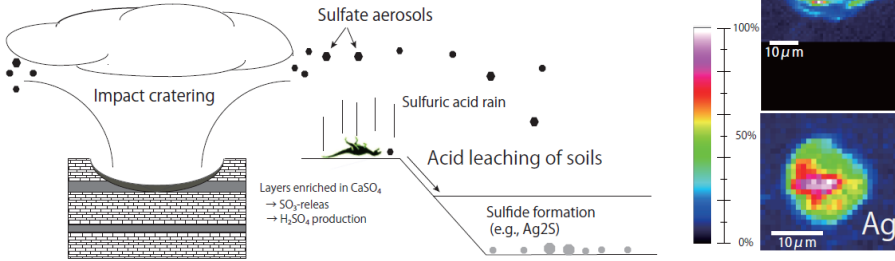
Reference: T. Sakamaki *et al.*, *Sci. Adv.*, **2**, e1500802 (2016)

BL37XU

What happened after the meteoroid impacted at the K-Pg boundary?

- 1-10- μm -sized grains enriched in Cu or Ag were found in the Cretaceous-Paleogene (K-Pg) boundary clays
- Cu and Ag are typically present in acid-soluble sulfides
- The evidence supports that Cu and Ag via leaching caused by highly acidic rain immediately followed the K-Pg meteoroid impact

Fine grains enriched in Cu or Ag ("acid-soluble" chalcophile elements) were found in the sediment deposited just after the K-Pg meteoroid impact



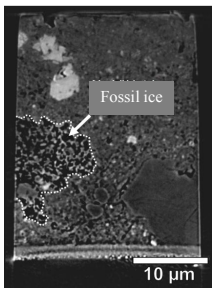
Reference: T. Maruoka *et al.*, *GSA Bulletin*, **132**, 2055 (2020)

BL47XU

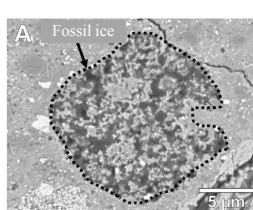
Discovery of "Fossil Ice" in a primitive meteorite

- X-ray CT revealed pore-rich regions in a carbonaceous chondrite, thought to be formed by the melting and accumulation of ice
- Estimation of the distribution of ice in the body was successful based on occurrences of the ice traces
- A new growth model was proposed describing an accumulation of dust containing ice as the meteorite moves from the outside to the inside of the solar system

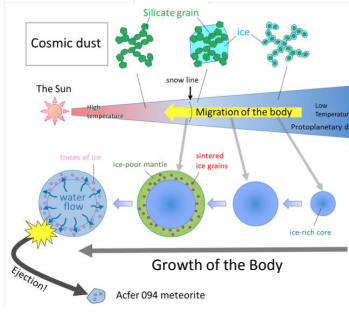
CT image of fossil ice



SEM image of fossil ice



We can postulate where the meteorite was formed and the internal structure of its parent body from the size and microstructure of the ice.

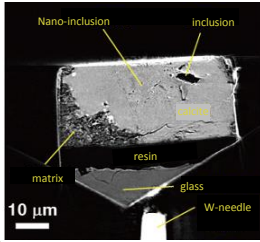


Reference: M. Matsumoto *et al.*, *Sci. Adv.*, **5**, eaax5078 (2019)

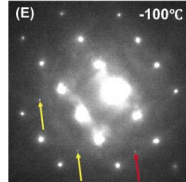
Discovery of CO₂ enriched fluid in a meteorite

- X-ray CT successfully visualize the nano-scale textures of carbonaceous chondrite
 - CO₂-enriched fluid was present in a nano-pore
 - Indicating formation of the body at the outer solar system, where dry ice is stable, then followed by migration into the inner solar system
- Material-based evidence supporting recently proposed dynamic solar system formation models indicating orbits of the planets and drastic asteroid changes

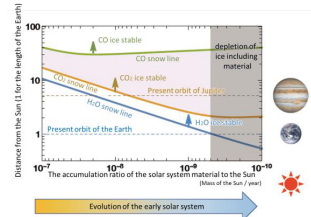
CT image of fluid bearing mineral



Electron diffraction pattern



Additional diffraction spots appear at low-temperature, thought to be derived from dry ice and/or CO₂ hydrate.



The stable region is limited to the ice of H₂O and CO₂ in the solar system. The presence of “carbonated water” implies the formation of the body at outer regions from the present Jupiter orbit.

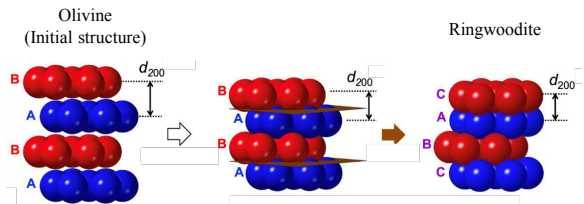
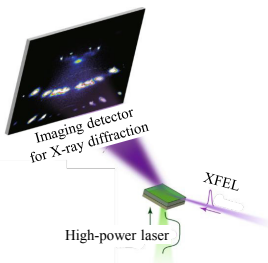


Reference: A. Tsuchiyama *et al.*, *Sci. Adv.*, 7, abg9707 (2021)

Interpreting the history of the solar system

- An environment with ~100 million atmospheres of pressure was produced in a sample in experiments using a high-power optical laser
 - The X-ray free-electron laser (XFEL) captured the structure transformation of samples due to the high-pressure that can also occur in the processes of impact events
- Expected as a new approach to fully understand the history of the solar system

Experiments using high-power laser and XFEL to simulate impact events occurring in the early solar system revealed the sample structure transformed on a timescale of ~10 ns.



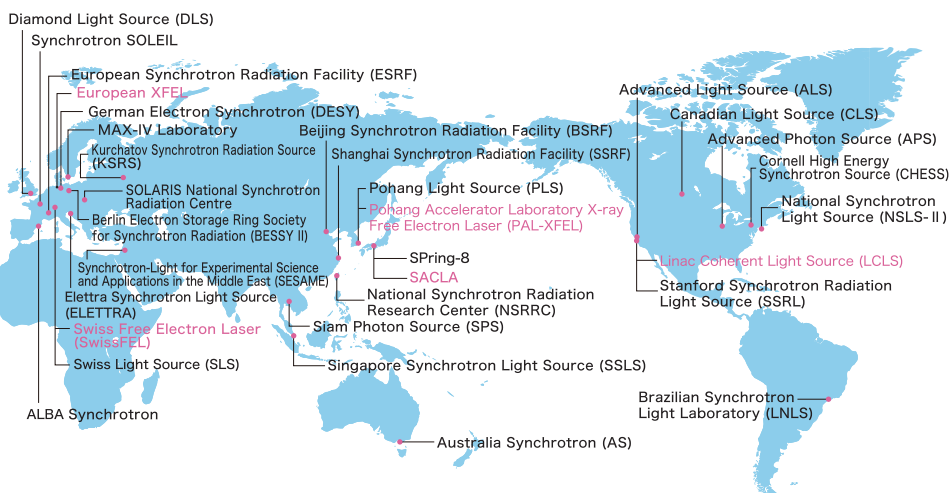
Reference: T. Okuchi *et al.*, *Nat. Commun.*, 12, 4305 (2021)



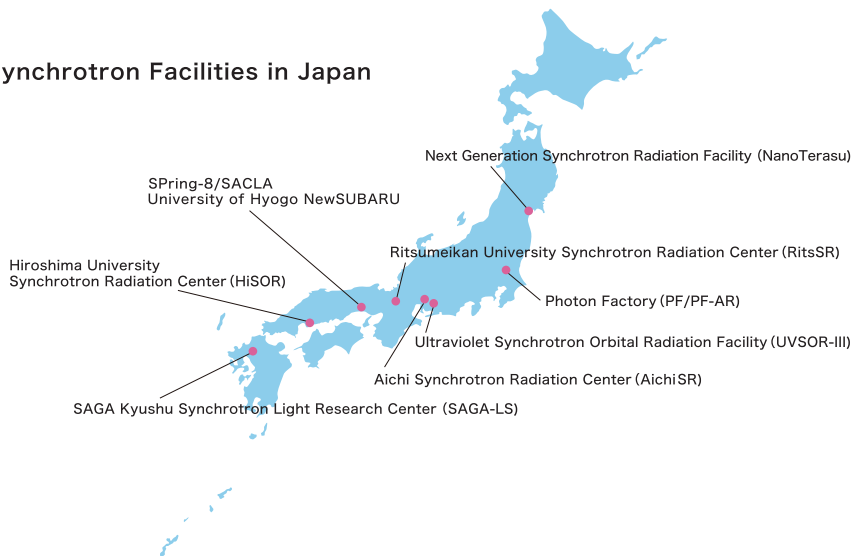
Synchrotron Facilities Around the World

Synchrotron radiation (SR) facilities generate intensive X-rays resulting from high-energy electrons. Many SR facilities are being built, not only in countries around the world, but also in various parts of Japan. Among them, SPring-8 and SACLA obtain the world's highest performance.

Synchrotron Facilities Around the World



Synchrotron Facilities in Japan



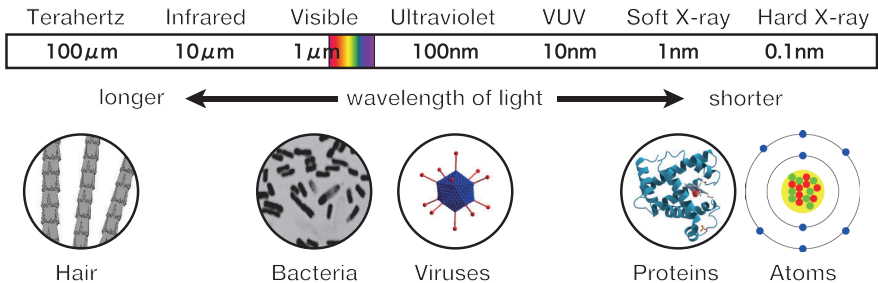
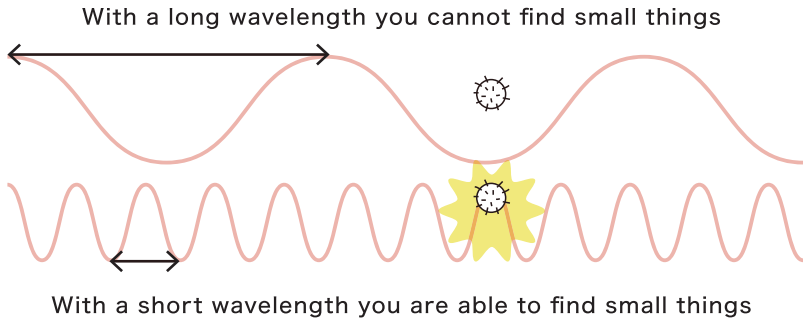


Introduction to X-rays



In 1895, Röntgen discovered a type of light able to penetrate materials. The X-rays were named after the 'X' used in mathematics to designate an unknown variable. The first X-ray image was the hand of his wife. Now X-rays are widely used in hospitals.

To see very small things, you need light with a short wavelength, X-rays.



SPring-8 can image small objects that have never been observed before by using very intense X-rays from a large accelerator. It is possible to visualize the structure of atoms and molecules that make up the inside of objects.

SPring-8

Opened in October 1997
Circular (Circumference 1,436m)
With generated X-rays that are
10 billion times more brilliant than the sun,
it is possible to observe a detailed
view of the nano world.

3 Generate X-rays from Electrons

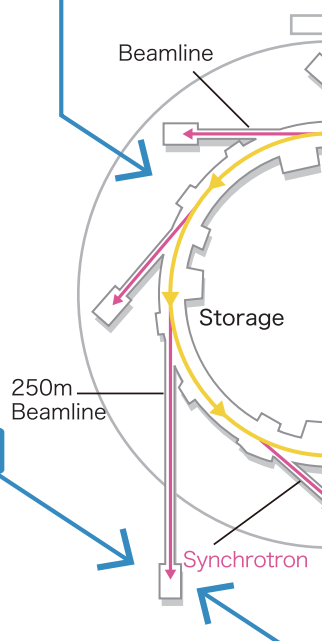


③The undulator produces X-rays (synchrotron radiation)

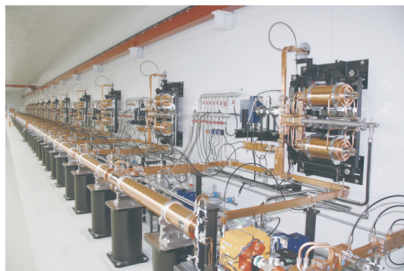
4 Strike a Sample



④The equipment and detectors used for X-ray irradiation (synchrotron radiation)



SACLA is an X-ray free electron laser facility that enables us to visualise ultrafast phenomena such as chemical reactions. The motion of atoms and molecules can be seen by using the intense coherent X-rays of SACLA.



② The C-band acceleration tube efficiently accelerates electrons

SACLA

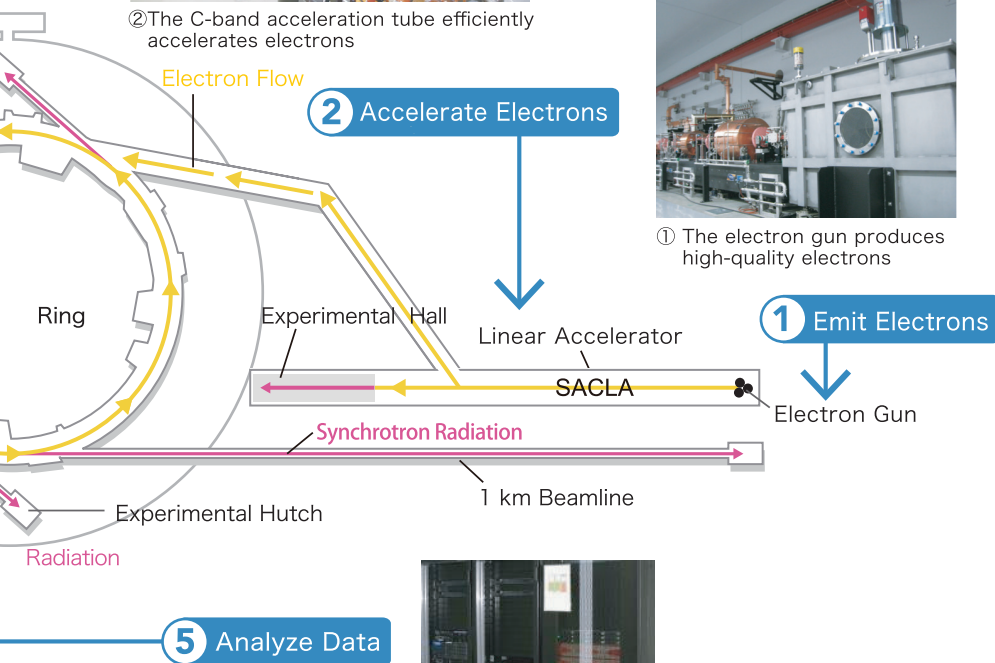
Opened in March 2012

Liner (700m)

With a generated X-ray laser that is a billion times more brilliant than SPring-8, it is possible to observe changes in the phenomena of the nano world.

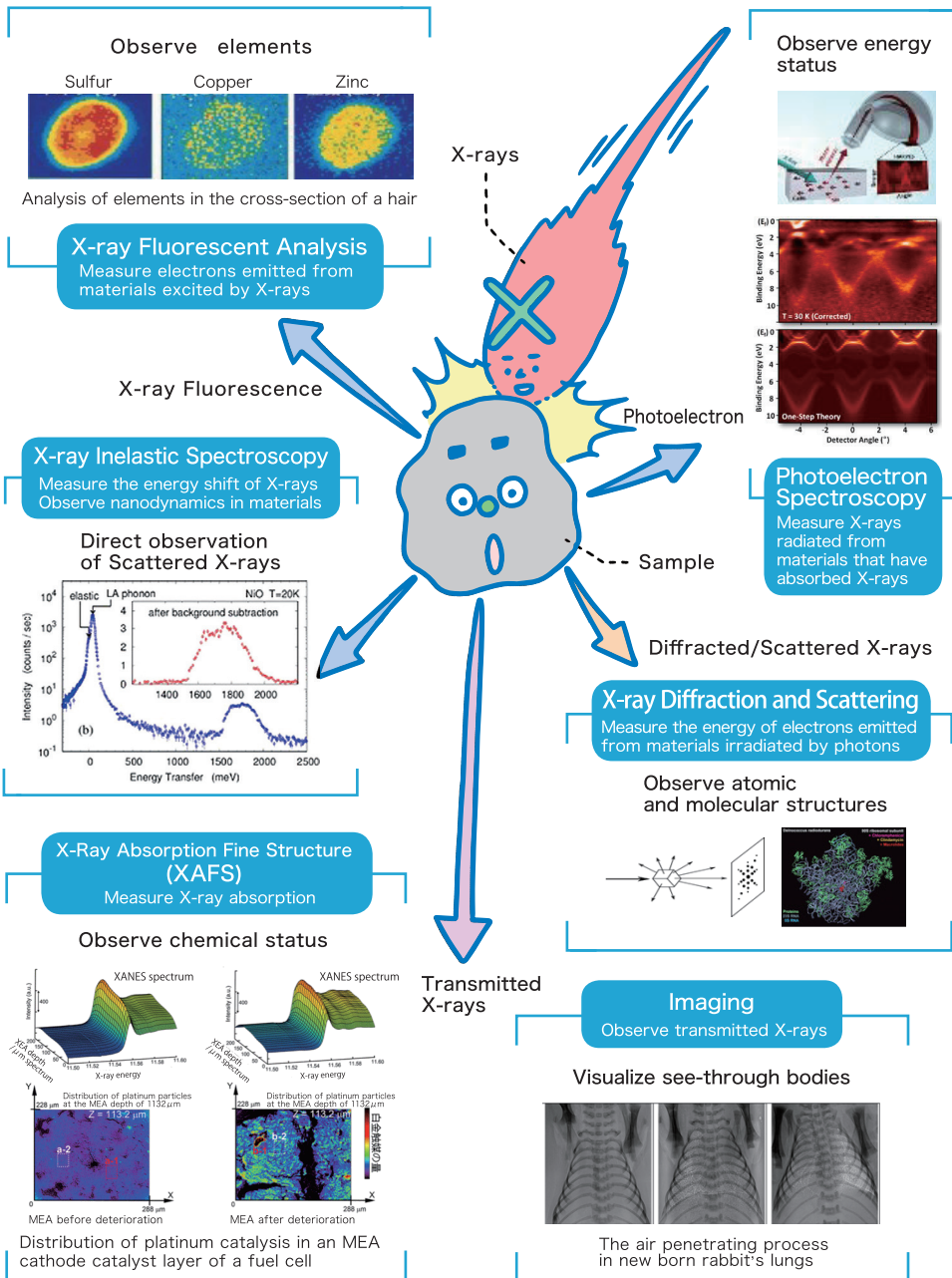


① The electron gun produces high-quality electrons



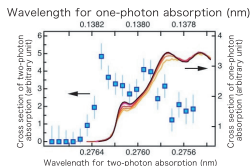
⑤ The storage environment for data analysis

How to observe small structures that we cannot view with our eyes alone



Various phenomena occur when X-rays strike a sample

Observe things that are difficult to see with conventional methods



Two-photon absorption spectrum of copper

X-ray Non-linear Spectroscopy

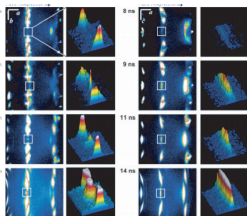
Analyze by using non-linear optical phenomena

X-ray Fluorescence

Time-resolved Analysis

Observe rapid changes in time sequence

Observe the movement of atoms and molecules directly

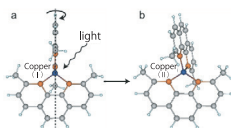
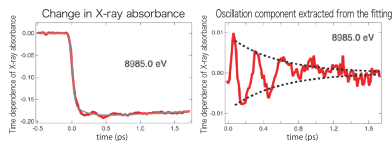


Visualization of crystal-structure changes that occur in 1/100,000,000 of a second

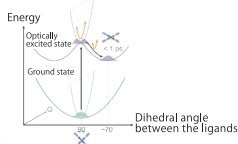
X-Ray Absorption Fine Structure (XAFS)

Measure X-ray absorption spectra

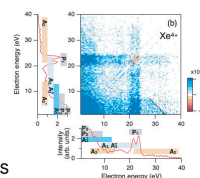
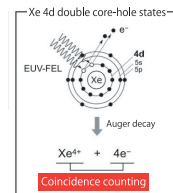
Observe chemical states



Observation of chemical-state changes in a Cu(I)-phenanthroline complex



Observe electronic structures



Observation of the double core-hole states in Xe atoms

Photoelectron Spectroscopy

Measure the energy of electrons emitted from a material irradiated by X-rays

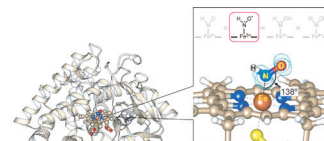
Photoelectrons

Diffacted/Scattered X-rays

X-ray Diffraction and Scattering

Measure X-rays diffracted/scattered by a material

Observe atomic and molecular structures



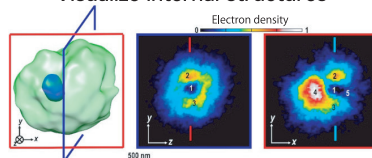
Structure of a reaction intermediate of nitric oxide reductase

Transmitted X-rays

Imaging

Measure the intensity distribution of transmitted X-rays

Visualize internal structures



3-dimensional observation of the internal structure of cyanobacteria



In Conclusion

We hope you enjoyed reading this summary of the research achievements at the SPring-8 and SACLA facilities. We are happy to share the wonders that result from combining the power of science and technology with the laws of nature to visualize the invisible forms and states of the nanomaterial world by using invisible light (X-rays).

Visualization of the nano-world can deepen our understanding of the natural world. It can also help us achieve a more affluent society through developing industrial applications that provide beneficial capabilities. At the same time, it provides insights for science and technology to help us achieve the SDG goals for 2030 and to become carbon neutral by 2050.

Visualizing the nano-world has become increasingly important to address the evolving COVID-19 virus and to prepare for viruses that will emerge in the future. Japan has long been well-known as a nation focused on science and technology. To live up to that ideal, it is essential that SPring-8 and SACLA provide the foundation supporting Japan's science and technology and continue to excel on the international stage as world-leading facilities. In this sense, the duties of RIKEN and JASRI, who operate the facilities, are exceedingly important.

We ask for your continued understanding and cooperation, and sincerely look forward to the participation of young researchers and the support of their generation, who are vital to the continued development of SPring-8 and SACLA.

September 2022

President
Japan Synchrotron Radiation
Research Institute

雨宮慶幸