【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Mathematics/Physics)

Title of Project : Uncover processes of slips-to-the-trench, their past and present

Ryota Hino
(Tohoku University, International Research Institute of Disaster Science, Professor)

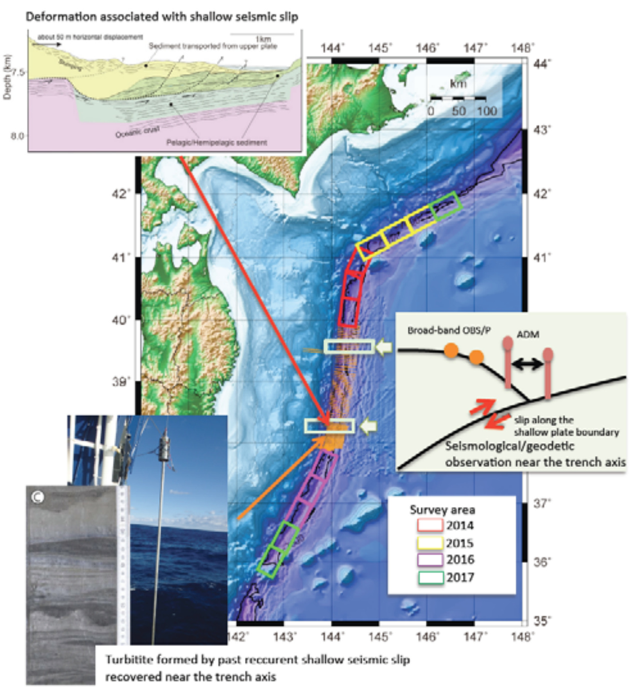
Research Project Number : 26000002 Researcher Number : 00241521
Research Area : Solid earth and planetary physics
Keyword : Earthquake phenomena, Crustal movement/Sea floor crustal movement, Tectonics

【Purpose and Background of the Research】

The huge coseismic slip of the 2011 Tohoku earthquake (Mw 9.0) near the Japan Trench caused devastating tsunamis along the northeast coast of Japan. Since then, the mechanical behavior of the shallowest part of the plate-boundary fault has drawn worldwide attention. We conduct a multidisciplinary research project to elucidate the history of recurring tsunamigenic slips near the trench (slips-to-the-trench, STT) before the 2011 earthquake and transient processes on the fault since the massive rupture of 2011.

【Research Methods】

In the 5-year project, we will: 1) Conduct high-resolution seismic surveys and use the resultant data to both elucidate the spatial extent of past STT events and identify deformation structures characteristic of STT events. 2) Determine the timing of past STT events by collecting sub-seafloor sedimentary core samples and identifying and dating earthquake-generated turbidite layers. 3) Identify postseismic deformation processes in the Japan Trench by using dense arrays of broadband seismic sensors (OBS), monitoring absolute pressure (OBP), and monitoring relative motion of the seafloor across the plate-boundary fault, by acoustic distance measurement (ADM) .



【Expected Research Achievements and Scientific Significance】

Systematic studies on past STT events will improve our understanding of the space–time history of large earthquakes, which has mostly derived from geological studies on tsunami deposits along coasts. The space–time history of large earthquakes will provide clues to understanding why earthquakes of M <8 have been frequent and those of M~9 infrequent in the same subduction system, a fundamental question raised by the 2011 Tohoku earthquake.

Since STT increases size of tsunamis associated with megathrust earthquakes, history of past STTs is crucial for evaluating tsunami hazard in regions facing to subduction zones. This project will establish a methodology to clarify reliable reccurence history of STTs in subduction zones in the world.

【Publications Relevant to the Project】

- Ito, Y.,T. Tsuji, Y. Osada, M. Kido, D. Inazu, Y. Hayashi, H. Tsushima, R. Hino, and H. Fujimoto (2011), Frontal wedge deformation near the source region of the 2011 Tohoku-Oki earthquake, *Geophys. Res. Lett.*, 38, L00G05, doi:10.1029/2011GL048355
- Kodaira, S., T. No, Y. Nakamura, T. Fujiwara, Y. Kaiho, S. Miura, N. Takahashi, Y. Kaneda, and A. Taira (2012), Coseismic fault rupture at the trench axis during the 2011 Tohoku-oki earthquake, *Nature Geoscience*, *5*(9), 646-650, doi:10.1038/ngeo1547

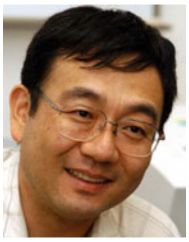
【Term of Project】 FY2014-2018

【Budget Allocation】 426,100 Thousand Yen

【Homepage Address and Other Contact Information】
http://www.jdash.org

【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Mathematics/Physics)



Title of Project : Observation of supernova neutrinos with neutron tagging

Masayuki Nakahata
(The University of Tokyo, Institute for Cosmic Ray Research, Professor)

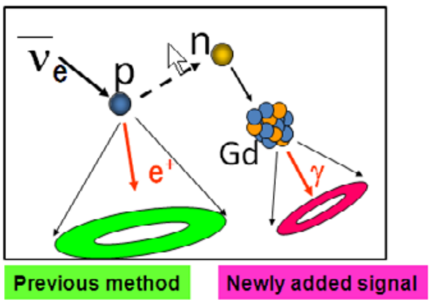
Research Project Number : 26000003 Researcher Number : 70192672
Research Area : Particle/Nuclear/Cosmic ray/Astro physics
Keyword : Cosmic ray (experiment)

【Purpose and Background of the Research】

The supernova explosion is the last phenomena of massive stars and it is triggered by a gravitational collapse of their iron cores, which results in formation of neutron stars and black holes. Huge amount of energy is produced at the time of the explosion for about 10 seconds and most of the energy is carried out by neutrinos. Actually, such neutrinos were observed by Kamiokande with the supernova SN1987A, and the basic scenario of the explosion mechanism was confirmed. However, because the number of observed neutrino events was only about ten, details of the mechanism was not clarified. Also, this was an observation of <u>one</u> supernova, and many supernovae are necessary to investigate a global picture. There are approximately 10^{20} stars in the universe, and about 0.3% of them, i.e. about 10^{17} stars have become supernovae so far. The neutrinos produced by those explosions are called supernova relic neutrinos (SRNs). The main purpose of this research is to observe SRNs. Another purpose is to determine the direction of supernova if it happens in our galaxy.

【Research Methods】

All types of neutrinos are emitted when a supernova explosion happens. Anti-electron-neutrinos are easiest to be detected and they produce positions and neutrinos with free proton interactions. In this research, we will detect the anti-electron-neutrinos with neutron tagging as shown in the left figure. It is predicted that SRNs dominate in the energy range from 10 to 30 MeV. However, a lot of solar neutrinos and spallation products of cosmic rays dominates in this energy range. That is why neutron-tagging is necessary to observe SRNs. Since the flux of SRNs is estimated to be small, a big detector like Super-Kamiokande (SK) will be necessary. In this research, we plan to put gadolinium into the SK water tank. Gadolinium has a large neutron capture cross section and emits high energy gamma rays which can be detected by SK.



If a supernova happens in our galaxy, many thousands of anti-electron-neutrino interactions and several hundred electron-scatterings happen at SK. Electron-scattering events, which have directional information, can be extracted using neutron anti-tagging and the pointing accuracy will be improved. In case of a nearby supernova such as Betelgeuse (if it happens), using anti-electron-neutrinos emitted during the silicon burning phase, a precursor of the explosion could be detected.

【Expected Research Achievements and Scientific Significance】

If this research is realized, it would be the first observation of SRNs in the world. It will reveal history of massive stars in the universe. Also, averaged neutrino energy spectrum could be observed. For the supernova in our galaxy, it is very important to dispatch the directional information to optical observatories as soon as possible. A supernova starts emitting photons when the shockwave reaches to the surface of the star, which usually takes from several hours to a day. With a quick dispatch of neutrino detection, optical observations can be started from its very early stage.

【Publications Relevant to the Project】

・"GADZOOKS! Anti-neutrino spectroscopy with large water Cherenkov detectors", J. F. Beacom, M. R. Vagins, Phys.Rev.Lett. 93 (2004) 171101.
・"Supernova Relic Neutrino Search at Super-Kamiokande", Super-Kamiokande Collaboration (K. Bays et al.), Phys.Rev. D85 (2012) 052007.

【Term of Project】 FY2014-2018

【Budget Allocation】 453,400 Thousand Yen

【Homepage Address and Other Contact Information】

http://www-sk.icrr.u-tokyo.ac.jp/~nakahata/tokusui
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Title of Project: MEG II Experiment – Highest Sensitivity Search for Rare Muon Decay to Explore Grand Unified Theories

Toshinori Mori
(The University of Tokyo, International Center for Elementary Particle Physics, Professor)

Research Project Number : 26000004 Researcher Number : 90220011
Research Area : Physics, Particle/Nuclear/Cosmic ray/Astrophysics
Keyword : Particle physics (experiment)

【Purpose and Background of the Research】

Based on several years of experience of detector operation in the world-leading MEG experiment and intensive R&D efforts, we came to an idea of an upgrade experiment, MEG II, which should reach an order of magnitude better sensitivity than the MEG experiment by running at the world's highest muon rate, improving the detector resolutions, and expanding the detector acceptance. Our MEG II proposal was immediately approved by the Scientific Advisory Committee of PSI in January 2013, which lead to this research project.

The goal of the project is to construct and carry out the MEG II experiment in order to search for the $\mu \rightarrow e\gamma$ decay with a sensitivity of $O(10^{-14})$ and explore Grand Unified Theories (GUTs), a key to solve the mysteries in the early Universe.

【Research Methods】

In the MEG II experiment (Figure 1) newly developed experimental devices, such as VUV sensitive solid sensors that will replace old-fashined PMTs in the LXe photon detector (Figure 2), to improve detector resolutions, lower the accidental background and enable running at the highest available muon rate, which enables the world's highest sensitivity to the $\mu \rightarrow e\gamma$ decay.

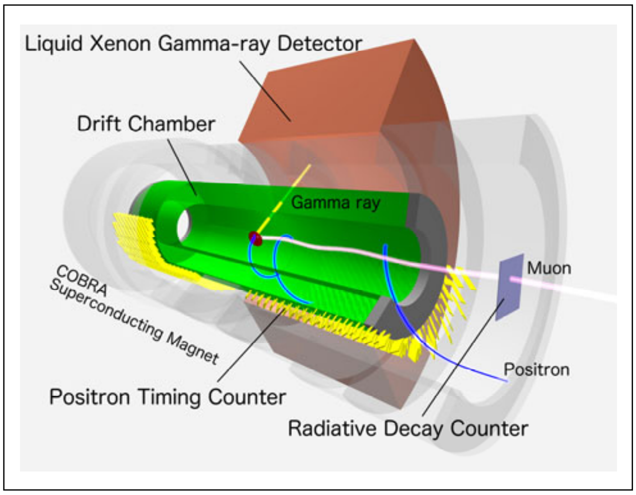

Figure 1 A schematic of MEG II experiment

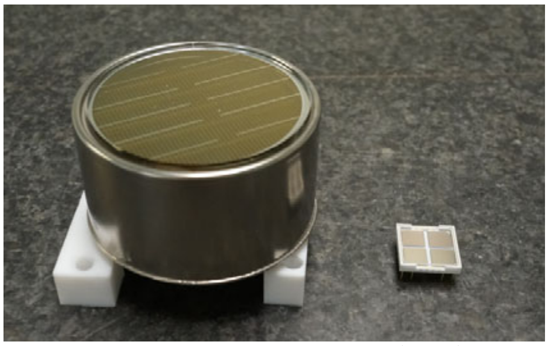

Figure 2 a newly developed sensor (right) and a PMT

【Expected Research Achievements and Scientific Significance】

As implied by a possible unification of the coupling constants (GUTs), new physics beyond the Standard Model must have played a very important role in the early Universe. While the energy frontier LHC experiments are looking for evidences of such new physics, the MEG II experiment will also explore them with a similar sensitivity but in a different and complementary way. A discovery of the $\mu \rightarrow e\gamma$ decay would have a tremendous impact on the future direction of the particle physics researches. Even non-discovery will be transformative by strongly constraining possible types of new physics.

【Publications Relevant to the Project】

- MEG Collaboration, "New Constraint on the Existence of the mu-e-gamma Decay," Phys. Rev. Lett. 110 (2013) 201801
- MEG II Collaboration, "MEG Upgrade Proposal," arXiv:1301.7225

【Term of Project】 FY2014-2018

【Budget Allocation】 425,100 Thousand Yen

【Homepage Address and Other Contact Information】

http://meg.icepp.s.u-tokyo.ac.jp/
http://www.icepp.s.u-tokyo.ac.jp/meg/

【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Mathematics/Physics)

Title of Project : Detection of gravitational waves with a cryogenic interferometer

Takaaki Kajita
(The University of Tokyo, Institute for Cosmic Ray Research, Professor)

Research Project Number : 26000005 Researcher Number : 40185773
Research Area : Mathematical and physical science
Keyword : Cosmology/Gravitation (experiment)

【Purpose and Background of the Research】

Gravitational wave (GW), distortion of the space-time structure propagating at the speed of light, by accelerating masses was predicted by Albert Einstein from his theory of general relativity. There are various astrophysical phenomena that could produce strong GW such as mergers of binary neutron stars or binary black-holes, or supernova explosions.

A 3km baseline laser interferometer KAGRA will be the key infrastructure in this research. We plan to achieve the world's highest sensitivity, operate the instrument for more than a year, and observe the GW signal for the first time and create a new scientific filed of "gravitational wave astronomy".

【Research Methods】

Key features of KAGRA include the seismically quiet underground site of Kamioka mine and the reduction of thermal noises by cooling the interferometer mirrors down to 20K (Figure 1).

We plan to carry out various research and developments (R&D's) in order to achieve the very high sensitivity in the GW signal detection. These R&D's include the advanced suspension system for the cryogenic mirrors, the method to accelerate the cooling speed, and the advanced interferometer control system.

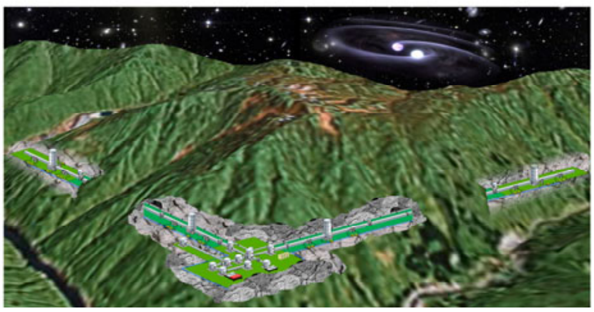

Figure 1 KAGRA detector

After these R&D's, we plan to operate the instrument for more than a year during this research period.

【Expected Research Achievements and Scientific Significance】

We expect to observe the GW signals from the following astrophysical phenomena:

1) Merger of binary neutron stars (Figure 2). The expected event rate is more than a few per year. Therefore, this is the primary candidate for the first detection of the GW signal.

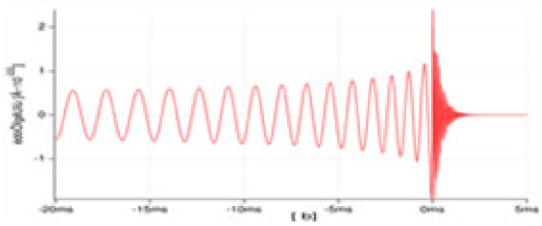

Figure 2 Expected GW signal for a merger of binary neutron stars (x- and y-axes show time and the amplitude, respectively.)

2) Merger of binary black-holes. (The event rate has a large uncertainty.)
3) Supernova explosion. (The event rate is low (1 per 10 years?)).

Observation of GW signals from one or some of the sources will open the new scientific filed of "gravitational wave astronomy".

【Publications Relevant to the Project】

・"Reduction of thermal fluctuations in a cryogenic laser interferometric gravitational wave detector" Takashi Uchiyama, Shinji Miyoki *et al.*, Phys. Rev. Lett. 108 (2012) 141101

・"Observing gravitational waves – from the investigation of the existence to the detection ", ed. Takashi Nakamura, Norikatsu Mio, and Masatake Ohashi, Kyoto Univ. Press (1998) (in Japanese).

【Term of Project】 FY2014-2018

【Budget Allocation】 446,800 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.icrr.u-tokyo.ac.jp/gr/SPR/index.html

【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Mathematics/Physics)

Title of Project : Material Sciences at Very High Pressure: Frontier of Mbar Chemistry

Katsuya Shimizu
(Osaka University, Graduate School of Engineering Science, Professor)

Research Project Number : 26000006 Researcher Number : 70283736
Research Area : Material Science
Keyword : High Pressure, Superconductivity, Metals, Magnetism

【Purpose and Background of the Research】

To explore material science at extreme condition of ultra-high pressure exceeding megabar (100 GPa), original designed high-pressure technique will be investigated. The pressure-induced superconductivity in simple systems such as elemental material, organic and inorganic molecular crystals were found at high pressure, and it was recently found that some of them show complete different phenomena at megabar pressures. This project forms following 3 parts. A: Materials science at very high pressure on simple systems. B: High-pressure synthesis of functional materials. C: Developments of multi-megabar technique and theoretical calculations.

【Research Methods】

A: The most attractive among various elements is hydrogen in the condensed phase as solid metallic hydrogen is expected to be a room-temperature superconductor. Also, fluid metallic hydrogen under high pressure and at high temperature may provide important information about the interior of giant planets. Light halogen elements and metal hydrides are also subject of the research.

B: High efficiency needs in materials such as thermoelectric, multiferroic, magnetoresistic, carbon system, nano meterials, and hydrogen storage materials. The physical properties of these materials will be clarified, and new functions and chemical reaction will be tested.

C: Technical development: To exceeding 4 megabar that is known as the generating limit of a diamond anvil cell. The precise structural analysis of the submicron size will be performed using a synchrotron X-ray with simultaneous physical measurements in the range of large temperature and pressure by developing of so called megabar platform. The computer simulation using ab-initio calculation is a powerful technique at the prediction and analysis under ultra-high pressure. The precise theoretical calculation will be performed in physical properties, such as pressure-induced phase transition, structural stability, and pressure-induced superconductivity in A and B.

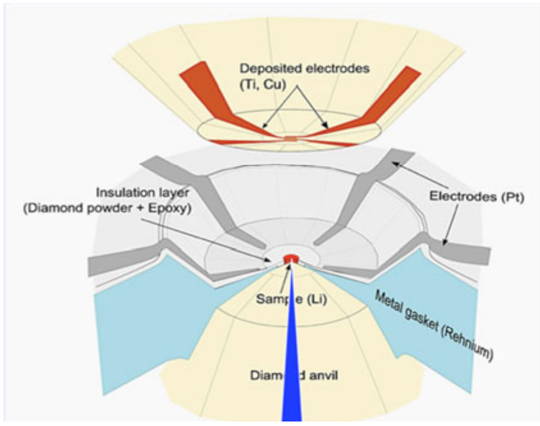

Figure 1. “megabar” platform

【Expected Research Achievements and Scientific Significance】

The impact of the realization of the RTS (Room Temperature Superconductivity) of the metallic hydrogen is immeasurable. Not only RTS but also developing new functions of materials must be great influence in our energy, electronics, and communications system in our human beings. The establishment of a synthetic method by the megabar pressure can be a breakthrough of the limit of materials developments by substitution and doping method, etc.

【Publications Relevant to the Project】

K. Shimizu, “Elemental Superconductors” 100 years of Superconductivity 4-8, 278-282, CRC Press, Taylor & Francis (2011).

T. Matsuoka and K. Shimizu, Direct observation of a pressure-induced metal-to- semiconductor transition in lithium, Nature 458, 186-189 (2009).

【Term of Project】 FY2014-2018

【Budget Allocation】 395,500 Thousand Yen

【Homepage Address and Other Contact Information】

http://hpr.stec.es.osaka-u.ac.jp
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Title of Project : Chemical Biology Studies on Trinucleotide Repeat Disease using Repeat-Binding Molecules

Kazuhiko Nakatani
(Osaka University, The Institute of Scientific and Industrial Research, Professor)

Research Project Number : 26000007 Researcher Number : 70237303
Research Area : Chemical Biology
Keyword : In vivo functional expression, chemical probes, hereditary diseases, toxic RNA

【Purpose and Background of the Research】

Huntington disease and Fragile X syndrome are classified as neurological disorders so called trinucleotide repeat diseases. Other well-known trinucleotide repeat disease is Myotonic Dystrophy caused by the expansion of d(CTG) repeat. Because these trinucleotide diseases are genetic disorders, there is no way of treatment for complete cure. Thus, it is extremely important to keep or improve the "Quality of Life" of patients. With these molecules specifically bind to the d(CAG)n and d(CGG)n repeats relating neurological disorders in hand, we were eagerly looked for the opportunities of collaborative research with researchers and medical doctors who are studying in the field of neurological disorders in order to make use of our molecules for any possible ways to contribute to keep the QOL of patients.

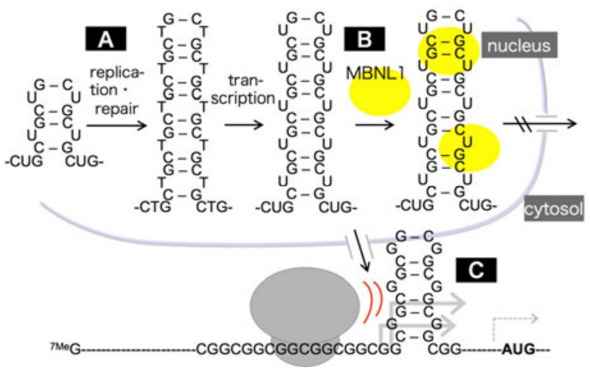

Figure 1. Three stages related the onset of trinucleotide repeat diseases. A) Repeat instability on replication and repair, B) Secretion of nuclear protein by toxic RNA, C) RAN Translation

【Research Methods】

Our research methods are as follows: 1) Elucidation of molecular mechanism of repeat instability (expansion and contraction) in cell. We study the structure optimization of probe to minimize the cytotoxic activity, and investigate new molecules specifically binding d(CTG) repeat. 2) Sequestration of toxic RNA. Molecules binding to r(CGG)n and r(CUG)n repeats are expected to sequester these toxic RNA from MBNL1. 3) Elucidation of molecular mechanism and method to modulate RAN (Repeat Associated Non-AUG) translation. Our probe molecules will be useful for the deeper understanding of RAN translation.

【Expected Research Achievements and Scientific Significance】

The importance of our proposed research is that the research will provide the deeper understanding of the trinucleotide repeat disorders, which will be indispensable for the more accurate diagnosis and adequate suggestion on the genetic inquiry. In addition, the research may provide with the novel molecules that interfere with the expansion of trinucleotide repeats during aging. For the patients and people before the onset, it is ideal to contract the expanded repeat, which results in preventing aggravation of disease conditions and onset of disease. Thus, molecules effectively suppress the repeat expansion and/or contract the expanded repeat is quite important for the QOL of patients.

【Publications Relevant to the Project】

1) Nakatani, K. et al. Small-molecule ligand induces nucleotide flipping in (CAG)n trinucleotide repeats, *Nature Chemical Biology* **2005**, *1*, 39–43.
2) Hagihara, M.; He, H.; Kimura, M.; Nakatani, K. A Small Molecule Regulates Hairpin Structures in d(CGG) Trinucleotide Repeats. *Bioorg. Med. Chem. Lett.* **2012**, *22*, 2000-2003.

【Term of Project】 FY2014-2018

【Budget Allocation】 303,404 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.sanken.osaka-u.ac.jp/labs/rbc/english/index_e.html
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【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Chemistry)

Title of Project : New Energy Sources from Hydrogenase-Photosysnthesis Models

Seiji Ogo
(Kyushu University, Graduate School of Engineering, Professor)

Research Project Number : 26000008 Researcher Number : 60290904
Research Area : Chemistry
Keyword : Hydrogenase, Photosystems, Energy

【Purpose and Background of the Research】

A new energy system independent of fossil fuels is required in order to realize a sustainable environmentally friendly society. The extraction of electrons from H_2 and H_2O and their use in energy applications are a necessary part of this goal. H_2 and H_2O are expected to become new energy sources or energy carriers to replace fossil fuels. In natural systems, hydrogenase, an H_2-activating enzyme, catalyzes extraction of electrons from H_2, and photosystem II, an H_2O-activating enzyme, catalyzes extraction of electrons from H_2O. Such enzymes function under mild conditions but are inactivated under extreme conditions. However, enzymes contained in extremophile bacteria are robust because they have self-repairing systems to protect the active centers.

In this study, we create an innovative energy conversion technology for practical use on the basis of chemistry (coordination chemistry, biochemistry, and electrochemistry) and agriculture (applied microbiology) by elucidating the catalytic reaction mechanism using the robust enzymes.

【Research Methods】

We develop novel model catalysts for hydrogenase and photosystem II in order to extract electrons from H_2 and H_2O. Based on a biomimetic approach from nature to technology, we conduct research with the following themes to achieve a practical application of the catalysts.

Theme 1: Search for new hydrogenases. We look for unknown robust hydrogenases under extreme conditions, investigate the catalytic mechanism for H_2-activation, and analyze the genome.

Theme 2: Synthesis of hydrogenase models. By mimicking the structure and function of the active center of hydrogenase, we develop novel model catalysts to activate H_2.

Theme 3: Development of electrode catalysts for a fuel cell. We apply the hydrogenase model catalysts to the electrodes of fuel cells and investigate the performance of the catalysts.

Theme 4: Search for new photosystem II enzymes. We look for unknown robust photosystem II enzymes under extreme conditions to investigate the catalytic mechanism for H_2O-activation.

Theme 5: Synthesis of a photosystem II model. We produce novel biomimetic catalysts to activate H_2O based on photosystem II.

Theme6: Development of an artificial photosynthesis catalyst. We apply the photosystem II model catalysts to an artificial photosynthesis system and investigate the performance.

【Expected Research Achievements and Scientific Significance】

The achievements of this project will have a great impact on human society with regard to energy, resources, and environmental problems. In this project, we focus on activation of H_2 and H_2O by hydrogenase and photosystem II, respectively, to develop artificial catalysts for practical use on the basis of agriculture (applied microbiology), chemistry (coordination chemistry, biochemistry, and electrochemistry), and practical engineering. The results to be obtained from this project are significant in the field of basic science, and will also a have high impact in the chemical industry. The achievements will be transferable to industrial technologies.

【Publications Relevant to the Project】

・S. Ogo, K. Ichikawa, T. Kishima, T. Matsumoto, H. Nakai, K. Kusaka, T. Ohhara, *Science* **2013**, *339*, 682–684.
・S. Ogo, R. Kabe, K. Uehara, B. Kure, T. Nishimura, S. C. Menon, R. Harada, S. Fukuzumi, Y. Higuchi, T. Ohhara, T. Tamada, R. Kuroki, *Science* **2007**, *316*, 585–587.

【Term of Project】 FY2014–2018

【Budget Allocation】 437,900 Thousand Yen

【Homepage Address and Other Contact Information】

http://web.cstm.kyushu-u.ac.jp/ogo/
ogolab@mail.cstm.kyushu-u.ac.jp

Title of Project : **Proposal of multi-functional coherent Nyquist pulse and its ultrahigh-speed and highly-efficient optical transmission**

Masataka Nakazawa
(Tohoku University, Research Institute of Electrical Communication, Professor)

Research Project Number : 26000009 Researcher Number : 80333889
Research Area : Engineering
Keyword : Communication systems (wireless, wired, satellite, optical, mobile)

【Purpose and Background of the Research】

Motivated by the growing demand for larger transmission capacity in optical backbone networks, it has been an important subject to increase both bit rate per wavelength and spectral efficiency (SE) simultaneously. In general, however, there exists an inevitable trade-off between the bit rate and SE. To overcome this limitation, we recently proposed a new type of optical pulse, which we call an “optical Nyquist pulse,” and its overlapped time-division multiplexing (“Nyquist TDM”). The goal of this project is to achieve an ultrahigh bit rate (> Tbit/s) and SE (> 10 bit/s/Hz) simultaneously by adopting coherent Nyquist pulses and employing their TDM and multi-level quadrature amplitude modulation (QAM) techniques.

【Research Methods】

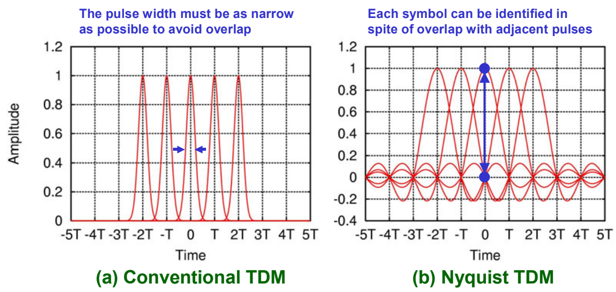

Figure 1 Comparison of conventional TDM (a) and our proposed Nyquist TDM (b).

Figure 1 shows the concept of Nyquist TDM and compares it with conventional TDM. The shape of the optical Nyquist pulse is given by the sinc-function (sin$t$ / t). It is characterized by the ringing in the tail, which crosses zero periodically. Therefore, in the TDM of optical Nyquist pulses, each symbol can be identified without being affected by intersymbol interference (ISI) despite a strong overlap with neighboring pulses, as shown by the blue dots. This is very advantageous compared with the conventional TDM of pulses shown in Fig. 1(a) in which the minimum pulse width is needed to avoid ISI as the symbol rate increases. The optical Nyquist pulse thus allows the signal bandwidth to be narrowed as much as possible without ISI.

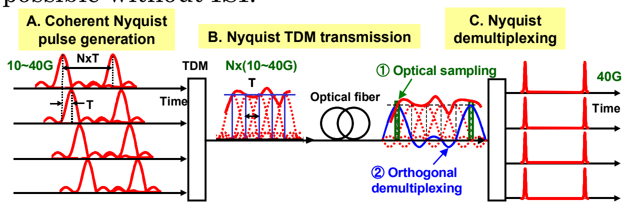

Figure 2 Basic configuration for high-speed and high-density Nyquist TDM transmission.

The basic configuration for coherent Nyquist TDM transmission is shown in Fig. 2. In this project, we establish fundamental technologies for coherent Nyquist TDM transmission by utilizing the multi-functionalities inherent in Nyquist pulses, especially their time-domain orthogonality. A key component is a coherent Nyquist pulse generator. By taking full advantage of the time-domain orthogonality of Nyquist pulses, we will develop novel demodulation and demultiplexing techniques which can provide a high SNR sufficient for ultrahigh QAM multiplicity.

【Expected Research Achievements and Scientific Significance】

We expect to realize innovative high-speed and high-density transmission with the highest possible channel bit rate and SE approaching the Shannon limit. Coherent Nyquist pulses are expected to be ideal transmission pulses that can demonstrate their excellent advantages of high speed and coherence, and find a variety of applications including signal processing and measurements.

【Publications Relevant to the Project】

M. Nakazawa, T. Hirooka, P. Ruan, and P. Guan, "Ultrahigh-speed “orthogonal” TDM transmission with an optical Nyquist pulse train," Opt. Express vol. 20, no. 2. pp. 1129-1140, Jan. (2012).

【Term of Project】 FY2014-2018

【Budget Allocation】 436, 600 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.nakazawa.riec.tohoku.ac.jp
nakazawa@riec.tohoku.ac.jp

Title of Project : **Research on reconfigurable unitary optical mode converters and wavefront synthesizers using semiconductor photonic integrated circuits**

Yoshiaki Nakano
(The University of Tokyo, Graduate School of Engineering, Professor)

Research Project Number : 26000010 Researcher Number : 50183885
Research Area : Optoelectronics
Keywords : Monolithically integrated photonic circuit, semiconductor optical device, InP

【Purpose and Background of the Research】

Space optics have conventionally been used in order to synthesize a desired optical wavefront by controlling optical phase in space. However, their operation speed has been limited in a few milli-second range due mainly to their large sizes. In this research, we will realize adaptive optical wavefront synthesizer circuits monolithically integrating a few hundreds/thousands of active optical components, such as lasers, optical amplifiers, optical phase controllers, polarization controllers, and optical power monitors, on an InP substrate, based on our semiconductor monolithic photonic integration technologies developed over the past years. We will extend the circuit to more universal multiple input arbitrary optical unitary conversion circuits so that they would widely be utilized in next generation optical communications, optical interconnects, medical/bio imaging, and optical quantum computing.

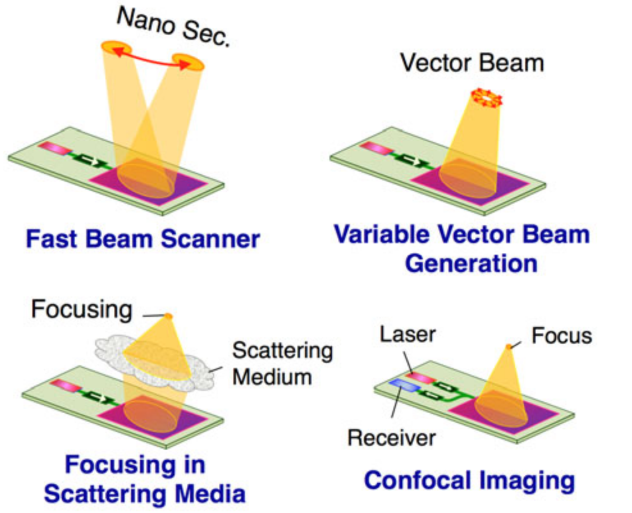

Fig. 1 Applications of adaptive lightwave synthesizer circuits.

【Research Methods】

By making use of high-efficiency modulation by carriers and electro-optic effects in InP-related semiconductors, we will make fast (less than nano second) and low power adaptive optical wavefront synthesis possible. In addition, we make high-power operation possible by integrating lasers and optical amplifiers monolithically, which is not possible in passive materials like silicon or silica glass.
Moreover, by extending the function of the wavefront synthesizer chip, we will develop an optical circuit chip transforming N mutually-orthogonal

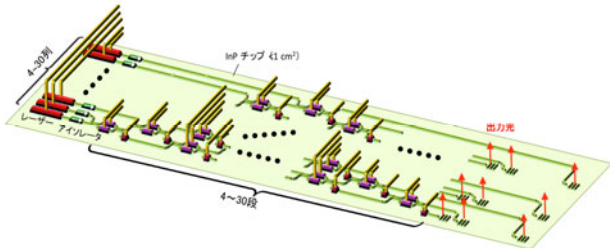

Fig. 2 Arbitrary optical unitary conversion circuit.

optical beam inputs into desired different optical beams each simultaneously, or in other words, performing N x N unitary conversion among arbitrary Nth-dimension orthogonal bases. By integrating multiple waveguide 2 x 2 optical couplers in tandem, we realize a large scale unitary conversion circuit with $N \geq 10$ on a small chip less than 1cm^2.
We will also integrate many InP micro optical power monitors to rapidly control the coupling ratio of each optical coupler, so that we can materialize an adaptive multiple input arbitrary optical unitary conversion circuit for the first time.

【Expected Research Achievements and Scientific Significance】

Since the wavefront synthesizer circuit will make fast beam scanning of sub-nano-second level possible, it can be directly applied to reconfigurable optical interconnects, resulting in reduction of power consumption in IT equipments largely. It also realizes 3 dimensional optical imaging in scattering media at a low cost, and thereby bringing about revolutionary change in the fields of medicine, biology, and environmental sensing.
On the other hand, the multiple input arbitrary optical unitary conversion circuit will be directly applied to transceivers for the mode division multiplexed optical communication link, which is regarded as the next generation high-capacity optical communication scheme. Furthermore, the circuit is expected to bring ultimate sensitivity to optical sensing and optical quantum computing.

【Publications Relevant to the Project】

T. Tanemura, Y. Nakano, et al., “Integrated phased-array switches for large- scale photonic routing on chip,” Laser & Photonics Reviews, Wiley-VCH, vol. 6, no. 4, pp. 549-563, July 2012.

【Term of Project】 FY2014-2018

【Budget Allocation】 434,000 Thousand Yen

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【Grant-in-Aid for Specially Promoted Research】

Science and Engineering (Engineering)

Title of Project : Molecular imaging of living cells with metallic nanoparticles

Satoshi Kawata
(Graduate School of Engineering, Osaka University, Professor)

Research Project Number : 26000011 Researcher Number : 30144439
Research Area : Nanophotonics
Keyword : nanophotonics, plasmonics, nanoimaging, bioimaging

【Purpose and Background of the Research】

In various research fields, such as material science, bioscience, organic chemistry, and electrical devices, the demand for analytical imaging with nanometer-scale resolution has been steadily increasing over the past decade and has been the driving force behind recent advances in microscopy. For example, electron microscopy and probe microscopy have enabled us to observe atomic scale structures. However, their applications in the observation of living specimens are still limited.

To overcome the limitations of electron microscopy and probe microscopy, we have utilized optical light to develop optical microscopy techniques with nanometer resolution and have been leading this research field. Recently, we demonstrated a 4 nm spatial resolution to observe carbon nanotubes using near field optical microscopy, realizing the highest spatial resolution in optical microscopy. By combining near-field optical microscopy and surface-enhanced Raman scattering technique, we have further added the capability of material analysis and expanded its application into various other scientific research fields including cellular imaging, but the observation was still limited in the 2D plane. In this research, the research group aims to develop imaging techniques for observing the intracellular 3D space with capability for material and environmental analysis.

【Research Methods】

In this research, we develop a new optical microscope which can resolve intracellular structures in 3D with nanometer-scale resolution. Our approach is to introduce a metallic nanoparticle into a living cell and utilize it as a probe for imaging and analysis of intracellular molecules. The metallic nanoparticle explores the cell by being transported by cellular functions or diffusion while illuminating adjacent molecules through the light field localized by plasmon polariton. Since the illuminated molecules reveal their presence to us by scattering the localized light, the measurement of the scattering light and the particle position in the sample provides a precise position of the molecules. A time-sequential detection of Raman spectra and particle positions visualizes the molecule distribution of the nanoparticle pathways, finally revealing the intracellular structures in 3D.

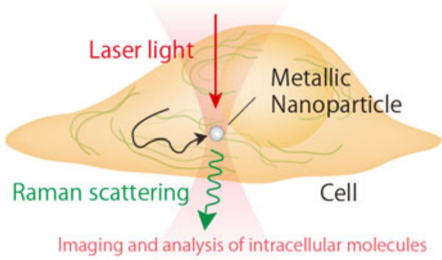

Figure 1 Molecular imaging of a living cell with metallic nanoparticles

【Expected Research Achievements and Scientific Significance】

In this research, we will develop a microscopy technique that allows us to observe biological samples with nanometer scale resolution in 3D space without labeling. The technique will provide distribution of molecular vibrations in the 3D space of a living cell, with which we can derive information about chemical environments and biomolecule responses to exogenous stimuli, such as pharmaceutical treatments.

【Publications Relevant to the Project】

- Yano et al., Nat. Commun., **4**, 2592 (2013).
- Palonpon et al., Nat. Protoc., **8**, 677 (2013).
- Okada et al., PNAS, **109**, 28 (2012).
- Ando et al., Nano Lett., **11**, 5344 (2011).
- Yano et al., Nat. Photon., **3**, 473 (2009).

【Term of Project】 FY2014-2018

【Budget Allocation】 401, 600 Thousand Yen

【Homepage Address and Other Contact Information】

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