Title of Project : Investigation of novel engineering and scientific applications of ultra-precise optical lattice clocks

Hidetoshi Katori
(The University of Tokyo, Graduate School of Engineering, Professor)

Research Project Number : 16H06284 Researcher Number : 30233836
Research Area : Mathematical and Physical Sciences
Keyword : Quantum Electronics

【Purpose and Background of the Research】

Accurate atomic clocks not only support the foundations of sciences but also have an immense impact on applications in modern society, including positioning with Global Navigation Satellite System and synchronization of high-speed communication networks. The optical lattice clock, which we proposed in 2001, has so far achieved the relative uncertainty of 10^{-18}. Such optical clocks have surpassed the uncertainty of Cesium clocks that define the second of the International System of units (SI) by two orders of magnitude, which initiated the discussions toward the redefinition of the second.

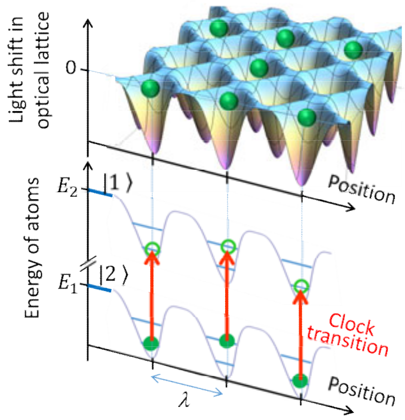

Figure 1: Schematic diagram of an optical lattice clock. Atoms are confined in an optical lattice, where the light shift perturbations on the clock transition is eliminated by tuning a lattice-trap laser to the magic frequency.

【Research Methods】

The project shall demonstrate a new concept of "operational magic frequency" that reduces the fractional uncertainty of the total light shift to less than 10^{-18} by including the higher-order light-shift perturbations. We will apply this new protocol to Sr, Yb, Hg, and Cd based optical lattice clocks to establish a highly precise clock network as shown in Fig. 2. With these clocks, we experimentally discuss the most suitable atomic elements for the future clock and demonstrate frequency ratio measurements with an uncertainty of 10^{-19}.

【Expected Research Achievements and Scientific Significance】

High-performance optical lattice clocks will impact on discussions toward the redefinition of the SI second. On the other hand, such clocks will function as probes 1) to explore "new physics" by investigating the stability of the fundamental constants and anisotropy of space and 2) to develop the "relativistic geodesy" that relies on the gravitational red shift, both of which will drastically alter the existing methodologies.

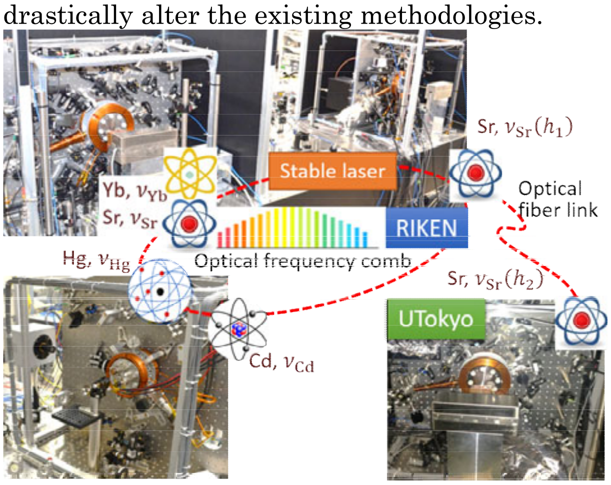

Figure 2: Establish optical lattice clocks consisted of different atomic elements. Frequency ratios of such clocks may probe the stability of the constants.

【Publications Relevant to the Project】

- H. Katori, Optical lattice clocks and quantum metrology, Nature Photon. 5, 203 (2011).
- H. Katori, et al., Strategies for reducing the light shift in atomic clocks, Phys. Rev. A 91, 052503 (2015).

【Term of Project】 FY2016-2020

【Budget Allocation】 452,600 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.amo.t.u-tokyo.ac.jp/index.html
katori@amo.t.u-tokyo.ac.jp

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

Title of Project : Behaviour of liquids under high pressure and the early evolution of the Earth

Kei Hirose
(Tokyo Institute of Technology, Earth-Life Science Institute, Director / Professor)

Research Project Number : 16H06285 Researcher Number : 50270921
Research Area : Mathematics/Physics
Keyword : Early Earth, High pressure, Liquid

【Purpose and Background of the Research】
We have been working on static ultrahigh pressure and temperature experiments using laser-heated diamond-anvil cell (DAC) (Fig. 1). By using such

図１． Fig. 1. Diamond-anvil cell (DAC) high-pressure device

techniques, materials and dynamics of the Earth's deep interior, in particular the deep lower mantle and metallic core have been examined. While these studies mainly aimed to understand the present-day Earth, this new project focuses on the "Early Earth". Melts and liquids were main players in the early evolution of the Earth. We will therefore measure physical and chemical properties of melts (liquids), such as crystallization, element partitioning, density, sound velocity, and thermal conductivity. These measurements will help understand magma ocean processes, separation of mantle and core, and core evolution and early dynamo.

【Research Methods】
We will perform a variety of measurements under high pressure and high temperature (*P-T*) in a laser-heated DAC (Fig. 1). With such techniques, materials property has been determined at high *P-T* even beyond the condition at the center of the Earth (364 GPa, ~6000 K). For high-pressure melting/crystallization experiments, a cross section of a tiny sample (~10 μm) that has been melted at high *P-T* will be precisely prepared by Focused Ion Beam and then examined for its texture and chemical composition under an electron microprobe (FE-EPMA and TEM). We will also introduce XAFS measurement system at the beamline BL10XU of SPring-8 synchrotron radiation facility. It enables us to determine the valence and electronic states of elements, which is important to better understand element partitioning during core formation and the solidification of magma ocean. We will also construct high-resolution imaging system at the BL10XU, with which we can determine the density and electrical/thermal conductivity.

【Expected Research Achievements and Scientific Significance】
The Earth was originally covered with a deep manga ocean. Its solidification defines the initial condition of the solid Earth. Understanding the solidification of the magma ocean is important also for better understanding of the present-day Earth. The segregation of the core from the mantle (core formation) is the biggest event on the early Earth. Its understanding is a key to the understanding of the initial condition for the core and its evolution. We will also try to clarify the mechanism of generation of geomagnetic field based on the examination of core compositional evolution before the birth of inner core.

【Publications Relevant to the Project】
Nomura, R., Hirose, K., Uesugi, K., Ohishi, Y., Tsuchiyama, A., Miyake, A., Low core-mantle boundary temperature inferred from the solidus of pyrolite, ***Science***, 343, 522-525, DOI: 10.1126/science.1248186, 2014.
Ohta, K., Kuwayama, Y., Hirose, K., Shimizu, K., Ohishi, Y., Experimental determination of the electrical resistivity of iron at Earth's core conditions, ***Nature***, 534, 95-98, doi:10.1038/nature17957, 2016.

【Term of Project】 FY2016-2020

【Budget Allocation】 387,500 Thousand Yen

【Homepage Address and Other Contact Information】
https://members.elsi.jp/~kei/en/director@elsi.jp

Title of Project : Study of dynamical variation of particles and waves in the inner magnetosphere using ground-based network observations

Kazuo Shiokawa
(Nagoya University, Institute for Space-Earth Environmental Research, Professor)

Research Project Number : 16H06286 Researcher Number : 80226092
Research Area : Aeronomy
Keyword : Magnetosphere and Ionosphere, Aeronomy, Space Science, Upper Atmosphere, Geospace

【Purpose and Background of the Research】

The dynamical variation of particles and waves in the inner magnetosphere is one of the most important research topics in recent space physics. The inner magnetosphere contains plasmas in wide energy ranges from below electron volts to Mega-electron volts. These plasmas (electrons and ions) interact with ULF/ELF/VLF waves at frequencies of 0.1 Hz to 10 kHz to cause their energization in the equatorial plane of the magnetosphere and loss into the ionosphere. The objectives of this project is to provide global distribution and quantitative evaluation of the dynamical variation of plasmas and waves in the inner magnetosphere.

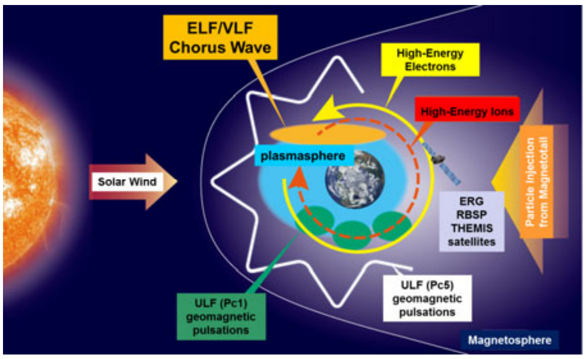

Figure 1. Particles and waves in the inner magnetosphere (looking down from the north pole).

【Research Methods】

We construct a longitudinal observation network at 8 ground-based stations at subauroral latitudes (magnetic latitudes: ~60 degree) to monitor 2-dimentional images of particle precipitation and ULF/ELF/VLF waves at frequencies of 0.1Hz – 10 kHz. We combine these longitudinal network observations with the ERG satellite, which will be launched in fiscal year 2016, and global modeling. Using these comprehensive observations and modeling, we provide global distribution and quantitative evaluation of the dynamical variation of plasmas and waves in the inner magnetosphere at L~4 Re near the plasmapause.

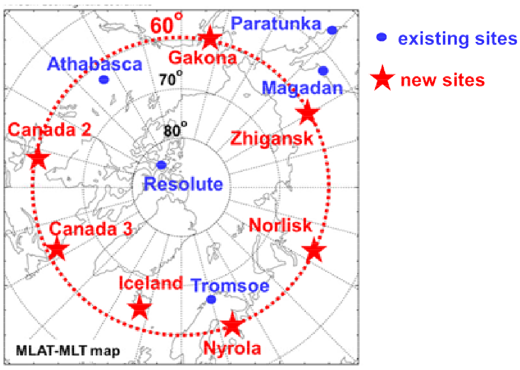

Figure 2. Ground network sites which will be deployed in this project.

【Expected Research Achievements and Scientific Significance】

The MeV-energy electrons in the inner magnetosphere forms the radiation belts around the Earth, which are continuous thread for space vehicles and human bodies in space. The outcome from our project will increase the accuracy of forecasting the variations of radiation belt particles in the inner magnetosphere and contribute to the safe operation of human activities in space. The results of our project are applicable to any astronomical bodies which have dipole magnetic field and atmosphere, and will increase the basic understanding of physical processes on the energization and loss of plasmas in space.

【Publications Relevant to the Project】

Miyoshi et al., The Energization and Radiation in Geospace (ERG) Project, in Dynamics of the Earth's Radiation Belts and Inner Magnetosphere, Geophys. Monogr. Ser., 199, pp.103-116, AGU, doi:10.1029/2012BK001304, 2012.

【Term of Project】 FY2016-2020

【Budget Allocation】 376,100 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.isee.nagoya-u.ac.jp/dimr/PWING/

【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Mathematics/Physics)

Title of Project : Search for cold exoplanets and free-floating planets by near infrared gravitational microlensing observation

Takahiro Sumi
(Osaka University, Graduate School of Science, Associate Professor)

Research Project Number : 16H06287 Researcher Number : 30432214
Research Area : Astronomy
Keyword : Exoplanet, gravitational microlensing, Infrared

【Purpose and Background of the Research】

Since the first discovery of exoplanets orbiting main-sequence stars in 1995, more than 3,000 exoplanets have been discovered by the radial velocity, transit and other techniques. Most of them have Neptune-Jupiter mass. Super-earths or Earth-radius planets have been discovered only near the host stars. The gravitational microlensing is uniquely sensitive to cold, low-mass planets and planets not orbiting any host star, called "free-floating planets", thus complementary to other techniques.

The MOA collaboration is carrying out the microlensing exoplanet survey by using a 1.8m wide field of view (FOV) telescope at Mt. John Observatory in New Zealand. We found the first exoplanet via microlensing and a 5.5 Earth-mass planet which was the lowest mass at that time, etc. We found that cold Neptunes are the most common type of exoplanet yet discovered. But we have detected planets only down to two Earth-mass, we do not know frequency of Earth-mass planets. To increase the planet discoveries, we need to observe stellar-crowded fields near the Galactic center. This cannot be done in optical due to the high interstellar dust extinction and needs IR surveys.

【Research Methods】

When a foreground "lens" star aligns almost perfectly along the line of sight toward a background source star, the gravity of the lens star magnifies the light from the source star. If a planet orbits around the lens star, we can see a brief disturbance in the light curve due to the gravity of the planet (Fig.1) by long continuous and high cadence monitoring of millions of stars. In this research, we conduct the IR microlensing exoplanets search for the first time by construction a new 1.8m wide FOV telescope equipped with the world largest-class IR camera at South Africa. This becomes possible by making use of existing large IR detectors loaned from the team of NASA's future WFIRST space-mission.

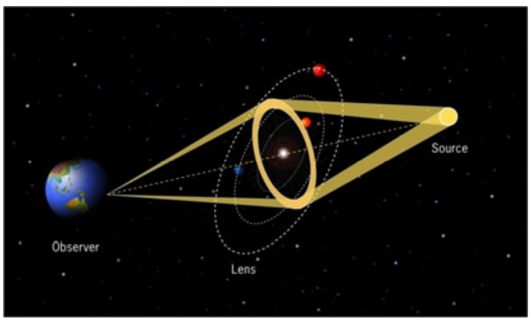

Fig 1 : A schematic of the microlensing exoplanet search technique.

【Expected Research Achievements and Scientific Significance】

By conducting the first IR microlensing exoplanet search toward the galactic bulge, we increase the event rates and expect to detect a few tens of exoplanets including Earth-mass planets and free-floating planets. This allow us to understand the formation mechanism and evolution of exoplanets. We can also compare the planet abundance in the stellar crowded region in the bulge to that of other fields. This dataset also allows us to optimize the observational fields for the future WFIRST microlensing exoplanet search.

【Publications Relevant to the Project】

"Unbound or distant planetary mass population detected by gravitational microlensing", Sumi, T. et al., Nature, 473, 7347, 349-352, 2011
"A Cold Neptune-Mass Planet OGLE-2007-BLG-368Lb: Cold Neptunes Are Common", Sumi, T., et al., The Astrophysical Journal, 710, 1641-1653, 2010

【Term of Project】 FY2016-2020

【Budget Allocation】 450,400 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.phys.canterbury.ac.nz/moa/

Title of Project : Measurement of CP symmetry of neutrino by upgrading T2K experiment

Takashi Kobayashi
(High Energy Accelerator Research Organization, Institute of Particle and Nuclear Studies, Professor)

Research Project Number : 16H06288　Researcher Number : 70291317
Research Area : Particle Physics Experiment
Keyword : Neutrino oscillation, CP symmetry, J-PARC, T2K, Super-Kamiokande

【Purpose and Background of the Research】

T2K is an experiment to elucidate mystery of neutrinos, one of the most unknown elementary particles by measuring a phenomena called neutrino oscillation in which a type of neutrino changes into different types of neutrinos during flight. The neutrino beam is produced at J-PARC, high intensity proton accelerator complex at Tokai-village, and detected by the Super-Kamiokande (SK) detector at 295km from J-PARC. T2K discovered new type of oscillation from muon-type neutrino to electron-type neutrino through 2011 to 2013. This KAKENHI research will improve sensitivity of the T2K experiment by upgrading beam power and detectors, and will first look for anti-muon neutrino to anti-electron neutrino oscillation, and then try to measure whether the probability of those oscillations for neutrinos and anti-neutrinos are different (CP violation) each other or not. If CP violation in neutrino is found, it could bring us a hint to solve the mystery of why matter exists in our Universe.

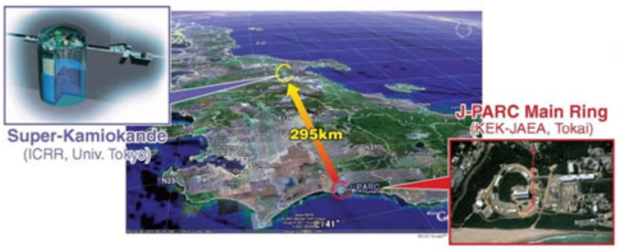

Fig. 1　Overview of T2K experiment

【Research Methods】

In this research, T2K sensitivity will be improved by reducing both statistical and systematic uncertainties. To improve the statistical precision, the number of neutrinos detected at Super-Koamokande have to be increased which means more neutrinos need to be produced at J-PARC. In order for that higher intensity, and high stability proton beam operation for long term is vital. To realize stable operation of high intensity proton beam, the proton beam monitors will be upgraded to improve performance/precision of proton beam monitoring of, such as beam position and beam width. In addition, a device called electromagnetic horn will be improved to increase number of neutrinos reaching to SK. To improve systematic precision, neutrino detector in J-PARC site to measure properties of neutrinos just after production will be upgraded.

【Expected Research Achievements and Scientific Significance】

Within 1 to 2 years, it is expected to discover anti-muon neutrino to anti-electron neutrino oscillation. Within the period of this KAKENHI research, evidence of CP violation at 95~99% confidence level is expected if CP is maximally violated. Continuing the measurement for additional ~5 years, CP violation could be discovered at 99.9% confidence level for maximal CP violation.

【Publications Relevant to the Project】

・“Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam”, T2K Collaboration (K. Abe (Tokyo U., ICRR) et al.), Phys.Rev.Lett. 107 (2011) 041801
・“Expression of Interest for an Extended Run at T2K to 20×10^{21}POT”, T2K Collaboration, Jan. 6, 2016, http://j-parc.jp/researcher/Hadron/en/pac_1601/pdf/EoI_2016-10.pdf

【Term of Project】FY2016-2020

【Budget Allocation】418,600 Thousand Yen

【Homepage Address and Other Contact Information】

http://t2k-experiment.org/

【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Chemistry)

Title of Project : Addressing Quantum Many-Body Dynamics by Ultrafast Coherent Control with Attosecond Precision

Kenji Ohmori
(National Institutes of Natural Sciences, Institute for Molecular Science, Professor)

Research Project Number : 16H06289 Researcher Number : 10241580
Research Area : Physical Chemistry, AMO Physics
Keyword : Ultrafast coherent control, Attosecond, Quantum many-body problem, Quantum simulator

【Purpose and Background of the Research】

The quantum many-body problem governs a variety of physical and chemical functionalities ranging from superconducting and magnetic materials to drug molecules. However, it is impossible to calculate stationary eigenstates of a quantum many-body system with more than 30 particles even with the "post-K" supercomputer planned to be completed by 2020 in Japan. The nonstationary dynamics is even more difficult to calculate.

In this research project, we will develop a novel "ultrafast quantum simulator" that can simulate the quantum many-body dynamics for more than 1000 particles within one nanosecond without approximations.

【Research Methods】

In real bulk solids and liquids, a wave function delocalized over many atoms and molecules is localized extremely fast due to thermal fluctuations. It is thus difficult to observe the dynamics during this localization even with our ultrafast coherent control with attosecond precision.

We therefore combine our coherent control with attosecond precision and a strongly-correlated ensemble of ultracold Rb Rydberg atoms (see Fig. 1), which is used as a model system of solids and liquids, to observe and control spatio-temporal evolutions of its many-body wave function. The precise and arbitrary assembly of the atoms is implemented with a new atom-trap technique based on advanced photonics and developed with Hamamatsu Photonics K.K..

【Expected Research Achievements and Scientific Significance】

The ultrafast quantum simulator will simulate the quantum many-body dynamics around the quantum-classical boundary for more than 1000 particles without approximations. Those simulations should allow us to better understand the boundary and the emergence of the physical and chemical functionalities mentioned above.

We anticipate that this ultrafast quantum simulator will develop into a large-scale simulation platform for the design of functional matter such as superconducting and magnetic materials and drug molecules in the future.

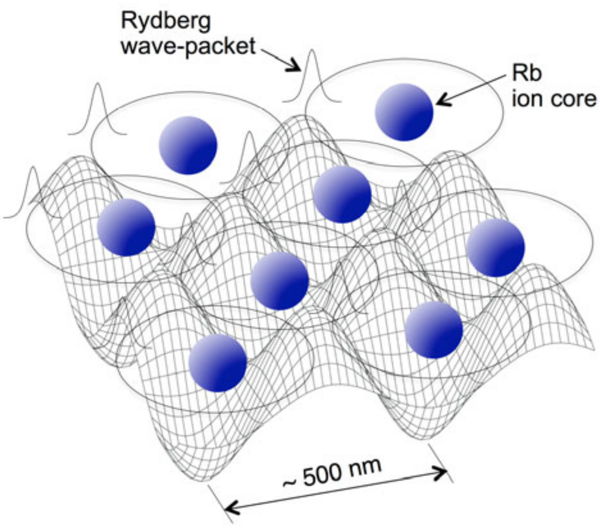

Figure 1 Ultrafast quantum simulator
(K. Ohmori, Found. Phys. **44**, 813 (2014))

【Publications Relevant to the Project】

・"Ultrafast Fourier transform with a femtosecond laser driven molecule," K. Hosaka and K. Ohmori *et al.*, Phys. Rev. Lett. **104**, 180501 (2010).
・"Strong-laser-induced quantum interference," H. Goto and K. Ohmori *et al.*, Nature Phys. **7**, 383-385 (2011).
・"All-optical control and visualization of ultrafast two-dimensional atomic motions in a single crystal of bismuth," H. Katsuki and K. Ohmori *et al.*, Nature Commun. **4**, 2801 (2013).

【Term of Project】 FY2016-2020

【Budget Allocation】 426,400 Thousand Yen

【Homepage Address and Other Contact Information】

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ohmori@ims.ac.jp

Title of Project : Chemical Biology of ER Related Glycan Modifications

Yukishige Ito
(RIKEN, Synthetic Cellular Chemistry Laboratory, Chief Scientist)

Research Project Number : 16H06290 Researcher Number : 80168385
Research Area : Biological Chemistry
Keyword : Carbohydrate Chemistry/Glycotechnology, Glycoprotein, Glycolipid, The Endoplasmic Reticulum

【Purpose and Background of the Research】

The endoplsmic reticulum (ER) is a venue of protein N-glycosylation as well as other types of glycan modification. For instance, recent study revealed the presence of a peculiar structure of C-mannosylation in various proteins. N-glycosylation of proteins is known to function as a tag that reflect their degree of folding. In the ER, a variety of lectins and enzymes work cooperatively to regulate glycoprotein folding through their ability to recognize specific high-mannose-type glycans, constituting glycoprotein “quality control” machinery.
On the other hand, the role of C-mannosylated tryptophan has been poorly, whereas its involvement in protein quality control mechanism in addition to natural immune signaling control has been implicated. Endoplasmic reticulum is also responsible for the synthesis of various lipids. Most notably, glucose containing novel glycolipids, such as cholesteryl glucoside and phosphatidyl glucoside (PtdGlc) have been found in brain tissue. Very recently, evidences to suggest the role of lyso PtdGlc (LPG) in nerve cell signaling and axon guidance were provided.
Based on these, this project aims to explore common principles among glycan modifications in the ER and ultimately to discover lead molecules for future drug discovery. Main focuses will be placed on 1) functions of glycans in protein folding regulating system in the ER, 2) functional analysis of glucosylation in the ER, 3) modulation of cellular functions through creation of novel LPG related compounds, and 4) relationship between protein C-mannosylation and quality control system.

【Research Methods】

As principal technology, 1) comprehensive synthesis of vesicular type oligosaccharides, 2) chemical synthesis of glycoproteins, 3) protein expression system of ER proteins, 3) carbohydrate-protein interaction analysis system, 4) synthetic method for C-linked mannose-containing glycopeptide, 5) anti-C-mannosiyl tryptophan antibody, 6) synthesis of PtdGlc, lyso PtdGlg (LPG) and their analogues, 7) PtdGlc specific antibody. In addition attempts will made to develop new techniques to facilitate and expand systematic analysis. Effort will be made to secure constant supply of oligosaccharide samples.

【Expected Research Achievements and Scientific Significance】

This project will unravel functions of various sugars signal produced in the endoplasmic reticulum. Establishment of new areas across carbohydrate-lipid-protein, and creation of new molecules having abilities to control cell functions are expected.

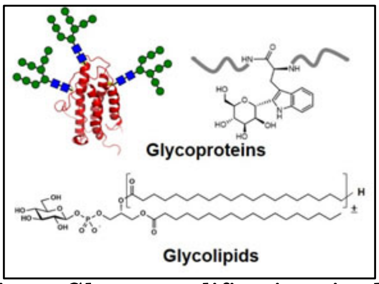

Fig. 1. Glycan modifications in the ER

【Publications Relevant to the Project】

- Y. Ito, Y. Takeda, A. Seko, M. Izumi, Y. Kajihara “Functional anaylsis of endoplasmic reticulum glucosyltransferase (UGGT): Synthetic chemistry’s initiative in glycobiology”, *Semin. Cell Dev. Biol.*, 41, 90-98 (2015)
- A. T. Guy, Y. Nagatsuka, N. Ooashi, M. Inoue, A. Nakata, P. Greimel, A. Inoue, T. Nabetani, A. Murayama, K. Ohta, Y. Ito, J. Aoki, Y. Hirabayashi, H. Kamiguchi “Glycerophospholipid regulation of modality-specific sensory axon guidance in the spinal cord”, *Science*, **349**, 974-977 (2015)

【Term of Project】 FY2016-2020

【Budget Allocation】 319,400 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.riken.jp/research/labs/chief/synth_cell_chem/ (yukito@riken.jp)

Title of Project : New frontiers in global hydrology

Taikan Oki
(The University of Tokyo, Institute of Industrial Science, Professor)

Research Project Number : 16H06291 Researcher Number : 50221148
Research Area : Global hydrology
Keyword : Hydrology, Integrated hydrological cycles and water resources model

【Purpose and Background of the Research】

The field of global hydrology today has certainly evolved and established itself nearly three decades after Bras et al. (1987) led the call for greater prominence. Current hydrology has a capability to monitor, understand, and predict global hydrological cycles of social-ecological systems, combining both human and natural systems.

The purpose of this project is to develop fundamentals for Terrestrial Model in the Next Generation (TiMiNG), which enables millenary global 1km simulation and should be a flag ship of global hydrology for coming 20 years.

【Research Methods】

This project will develop a new terrestrial model in the next generation (TiMiNG) based on the hydrodynamic river model CaMa-Flood (Yamazaki et al., 2011), combining water and energy cycles represented in a land surface model MATSIRO (Takata et al., 2003), water isotope processes (Yoshimura et al., 2006), human interventions of H08 (Hanasaki et al., 2010), glacier mass changes (Hirabayashi et al. ,2013), and a global deep ground water (Koirala et al., 2014), with a comprehensive representation of the expansion and shrink of water surface of lakes, river surface including flood inundation for surface water and energy cycles. TiMiNG will have a capability to couple with general circulation models (GCMs) or Earth System models (ESMs) through appropriate couplers, and a flexible structure to incorporate various terrestrial processes, such as redistribution of soil moisture and ground water by sub-grid scale topography, water temperature, glacier, sediment cycles, and long-range transfer.

In parallel with the development of TiMiNG, 4 sets of numerical experiment will be challenged under this proposal in order to solve the current issues in global hydrology and preparing for the forthcoming 1 km global simulation for 1000 years.

1) Real-time 1 km simulation over Japan
2) Hyper-resolution simulation over the Aral Sea Basin in Western Asia for 50 years
3) Hyper-resolution simulation over the globe for one year
4) 250 years simulation from 1850 through 2100 (under the 3rd phase of the Global Soil Wetness Project; GSWP3)

【Expected Research Achievements and Scientific Significance】

With TiMiNG, it is expected that community development of terrestrial modeling would be much easier and smooth, and up-to-date knowledge on terrestrial processes will be reflected promptly. Also, leading and managing the GSWP3 and Land Surface, Snow, Soil-moisture Model Inter-comparison Project (LS3MIP) in the CMIP6 will evaluate the state-of-the-art modeling systems and generate a comprehensive set of quantities for global energy, water and carbon cycles, which is necessary to increase the depth of our understanding of the global hydrology.

【Publications Relevant to the Project】

Oki, T., and S. Kanae, 2006: Global Hydrological Cycles and World Water Resources, *Science*, **313**(5790), 1068-1072.
Hanasaki, N., S. Kanae, T. Oki, K. Masuda, K. Motoya, N. Shirakawa, Y. Shen, and K. Tanaka, 2008: An integrated model for the assessment of global water resources - Part 1: Model description and input meteorological forcing, *Hydrol. Earth Syst. Sci.*, **12**, 1007-1025.
Yamazaki, D., S. Kanae, H. Kim, T. Oki, 2011: A physically based description of floodplain inundation dynamics in a global river routing model, *Water Resour. Res.*, **47**(4), W04501.

【Term of Project】 FY2016-2020

【Budget Allocation】 340,700 Thousand Yen

【Homepage Address and Other Contact Information】

http://hydro.iis.u-tokyo.ac.jp/

Title of Project : High-performance semiconductor terahertz devices unifying quantum transition and traveling of electrons

Masahiro Asada
(Tokyo Institute of Technology, Institute of Innovative Research, Professor)

Research Project Number : 16H06292 Researcher Number : 30167887
Research Area : Engineering
Keyword : Electron devices, Quantum devices, Terahertz waves

【Purpose and Background of the Research】

High performance semiconductor terahertz sources, such as those with high output power, room-temperature operation and compactness, are key components for the unexplored terahertz frequency range. Up to now, we have succeeded a room-temperature oscillation of resonant tunneling diodes (RTDs) above 1 THz. This is the first-time achievement in electronic single devices. Because the terahertz range is located between radio waves and light waves, and also because its photon energy is non-negligible, it is necessary to establish a comprehensive base of terahertz device physics including electron travelling and quantum-mechanical transition in order to realize high performance terahertz sources.

Based on these background, we aim in this research at establishment of terahertz device physics and realization of high performance terahertz sources for various applications.

【Research Methods】

1. Terahertz device physics: By measuring temperature dependence of several oscillation characteristics including output power, frequency, and coherence of RTD oscillators, we intend to experimentally and theoretically figure out the transition of operation from those of electron to optical devices, and to establish the base of terahertz device physics.
2. High performance terahertz sources: We intend to realize RTD oscillators with high frequency and high output power by taking into account the optical device operation based on the results in 1 together with suitable structures for resonators and antennas. Wide frequency weep and narrow spectrum are also intended.
3. Application of high performance terahertz sources: Basic experiments toward terahertz applications, such as high-sensitivity real time imaging, high-resolution spectroscopy, and high-capacity wireless communication, will be done using high performance terahertz sources.

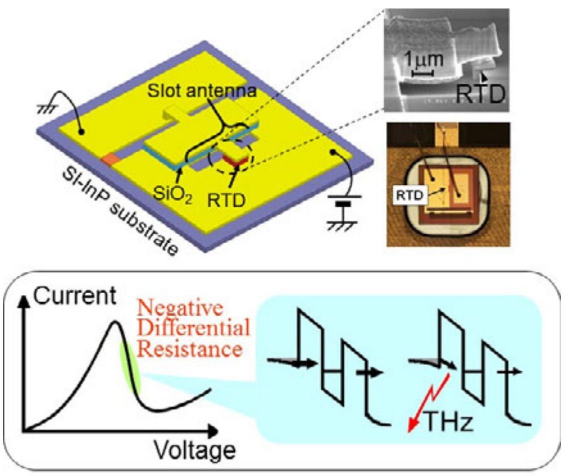

Figure 1 Terahertz oscillator using resonant tunneling diode (RTD) and negative differential resistance in the current-voltage characteristics

【Expected Research Achievements and Scientific Significance】

A comprehensive base of terahertz device physics bridging between optical and electronic devices, is expected to be established. Using this base, realization of high performance terahertz sources will become possible, which lead the research field of the terahertz waves as a break through.

【Publications Relevant to the Project】

T. Maekawa, H. Kanaya, S. Suzuki, and M. Asada, "Oscillation up to 1.92 THz in resonant tunneling diode by reduced conduction loss," Appl. Phys. Express **9**, 024101 (2016).
S. Kitagawa, S. Suzuki and M. Asada, "Wide frequency-tunable resonant tunnelling diode terahertz oscillators using varactor diodes," Electron. Lett. **52**, pp.479–481 (2016).

【Term of Project】 FY2016-2020

【Budget Allocation】 413,700 Thousand Yen

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Title of Project : Creation of Novel High Performance Catalyst Tailored by Chemo-mechanical Effects

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Research Project Number : 16H06293 Researcher Number : 80184555
Research Area : Engineering
Keyword : Catalyst, Chemo-mechanical effects, Nano size effects, Ion conductivity

【Purpose and Background of the Research】

Although it is known that chemo-mechanical stress can have a large influence on many materials properties, especially ionic conductivity [1], its influence on surface activity and catalytic activity has not yet been studied in detail. In a previous study, we showed that the tensile stress caused by chemical relaxation can significantly enhance bulk oxide ion conductivity as well as surface activation to oxygen dissociation. Building on these promising results, the proposed study will systematically investigate the effects of chemo-mechanical strain on the surface chemistry and associated catalytic activity of the oxide. Since significant increases in activity are necessary in many applications, the influence of such strain effects on the performance of air electrodes in fuel cells, for NO decomposition reactions, for diesel particulate matter (PM) oxidation catalysts, and even photocatalytic reactions, will be investigated.

The originality of this study lies in harnessing these chemo-mechanical strain effects to develop a new class of catalysts. The present study seeks to apply an approach which has not yet been explored, to increase the diffusivity of lattice oxygen (or oxygen vacancies) to these important area.

【Research Methods】

Details of this research are 1) To tailor chemo-mechanical strain in materials such as perovskite, or oxygen deficient fluorite, oxides. For this purpose, we will use laminated epitaxial films with nm thickness and controlled mismatch between lattice sizes. A second approach will involve the dispersion of metal or metal nitrate nano-particles having different thermal expansion in the oxide matrix (Figure). 2) The effect of such strain on surface chemistry, catalytic activity, or electrochemical activity will elucidated. 3) Change in gas adsorption or desorption properties (O_2, NO, and H_2) will be evaluated, and the relationship between changes in structure (by neutron diffraction, EXAFS, TEM, XPS etc.) and properties (charge carrier density, spin state, oxygen non-stoichiometry) will be discussed from chemo-mechanical strain effects. 4) The mechanism for beneficial effects of chemo-mechanical strain on surface chemistry and activity will be analyzed based on first principles DFT calculation. From this study, we expect to demonstrate a new concept for catalyst design.

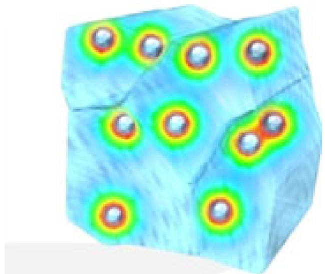

Fig. Image of nano strain effects formed by dispersion of nano particle.

【Expected Research Achievements and Scientific Significance】

We will investigate the effect of lattice strain on NO decomposition, low temperature diesel PM oxidation, and photocatalytic activity, which are also important applications to address environmental issues. Therefore, the topic studied in this project will have a broad impact for energy and environmental applications, and significantly benefit society.

【Publications Relevant to the Project】

J. Druce, H. Tellez, M. Burriel, M. Sharp, L. Fawcett, S. N Cook, D. McPhail, T. Ishihara, H. H. Brongersma and J. A Kilner, Energy & Environmental Science, 7(11), 3993-3599, (2014)

【Term of Project】 FY2016-2020

【Budget Allocation】 380,700 Thousand Yen

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