Title of Project : Extended Telescope Array Experiment - Nearby Extreme Universe Elucidated by Highest-energy Cosmic Rays

Hiroyuki Sagawa
(The University of Tokyo, Institute for Cosmic Ray Research, Associate Professor)

Research Project Number : 15H05693 Researcher Number : 80178590
Research Area : Particle/Nuclear/Cosmic ray/Astro physics
Keyword : Cosmic ray (experiment)

【Purpose and Background of the Research】

Due to cosmic magnetic fields, arrivals of cosmic rays from the universe are largely isotropic. The Telescope Array (TA) is the largest cosmic-ray observatory in the northern hemisphere, and has recently found an evidence for an excess spot (hot spot) in the arrival directions of cosmic rays among 72 events with energies greater than 5.7×10^{19} electron volts (E_{cutoff}) near the direction of the Great Bear using five years of data since 2008. Our experiment TA also confirmed a suppression of the flux of cosmic rays beyond E_{cutoff}, which supports a scenario that sources of highest-energy cosmic rays exist within 200 million light years from the Earth. These are the first results from which we expect to observe sources of highest-energy cosmic rays by expected rectilinearity in the universe.

【Research Methods】

When ultra-high-energy cosmic rays enter the atmosphere, an enormous number of secondary particles are generated. They arrive at the ground over an area of 10 kilometers in diameter. TA is located in Utah, USA, and uses an array of 507 surface detectors (SDs) deployed over an area of 700 square kilometers to detect the secondary particles.

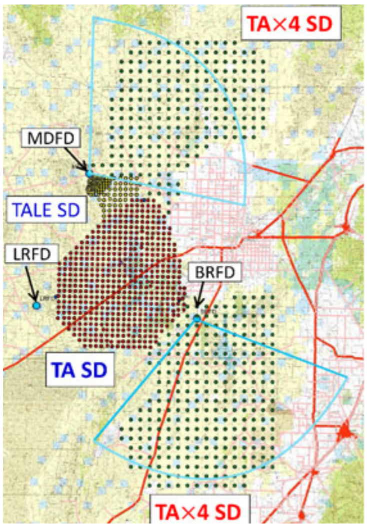


Figure 1 TAx4

Each SD has 3 square meters of plastic scintillator and they are placed on a square grid of 1.2 kilometer spacing. Our new research TAx4 adds 500 SDs with 2.08 kilometer spacing to the east of the present TA array to quadruple the TA aperture to approximately 3,000 square kilometers in total. TAx4 detects highest-energy cosmic rays with high statistics and measures their energy spectrum, arrival directions and mass composition in the northern sky.

【Expected Research Achievements and Scientific Significance】

We accumulate the equivalent to 19 years of the current TA data in the research period including data already taken, and expect to observe approximately 300 cosmic rays above E_{cutoff}. We will confirm the hot spot and explore its origin along with the search for other excess spots. We will search for correlations with nearby galaxies and active galactic nuclei. And we will search for point sources of highest-energy cosmic rays.

【Publications Relevant to the Project】

・"The cosmic-ray energy spectrum observed with the surface detector of the Telescope Array experiment", T. Abu-Zayyad et al., Astrophys. J., 768:L1 (5pp), 2013.
・"Indications of intermediate-scale anisotropy of cosmic rays with energy greater than 57 EeV in the northern sky measured with the surface detector of the Telescope Array experiment", R.U. Abbasi et al., Astrophys. J., 790:L21 (5pp), 2014.

【Term of Project】 FY2015-2019

【Budget Allocation】 447,100 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.icrr-tokyo.ac.jp/~hsagawa/TAx4/
hsagawa@icrr.u-tokyo.ac.jp

Title of Project : Innovation of the “interstellar medium” by accurate measurements of the interstellar hydrogen

Yasuo Fukui
(Nagoya University, Graduate School of Science, Professor)

Research Project Number : 15H05694 Researcher Number : 30135298
Research Area : Astronomy
Keyword : Interstellar Hydrogen, Interstellar Dust, Gamma-rays, Baryon, NANTEN2

【Purpose and Background of the Research】

It is one of the most fundamental issues in astronomy to understand the behavior of hydrogen in the interstellar medium (ISM), because hydrogen is the most abundant element in the Universe. Neutral atomic hydrogen HI is the most abundant in the interstellar space and it reacts with each other on dust surfaces to form molecular hydrogen H_2. In order to better understand the ISM and its evolution in galaxies, we should have precise measurements of the hydrogen mass and its physical properties including density and temperature. Generally, 21 cm HI emission is assumed to be optically thin and the HI column density N_{HI} is calculated under the assumption. Recent two papers, Fukui et al. (2014, 2015), present a new analysis of HI and the Planck dust optical depth and concluded that the HI emission is often optically thick with an average optical depth of around 2 in the local space within a few 100 pc of the sun. This implies that the N_{HI} in the interstellar space is to be doubled due to the opacity correction as compared with the classical optically thin approximation, and, in addition, leads to a conclusion that the optically thin HI is identified in the warmest dust temperature.

The research has a potential to alter significantly a number of important issues on the ISM; they include the accurate density distribution of the interstellar clouds both in HI and H_2, the observational identification of conversion of HI into H_2, the origin of gamma rays and cosmic ray density, and the star formation history of galaxies over 10 Byrs [star formation rate is given as a ratio of the stellar mass and the hydrogen mass.

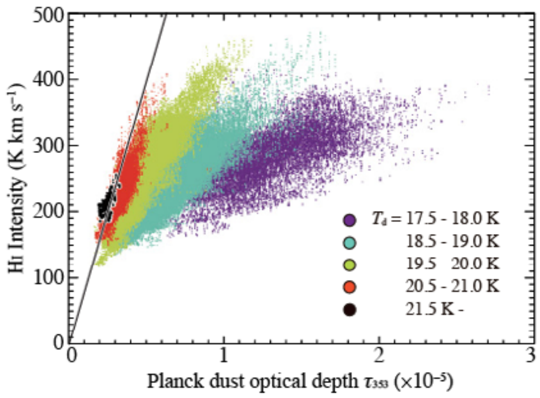


Fig.1 Scatter plots of the dust optical depths and HI intensity for the dust temperature in window of 0.5 K intervals every 1 K.

【Research Methods】

The proposed research aims at obtaining the best view of the interstellar hydrogen by new large scale observations of CO and HI combined with extremely high angular resolution observations for selected regions.

The new CO observations with NANTEN2 will cover 40 % of the sky with the 4-beam (dual polarization) array receiver, where Planck 353 GHz dust opacity is greater than $\sim 5\times10^{-6}$ well beyond the CO detection limit. The HI data will be taken in the GASKAP project at typically 20–60 arcsec resolution. The lower-resolution large-scale studies of CO and HI planned on NANTEN2 (CO) and GASKAP (HI) will be followed up by higher resolution studies with ALMA both in CO and dust continuum emission.

【Expected Research Achievements and Scientific Significance】

The expected outputs of the proposed research include accurate projected distribution of all hydrogen in nearby interstellar cloud with unprecedented accuracy in the order of 10 % as compared with the typical accuracy of a factor of two. Since the derived N_{HI} will be significantly larger by a factor of 2–5 than that estimated by the optically thin approximation, the resultant density distribution should be significantly different and denser in the transition layer of HI–H_2. This naturally requires new exploration of the cloud structure of physical evolution which leads to star formation and has a significant impact on our understanding clouds and star formation therein.

【Publications Relevant to the Project】

“HI, CO, and Planck/IRAS Dust Properties in the High Latitude Cloud Complex, MBM 53, 54, 55 and HLCG 92-35. Possible Evidence for an Optically Thick HI Envelope around the CO Clouds”, Fukui, Y., Yamamoto, H., Tachihara, K. et al. ApJ, 796, 59–69, 2014
“Optically Thick HI Dominant in the Local Interstellar Medium: An Alternative Interpretation to "Dark Gas"”, Fukui, Y., Yamamoto, H., Tachihara, K., Sano, H. et al. ApJ, 798, 6–20, 2015

【Term of Project】 FY2015-2019

【Budget Allocation】 424,200 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.a.phys.nagoya-u.ac.jp/nanten/en/

【Grant-in-Aid for Specially Promoted Research】
Science and Engineering (Mathematics/Physics)

Title of Project : A model for formation and evolution of solid materials in space based on 3D structures of solar primitive materials

Akira Tsuchiyama
(Kyoto University, Graduate School of Science, Professor)

Research Project Number : 15H05695 Researcher Number : 90180017
Research Area : Earth and Planetary Science, Petrology, Mineralogy and Economic Geology
Keyword : Earth and Planetary Materials, Condensation, Space Weathering, Hayabusa2

【Purpose and Background of the Research】
According to an astronomical model, dust particles formed by condensation from high temperature gas around evolved stars. They then metamorphosed under particle-beam irradiation (space weathering) in interstellar space, and eventually accumulated to give birth to the solar system (Figure 1). However, this model has not been verified in terms of material science. Examination of particles preceding the formation of the solar system found in cosmic dust and primitive meteorites can reveal solid formation and evolution not only in the solar system but also in the pre-solar environments. In particular, 3D structures of extraterrestrial samples (Figure 2) are expected to give new insights. The purpose of this research is to construct a robust model for solid formation and evolution in space by analyzing the 3D structures together with their reproduction experiments.

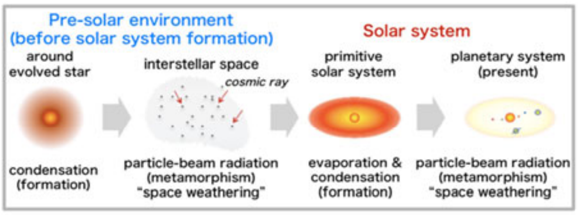


Figure 1. Solid formation and evolution in space.

【Research Methods】
(1) Dust formation: amorphous silicate particles with metallic iron and iron sulfide nanoparticles (GEMS), which might be source materials for the solar system, are present in cometary dust (Figure 3). Their formation conditions and origins are revealed by combining 3D structure analysis of GEMS with condensation experiments. (2) Dust evolution: conditions of space weathering and its role in interstellar space are elucidated by combining 3D structure analysis of space-weathered samples with ion-beam irradiation experiments. (3) 3D structures of cosmic dust and meteorites, which contain organic materials and water as well as minerals, are obtained in order to reveal their formation and evolution processes. (4) Techniques for multiscale 3D structure analysis are established.

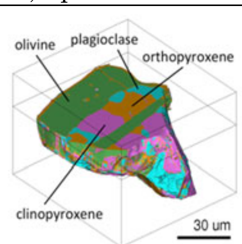


Figure 2. 3D structure of a Hayabusa particle.

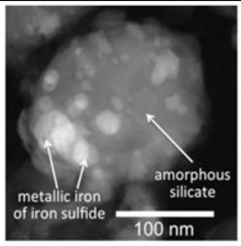


Figure 3. 2D TEM image of GEMS.

【Expected Research Achievements and Scientific Significance】
This research will give a deep understanding of the formation and evolution processes of solid materials from pre-solar to solar systems, in particular the formation environment of solids in space and the space weathering in interstellar space, which cannot be revealed by astronomical observation alone. This will allow us to expand our understanding of the history of the solar system back to the pre-solar stage; moreover, the initial conditions of the formation of the Earth and the other planets can be obtained as the source materials of the solar system. The expected results of this research are of paramount importance for the analysis of the samples returned from asteroids in JAXA Hayabusa2 mission in 2020 and NASA OSIRIS-REx mission in 2023.

【Publications Relevant to the Project】
・A. Tsuchiyama, M. Uesugi, T. Matsushima, et al., Three-Dimensional Structure of Hayabusa Samples: Origin and Evolution of Itokawa Regolith. *Science*, 333, 1125-1128 (2011)
・A. Tsuchiyama, Asteroid Itokawa: A source of ordinary chondrites and a laboratory for surface processes. *Elements*, 10, 45-50 (2014)

【Term of Project】 FY2015-2019

【Budget Allocation】 394,900 Thousand Yen

【Homepage Address and Other Contact Information】
http://www.kueps.kyoto-u.ac.jp/~web-min/

【Grant-in-Aid for Specially Promoted Research】
Science and Engineering (Chemistry)

Title of Project : Sub-femtosecond molecular imaging

Kaoru Yamanouchi
(The University of Tokyo, Graduate School of Science, Professor)

Research Project Number : 15H05696 Researcher Number : 40182597
Research Area : Basic chemistry, Physical chemistry
Keyword : Ultrafast chemistry, Reaction dynamics

【Purpose and Background of the Research】

Recent advances in the ultrashort pulsed laser technologies enabled us to generate laser pulses with the duration of ~5 fs, with which a variety of characteristic ultrafast molecular processes have been elucidated. However, the temporal resolution of ~5 fs is not short enough to probe in real time the intramolecular charge transfer occurring within molecules in response to an ultrashort pulsed laser field as well as the subsequent correlated motion of hydrogen atoms within those molecules. Currently, elucidation of such early stage dynamics proceeding within the sub-femtosecond (<1 fs) timescale is considered as the most urgent issue in ultrafast chemistry.

In this project, on the basis of experimental techniques and quantal dynamics theories we have developed by ourselves, we will investigate ultrafast intramolecular charge transfer processes and subsequent changes in the geometrical structure of molecules with the sub-femtosecond temporal resolution.

【Research Methods】 (See Fig. 1)

In order to clarify how the electronic response to an intense laser field triggers motion of light atoms such as hydrogen atoms and the other heavier atoms within a molecule, leading to breaking and rearrangement of chemical bonds, we will develop two experimental techniques; (i) coincidence momentum imaging (CMI) by which geometrical structures of molecules are determined from momenta of photoelectrons and fragment ions generated through multiple ionization of molecules followed by Coulomb explosion processes and (ii) laser-assisted electron diffraction (LAED) by which snapshots of instantaneous geometrical structures of molecules are obtained. Furthermore, by constructing a theoretical framework beyond the Born-Oppenheimer approximation, we will investigate mechanisms of ultrafast intra-molecular charge transfer occurring within a laser field and the subsequent ultrafast hydrogen migration.

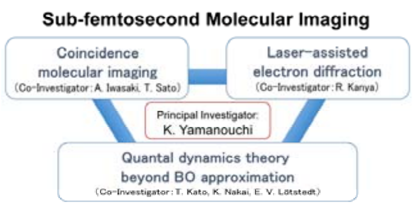


Fig. 1. Our Research Organization

【Expected Research Achievements and Scientific Significance】

By the CMI, the electronic excitation processes of molecules occurring within the duration of laser pulses as well as the accompanying ultrafast nuclear motion leading to chemical bond breaking and rearrangement will be elucidated. By the LAED, ultrafast variations of the electron density distribution as well as the distribution of nuclei within a molecule will be visualized with the sub-femtosecond temporal resolution. On the other hand, by developing non-adiabatic theories, correlated motion among electrons and nuclei in a sub-femtosecond timescale will be investigated, through which procedures for extracting the information of the electron-nuclear correlation from experimental data will be proposed.

By the experimental and theoretical studies described above, we will be able to understand the very early stage molecular dynamics, in the sub-femtosecond time domain in which electrons and nuclei within a molecule are correlated, leading to the chemical bond breaking and rearrangement processes occurring in the later stage in the femtosecond time domain.

【Publications Relevant to the Project】

K. Kurihara, H. Kono, H. Fukumura, K. Yamanouchi, *eds.*, "Kyokoushiba no Kagaku," *CSJ Current Review* **18**, pp. 1-28, 65-76, and 98-102 (Kagaku Dojin, 2015).

【Term of Project】 FY2015-2019

【Budget Allocation】 399,600 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.yamanouchi-lab.org/index.html
kaoru@chem.s.u-tokyo.ac.jp

Title of Project : Design of light- or electromagnetic-wave-correlating phase transition materials and research of their advanced functionalities

Shin-ichi Ohkoshi
(The University of Tokyo, Graduate School of Science, Professor)

Research Project Number : 15H05697 Researcher Number : 10280801
Research Area : Chemistry
Keyword : Light, Electromagnetic-wave, Phase transition, Physical chemistry

【Purpose and Background of the Research】

Phase transition materials exhibiting ferromagnetic, ferroelectric, metal-insulator phase transitions, etc., are important for electronics and recording devices supporting the basis of modern society. Light or electromagnetic (EM) waves, ranging from ultraviolet-visible light to radio waves, correlate with materials in various ways and excite different quantum states depending on the frequency. In this project, we will develop novel phase transition materials responsive to light or EM waves from the approach of basic chemistry, physical chemistry, and synthetic chemistry, and we will promote research on novel functionalities contributing to next-generation devices or energy and environmental issues. Another goal is to observe magnetic dipole excited optical effect in the millimeter wave range by the magnetic field component of the EM wave, and to construct a new field of "millimeter wave materials science".

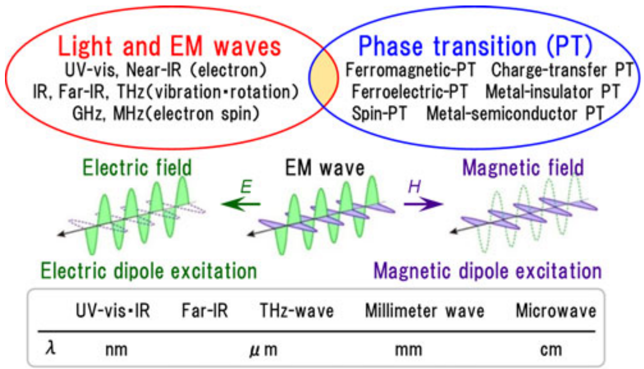
【Research Methods】

In this project, we will synthesize metal complexes and metal oxides with various optical, electrical, and magnetic functionalities and observe drastic color change and optical-switching of ionic conductivity, ferroelectricity, and ferromagnetism at room temperature triggered by light-induced phase transitions. Focusing on the wave properties of EM waves, we aim to observe instantaneous switching of nonlinear magneto-optical phenomena by external stimuli such as light, electric current, and electric field in spatially and temporally non-centrosymmetric materials such as chiral magnets or pyroelectric magnets with both electric polarization and magnetic polarization. Another goal is to discover a material group exhibiting metal-semiconductor phase transition by external stimuli.

In the millimeter wave range, the rotation angle and ellipticity of light change when the magnetic dipole is excited by the magnetic field component of the EM wave. Based on this property, we will demonstrate high performance millimeter wave Faraday effect by magnon excitation and improve the rotation and absorption efficiency. We will also investigate the coupling effect between coherent magnon and lattice vibration in metal or insulator nanomaterials.

【Expected Research Achievements and Scientific Significance】

This research project is expected to indicate new guidelines for material development from the viewpoint of correlation between light or EM waves and phase transition materials, and should provide important knowledge in the field of magnetism, photonics, etc. Construction of a new academic field "millimeter wave materials science" is also expected.



【Publications Relevant to the Project】

- "90-degree optical switching of output second-harmonic light in chiral photomagnet", S. Ohkoshi et al., **Nature Photonics**, 8, 65 (2014).
- "Hard magnetic ferrite with a gigantic coercivity and high frequency millimetre wave rotation", A. Namai et al., **Nature Communications**, 3, 1035 (2012).
- "Synthesis of a metal oxide with a room-temperature photoreversible phase transition", S. Ohkoshi et al., **Nature Chemistry**, 2, 539 (2010).

【Term of Project】 FY2015-2019

【Budget Allocation】 374,700 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.chem.s.u-tokyo.ac.jp/users/ssphys/english/index.html
ohkoshi@chem.s.u-tokyo.ac.jp

Title of Project : Revolutionizing organic chemistry by utilizing water as solvent

Shu Kobayashi
(The University of Tokyo, Graduate School of Science, Professor)

Research Project Number : 15H05698 Researcher Number : 50195781
Research Area : Chemistry
Keyword : Organic chemistry, water

【Purpose and Background of the Research】

One of the central principles in chemistry lies in the concept that "like dissolves like." In contrast to the long-standing belief that organic solvents are required to conduct reactions with organic compounds, the ideal chemical processes using water as a solvent have made quite a splash in society. Our internationally acclaimed achievements in water-centered research have provided profound insights into the unique reactivities and selectivities found in organic chemistry conducted exclusively in water. Continuous progress in this field is of crucial importance since cutting-edge research bolsters Japan's global competitiveness and status as a science-oriented nation. The applicant aims to make a paradigm shift from our reliance on organic solvents to water in order to achieve novel modes of chemical transformation.

【Research Methods】

In order to achieve the aforementioned objective, the research will be conducted under the following five sub-themes: (1) development of highly active catalysts for efficient synthesis in water, (2) elucidation of the function of water in catalysis and organic reactions, (3) development of new methodology for analyzing organic reactions in water, (4) construction of functional artificial enzyme-like systems in water, and (5) basic research for industrial processes using water as a solvent.

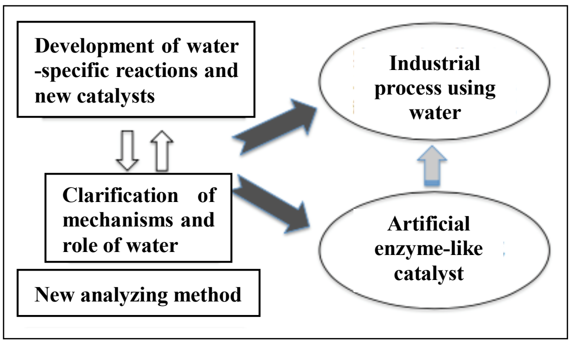


Figure 1 water-centered research project

【Expected Research Achievements and Scientific Significance】

Chemistry in water enables novel modes of chemical transformations that may normally be difficult or sluggish to perform in organic solvents. In order to make significant contributions to synthetic chemistry as well as minimize the ecological footprint of organic chemistry, fundamental and applied research is indispensable to cause a drastic paradigm shift of chemical synthesis in both academia and industry from "in organic solvent" to "in water" both in industrial and in chemical society. The outcomes of this research would advance our scientific understandings of the fundamental interactions between water, organic matter, and metal catalysts, which might serve as the foundation to elucidate the biochemical mechanism that still remains unclear in the cellular environment. In that sense, this research project should be highly valued as a multidisciplinary study that may solve a plethora of global and scientific problems.

【Publications Relevant to the Project】

- Chiral Copper(II)-Catalyzed Enantioselective Boron Conjugate Additions to α,β-Unsaturated Carbonyl Compounds in Water, S. Kobayashi, P. Xu, T. Endo, M. Ueno, T. Kitanosono, *Angew. Chem. Int. Ed.*, **51**, 12763 (2012).
- The New World of Organic Reactions in Water, S. Kobayashi, *Pure Appl. Chem.*, **85**, 1089 (2013).
- Chemistry-Based Design of the Simplest Metalloenzyme-Like Catalyst That Works Efficiently in Water, T. Kitanosono, S. Kobayashi, *Chem. Asian J.*, **10**, 133 (2015).

【Term of Project】 FY2015-2019

【Budget Allocation】 421,200 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.chem.s.u-tokyo.ac.jp/users/synorg/index.html

Title of Project : Spin-orbit Engineering

Junsaku Nitta
(Tohoku University, Graduate School of Engineering, Professor)

Research Project Number : 15H05699 Researcher Number : 00393778
Research Area : Science and Engineering
Keyword : Spintronics

【Purpose and Background of the Research】

Spin-orbit interaction gives rise to an effective magnetic field on moving electrons in an electric field. So, it is possible to generate, manipulate, and detect electron spins without using a magnetic field. Recently, novel spin related phenomena based on spin-orbit interaction are discovered in various materials such as ferromagnets, metals and topological insulators. It is expected that spin-orbit interaction is enhanced at the hetero-interface because of strong electric fields. The purpose of this project is to explore new spin functionalities and new research fields of spintronics based on spin-orbit interaction.

【Research Methods】

(1) Spin-orbitronics
Electrical spin generation, manipulation, and detection will be integrated into new spin functional devices with suppression of spin relaxation.
(2) Exploration of giant Rashba effect
Strong spin-orbit interaction strengths are reported in heavy metal/ferromagnets hetero-interface structures. We will clarify the mechanism of spin-orbit interaction by transport properties and will explore all metal spin transistor with the utilization of gate controlled giant Rashba spin-orbit interaction.
(3) Novel spin dependent electromagnetic fields
Spatial/temporal variation of spin-orbit interaction generates spin-dependent magnetic/ electric fields since spin-orbit interaction works as if spin-dependent vector potential. We will pursue novel spin functionalities based on this relativistic quantum effects.

【Expected Research Achievements and Scientific Significance】

Since electron spins are mainly controlled by magnetic field, local spin manipulations at high speed are impossible. The relativistic spin-orbit interaction enables an electrical local spin manipulation with high speed and low power consumption. The concept of spin-orbit engineering is ubiquitous among various materials systems and leads to spintronics innovation.

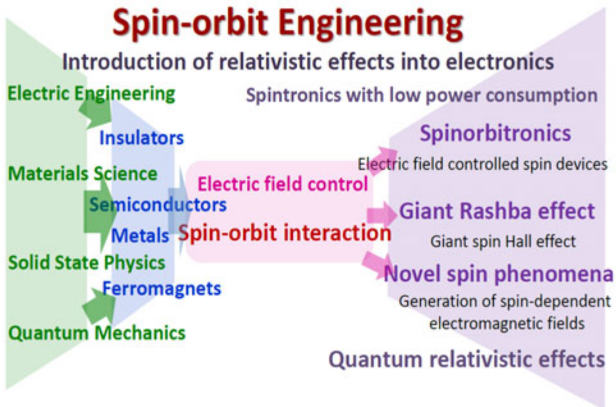


Fig. 1 Concept of spin-orbit engineering

【Publications Relevant to the Project】

- "Direct determination of spin-orbit interaction coefficients and realization of the persistent spin helix symmetry", A. Sasaki, S. Nonaka, Y. Kunihashi, M. Kohda, T. Bauernfeind, T. Dollinger, K. Richter, and J. Nitta, *Nature Nanotechnology* 9, 703-709 (2014)
- "Manipulation of mobile spin coherence using magnetic-field-free electron spin resonance", H. Sanada, Y. Kunihashi, H. Gotoh, M. Kohda, J. Nitta, P. V. Santos, and T. Sogawa, *Nature Physics* 9, 280-283 (2013)
- "Control of the spin geometric phase in semiconductor rings", F. Nagasawa, D. Frustaglia, H. Saarikoski, K. Richter, and J. Nitta, *Nature Communications* 4, 2526-1 -7, (2013)

【Term of Project】FY2015-2019

【Budget Allocation】445,800 Thousand Yen

【Homepage Address and Other Contact Information】

http:// www.material.tohoku.ac.jp/~kotaib/
nitta@material.tohoku.ac.jp

Title of Project : Solid-state Quantum Electrodynamics in Quantum Dot-Nanocavity Multiply-Coupled Quantum Systems and Its Application to Novel Light Sources

Yasuhiko Arakawa
(The University of Tokyo, Institute of Industrial Science, Professor)

Research Project Number : 15H05700　Researcher Number : 30134638
Research Area : Quantum Nanodevice Engineering
Keyword : Quantum Dots, Photonic Crystals, Cavity Quantum Electrodynamics, Semiconductor Lasers

【Purpose and Background of the Research】

The physics of light matter interaction is of intense scientific interest and provides a strong basis for advancing diverse optoelectronic devices. In particular, cavity quantum electrodynamics (CQED), in which the interaction between cavity photons and quantum emitters is treated, has played an essential role in the development of quantum optics as well as state-of-the-art lasers.
In this project, we will explore the frontiers of solid-state CQED using quantum dots (QD) coupled to photonic crystal nanocavities realized on tiny semiconductor chips. We will primarily investigate CQED physics in QD-nanocavity multiply-coupled quantum systems via developing the technological foundations required for the tailored fabrication of such systems. We will further conduct fundamental research to carry forward scientific progress to the development of novel light sources including few-QD nanolasers.

【Research Methods】

We will intensively elaborate the fabrication technologies for improving QD-CQED systems and build up a basis for fabricating multiply-coupled QD-nanocavity systems. These efforts will open an avenue for pursuing advanced solid-state CQED, including single-photon-level nonlinear optical phenomena as well as cooperative effects in multiple quanta systems. We will also seek novel functionalities in multiply-coupled CQED systems using modern theoretical methods rooted in statistics. Further effort will be spent into developing next-generation QD light sources. We will endeavor to attain control over some of the physical processes in QD-based systems for boosting light source performance. We will also work on functional QD light sources that take advantage of high integratability, quantum spin, and the possibility of high temperature and current-driven operation of QD-CQED systems.

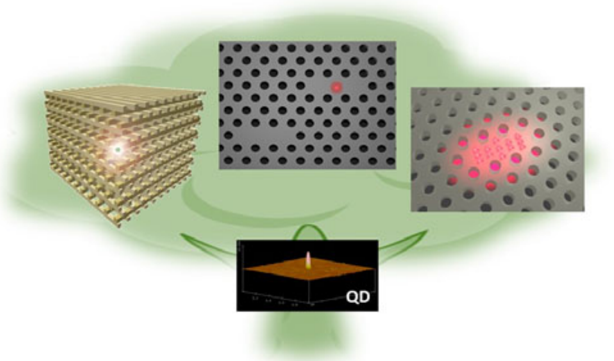


Fig.1 Conceptual schematic of the QD-CQED systems targeted in this project.

【Expected Research Achievements and Scientific Significance】

We believe that our research here will lay the groundwork for accessing diverse physics in high quality QD-CQED systems as well as in multiply-coupled quantum systems. These activities could have a lasting impact on the entire CQED research field. In addition to the influence on basic science, the advances into QD-based light sources that will be made here will open a new field of semiconductor light sources, potentially playing key roles in the forthcoming data-driven society, where ultra-compact low-energy-consumption light sources would be required for widely spread cyber physical systems.

【Publications Relevant to the Project】

・M. Nomura, N. Kumagai, S. Iwamoto, Y. Ota, and Y. Arakawa: Laser oscillation in a strongly coupled single quantum dot nanocavity system, Nat. Phys., **6**, 279–283 (2010).
・Y. Arakawa, S. Iwamoto, M. Nomura, A. Tandaechanurat and Y. Ota: Cavity Quantum Electrodynamics and Lasing Oscillation in Single Quantum Dot-Photonic Crystal Nanocavity Coupled Systems, *IEEE J. Sel. Top. Quantum Electron.*, **18**, 1818–1829 (2012).

【Term of Project】 FY2015-2019

【Budget Allocation】 399,500 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.qdot.iis.u-tokyo.ac.jp/
arakawa@iis.u-tokyo.ac.jp

Title of Project : Development of advanced energy storage system based on overall strategies on new materials and new interface

Atsuo Yamada
(The University of Tokyo, Graduate School of Engineering, Professor)

Research Project Number : 15H05701 Researcher Number : 30359690
Research Area : Engineering
Keyword : Secondary Battery

【Purpose and Background of the Research】

Importance of chemical energy storage technology is well recognized toward future "green" society. Many researches are now independently in progress by just deeply focusing on one element, either already known electrode (cathode or anode) material or already known electrolyte materials. Their combination and a resultant interface (interphase) are optimized based on repeated try&errors and/or empirical guiding principles. Then, the present technology is suffered from limited number of practical materials; only a few electrode materials can be applied to the practical batteries. This situation has forced to apply only one-kind of ethylene carbonate-based electrolyte for more than 20 years. Therefore, a variety of the materials selection is very much limited and it is this situation that has delayed the technical progress in this field.

In this project, we will dramatically increase the variety of guest-ions, host frameworks, and electrolytes as well as their interfacial properties with firm progresses as a battery system.

【Research Methods】

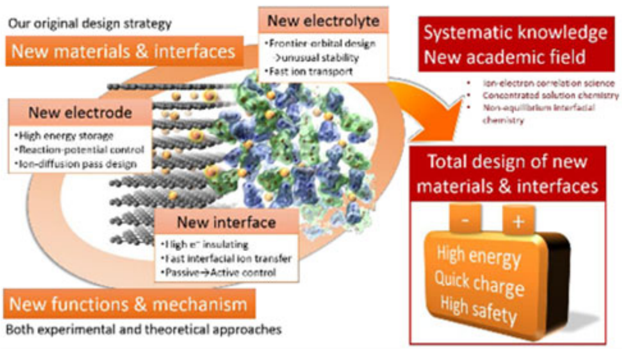


Fig. 1 Overall strategy

Based on our original strategies, we will develop and optimize new cathode materials, new anode materials, and new electrolyte materials. However, exploration and optimization will not be limited to materials issues but extended to overall battery system, where we will try to set even interface (interphase) issues under control with full understanding of the formation mechanisms using the most advanced ab initio molecular dynamics method as well as spectroscopy equipped in SPRING-8 beam line.

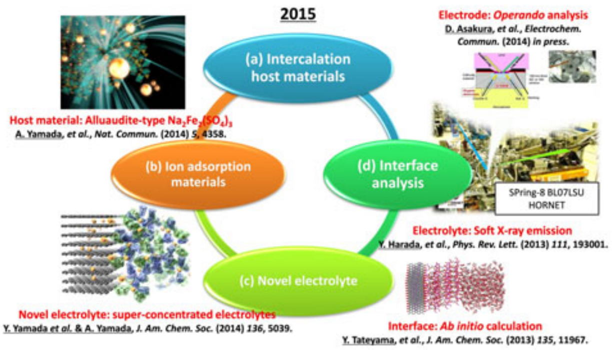


Fig. 2 Methodologies

【Expected Research Achievements and Scientific Significance】

Overall strategies will be established based on the total design of new materials and new interfaces, which we believe to realize new battery system with much more superior properties though sophisticated scientific body of knowledge.

【Publications Relevant to the Project】

- Nature Comm., 5, 4358 (2014)
- Nature Comm., 6, 6544 (2015)
- J. Am. Chem. Soc., 136, 5039 (2014)
- Adv . Energy Mater., 2, 841 (2012)

【Term of Project】 FY2015-2019

【Budget Allocation】 437,100 Thousand Yen

【Homepage Address and Other Contact Information】

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【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Engineering)

Title of Project : Spin-orbitronics and device application

Teruo Ono
(Kyoto University, Institute for Chemical Research, Professor)

Research Project Number : 15H05702 Researcher Number : 90296749
Research Area : Science and Engineering
Keyword : Spin device

【Purpose and Background of the Research】

The aim of this project is to establish the field of Spin-orbitronics: we will exploit the spin-orbit interaction of electrons in solids to form new materials with novel functionalities and find new physics, which will enable development of high speed, energy efficient electronic devices and technological innovations.

【Research Methods】

To meet the goal of this project, we focus on the following key areas.
(1)Explore materials using spin-orbit engineering
(2)Develop means of manipulating spins via the spin-orbit effects

The spin-orbit effects we focus on here are the Dzyaloshinskii-Moriya interaction, the spin Hall effect and the Rashba effect, which all take place in systems with broken structural inversion symmetry. The spin-orbit effects can be engineered by building artificial materials with broken structural inversion symmetry at the atomic scale using state of the art film deposition techniques. As first principle calculations and related theoretical frameworks can predict the physical properties of such artificial materials, we will collaborate with experts on theory and computations to design new material systems.

【Expected Research Achievements and Scientific Significance】

This project will explore new physics and phenomena based on the spin-orbit effects. The significance of this project is, however, not only to impact academic research but also to create technological innovations that will impact the industries.

The explosion of the amount of digital data stored in personal computers, servers and data centers in the last decade is causing concern on the sustainability of the information storage technologies due to power consumption problem. To tackle this problem, it has been suggested that all volatile semiconductor memories need to be converted to non-volatile memories and such non-volatile memories need to be implemented with logic devices to reduce the power consumption. However, such approach is expected to face challenges in the future: as further scaling of the technology node reduces stability of digital data bits and the power needed to “write” information becomes too large. With regard to storage devices, such as the hard disk drives and the solid state drives (e.g. NAND-flash), there is an increasing demand in developing fast storage technology that can keep up with the data transfer rates of communication devices. Currently transferred data are temporarily stored in the semiconductor volatile memories before permanently being written in the storage devices. The use of volatile memory layers lead to complicated and costly memory architectures and to consume extra power. The goal of this project is to provide solutions to these issues by engineering non-volatile materials and developing means to write information with extremely small power based on Spin-orbitronics.

【Publications Relevant to the Project】

・D. Chiba, S. Fukami, K. Shimamura, N. Ishiwata, K. Kobayashi, T. Ono, “Electrical control of the ferromagnetic phase transition in cobalt at room temperature”, Nature Materials 10, 853 (2011).

・T. Moriyama, S. Takei, M. Nagata, Y. Yoshimura, N. Matsuzaki, T. Terashima, Y. Tserkovnyak, T. Ono, “Anti-damping spin transfer torque through epitaxial nickel oxide”, Appl. Phys. Lett. 106, 162406 (2015).

【Term of Project】 FY2015-2019

【Budget Allocation】 432,500 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.scl.kyoto-u.ac.jp/~onoweb/