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Center for Emergent Matter Science

2026

CEMS

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Building a sustainable society that can co-exist in harmony with the environment

Message From the Director

RIKEN Center for Emergent Matter Science (CEMS) was established in 2013 as a research center which bound the basics of physics, chemistry, and electronics, where top leaders and young researchers collaborate with each other. Here, ‘emergence’ means that an aggregate system composed of many elements may exhibit qualitatively different behaviors beyond just the sum of each element’s behaviors.

We aim to design novel material functions and to realize them by producing materials and devices as their stage. The basic research fields of CEMS are ‘strong correlation physics’, ‘supramolecular chemistry’, and ‘quantum information electronics’. Researchers in each field aim to create new knowledge based on their own interests, which are combined to contribute to the sustainability of the earth’s environment and the future development of the human beings.

CEMS has been dealing with developing energy functions of electrons in condensed matters which open the door to ‘the third energy revolution’. The industry revolution in the late 18th century replaced manual and animal labor with machines powered by energy from coal. In 19th century, humans began harnessing electrical energy, a discovery that was rooted in the newly understood principles of electromagnetism. Most of the electrical energy today is still obtained from coal, oil, natural gas, nuclear power, water flow and wind through electromagnetic induction. However, the realization of carbon neutral requires the direct transformation from light, heat, etc. to the electrical energy. CEMS keeps trying to construct new electromagnetism based on the emergence in condensed matters, looking back the fact that the electrical energy originates from electrons in materials.

We must also be conscious about the fact that the rapid information revolution today is accelerating the global boiling. Energy consumption in acquisition, storage, calculation, and communication of information is steeply growing. The storage and conversion of information are essentially equivalent to those of energy in condensed matters. The emergent electromagnetism should contribute to the realization of information society with suppressed energy consumption.

CEMS keeps exploring innovative principles and new materials that cannot be approached by any extension of conventional technology but only by basic material science.

Taka-hisa Arima
Director, RIKEN Center for Emergent Matter Science

RIKEN Center for Emergent Matter Science

The Center for Emergent Matter Science (CEMS) brings together leading scientists in three areas—physics, chemistry, and electronics—to elaborate the principles of emergent phenomena and to open the path to potential applications.

CEMS carries out research in three areas: strongly-correlated materials, supramolecular functional chemistry, and quantum information electronics. It incorporates about 170 researchers from around the world, organized into about 40 research groups and teams.

There are other leading centers around the world working in each of the three areas covered by CEMS, but nowhere in the world is there a center that brings the three together in one place. In order to create a sustainable society that can co-exist with the natural environment, cooperation between the fields of physics, chemistry, and electronics is critical.

Bringing these three areas together allows “emergent phenomena” to take place within the center’ s research as well, making possible breakthroughs in research that could not be predicted from the outset.

The goal of CEMS is not to develop technologies that can be immediately put into application. It is not to push existing technologies forward, but rather to pursue radical new technological principles that will contribute to human society in five decades or even a century in the future. To do this, it focuses on basic research and the development of new theories.

Researchers who have pioneered these three fields have been brought together along with young scientists who are not held back by existing theories, to work as a team to take on this truly challenging research. This is the real work of CEMS.

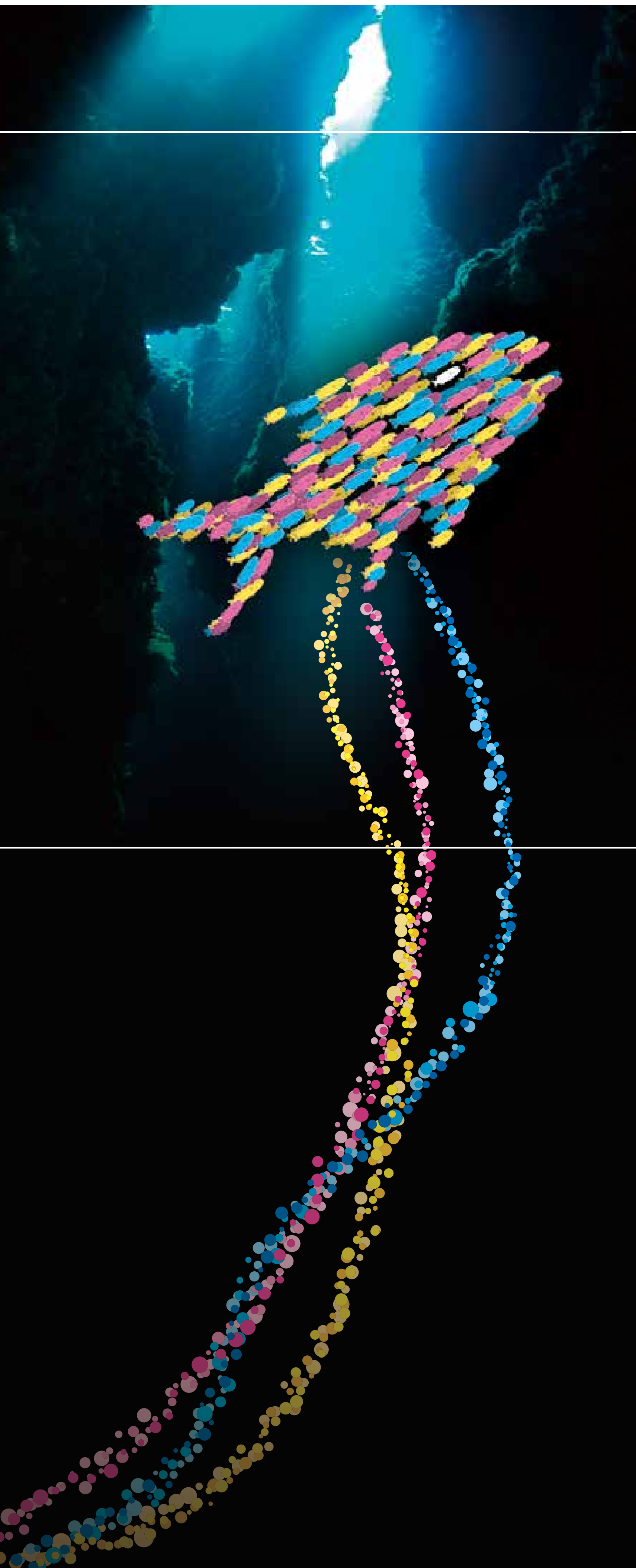
Introduction to EMS

“Emergence” refers to the phenomenon in which a number of elements that are brought together gain properties that could not be predicted from the individual elements. For example, when a large number of electrons become strongly correlated, they can give rise to extremely strong electrical and magnetic action that could not be predicted from the actions of a single electron.

Additionally, by linking together a large number of molecules, it is possible to create materials with new functionalities that were not possessed by the individual molecules. In this way, when particles such as electrons or molecules gather together, they can give rise to surprising materials and functions that could not be predicted simply as an aggregation of the original constituent elements.

The science that attempts to elucidate the principles of emergent phenomena and create new materials and functions based on these principles is known as emergent matter science. For example, the phenomenon of superconductivity, where metals and other compounds suddenly lose all their electrical resistance when cooled to a certain degree, is a phenomenon that arises from the mutual interactions between electrons. Normally, superconductivity appears at very low temperatures, but if we are able to design and develop materials that are high-temperature superconductors, it will become possible to transmit electricity without any loss.

In that way, emergent matter science has the potential to trigger a major revolution in our lifestyles, and contribute to the achievement of a sustainable society that can co-exist in harmony with the environment.



Strong Correlation Physics Division

Supramolecular Chemistry Division

Quantum Information Electronics Division

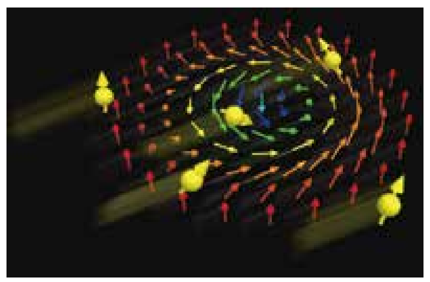
Cross-Divisional Materials Research Program

Office of the Center Director

Strong Correlation Physics Research Group

Topological spin textures and emergent electromagnetic functions

Nanometric spin texture called "skyrmion". The skyrmion is the idea coined by Tony Skyrme, a nuclear physicist, to describe a state of nucleon as the topological soliton. It has recently been demonstrated that such a kind of topological particle should exist widely in ubiquitous magnetic solids. The arrows in the figure represent the directions of the spin (electron's magnetic moment); the spins direct up at the peripheral, swirl in going to the inside, and direct down at the core. This topology cannot be reached via continuous deformation from the conventional spin orders, meaning that the skyrmion can be viewed by a topologically protected particle. The skyrmion can carry a fictitious (emergent) magnetic field working on moving conduction electrons (represented by yellow balls), and hence causes the topological Hall effect (transverse drift of the current). Furthermore, the electric current itself can drive the skyrmion. The critical current density for the drive of skyrmions is around 100 A/cm^2, by five orders of magnitude smaller than the conventional value for the drive of magnetic domain walls. These features may favor the application of skyrmions to innovative spintronics, i.e. toward "skyrmionics".



Skyrmion and conduction electron motion

Publications

1. M. T. Birch, Y. Fujishiro, I. Belopolski, M. Mogi, Y.-L. Chiew, Z. Li, X. Yu, N. Nagaosa, M. Kawamura, and Y. Tokura, "Nanosculpted 3D helices of a magnetic Weyl semimetal with switchable non-reciprocal electron transport" *Nat. Nanotechnology*, 21, 352–358 (2026).
2. D. Yamaguchi, A. Kitaori, N. Nagaosa and Y. Tokura, "Current Control of Spin Helicity and Nonreciprocal Charge Transport in a Multiferroic Conductor", *Adv. Mater.*, 37, 2420614 (2025).
3. K. Ueda, T. Yu, M. Hirayama, R. Kurokawa, T. Nakajima, H. Saito, M. Kriener, M. Hoshino, D. Hashizume, T.-h. Arima, R. Arita, and Y. Tokura, "Colossal negative magnetoresistance in field-induced Weyl semimetal of magnetic half-Heusler compound", *Nat. Commun.*, 14, 6339 (2023).
4. T. Yokouchi, F. Kagawa, M. Hirschberger, Y. Otani, N. Nagaosa, and Y. Tokura, "Emergent electromagnetic induction in a helical-spin magnet", *Nature*, 586, 232 (2020).
5. T. Kurumaji, T. Nakajima, M. Hirschberger, A. Kikkawa, Y. Yamasaki, H. Sagayama, H. Nakao, Y. Taguchi, T. Arima, Y. Tokura, "Skyrmion lattice with a giant topological Hall effect in a frustrated triangular-lattice magnet", *Science*, 365, 914 (2019).

Yoshinori Tokura (D.Eng.), Group Director

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Research field

Physics, Engineering, Materials Science

Keywords

Strongly correlated electron system, Topological insulators, Spin-orbit interaction, Berry phase physics, Multiferroics, Skyrmion

Brief resume

1981 D. Eng., University of Tokyo
1986 Associate Professor, University of Tokyo
1994 Professor, Department of Physics, University of Tokyo
1995 Professor, Department of Applied Physics, University of Tokyo
2001 Director, Correlated Electron Research Center, AIST
2007 Group Director, Cross-Correlated Materials Research Group, RIKEN
2008 AIST Fellow, National Institute of Advanced Industrial Science and Technology (-present)
2010 Director, Emergent Materials Department, RIKEN
2010 Group Director, Correlated Electron Research Group, RIKEN
2013 Director, RIKEN Center for Emergent Matter Science (CEMS)
2013 Group Director, Strong Correlation Physics Research Group, Strong Correlation Physics Division, RIKEN CEMS (-present)
2014 Team Leader, Strong Correlation Quantum Transport Research Team, RIKEN CEMS (-present)Position name has been changed to Team Director as of April 1,2025
2017 Distinguished University Professor, University of Tokyo (-present)
2019 Special University Professor, University of Tokyo
2024 Special Advisor to the President, RIKEN
2025 Executive Director of Science, RIKEN (-present)

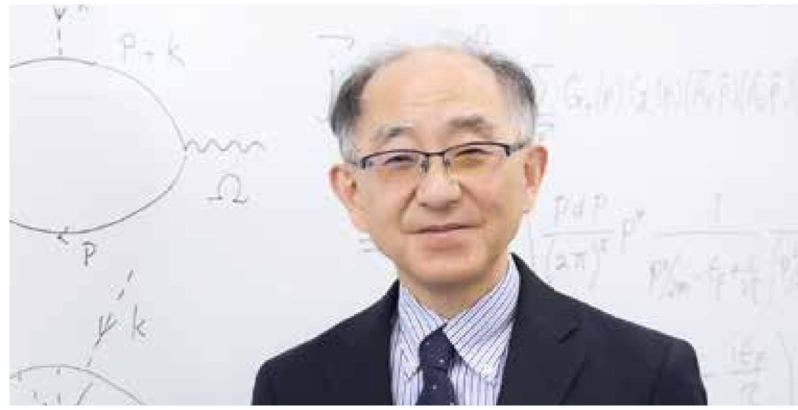
Outline

Our group investigates a variety of emergent phenomena in strongly correlated electron systems, which cannot be understood within the framework of conventional semiconductor/metal physics, to construct a new scheme of science and technology. In particular, we focus on transport, dielectric and optical properties in non-trivial spin/orbital structures, aiming at clarifying the correlation between the response and the spin/orbital state. In addition, we investigate electron systems with strong relativistic spin-orbit interaction, unraveling its impact on transport phenomena and other electronic properties. Target materials include high-temperature superconductors, colossal magnetoresistance systems, multiferroics, topological insulators, and skyrmion materials.

Core members

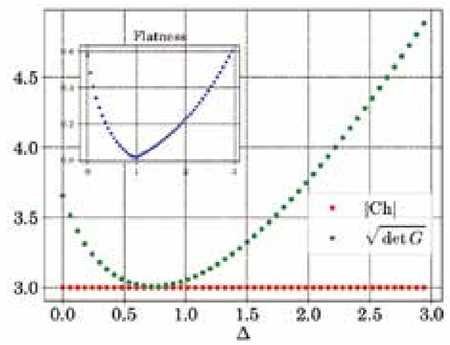
(Senior Research Scientist) Masamichi Nakajima
(Research Scientist) Max Birch
(Special Postdoctoral Researcher) Xue Han
(Senior Technical Scientist) Chieko Terakura

Strong Correlation Theory Research Group



Quantum geometric bounds for observables: Linear responses, Drude weight, and orbital magnetization

The quantum geometric tensor (QGT) provides nontrivial bounds among physical quantities, as exemplified by the metric-curvature inequality. We investigated various bounds for different observables through certain generalizations of the QGT. First, we demonstrate that bounds hold for all linear responses, which are produced by a QGT extended to many-body states, finite temperature, and general parameter space. As an application, we show the thermodynamic inequality originating from the convexity of free energy can be further tightened. Second, we establish a bound between the Drude weight and the orbital magnetization. This equality is exactly satisfied in the Landau level system, and systems with nearly flat bands tend to approach equality as well. We apply the resulting inequality to two orbital ferromagnets and support that the twisted bilayer graphene system is close to the Landau level system. Moreover, we show that an analogous inequality also holds for a higher-order multipole, magnetic quadrupole. Finally, we discuss the analogy between the QGT and the uncertainty principle, emphasizing that the existence of nontrivial bounds necessarily reflects quantum effects.



The relation between the flatness of the band (inset) and the inequality between the Chern number and determinant of the quantum metric tensor G. The inequality is almost saturated when the band becomes flat. DOI: https://doi.org/10.1103/qxbl-qd4f

Publications

1. Koki Shinada and Naoto Nagaosa, "Quantum geometric bounds for observables: Linear responses, Drude weight, and orbital magnetization", *Phys. Rev. B* 112, 155158 (2025).
2. H.-L. Kim, T. Saito, H. Yang, H. Ishizuka, M. John Coak, J. H. Lee, H. Sim, Y. S. Oh, N. Nagaosa, J.-G. Park, "Thermal Hall effects due to topological spin fluctuations in $YMnO_3$", *Nat. Commun.*, 15, 243 (2024).
3. J. Ahn, G.Y. Guo, N.Nagaosa, A. Vishwanath, "Riemannian geometry of resonant optical responses", *Nat. Phys.* 18, 290 (2022).
4. N. Nagaosa, "Emergent inductor by spiral magnets", *JJAP* 58, 12909 (2019).
5. R. Wakatsuki, Y. Saito, S. Hoshino, Y. M. Itahashi, T. Ideue, M. Ezawa, Y. Iwasa, and N. Nagaosa, "Nonreciprocal charge transport in noncentrosymmetric superconductors", *Sci. Adv.*, 3, e1602390 (2017).

Naoto Nagaosa (D.Sci.), Group Director

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Research field

Physics, Engineering, Materials Sciences

Keywords

Emergent electromagnetism, Magnetoelectric effect, Shift current, Non-reciprocal effect, Spin Hall effect, Interface electrons, Superconductivity

Brief resume

1983 Research Associate, University of Tokyo
1986 D.Sci., University of Tokyo
1998 Professor, University of Tokyo
2001 Team Leader, Theory Team, Correlated Electron Research Center, National Institute of Advanced Industrial Science and Technology
2007 Team Leader, Theoretical Design Team, RIKEN
2010 Team Leader, Strong-Correlation Theory Research Team, RIKEN
2013 Deputy Director, RIKEN Center for Emergent Matter Science (CEMS)
2013 Group Director, Strong Correlation Theory Research Group, Division Director, Strong Correlation Physics Division, RIKEN CEMS (-present)
2024 Director, Fundamental Quantum Science Program (-present)

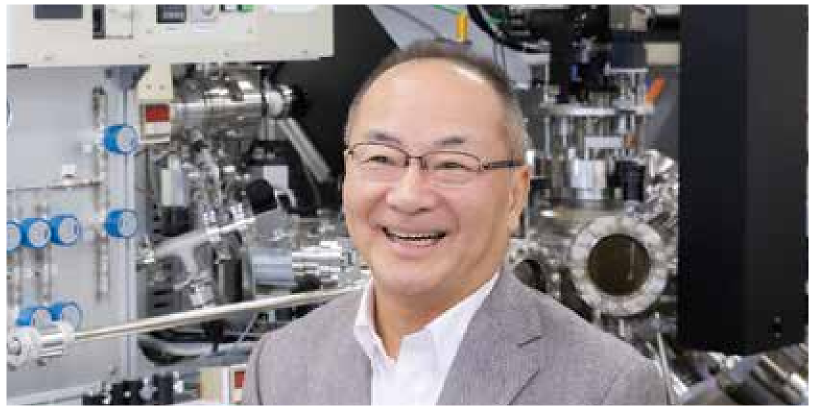
Outline

We study theoretically the electronic states in solids from the viewpoint of topology and explore new functions with non-dissipative currents. Combining first-principles calculations, quantum field theory, and numerical analysis, we predict and design magnetic, optical, transport and thermal properties of correlated electrons focusing on their internal degrees of freedom such as spin and orbital. In particular, we study extensively the nontrivial interplay between these various properties, i.e., cross-correlation, and develop new concepts such as electron fractionalization and non-dissipative quantum operation by considering the topology given by the relativistic spin-orbit interaction and/or spin textures.

Core members

(Senior Research Scientist) Wataru Koshibae
(Special Postdoctoral Researcher) Koki Shinada, Yingming Xie
(Postdoctoral Researcher) Evgenii Barts, Ziting Sun

Strong Correlation Interface Research Group



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Research field

Physics, Engineering, Chemistry, Materials Sciences

Keywords

Topological electronics, Thin films and interfaces, Topological materials, Unconventional photovoltaic effect, Unconventional Hall effect

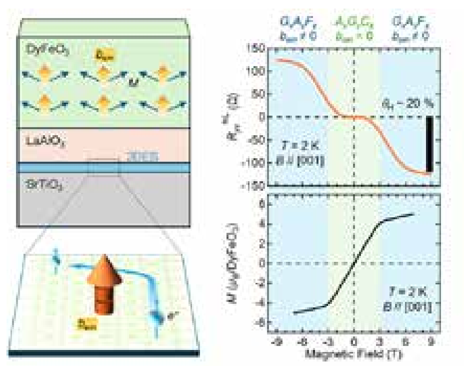
Brief resume

1989 D.Eng., University of Tokyo
1989 Postdoctoral Fellow, Japan Society for the Promotion of Science
1989 Postdoctoral Fellow, T. J. Watson Research Center, IBM, USA
1991 Research Associate, Tokyo Institute of Technology
1997 Associate Professor, Tokyo Institute of Technology
2001 Professor, Tohoku University
2007 Team Leader, Functional Superstructure Team, RIKEN
2010 Team Leader, Strong-Correlation Interfacial Device Research Team, RIKEN
2011 Professor, University of Tokyo
2013 Deputy Director, RIKEN Center for Emergent Matter Science (CEMS)
2013 Group Director, Strong Correlation Interface Research Group, Strong Correlation Physics Division, RIKEN CEMS (-present)
2023 Research Strategy Advisor, RIKEN
2025 Executive Vice President, RIKEN (-present)

Giant anomalous Hall effect driven by proximity-induced emergent fields

Emergent fields are fictitious magnetic fields experienced by electrons as they propagate through specific magnetic spin textures. Because these fields can trigger massive electronic responses without the need for external magnetic bias, they have attracted attention as a fundamental principle for next-generation electronics. Our group is pioneering a new research direction that goes beyond conventional magnetic metals by focusing on proximity-induced emergent magnetic transport phenomena at oxide heterointerfaces composed of a nonmagnetic metal and a magnetic insulator.

In this study, we successfully engineered a spin-polarized electron system by projecting emergent fields from $DyFeO_3$, a canted antiferromagnetic insulator, into the high-mobility two-dimensional electron system at the $LaAlO_3/SrTiO_3$ interface via proximity effect. We observed a giant anomalous Hall angle of approximately 20%, unprecedented in oxide heterointerfaces. This distinctive Hall response arises from the interplay between high-mobility carriers and emergent fields, providing key insight into novel spintronic functionalities. Furthermore, our findings demonstrate the feasibility of oxide spintronics based on proximity-induced emergent fields.



(Left) Schematic of the fabricated heterointerface and the concept of emergent-field-driven interfacial magnetotransport. (Top Right) Observed giant anomalous Hall effect and (Bottom Right) the corresponding magnetization curve of $DyFeO_3$. A significant enhancement in the anomalous Hall angle occurs at ~3 T, driven by emergent magnetic fields arising from the magnetic transition of $DyFeO_3$.

Outline

Thin films and interfaces of topological materials are the playground of our research. Chiral spin textures in real space and magnetic monopoles in momentum space are the sources of non-trivial Hall effect. Photo-excited polar crystals generate unconventional photocurrent. Not classical mechanics but quantum mechanics is needed to understand those examples. We will design and demonstrate possible devices that utilize expectedly dissipationless electron flow exemplified as above. The device physics study will open a new avenue towards topological electronics that manage flow of information and energy carried by such topological current.

Publications

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2. T. Yasunami, M. Nakamura, Y. Tokura, and M. Kawasaki "Enhanced mobility of p-type transparent semiconductor CuI thin films grown on thermal expansion matched substrates", *APL Mater.* 13, 081121 (2025).
3. T. C. Fujita, S. Senzaki, M. Kawasaki "Anisotropic magnetoresistance in non-magnetic $Pb_2Ru_2O_{6.5}$ interfaced with spin ice insulator $Ho_2Sn_2O_7$", *APL Mater.* 13, 101104 (2025).
4. T. C. Fujita, D. Kataoka, N. Takahara, K. S. Takahashi, and M. Kawasaki "Proximitized magnetotransport at $SrVO_3/ErCrO_3$ heterointerface", *Appl. Phys. Lett.* 126, 221602 (2025).
5. N. Takahara, K. S. Takahashi, Y. Tokura, M. Kawasaki "Positive magnetoconductance in $SrVO_3$ double quantum wells with a magnetic $EuTiO_3$ barrier", *Phys. Rev. B* 112, 165146 (2025).

Core members

(Senior Research Scientist) Denis Maryenko
(Research Scientist) Takahiro Fujita
(Visiting Scientist)
Masao Nakamura, Kei Takahashi, Jobu Matsuno

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Research field

Materials Science, Physics

Keywords

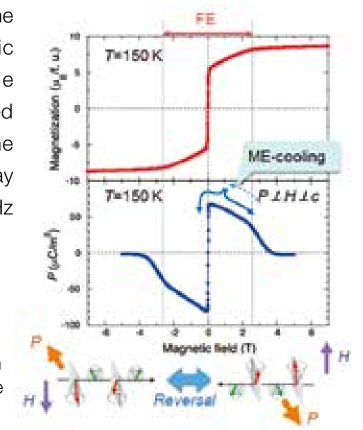
X-ray scattering, Neutron scattering, Electron diffraction, Structure science, Imaging

Brief resume

1988 TORAY Co. Ltd.
1991 Research Associate, Faculty of Science, University of Tokyo
1994 Ph.D. (Science), University of Tokyo
1995 Research Associate, Graduate School of Engineering, University of Tokyo
1995 Associate Professor, Institute of Materials Science, University of Tsukuba (2001-2006 Group Leader, ERATO Tokura Spin Super Structure Project)
2004 Professor, Institute of Multidisciplinary Research for Advanced Materials, Tohoku University
2011 Professor, Graduate School of Frontier Sciences, University of Tokyo (-present)
2007 Team Leader, Spin Order Research Team, RIKEN SPring-8 Center
2013 Team Leader, Strong Correlation Quantum Structure Research Team, RIKEN Center for Emergent Matter Science
2023 Deputy Director, RIKEN Center for Emergent Matter Science (CEMS)
2023 Group Director, Strong Correlation Quantum Structure Research Group, RIKEN Center for Emergent Matter Science (-present)
2024 Director, RIKEN Center for Emergent Matter Science (CEMS) (-present)

Spin-driven ferroelectricity and electromagnon in multiferroic Y-type hexaferrite compounds

Y-type hexaferrite compounds are composed of an alternate stacking of spinel block layers and hexagonal perovskite block layers. The magnetic anisotropy of each layer and effective exchange interaction are dependent on the composition. As a consequence, various magnetic orders appears in the temperature-magnetic field plane. It is predicted that two kinds of magnetic orders, transverse cone and double fan, can host electric polarization via the inverse Dzyalloshinsky-Moriya interaction. We performed measurements of magnetization, electric polarization, and spin-polarized neutron scattering in $BaSrCo_2Fe_{11}AlO_{22}$. It has been found that the alternate longitudinal cone first appears by cooling from a high temperature at zero magnetic field. If a magnetic field is once applied perpendicular to the c-axis at low temperatures, the double fan replaces and survives even after the magnetic field is turned off. The electric polarization is also induced along the axis perpendicular both to the c-axis and to the magnetic field. The electric polarization is reversed by switching the magnetic field direction. Inelastic spin-polarized neutron scattering has predicted that both the double fan and alternative longitudinal cone may host an electromagnon (magnon excited by THz electric field).



Magnetic-field induced reversal of electric polarization and possible change in magnetic structure in a Y-type hexaferrite $BaSrCo_2Fe_{11}AlO_{22}$.

Outline

Strongly correlated electron systems may exhibit various interesting emergent phenomena such as superconductivity, colossal magneto-resistance, and giant magneto-electric effects. These emergent phenomena are directly associated with the spatial distributions as well as the spatial and temporal fluctuations of atoms, electron density, and spin density. To reveal these phenomena, we perform crystallographic and magnetic structure analyses, spectroscopies, and microscopies by using synchrotron x-rays, neutrons, and high-energy electron beams.

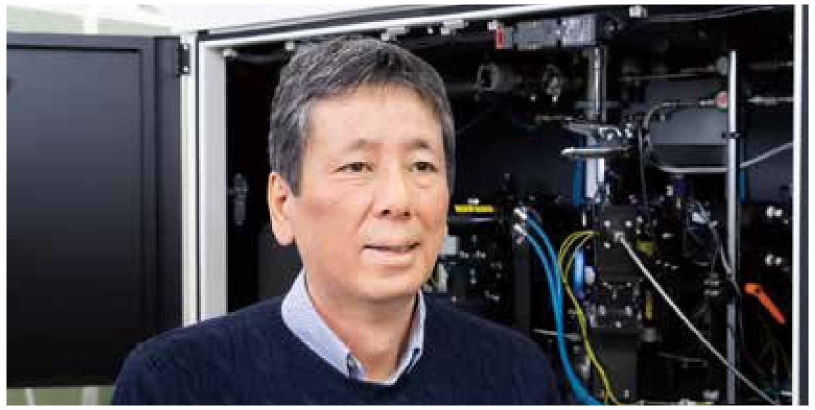
Publications

1. S. Kitou, K. Ueda, Y. Nakamura, K. Sugimoto, Y. Nomura, R. Arita, Y. Tokura, T. Arima, "Visualization of spin–orbit-entangled 4f electrons in crystalline materials", *PNAS* 122, e2500251122 (2025).
2. M. Gen, K. Noda, K. Shimbori, T. Tanaka, D. Bhoi, K. Seki, H. Kobayashi, K. Gautam, M. Akaki, Y. Ishii, Y. H. Matsuda , Y. Kubota, Y. Inubushi, M. Yabashi, Y. Kohama, T. Arima, A. Ikeda, "X-ray diffraction study of the magnetization plateau above 40 T in the frustrated helimagnet $CuGaCr_4S_8$", *Phys. Rev. B* 111, 214441 (2025).
3. M. Gen, T. Nakajima, H. Saito, Y. Tokunaga, T. Arima, "Spin-Lattice-Coupled Helical Magnetic Order in Breathing Pyrochlore Magnets, $CuAlCr_4S_8$ and $CuGaCr_4S_8$", *J. Phys. Soc. Jpn.* 93, 104602 (2024).
4. T. Kurumaji, M, Gen, S. Kitou, T. Arima, "Metamagnetism and anomalous magnetotransport properties in rare-earth-based polar semimetals RAuGe (R = Dy, Ho, and Gd)", *Phys. Rev. B* 110, 064409 (2024).
5. S. Kitou, A. Nakano, M. Imaizumi, Y. Nakamura, I. Terasaki, T. Arima, "Molecular orbital formation and metastable short-range ordered structure in VO_2", *Phys. Rev. B* 109, L100101 (2024).

Core members

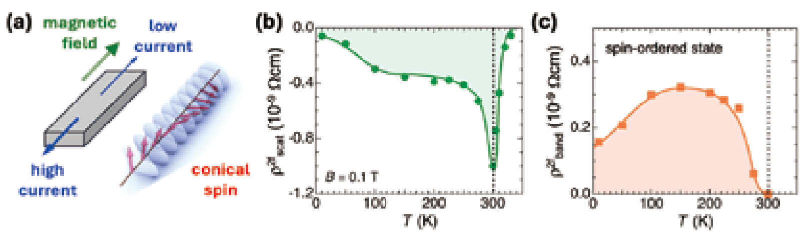
(Research Scientist) Yukiaki Ishida
(Postdoctoral Researcher) Heejun Yang

Strong Correlation Materials Research Group



Nonreciprocal charge transport in a room-temperature chiral magnet

Nonlinear electrical responses are attracting much interest in solid-state physics because of their useful functions such as rectification and amplification. Our group focuses on nonreciprocal charge transport and aims to clarify its relationship with chiral spin structures in magnetic materials. In the chiral magnet $Co_8Zn_9Mn_3$, a conical spin structure emerges, as shown in (a). The nonreciprocal charge transport is observed over a wide temperature range including room temperature. We further identify two distinct nonreciprocal components under different temperature and magnetic-field conditions. One originates from asymmetric spin scattering from thermally fluctuating vector spin chirality affected by the Dzyaloshinskii–Moriya interaction, showing prominent contribution near the transition temperature, as shown in (b). The other arises from an asymmetric electronic band structure formed through exchange coupling between the conical spin structure and conduction electrons, dominating the conically spin-ordered state, as shown in (c).



(a) Schematics of nonreciprocal resistivity and conical spin structure, temperature dependence of nonreciprocal resistivity arising from (b) spin scatterings from vector spin chirality, and (c)asymmetric band dispersions due to conical spin order.

Publications

1. D. Nakamura, M.-K. Lee, K. Karube, M. Mochizuki, N. Nagaosa, Y. Tokura, and Y. Taguchi, "Nonreciprocal transport in a room-temperature chiral magnet", *Science Advances*, 11, eadw8023 (2025).
2. D. Nakamura, K. Karube, Y. Liu, F. Kagawa, X.-Z. Yu, Y. Tokura and Y. Taguchi, "Observation of resonant spin excitation with in-plane spin-wave propagation in hybrid antiskyrmion strings", *Phys. Rev. B*, 110, 024418 (2024).
3. D. Nakamura, K. Karube, K. Matsuuara, F. Kagawa, X.Z. Yu, Y. Tokura, and Y. Taguchi, "Transport signatures of magnetic texture evolution in a microfabricated thin plate of antiskyrmion-hosting $(Fe,Ni,Pd)_3P$", *Phys. Rev. B*, 108, 104403 (2023).
4. K. Karube, L. C. Peng, J. Masell, X. Z. Yu, F. Kagawa, Y. Tokura, and Y. Taguchi, "Room-temperature antiskyrmions and sawtooth surface textures in a non-centrosymmetric magnet with S_4 symmetry", *Nature Materials* 20, 335 (2021).
5. M. Kriener, M. Sakano, M. Kamitani, M. S. Bahramy, R. Yukawa, K. Horiba, H. Kumigashira, K. Ishizaka, Y. Tokura, and Y. Taguchi, "Evolution of Electronic States and Emergence of Superconductivity in the Polar Semiconductor GeTe by Doping Valence-Skipping Indium", *Phys. Rev. Lett.*, 124, 047002 (2020).

Yasujiro Taguchi (D.Eng.), Group Director
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Research field

Physics, Engineering, Materials Science

Keywords

Strongly correlated electron system, Skyrmion, Multiferroics, Thermoelectric effect, Superconductivity

Brief resume

1993 Researcher, SONY Corporation
1997 Research Associate, University of Tokyo
2002 D.Eng., University of Tokyo
2002 Associate Professor, Institute for Materials Research, Tohoku University
2007 Team Leader, Exploratory Materials Team, RIKEN
2010 Team Leader, Strong-Correlation Materials Research Team, RIKEN
2013 Team Leader, Strong Correlation Materials Research Team, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science
2018 Group Director, Strong Correlation Materials Research Group, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science (-present)
2018 Director, Office of the Center Director, RIKEN Center for Emergent Matter Science
2024 Deputy Director, RIKEN Center for Emergent Matter Science (-present)

Outline

Our group aims at obtaining gigantic cross-correlation responses, understanding their mechanisms, and developing new functions in strongly-correlated-electron bulk materials, such as transition-metal oxides. To this end, we try to synthesize a wide range of materials using various methods, including high-pressure techniques, and investigate their physical properties. Specific targets are: (1) exploration of new skyrmion materials; (2) obtaining gigantic magnetoelectric responses in multiferroic materials at high temperatures; (3) exploration of new magnetic materials; (4) exploration of new thermoelectric materials; (5)exploration of new superconductors.

Core members

(Senior Research Scientist)
Markus Kriener, Daisuke Nakamura
(Senior Technical Scientist) Akiko Kikkawa
(Postdoctral Researcher) Zhehong Liu
(Technical Staff I) Gurvan Bosser

Quantum Matter Theory Research Group

Classifying topological insulators and topological superconductors

Modern electronics is based on the band theory that describes quantum mechanical motion of electrons in a solid. The band theory can explain properties of metals, insulators and semiconductors, and led to the invention of transistors. However, recent studies revealed some important physics which was missed in the standard band theory. Namely, electron wave functions can have a nontrivial topological structure in momentum space, and this leads to a topological insulator. In addition, superconductors with gapped quasiparticle excitations can be a topological superconductor. In principle there are various types of topological insulators (TIs) and topological superconductors (TSCs) in nature.

We constructed a general theory that can classify TIs and TSCs in terms of generic symmetries. This theory shows that in every spatial dimension there are three types of TIs/TSCs with an integer topological index and two types of TIs/TSCs with a binary topological index. We extend our theory to understand the effect of crystalline symmetry and electron correlation.

A coffee mug and a donut are equivalent in topology because they can be continuously deformed from one to the other. The wave functions of electrons in insulators can be topologically lassified.

Publications

1. M. Sato, S. Kobayashi, and A. Furusaki, "Three-dimensional spinless Euler insulators with rotational symmetry", *Phys. Rev. B* 112, 195108 (2025).
2. M. Naka, Y. Motome, and H. Seo, "Altermagnetic perovskites", *npj Spintronics* 3, 1 (2025).
3. T. Momoi, "Dynamics of quantum spin-nematics: Comparisons with canted antiferromagnets", *Phys. Rev. Research*, 6, 013169 (2024).
4. Y. Yao, M. Oshikawa, and A. Furusaki, "Gappability index for quantum many-body systems", *Phys. Rev. Lett.*, 129, 017204 (2022).
5. S. Kobayashi and A. Furusaki, "Fragile topological insulators protected by rotation symmetry without spin-orbit coupling", *Phys. Rev. B*, 104, 195114 (2021).

Akira Furusaki (Ph.D.), Group Director
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Research field

Physics, Materials Science

Keywords

Electron correlation, Frustrated quantum magnets, Topological insulators, Topological superconductivity

Brief resume

1991 Research Associate, Department of Applied Physics, University of Tokyo
1993 Ph.D., University of Tokyo
1993 Postdoctoral Associate, Massachusetts Institute of Technology, USA
1995 Research Associate, Department of Applied Physics, University of Tokyo
1996 Associate Professor, Yukawa Institute for Theoretical Physics, Kyoto University
2003 Chief Scientist, Condensed Matter Theory Laboratory, RIKEN
2013 Team Leader, Quantum Matter Theory Research Team, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science
2024 Group Director, Quantum Matter Theory Research Group, RIKEN Center for Emergent Matter Science (-present)
2024 Deputy Director,RIKEN Center for Emergent Matter Science (-present)

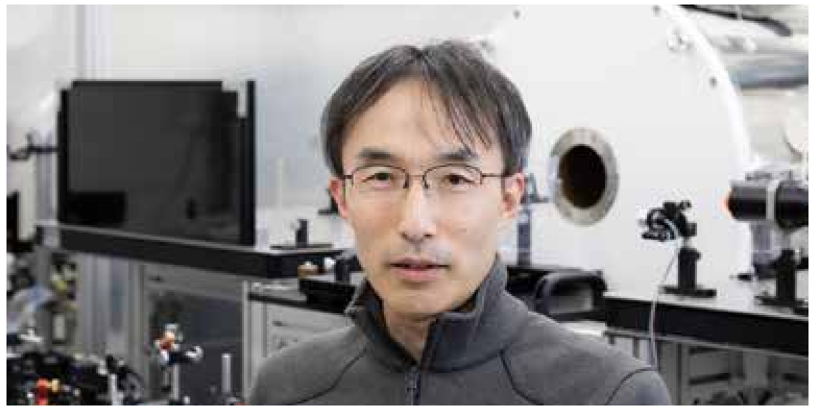
Outline

We investigate novel quantum phases of many-electron systems in solids which emerge as a result of strong electron correlation and quantum effects. We theoretically study electronic properties of these new phases (such as transport and magnetism) and critical phenomena at phase transitions. Specifically, we study topological insulators and superconductors, frustrated quantum magnets, and other strongly correlated electron systems in transition metal oxides and molecular conductors, etc. We construct effective models for electrons in these materials and unveil their various emergent phases by solving quantum statistical mechanics of these models using both analytical and numerical methods.

Core members

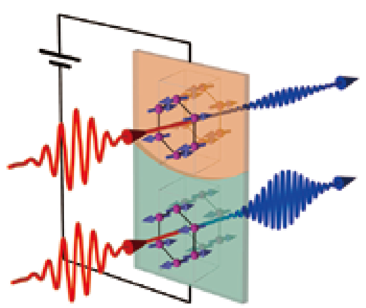
(Senior Research Scientist)
Tsutomu Momoi, Shigeki Onoda, Hitoshi Seo
(Special Postdoctoral Researcher)
Yutaro Tanaka, Moritz Hirschmann
(Postdoctoral Researcher) Shuhei Ohyama
(Junior Research Associate)
Lingzhi Zhang, Takumi Fukushima

Emergent Photodynamics Research Group



Electric-filed control of domain contrast and nonreciprocity in a van-der-Waals antiferromagnet

Effective control of nonreciprocal optical responses is crucial in all-optical devices. Until recently, such control largely relies on external magnetic fields, requiring bulky device structures with slow response time. We demonstrate a general strategy for modifying nonreciprocal optical second-harmonic generation (SHG) by using electric fields, offering a compact structure, fast response, and a substantial tuning range of ±90% in van der Waals antiferromagnet $MnPS_3$ as proof-of-concept. In our experiment, microscopic SHG imaging was performed on sample flakes with an electric field applied in specific crystallographic direction, at varying excitation photon energy, polarization and sample temperature. Antiferromagnetic (time-reversal) domains in $MnPS_3$ were found to exhibit distinct contrast originating from nonreciprocity, which changes with the applied electric field. By further analyses on the polarimetry, we revealed that this effect originates from the interference between electric-dipole, magnetic-dipole, and electric-field-induced SHG sources, consistent with our theoretical design based on symmetry.



Schematic illustration of time-reversal domains in an antiferromagnet and corresponding nonreciprocal SHG.

Publications

1. Z. Wang, M. Wang, J. Lehmann, Y. Shiomi, T. Arima, N. Nagaosa, Y. Tokura, N. Ogawa, "Electric-field-enhanced second-harmonic domain contrast and nonreciprocity in a van der Waals antiferromagnet", *Nature Commun.* 15, 7542 (2024).
2. Z. Wang, X.-X. Zhang, Y. Shiomi, T. Arima, N. Nagaosa, Y. Tokura, and N. Ogawa, "Exciton-magnon splitting in van der Waals antiferromagnet $MnPS_3$ unveiled by second-harmonic generation", *Phys. Rev. Res.* 5, L042032 (2023).
3. S. Toyoda, M. Fiebig, L. Forster, T. Arima, Y. Tokura, and N. Ogawa, "Writing of strain-controlled multiferroic ribbons into $MnWO_4$", *Nature Commun.* 12, 6199 (2021).
4. S. Toyoda, M. Fiebig, T. Arima, Y. Tokura, and N. Ogawa, "Nonreciprocal second harmonic generation in a magnetoelectric material", *Sci. Adv.* 7, eabe2793 (2021).
5. M. Sotome, M. Nakamura, J. Fujioka, M. Ogino, Y. Kaneko, T. Morimoto, Y. Zhang, M. Kawasaki, N. Nagaosa, Y. Tokura, and N. Ogawa, "Spectral dynamics of shift-current in ferroelectric semiconductor SbSI", *Proc. Natl. Acad. Sci.,* 116, 1929 (2019).

Naoki Ogawa (D.Eng.), Group Director
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Research field

Physics, Materials Science, Engineering

Keywords

Strongly correlated electron systems, Quantum materials, Ultrafast/broadband optical spectroscopy, Photocurrent spectroscopy, Opto-spintronics

Brief resume

2004 D. Eng., University of Tokyo
2004 Postdoctoral Associate, University of California at Irvine
2004 Research Fellow of the Japan Society for the Promotion of Science
2006 Project Assistant Professor, University of Tokyo
2008 Assistant Professor, University of Tokyo
2012 ASI Research Scientist, RIKEN
2013 Senior Research Scientist, RIKEN Center for Emergent Matter Science
2015 Unit Leader, Emergent Photodynamics Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science
2017 JST PRESTO Researcher
2018 Team Leader, Emergent Photodynamics Research Team, RIKEN Center for Emergent Matter Science
2020 Guest Professor, University of Tokyo
2024 Director, Office of the Center Director, RIKEN Center for Emergent Matter Science
2024 Group Director, Emergent Photodynamics Research Group, RIKEN Center for Emergent Matter Science (-present)

Outline

Our group explores novel photodynamics of electron/spin/lattice in bulk crystals and at thin-film interfaces emerging via electron-correlation, strong spin-orbit interaction, and topology. Examples are ultrafast spectroscopy on quantum-mechanical photocurrent, manipulation of Dirac/Weyl electrons and topological spin textures, and search for nonreciprocal optical phenomena. With a strong command of photons, we try to realize new photo-electric/magnetic effects in solids and visualize spatiotemporal propagation of various elemental excitations at sub-diffraction limit.

Core members

(Research Scientist) Shingo Toyoda
(Postdoctoral Researcher) Joanna Lucie Paulette Wolff

Strong Correlation Quantum Transport Research Team

Quantum transport phenomena of surface Dirac states in thin film superstructures

The topological insulator is a new state of matter, whose bulk is a three-dimensional charge-gapped insulator but whose surface hosts a two-dimensional Dirac electron state. Surface Dirac states are characterized by massless electrons and holes whose spins are polarized perpendicular to their crystal momentum. As a result, the quantum transport phenomena stemming from their charge and spin degrees of freedom are promising for the applications to low-power consumption electronic devices. The well-known example for this is the quantum anomalous Hall effect (QAHE) in which one-dimensional conducting channel without any dissipation emerges at zero magnetic field. We established the growth of high quality thin film superstructure of topological insulator $(Bi_xSb_{1-x})_2Te_3$ sandwiched by ferromagnetic insulator (Zn,Cr)Te, by means of molecular beam epitaxy (MBE) method. We cooled down to cryogenic temperature, and successfully observed QAHE. We will make full use of the thin film superstructure to add functionality to topological materials. In particular, we now embark on the observation or control of the Majorana quasiparticle, which is expected to be applied to quantum computers.

Schematic of the quantum Hall effect on the surface of a topological insulator

Publications

1. S. Nagahama, Y. Sato, M. Kawamura, I. Belopolski, R. Yoshimi, A. Tsukazaki, N. Kanazawa, K. S. Takahashi, M. Kawasaki, and Y. Tokura, "Two-Dimensional Superconducting Diode Effect in Topological Insulator/Superconductor Heterostructure", *Phys. Rev. Lett.,* 135, 246003 (2025).
2. R. Yoshimi, R. Kurihara, Y. Okamura, H. Handa, N. Ogawa, M. Kawamura, A. Tsukazaki, K. S. Takahashi, M. Kawasaki, Y. Takahashi, M. Tokunaga and Y. Tokura, "Emergence of Ferroelectric Topological Insulator as Verified by Quantum Hall Effect of Surface States in (Sn,Pb,In)Te Films", *Phys. Rev. Lett.,*134,176602 (2025).
3. I. Belopolski, R. Watanabe, Y. Sato, R. Yoshimi, M. Kawamura, S. Nagahama, Y. Zhao, S. Shao, Y. Jin, Y. Kato, Y. Okamura, X.-X. Zhang, Y. Fujishiro, Y. Takahashi, M. Hirschberger, A. Tsukazaki, K. S. Takahashi, C.-K. Chiu, G. Chang, M. Kawasaki, N. Nagaosa, and Y. Tokura, "Synthesis of a semimetallic Weyl ferromagnet with point Fermi surface", *Nature* 637, 1078 (2025).
4. M. T. Birch, I. Belopolski, Y. Fujishiro, M. Kawamura, A. Kikkawa, Y. Taguchi, M. Hirschberger, N. Nagaosa, and Y. Tokura, "Dynamic transition and Galilean relativity of current-driven skyrmions", *Nature* 633, 554 (2024).
5. M. Mogi, Y. Okamura, M. Kawamura, R. Yoshimi, K. Yasuda, A. Tsukazaki, K. S. Takahashi, T. Morimoto, N. Nagaosa, M. Kawasaki, Y. Takahashi, and Y. Tokura, "Experimental signature of the parity anomaly in a semi-magnetic topological insulator", *Nat. Phys.*,18, 390 (2022).

Yoshinori Tokura (D.Eng.), Team Director
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Research field

Physics, Engineering, Materials Science

Keywords

Strongly correlated electron system, High-temperature superconductor, Spin-orbit interaction, Topological insulators, Interface electronic structure

Brief resume

1981 D. Eng., University of Tokyo
1986 Associate Professor, University of Tokyo
1994 Professor, Department of Physics, University of Tokyo
1995 Professor, Department of Applied Physics, University of Tokyo
2001 Director, Correlated Electron Research Center, AIST
2007 Group Director, Cross-Correlated Materials Research Group, RIKEN
2008 AIST Fellow, National Institute of Advanced Industrial Science and Technology (-present)
2010 Director, Emergent Materials Department, RIKEN
2010 Group Director, Correlated Electron Research Group, RIKEN
2013 Director, RIKEN Center for Emergent Matter Science (CEMS)
2013 Group Director, Strong Correlation Physics Research Group, Strong Correlation Physics Division, RIKEN CEMS (-present)
2014 Team Leader, Strong Correlation Quantum Transport Research Team, RIKEN CEMS (-present)Position name has been changed to Team Director as of April 1,2025
2017 Distinguished University Professor, University of Tokyo (-present)
2019 Special University Professor, University of Tokyo
2024 Special Advisor to the President, RIKEN
2025 Executive Director of Science, RIKEN (-present)

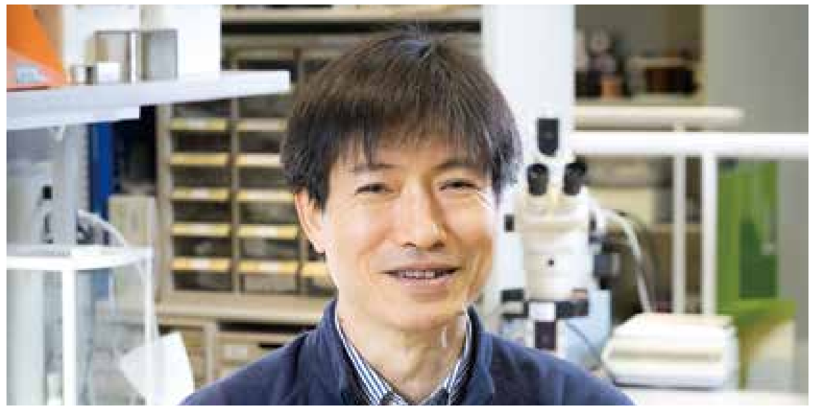
Outline

We study various kinds of quantum transport phenomena which emerge in bulk materials and at hetero-interfaces of thin films, focusing on electron systems with strong correlation and/or strong spin-orbit interactions. Specifically, we try to clarify quantum states of Dirac electrons at surface/interfaces of topological insulators as well as in bulk Rashba system with broken inversion symmetry, by observing Landau level formation, quantum (anomalous) Hall effect, and various quantum oscillation phenomena at low temperatures and in high magnetic fields. Also, we synthesize high-temperature superconducting cuprates in bulk forms and various transition-metal oxides thin films, and measure transport properties under high pressure or high magnetic-field, aiming at increasing superconducting transition temperature and at finding novel magneto-transport properties.

Core members

(Postdoctoral Researcher) Lixuan Tai, Toshiya Ikenobe

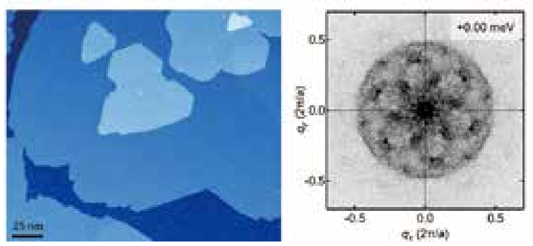
Emergent Phenomena Measurement Research Team



Twist-controlled superconducting gap in an atomically thin superconductor

In recent years, advances in nano-fabrication techniques have enabled the synthesis of two-dimensional monolayer atomic sheets, the basic building blocks of layered compounds. These atomic sheets can exhibit properties distinct from those of their bulk counterparts and allow the emergence and control of novel properties through stacking different atomic layers and controlling the twist angle between them. Among these, the artificial tuning of superconductivity is particularly compelling from both fundamental and applied perspectives. However, experimental investigations have been challenging because the superconducting transition temperatures of atomic-sheet superconductors are typically as low as 1 K.

Using spectroscopic imaging with an ultralow-temperature scanning tunneling microscope operating below 0.1 K, we directly observed the superconducting gap of a monolayer of $NbSe_2$ fabricated on graphene. Analysis of quasiparticle interference patterns revealed that the twist-angle-dependent overlap between the Fermi surfaces of graphene and $NbSe_2$ modifies the superconducting gap. These results demonstrate a new approach to controlling superconductivity in momentum space.



Scanning tunneling microscope image of atomically thin $NbSe_2$ on graphene (left) and the Fourier-transformed quasiparticle interference pattern revealing the momentum-space structure of the superconducting gap (right).

Publications

1. C. J. Butler, M. Naritsuka, and T. Hanaguri, "Topical review: the nature of the ground state and possibility of a quantum spin liquid in 1T metal dichalcogenides", *J. Phys.: Condens. Matter* 37 403002 (2025).
2. H. Nishimichi, T. Machida, S. Ichinokura, S. Kaku , K. Ishihara, K. Tanaka, T. Hanaguri, and T. Hirahara, "Momentum-resolved spectroscopic evidence of a metal-insulator transition in Si(111)√3 ×√3-Sn", *Phys. Rev. B* 111, 235134 (2025).
3. M. Naritsuka, T. Machida, S. Asano, Y. Yanase, and T. Hanaguri, "Superconductivity controlled by twist angle in monolayer $NbSe_2$ on graphene", *Nature Phys.* 21, 746 (2025).
4. C. J. Butler, M. Murase, S.Sawada, M-C Jiang, D. Hashizume, G-Y Guo, R. Arita, T. Hanaguri, and T. Sasagawa, "Valley Polarization of Landau Levels in the ZrSiS Surface Band Driven by Residual Strain", *Phys. Rev. X* 15, 011033 (2025).
5. T. Machida, and T. Hanaguri, "Searching for Majorana quasiparticles at vortex cores in iron-based superconductors", *Prog. Theor. Exp.Phys.* 2024, 08C103, (2024).

Tetsuo Hanaguri (D.Eng.), Team Director
hanaguri@riken.jp

Research field

Physics, Engineering, Materials Sciences

Keywords

Scanning tunneling microscopy, Superconductivity, Topological insulators

Brief resume

1993 D.Eng., Tohoku University
1993 Research Associate, Department of Basic Science, The University of Tokyo
1999 Associate Professor, Department of Advanced Materials Science, The University of Tokyo
2004 Senior Research Scientist, Magnetic Materials Laboratory, RIKEN
2013 Team Leader, Emergent Phenomena Measurement Research Team, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science (-present)
Position name has been changed to Team Director as of April 1, 2025

Outline

We experimentally study electronic states related to emergent phenomena in electron systems, such as high-temperature superconductivity and topological quantum phenomena. For this purpose, we use scanning tunneling microscopes working under combined extreme conditions of very low temperatures, high magnetic fields and ultra-high vacuum. Modern scanning-tunneling-microscopy technology enables us to obtain a "map of the electronic state" with atomic-scale spatial resolution. We make and analyze the maps of various materials and establish the relationships between material properties and electronic states. We also pursue the development of novel measurement techniques to discover new emergent phenomena in condensed matter.

Core members

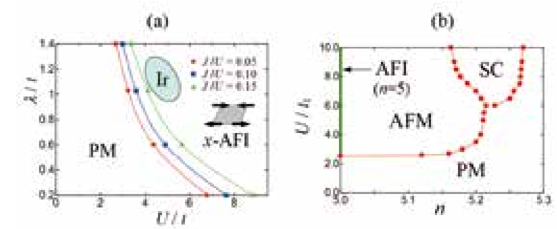
(Senior Research Scientist)
Tadashi Machida, Christopher John Butler
(Research Scientist) Masahiro Naritsuka
(Special Postdoctoral Researcher) Katsuki Nihongi

Computational Quantum Matter Research Team

Mechanism of novel insulating state and possible superconductivity induced by a spin-orbit coupling

Electrons in solids are moving around, affected by the Coulomb interaction, electron-lattice interaction, and spin-orbit interaction, which induces different behaviors characteristic of each material. Recently, the study for the spin-orbit coupling has greatly progressed and attracted much attention. In the 5d transition metal oxide Sr_2IrO_4, the spin and orbital degrees of freedom are strongly entangled due to the large spin-orbit coupling and the novel quantum state is formed. Sr_2IrO_4 is also expected to be a possible superconducting material with a great deal of similarities to the parent compound of cuprate high-temperature superconductivity.

We have studied the detailed electronic properties of a 3-orbital Hubbard model for Sr_2IrO_4 with several computational methods. Our calculations have clearly shown that the ground state of this material is an effective total angular momentum J_{eff}=1/2 antiferromagnetic insulator, where J_{eff} is "pseudospin",formed by spin and orbital degrees of freedom due to the strong spin-orbit coupling (x-AFI in Fig. (a)). We have also proposed that the $d_{x^2-y^2}$-wave "pseudospin singlet" superconductivity (SC in Fig. (b)) is induced by electron doping into the J_{eff}=1/2 antiferromagnetic insulator Sr_2IrO_4.



Ground state phase diagram of 3-orbital Hubbard model with a spin-orbit coupling. (a) Electron density n=5, (b) n>5.

Publications

1. K. Shinjo, S. Sota, S. yunoki, and T. Tohyama, "Controlling inversion and time-reversal symmetries by subcycle pules in the one-dimensional extended Hubbard model", *Phys. Rev. B* 107, 195103 (2023).
2. H. Watanabe, T. Shirakawa, K. Seki, H. Sakakibara, T. Kotani, H. Ikeda, and S. Yunoki, "Monte Carlo study of cuprate superconductors in a four-band d-p model: role of orbital degrees of freedom", *J. Phys.: Condens. Matter* 35, 195601 (2023).
3. F. Lange, S. Ejima, J. Fujimoto, T. Shirakawa, H. Fehske, S. Yunoki, and S. Maekawa, "Generation of current vortex by spin current in Rashba systems", *Phys. Rev. Lett.* 126, 157202 (2021).
4. H. Watanabe, T. Shirakawa, K. Seki, H. Sakakibara, T. Kotani, H. Ikeda, and S. Yunoki, "Unified description of cuprate superconductors suing a four-band d-p model", *Phys. Rev. Research* 3, 033157 (2021).
5. T. Kaneko, T. Shirakawa, S. Sorella, and S. Yunoki, "Photoinduced eta pairing in the Hubbard model", *Phys. Rev. Lett.* 122, 077002 (2019).

Seiji Yunoki (D.Eng.), Team Director
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Research field

Physics, Materials Science

Keywords

Strongly correlated electron system, Magnetism, Superconductivity, Computational condensed matter physics

Brief resume

1996 D.Eng., Nagoya University
1996 Postdoctoral Researcher, National High Magnetic Field Laboratory, USA
1999 Postdoctoral Researcher, Materials Science Center, Groningen University, Netherlands
2001 Postdoctoral Researcher, International School for Advanced Studies, Italy
2006 Long-Term Researcher and Research Assistant Professor, Oak Ridge National Laboratory and University of Tennessee, USA
2008 Associate Chief Scientist, Computational Condensed Matter Physics Laboratory, RIKEN
2010 Team Leader, Computational Materials Science Research Team, RIKEN Advance Institute for Computational Science
2013 Team Leader, Computational Quantum Matter Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
2017 Chief Scientist, Computational Condensed Matter Physics Laboratory, RIKEN (-present)
2018 Team Leader, Computational Materials Science Research Team, RIKEN Center for Computational Science (-present) Position name has been changed to Team Director as of April 1, 2025
2021 Team Leader, Quantum Computational Science Research Team, RIKEN Center for Quantum Computing (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

Electrons in solids are in motion within the energy band reflecting the lattice structure of each material. The Coulomb interaction, electron-lattice interaction, and spin-orbit interaction have nontrivial effects on the motion of electrons and induce various interesting phenomena. Our aim is to elucidate the emergent quantum phenomena induced by cooperation or competition of these interactions, using state-of-the-art computational methods for condensed matter physics. Our current focus is on various functional transition metal oxides, topological materials, and heterostructures made of these materials. Our research will lead not only to clarify the mechanism of quantum phenomena in existent materials but also to propose novel materials.

Core members

(Reseach Scientist) Kazuya Shinjo
(Postdoctoral Researcher) Yixuan Huang

First-Principles Materials Science Research Team

Ryotaro Arita (D.Sci.), Team Director
arita@riken.jp

Research field

Physics, Materials Science

Keywords

First-principles calculations, Theoretical materials design, Strongly correlated electron systems

Brief resume

2000 D.Sci., University of Tokyo
2000 Research Associate, Department of Physics, University of Tokyo
2004 Postdoctoral Researcher, Max Planck Institute for Solid State Research
2006 Research Scientist/Senior Research Scientist, Condensed Matter Theory Laboratory, RIKEN
2008 Associate Professor, Department of Applied Physics, University of Tokyo
2011 PRESTO, Japan Science and Technology Agency
2014 Team Leader, First-Principles Materials Science Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
2018 Professor, Department of Applied Physics, University of Tokyo
2022 Professor, Research Center for Advanced Science and Technology, University of Tokyo
2024 Professor, Department of Physics, University of Tokyo (-present)

Outline

By means of first-principles methods, our team studies non-trivial electronic properties of materials which lead to new ideas/notions in condensed matter physics or those which have potential possibilities as unique functional materials. Especially, we are currently interested in strongly correlated/topological materials such as high T_c cuprates, iron-based superconductors, organic superconductors, carbon-based superconductors, 5d transition metal compounds, heavy fermions, giant Rashba systems, topological insulators, zeolites, and so on. We aim at predicting unexpected phenomena originating from many-body correlations and establishing new guiding principles for materials design. We are also interested in the development of new methods for *ab initio* electronic structure calculation.

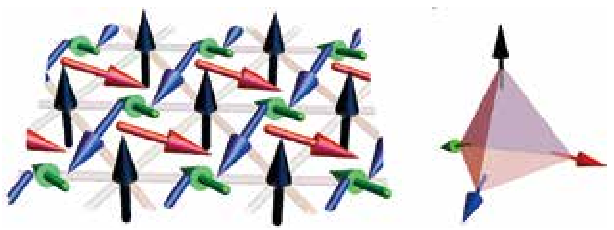
Core members

(Research Scientist)
Jean B.P.G. Moree, Kosuke Nakano
(Special Postdoctoral Researcher) Ming-Chun Jiang
(Postdoctoral Researcher) Abhishek Raghav

Classification of emergent responses of magnetic materials based on spin crystallographic groups

The spin, an intrinsic degree of freedom of electrons, brings about diverse physical properties through its ordering (magnetism). In particular, when there is the spin-orbit interaction (SOI), which links the spin and orbital degrees of freedom, magnetism is associated with the physical properties of materials, such as electrical conductivity and elasticity. This is evident in phenomena like the anomalous Hall effect and magnetostriction. However, the impact of SOI is limited in elements such as Fe and Mn due to its relativistic nature, which constrains material exploration. On the other hand, thanks to their non-trivial magnetic structures, some antiferromagnets show emergent electromagnetic responses independent of SOI.

When exploring the properties of such antiferromagnetic materials, analyzing the symmetry of magnetic structures plays a crucial role. Magnetic space groups are commonly used for this purpose, but they implicitly assume the presence of spin-orbit interaction, making them unsuitable for the symmetry analysis of emergent electromagnetic phenomena. We have focused on spin space groups that do not consider the constraints of spin-orbit interaction. We developed a method to conveniently identify magnetism-driven properties. This method serves as a guideline for understanding and predicting emergent properties.



Example of a non-coplanar spin structure with nontrivial spin space group symmetry.

Publications

1. K. Hattori, H. Watanabe, R. Arita, “Dirac Charge in Antiferromagnetic Topological Semimetals”, *Phys. Rev. Lett.* 136, 046603 (2026)
2. T. Hatanaka, J. Bouaziz, T. Nomoto and R. Arita, “Calculation of the Biquadratic Spin Interactions Based on the Spin Cluster Expansion for *Ab initio* Tight-binding Models”, *J. Phys. Soc. Jpn.*, 94 124709 (2025) (Editors' choice)
3. J. Matsuda, H. Watanabe, R. Arita, “Multiferroic Collinear Antiferromagnets with Hidden Altermagnetic Spin Splitting”, *Phys. Rev. Lett.* 134, 226703 (2025)
4. H.-Y. Chen, T. Nomoto, M. Hirschberger, R. Arita, “Topological Hall Effect of Skyrmions from first Principles”, *Phys. Rev. X* 15, 011054(2025).
5. H. Watanabe, K. Shinohara, T. Nomoto, A. Togo, and R. Arita, “Symmetry analysis with spin crystallographic groups: Disentangling effects free of spin-orbit coupling in emergent electromagnetism”, *Phys. Rev. B* 109 094438 (2024) (Editors' suggestion)

Electronic State Spectroscopy Research Team

Kyoko Ishizaka (Ph.D.), Team Director
kyoko.ishizaka@riken.jp

Research field

Physics, Materials Science

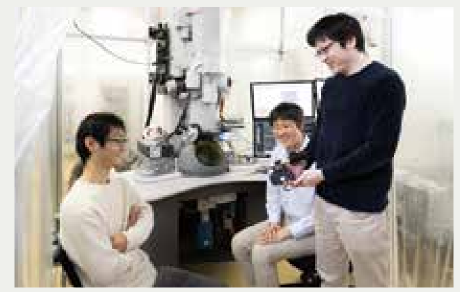
Keywords

Ultrafast time-resolved TEM, Photoelectron Spectroscopy, Strongly Correlated Electron System, Superconductivity, Topological Materials

Brief resume

2004 Ph.D., Engineering, University of Tokyo
2004 Research Associate, Institute for Solid State Physics, University of Tokyo
2010 Associate Professor, Department of Applied Physics, School of Engineering, University of Tokyo
2014 Associate Professor, Quantum-Phase Electronics Center, School of Engineering, University of Tokyo
2016 Team Leader, Electronic States Spectroscopy Research Team, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
2018 Professor, Quantum-Phase Electronics Center, School of Engineering, University of Tokyo (-present)

Outline



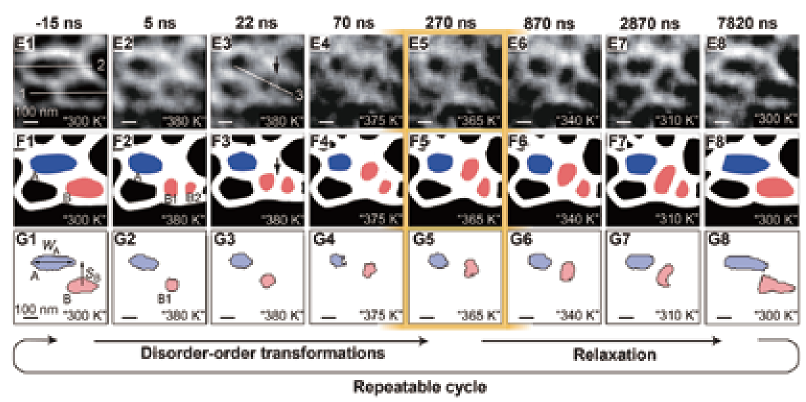
We investigate the electronic states of materials showing a variety of physical properties, functions, and quantum phenomena. By utilizing spin- and angle-resolved photoemission spectroscopy, which can probe the energy, momentum, and spin of electrons, we investigate new materials, topological quantum states, and many-body effects in strongly correlated systems. We are also developing the pulsed-laser based ultrafast transmission electron microscopy, aiming for probing the dynamical states of nanoscale spin/lattice/charge textures, materials, and devices.

Core members

(Research Scientist) Asuka Nakamura
(Technical Staff I) Hidenori Tsuji
(Junior Research Associate) Dongxue Han

Nano-to-micro spatiotemporal imaging of magnetic skyrmions

Magnetic skyrmions are self-organized topological spin textures that behave like particles. Because of their fast creation and typically long lifetime, experimental verification of skyrmion's creation/annihilation processes has been challenging. Our team successfully tracked skyrmion dynamics in a room-temperature chiral magnet by using pump-probe Lorentz transmission electron microscope. Following the nanosecond photothermal excitation, we resolved 160-nm skyrmion's proliferation at <1 ns, contraction at 5 ns, drift from 10 ns to 4 µs, and coalescence at ~5 µs. These motions relay the multiscale arrangement and relaxation of skyrmion clusters in a repeatable cycle. Such repeatable dynamics of skyrmions, arising from the weakened but still persistent topological protection around defects, enables us to visualize the whole life of the skyrmions and demonstrates the possible high-frequency manipulations of topological charges brought by skyrmions.

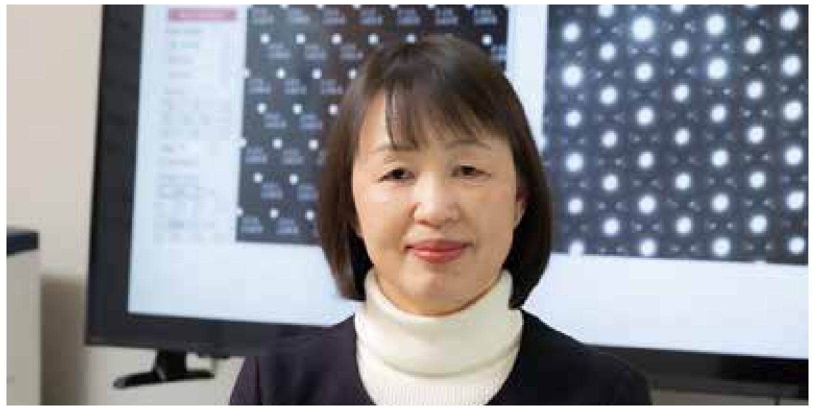


Spatiotemporal imaging of magnetic skyrmions recorded by ultrafast Lorentz electron microscope.
Copyright: https://www.science.org/doi/10.1126/sciadv.abg1322

Publications

1. A. Nakamura, T. Shimojima, K. Ishizaka, “Characterizing an Optically Induced Sub-micrometer Gigahertz Acoustic Wave in a Silicon Thin Plate”, *Nano Lett.* 23, 2490–2495 (2023).
2. T. Shimojima, A. Nakamura, X. Z. Yu, K. Karube, Y. Taguchi, Y. Tokura, K. Ishizaka,“Nano-to-micro spatiotemporal imaging of magnetic skyrmion's life cycle”, *Sci. Adv.* 7, eabg1322/1-8 (2021).
3. A. Nakamura, T. Shimojima, Y. Chiashi, M. Kamitani, H. Sakai, S. Ishiwata, H. Li, and K. Ishizaka, “Nanoscale Imaging of Unusual Photoacoustic Waves in Thin Flake VTe_2”, *Nano Lett.* 20, 7, 4932 (2020).
4. N. Mitsuishi, T. Shimojima, K. Ishizaka et al., “Switching of band inversion and topological surface states by charge density wave”, *Nature Commun.* 11, 2466 (2020).
5. T. Shimojima, Y. Suzuki, A. Nakamura, N. Mitsuishi, S. Kasahara, T. Shibauchi, Y. Matsuda, Y. Ishida, S. Shin and K. Ishizaka, “Ultrafast nematic-orbital excitation in FeSe”, *Nature Commun.* 10, 1946 (2019).

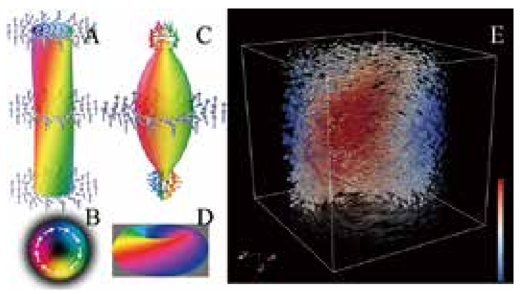
Electronic States Microscopy Research Team



Vector-field mapping of three-dimensional topological spin textures

Three-dimensional topological spin textures, including twisted skyrmion strings, torons, and hopfions, host emergent electromagnetic fields and nonreciprocal dynamics that are fundamentally distinct from their two-dimensional counterparts. Their chirality-dependent transport and direction-sensitive responses make them promising for future spintronic and neuromorphic devices, yet direct experimental observation has remained difficult due to limited spatial and vector-field resolution of existing magnetic imaging methods, particularly under cryogenic conditions.

We develop a cryogenic scalar- and vector-field electron tomography technique that enables real-space imaging of three-dimensional spin textures with nanometer-scale resolution at low temperatures. Using this approach, we visualize twisted skyrmion strings, cryogenically stabilized magnetic hopfions, and a toron lattice embedded in relatively thick chiral-lattice magnets, achieving the first three-dimensional reconstructions of these textures in real materials.



A, Schematic illustration of a twisted skyrmion string and its in-plane projection (B). Arrows and colors indicate the spin directions. C–D, Schematic illustrations of (C) a toron and (D) a hopfion. E, Experimental observation of the three-dimensional vector-field map of a toron. The color bar indicates upward-pointing (red) and downward-pointing (blue) vector fields.

Publications

1. Xiuzhen Yu, Nobuto Nakanishi, Yi-Ling Chiew, Yizhou Liu, Kiyomi Nakajima, Naoya Kanazawa, Kosuke Karube, Yasujiro Taguchi, Naoto Nagaosa, Yoshinori Tokura, "3D skyrmion strings and their melting dynamics revealed via scalar-field electron tomography", *Commun Mater* 5, 80 (2024).
2. Y. Guang, X. C. Zhang, Y. Z. Liu, L. C. Peng, F. S. Yasin, K. Karube, D. Nakamura, N. Nagaosa, Y. Taguchi, M. Mochizuki, Y. Tokura, and X. Z. Yu, "Confined antiskyrmion motion driven by electric current excitations" *Nature Communications* 15, 7701. (2024).
3. Xiuzhen Yu, Naoya Kanazawa, Xichao Zhang, Yoshio Takahashi, Konstantin V. Iakoubovskii, Kiyomi Nakajima, Toshiaki Tanigaki, Masahito Mochizuki, Yoshinori Tokura, "Spontaneous vortex-antivortex pairs and their topological transitions in a chiral-lattice magnet", *Advanced Materials* 2306441 (2023).
4. X. Z. Yu, F. Kagawa, S. Seki, M. Kubota, J. Masell, F. S. Yasin, K. Nakajima, M. Nakamura, M. Kawasaki, N. Nagaosa and Y. Tokura, "Real-space observations of 60-nm skyrmion dynamics in an insulating magnet under low heat flow", *Nature Communications* 12, 5079 (2021).
5. N. D. Khanh, T. Nakajima, X. Z. Yu, S. Gao, K. Shibata, M. Hirschberger, Y. Yamasaki, H. Sagayama, H. Nakao, L. Peng, K. Nakajima, R. Takagi, T. Arima, Y. Tokura, S. Seki, "Nanometric square skyrmion lattice in a centrosymmetric tetragonal magnet", *Nature Nanotechnology* 15, 444 (2020).

Xiuzhen Yu (D.Sci.), Team Director
yu_x@riken.jp

Research field

Physics, Engineering, Materials Science

Keywords

Electronic states, Lorentz microscopy, Analytical electron microscopy, High-resolution electron microscopy, Differential phase-contrast microscopy, 3D magnetic imaging

Brief resume

- 1990 Master, Department of Semiconductor, Jilin University
- 2002 Technician, Tokura Spin Superstructure Project, ERATO, Japan Science and Technology Agency
- 2006 Engineer, Advanced Electron Microscopy Group, Advanced Nano Characterization Center, NIMS
- 2008 Doctor of Science, Department of Physics, Tohoku University
- 2008 Researcher, Advanced Electron Microscopy Group, Advanced Nano Characterization Center, NIMS
- 2010 Researcher, Tokura Multiferroic Project, ERATO, Japan Science and Technology Agency
- 2011 Postdoctoral Researcher, Quantum Science on Strong Correlation Group, Advanced Science Institute, RIKEN
- 2013 Senior Research Scientist, Strong Correlation Physics Research Group, Strong Correlation Physics Division, RIKEN Center for Emergent Matter Science (CEMS)
- 2017 Team Leader, Electronic States Microscopy Research Team, RIKEN CEMS (-present) Position name has been changed to Team Director as of April 1, 2025
- 2024 Specially Appointed Professor, Institute of Science Tokyo, School of Science (-present)

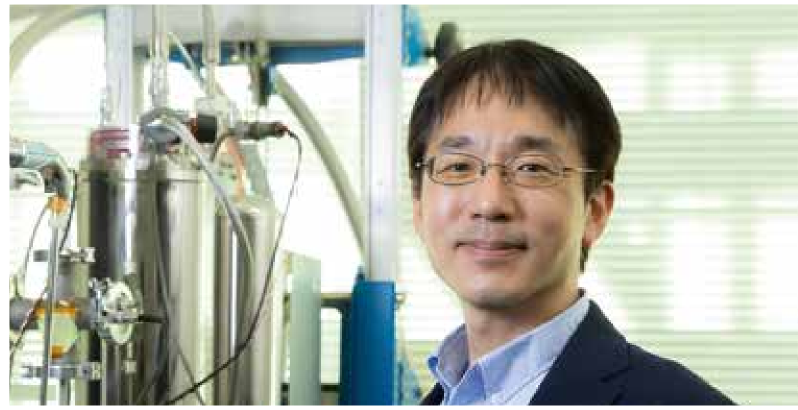
Outline

Our team utilizes atomic-scale transmission electron microscopes to elucidate electronic states, including electron charges, spins, and their dynamics in materials through in-situ observations. By leveraging advanced electron microscopy techniques, such as fast electron microscopy and quantitative measurements of nanoscale magnetic and electric fields, we investigate materials such as high-temperature superconductors, transition metal chalcogenides, topological magnetic materials, and heterostructured thin films. These studies aim to uncover insights into electronic states, elemental distributions, interface structures, and phase transitions. This research on nanoscale electronic states through microscopy advances the understanding of emergent phenomena in various materials.

Core members

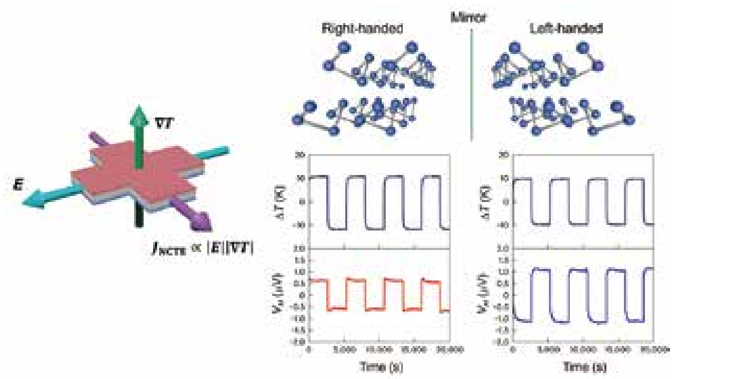
(Postdoctoral Researcher) Yao Guang, Zhuolin Li
(Technical Staff II) Kiyomi Nakajima
(Technical Staff I) Keiko Shimada

Dynamic Emergent Phenomena Research Team



Discovery of a new Hall effect driven by an electric field and a temperature gradient

Chiral materials are promising platforms for quantum-geometry-driven transport, where nonlinear thermoelectric effects beyond simple proportional responses are predicted but have lacked experimental verification. Here, we demonstrate the nonlinear chiral thermoelectric Hall effect, in which a transverse voltage arises from the coexistence of an electric field and a temperature gradient. Using single crystals of the helical semiconductor tellurium, we show that a Hall voltage appears even without a magnetic field, reverses sign with crystal chirality, and agrees with first-principles calculations, establishing experimental evidence of nonlinear thermoelectric effects in chiral materials and suggesting potential applications in heat-flow control and waste-heat energy harvesting.



Schematic illustration of the nonlinear thermoelectric Hall effect driven by an electric field and a temperature gradient (left), and Hall voltages generated in right-handed and left-handed tellurium crystals as a function of the temperature gradient (right). The relationship between the sign of the temperature gradient and that of the Hall voltage is reversed between the two chiralities.

Publications

1. T. Nomoto, A. Kikkawa, K. Nakazawa, T. Yamaguchi, and F. Kagawa, "Observation of the nonlinear chiral thermoelectric Hall effect in tellurium", *Nat. Phys.* 21, 1920 (2025).
2. M. Wang, J. Zhang, D. Tian, P. Yu and F. Kagawa, "Unveiling an in-plane Hall effect in rutile RuO_2 films", *Commun. Phys.* 8, 28 (2025).
3. S. Furuta, W. Koshibae, K. Matsuura, N. Abe, F. Wang, S. Zhou, T. Arima, and F. Kagawa, " Reconsidering nonlinear emergent inductance: Time-varying Joule heating and its impact on AC electrical response", *Phys. Rev. B* 110, 174402 (2024).
4. M. Wang, K. Tanaka, S. Sakai, Z. Wang, K. Deng, Y. Lyu, C. Li, D. Tian, S. Sheng, N. Ogawa, N. Kanazawa, P. Yu, R. Arita, and F. Kagawa, "Emergent zero-field anomalous Hall effect in a reconstructed rutile antiferromagnetic metal", *Nat. Commun.* 14, 8240 (2023).
5. K. Matsuura, Y. Nishizawa, Y. Kinoshita, T. Kurumaji, A. Miyaka, H. Oike, M. Tokunaga, Y. Tokura, and F. Kagawa, "Low-temperature hysteresis broadening emerging from domain-wall creep dynamics in a two-phase competing system", *Commun. Mat.* 4, 71 (2023).

Fumitaka Kagawa (D.Eng.), Team Director
fumitaka.kagawa@riken.jp

Research field

Materials Science, Physics

Keywords

Strongly correlated electron system, Phase control, Scanning probe microscopy, Spectroscopy

Brief resume

- 2006 D.Eng., University of Tokyo
- 2006 Research fellowship for young scientists
- 2007 Researcher, JST-ERATO Multiferroic project
- 2010 Project Lecturer, Quantum-Phase Electronics Center, University of Tokyo
- 2012 Lecturer, Department of Applied Physics, University of Tokyo
- 2013 Unit Leader, Dynamic Emergent Phenomena Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science
- 2017 Associate Professor, Department of Applied Physics, University of Tokyo
- 2022 Professor, Department of Physics, Tokyo Institute of Technology
- 2022 Team Leader, Dynamic Emergent Phenomena Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
- 2024 Professor, Department of Physics, Institute of Science Tokyo (Name change due to university integration) (-present)

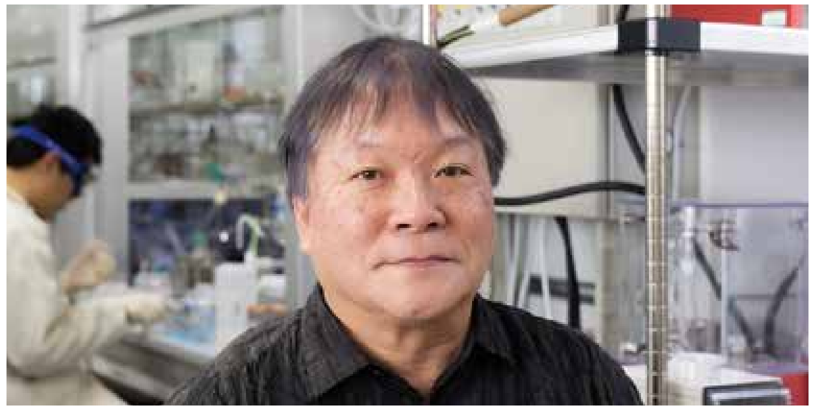
Outline

Our team explores dynamic phenomena and nonlinear responses exhibited by strongly correlated electron systems in both bulk and device structures to construct a new scheme for scientific investigation. In particular, we study external-field-driven dynamic phenomena exhibited by sub-micron-scale structures, such as topological spin textures and domain walls, using spectroscopy of dielectric responses and resistance fluctuations from the millihertz to gigahertz region. We also pursue real-space observations and measurements of local physical properties using scanning probe microscopy as a complementary approach. We are aiming to control novel physical properties exhibited by topological structures in condensed matter systems on the basis of knowledge obtained from these methods.

Core members

(Postdoctoral Researcher)
Tetsuya Nomoto, Samiran Banu
(Visiting Scientist) Keisuke Matsuura

Emergent Soft Matter Function Research Group



Takuzo Aida (D.Eng.), Group Director
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Research field

Chemistry, Materials Science

Keywords

Soft material, Molecular design, Self-assembly, Energy conversion, Biomimetics, Stimuli-responsive material, Electronic material, Photoelectric conversion material, Environmentally friendly material

Brief resume

1984 D.Eng., University of Tokyo
1984 Research Assistant / Lecturer, University of Tokyo
1991 Associate Professor, University of Tokyo
1996 Professor, University of Tokyo (-present)
2000 Project Leader, ERATO Aida Nanospace Project, Japan Science and Technology Corporation
2007 Group Director, Responsive Matter Chemistry & Engineering Research Group, RIKEN
2010 Group Director, Functional Soft Matter Research Group, RIKEN
2011 Team Leader, Photoelectric Conversion Research Team, RIKEN
2013 Deputy Director, RIKEN Center for Emergent Matter Science (CEMS)
2013 Group Director, Emergent Soft Matter Function Research Group, Division Director, Supramolecular Chemistry Division, RIKEN CEMS (-present)
2022 Distinguished University Professor, University of Tokyo (-present)

Outline

With world's focus on environment and energy issues, our group aims to establish a novel principle of material sciences addressing these problems, through the development of unprecedented functional materials with precisely controlled structure and properties at molecular to nanoscale levels. The main research subjects include (1) the development of novel organic catalysts consisting only of ubiquitous elements for high efficient water photolysis, (2) the development of the solution-processable organic ferroelectric materials for the application to memory devices, and (3) the development of precise supramolecular polymerizations.

Core members

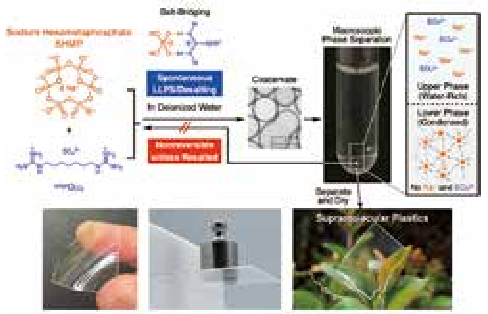
(Postdoctoral Researcher) Kiichi Mizukami
(Technical Staff I) Hiroyuki Inuzuka, Xingmei Ouyang
(Research Part-Time Worker) Sei Obuse
(Visiting Researcher)
Wenlang Li, Satyajit Das, Yang Hong
(Junior Research Associate) Ying Feng
(Student Trainee) Yulong Ji, Kaiyuan He, Xingjian Sun, Hanyu Linag, Zhenghong Chen, Chenhao Chen, Kenta Komatsu

Mechanically strong yet readily metabolizable supramolecular plastics

Plastics formed by covalent polymerization are indispensable to modern society because of their robustness and durability; however, their resistance to degradation causes persistent microplastic pollution in marine environments, posing risks to ecosystems and human health. Plastics that can metabolize in oceans are therefore highly sought for a sustainable future.

In this work, we develop the unprecedented non-covalent supramolecular plastics that are mechanically robust yet metabolizable under biologically relevant conditions, owing to their electrolyte-induced dissociative nature. Simply mixing two metabolizable ionic monomers—sodium hexametaphosphate and guanidinium sulfate—in water induces strong salt-bridging interactions, forming a three-dimensionally cross-linked network stabilized by liquid–liquid phase separation.

Drying the condensed phase yields transparent, glassy plastics with a high Young's modulus, excellent durability, and a well-defined glass transition temperature, enabling thermal reshaping similar to conventional thermoplastics. Unlike conventional plastics, these materials readily dissociate into monomers in seawater, allowing complete recovery and recycling without property degradation.



Nonreversible Supramolecular Polymerization by Desalting through Liquid–Liquid Phase Separation (LLPS)

Publications

1. Z. Chen, Y. Hong, H. Inuzuka, K. Mizukami, and T. Aida, "Supramolecular Ionic Polymerization: Cellulose-Based Supramolecular Plastics with Broadly Tunable Mechanical Properties", *J. Am. Chem. Soc.*, 147, 44507–44514 (2025).
2. Y. Itoh, T. Fu, P. Chanpagne, Y. Yokoyama, K. Numabe, Y. Hong, Y. Nishiyama, H-F. Wang, A. Kumagai, H. Jinnai, H. Watanabe, T. Seki, A. Nagao, T. Suzuki, Y. Saito, K. Wakabayashi, T. Yoshii, A. Izumi, K. Hagita, J. Furukawa, and T. Aida, "Electric double-layer synthesis of a spongelike, lightweight reticular membrane", *Science*, 389, 73–77 (2025).
3. H. Gong, Y. Sakaguchi, T. Suzuki, M. Yanagisawa, and T. Aida, "Near-identical macromolecules spontaneously partition into concentric circles", *Nature*, 636, 92–99 (2024).
4. Y. Chen, E. Hirano, M. Kuwayama, E. W. Meijer, H. Huang, and T. Aida, "Mechanically strong yet metabolizable supramolecular plastics by desalting upon phase separation", *Science*, 386, 875–881 (2024).
5. K. Kikkawa, Y. Sumiya, K. Okazawa, K.Yoshizawa, Y. Ito, and T. Aida, "Thiourea as a "polar hydrophobic" hydrogen-bonding motif: application to highly durable all-underwater adhesion", *J. Am. Chem. Soc.*, 146, 21168–21175 (2024).

Emergent Molecular Function Research Group

Kazuo Takimiya (D.Eng.), Group Director
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Research field

Chemistry, Engineering, Materials Science

Keywords

Organic semiconductor, Pi-electronic compound, Organic Synthesis, Organic field-effect transistor, Organic solar cells, Organic thermoelectric materials

Brief resume

1994 Ph.D., Hiroshima University
1994 Research Associate, Hiroshima University
1997 Visiting Researcher, Odense University, Denmark
2003 Associate Professor, Hiroshima University
2007 Professor, Hiroshima University
2012 Team Leader, Emergent Molecular Function Research Team, RIKEN
2013 Group Director, Emergent Molecular Function Research Group, Supramolecular Chemistry Division, RIKEN CEMS
2017 Professor, Tohoku University (-present)
2018 Team Leader, Emergent Molecular Function Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science
2024 Group Director, Emergent Molecular Function Research Group, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present)
2024 Deputy Director, RIKEN Center for Emergent Matter Science (-present)

Outline

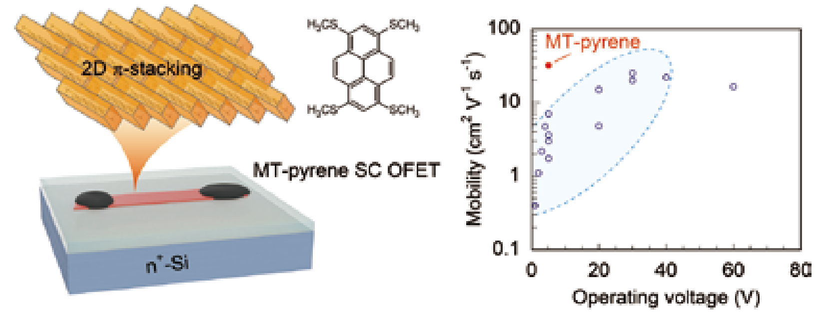
Our research activity is based upon organic synthesis that can afford new organic materials utilized in opto-electronic devices, such as organic field-effect transistors (OFETs), organic solar cells (organic photovoltaics, OPVs), and organic thermoelectric devices (OTE). To this end, our team develops new organic materials, which can be designed and synthesized in order to have appropriate molecular and electronic structures for target functionalities. Our recent achievements are: 1) high-performance molecular semiconductors applicable to OFETs with the high mobilities, 2) new non-fullerene acceptors and their OPVs showing high power conversion efficiencies, and 3) new molecular design strategies to control packing structures of organic semiconductors.

Core members

(Researcher) Kirill Bulgarevich
(Postdoctoral Researcher) Kai Wang
(Senior Visiting Scientist) Takehiko Mori
(Visiting Scientist) Prasanta Pal, Kohsuke Kawabata

Development of high-mobility organic semiconductors by controlling molecular arrangement

Solid-state properties of organic semiconductors, e.g., carrier mobility, are largely dependent not only on the molecular structure but also packing structure and molecular orientation in the solid state. However, it is very difficult to predict and control the crystal structure at the stage of molecular design, and the development of methodologies for controlling the crystal structure of organic semiconductors is an important issue. We have found that it is possible to lead to a crystal structure suitable for high mobility by introducing a simple substituent such as a methylthio group at an appropriate position in the organic semiconductor skeleton. For example, When four methylthio groups were regio-selectively introduced into pyrene that crystalizes into a sandwich herringbone structure, the crystal structure changes dramatically into a brickwork structure, which enables two-dimensional conduction. The carrier mobility evaluated by using single-crystal field-effect transistors was higher than 30 cm^2 V^{-1} s^{-1}, which was among the highest for organic semiconductors.



Development of high-mobility organic semiconductors by controlling molecular arrangement

Publications

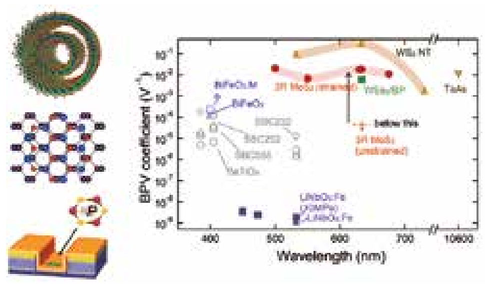
1. K. Takimiya, S. Usui, R. Hanaki, K. Bulgarevich, K. Kawabata, K. Nakano, K. Tajima, "Significant decrease in the ionization energy of dinaphtho[2,3b:2',3'-f]thieno[3,2-b]thiophene (DNTT) solid induced by a pinacolborane group", *Mater. Horiz.*,13, 3117-3126 (2026).
2. H. Sanematsu, R. Matsidik, B. Dhara,K. Takimiya, "Construction of a two-dimensional molecular slab with a π-extended hexaarylbenzene molecule", *Angew. Chem. Int. Ed.*, 65, e24473 (2026)
3. P. Pal, K. Bulgarevich, R. Hanaki, K. Kawabata, K. Takimiya, "Extension of the π-conjugated core of methylchalcogenolated polycyclic aromatic hydrocarbon: synthesis and characterization of 1,4,7,10-tetrakis(methylthio)- and tetramethoxy-coronene", *Chem. Sci.*, 16, 15368-15377 (2025).
4. K. Bulgarevich, K. Takimiya, "What makes brickwork crystal structures favorable? a case study on methylthiolated arenes and heteroarenes for high-mobility molecular semiconductors", *CrystEngComm*, 27, 4776-4786 (2025).
5. H. Sanematsu, K. Bulgarevich, B. Dhara, K. Takimiya, "Synthesis of parent peropyrene and its derivatization", *Org. Lett.*, 27, 5948-5952 (2025).

Emergent Device Research Group

Bulk photovoltaic effect induced by symmetry control of two-dimensional materials

Our group is studying nonreciprocal transport in semiconductors and superconductors. One of them is a bulk photovoltaic effect, where the photoelectric conversion occurs without PN junctions.

Monolayer transition metal dichalcogenides (TMDs) are two-dimensional materials with three-fold symmetry, which are known not to exhibit bulk photovoltaics. However, such a nanomaterial is capable of changing symmetry either by deforming or creating heterojunctions. This is a unique and important feature of nanomaterials that distinguishes them from bulk. Specifically, we have found strong bulk photovoltaic effects in the visible to infrared region in WS_2 nanotubes, WSe_2/black phosphorus van Waals heterojunctions, and strained MoS_2 (Refs. Nature (2019), Science (2021), 4). We found that the shift current mechanism plays an important role in this photovoltaic effect. Symmetry-controlled nanomaterials showing such large photovoltaic effects will be a promising new platform for high-efficiency photovoltaics and sensors.



Left: Symmetry controlled TMDs. From the top, TMD nanotube, van der Waals heterostructure, and strained device. Copyright: Adapted from "Nature Nanotechnology 18, 36 (2023)." Right: Wave length dependence of bulk photovoltaic coefficient for nano TMDs.

Publications

1. Y. M. Itahashi, Y. Nohara, M. Chazono, H. Matsuoka, K. Arioka, T. Nomoto, Y. Kohama, Y. Yanase, Y. Iwasa, and K. Kobayashi, "Misfit layered superconductor $(PbSe)_{1.14}(NbSe_2)_3$ with possible layer-selective FFLO state", *Nature Communications* 16, 7022 (2025).
2. F. Liu, Y. M. Itahashi, S. Aoki, Y. Dong, Z. Wang, N. Ogawa, T. Ideue, Y. Iwasa, "Superconducting diode effect under time-reversal symmetry", *Science Advances* 10, eado1502 (2024).
3. H. Matsuoka, S. Kajihara, Y. Wang, Y. Iwasa, M. Nakano, "Band-driven switching of magnetism in a van der Waals magnetic semimetal", *Science Advances* 10, eadk1415 (2024).
4. Y. Dong, M. -M. Yang, M. Yoshii, S. Matsuoka, S. Kitamura, T. Hasegawa, N. Ogawa, T. Morimoto, T. Ideue, Y. Iwasa, "Giant bulk piezophotovoltaic effect in 3R-MoS_2", *Nature Nanotechnology* 18, 36-41 (2023).
5. Y. Nakagawa, Y. Kasahara, T. Nomoto, R. Arita, T. Nojima, Y. Iwasa, "Gate-controlled BCS-BEC crossover in a two-dimensional superconductor", *Science*, 372, 190 (2021).

Yoshihiro Iwasa (D.Eng.), Group Director
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Research field

Physics, Engineering, Chemistry, Materials Science

Keywords

2D materials, Nanotubes, Topological materials, Superconductivity, Thermoelectric effect, Nonreciprocal transport, Anomalous photovoltaic effect

Brief resume

- 1986 Ph. D., University of Tokyo
- 1986 Research Associate, Department of Applied Physics, University of Tokyo
- 1991 Lecturer, Department of Applied Physics, University of Tokyo
- 1994 Associate Professor, School of Materials Science, Japan Advanced Institute of Science and Technology
- 2001 Professor, Institute for Materials Research, Tohoku University
- 2010 Professor, Quantum-Phase Electronics Center, University of Tokyo
- 2010 Team Leader, Strong-Correlation Hybrid Materials Research Team, RIKEN
- 2013 Team Leader, Emergent Device Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science
- 2024 Group Director, Emergent Device Research Group, RIKEN Center for Emergent Matter Science (-present)
- 2024 Deputy Director, RIKEN Center for Emergent Matter Science (-present)

Outline

The purpose of our group is to discover novel properties and create revolutionary functions, based on nanodevices of two-dimensional (2D) materials, 1D nanotubes, and 0D quantum dots (QD) as well as topological materials. Our focus is superconductivity, phase transitions, and nonreciprocal transport, using 2D materials and their van der Waals heterostructures, and a wide range of carrier density tuning using electric double layer transistors. We also develop several novel solution-processable QDs, assemble them into various arrangements, and realize various functionalities including thermoelectricity, photovoltaics, and charge storage.

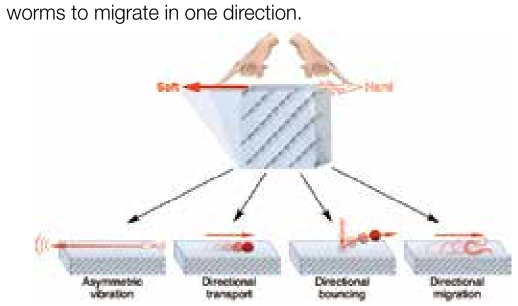
Core members

(Special Postdoctoral Researcher)
Yuki Itahashi, Oleksandr Zheliuk
(Postdoctoral Researcher) Dong Li, Yu Dong
(Visiting Scientist)
Masaki Nakano, Hideki Matsuoka, Lara Perren
(International Program Associate) Alec Paul Romagosa

Emergent Bioinspired Soft Matter Research Team

Mechanically polar gel for rectifying materials, energies, and creatures against the increase of entropy

Materials that respond to external stimuli in a polar fashion, i.e. they respond differently to stimuli applied from the left or right, have attracted increasing attention. While materials that exhibit polar response to electrical, magnetic, and optical stimuli have been studied for many years, those exhibiting polar response to mechanical force have not even been imagined. As a first example, we have developed a composite gel composed of obliquely oriented graphene-oxide nanosheets embedded in a three-dimensional polymer network. When the gel is subjected to leftward shear, the nanosheets immediately buckle and lose their reinforcing ability, causing the gel to deform easily. In contrast, under rightward shear, the nanosheets do not buckle and continue to reinforce the gel. There is a 67-fold difference in stiffness between the left and right shear, and the gel behaves like a one-way door. As a result, the gel can perform a variety of functions against the increase of entropy, such as generating asymmetric vibrations from symmetric or random vibrations, transporting contacting objects in one direction, asymmetrically bouncing colliding objects, and causing a group of small worms to migrate in one direction.



Mechanically polar gel for rectifying materials, energies, and creatures

Publications

1. S. Wang, L. Kang, P. Salamon, X. Wang, N. Uchida, F. Araoka, T. Aida, Z. Dogic, and Y. Ishida, "Stimuli-responsive self-regulating assembly of chiral colloids for robust size and shape control", *Nat. Commun.*, 15, 9891 (2024).
2. X. Wang, Z. Li, S. Wang, K. Sano, Z. Sun, Z. Shao, A. Takeishi, S. Matsubara, D. Okumura, N. Sakai, T. Sasaki, T. Aida, and Y. Ishida, "Mechanical non-reciprocity in a uniform composite material", *Science*, 380, 192 (2023).
3. K. Salikolimi, V. K. Praveen, A. A. Sudhakar, K. Yamada, N. N. Horimoto, and Y. Ishida, "Helical supramolecular polymers with rationally designed binding sites for chiral guest recognition", *Nat. Commun.*, 11, 2311 (2020).
4. Y. S. Kim, M. Liu, Y. Ishida, Y. Ebina, M. Osada, T. Sasaki, T. Hikima, M. Takata, and T. Aida, "Thermoresponsive actuation enabled by permittivity switching in an electrostatically anisotropic hydrogel", *Nat. Mater.*, 14, 1002 (2015).
5. M. Liu, Y. Ishida, Y. Ebina, T. Sasaki, T. Hikima, M. Takata, and T. Aida, "An anisotropic hydrogel with electrostatic repulsion between cofacially aligned nanosheets", *Nature*, 517, 68 (2015).

Yasuhiro Ishida (D.Eng.), Team Director
y-ishida@riken.jp

Research field

Chemistry, Materials Science

Keywords

Biomimetics, Soft material, Anisotropy, Autonomy, Polarity, Hierarchy

Brief resume

- 2001 D.Eng., University of Tokyo
- 2001 Assistant Professor, Graduate School of Frontier Sciences, University of Tokyo
- 2002 Assistant Professor, Graduate School of Engineering, University of Tokyo
- 2007 Lecturer, Graduate School of Engineering, University of Tokyo
- 2007 Researcher, PRESTO, Japan Science and Technology Agency
- 2009 Team Leader, Nanocomposite Soft Materials Engineering Team, RIKEN
- 2010 Team Leader, Bioinspired Material Research Team, RIKEN
- 2013 Team Leader, Emergent Bioinspired Soft Matter Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

Owing to intrinsic similarity to living organisms, such as lightweight, softness, and biocompatibility, soft materials have attracted increasing attention for biomedical applications, including artificial organs. However, in terms of structure, there is a significant difference between synthetic soft materials and living organisms; most synthetic soft materials are of isotropic structures, while living tissues are anisotropic. As seen in muscular, bone, and nerval textures, such anisotropic structures play critical roles for exhibiting their superb functions. By using external fields for orienting constituents, we have developed various anisotropic soft materials with highly oriented structure and unprecedented unique functions reminiscent of living organisms.

Core members

(Expert Technician) Kuniyo Yamada
(Special Postdoctoral Researcher) Yunlei Zhang
(Postdoctoral Researcher) Zhiming Shen
(Technical Staff I) Hayato Kanai
(Visiting Researcher) Qifeng Mu

Emergent Soft System Research Team

Ultraflexible, high-performance and stable organic solar cells

One of the requirements of the Internet of Things—referring to a world where devices of all sorts are connected to the Internet—is the development of power sources for a host of devices, including devices that can be worn on the body. These could include sensors that record heartbeats and body temperature, for example, providing early warning of medical problems. In the past, attempts have been made to create photovoltaics that could be incorporated into textiles, but typically they lacked at least one of the important properties—long-term stability in both air and water, energy efficiency, and robustness including resistance to deformation—that are key to successful devices.

We have developed an ultraflexible organic photovoltaic (OPV) that achieves sufficient thermal stability of up to 120 °C and a high power conversion efficiency of 13% with a total thickness of 3 μm. Additionally, our ultraflexible organic solar cells exhibit prolonged device storage lifetime to >3,000 h at room temperature. Our ultraflexible OPVs possessing extraordinary thermal durability allow a facile bonding onto textiles through the hot-melt adhesive technology.

(Left) Ultraflexible organic solar cells manufactured on a 1 μm-thick plastic film.
(Right) Photograph of the washing process for the devices conforming to a dress shirt.

Publications

1. S. Lee, K. Takano, W. Yukita, Y. Tagawa, L. Sun, S. Wang, J.-S. Kim, T. Yokota, and T. Someya, "A body-scale textile-based electromyogram monitoring system with coaxially shielded conductive yarns", *Sci. Adv.*, 11, eadx4518 (2025).
2. S. Xiong, K. Fukuda, K. Nakano, S. Lee, Y. Sumi, M. Takakuwa, D. Inoue, D. Hashizume, B. Du, T. Yokota, Yi. Zhou, K. Tajima, and T. Someya, "Waterproof and ultraflexible organic photovoltaics with improved interface adhesion", *Nat. Commun.*, 15, 681 (2024).
3. Z. Jiang, N. Chen, Z. Yi, J. Zhong, F. Zhang, S. Ji, R. Liao, Y. Wang, H. Li, Z. Liu, Y. Wang, T. Yokota, X. Liu, K. Fukuda, X. Chen, and T. Someya, "A 1.3-micrometre-thick elastic conductor for seamless on-skin and implantable sensors", *Nat. Electron.*, 5, 784-793 (2022).
4. M. Takakuwa, K. Fukuda, T. Yokota, D. Inoue, D. Hashizume, S. Umezu, T. Someya, "Direct gold bonding for flexible integrated electronics", *Sci. Adv.*, 7, eabl6228 (2021).
5. S. Park, S.-W. Heo, W. Lee, D. Inoue, Z. Jiang, K. Yu, H. Jinno, D. Hashizume, M. Sekino, T. Yokota, K. Fukuda, K. Tajima, and T. Someya "Self-powered ultra-flexible electronics via nano-grating-patterned organic photovoltaics", *Nature*, 551, 516-521 (2018).

Takao Someya (Ph.D.), Team Director
takao.someya@riken.jp

Research field

Electronic Engineering, Materials Science

Keywords

Organic electronics, Organic field-effect transistor, Organic light emitting devices, Organic solar cells, Organic sensors

Brief resume

1997 Ph.D., Electronic Engineering, University of Tokyo
1997 Research Associate, University of Tokyo
1998 Lecturer, University of Tokyo
2001 JSPS Postdoctoral Fellowship for Research Abroad (Columbia University)
2002 Associate Professor, University of Tokyo
2009 Professor, University of Tokyo (-present)
2015 Chief Scientist, Thin-Film Deice Laboratory, RIKEN (-present)
2015 Team Leader, Emergent Soft System Research Team, Supramolecular Chemistry Division, RIKEN CEMS (-present) Position name has been changed to Team Director as of April 1, 2025
2020 Dean, School of Engineering, University of Tokyo (-2023)
2023 Executive Director and Vice President, University of Tokyo (-present)

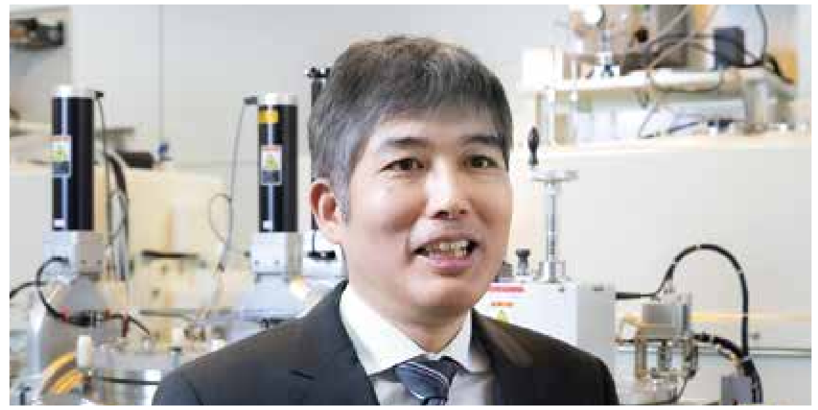
Outline

Electronics is expected to support the foundation of highly develop ICT such as Internet of Things (IoT), artificial intelligence (AI), and robotics. In addition to improve the computing speed and storage capacity, it is required to minimize negative impact of machines on environment and simultaneously to realize the harmony between human and machines. We make full use of the novel soft electronic materials such as novel organic semiconductors in order to fabricate emergent thin-film devices and, subsequently, to realize emergent soft systems that exhibit super-high efficiency and harmonization with humans. The new soft systems have excellent features such as lightweight and large area, which are complimentary to inorganic semiconductors, are expected to open up new eco-friendly applications.

Core members

(Research Scientist) Sunghoon Lee
(Special Postdoctoral Researcher) Shuxu Wang, Sangmin Chae
(Senior Technical Staff) Rasha Bayomi
(Junior Research Associate) Shumpei Katayama
(RIKEN Student Researcher D) Karin Iwa
(Student Trainee) Keigo Ando, Teruki Shigehara

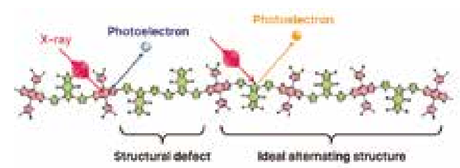
Emergent Functional Polymers Research Team



Unveiling the cause of performance variations in organic semiconductor polymers for solar cells

Organic thin-film solar cells have attracted attention as next-generation energy sources due to their lightweight and flexible properties. However, a significant challenge lies in the performance variation of the semiconductor polymers used in these solar cells, which occurs between different synthesis batches. This variation is generally attributed to differences in molecular weight distribution, but this factor alone cannot fully explain the observed performance inconsistencies. In particular, the high-performance semiconductor polymer PM6 is composed of two alternating units, BDT and BDD. During synthesis, structural defects such as "-A-B-B-A-B-" may occur instead of the ideal alternating structure "-A-B-A-B-". Such structural defects are believed to contribute to performance variations, yet methods for their quantitative evaluation have been limited.

In this study, we developed a novel method using X-ray photoelectron spectroscopy (XPS) to precisely evaluate the main chain structure of semiconductor polymers. By employing Y6 and BTP-eC9 as standard samples, we accurately calculated the relative sensitivity factor (RSF), enabling the unit ratio in PM6 to be assessed with a precision of approximately 1%. Evaluation of three commercial PM6 samples revealed that all samples exhibited an excess of BDD units, with the degree of excess varying between suppliers. This structural deviation correlated with variations in solar cell performance. These findings provide valuable insights for semiconductor polymer quality control and material design, contributing to the stable production of high-efficiency organic thin-film solar cells.



Main Chain Structure Repetition and Structural Defects in Semiconductor Polymer PM6

Publications

1. H. Jung, K. Nakano and K. Tajima, "One-Pot Stille Coupling Homopolymerization Toward Bithiophene–Quinoxaline Copolymers with Reduced Sequence Defects", *ACS Appl. Mater. Interfaces*, 17, 66980 (2025).
2. T. Yokoyama and K. Tajima, "Quantifying Anisotropic Mobility Enhancement in Uniaxially Aligned Polythiophene Films via Ion-Exchange Doping", *J. Mater. Chem. C*, 14, 243 (2026).
3. R. Suzuki, K. Nakano, M. Miyasaka and K. Tajima, "Vertical Component Distributions in Organic Solar Cells Controlled by Photocrosslinking and Layer-by-Layer Deposition", *Small*, 22, 2411988 (2025).
4. K. Nakano, Y. Kaji, R. Suzuki, K. Tajima, "Quantifying Unit Ratios in Semiconducting Copolymers and Effect of Structural Deviations on Photovoltaic Performance", *Commun. Mater.*, 6, 37 (2025).
5. K. Nakano and K. Tajima, "Insights from Planar Heterojunctions: Understanding Charge Carrier Generation in Organic Photovoltaics", *ACS Appl. Mater. Interfaces*, 17, 8 (2025).

Keisuke Tajima (Ph.D.), Team Director
keisuke.tajima@riken.jp

Research field

Chemistry, Engineering, Materials Science

Keywords

Organic electronics, Organic solar cells, Polymer synthesis, Self-assembly, Nanostructure control

Brief resume

2002 Ph.D., The University of Tokyo
2002 Postdoctoral Researcher, Northwestern University
2004 Research Associate, The University of Tokyo
2009 Lecturer, The University of Tokyo
2011 Associate Professor, The University of Tokyo
2011 PRESTO Researcher, Japan Science and Technology Agency (-2017)
2012 Team Leader, Emergent Functional Polymers Research Team, RIKEN
2013 Team Leader, Emergent Functional Polymers Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

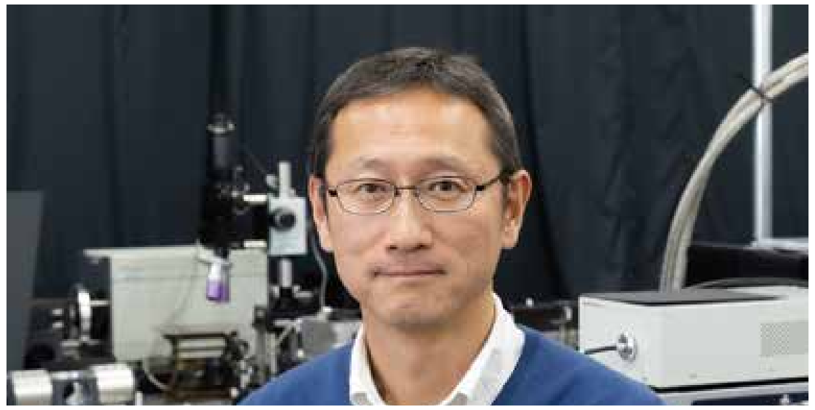
Outline

We work on the development of new organic semiconducting polymer materials and their application to organic electronic devices. Specifically, relying on the basic chemistry of the intermolecular interactions during the film forming process from the solutions, we seek the methodology and the molecular design to control the precise structures in molecular- and nano-scale at our will, and try to find breakthroughs to drastically enhance the performance of the organic electronic devices. Targets of our research are not only the conventional organic solar cells and field-effect transistors, but also the organic electronic devices with new functions based on the structure controls.

Core members

(Senior Research Scientist) Kyohei Nakano
(Special Postdoctoral Researcher) Takaho Yokoyama
(Postdoctoral Researcher) Hyeonwoo Jung, Dylan Wilkinson
(Technical Staff II) Yumiko Kaji
(Junior Research Associate) Ryo Suzuki

Emergent Supramolecular Materials Research Team



Yong-Jin Pu (D.Eng.), Team Director
yongjin.pu@riken.jp

Research field

Chemistry, Materials Science

Keywords

Excited State, Interstate Transition, Organic Semiconductor, Semiconductor Nanoparticle, Colloidal Quantum Dot

Brief resume

2002 D. Eng., Waseda University
2002 Research associate, Waseda University
2004 JSPS Postdoctoral Fellowship for Research Abroad (University of Oxford)
2006 Research associate, Yamagata University
2010 Associate Professor, Yamagata University
2013 PRESTO Researcher, Japan Science and Technology Agency
2017 Team Leader, Emergent Supramolecular Materials Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

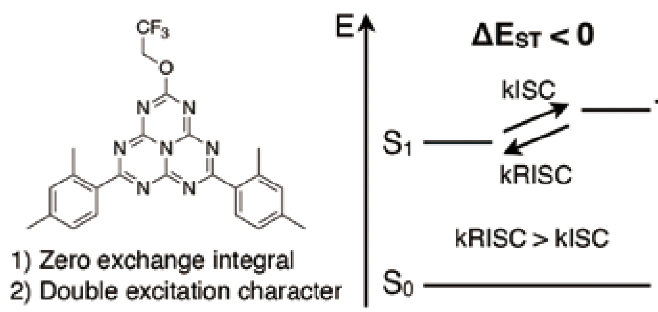
We precisely control the energy levels, interstate transition rate, luminescence efficiency, spin multiplicity etc. of organic/inorganic semiconductors and nanoparticles by their dynamic and static molecular structure, shape/size, chemical composition, and assembly pattern, for creating innovative energy- and sensing-related technologies.

Core members

(Research Scientist) Kazushi Enomoto
(Special Postdoctoral Researcher)
Retno Miranti, Guanhao Liu
(Visiting Scientist) Ryutaro Komatsu

Luminescence and excited states of the molecules with double excitation character

In molecular excited states, the energy level of S1 is higher than that of T1, because of the exchange energy of two electrons in the excited state derived from the Fermionic nature of electrons and the Pauli exclusion principle. Cyclazine and heptazine derivative have been reported to have un-overlapped HOMO and LUMO and to possibly show negative ΔEST (E(S1) – E(T1)) (Leupin et al., JACS 1980; Ehrmaier et al., J. Phys. Chem. A 2019). We designed and synthesized the substituted heptazine molecule and experimentally proved its negative ΔEST of −11 meV by the temperature dependence of delayed fluorescence and transient absorption. Conventional DFT quantum chemical calculation with one-electron description gave the positive ΔEST, while wavefunction-based quantum chemical calculation gave the negative ΔEST, indicating the double excitation character of the molecule. The reverse intersystem crossing rate was faster than the intersystem crossing rate, and much shorter delayed fluorescence and transient EL lifetime were exhibited. These results are the demonstration of unique luminescence from the molecule with inverted S1 and T1 derived from double excitation character in the excited state.

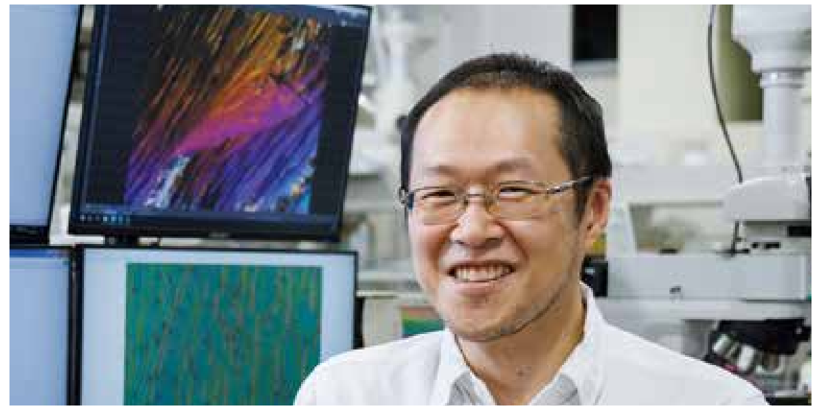


Molecules showing the inverted singlet and triplet excited state and energy diagram

Publications

1. R. Komatsu, N. L. H. Hoang, M. Kim, S. U. Ryu, K. Enomoto, D. Hashizume, T. Park, Y.-J. Pu, "An Anthracene Derivative with a Highly Vertical Molecular Orientation", *J. Phys. Chem. Lett.*, 16, 4489-4495 (2025).
2. Y.-J. Pu, "Computational Design of Molecules Having Less Overlapping HOMO and LUMO in the Same Plane", *J. Phys. Chem. A*, 129, 3466–3473 (2025).
3. R. Miranti, R. Komatsu, K. Enomoto, D. Inoue, Y.-J. Pu, "Symmetry-Broken Electronic State of $CsPbBr_3$ Cubic Perovskite Nanocrystals", *J. Phys. Chem. Lett.*, 15, 10009-10017 (2024).
4. K. Enomoto, R. Miranti, J. Liu, R. Okano, D. Inoue, D. Kim, Y.-J. Pu, "Anisotropic Electronic Coupling in Three-Dimensional Assembly of $CsPbBr_3$ Quantum Dots", *Chem. Sci.*, 15, 13049-13057 (2024).
5. N. Aizawa, Y.-J. Pu, Y. Harabuchi, A. Nihonyanagi, R. Ibuka, H. Inuzuka, B. Dhara, Y. Koyama, K. Nakayama, S. Maeda, F. Araoka, D. Miyajima, "Delayed fluorescence from inverted singlet and triplet excited states", *Nature*, 609, 502 (2022).

Physicochemical Soft Matter Research Team



Fumito Araoka (D.Eng.), Team Director
fumito.araoka@riken.jp

Research field

Physical and Structural Properties of Functional Organic Materials

Keywords

Liquid crystals, Polymeric materials, Soft-matter physics, Optical properties, Organic nonlinear optics, Organic ferroelectrics

Brief resume

2003 Ph.D. in Engineering, Tokyo Institute of Technology, Japan
2003 Postdoctoral Researcher, Catholic University of Leuven, Belgium
2005 Postdoctoral Researcher, The University of Tokyo
2006 Postdoctoral Researcher, Tokyo Institute of Technology
2007 Assistant Professor, Tokyo Institute of Technology
2013 Unit Leader, Physicochemical Soft-Matter Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science
2018 Team Leader, Physicochemical Soft-Matter Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

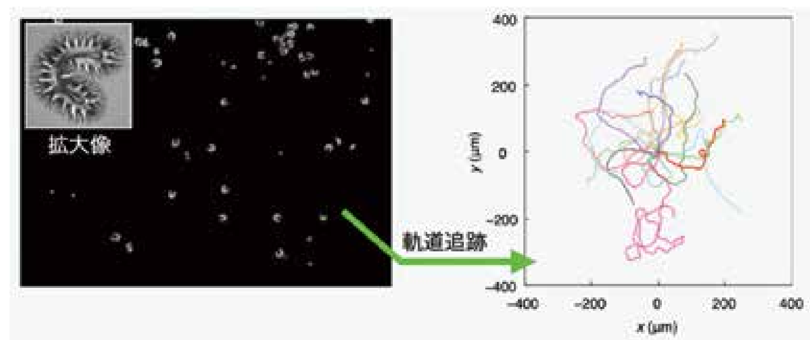
Our team is mainly working on functionality of soft-matter systems from the viewpoints of physical experiments and analyses. In our research unit, particular attention is paid to liquid crystals due to their self-organizability leading to multifarious structures in which many interesting physical phenomena emerge. Our interest also covers potential applications of such soft-matter systems towards optical/electronic or chemical devices. For example, 1. Ferroelectric interactions and switching mechanisms in novel liquid crystalline ferroelectric materials, 2. Chirality related phenomena - origin and control of emergence, as well as applications of superstructure chirality in self-organized soft-matter systems, 3. Novel optical/electronic devices based on self-organized soft-matter systems.

Core members

(Research Scientist) Hiroya Nishikawa
(Postdoctoral Researcher) Dennis Kwaria
(JSPS PD Researcher) Keita Saito

Electric-field driven ferroelectric micro-droplets

The recently-found ferroelectric nematics have been attracting much attention due to its proper ferroelectricity with highly fluidic nature. This state is enthusiastically investigated for its possibility towards epoch-making applications, as well as for fundamental science issues beneath the emergence of unprecedented physical properties, such as large apparent permittivity. Our group recently found a complex dynamic behavior, in which ferroelectric nematic microdroplets were transformed and dynamically driven by an ac electric field and crawled like some kind of micro creatures. This non-equilibrium phenomenon is resulted from the competition of electrostrictive and piezoelectric effects, and hence the shapes and dynamics of the droplets transit among various states, depending on the field conditions (amplitude, frequency, etc.). Interestingly, these dynamic droplets sometime move collectively like a swarm and thus possess active matter nature. Each individual droplet is considered as a micro-robot, thus named "Febot".

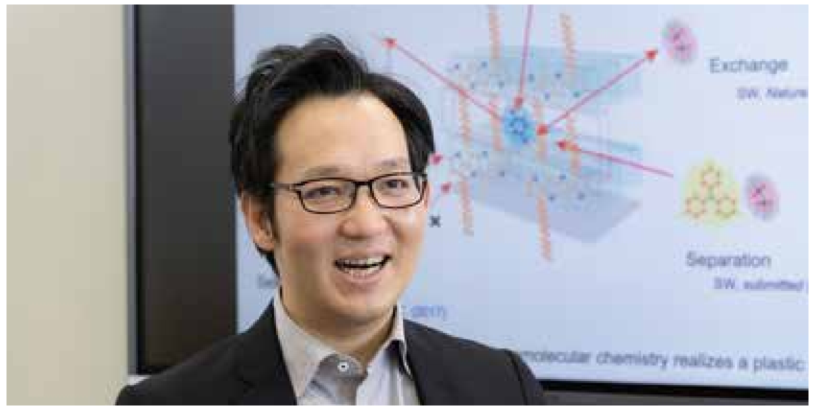


"Febots" in collective motion, and their traces visualized by the motion capturing.

Publications

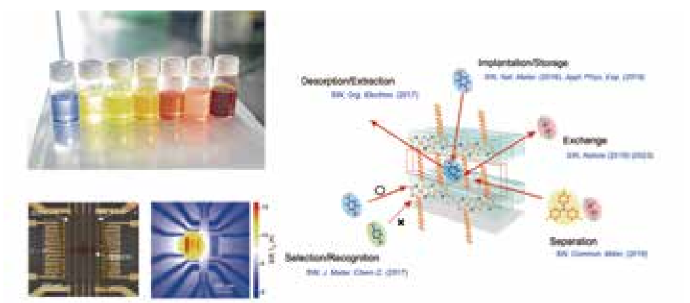
1. M. Máthé, H. Nishikawa, F. Araoka*, A. Jákli*, P. Salamon*, "Electrically activated ferroelectric nematic microrobots", *Nat. Commun.*, 15, 6928 (2024).
2. D. Okada, F. Araoka, "Magneto‐chiral Nonlinear Optical Effect with Large Anisotropic Response in Two-Dimensional Halide Perovskite", *Angew. Chem. Int. Ed.*, 63, e202402081 (2024).
3. H. Nishikawa, K. Sano and F. Araoka, "Anisotropic fluid with phototunable dielectric permittivity", *Nat. Commun.*, 13, 1142 (2022).
4. H. Nishikawa and F. Araoka, "A New Class of Chiral Nematic Phase with Helical Polar Order", *Adv. Mater.*, 33, 2101305 (2021).
5. S. Aya and F. Araoka, "Kinetics of motile solitons in nematic liquid crystals", *Nat. Commun.*, 11, 3248 (2020).

Emergent Molecular Electronics Research Team



Towards supramolecular alchemy

Organic compounds such as rubber and plastics are indispensable functional materials in our lives as good electrical insulators. On the other hand, organic compounds with a special skeleton called a pi-conjugated system, in which single and double bonds are alternately repeated between carbon atoms, exhibit various physical properties such as light absorption, luminescence, electrical conductivity, and magnetism. Organic compounds that conduct electricity have a history of 70 years since discovered in Japan, but in terms of understanding their physical properties, developing new materials, and returning their value to society, it is necessary to continue research that covers everything from basics to applications. Our team has realized metallic plastics that conduct electrons and heat like metals by using an original technology that precisely combines polymers, small molecules, and ions. We regard this as the alchemy of plastics and explore the possibility of new electronic states and electronic phase transitions in polymer materials.



(Top left) Ink made from pi-conjugated organic compounds. Different molecular structures produce different band gaps, allowing for inks of a variety of colors to be obtained. (Bottom left) A microfabricated device that can simultaneously measure the transport of electrons and heat. (Right) The development of functional materials using ion dynamics in crystalline polymer semiconductors.

Publications

1. N. Kasuya, J. Tsurumi, T. Okamoto, S. Watanabe*, and J. Takeya* (*correspondingauthor) "Two-dimensional hole gas in organic semiconductors", *Nat. Mater.* 20 1401 (2021).
2. Y. Yamashita, J. Tsurumi, M. Ohno, R. Fujimoto, S. Kumagai, T. Kurosawa,T. Okamoto, J. Takeya, and S. Watanabe* (*corresponding author) "Efficient molecular doping of polymeric semiconductors driven by anion exchange", *Nature*, 572, 634 (2019).
3. J. Tsurumi, H. Matsui, T. Kubo, R. Hausermann, C. Mitsui, T. Okamoto, S. Watanabe*, and J. Takeya* (*corresponding author) "Coexistence of ultra-long spin relaxation time and coherent charge transport in organic single-crystal semiconductors", *Nat. Phys.*, 13, 994 (2017).
4. K. Kang*, S. Watanabe*, K. Broch, A. Sepe, A. Brown, I. Nasrallah, M. Nikolka, Z. Fei, M. Heeney, D. Matsumoto, K. Marumoto, H. Tanaka, S. Kuroda, and H. Sirringhaus (*equal contribution) "2D coherent charge transport in highly ordered conducting polymers doped by solid state diffusion", *Nat. Mater.*, 15, 896 (2016).
5. S. Watanabe*, K. Ando*, K. Kang, S. Mooser, Y. Vaynzof, H. Kurebayashi, E. Saitoh, and H. Sirringhaus (*equal contribution) "Polaron spin current transport in organic semiconductors", *Nat. Phys.*, 10, 308 (2014).

Shun Watanabe (Ph.D), Team Director
shun.watanabe.ey@riken.jp

Research field

Materials Sciences, Physics, Engineering, Chemistry

Keywords

Organic electronics, Organic semiconductor, Pi-electronic compound, Nanodevices, Organic Synthesis

Brief resume

2011 PhD, Department of Materials Science, Graduate School of Engineering, Nagoya University
2011 JSPS DC2
2012 Post-doc researcher, the Cavendish Laboratory, the University of Cambridge
2014 Visiting researcher, Department of Advanced Materials Science, the University of Tokyo
2015 JST PREST researcher
2016 Projected associate professor, Department of Advanced Materials Science, the University of Tokyo
2020 Associate Professor, Department of Advanced Materials Science, the University of Tokyo
2024 PI, Associate Professor, Department of Advanced Materials Science, the University of Tokyo
2024 Team Leader, Emergent Molecular Electronics Research Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

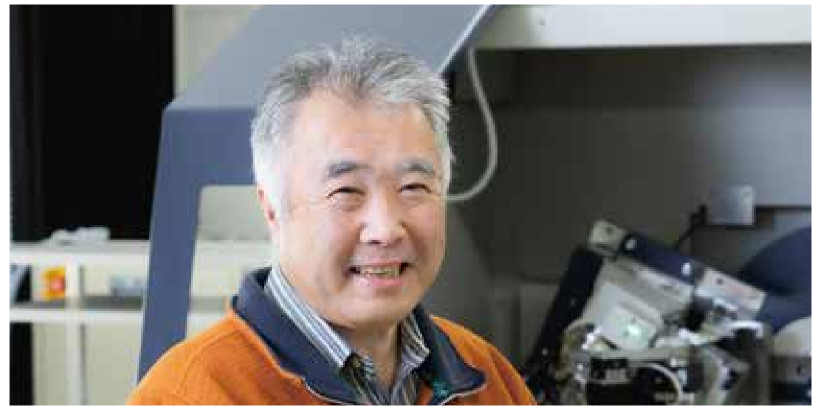
Outline

Organic compounds with a unique skeleton called a pi-conjugated system exhibit various physical properties. Our team uses an original technology that precisely combines polymers and small molecules with ions to develop "metallic plastic materials" that conduct electrons and heat like a metal. Our team conducts consistent research from basic to applied sciences in the sense of understanding the physical properties, synthesizing new materials, and returning the value of these materials to society.

Core members

(Postdoctoral Researcher)
Hai Wang, Retno Wulandari, Shunichiro Ito
(Student Trainee / Research Part-time Woker I)
Takahiro Kaneta
(Student Trainee) Yiyang Dong, Mingqian Wang, Junliang Lin, Ayuto Kouta

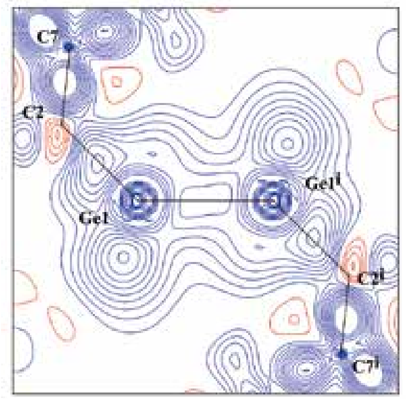
Materials Characterization Support Team



Visualization of chemical bonds by accurate X-ray analysis

Our team has investigated the nature of molecules, which have unusual chemical bonds and show less stability, in the crystalline state by analyzing the distribution of valence electrons derived from accurate and precise single-crystal X-ray crystal structure analysis.

The conventional X-ray diffraction method clarifies the arrangement of atoms in the crystalline state by modeling total electron density distribution using spherical atom (isolated atom) models. As widely recognized, the resulting structures give important information on the nature of molecules. However, valence density distribution, which plays a critical role in the chemistry of molecules, is not included in the resulting models. For a deeper understanding of the nature and chemistry of the analyzed molecule, in particular, reactivity, charge separation, bonding mode, and intermolecular interaction, the valence densities should be analyzed. In this study, the valence densities are analyzed by applying multipole models instead of the spherical atom models to gain much direct information on the electronic structure of molecules.



Distribution of the Ge-Ge π-electron density in a 1,2-digermacyclobutadiene, Licensed under CC BY 4.0.

Publications

1. N. Nakamura, Y. Sahara, Y. Yamazaki, D. Inoue, D. Hashizume, and S. Ohta, "Dynamics in Anisotropic Disassembly process of DNA-assembled core-satellite superstructure of gold-nanoparticles at nanometer order", *J. Am. Chem. Soc.*, 147, 47595 (2025).
2. A. Li, S. Kong, H. Ooka, S. Kong, K. Adachi, Y. Zhang, K. Fushimi, S. Hamamoto, M. Oura, S. Kim, D. Hashizume, and R. Nakamura, "Oxygen evolution electrocatalysis resilient to voltage fluctuations", *Nat. Sustain.*, 8, 1533 (2025).
3. J. M. L. Baeza, H. Xu, S. Takahashi, A. Baceiredo, R. S. R. Guerrero, D. Hashizume, N. Saffon-Merceron, V. Branchadell, and T. Kato, "Isolable three-coordinate base-stabilized alumylene: a precursor of persistent acceptor-free monomeric aluminum oxide", *Angew. Chem. Int. Ed.*, 64, e202505181 (2025).
4. H. Huang, G. Chen, M. Hoshino, K. Adachi, D. Hashizume, H. Sato, Z. Chen, S. Zhang, K. Wang, X. Lin, Y. Zhao, and T. Aida, "Emergence of chirality in an optically active two-dimensional crystal with a spiral surface pattern", *J. Am. Chem. Soc.*, 147, 3206 (2025).
5. T. Sugahara, D. Hashizume, A. Espinosa Ferao, K. Masada, N. Tokitoh, and T. Sasamori, "Experimental and theoretical characterization of 4π-electron Möbius aromatic system of a 1,2-digermacyclobutadiene", *Angew. Chem. Int. Ed.*, 64, e202413426 (2025).

Daisuke Hashizume (D.Sci.), Team Director
hashi@riken.jp

Research field

Structural Chemistry, Analytical Chemistry, Materials Science

Keywords

X-ray crystal structure analysis, Electron microscopy, Chemical analysis

Brief resume

1997 Tokyo Institute of Technology, PhD in Chemistry
1997 Research Associate, Department of Applied Physics and Chemistry, Univ. of Electro-Communications
2002 Research Scientist, Molecular Characterization Team, Advanced Development and Support Center, RIKEN
2011 Senior Research Scientist, Materials Characterization Team, Advanced Technology Support Division, RIKEN
2013 Unit Leader, Materials Characterization Support Unit, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science
2018 Team Leader, Materials Characterization Support Team, Supramolecular Chemistry Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

Our team provides research support using X-ray diffractometry, electron microscopy, and elemental analysis. In addition to supporting the individual method, we propose multifaceted research support by combining these methods. To keep our support at the highest quality in the world, we always update our knowledge and technical skills. We make tight and deep collaborations with researchers to achieve their scientific purposes and to propose new insights into the research from an analytical point of view, in addition to providing routine analysis. Beyond routine analysis, we explore and develop new measurement methods directed to more advanced and sophisticated analyses.

Core members

(Senior Technical Scientist) Keiko Suzuki
(Expert Technician) Daishi Inoue
(Special Postdoctoral Researcher) Kiyohiro Adachi
(Postdoctoral Researcher)
Priyanka Sharma, Jiten Yadav
(Technical Staff I) Mohamed Arfaoui

Quantum Functional System Research Group

Quantum error correction with silicon spin qubits

Silicon-based spin qubits offer an outstanding nanofabrication capability for scaling up. Here we demonstrate a basic quantum error correction using silicon spin qubits. We implement a Toffoli-class three-qubit gate by a single pulse under simultaneous exchange coupling. We then synthesize a three-qubit repetition code to demonstrate the correction of a phase flip error on one of the three qubits.

We accurately control the three-spin system defined in a triple quantum dot of silicon/silicon-germanium by electric-dipole spin resonance and adiabatic pulsing of exchange coupling. We combine the single-qubit and two-qubit gates to encode a spin qubit state to a three-qubit entangled state. Then we implement a three-qubit Toffoli gate by a single rotation pulse under simultaneous nearest-neighbor exchange interaction.

We intentionally introduce a phase error with various error angles in one of the three qubits and measure the process fidelity of the data qubit with and without error correction. The measured fidelity decreases monotoniclly with increasing error angle withou error correciton,whereas well recovered with error correction, indicating the errror correciton protocol works well.

This is the first proof-of-principle experiment of error correciton in the spin qubit system, and will encourage development of scalable multi-qubit devices in silicon.

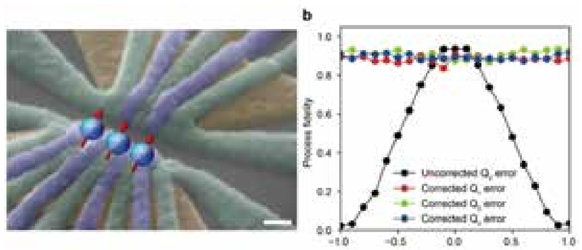


Figure (Left) Silicon three quantum bit device used for the experiment. (Right) Result of quantum phase error correction (Error recovery for the data qubit Q2).

Publications

1. K. Takeda, A. Noiri, T. Nakajima, L. C. Camenzind, T. Kobayashi, A. Sammak, G. Scappucci, and S. Tarucha, "Rapid single-shot parity spin readout in a silicon double quantum dot with fidelity exceeding 99 %", *npj Quantum Info.* 10, 22 (2024).
2. Y.-H. Wu, L. C. Camenzind, A. Noiri, K. Takeda, T. Nakajima, T. Kobayashi, C.-Y. Chang, A. Sammak, G. Scappucci, H.-S. Goan, and S. Tarucha, "Hamiltonian Phase Error in Resonantly Driven CNOT Gate Above the Fault-Tolerant Threshold", *npj Quantum Info.* 10, 8 (2024).
3. J. Yoneda, J. S. Rojas-Arias, P. Stano, K. Takeda, A.Noiri, T. Nakajima, D. Loss, and S. Tarucha, "Noise-correlation spectrum for a pair of spin qubits in silicon", *Nat. Phys.*. 19, 1793 (2023).
4. K. Takeda, A. Noiri, T. Nakajima, T. Kobayashi, and S. Tarucha, "Quantum error correction with silicon spin qubits", *Nature* 608, 682-686 (2022).
5. A. Noiri, K. Takeda, T. Nakajima, T. Kobayashi, A. Sammak, G. Scappucci, and S. Tarucha, "Fast universal quantum gate above the fault-tolerance threshold in silicon", *Nature* 601, 338 (2022).

Seigo Tarucha (D.Eng.), Group Director
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Research field

Physics, Engineering

Keywords

Quantum information devices, Quantum entanglement, Quantum coherence, Topological particles

Brief resume

- 1978 Staff member at the Basic Research Laboratories of Nippon Tel. & Tel. Corp.
- 1998 Professor, Department of Physics, University of Tokyo
- 2004 Professor, Department of Applied Physics, University of Tokyo
- 2012 Group Director, Quantum Functional System Research Group, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present)
- 2018 Deputy Director, RIKEN Center for Emergent Matter Science
- 2021 Team Leader, Semiconductor Quantum Information Device Research Team, RIKEN Center for Quantum Computing (-present) Position name has been changed to Team Director as of April1, 2025.
- 2024 Team Leader, Emergent Phenomena Observation Technology Research Team, RIKEN Center for Emergent Matter Science

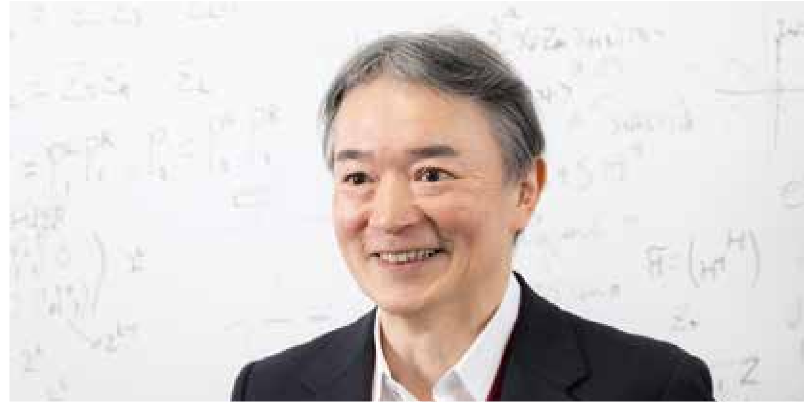
Outline

Quantum information processing is an ideal information technology whose operation accompanies low-energy dissipation and high information security. We aim at demonstrating the ability of the solid-state information processing, and finally paving the way for the realization with innovative concepts and technology. The specific research targets are implementation of small-scale quantum processing circuits with spins in silicon, development of control methods of quantum coherence and entanglement in the circuits, and development of innovative quantum information devices.

Core members

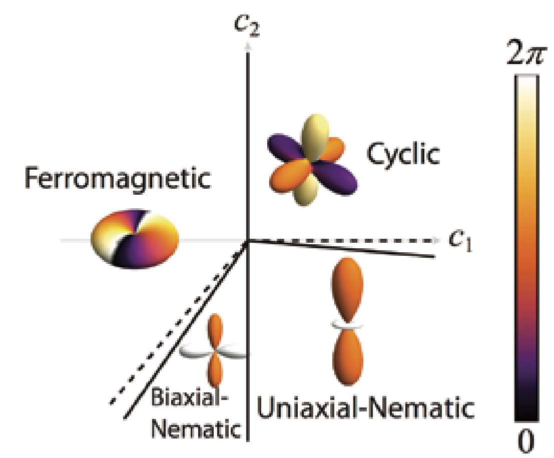
(Senior Research Scientist) Takashi Nakajima, Kenta Takeda, Michael Desmond Fraser, Akito Noiri
(Senior Research Scientist) Keiji Ono
(Research Scientist) Leon Camenzind
(Postdoctoral Researcher) Fan Zhang, Jacob Francis Chittock-wood, Jing Huang
(Visiting Scientist) Tomohiro Otsuka, Sadashige Matsuo, Raisei Mizokuchi, Noriyuki Lee, Takeru Utsugi
(Technical Staff I) Soichiro Teraoka
(Student Trainee) Chutian Wen, Shohei Kobayashi, Yuto Arakawa, Bo Jiang, Ai Hirade, Ryusei Kawasoko, Ryunosuke Nagara, Kanta Fujii

Quantum Condensate Research Team



Topological excitations in Bose-Einstein condensates

Bose-Einstein condensates offer a cornucopia of symmetry breaking because a rich variety of internal degrees of freedom are available depending on the atomic species. We have used these degrees of freedom to explore various aspects of symmetry breaking and topological excitations. Among them are the so-called Kibble-Zurek mechanism in which the order parameter develops singularities after some parameter of the system is suddenly quenched. Ordinary vortices and spin vortices are found to emerge. We also investigate novel topological phenomena such as knot excitations in an antiferromagnetic Bose-Einstein condensate.



Ground-state phase diagram of a spin-2 Bose-Einstein condensate (BEC). Depending on the phase, different topological excitations appear.

Publications

1. M. Nakagawa and M. Ueda, "Topology of Discrete Quantum Feedback Control", *Phys. Rev. X* 15, 021016 (2025).
2. L. Dabelow and M. Ueda, "Three learning stages and accuracy-efficiency tradeoff of restricted Boltzmann machines", *Nat. Commun.* 13, 5474 (2022).
3. E. Yukawa and M. Ueda, "Mophological Superfluid in a Nonmagnetic Spin-2 Bose-Einstein Condensate", *Phys. Rev. Lett.* 124, 105301 (2020).
4. K. Kawabata, K. Shiozaki, M. Ueda and M. Sato, "Symmetry and Topology in Non-Hermitian Physics", *Phys. Rev. X* 9, 041015 (2019).
5. K. Kawabata, S. Higashikawa, Z. Gong, Y. Ashida, and M. Ueda, "Topological unification of time-reversal and particle-hole symmetries in non-Hermitian physics", *Nat. Commun.* 10, 297 (2019). [selected as Editors' Highlights]

Masahito Ueda (Ph.D.), Team Director
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Research field

Physics, Engineering, Mathematics, Multidisciplinary

Keywords

Cold atoms, Bose-Einstein condensates, Nonequilibrium open quantum systems, Quantum thermodynamics

Brief resume

- 1988 Resercher, NTT Basic Research Laboratories
- 1994 Associate Professor, Hiroshima University
- 2000 Professor, Tokyo Institute of Technology
- 2008 Professor, University of Tokyo (-present)
- 2014 Team Leader, Quantum Condensate Research Team, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
- 2026 Deputy Director, TRIP Headquarters Fundamental Quantum Science Program (-present)

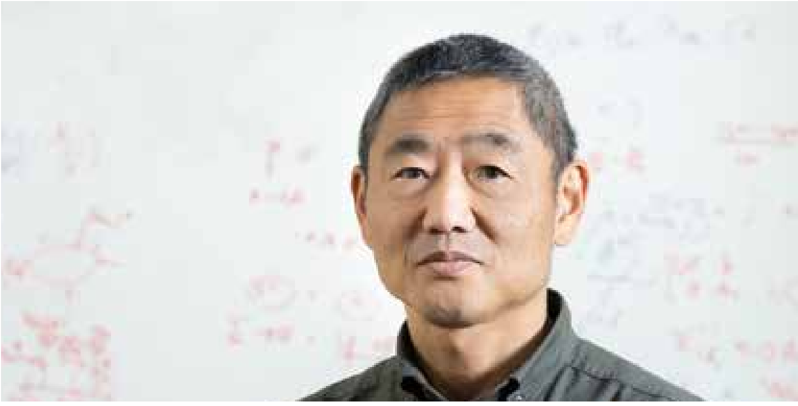
Outline

We aim to explore physics frontiers that lie at the borderlines between quantum physics, quantum measurement, information, thermodynamics, and machine learning. In particular, we explore nonequilibrium open quantum physics and quantum thermodynamics by using ultracold atoms in which almost all parameters such as the interparticle interaction are tunable.

Core members

(Research Scientist) Kenji Shu, Ken Nakanishi, Yusuke Morita
(Postdoctoral Researcher) Kai Li, Arpana Saboo
(Senior Visiting Scientist) John Morrissey Doyle
(Visiting Scientist) Naoto Tsuji

Spin Physics Theory Research Team



Gen Tatara (D.Sci.), Team Director
gen.tatara@riken.jp

Research field

Physics, Engineering, Materials Science

Keywords

Spintronics, Spin-orbit interaction, Domain wall, Monopole, Spin current, Metamaterial

Brief resume

- 1992 Doctor of Science, Department of Physics, Faculty of Science, University of Tokyo
- 1992 Postdoctoral Fellow, The Department of Physics, Faculty of Science, University of Tokyo
- 1994 Postdoctoral Fellow, The Institute of Physical and Chemical Research, RIKEN
- 1996 Assistant Professor, Graduate School of Science, Osaka University
- 2004 PRESTO, Japan Science and Technology Agency
- 2005 Associate Professor, Graduate School of Science and Engineering, Tokyo Metropolitan University
- 2012 Team Leader, Emergent Spintronics Theory Research Team, RIKEN
- 2013 Team Leader, Spin Physics Theory Research Team, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Microscopic theory of spintronics

Spin-charge conversion effects in spintronics have been conventionally argued based on the concept of spin current, which has a fundamental ambiguity that cannot be avoided arising from its non-conservation. We have presented a linear response theory formulation to describe the effects in terms of response functions between physical observable, free from ambiguity. Our formalism without phenomenological constants like spin mixing conductance is expected to be important for trustable predictions and designs of spintronics devices.

Theoretical description of spintronics effects in analogy with electromagnetism has also been carried out. The results would be useful for integration of spintronics into electronics.

In ferromagnetic metals, spin of electrons traveling through a magnetization structure follows the local spin and acquires a quantum phase. This phase acts as an effective electromagnetic fields that couples to electron spin.

Outline

Our aim is to explore novel spin-related effects with extremely high efficiency in condensed matters. We thus contributes to development of spintronics, a technology using spin as well as charge of electrons, and to realization of ultrafast and high-density information technology with low energy consumption. Our particular interest is at present in a strong quantum relativistic effect in solids, which is applicable to very strong magnets and efficient conversion of spin information to an electric signal. Our main method is a field theory.

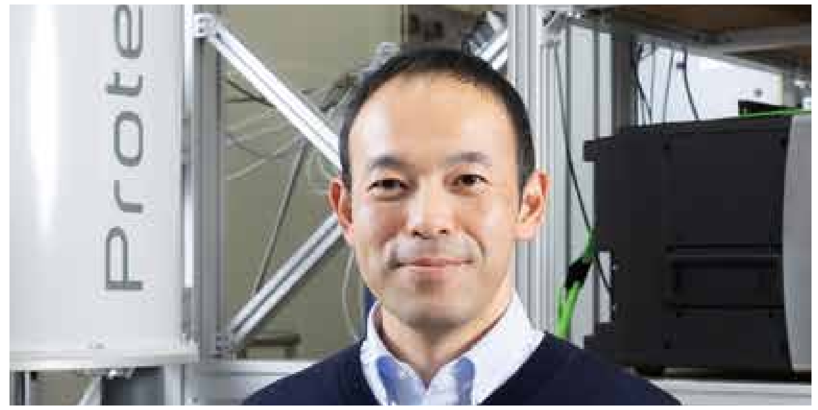
Publications

1. H. Funaki, and G. Tatara, "Hydrodynamic theory of chiral angular momentum generation in metals", *Phys. Rev. Research*, 3, 023160(9) (2021).
2. G. Tatara, C. A. Akosa, and R. M. Otxoa de Zuazola, "Magnon pair emission from a relativistic domain wall in antiferromagnets", *Phys. Rev. Research*, 2, 043226(17) (2020).
3. G. Tatara, "Effective gauge field theory of spintronics", *Physica E: Low-dimensional Systems and Nanostructures*, 106, 208-238 (2019).
4. C. A. Akosa, O. A.Tretiakov, G. Tatara, and A. Manchon, "Theory of the Topological Spin Hall Effect in Antiferromagnetic Skyrmions: Impact on Current-Induced Motion", *Phys. Rev. Lett.*, 121, 097204(5) (2018).
5. T. Kikuchi, T. Koretsune, R. Arita, and G. Tatara, "Dzyaloshinskii-Moriya Interaction as a Consequence of a Doppler Shift due to Spin-Orbit-Induced Intrinsic Spin Current", *Phys. Rev. Lett.*,116, 247201 (1-6) (2016). (PRL Editors'Suggestion).

Core members

(Research Scientist) Mohammad Hussein Naseef Al Assadi
(Special Postdoctoral Researcher) Dapeng Yao
(Postdoctoral Researcher) Kabir Salihu Suraj
(Research Associate) Ambalika Halder
(Visiting Scientist) Terufumi Yamaguchi

Quantum Electron Device Research Team



Michihisa Yamamoto (D.Sci.), Team Director
michihisa.yamamoto@riken.jp

Research field

Physics, Engineering

Keywords

Two-dimensional electron systems, Single electron manipulation, Nanodevices, Quantum coherence, Quantum correlations

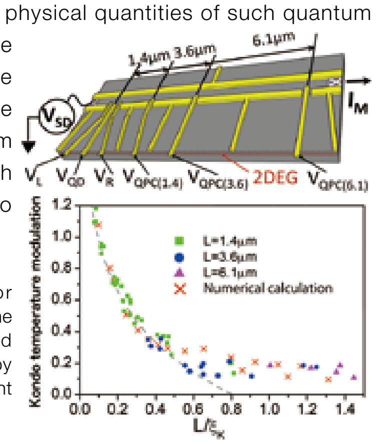
Brief resume

- 2004 Ph. D. in Physics, The University of Tokyo, Japan
- 2004 Research Associate, Department of Applied Physics, The University of Tokyo
- 2014 Lecturer, Department of Applied Physics, The University of Tokyo
- 2017 Associate Professor, Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo
- 2017 Unit Leader, Quantum Electron Device Research Unit, RIKEN Center for Emergent Matter Science
- 2020 Team Leader, Quantum Electron Device Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025
- 2023 Professor, Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo (-present)

Electrical control of the Kondo screening cloud and quantum simulation of quantum many-body systems

The Kondo effect, an archetype of many-body correlations, arises from the interaction between a localized spin and surrounding conducting electrons. Since conducting electrons form a spin cloud to screen the localized spin, the Kondo state is also called as the Kondo screening cloud. The size of the Kondo cloud is inverse proportional to the Kondo temperature and the cloud has the universal shape.

The Kondo cloud can be formed by confining a localized spin in a semiconductor artificial atom coupled to conducting electrons. Our recent experiment has revealed that the quantum interference can deform the cloud and modulate the entanglement between the localized spin and conducting electron spins. We are now investigating systems, where multiple Kondo clouds overlap and mediate coupling between distant localized spins. Quantitative calculation of physical quantities of such quantum many-body states is known to be difficult in the current technology. Precise and quantitative control of quantum systems based on the tunable Kondo cloud should enable quantum simulation of many-body systems with long-range spin coupling and its applications to the quantum information technology.



Schematic illustration of the device used for observation of the Kondo cloud and real shape of the Kondo cloud. The Kondo cloud shape was obtained by quantifying the Kondo temperature modulation by the gate voltage VQPC applied to the quantum point contacts. Figure taken from Nature 579, 210 (2020).

Outline

We develop quantum electron devices based on manipulation and transfer of quantum degrees of freedom in solids. We employ quantum electron optics, where quantum states of propagating electrons are manipulated in a single electron unit, and experiments on transfer and manipulation of novel quantum degrees of freedom in atomic-layer materials. These experiments aim to reveal physics of quantum coherence, quantum correlations, and quantum conversions, as guiding principles for quantum electron devices. We also employ state of the art quantum technologies to solve long-standing problems in condensed matter physics from microscopic points of view.

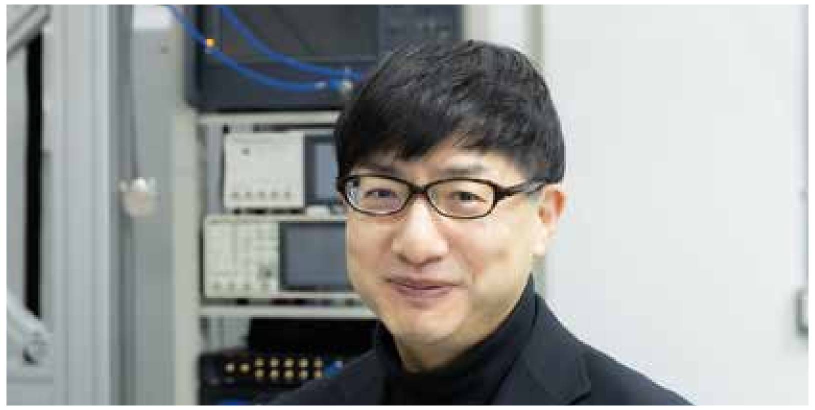
Publications

1. S. Takada, G. Georgiou, J. Wang, Y. Okazaki, S. Nakamura, D. Pomaranski, A. Ludwig, A. D. Wieck, M. Yamamoto, C. Bäuerle, and N.-H. Kaneko, "Eigenstate control of plasmon wavepackets with electron-channel blockade", *Nat. Commun.* 16, 9942 (2025).
2. M. Tanaka, K. Watanabe, T. Taniguchi, K. Nomura, S. Tarucha, and M. Yamamoto, "Temperature-induced phase transitions in the correlated quantum Hall state of bilayer graphene", *Phys. Rev. B*, 105, 075427 (2022).
3. R. Ito, S. Takada, A. Ludwig, A. D. Wieck, S. Tarucha, and M. Yamamoto, "Coherent beam splitting of flying electrons driven by a surface acoustic wave", *Phys. Rev. Lett.*, 126, 070501 (2021).
4. M. Tanaka, Y. Shimazaki, I. V. Borzenets, K. Watanabe, T. Taniguchi, S. Tarucha, and M. Yamamoto, "Charge Neutral Current Generation in a Spontaneous Quantum Hall Antiferromagnet", *Phys. Rev. Lett.*, 126, 016801 (2021).
5. I. V. Borzenets, J. Shim, J. C. H. Chen, A. Ludwig, A. D. Wieck, S. Tarucha, H.-S. Sim, and M. Yamamoto, "Observation of the Kondo screening cloud", *Nature*, 579, 210 (2020).

Core members

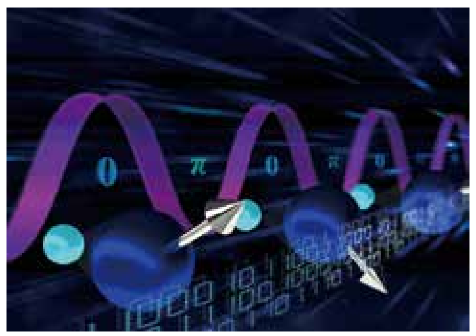
(Research Scientist) Ngoc Han Tu
(Visiting Scientist) David Pomaranski
(Student Trainee) Hiyu Kozaki, Koichi Aoki

Emergent Spintronics Research Team



Creating the principles of future quantum devices with spintronics

Quantum spintronics provides essential guiding principles for achieving innovative devices. It explores the physics of the interaction between the spin degrees of freedom of electrons and the diverse ordering in condensed matter, bridging the way to practical applications. Spin dynamics exhibiting strong nonlinearity due to the shape effects of nano magnets demonstrate exotic responses such as squeezing and nonlinear bifurcation phenomena, which can be controlled by spin and electric currents. Research on prominent nonlinear parametric processes in nano magnets is conducted, paving the way for nonlinear and quantum regimes in collective spin excitations. In particular, quantum squeezed magnons (spin waves) associated with strong nonlinearity and high coherence serve as promising magnetic quantum information carriers, offering potential applications in quantum information electronics and quantum sensors (e.g., magnetic field sensors, thermal and thermal fluctuation sensors). Furthermore, thermally squeezed magnons hold promise for applications in thermal control and power generation devices. Additionally, beyond ferromagnetic order, various ordered phases exist in condensed matter, and their coupling with electric and spin currents can yield exciting results. Leveraging the spintronics measurement techniques in our group, we also explore new realms of material science that this coupling can bring.



Parametron in nano magnets

Publications

1. H. Arisawa, Y. Fujimoto, T. Kikkawa, and E. Saitoh, "Observation of nonlinear thermoelectric effect in MoGe/$Y_3Fe_5O_{12}$", *Nat. Commun.* 15, 6912 (2024).
2. T. Makiuchi, T. Hioki, H. Shimizu, K. Hoshi, M. Elyasi, K. Yamamoto, N. Yokoi, A. A. Serga, B. Hillebrands, G. E. W. Bauer, and and, E. Saitoh, "Persistent magnetic coherence in magnets", *Nature Mater.* 23, 627 (2024).
3. H. Arisawa, H. Shim, S. Daimon, T. Kikkawa, Y. Oikawa, S. Takahashi, T. Ono, and and, E. Saitoh, "Observation of spin-current striction in a magnet", *Nat. Commun.* 13, 2440 (2022).
4. S. Daimon, K. Tsunekawa, S. Kawakami, T. Kikkawa, R. Ramos, K. Oyanagi, T. Ohtsuki, and E. Saitoh, "Deciphering quantum fingerprints in electric conductance", *Nat. Commun.* 13, 3160 (2022).
5. T. Kikkawa, D. Reitz, H. Ito, T. Makiuchi, T. Sugimoto, S. Daimon, K. Oyanagi, R. Ramos, S. Takahashi, Y. Shiomi, Y. Tserkovnyak, and E. Saitoh, "Observation of nuclear-spin Seebeck effect", Nat. Commun. 12, 4356 (2021).

Eiji Saitoh (Ph.D.), Team Director
eiji.saitoh@riken.jp

Research field

Physics, Engineering, Materials Sciences

Keywords

Spintronics, Energy conversion, Quantum device, Quantum information, Machine learning physics

Brief resume

- 2001 Ph.D., Engineering, University of Tokyo
- 2001 Research Associate, Department of Physics, Keio University
- 2006 Senior Lecturer, Department of Applied Physics, Keio University
- 2009 Professor, Institute for Materials Research, Tohoku University
- 2012 Professor, Principal Investigator at WPI-AIMR, Tohoku University
- 2018 Professor, Department of Applied Physics, University of Tokyo (-present)
- 2023 Team Leader, Emergent Spintronics Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

Outline

Our research team is conducting research on various quantum spintronics phenomena in nanoscale shape-controlled composite structures of magnetic materials, inorganic and organic semiconductors, and superconductors. Focusing on quantum spin dynamics, spin transport, and the interaction between spin and macroscopic order parameters, we are conducting experiments using methods such as transport measurements, optical measurements, and ultra low temperature microwave spectroscopy. Through this research, we aim to extend spintronics to the quantum domain, construct a fundamental physics system, and apply it to information processing and energy conversion.

Core members

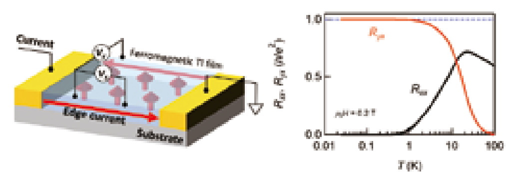
(Research Scientist) Takahiko Makiuchi
(Special Postdoctoral Researcher) Tomonao Araki
(Postdoctoral Researcher) Geil Emdi
(Visiting Scientist) Tomosato Hioki, Hiroki Arisawa, Naoto Yokoi, Koujiro Hoshi

Topological Electronics Research Team

Development of quantum resistance standard devices using magnetic topological insulators

Topological insulators are a class of materials that act as insulators in their interior but possess unique electrically conductive layers on their surfaces. In magnetic topological insulators, created by adding magnetic elements to these materials, the Hall resistance becomes quantized to the von Klitzing constant h/e^2, where h is Planck's constant and e is the elementary charge, even in the absence of an external magnetic field. This phenomenon, known as the quantum anomalous Hall effect, does not require massive high-field superconducting magnets typically used in resistance metrology, and thus holds potential for application as a next-generation quantum resistance standard.

We have successfully fabricated high-quality magnetic topological insulator heterostructure thin films using molecular beam epitaxy. Our measurements confirmed that the Hall resistance matches the von Klitzing constant with an extremely high precision of eight digits. This achievement represents a significant step toward the realization of compact quantum resistance standards that do not require high-field magnets, accelerating the miniaturization and widespread adoption of precision measurement technologies.



(Left) Schematic illustration of the quantum anomalous Hall effect device. (Right) Temperature dependence of the longitudinal (R_{xx}) and Hall (R_{yx}) resistance.

Publications

1. Y. Sato, S. Nagahama, S. Kitou, H. Sagayama, I. Belopolski, R. Yoshimi, M. Kawamura, A. Tsukazaki, N. Kanazawa, T. Nomoto, R. Arita, T. Arima, M. Kawasaki, and Y. Tokura "Superconductivity and suppressed monoclinic distortion in FeTe films enabled by higher-order epitaxy", *Nat. Commun.* 16, 10913 (2025).
2. Y. Sato, S. Nagahama, I. Belopolski, R. Yoshimi, M. Kawamura, A. Tsukazaki, A. Yamada, M. Tokunaga, N. Kanazawa, K. S. Takahashi, Y. Onuki, M. Kawasaki, and Y. Tokura "Non-Fermi liquid transport and strong mass enhancement near the nematic quantum critical point in $FeSe_xTe_{1-x}$ thin films", *Phys. Rev. B* 112, L041121 (2025).
3. M. Kawamura, M. Mogi, R. Yoshimi, T. Morimoto, K. S. Takahashi, A. Tsukazaki, N. Nagaosa, M. Kawasaki, and Y. Tokura "Laughlin charge pumping in a quantum anomalous Hall insulator", *Nat. Phys.* 19, 333 (2023).
4. M. Mogi, Y. Okamura, M. Kawamura, R. Yoshimi, K. Yasuda, A. Tsukazaki, K. S. Takahashi, T. Morimoto, N. Nagaosa, M. Kawasaki, Y. Takahashi, and Y. Tokura "Experimental signature of the parity anomaly in a semi-magnetic topological insulator", *Nat. Phys.* 18, 390 (2022).
5. Y. Okazaki, T. Oe, M. Kawamura, R. Yoshimi, S. Nakamura, S. Takada, M. Mogi, K. S. Takahashi, A. Tsukazaki, M. Kawasaki, Y. Tokura, and N. –H. Kaneko "Quantum anomalous Hall effect with a permanent magnet defines a quantum resistance standard", *Nat. Phys.* 18, 25 (2022).

Minoru Kawamura (Ph.D.), Team Director
minoru@riken.jp

Research field

Physics, Engineering, Materials Sciences

Keywords

Topological insulators, Topological superconductors, Thin films and interfaces, Quantum transport phenomena, Anomalous Hall effect

Brief resume

- 2001 Ph. D., The University of Tokyo
- 2001 Research Associate, NTT Basic Research Laboratories
- 2003 Special Postdoctoral Researcher, Low Temperature Physics Laboratory, RIKEN
- 2006 Assistant Professor, Institute of Industrial Science, The University of Tokyo
- 2008 Research Scientist, Low Temperature Physics Laboratory, RIKEN
- 2015 Senior Research Scientist, Strong Correlation Quantum Transport Research Team, RIKEN Center for Emergent Matter Science
- 2024 Team Leader, Topological Electronics Research Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April1, 2025

Outline

Our group investigates novel quantum transport phenomena emerging in thin films and interfaces of topological materials, as well as in their heterostructures. By leveraging advanced measurement techniques such as electrical transport measurements under extreme environments and microwave spectroscopy, we explore the non-trivial physical phenomena arising from electron correlation, geometric phases, and spin dynamics. Through these studies, we demonstrate innovative devices that utilize highly non-dissipative electron flows as carriers for information and energy, and we are committed to pioneering the new field of topological electronics.

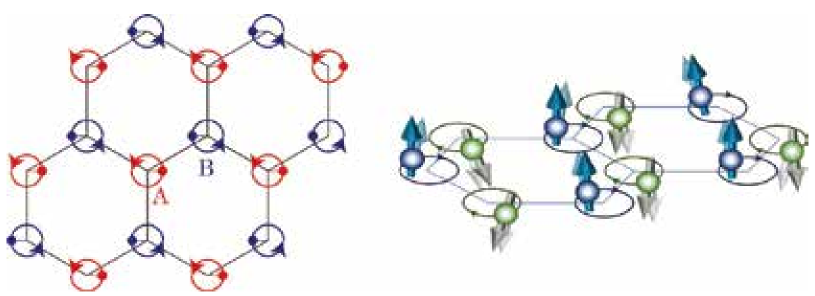
Core members

(Research Scientist) Ryo Ogawa, Yuki Sato

Topological Phenomena Theory Research Team

Theory of emergent phenomena by chiral phonons

Phonons are quantized vibrations of atoms in crystals, but in some materials, these phonons are accompanied by rotational motion. Such phonons are called chiral phonons. For example, in a system with a chiral crystal structure such as tellurium, the phonons are chiral phonons and involve angular momentum. We are theoretically studying new phenomena related to the angular momentum of such phonons. For example, we theoretically propose that in crystals with low symmetry, chiral phonons are induced when a temperature gradient is present in the crystal. Furthermore, we have theoretically shown that chiral phonons induce spin magnetization in electronic systems, noting that the angular momentum of phonons has the same symmetry as that of electron spin. This phenomenon is caused by the dynamical modulation of the electronic state by chiral phonons, which acquire a geometric phase (Berry phase) and induce spin polarization. Furthermore, we found that in localized spin systems such as ferromagnets and antiferromagnets, chiral phonons induce changes in magnon excitations. These indicate that chiral phonons act as an effective magnetic field for electrons and magnons.



Generation of spin polarization by chiral phonons

Publications

1. T. Jungwirth, J. Sinova, R. M. Fernandes, Q. Liu, H. Watanabe, S. Murakami, S. Nakatsuji, L. Šmejkal, "Symmetry, microscopy and spectroscopy signatures of altermagnetism", *Nature* 649, 837 (2026).
2. T. Zhang, S. Murakami, H. Miao, "Weyl phonons: the connection of topology and chirality", *Nat. Commun.* 16, 3560 (2025).
3. Y. Suzuki, S. Murakami, "Disorder-Induced Slow Relaxation of Phonon Polarization", *Phys. Rev. Lett.* 135, 046301 (2025)
4. Y. Tanaka, T. Zhang, M. Uwaha, S. Murakami, "Anomalous Crystal Shapes of Topological Crystalline Insulators" *Phys. Rev. Lett.* 129, 046802 (2022).
5. K. Yokomizo and S. Murakami, "Non-Bloch Band Theory of Non-Hermitian Systems", *Phys. Rev. Lett.* 123, 066404 (2019).

Shuichi Murakami (Ph.D.), Team Director
shuichi.murakami@riken.jp

Research field

Physics, Materials Sciences

Keywords

Topological insulator, Spintronics, Topological semimetal

Brief resume

- 1995 Research Associate, Department of Applied Physics, University of Tokyo
- 1999 Ph.D., University of Tokyo
- 1999 Visiting Scholar, Department of Physics, Stanford University
- 2007 Associate Professor, Department of Physics, Tokyo Institute of Technology
- 2007 PRESTO researcher, Japan Science and Technology Agency
- 2012 Professor, Department of Physics, Tokyo Institute of Technology
- 2016 Professor, Materials Research Center for Element Strategy, Tokyo Institute of Technology
- 2024 Professor, Department of Physics, Institute of Science Tokyo
- 2024 Specially Appointed Professor, International Institute for Sustainability with Knotted Chiral Meta Matter, Hiroshima University (-present)
- 2025 Professor, Department of Applied Physics, the University of Tokyo (-present)
- 2025 Team Director, Topological Phenomena Theory Research Team, RIKEN Center for Emergent Matter Science (-present)

Outline

Our team conducts theoretical research on emergent physical phenomena of electrons and quasiparticles in materials and waves in metamaterials, focusing on their topological structures. Our research methods are mainly analytical methods using models, and we find universal laws and phenomena from a broad perspective of quantum to classical systems. Our research activities cover a wide range of topics, from research on specific materials to the construction of theoretical frameworks for condensed matter and mathematical physics. Specifically, we are working in the fields such as topological phases, chiral phonons, electro-magnetic multipoles, non-Hermitian systems, and metamaterials.

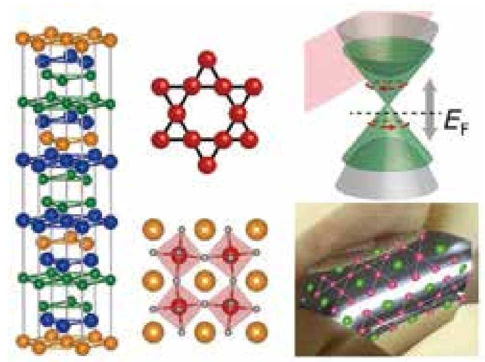
Core members

(Visiting Scientist) Yuta Suzuki
(Student Trainee) Hiroki Yoshida, Hidetoshi Wada, Ryoma Kurita

Quantum materials innovation research team

Creation of functional devices utilizing the characteristic electronic structure of quantum materials

Advances in computational and synthetic techniques are rapidly advancing our understanding of materials and the development of novel devices. For example, topological materials possess electronic states distinct from conventional semiconductors and metals, exhibiting new and intriguing physical properties derived from their characteristic electronic structures. Since numerous candidate materials exist for such quantum materials, efficiently identifying them and advancing synthesis and device demonstration is crucial. While advancing the exploration of quantum materials from the perspective of fundamental properties, we aim to create functional devices that utilize these properties to reduce the power consumption of various general-purpose devices.



Advancing device development through the exploration of quantum materials with various crystal structures and control of their electronic states

Publications

1. M. Osada, C. Terakura, A. Kikkawa, M. Nakajima, H.-Y. Chen, Y. Nomura, Y. Tokura, and A. Tsukazaki "Strain-tuning for superconductivity in $La_3Ni_2O_7$ thin films", *Communication Physics*, 8, 251 (2025).
2. S. Noguchi, K. Fujiwara, Y. Yanagi, M. Suzuki, T. Hirai, T. Seki, K. Uchida, and A. Tsukazaki, "Bipolarity of large anomalous Nernst effect in Weyl magnet-based alloy films", *Nature Physics,* 20, 254 (2024).
3. K. Fujiwara, Y. Kato, H. Abe, S. Noguchi, J. Shiogai, Y. Niwa, H. Kumigashira, Y. Motome, and A. Tsukazaki, "Berry curvature contributions of kagome lattice fragments in amorphous Fe–Sn thin films", *Nature Communications*, 14, 3399 (2023).
4. J. Shiogai, K. Fujiwara, T. Nojima, and A. Tsukazaki, "Three-dimensional sensing of the magnetic-field vector by a compact planar-type Hall device", *Communications Materials*, 2, 102 (2021).
5. J. Ikeda, K. Fujiwara, J. Shiogai, T. Seki, K. Nomura, K. Takanashi, and A. Tsukazaki, "Two-dimensionality of metallic surface conduction in $Co_3Sn_2S_2$ thin films", *Communications Physics*, 4, 117 (2021).

Tsukazaki Atsushi (D.Sc.), Team Director
atsushi.tsukazaki@riken.jp

Research field

Materials Sciences

Keywords

Thin films and interfaces, Interface electronic structure, Topological quantum matters, Quantum transport phenomena, Quantum devices

Brief resume

- 2005 Department of Chemistry, Tohoku University, Doctoral program
- 2005 Institute for Materials Research, Tohoku University, Postdoctoral researcher
- 2006 Institute for Materials Research, Tohoku University, JSPS research fellowship (PD), Postdoctoral researcher
- 2007 Institute for Materials Research, Tohoku University, Assistant Professor
- 2010 Quantum-Phase Electronics Center, University of Tokyo, Designated Lecturer
- 2012 Graduated School of Frontier Science, University of Tokyo, Associate Professor
- 2013 Institute for Materials Research, Tohoku University, Professor
- 2024 Quantum-Phase Electronics Center and Department of Applied Physics, University of Tokyo, Professor (-present)
- 2026 Team Director, Quantum Materials Innovation Research Team, RIKEN Center for Emergent Matter Science (-present)

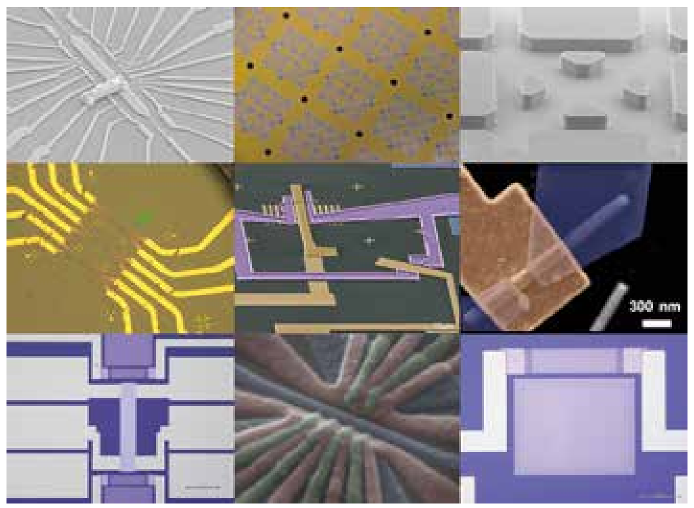
Outline

Our team focuses on the physical properties of quantum materials, specifically thin films and their stacked interfaces. We develop thin-film fabrication techniques for materials that exhibit topological electronic states, and evaluating the unique physical properties of thin films. In addition, by leveraging advanced thin-film techniques, we effectively explore novel quantum materials exhibiting remarkable physical properties. We aim to elucidate the origins of these properties and develop new functionalities. Our research extends to demonstrating functional creation through property control, aiming to develop low-power consumption devices.

Semiconductor Science Research Support Team

Supporting nano-device fabrication

To build a sustainable society, it is essential to realize devices with low power consumption and high-speed operation based on nanotechnologies. In Center for Emergent Matter Science, researchers are developing quantum and spin devices by using state-of-the-art equipment with its best condition Our team is established to support the researcher's activity by providing skillful expertise. We are responsible for the operation of equipment like lithography systems including electron-beam lithography systems, maskless UV photolithography systems, deposition systems like evaporators and sputters, dry and wet etching systems and observation system like scanning electron microscopy. We instruct users in the usage of equipment and provide technical information in fabrication. With our effort, the researchers are now able to fabricate and characterize various devices in the range of 10 nm – 10 μm routinely.



Devices fabricated in the cleanroom.

Fumihiro Matsukura (D.Sci.), Team Director
fumihiro.matsukura@riken.jp

Research field

Physics, Materials Science

Keywords

Nano-device fabrication, Device characterization, User education

Brief resume

2012 Professor, AIMR, Tohoku University
2018 Professor, CIES, Tohoku University
2023 Team Leader, Semiconductor Science Research Support Team, RIKEN Center for Emergent Matter Science (-present) Position name has been changed to Team Director as of April 1, 2025

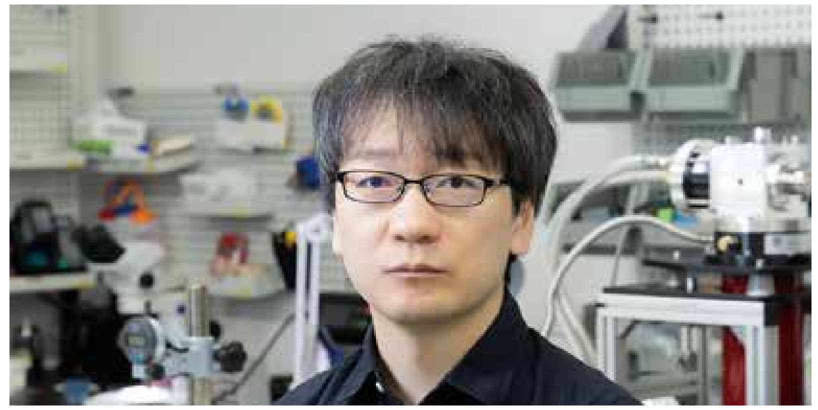
Outline

Our mission is to develop novel technologies in nanoscience and nanotechnology and to support the users in RIKEN for the fabrication and characterization of nanoscale devices. We are responsible for the operation of the facilities including the cleanroom (ISO class 5) and the chemical rooms with suitable safety measures by educating the users.

Core members

(Technical Staff I)
Reiko Nakatomi, Yoshio Taguchi, Hideaki Oyama
(Senior Technical Scientist) Tomohiro Yamaguchi

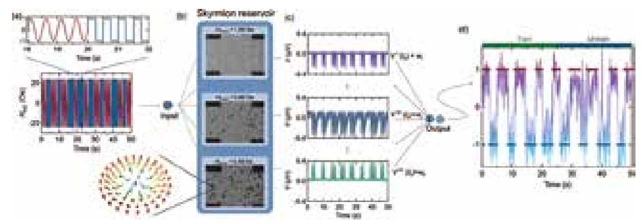
Emergent Quantum Spintronics Research Unit



Physical reservoir computing using skyrmions

Recently, artificial intelligence (AI), which is machine learning inspired by the design of the human brain, has been rapidly developing, leading to innovative technologies and services. However, addressing the substantial power consumption when executing AI with conventional computational devices has become an urgent issue. Consequently, the study of "neuromorphic devices", which mimic the brain's behavior at the device level aiming for higher performance and energy-efficient artificial intelligence, has become crucial.

We have demonstrated that a topological spin structure called a skyrmion can be used for "physical reservoir computing", a category of neuromorphic devices. First, we revealed that the skyrmion dynamics induced by a magnetic field satisfy the properties required for physical reservoir computing. Then, by fabricating skyrmion-based physical reservoir devices and conducting several benchmark tests, we found that the formation of skyrmions is vital for improving the performance. This discovery reveals the potential to improve the performance and energy efficiency of neuromorphic devices using skyrmions.



Schematics of the benchmark test for the skyrmion physical reservoir. (a) Waveform of the input signal. For the benchmark test, we input a combination of sine waves and square waves, and executed a problem that outputs 1 if the input is a sine wave and -1 if it is a square wave. (b) Schematic of the skyrmion physical reservoir device. The skyrmion physical reservoir device was constructed by connecting cross-shape devices in parallel. (c) Output waveforms from each cross-shape device. (d) Final output of the skyrmion physical reservoir computer. The red and blue horizontal lines indicate the correct output.

Publications

1. T. Yokouchi, Y. Ikeda, T. Morimoto, and Y. Shiomi, "Giant Magnetochiral Anisotropy in Weyl-semimetal WTe_2 Induced by Diverging Berry Curvature" *Phys. Rev. Lett.* 130, 136301 (2023).
2. T. Yokouchi, S. Sugimoto, B. Rana, S. Seki, N. Ogawa, Y. Shiomi S. Kasai, and Y. Otani "Pattern recognition with neuromorphic computing using magnetic-field induced dynamics of skyrmions" *Sci. Adv.* 8, abq5652 (2022).
3. T. Yokouchi, F. Kagawa, M. Hirschberger, Y. Otani, N. Nagaosa, and Y. Tokura "Emergent electromagnetic induction in a helical-spin magnet" *Nature* 586, 232 (2020).
4. T. Yokouchi, F. Kagawa, M. Hirschberger, Y. Otani, N. Nagaosa, and Y. Tokura "Creation of magnetic skyrmions by surface acoustic waves" *Nat. Nanotechnol.* 15, 361 (2020).
5. T. Yokouchi, S. Hoshino, N. Kanazawa, A. Kikkawa, D. Morikawa, K. Shibata, T. Arima, Y. Taguchi, F. Kagawa, N. Nagaosa, Y. Tokura, "Current-induced dynamics of skyrmion strings" *Sci. Adv.* 4, eaat1115 (2018).

Tomoyuki Yokouchi (D. Eng.), Unit Leader
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Research field

Physics, Engineering, Materials Sciences

Keywords

Spintronics, Artificial intelligence, Magnetic skyrmions, Spin dynamics, Spin Hall effect

Brief resume

2018 D. Eng., University of Tokyo
2018 Special Postdoctoral Researcher, RIKEN Center for Emergent Matter Science
2020 Assistant Professor, Graduate School of Arts and Sciences, The University of Tokyo
2023 Unit Leader, Emergent Quantum Spintronics Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (-present)

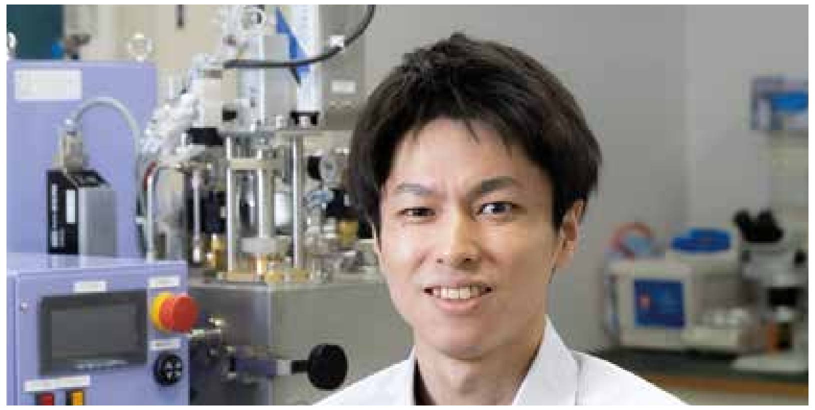
Outline

The aim of our unit is to understand the quantum and emergent properties in spintronics, which aims to utilize both the charge and spin of electrons, and to construct a new scheme for them. In particular, by employing microfabrication techniques, we will develop novel quantum spintronic and quantum transport phenomena in various magnetic materials. Our goal is to elucidate the mechanisms driving their emergence. Furthermore, by focusing on the classical and quantum dynamics of topological spin structures, we will also work to establish a new scheme for emergent computational techniques, such as physical reservoir computing.

Core members

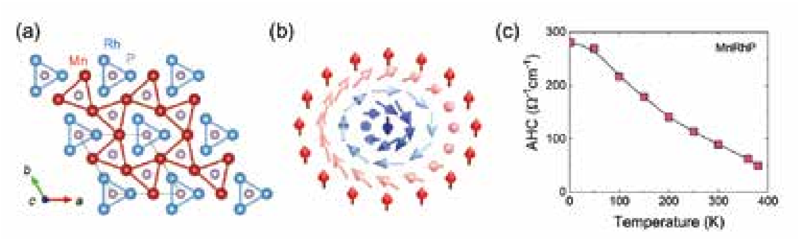
(Special Postdoctoral Researcher) Hikaru Fukuda
(Postdoctoral Researcher) Yunyoung Hwang

Emergent Functional Magnetic Materials Research Unit



Development of kagome lattice magnets hosting room-temperature skyrmions and large anomalous Hall effect

Magnetic materials with a kagome lattice have attracted considerable attention in recent years because their geometric structure gives rise to a variety of topological properties. However, materials that exhibit topological phenomena above room temperature have been limited so far. We have successfully synthesized single crystals of MnRhP, a magnetic material with a distorted kagome lattice, and systematically investigated its magnetic structure and electrical transport properties. We found that this material hosts magnetic skyrmions above room temperature and exhibits a large anomalous Hall effect. Furthermore, first-principles calculations reveal that this anomalous Hall effect originates from the Berry curvature associated with topological nodal lines. This study demonstrates that MnRhP is a rare kagome lattice magnet that possesses topological properties in both real space and momentum space.



(a) Schematic crystal structure of MnRhP. (b) Schematic spin texture of a magnetic skyrmion. (c) Temperature dependence of the anomalous Hall conductivity (AHC) in MnRhP.

Publications

1. K. Karube, M.-C. Jiang, L. Keller, J. S. White, Y. L. Chiew, X. Z. Yu, G.-Y. Guo, R. Arita, Y. Tokura, and Y. Taguchi, "Room-Temperature Magnetic Skyrmions and Intrinsic Anomalous Hall Effect in a Nodal-Line Kagomé Ferromagnet MnRhP", *Adv. Sci.*, e21734 (2026).
2. K. Karube, Y. Ōnuki, T. Nakajima, H.-Y. Chen, H. Ishizuka, M. Kimata, T. Ohhara, K. Munakata, T. Nomoto, R. Arita, T. Arima, Y. Tokura, and Y. Taguchi, "Giant Hall effect in a highly conductive frustrated magnet $GdCu_2$", *npj Quantum Mater.*, 10, 55 (2025).
3. J. S. White, V. Ukleev, L. Yu, Y. Tokura, Y. Taguchi, and K. Karube, "Anisotropy-Dependent Decay of Room Temperature Metastable Skyrmions and a Nascent Double-q Spin Texture in $Co_8Zn_9Mn_3$", *Adv. Mater.*, 37, 2501146 (2025).
4. K. Karube, L. C. Peng, J. Masell, M. Hemmida, H.-A. Krug von Nidda, I. Kézsmárki, X. Z. Yu, Y. Tokura, and Y. Taguchi, "Doping Control of Magnetic Anisotropy for Stable Antiskyrmion Formation in Schreibersite $(Fe,Ni)_3P$ with S_4 symmetry", *Adv. Mater.*, 34, 2108770 (2022).
5. K. Karube, L. C. Peng, J. Masell, X. Z. Yu, F. Kagawa, Y. Tokura, and Y. Taguchi, "Room-temperature antiskyrmions and sawtooth surface textures in a non-centrosymmetric magnet with S_4 symmetry", *Nat. Mater.*, 20, 335 (2021).

Kosuke Karube (Ph.D.), Unit Leader
kosuke.karube@riken.jp

Research field

Materials Sciences, Physics, Engineering

Keywords

Strongly correlated electron systems, Magnetism, Topological materials

Brief resume

2015 Ph.D., Kyoto University
2015 Postdoctoral Researcher, Strong-Correlation Materials Research Group, RIKEN Center for Emergent Matter Science
2019 Research Scientist, Strong-Correlation Materials Research Group, RIKEN Center for Emergent Matter Science
2023 Senior Research Scientist, Strong-Correlation Materials Research Group, RIKEN Center for Emergent Matter Science
2023 Unit Leader, Emergent Functional Magnetic Materials Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (-present)

Outline

Our unit aims to develop new magnetic materials with topological and high-performance magnetic functionalities. We focus on the exploration of novel intermetallic compounds and alloys using single-crystal growth and non-equilibrium methods, and elucidate their magnetic structures and topological properties through various experimental techniques, including magnetometry, electrical transport measurements, scanning probe microscopy, and neutron scattering.

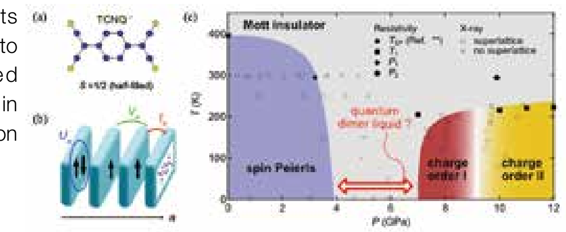
Core members

(Postdoctoral Researcher) Nikola Subotic

Extreme Quantum Matter Physics RIKEN ECL Research Unit

Ultra-high-pressure control of strongly correlated electron system

In strongly correlated electron systems, the conventional band picture breaks down under strong electron-electron interactions, giving rise to a variety of electronic phases such as Mott insulators and high-temperature superconductors. If we could freely control these interactions, it would open the door to new quantum phases and functionalities. We applied extremely high pressure to the half-filled, quasi-one-dimensional Mott insulator K-TCNQ and observed a transition from a Mott insulator with a spin-Peierls state to a charge-ordered phase. While this behavior aligns with the one-dimensional extended Hubbard model, it has never been experimentally confirmed. Furthermore, we discovered a novel ground state—referred to here as a "quantum dimer liquid"—in which dimer fluctuations persist even at the lowest temperatures. These findings were achieved through electrical resistivity measurements under high pressure using a diamond anvil cell, synchrotron X-ray diffraction, optical measurements, and collaborative research involving first-principles calculations. Going forward, we will continue to combine multifaceted experiments and theoretical analyses to explore the uncharted quantum phases hidden in strongly correlated electron systems.



(a) Chemical formula of TCNQ. (b) Schematic view of a TCNQ chain with on-site (Ua) and inter-site (Va) Coulomb interaction and transfer integral (ta). (c) Pressure-temperature phase diagram of K-TCNQ consisting of spin-Peierls and two distinct charge ordered states, along with the possible quantum dimer liquid.

Publications

1. H. Matsuoka*, Y. Fujishiro*, S. Minami, T. Koretsune, T. Ueda, N. Kanazawa, R. Arita, Y. Tokura, Y. Iwasa, "Electron-doped magnetic Weyl semimetal $Co_3Sn_2S_2$ by bulk-gating", *Physical Review Materials* 9, 064406 (2025) (*equal contributions)
2. M. Gen, Y. Fujishiro, K. Okigami, S. Hayami, M. T. Birch, K. Adachi, D. Hashizume, T. Kurumaji, H. Sagayama, H. Nakao, Y. Tokura, T. Arima, "Incommensurate broken helix induced by nonstoichiometry in the axion insulator candidate $EuIn_2As_2$", *Phys. Rev. B* 111, L081109 (2025)
3. Y. Fujishiro, C. Terakura, A. Miyake, N. Kanazawa, K. Nakazawa, N. Ogawa, H. Kadobayashi, S. Kawaguchi, T. Kagayama, M. Tokunaga, Y. Kato, Y. Motome, K. Shimizu, and Y. Tokura "Pressure-induced quantum melting of chiral spin order and subsequent transition to a degenerate semiconductor state in FeGe", *Phys. Rev. B* 110, L220401 (2024). *Editors' Suggestion
4. D. Singh, Y. Fujishiro, S. Hayami, S. Mooday, T. Nomoto, P. R. Baral, V. Ukleev, R. Cubitt, N-J. Steinke, D. J. Gawryluk, E. Pomjakushina, Y. Onuki, R. Arita, Y. Tokura, N. Kanazawa, and J. S. White "Transition between distinct hybrid skyrmion textures through their hexagonal-to-square crystal transformation in a polar magnet", *Nat. Commun.* 14, 8050 (2023).
5. Y. Fujishiro, N. Kanazawa, R. Kurihara, H. Ishizuka, T. Hori, F. S. Yasin, X. Z. Yu, A. Tsukazaki, M. Ichikawa, M. Kawasaki, N. Nagaosa, M. Tokunaga, and Y. Tokura "Giant anomalous Hall effect from spin-chirality scattering in a chiral magnet", *Nat. Commun.* 12, 317 (2021).

Yukako Fujishiro (D.Eng.), RIKEN ECL Unit Leader
yukako.fujishiro@riken.jp

Research field

Physics, Engineering, Materials Sciences

Keywords

Magnetic topological material, strongly correlated electron system, charge transport phenomena, intercalation, ultra-high pressure

Brief resume

2021 D. Eng., The University of Tokyo
2021 Special Postdoctoral Researcher, RIKEN Center for Emergent Matter Science
2024 RIKEN ECL Unit Leader, Extreme Quantum Matter Physics RIKEN ECL Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (–present)
2024 RIKEN ECL Unit Leader, Extreme Quantum Matter Physics RIKEN ECL Research Unit, RIKEN Cluster for Pioneering Research
2025 RIKEN ECL Unit Leader, Extreme Quantum Matter Physics RIKEN ECL Research Unit, RIKEN Pioneering Research Institute (–present)
2026 The University of Tokyo, School of Engineering, Institute of Engineering Innovation / Department of Applied Physics, Associate Professor (–present)

Outline

In our unit, we aim to investigate intriguing emergent phenomena in magnetic topological materials and strongly correlated electron system, with a particular emphasis on "extreme" conditions previously unattainable in earlier experiments. For instance, we employ microfabrication techniques on single crystalline quantum materials using focused ion beams (FIB). This enables us to (i) perform precise magneto-transport study under ultra-high pressure, (ii) explore magnetization dynamics in spin textures under high-density currents, and (iii) manipulate carrier densities in bulk layered materials through ion intercalation. Through these innovative approaches, we aim to reveal new quantum phases and elucidate their electronic functionalities.

Core members

(Postdoctoral Researcher) Haruto Yoshimochi

Topological Materials Design Research Unit

Motoaki Hirayama (Ph.D.), Unit Leader
motoaki.hirayama@riken.jp

Research field

Physics, Materials Science

Keywords

First-principles calculations, Theoretical materials design, Topological materials, Majorana fermions and parafermions, Spin-orbit interaction

Brief resume

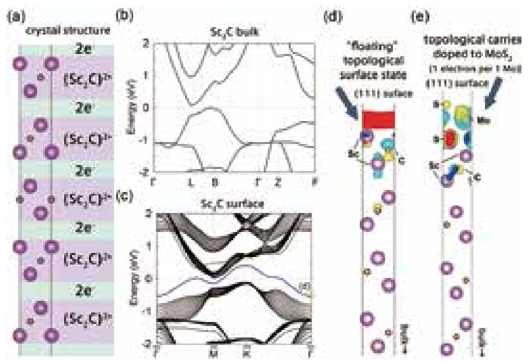
2013 Ph.D., Department of Applied Physics, University of Tokyo
2013 Postdoctoral Researcher, Nanosystem Research Institute, AIST
2015 Project Assistant Professor, Department of Physics, Tokyo Institute of Technology
2017 Research Scientist, First-Principles Materials Science Research Team, RIKEN Center for Emergent Matter Science
2020 Unit Leader, Topological Materials Design Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (-present)
2020 Project Associate Professor, Quantum-Phase Electronics Center, The University of Tokyo (-present)

Outline

In our unit, we explore novel materials and their properties using first-principles calculations, which are numerical methods for realistic materials. In particular, we focus on the topological properties of the electronic band structure and search for topological materials with non-trivial properties. We investigate the properties and applications of these unique electronic states. We also include superconducting states and propose the emergence of Majorana fermions. In addition, we develop ab initio methods to treat correlation effects and design a wide range of materials including strongly correlated systems and magnetic systems. We design materials across a wide range of fields, including materials in the chemical and materials fields, such as electrides.

Electrides as a new platform of topological materials

Our unit propose e lectrides as a new platform of topological materials. Electrides are a group of materials in which electron e^- exists in the interstitial region and stabilizes the structure as an anion. Electrides are being studied in the field of catalysis because of their small work function. For example, in the layered material Sc_2C (Fig. (a)), electrons enter the cavities between the layers and exhibit insulating properties as shown in Fig. (b). The charge density of $[Sc_2C]^{2+}2e^-$ extends to interlayer positions that are significantly displaced from the Sc_2C layer due to the anionic electrons $2e^-$, resulting in a non-trivial system with a quantized large polarization. Reflecting the bulk topology, a topologically-protected metallic state appears on the Sc_2C surface (Fig. (c)). The metallic surface state originates from the interstitial electron, and therefore floats above the Sc_2C surface (Fig. (d)). This electron cloud has a small work function, making it possible to use Sc_2C as a topological substrate for high-density electron doping. For example, one electron per Mo site can be doped for MoS_2 (Fig. (e)). We have discovered a variety of topological electrides including relativistic systems, which will lead to the development of topological properties across scientific fields.



(a) Crystal structure of the topological electride $[Sc_2C]^{2+}2e^-$, (b) band structure of Sc_2C, (c) band structure of the Sc_2C (111) surface, (d) floating topological surface state, (e) topological carrier doped to MoS_2

Publications

1. M. Sato, J. Bouaziz, S. Sumita, S. Kobayashi, I. Tateishi, S. Blügel, A. Furusaki, and M. Hirayama, "Ideal Spin-Orbit-Free Dirac Semimetal and Diverse Topological Transitions in Y_8CoIn_3 Family", *Commun. Mater.* 5 253 (2024).
2. M. Hirayama, T. Nomoto, and R. Arita, "Topological band inversion and chiral Majorana mode in hcp thallium", *J. Phys.: Condens. Matter* 36 275502, (2024).
3. T. Yu, R. Arita, and M. Hirayama, "Interstitial-Electron-Induced Topological Molecular Crystals", *Adv. Phys. Res.* 2200041 (2023).
4. T. Tsuda, M. Sheng, H. Ishikawa, S. Yamazoe, J. Yamasaki, M. Hirayama, S. Yamaguchi, T. Mizugaki and T. Mitsudome, "Iron phosphide nanocrystals as an air-stable heterogeneous catalyst for liquid-phase nitrile hydrogenation", *Nat. Commun.* 14, 5959 (2023).
5. I. Tateishi and M. Hirayama, "Quantum spin Hall effect from multi-scale band inversion in twisted bilayer $Bi_2(Te_{1-x}Se_x)_3$", *Phys. Rev. Research* 4, 043045 (2022).

Strong Correlation Quantum Phase RIKEN ECL Research Unit

Rina Tazai (D.Sci.), RIKEN ECL Unit Leader
rina.tazai@riken.jp

Research field

Physics

Keywords

Magnetism, Superconductivity, Strongly correlated electron systems, Quantum correlations and Quantum transport phenomena

Brief resume

2020 D.Sci., Graduate School of Science, Nagoya University
2020 Project Assistant Professor, Graduate School of Science, Nagoya University
2022 Assistant Professor, Yukawa Institute for Theoretical Physics, Kyoto University
2026 Unit Leader, Strong Correlation Quantum Phase RIKEN ECL Research Unit, RIKEN Center for Emergent Matter Science (-present)

Outline

Our unit conducts theoretical research on strongly correlated electron systems in solid-state materials such as superconductors and magnets. Condensed matter physics has historically advanced through close collaboration between theory and experiment. With recent progress in high-precision experimental techniques and faster computational methods, previously inaccessible phenomena are now being uncovered. Starting from microscopic theoretical models that describe individual electron behavior, our aim is to propose novel electronic phases, quantum phase transitions, and transport phenomena, thereby contributing to the deeper understanding of condensed matter systems and bridging theory with experiment.

Theoretical studies of superconductivity and novel quantum phases in metals

Metals exhibit a wide variety of physical states depending on temperature, pressure, and impurity. Among these, the superconducting state is one of the most fascinating quantum phenomena. Until now, superconductivity arises from the formation of electron pairs. However, the fundamental question of how electrons—despite their strong Coulomb repulsion—can form such pairs has not yet been fully clarified.

In particular, in materials where electron–electron repulsion is very strong, it has long been believed that electrons cannot easily form pairs at the same location, known as s-wave pairing. Nevertheless, recent studies have shown that even in heavy-fermion systems—where strong correlations give rise to extremely large effective electron masses, sometimes reaching nearly a thousand times that of free electrons—as well as in other strongly correlated materials, on-site pairing can indeed emerge.

Understanding why such pairing becomes possible in these systems remains an open challenge. A key concept is the presence of multiple internal degrees of freedom of electrons, such as spin, orbital, layer, and sublattice degrees of freedom. From this viewpoint, intensive theoretical efforts are currently underway to uncover the microscopic mechanisms of superconductivity in a wide range of materials.

Furthermore, these multiple electronic degrees of freedom are not only essential for superconductivity but are also closely related to the emergence of other unconventional quantum phases, including spatially inhomogeneous charge states, magnetism, itinerant loop-current phases, and bond-ordered states. In this unit, by studying electronic many-body systems with multiple degrees of freedom, we aim to explore and discover new quantum phenomena and possibilities arising from collective electronic behavior.

Publications

1. Rina Tazai, Youichi Yamakawa, Hiroshi Kontani, "Drastic magnetic-field-induced chiral current order and emergent current-bond-field interplay in kagome metals", *Proceedings of the National Academy of Sciences* 121, e2303476121 (2024).
2. Rina Tazai, Youichi Yamakawa, Hiroshi Kontani, "Charge-loop current order and Z_3 nematicity mediated by bond-order fluctuations in kagome metal AV_3Sb_5 (A=Cs,Rb,K)", *Nat. Commun.*,14, 7845 (2023).
3. Rina Tazai, Youichi Yamakawa, Seiichiro Onari, Hiroshi Kontani, "Mechanism of exotic density-wave and beyond-Migdal unconventional superconductivity in kagome metal AV_3Sb_5 (A = K, Rb, Cs)", *Science Advances*, 8, eabl4108 (2022).
4. Rina Tazai, Youichi Yamakawa, Hiroshi Kontani, "Emergence of charge loop current in the geometrically frustrated Hubbard model: A functional renormalization group study", *Phys. Rev. B* 103, L161112 (2021).
5. Rina Tazai, Hiroshi Kontani, "Fully gapped s-wave superconductivity enhanced by magnetic criticality in heavy fermion system", *Phys. Rev. B* 98, 205107 (2018).

Molecular Materials Synthesis Research Unit

Midori Akiyama (Ph.D.), Unit Leader

midori.akiyama@riken.jp

Research field

Chemistry

Keywords

Organic synthesis, Structural organic chemistry, Fluorine compounds, Polymer synthesis

Brief resume

2017 PhD., Department of Chemistry and Biotechnology, Graduate School of Engineering, The University of Tokyo

2017 Project Assistant Professor, Department of Chemistry and Biotechnology, School of Engineering, The University of Tokyo

2022 Assistant Professor, Department of Molecular Engineering, Graduate School of Science, Kyoto University

2026 Unit Leader, Emergent Functional Magnetic Materials Research Unit, Cross-Divisional Materials Research Program, RIKEN CEMS(-present)

Outline

Our group aim to create novel molecular materials based on original synthetic methodologies and to uncover new functionalities. Our current research focuses on fluorinated compounds, with particular emphasis on developing synthetic methods for both small molecules and polymers using fluorine gas. Through these efforts, we seek to explore previously uncharted chemical space.

Core members

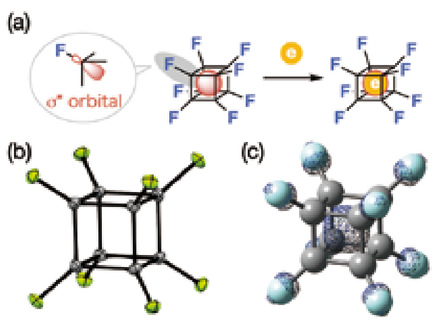
(Student Trainee) Keima Higashio, Yuki Kitayama

Molecular boxes to trap electrons: synthesis and observation of a confined electron

Polyhedral molecules fully substituted with fluorine atoms have long been predicted to accept an electron within their interiors. However, the synthesis of such molecules had remained an unsolved challenge. In this work, we achieved the first synthesis of perfluorocubane, a cubic molecule in which fluorine atoms are bound to all eight vertices, and demonstrate the confinement of an electron inside its molecular framework.

The key to this achievement is the controlled use of fluorine gas. Although fluorine gas is known for its extremely high reactivity and explosive reactions with organic compounds, making it unsuitable for conventional organic synthesis. On the other hand, we achieved the synthesis of perfluorocubane by employing our original method enabling introduction of fluorine atoms while suppressing uncontrollable reactions.

Traditionally, electron-accepting compounds have been designed by constructing π-conjugated systems to stabilize low-lying molecular orbitals. In contrast, we demonstrate an fundamentally different design principle: electron acceptance without π-conjugation. Therefore, this work represents a paradigm shift in designing organic functional molecules.



(a) Electron acceptance of perfluorocubane. (b) Single crystal structure of perfluorocubane. (c) Spin density of the reduced species of perfluorocubane.

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1. M. Akiyama, Y. Amabe, M. Sugiyama, K. Sugiyama, T. Gatzenmeier, and T. Okazoe, "The Tetrafluoroethylene-MM.ediated Ring-Closing Metathesis: Enabling Unfavored Reactions", *Journal of the American Chemical Society*, 146, 32550 (2024).
2. M. Sugiyama, Y. Uetake, N. Miyagi, M. Yoshida, K. Nozaki, T. Okazoe, and M. Akiyama, "Exceptionally Short Tetracoordinated Carbon–Halogen Bonds in Hexafluorodihalocubanes", *Journal of the American Chemical Society*, 146, 30686 (2024).
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4. M. Akiyama, Y. Yasuda, D. Kisoi, Y. Kusakabe, H. Kaji, and H. Imahori, "Perfluoroadamantyl Group: Bulky and Highly Electron-Withdrawing Substituent in Thermally Activated Delayed Fluorescence Materials" *Bulletin of the Chemical Society Japan*, 97, uoae025 (2024).
5. M. Sugiyama, M. Akiyama, Y. Yonezawa, K. Komaguchi, M. Higashi, K. Nozaki, and T. Okazoe, "Electron in a cube: synthesis and characterization of perfluorocubane as an electron acceptor", *Science*, 377, 756 (2022).

Emergent Functionality Design Research Unit

Shun Okumura (Ph.D.), Unit Leader

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Research field

Physics, Engineering, Materials Science

Keywords

Theoretical materials design, Emergent electromagnetism, Topological materials, Optical properties, Spintronics

Brief resume

2020 Ph.D., Department of Applied Physics, The University of Tokyo

2020 JSPS Postdoctoral Researcher, Department of Applied Physics, The University of Tokyo

2021 Project Assistant Professor, Institute for Solid State Physics, The University of Tokyo

2023 Assistant Professor, Department of Applied Physics, The University of Tokyo

2025 Unit Leader, Emergent Functionality Design Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (-present)

2025 Project Associate Professor, Quantum-Phase Electronics Center, The University of Tokyo (-present)

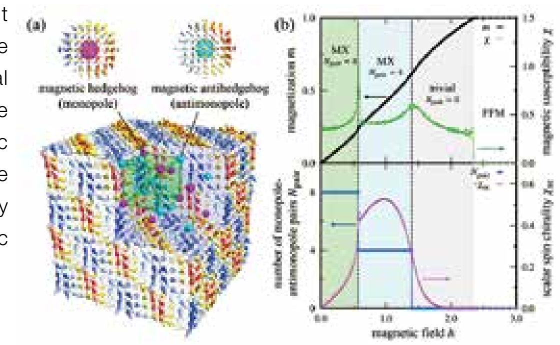
Outline

Our unit theoretically investigates emergent functionalities in quantum materials, such as electrical conductivity and magnetism. We use numerical and analytical calculations to explore the rich functional phenomena in strongly correlated electron systems where various degrees of freedom interact, such as charge, spin, orbital, and sublattice. Specifically, we calculate the electrical and optical conductivity by linear and nonlinear response theory, numerically simulate thermal equilibrium states and non-equilibrium dynamics, and design new materials based on first-principles calculations for spin-charge coupled systems, topological magnetic textures, and topological electronic states.

Theoretical investigation of magnetic monopole crystals

Magnetic monopole is one of the elementary particles that have not yet been observed in high-energy physics experiments. However, in quantum materials, magnetic monopoles can be formed by an emergent magnetic field that reflects the geometric phase generated by electron spins. This emergent magnetic field has been actively studied in topological magnetic textures, e.g. magnetic skyrmions, as an origin of emergent electromagnetic phenomena such as the topological Hall effect.

We theoretically study magnetic monopole crystals in which magnetic monopoles and antimonopoles are periodically arranged in three-dimensional magnets. Magnetic monopoles are regarded as quasiparticles in three-dimensional topological defects called magnetic hedgehogs. We have found for the first time that magnetic monopole crystals can be stabilized in zero magnetic field and the ground state by multi-spin interactions mediated by itinerant electrons. Furthermore, we have revealed topological transitions where the number of magnetic monopole-antimonopole pairs changes sequentially in an external magnetic field.



(a) Spin texture of the monopole crystal (MX). The topological defect, magnetic (anti)hedgehog, corresponds to the magnetic (anti)monopole. (b) Magnetic field dependence of the MX. The MX turns into the forced ferromagnetic state (FFM) after the topological transitions where the number of the monopole-antimonopole pairs sequentially changes.

Publications

1. N. Yoshikawa, S. Okumura, Y. Hirai, K. Ogawa, K. Fujiwara, J. Ikeda, A. Ozawa, T. Koretsune, R. Arita, A. Mitra, A. Tsukazaki, T. Oka, and R. Shimano, "Light-induced anomalous Hall conductivity in massive 3D Dirac semimetal $Co_3Sn_2S_2$", *Phys. Rev. B* 111, 245104 (2025).
2. Y. Hirai, S. Okumura, N. Yoshikawa, T. Oka, and R. Shimano "Floquet Weyl states at one-photon resonance: An origin of nonperturbative optical responses in three-dimensional materials", *Phys. Rev. Research* 6, L012027 (2024).
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4. S. Okumura, T. Morimoto, Y. Kato, and Y. Motome "Quadratic optical responses in a chiral magnet", *Phys. Rev. B* 104, L180407 (2021).
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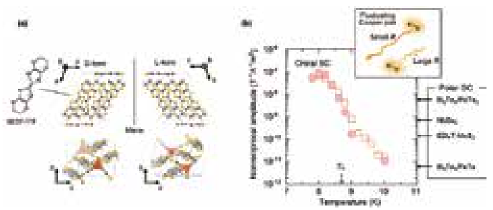
Low-Dimensional Quantum Phases Research Unit

Giant nonreciprocal superconductivity induced by structural chirality

Chirality, typified by helical structures, is a representative example of structures lacking spatial inversion symmetry. Recently, a growing number of studies have reported that when electrons propagate through chiral organic molecules, an unexpectedly large spin polarization is induced—far exceeding what can be explained by the intrinsically weak spin–orbit coupling (SOC) in organic systems. This phenomenon, known as chirality-induced spin selectivity (CISS), is believed to originate from a nontrivial coupling between charge motion and spin that is intrinsically embedded in chiral structures. However, because molecular systems are extremely small, quantitatively evaluating this nontrivial SOC has remained elusive, making it one of the central issues in CISS research.

To address this challenge, we focus on low-dimensional organic superconductors with chiral symmetry and investigate nonreciprocal charge transport as a bulk response closely related to SOC. As a result, we successfully observed a gigantic nonreciprocal transport in the superconducting state, exceeding theoretical predictions by several orders of magnitude. Remarkably, this giant response emerges in organic materials where SOC—considered essential for nonreciprocal transport—is inherently very small. These findings demonstrate that chirality induces an effectively strong coupling between charge motion and spin, which plays a crucial role in governing bulk properties.



(a) Crystal structure of chiral organic superconductor, κ-(BEDT-TTF)$_2$Cu(NCS)$_2$, and (b) temperature dependence of nonreciprocal amplitude observed in its superconducting state. The amplitude in our chiral organic superconductor with intrinsically weak spin-orbit coupling exceeds those of polar inorganic superconductors with large spin-orbit couplings.

Publications

1. T. Sato, H. Goto, and H. M. Yamamoto, "Sturdy spin-momentum locking in a chiral organic superconductor", *Phys. Rev. Research* 7, 023056 (2025).
2. H. Aizawa, T. Sato, S. Maki-Yonekura, K. Yonekura, K. Takaba, T. Hamaguchi, T. Minato, and H. M. Yamamoto, "Enantioselectivity of discretized helical supramolecule consisting of achiral cobalt phthalocyanines via chiral-induced spin selectivity effect" *Nat. Commun.* 14, 4530 (2023).
3. T. Sato, W. Koshibae, A. Kikkawa, T. Yokouchi, H. Oike, Y. Taguchi, N. Nagaosa, Y. Tokura, and F. Kagawa, "Slow steady flow of a skyrmion lattice in a confined geometry probed by narrow-band resistance noise" *Phys. Rev. B* 100, 094410 (2019).
4. T. Sato, K. Kitai, K. Miyagawa, M. Tamura, A. Ueda, H. Mori, and K. Kanoda, "Strange metal from a frustration-driven charge order instability" *Nat. Mater.* 18, 229 (2019).
5. T. Sato, K. Miyagawa, and K. Kanoda, "Electronic crystal growth" *Science* 357, 1378 (2017).

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Research field

Physics, Engineering

Keywords

Chirality, Strongly correlated electron system, Two-dimensional materials (2D materials), Pi-electronic compound

Brief resume

- 2017 Ph.D., Department of Applied Physics, The University of Tokyo
- 2017 Postdoctoral Researcher, RIKEN Center for Emergent Matter Science
- 2021 Assistant Professor, Research Center of Integrative Molecular Systems, Institute for Molecular Science
- 2023 JST PREST, researcher (-present)
- 2025 JST ERATO, Group Leader (-present)
- 2026 Unit Leader, Low-Dimensional Quantum Phases Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science (-present)
- 2026 Associate Professor, Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo (-present)

Outline

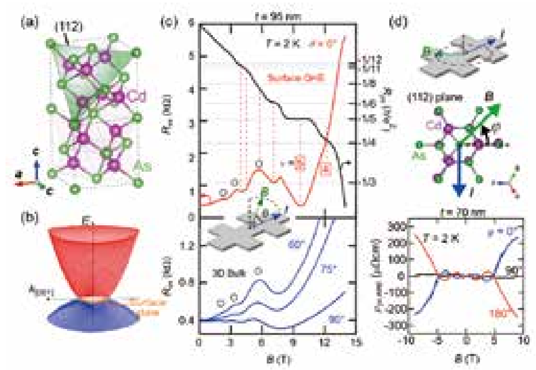
Low-dimensional systems, exemplified by organic conductors and two-dimensional materials, provide a fertile platform for the emergence of diverse quantum phases driven by strong electronic correlations. We focus on the controllability of such low-dimensional systems and develop novel devices in which the breaking of spatial inversion and time-reversal symmetries is strategically incorporated. By combining bottom-up approaches to symmetry control with dynamic symmetry modulation induced by external fields, we aim to explore emergent quantum phases coupled to symmetry breaking. Furthermore, we extend our research scope to nonlinear and nonequilibrium responses that become prominent under low-dimensional and low-symmetry conditions, with the goal of realizing functionalities intrinsic to the quantum phases.

Emergent Interface Functionality Research Unit

Quantum transport phenomena in high-mobility Dirac semimetal films

Topological materials have attracted broad interest in both fundamental and applied physics owing to their novel transport properties, including low-dissipation surface conduction and unconventional Hall responses arising from their nontrivial electronic structure. In particular, topological semimetals hosting massless Dirac fermions in three dimensions provide an ideal platform for quantum transport studies because of their high mobility and robust topological properties.

We have fabricated high-quality thin films of Cd_3As_2, a prototypical nonmagnetic Dirac semimetal, and investigated quantum transport phenomena, including the surface-state-driven quantum Hall effect, by controlling the film thickness, carrier density, and interfaces. Furthermore, by analyzing the Hall response to magnetic fields applied within the film plane, we quantitatively clarified the magnetic-field-induced anomalous Hall component in this nonmagnetic system.



Examples of transport phenomena observed in high-mobility Dirac semimetal films. Illustration of (a) crystal structure and (b) band structure of Cd_3As_2. (c) Quantum Hall effect derived from the surface states (top), and quantum oscillations from three-dimensional bulk states that remain when the magnetic field is tilted toward the in-plane direction (bottom). (d) Magnetic-field-induced anomalous Hall effect observed under the in-plane field applied within the (112) plane.

Publications

1. S. Nishihaya, Y. Matsuki, H. Kaminakamura, Y. Murakami, H. Ishizuka, and M. Uchida "Spontaneous in-plane anomalous Hall response observed in a ferromagnetic oxide", *Adv. Mater.*, 37, e02624 (2025) .
2. S. Nishihaya, H. Ishizuka, Y. Deguchi, A. Nakamura, T. Yoneda, H. Lee, M. Kriener, and M. Uchida "Anomalous Hall effect in the Dirac semimetal Cd_3As_2 probed by in-plane magnetic field", *Phys. Rev. Lett.* 135, 106603 (2025).
3. S. Nishihaya, M. J. A. Jardine, H. S. Inbar, A. Goswami, J. T. Dong, A. N. Engel, Y.-H. Chang, C. P. Dempsey, M. Hashimoto, D. Lu, N. Marom, and C. J. Palmstrøm "Near-half-metallic state in the half Heusler PtMnSb film on a III-V substrate", *Phys. Rev. Mater.* 9, 044403 (2025).
4. S. Nishihaya, M. Uchida, Y. Nakazawa, M. Kriener, Y. Taguchi, and M. Kawasaki "Intrinsic coupling between spatially-separated surface Fermi-arcs in Weyl orbit quantum Hall states", *Nat. Commun.* 12, 2572 (2021).
5. S. Nishihaya, M. Uchida, Y. Nakazawa, M. Kriener, Y. Kozuka, Y. Taguchi, and M. Kawasaki "Gate-tuned quantum Hall states in Dirac semimetal $(Cd_{1-x}Zn_x)_3As_2$", *Sci. Adv.* 4, eaar5668 (2018).

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Research field

Physics, Engineering, Materials Science

Keywords

Thin films and interfaces, Topological materials, Quantum transport phenomena, Unconventional Hall effect, Nanometer scale fabrication

Brief resume

- 2020 Ph.D., Department of Applied Physics, The University of Tokyo
- 2020 JSPS Overseas Research Fellow at University of California, Santa Barbara
- 2022 Assistant Professor, Department of Physics, Tokyo Institute of Technology
- 2024 Assistant Professor, Department of Physics, Institute of Science Tokyo
- 2026 Unit Leader, Emergent Interface Functionality Research Unit, Integrated Condensed Matter Science Research Program, RIKEN (-present)
- 2026 Lecturer, Quantum-Phase Electronics Research Center, Graduate School of Engineering, The University of Tokyo (-present)

Outline

In this unit, we explore and understand quantum physical phenomena in artificially engineered interfaces and nanostructures fabricated from a wide range of materials. We focus on high-mobility materials, including Weyl and Dirac semimetals, topological insulators, and compound semiconductors. Through advanced epitaxial growth techniques, we realize thin-film and membrane samples and fabricate diverse heterointerfaces and local structures with controlled spatial inhomogeneity. By integrating structural design across multiple length scales with high-precision electrical transport measurements and local probe techniques, we seek to uncover novel quantum phases and transport functionalities that cannot be achieved in homogeneous structures or flat crystalline planes.

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