Title of Project : Information communication technology ensuring the long term security over a century

Akihisa Tomita
(Hokkaido University, Graduate School of Information Science and Technology, Professor)

Research Project Number : 18H05237 Researcher Number : 60501434
Keyword : Information theory, network, cryptography

【Purpose and Background of the Research】

Recently, our society is getting to rely on the electronic data that should be kept secret for a long period. For example, genome information, should be stored securely for more than human lifetime, *i.e.*, a hundred years. However, modern cryptographic protocols have been periodically updated to keep security. The present cryptographic technology can hardly guarantee the secrecy over a century.

This project therefore is aimed to develop an information theoretically secure storage, the security of which will never compromised by any technological progress. We combine secret sharing and quantum cryptography to achieve the information theoretical security.

【Research Methods】

Figure 1 depicts the network scheme developed in this project. Secret-sharing servers provide network functions such as multi-user management, synchronization and secret computing. Short distance high speed quantum key distribution (QKD) links provide secure communication between a server and a user and between servers. Even distant users can access the data securely through the user authentication with a password shared with a long distance (loss tolerant) QKD link.

The project contains four subjects: network construction and control, long distance QKD, high speed QKD, and theories on security certification and efficient key generation. The first half of the project will devote to examine candidates to achieve the project goal. Then, in the second half, we develop the devices and software to integrate the secure storage network.

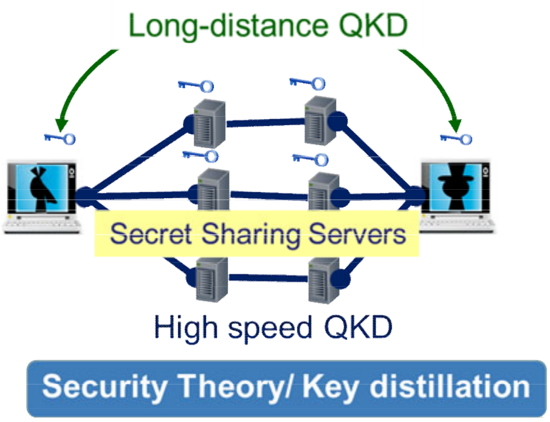


Figure 1 Information theoretically secure storage network

【Expected Research Achievements and Scientific Significance】

The project will realize an information communication and storage network secure against any possible attacks for over a century. This goal will be achieved by our newly developing technology combining the information theoretical secure modern cryptography and QKD. We will establish the technological frame work to construct practically useful combination.

The technological elements developed in the project, such as the optical pulses synchronization and precise control of the phase and frequency, will also advance the coherent optical communication.

【Publications Relevant to the Project】

K. Nakata, A. Tomita, M. Fujiwara, K. Yoshino, A. Tajima, A. Okamoto, and K. Ogawa," Intensity fluctuation of a gain-switched semiconductor laser for quantum key distribution system," Optics Express, **25**, 622-634 (2017)

M. Fujiwara, A. Waseda, R. Nojima, S. Moriai, O. Wakaha, and M. Sasaki, "Unbreakable distributed storage with quantum key distribution network and password authenticated secret sharing," Scientific Reports, 6: 29988 (2016).

【Term of Project】 FY2018-2022

【Budget Allocation】 148,200 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.eng.hokudai.ac.jp/labo/hikari/index.htm

Title of Project : Study on digital frontier photonic sensing based on omnipotent fiber lasers

Shinji Yamashita
(The University of Tokyo, Research Center for Advanced Science and Technology, Professor)

Research Project Number : 18H05238 Researcher Number : 40239968
Keyword : Sensing devices, Signal processing

【Purpose and Background of the Research】

In future Society 5.0, mutual interactions between physical space and cyber space are expected to create new industry/service. There, sensing technologies are indispensable.

In this project, we aim at realizing omnipotent fiber lasers, and the innovative digital frontier photonic sensing by integrating the omnipotent fiber lasers and digital coherent signal processing technologies, as depicted in Fig.1.

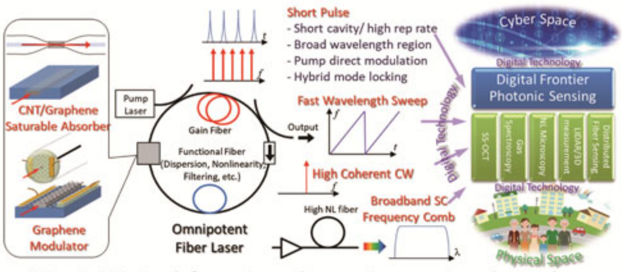


Fig.1 Digital frontier photonic sensing based on omnipotent fiber lasers

【Research Methods】

This project is based on our two original technologies. One is the passively mode-locked fiber lasers using carbon nanotube (CNT) and graphene. CNT and graphene are ultrafast, nano-size, and low-cost saturable absorbers, compatible with fiber/waveguide, and features broad wavelength operation. The other is the dispersion tuned actively mode-locked fiber lasers, which can sweep lasing wavelength with the use of active mode locking and fiber dispersion. It does not require any optical filters, as the result not limited by the speed or bandwidth of optical filters.

We have been developing omnipotent fiber lasers, as shown in Fig.1, which are actively or passively mode-locked fiber lasers having, not only intense short pulse output, but also digital features and high functionalities, such as, high repetition rate, broad bandwidth, and fast sweep, by fully utilizing functional (dispersion, nonlinearity, etc.) fibers. Omnipotent fiber lasers elicit various high functionalities in lasers from a single technique, mode locking.

Here we promote digital frontier photonic sensing. In the conventional analog photonic sensing, physical quantities are measured by interference of laser light beams in free space, and only the amplitude of interfered signals is processed in analog circuits. By contrast, in digital frontier photonic sensing, they are measured not only in free space but also in waveguides or fibers, and both amplitude and phase of interfered signals are digitally processed using digital coherent receivers. The digital signals are processed further with higher-level processing, such as compressed sensing or deep learning, to bridge between physical and cyber spaces. Thus, it is an innovative photonic sensing technology that fully utilizes lasers with digital features and high functionalities, and digital signal processing.

【Expected Research Achievements and Scientific Significance】

By applying the digital frontier photonic sensing to various sensings, such as optical coherence tomography (OCT), gas spectrometry, nonlinear microscope, LIDAR/3D measurement, and optical fiber sensors, as listed in Fig.1, we expect to contribute to realization of Society 5.0.

【Publications Relevant to the Project】

・S. Yamashita, A. Martinez, and B. Xu, "Short pulse fiber lasers mode-locked by carbon nanotube and graphene (Invited)," Optical Fiber Technology, vol.20, no.6, pp.702-713, Dec. 2014.
・S. Yamashita, "Dispersion-tuned swept lasers for optical coherence tomography (Invited)," IEEE Journal of Selected Topics in Quantum Electronics, vol.24, no.3, 6800109, May 2018.

【Term of Project】 FY2018-2022

【Budget Allocation】 144,800 Thousand Yen

【Homepage Address and Other Contact Information】

http:// www.cntp.t.u-tokyo.ac.jp

Title of Project : Development of crust imaging enhanced by hetero-computing for reducing earthquake disaster

Tsuyoshi Ichimura
(The University of Tokyo, Earthquake Research Institute, Associate Professor)

Research Project Number : 18H05239 Researcher Number : 20333833
Keyword : Earthquake engineering, Earthquake disaster mitigation, Applied mechanics, Computer science

【Purpose and Background of the Research】

The goal of this study is to develop next-generation crustal imaging methods for estimating crustal structure, source area state, etc. for earthquake disaster mitigation through a combination of cutting-edge computational science and observations. Although the recent development of seismological and geodetic observations (e.g., observations of the ocean bottom just above the offshore source area of megathrust earthquakes) has increased the possibility of developing such imaging methods, they remain difficult to realize due to the huge analysis cost. In this study, we aim to realize crustal imaging methods by using a heterogeneous computing approach. Furthermore, using the developed methods and real observation data, we will attempt to perform crustal imaging of real targets.

【Research Methods】

Prof. Tsuyoshi Ichimura's group will develop an optimization method based on an ultra-high-speed computing method for seismic waves and crustal deformation, using heterogeneous computing and a large-scale finite element method. These methods will be implemented in a heterogeneous computing environment and their effectiveness will be investigated. Dr. Takane Hori's group will develop a method to assimilate on- and offshore crustal data and a model of spatiotemporal variation in the source area. Furthermore, the methods developed by Prof. Ichimura's group will be introduced stepwise to construct a prototype of a crustal imaging system with the aim of conducting crustal imaging using real observation data.

【Expected Research Achievements and Scientific Significance】

Earthquake damage estimation is important for mitigating earthquake disasters. To estimate the damage, information about the crustal structure and source area state is of fundamental importance. This study aims to improve the reliability of such information by combining cutting-edge computational science and observations. Hence, a substantial contribution toward earthquake disaster mitigation is expected.

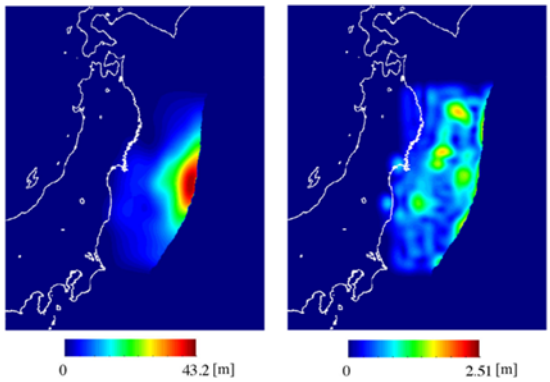


Fig: Example of the fault slip distribution considering the uncertainty of the crust structure (left: mean, right: deviation).

【Publications Relevant to the Project】

・Ichimura, T., Fujita, K., Quinay, P. E. B., Maddegedara, L., Hori, M., Tanaka, S., Shizawa, Y., Kobayashi, H. and Minami, K., Implicit Nonlinear Wave Simulation with 1.08T DOF and 0.270T Unstructured Finite Elements to Enhance Comprehensive Earthquake Simulation, SC15: International Conference for High Performance Computing, Networking, Storage and Analysis, Article No. 4, 2015.
・Hori, T., Hyodo, M., Nakata, R., Miyazaki, S., Kaneda, Y., A forecasting procedure for plate boundary earthquakes based on sequential data assimilation, Oceanography, 27, 2, 94-102, 2014.

【Term of Project】 FY2018-2022

【Budget Allocation】 144,700 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.eri.u-tokyo.ac.jp/sensing_and_simulation/index.html
http://www.jamstec.go.jp/ceat/e/etfsrg/

Title of Project : Ultimately-Time-Resolved Imaging Devices Using Ultrafast Hybrid Cascade Photo-Charge Modulators and Their Applications

Shoji Kawahito
(Shizuoka University, Research Institute of Electronics, Professor)

Research Project Number : 18H05240 Researcher Number : 40204763
Keyword : Time-resolved imaging, photo-charge modulator, Biomedical imaging, Time-of-flight imaging

【Purpose and Background of the Research】

In this study, we investigate ultimately time-resolved imaging devices for detecting very weak light, non-visible light or very weak light under a strong ambient light and their applications. A new high-speed photo-charge modulator so-called the HyCAM (Hybrid cascade photo-charge modulator) is proposed for the visible and near-infrared ultra-highly time-resolved imaging particularly with multiple-window time-resolved pixels. The purpose of this study is to demonstrate the significance of the HyCAM in biological, medical, scientific and industrial applications by actually using the implemented time-resolved image sensors.

【Research Methods】

The HyCAM is a high-speed highly-sensitive low-noise charge modulation device that uses both vertical electric field created by tapped p+ electrodes in a pinned photodiode and lateral electric field created by a set of gates arranged along the channel of photo-carrier transportation and is suitable for large-aperture multiple-window time-resolved pixels. To investigate the optimal structures and dimensions and a new function of the HyCAM pixels, a test element group of the HyCAM pixels with different designs and parameters and 2D pixel arrays or time-resolved image sensors (TRISs) will be implemented and characterized. The implemented TRISs are used for a FLIM (fluorescence lifetime imaging microscopy) -based biomedical imaging for tumor detection, spatial- and time-resolved NIRS (near infrared spectroscopy) for monitoring brain activity, a SRS (stimulated Raman spectroscopy)-based unstained bio-imaging, and extremely depth-resolved TOF (time of flight) range image sensors in order to investigate what new values and findings are obtained by the TRIS chips.

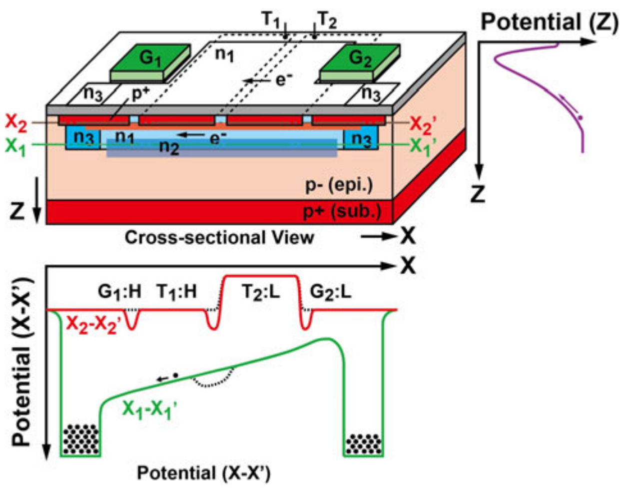


Figure 1 Hybrid cascade photo-charge modulator.

【Expected Research Achievements and Scientific Significance】

The HyCAM and TRISs using the HyCAM pixels will bring a significant paradigm shift in time-resolved imaging system concept from a spatial- and time-scanning based system to spatially-parallel (pixel-array) and multiple-window time-resolved pixel based system. This semiconductor-based system will be one of key technologies in next-generation biological, medical, scientific and industrial imaging tools.

【Publications Relevant to the Project】

・M.-W. Seo, Y. Shirakawa, Y. Kawata, K. Kagawa, K. Yasutomi, S. Kawahito, "A time-resolved four-tap lock-in pixel CMOS image sensor for real-time fluorescence lifetime imaging microscopy", IEEE J. Solid-State Circuits, pp.1-12, vol.53, 2018.
・D. X. Lioe, K. Mars, S. Kawahito, M. Hashimoto, "A stimulated Raman scattering CMOS pixel using a high-speed charge modulator and lock-in amplifier," Sensors, vol. 16, pp.532-547 , 2016.

【Term of Project】 FY2018-2022

【Budget Allocation】 147,600 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.idl.rie.shizuoka.ac.jp/
kawahito@idl.rie.shizuoka.ac.jp

Title of Project : Design on Mechanical and Multi-Physics Properties of Nano-Structured Meta-Interface

Takayuki Kitamura
(Kyoto University, Graduate School of Engineering, Professor)

Research Project Number : 18H05241 Researcher Number : 20169882
Keyword : Nano-structure, Meta-interface, Mechanics, Multi-physics, Design

【Purpose and Background of the Research】

As a small device consists of many kinds of materials, dissimilar interfaces are inevitably included inside it. The material properties at interfaces are inferior in general. This project aims to investigate novel properties of nano-structured meta-interface on the basis of inquiry of their mechanisms in detail, and to contribute the innovative design of devices.

(1) We develop a methodology to examine the mechanical properties of a nanometer-scaled (10-30nm) element, which composes the meta-interface, and evaluate the effect of geometry and size of single element.
(2) Considering the interaction, we design the mechanical function of meta-interface. We experimentally examine it as well.
(3) We develop a methodology to examine the multi-physics (ferro-magnetics, ferro-electrics, mechanics and so on) properties of the nanometer-scaled element and investigate the characteristics of meta-interface.

【Research Methods】

We have a technique to make a layer composed of numerous nanometer-scaled elements by a dynamic oblique deposition method. The shape and size of elements can be precisely controlled (sculptured nano-elements; see Fig. 1). The nano-structured meta-interface can be formed by the method and we recently get some clues of innovative functions by preliminary investigations. Thus, we will develop equipment to examine the mechanical behavior of nano-elements (Fig.2) and will inquire the property of the interface. Then, by the first principle simulation and conversion of equipment, we will extend our challenge toward the multi-physics properties of nano-structured meta-interface.

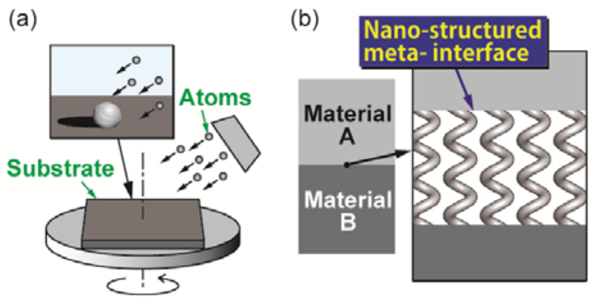


Figure 1 (a) Dynamic oblique deposition, (b) Nano-structured meta-interface.

【Expected Research Achievements and Scientific Significance】

While a dissimilar interface in a device has been considered as weak point in general, we can introduce innovative mechanical properties by this research exploring mechanics on deformation of nano-elements and interactions among numerous elements.
We extend the function to multi-physics properties in nanometer scale. We try to establish a new scientific field; mechanics and multi-physics in assembled nano-structures.

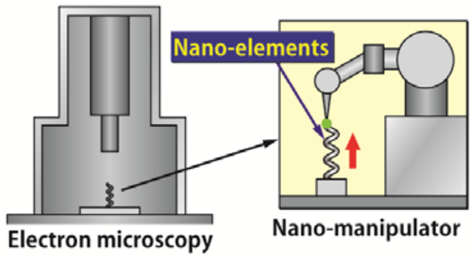


Figure 2 Equipment to examine the mechanical behavior of nano-elements.

【Publications Relevant to the Project】

T. Kitamura, T. Sumigawa, H. Hirakata and T. Shimada, "FRACTURE NANOMECHANICS" 2nd Edition (Pan Stanford Publishing Pte. Ltd., (2016)), ISBN 978-981-4669-04-7.
Y. Umeno, T. Shimada, Y. Kinoshita and T. Kitamura, "MULTIPHYSICS IN NANOSTRUCTURES" (Springer, (2017)), ISBN 978-4-431-56571-0.

【Term of Project】 FY2018-2022

【Budget Allocation】 150,700 Thousand Yen

【Homepage Address and Other Contact Information】

https://www.me.t.kyoto-u.ac.jp/ja/research/introduction/zairyoubussei

Title of Project : Dynamical flow control of nanoparticles by machine learning and its application to single molecule identification technologies

Satoyuki Kawano
(Osaka University, Graduate School of Engineering Science, Professor)

Research Project Number : 18H05242　Researcher Number : 00250837
Keywords : Molecular fluid dynamics, Nanoparticles, Single molecule measurement, Machine learning

【Purpose and Background of the Research】

In this project, we aim to comprehensively investigate the flow dynamics of ions, molecules and charged particles in the presence of electromagnetic fields, and to pioneer new research areas. As shown in Figure 1, our approach integrates thermal fluctuations, large deviation principles, thermophoresis, optical pressure, electrophoresis, quantum electronics and machine learning into the field of molecular fluid dynamics. Our practical challenge will be the development of a novel fluidic device with sensing nanogap electrodes for identifying nanoparticles.

【Research Methods】

This project will consist of three different research topics. The first involves the identification of single molecules using a statistical approach to thermal fluctuations. We will define additional dynamics parameters that extend the scope of the fluctuation-dissipation theorem. Novel methods for evaluating and controlling rare events will be developed based on large deviation principles. The second research topic addresses high-speed measurement of the tunneling current between nanogap electrodes, which is a quantum mechanical effect, by sensing nanoparticle flow in a liquid phase based on multiscale electrohydrodynamics (EHD). We intend to establish in situ feedback control of an EHD flow and to design optimized fluidic channels using machine learning. The final research topic involves manipulation of individual molecules using laser irradiation. The application of optical pressure to drive nanoparticles towards nanogap electrodes will be investigated for the purpose of achieving a higher yield. The thermophoretic force, which can act in a positive or negative direction, and is still not fully understood, will also be utilized. In the second half of the research period, all of the results obtained will be combined in order to develop a micro/nano-fluidic device with embedded nanogap electrodes.

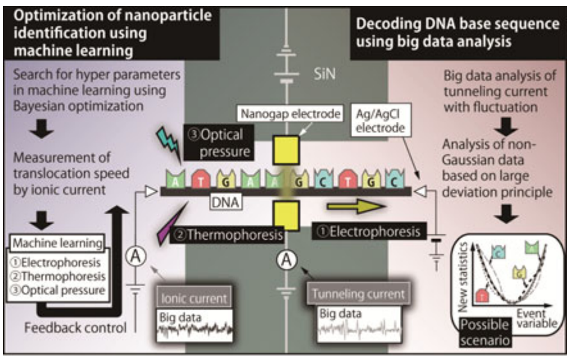


Figure 1　Overview of fluidic device for identifying pollen allergens, viruses, and DNA molecules

【Expected Research Achievements and Scientific Significance】

By integrating quantum electronics, life sciences, statistical mechanics and information technology into micro/nano fluid engineering, we expect to establish a new academic field called “Molectro-Fluid Science and Informatics,” and develop new techniques for measuring single molecules utilizing fluidic devices. Such devices can be used for high-speed identification of micro/nano-particles such as pollen allergens, viruses, and DNA molecules.

【Publications Relevant to the Project】

・C. Kawaguchi, T. Noda, M. Tsutsui, M. Taniguchi, S. Kawano, T. Kawai, Electrical Detection of Single Pollen Allergen Particles Using Electrode-Embedded Microchannels, **J. Phys.: Condens. Matter**, 24, 164202, 2012.
・I. Hanasaki, N. Yukimoto, S. Uehara, H. Shintaku, S. Kawano, Linearisation of λDNA Molecules by Instantaneous Variation of the Trapping Electrode Voltage Inside a Micro-Channel, **J. Phys. D**, 48, 135402, 2015.

【Term of Project】 FY2018-2022

【Budget Allocation】 119,000 Thousand Yen

【Homepage Address and Other Contact Information】

http://bnf.me.es.osaka-u.ac.jp/

Title of Project : Fundamental Study of Robust Molecule Recognition Electronics

Takeshi Yanagida
(Kyushu University, Institute of Material Chemistry and Engineering, Professor)

Research Project Number : 18H05243　Researcher Number : 50420419
Keyword : Nanomaterials, Molecule Recognition, Electronics

【Purpose and Background of the Research】

Sensor electronics that measures our personal information in "long term" and accumulate in cyberspace opens up new academies and industries. Currently, a robust physical sensor is the mainstream of its research, but molecular sensor electronics that distinguishes "chemical" molecular information (biological gas etc.) in the long term "electric" is still limited. In this research, we develop "robust molecular sensor electronics" as a bridge of chemical information between real world and cyber space around us by metal oxide nanowire interface with molecular identification function and integrated hybrid molecular sensor.

【Research Methods】

Using a group of volatile molecules in exhaled breath as a target, we investigate the molecule's information on the surface of oxide nanowire surfaces including 1) functional groups (alcohols, aldehydes, ketones, carboxylic acids, amines), 2) molecular weight, 3) structural isomers, in order to verify the molecular recognition ability. As a verification method, the influence of these molecular skeleton parameters on molecular recognition ability (GC-MS desorption spectral analysis) is analyzed by the solid surface structure (TEM analysis, Raman spectroscopy) and molecular adsorption state (infrared spectroscopic pMAIRS method) In consideration of the information on the information. As a different approach, when a shell layer of core / shell nanowire structure is formed, a target molecule is interposed and a nanowire surface storing the molecular shape is formed. With this method, it becomes possible to conduct experiments in a wider crystal growth atmosphere beyond the framework of anisotropic crystal growth, and it is expected that the range of applicable molecular species can be expanded.

By examining the temperature dependence, we verify the robustness of nanowire molecule identification function and its mechanism. Physical properties responsible for robustness are bond energies of metal ions and oxygen ions in oxides. An oxide nanowire having a molecular recognition function is formed as an integrated hybrid molecular sensor on a silicon substrate by utilizing a space selective crystal growth technique. I) an oxide nanowire structure as a molecular collector having a molecular recognition function and ii) a structure in which a current detection sensor part is hybrid arrayed on a micro / nanoscale. Regarding the molecular recognition ability, we will also consider improving the recognition ability by controlling the adsorption temperature in addition to the desorption temperature. Electrical molecular discrimination is carried out using various integrated hybrid molecular sensors fabricated for the aforementioned target molecule mixture. We demonstrate further improvement of molecular discrimination ability by multiplying the molecular discrimination ability on the oxide nanowire surface by the discrimination ability at the sensor part.

【Expected Research Achievements and Scientific Significance】

"Rigid" oxide nano surface spreads to research fields that distinguish "soft" molecular shape, and not only sensor research but also a wide spread effect on molecular selective catalyst research field is expected. By utilizing its robustness, deployment to an IoT molecular sensor that enables constant breath diagnosis by smartphones and the like is a major industrial development.

【Publications Relevant to the Project】

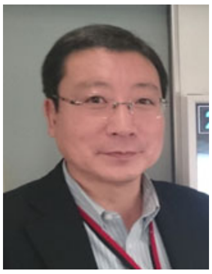
・ Nanoscale Thermal Management of Single SnO_2 Nanowire: pico-Joule Energy Consumed Molecule Sensor, G.Meng, F.Zhuge, K.Nagashima, A.Nakao, M.Kanai, Y.He, M.Boudot, T.Takahashi, K.Uchida and T.Yanagida, ***ACS Sensors***, 1, 997 (2016).
・ Long-Term Stability of Oxide Nanowire Sensors via Heavily-Doped Oxide Contact, H.Zeng, T.Takahashi, M. Kanai, G.Zhang, Y.He, K.Nagashima and T.Yanagida
ACS Sensors, 2, 1854 (2017). *Cover of ACS Sensors*

【Term of Project】 FY2018-2022

【Budget Allocation】 150,200 Thousand Yen

【Homepage Address and Other Contact Information】

https://yanagida.weebly.com/



Title of Project : **Establishment of design principle and basic technology for next generation medical high temperature superconducting skeleton-cyclotron**

Atsushi Ishiyama
(Waseda University, Graduate School of Science and Engineering, Professor)

Research Project Number : 18H05244 Researcher Number : 00130865
Keyword : Electrical machine, Superconducting material, Accelerator, Quantum beam, Cancer

【Purpose and Background of the Research】

For advanced cancer therapy, "targeted α-particle therapy" is very promising. To widely use the targeted–particle therapy, a large amount of Radio Isotope (^{211}At) which radiates α-rays must be stably produced. The final goal of this study is to develop an extremely compact and variable-energy HTS (High Temperature Superconducting) accelerator called "Skelton Cyclotron (HTS-SC)". Until now, we have been working on the development of fundamental technologies that enable "5-High: high mechanical strength, high current density, high thermal stability, high magnetic field, and high precision magnetic field". In this research project, in order to realize a HTS multi-coil system for forming a magnetic field distribution indispensable for beam acceleration, we develop innovative magnet technology integrating the 5-High technology and we aim to establish the design principle and basic technology of HTS-SC.

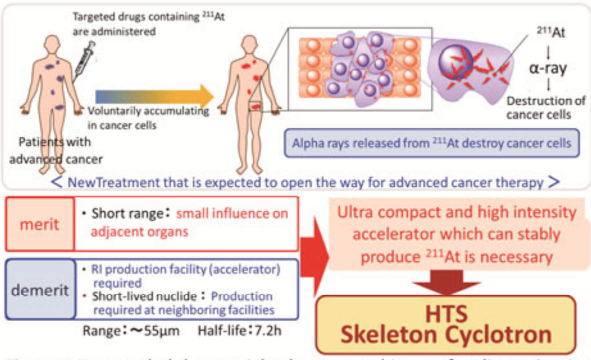


Figure 1 Targeted alpha-particle therapy and issues for dissemination

【Research Methods】

HTS-SC performs high "precision magnetic field necessary for beam acceleration with only a HTS multi-coil system consisting of air-core coils. As a result, in addition to reduction in size and weight, the magnetic field can be changed without being affected by the nonlinear magnetization characteristics of the iron core, and the output can be controlled. Therefore, multi-functionalization becomes possible. In this research, as innovative magnet technologies for the purpose of developing a multi-coil system for HTS-SC, 1)coil reinforcing structure for high mechanical strength, 2)technology to achieve both high current density and high thermal stability, 3)technology for generating high-precision magnetic field, and 4)optimal design technology of multi-coil system, will be established. And then, the feasibility and effectiveness (variable output energy) of HTS-SC will be demonstrated by a small model, "Baby HTS-SC coil system".

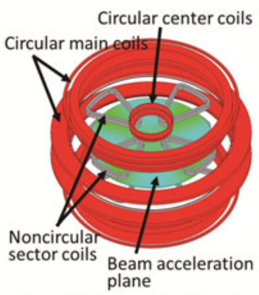


Figure 2 HTS multi-coil system

【Expected Research Achievements and Scientific Significance】

Through the development of HTS-SC, it can be expected to develop compact and lightweight heavy-particle accelerator for cancer treatment. Furthermore, if an innovative magnet technology is established, it can be applied to not only for medical use but also for unexplored stage applications such as coils for next generation compact nuclear fusion reactor and ultra-high density superconducting magnetic energy storage device.

【Publications Relevant to the Project】

・A.Ikeda et al., "Transient Behaviors of No-Insulation REBCO Pancake Coil during Local Normal-State Transition," IEEE Transactions on Applied Superconductivity, Vol. 26, No. 4, 4600204, 2016
・H.Ueda et al., "Conceptual design of next generation HTS cyclotron" IEEE Transactions on Applied Superconductivity, Vol. 23, No.2, 4100205, 2014

【Term of Project】 FY2018-2022

【Budget Allocation】 148,800 Thousand Yen

【Homepage Address and Other Contact Information】
http:// http://www.eb.waseda.ac.jp/ishiyama/

Title of Project : Development of new imaging technology based on superconducting single-photon camera

Hirotaka Terai
(National Institute of Information and Communications Technology, Advanced ICT Research Institute, Executive Researcher)

Research Project Number : 18H05245 Researcher Number : 10359094
Keyword : Single-photon detector, Image sensor, Superconducting digital signal processing

【Purpose and Background of the Research】

Photon detection technique with high spatial and temporal precision is fundamental in a wide range of fields such as quantum information and processing, quantum communication, photon spectroscopy, astronomical observation, bioimaging and so on. Cooled CCD is the most sensitive image sensor that can detect extremely weak light by a factor of 100 million lower than moonlight, but it still has several tens of thousands of photons per second. In addition, the sensitivity of CCD in near infrared region is not good enough, while the near infrared light is useful because it can penetrate deep inside the biological sample. Furthermore, the frame rate is also slow as several tens kHz even in high-speed electron multiplying CCD.
The superconducting nanowire photon detectors (SSPDs) have sensitivity in a wide spectral range from deep ultraviolet to mid infrared, and have been already used in many advanced experiments in quantum information field. The SSPD has detection efficiency over 90% at 1.55 μm, low dark count rate below 1 cps, excellent timing jitter below 20 ps. Photon imaging technology with a wide spectral range, ultra-low noise, high spatial and temporal resolution will be possible by realizing two-dimensional SSPD array, but the number of pixels demonstrated so far is as large as 64 due to the difficulty in signal readout.

【Research Methods】

We aim to realize a large-scale SSPD image sensor with the configuration shown in Fig. 1, where SSPD array with row-column readout scheme and a single flux quantum (SFQ) signal processing circuit are employed. We also introduce an adiabatic flux quantum parametron (AQFP) circuit in addition to the SFQ circuit to reduce the bias current, where the SFQ/AQFP hybrid signal processor will be fabricated by using the AIST Nb standard process. Our goal is to realize SSPD image sensor with 100 × 100 pixels and it will be applied to photon spectroscopy and bioimaging system.

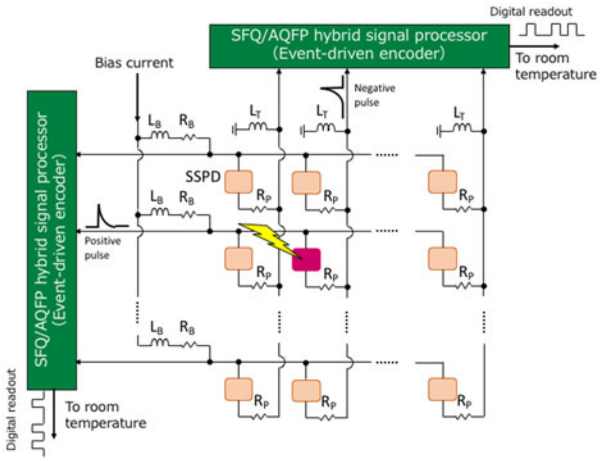


Figure 1 Configuration of superconducting single-photon image sensor

【Expected Research Achievements and Scientific Significance】

By realizing an image sensor with a photon countable sensitivity, extremely low noise, high spatial and temporal resolution with a wide spectral range from deep ultraviolet to mid infrared, it will be an innovative tool in various fields and make a big contribution to create new academies.

【Publications Relevant to the Project】

・N. Takeuchi, T. Yamashita, S. Miyajima, S. Miki, N. Yoshikawa, and H. Terai, Optics Express 25, 32650 (2017).
・H. Terai, S. Miki, and Z. Wang, IEEE Trans. on Supercond. 19, 350 (2009).

【Term of Project】 FY2018-2022

【Budget Allocation】 149,400 Thousand Yen

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