【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : High-mobility Semiconductor Devices due to Control of Phonon Field caused by Defect-free Nano-periodic Structures

SAMUKAWA Seiji
(Tohoku University, Instutute of Fluid Science, Professor)

Research Project Number: 20H05649 Researcher Number : 30323108
Keyword : neutral beam, damage-free nano-periodic structure, phonon field control, phonon scattering suppression

【Purpose and Background of the Research】

Higher levels of performance in information-communication devices like mobile terminals and sensors are leading to dramatic jumps in data and traffic. To deal appropriately with this information explosion, technical innovations that can provide significantly higher performance and power savings in information processing and data storage are essential. Here, the problems of heat generation and heat dissipation brought on by the ongoing miniaturization of semiconductor integrated circuits are particularly prominent, so semiconductor devices with new structures that can lower heat generation and energy consumption are desirable. These needs can be met if electronic devices can be made even faster while suppressing heat generation, and if carrier-phonon scattering in the channel region of a MOS transistor can be suppressed, there would be no deterioration in mobility intrinsically caused by heat generation. This would simultaneously satisfy the two needs of the faster operation and lower heat generation.

We here propose the introduction of a composite structure as a transistor channel structure that embeds damage-free semiconductor nanopillars in a periodic manner using matrix material. This structure suppresses carrier-phonon scattering in the transistor channel area according to the material used, nanopillar size, and nanopillar interval and achieves a transistor channel layer with dramatically improved mobility and minimal heat generation.

【Research Methods】

Using damage-free nanostructure fabrication technology, we fabricate ultra-fine sub-10 nm periodic phononic-crystal nanopillars free of interface roughness and defects and establish technology for fabricating composite material embedding good-quality matrix material. At the same time, we establish technology for detecting phonon generation and transport characteristics in this composite material on a nanometer order and technology for analyzing electron and phonon bands. Based on these technologies, we develop a transistor that uses composite material in the channel layer to enable phonon fields and carrier transport to be controlled as needed.

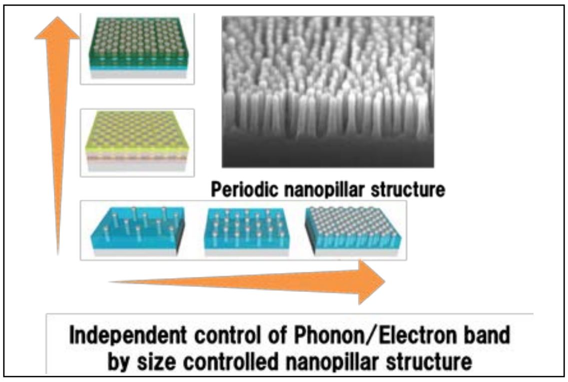

Figure 1 Defect-free Nanostructures fabricated by neutral beam etching.

【Expected Research Achievements and Scientific Significance】

To date, there have been no empirical studies on electron transport in a phonon-field control system, so exploring the possibility of electron-transport control by simultaneous control of phonon and electron bands from an experimental and theoretical basis is very significant from an academic viewpoint. This problem also presents a challenge to explore the possibility of applying such electron-transport control to electronic devices based on a totally new concept.

In applications, achieving high-mobility and low-heat-generation semiconductor devices will make possible not only high-speed calculations but also diverse types of energy-saving electronic equipment. This, in turn, will lead to a quantum leap in the state of electronics while also contributing to solutions to energy and environmental problems. In short, we anticipate research results having a great ripple effect on electronics and society.

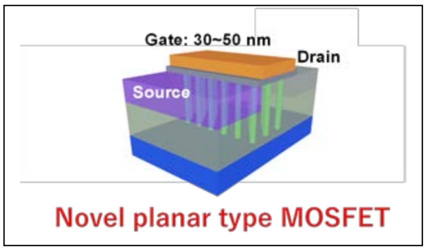

Figure 2 MOSFET device containing nanopillar structure for channel region.

【Publications Relevant to the Project】

· K. Endo, S. Samukawa et. al., IEEE Transactions on Electron Devices, Vol. 53,1826 (2006).
· A. Kikuchi, A. Yao, I. Mori, T. Ono and S. Samukawa, J. Appl. Phys. **122** (16), 165302 (2017).
· X. Huang, D. Ohori, R. Yanagisawa, R. Anufriev, S. Samukawa and M. Nomura, ACS Applied Materials & Interfaces **12** (22), 25478(2020).
· T. Harada, T. Aki, D. Ohori, S. Samukawa, T. Ikari and A. Fukuyama, Japanese Journal of Applied Physics 59 (SK), SKKA08 (2020).

【Term of Project】 FY2020-2024

【Budget Allocation】 150,000 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.ifs.tohoku.ac.jp/samukawa/japanese/index.html

Title of Project：Creation of New Spin-Functional Materials and Devices by Renaissance of Ferromagnetic Semiconductors

TANAKA Masaaki
(The University of Tokyo, Graduate School of Engineering, Professor)

Research Project Number: 20H05650　　Researcher Number：30192636
Keyword：ferromagnetic semiconductor, spin, heterostructure, band structure, device

【Purpose and Background of the Research】

By integrating different characteristics and functions of semiconductors and ferromagnets, we can create high-speed, and low-power semiconductor devices with nonvolatile memory functionalities, leading to innovative information systems. As a new class of materials which have both the properties of semiconductors and ferromagnets, ferromagnetic semiconductors (FMSs) are most promising. Not only Mn-doped FMSs such as (Ga,Mn)As we have investigated so far, we extend our research to new Fe-doped zinc-blende type narrow-gap FMS thin films, heterostructures and nanostructures. We aim to explore and control the properties, and apply them to spin-based devices. Herewith we solve all the main problems and issues of FMSs: 1) We create both n-type and p-type FMSs. 2) We increase the Curie temperature (T_C) of FMSs to be higher than room temperature (300 K) and control the properties of FMSs at room temperature. 3) We understand the mechanism of ferromagnetism in FMSs in a unified way. 4) We realize new low-power devices, such as spin transistors with non-volatility and flexible information processing functions, quantum devices using spin-dependent band structures, and functional devices using topological states, which will be suitable for future information technology.

【Research Methods】

(1) We grow Fe-doped and Mn-doped FMS thin films and heterostructures by molecular beam epitaxy.
(2) We explore the properties of FMS thin films and heterostructures, including their quantum effects.

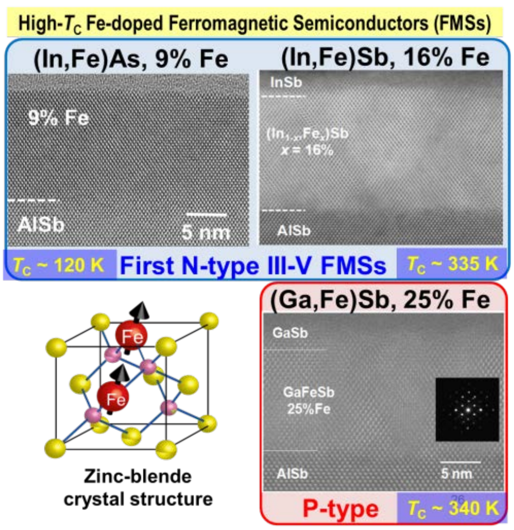

Fig. 1　Fe-doped III-V ferromagnetic semiconductors (FMSs) with high T_C.

(3) We aim to control the various quantum effects in FMS thin films, heterostructures and nanostructures, and related giant spin-related responses, such as giant magnetoresistance ((1) ~ (3) will be carried out by Tanaka, Ohya and Anh).
(4) We electrically control the magnetic properties of FMS quantum wells in field effect transistor (FET) structures using wave-function engineering (by Anh, Ohya, Tanaka).
(5) Along with these experiments, we design the materials and devices by theoretical calculations (by Yoshida, Tanaka).
(6) We fabricate spin transistors and topological transistors using FMS heterostructures with low power consumption (by all members).

【Expected Research Achievements and Scientific Significance】

We solve all the main problems of FMSs: 1) Create both n-type and p-type FMSs. 2) Increase the Curie temperature of FMSs to be higher than room temperature and control the properties of FMSs at room temperature. 3) Understand the mechanism of ferromagnetism in FMSs in a unified way. 4) Realize new spin-functional devices with low power, such as spin transistors with non-volatility and flexible information processing functions, quantum devices using spin-dependent band structures, and functional devices using topological states, which will be suitable for future information technology.

【Publications Relevant to the Project】

・ Kosuke Takiguchi, Le Duc Anh, Takahiro Chiba, Tomohiro Koyama, Daichi Chiba, Masaaki Tanaka, "Giant gate-controlled proximity magnetoresistance in semiconductor-based ferromagnetic/nonmagnetic bilayers", Nature Physics **15**, 1134 (2019).
・ Miao Jiang, Hirokatsu Asahara, Shoichi Sato, Toshiki Kanaki, Hiroki Yamasaki, Shinobu Ohya, and Masaaki Tanaka, "Efficient full spin-orbit torque switching in a single layer of a perpendicularly magnetized single-crystalline ferromagnet", Nature Commun. **10**, 2590 (2019).
・ Nguyen Thanh Tu, Pham Nam Hai, Le Duc Anh, and Masaaki Tanaka, "Heavily Fe-doped n-type ferromagnetic semiconductor (In,Fe)Sb with high Curie temperature and large magnetic anisotropy", Appl. Phys. Express **12**, 103004 (2019).

【Term of Project】 FY2020 - 2024

【Budget Allocation】 151,800 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.cryst.t.u-tokyo.ac.jp/home/

【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : Ultra High Sensitive Electric Nose for Medical Engineering Applications

TABATA Hitoshi
(The University of Tokyo, Graduate School of Engineering, Professor)

Research Project Number: 20H05651 Researcher Number : 00263319
Keyword : Electric nose, Body gas, Tandem type gas sensor, Olfactory diagnosis, Stochastic resonance

【Purpose and Background of the Research】

In the olden days, the relationship between body gas and health condition was called olfactory diagnosis, which depended on the senses and experience of medical doctors, and it was difficult to quantify and objectively evaluate.

Currently, medical institutions and the like collect biological samples such as blood, lymph, and cerebrospinal fluid to confirm their health condition and diagnose their illness. However, since the collection of these biological samples involves the risk of invasion to the human body, the risk of infection, and the mental burden, the realization of simple and easy non-invasive measurement is an urgent issue. On the other hand, body gas (breathing, skin gas) is easy to collect, non-invasive, and can be measured sequentially, and contains real-time health condition, biochemistry, and pathological condition information of the individual. In particular, skin gas (including information derived from blood) is unconsciously constantly released from the skin surface, so there is no need to spray it like exhaled breath. However, the device does not exist which has an ultra-sensitive measurement mechanism on the order of ppb (pert per billion) and ppt (pert per trillion) required for skin gas measurement, and is wearable and can measure skin gas repeatedly.

In this research, we aim to "establish an academic concept for health status / pathology and body gas correlation". As a key technology for that, we will establish the basic technology of ultra-high sensitive electronic nose as a skin gas sensor which is a compact and wearable for realizing continuous monitoring the skin gas of our physical condition.

【Research Methods】

In this study, (1) skin gas is selectively concentrated using a functional porous material (zeolite). (2) measure the concentrated skin gas with an oxide semiconductor gas sensor with nanostructural control. By using a multi-functional (tandem type) gas sensor, we try to achieve ultra-high sensitivity at the level of ppb (pert per billion). In addition, for further performance improvement (ppt: pert per trillion), oxide semiconductor core / shell type nanorods having a two-layered structure (adsorption layer / detection layer) will be used. And moreover, genetically reorganized mosaic virus will be used for utilizing a scaffold for self-assembled nanowires as a template of bio mineralization.

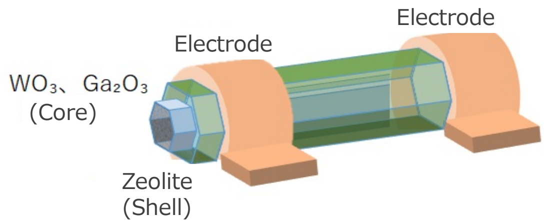

Figure 1 Core-Shell structured gas sensor

【Expected Research Achievements and Scientific Significance】

From early detection to non-illness, it is the key to extending healthy life expectancy in an aging society.

(1) Support for watching over the elderly, support for diabetics and preliminary patients

More appropriate care can be achieved by sharing the dietary intake status of dementia patients with their families & caregivers. It is also effective in diagnosing diabetes, following up, and preventing ketoacidosis.

(2) Prevention of various diseases and pathological management

Nonanal (lung cancer), methyl mercaptan (colon cancer), acetaldehyde (esophageal cancer), nitrogen monoxide (asthma, respiratory tract infection), ammonia (hepatitis), hydrogen (intestinal flora) as skin gases closely related to the disease Etc. are known. The ultra-sensitive skin gas sensor technology developed by this application research is considered to be extremely effective for measuring these pathological conditions.

【Publications Relevant to the Project】

- Y. Yamada, S. Hiyama, T. Toyooka, S. Takeuchi, K. Itabashi, T. Okubo and H. Tabata, Ultratrace Measurement of Acetone from Skin Using Zeolite: Toward Development of a Wearable Monitor of Fat Metabolism, Anal. Chem., 87(15), 7588-7594 (2015)
- H. Tabata、Fusion of bio inspired Yuragi and electronics,
- Oyobutsuri, 86(1), 12-24 (2017)

【Term of Project】 FY2020-2024

【Budget Allocation】 151,200 Thousand Yen

【Homepage Address and Other Contact Information】

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Title of Project：Elucidation of magnetic particle dynamics for diagnostic and therapeutic applications

TAKEMURA Yasushi
(Yokohama National University, Faculty of Engineering, Professor)

Research Project Number: 20H05652 Researcher Number：30251763
Keyword：magnetic nanoparticles, magnetization dynamics, magnetic particle imaging, hyperthermia

【Purpose and Background of the Research】

Development of methods for early detection of disease and treatment with less patient's burden is significant. In this project, we study new diagnostic and therapeutic methods using magnetic nanoparticles.

When an alternating magnetic field is applied to the magnetic nanoparticles selectively accumulated in a tumor, the magnetic nanoparticles rotate (physical rotation) and the magnetization in the magnetic nanoparticles rotate simultaneously as to respond the magnetic field (Fig. 1). These rotation can be detected as an electromotive force induced in a coil positioned outside of the body. The detected signal is used for a medical imaging to diagnose disease called magnetic particle imaging. In case of applying the magnetic field at higher frequency, the magnetic nanoparticles are heated. This heat dissipation can be used for thermal therapy for cancer (hyperthermia).

The purpose of this project is to elucidate the magnetization response (dynamics) of magnetic nanoparticles and to develop these diagnostic and therapeutic methods.

【Research Methods】

Two types of responses of magnetic nanoparticles are shown in Fig. 2. They have different characteristics especially their frequency dependence. We will observe these two responses accurately by using the measurement system developed in this project. As for the measurement samples, we use magnetically fractionated particles with less size distribution, and particles of oriented

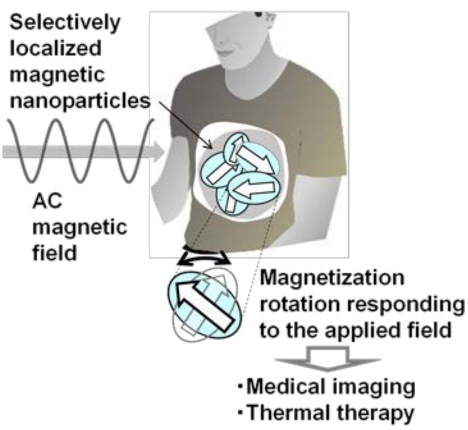

Figure 1 Magnetic nanoparticles for diagnosis and therapy

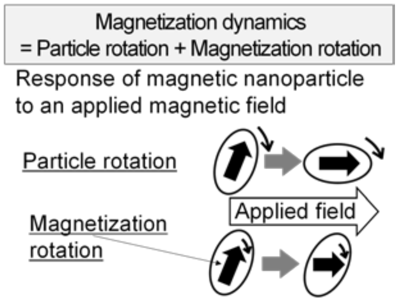

Figure 2 Magnetization dynamics of magnetic nanoparticle

magnetization easy axis. By elucidating the magnetization dynamics, we will optimize the field condition to maximize the intensity of detected signal for medical imaging, and heat generation for thermal therapy.

【Expected Research Achievements and Scientific Significance】

This project is expected to improve the detection sensitivity of magnetic nanoparticles in diagnostic imaging and the amount of heat generated for hyperthermia. The spatial resolution of 1 mm required for practical use of magnetic particle imaging can be achieved. As for hyperthermia, the magnetic field intensity and frequency can be reduced as to be capable in use of a body-sized coil.

【Publications Relevant to the Project】

- Satoshi Ota, Yasushi Takemura, "Characterization of Neel and Brownian relaxations isolated from complex dynamics influenced by dipole interactions in magnetic nanoparticles", The Journal of Physical Chemistry C, Vol. 123, No. 47, pp. 28859-28866, 2019.
- Suko Bagus Trisnanto, Yasushi Takemura, "Modulating relaxation responses of magnetic nanotracers for submillimeter imaging", Applied Physics Letters, Volume 115, Issue 12, 123101, 2019.

【Term of Project】 FY2020-2024

【Budget Allocation】 151,200 Thousand Yen

【Homepage Address and Other Contact Information】
http://www.takemura.ynu.ac.jp/

【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project：Nanomechanics on rewritable material strength by anomalous electrons

HIRAKATA Hiroyuki
(Kyoto University, Graduate School of Engineering, Professor)

Research Project Number: 20H05653　Researcher Number：40362454
Keyword：Material strength, Anomalous electrons, Mechanics of micro/nanomaterials, Nanomechanical experiments, First-principles analysis

【Purpose and Background of the Research】

For a long time, it has been believed that mechanical properties especially strength of materials are inherent to each material, that means, material constants are determined by the composition and microstructure of materials, and hence cannot be changed in principle. However, we found that the intrinsic strength of materials can be significantly altered by intentionally injecting excess electrons/holes, i.e., anomalous electrons, that cannot be present in nature (e.g., Fig. 1).

The purpose of this research project is to elucidate the fundamental mechanism of how anomalous electrons interfere with interatomic bonds and rewrite the strength and mechanical properties of various materials, and finally to establish a universal theory behind the exotic phenomena.

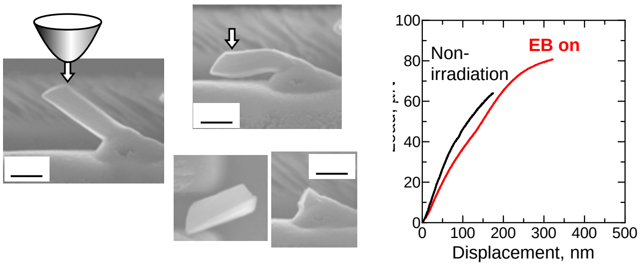

Figure 1 Effect of electrons on material strength

【Research Methods】

Plastic deformation and fracture are ultimately governed by the breaking of atomic bonds. To evaluate the ideal strength of materials that directly reflects the strength of interatomic bonds, we develop a series of experimental methods for nano/micromaterials without defects. In addition, we establish techniques for controlling (injecting, holding, and drawing) anomalous electrons in the material. By using these techniques, we conduct various experiments on electron-controlled specimens to elucidate the effects of anomalous electrons on material strength.

To understand the detailed transition of the bonding state by anomalous electrons and the accompanying change in deformation and fracture mechanisms from the viewpoint of quantum mechanics, we also perform first-principles strength simulations on materials with anomalous electrons. We systematically investigate the anomalous electron-induced strengthening characteristics for typical materials with covalent and ionic bonds via the development of the original theory (quantum-mechanics electronic stress theory) that decomposes and extracts the stress of each electron orbital and spin.

Based on the strength characteristics obtained by both the experiments and analyses, we elucidate the strengthening mechanisms by anomalous electrons and construct universal mechanical models.

【Expected Research Achievements and Scientific Significance】

-Elucidate the fundamental mechanism and principle of this anomalous phenomenon in which the macroscopic material strength can be changed by ultimately minute particles, i.e., electrons/holes.

-Propose rewritability that freely rewrites the material strength by controlling dynamic electrons. In other words, it brings conceptual innovation to material strength design from "making" materials to "drawing" functions.

-Establish the concept of basic evaluation technology for elucidating the effect of anomalous electrons on material strength.

-Extend the research field of anomalous electrons not only to mechanical properties but also to electric and magnetic properties and their multiphysics properties.

By realizing these, we will create a new scientific field for designing and creating a wide range of material functions.

【Publications Relevant to the Project】

・ Hiroyuki Hirakata, Kenta Konishi, Toshiyuki Kondo, Kohji Minoshima, Electron-beam enhanced creep deformation of amorphous silicon nano-cantilever, *Journal of Applied Physics*, Vol. **126**, 105102, 2019.
・ Hiroyuki Hirakata, Kyohei Sano, Takahiro Shimada, Electron-beam irradiation alters bond strength in zinc oxide single crystal, *Applied Physics Letters*, Vol. **116**, 111902, 2020.

【Term of Project】 FY2020-2024

【Budget Allocation】 154,800 Thousand Yen

【Homepage Address and Other Contact Information】

http://msr.me.kyoto-u.ac.jp

【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project： Hypersonic Airframe/Engine Integration Experiment Using a Sounding Rocket FTB

SATO Tetsuya
(Waseda University, Faculty of Science and Engineering, Professor)

Research Project Number: 20H05654 Researcher Number：80249937
Keyword：Hypersonic Vehicle, Flight Experiment, Airframe/Engine Integration, FTB

【Purpose and Background of the Research】

In Japan, system firing tests of hypersonic turbojet engines such as the ATREX and the Precooled Turbojet have been carried out ahead of other countries. However, little knowledge on the airframe/engine integration and control has been obtained under the actual flight condition due to the difficulty of conducting a hypersonic flight experiment. Thus, we propose a Mach-5 class flight experiment named “HIMICO” using a S-520 sounding rocket. “HIMICO” is an abbreviation for High Mach Integrated Control Experiment and its objective is to demonstrate the integration control technologies of the airframe and engine. Construction of the hypersonic flight technology using the sounding rocket is supposed to make a breakthrough in developing hypersonic transportation systems.

【Research Methods】

Figure 1 shows the sequence of the HIMICO flight test. The test vehicle is mounted in the nose cone of the S-520 sounding rocket. The nose cone is opened and the attitude of the rocket with HIMICO is controlled by RCS. Then, HIMICO is separated from the rocket. When the dynamic pressure is recovered, HIMICO is aerodynamically controlled to lift its nose up, which is called the “pull-up maneuver.” Finally, the ramjet engine starts at the condition with an altitude of about 20 km and Mach number of around 5. It splashes into the sea after the experiment. During the hypersonic flight, the air-intake and nozzle of the engine are controlled to match the flight condition while controlling the elevons and ladder of the airframe simultaneously.

Prior to the flight test, we plan to conduct an integrated airframe / engine control experiment using the Ramjet Test Facility (RJTF) of JAXA. This is a free-jet test. HIMICO installed on a thrust measurement test stand is exposed to air flow at a total temperature of Tt = 1320 K equivalent to Mach 5 condition. A three-component force balance is installed in the test stand. When the engine thrust is generated, a pitch-up moment is applied to the vehicle. The elevons attached to the horizontal tail are controlled so as to cancel this moment, which is measured by the balance. Compared to the flight test, RJTF test cannot simulate the unsteady condition of the freestream. However, it is possible to obtain detailed data including the unstart operation of the air intake. Figure 2 shows a photograph of the past combustion test at Mach 4 (Tt = 884 K) .

【Expected Research Achievements and Scientific Significance】

The expected outcome is to acquire the hypersonic flight data with strong airframe/engine interference. In addition, it is to acquire a Japanese unique flight test infrastructure with high independence and flexibility. These technologies will be applied to a sub-orbital spacecraft. This test covers many aerospace research fields and is expected to have educational effects for young researchers.

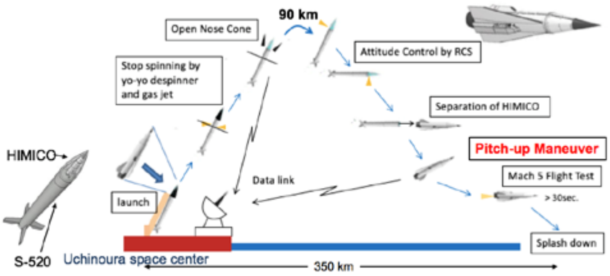

Figure 1 Flight sequence of HIMICO

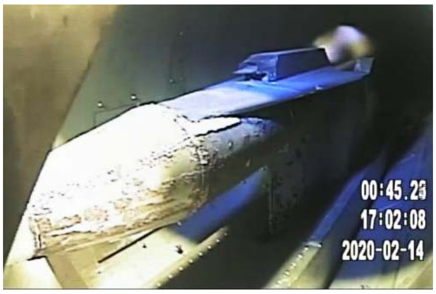

Figure 2 Combustion test under Mach 4 condition

【Publications Relevant to the Project】

・ Sato, T, et al., Program of High Mach Integrated Control Experiment, “HIMICO” using S-520 Sounding Rocket, Transactions of JSASS, Aerospace Technology Japan, to be published.

【Term of Project】FY2020-2024

【Budget Allocation】150,600 Thousand Yen

【Homepage Address and Other Contact Information】

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【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project： Development of artificial intelligence hardware using magnetic tunnel junctions

KUBOTA Hitoshi
(National Institute of Advanced Industrial Science and Technology, Department of Electronics and Manufacturing, Principal Research Manager)

Research Project Number: 20H05655 Researcher Number：30261605
Keyword：Magnetic tunnel junctions, artificial spin ice, natural computing

【Purpose and Background of the Research】

Internet-of-Things (IoT) and artificial intelligence (AI) are becoming popular nowadays. IoT connects various things through the internet. AI can surpass human ability in the recognition or prediction. They have been already adopted in several businesses and our daily lives. High computational performances in the IoT and AI are currently realized by von-Neuman architectures with various algorithms. Natural computing is a new computational system inspired from nature and has attracted much attention because of its potential achieving higher performance with lower power-consumption than von-Neumann architectures. Molecules and chemical-reaction system have been adopted to natural computing recently. In this study, we develop an artificial spin ice consisting of magnetic tunnel junctions (MTJs) and apply it to the natural computing. The MTJ is a core component in magneto-resistive random-access memory (MRAM), which is a typical commercial spintronic device. Nonvolatility, small size down to 40 nm, and low-power consumption of an MTJ are suitable for an implementation to high-density memory and/or logic circuit.

【Research Methods】

In this study, we develop artificial spin ices with MTJs for natural computing. The artificial spin ice consists of ferromagnets in submicron scale arranged as, for example, a square lattice. Figure 1 is a schematic illustration of the artificial spin ice with elliptical ferromagnet cells with in-plane magnetizations. Usually, the magnetization in a ferromagnet can point to either right or left directions of the ellipse. However, these states become unstable in the artificial spin ice due to complex interactions between magnetic cells. Then, a non-trivial alignment of the magnetizations, called frustration, appears. The frustrated physical system can show various kinds of reaction, such as an excitation, with respect to an injection of external stimulations. Such a dynamical behavior is similar to an activity of neurons in human brain. Therefore, the artificial spin ice is a promising candidate for the natural computing system. Our goal is to realize the highly energy-efficient natural computing based on the artificial spin ice by making full use of our technologies, ideas and experiences in magnetism and solid-state physics.

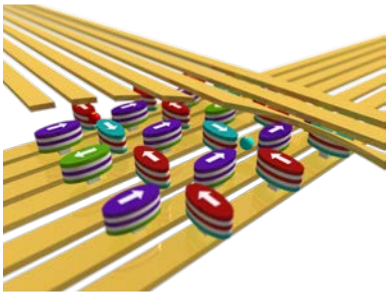

Figure 1 Artificial spin ice with magnetic tunnel junctions

【Expected Research Achievements and Scientific Significance】

We can clarify the relation between the computational performance and the statistical properties, such as a residual entropy and magnetic monopoles, in the artificial spin ice. Simulators for magnetism and natural computing with the artificial spin ice will be developed and opened for public, by which the realization of natural computing will be accelerated. Our research will open a new research field bridging solid-state physics, material sciences, and computer sciences.

【Publications Relevant to the Project】

・Reservoir computing using an interaction between nanomagnets, Hikaru Nomura, Hitoshi Kubota, Yoshishige Suzuki, Magnetics Japan vol. 14, No. 6, 321-328 (2019)
・Integrated reservoir computing modules with magnetic tunnel junctions, Hikaru Nomura, Hitoshi Kubota, Yoshishige Suzuki, The Institute of Electrical Engineering of Japan, Vol. 139, No. 10, 674-678 (2019).

【Term of Project】 FY2020-2024

【Budget Allocation】 154,500 Thousand Yen

【Homepage Address and Other Contact Information】

https://unit.aist.go.jp/d-tech/intra/RCECT/index.html

【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : Research and Demonstration of Next Generation Hall Thrusters and their Mechanism for Producing High-speed Plasma Jet

FUNAKI Ikkoh
(Japan Aerospace Exploration Agency, Institute of Space and Astronautical Sciences, Professor)

Research Project Number: 20H05656 Researcher Number : 50311171
Keyword : Aerospace engineering, Plasma and fusion, Spacecraft propulsion, Hall thruster, Hollow cathode

【Purpose and Background of the Research】

Orbital transfer capability of a spacecraft is usually limited by the amount of available velocity increment (ΔV), and higher values of ΔV are possible by increasing the velocity of a jet released from a spacecraft. In fact, increasing the jet velocity is the main topic in the research of spacecraft propulsion, and even small amount of velocity increment is considered significant because the velocity increase can improve the performance of a spacecraft. In this study, Hall thruster is dealt with. Commonly known feature of Hall thruster is a moderate jet velocity from 15 to 30 km/s and it is obtained by using electrostatic acceleration in an annular channel. Although this velocity range is suitable for Earth-orbiting missions, drastic improvement is preferred for interplanetary missions. The Hall thruster in this study is then targeting at velocities from 40 km/s up to 50 km/s which are necessary for Mars round-trip missions or explorations in the outer solar system. For this purpose, high discharge voltages as well as high magnetic fields in comparison with conventional Hall thrusters are used to optimize the design of plasma production and acceleration processes. It is possible that ions are heated up at high discharge voltages as a result of turbulent flow; in this case, the maximum velocity of a jet will be restricted. This study is, however, intended to overcome such difficulty by clarifying the background physics and by suppressing unstable effects.

【Research Methods】

Experimental study is to be conducted to evaluate the target jet velocity along with its plume characteristics. The target velocities to be demonstrated are plotted in Fig.1, in which 40-50 km/s range is highlighted. This regime is clearly distinguished from the previous studies at 30 km/s or lower velocities. Plan for this study is divided into three steps: 1) initial phase where the first very high voltage Hall thruster is tested; 2) optimization phase where various acceleration channel and cathode configurations are compared to find the best one, and 3) final phase where a system-level evaluation is conducted and application to deep space missions is proposed.

During the first phase, first laboratory model is designed and tested to experimentally demonstrate a Hall thruster at 40 km/s or higher velocity. After that, in the second phase, optimization process follows. If velocity limitation is found during this process, physical explanation is pursuit and corresponding thruster lifetime limitation is considered. Reflecting these results, a prototype model is designed to evaluate system-level feature. Finally, a mission proposal is released to show next generation solar system exploration using the new thruster system.

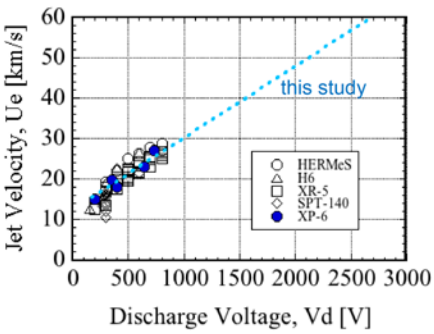

Figure 1 Regime of Hall thruster in this study.

【Expected Research Achievements and Scientific Significance】

Although the usage of electric propulsion is increasing in the world, there are some limitations in the current technologies for ion thrusters and Hall thrusters. That is, these thrusters can obtain either high velocity or high density, but both of these cannot be obtained simultaneously. This study tries to obtain both highly velocity and high density by exploiting Hall thruster's new regime. With the new thruster, various space exploration that were not possible in the past became realistic to reach unknown part of our solar system.

【Publications Relevant to the Project】

・ I. Funaki, et al., Development of a 6-kW-class Hall Thruster for Geostationary and Interplanetary Missions, Acta Astronautica, 170 (2020) pp.163-171.
・ I. Funaki, et al., 1,000-hours Demonstration of a 6-kW Class Hall thruster for All-Electric Propulsion Satellite, Aerospace Technology Japan, 17 (2019) pp.589-595.

【Term of Project】 FY2020-2024

【Budget Allocation】 146,500 Thousand Yen

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