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Institute of Advanced Energy
Kyoto University

ANNUAL REPORT 2015

京都大学エネルギー理工学研究所
Institute of Advanced Energy, Kyoto University

ANNUAL REPORT

2015

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Kyoto University

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CONTENTS

FOREWORD

Institute of Advanced Energy (IAE) was established in 1996 for the investigation of energy science and technology, aiming at sophistication of every process during the energy generation, energy conversion, and energy utilization. The energy system for next generation should be an environment-friendly (or ecologically sustainable) one. Crowned as the name of our institute is “Advanced Energy”, which means an energy system that has high-level compatibility between the “quality” ensuring the environmental-friendliness and the “sufficient amount” covering the global energy demand. Toward realization of such the Advanced Energy system, we have been preforming interdisciplinary studies to explore the new science and technology for the Advanced Energy.

These works are conducted by three research divisions in the institution, which have 14 research sections including two for guest researchers, as well as the Laboratory for Complex Energy Processes. The Laboraroty specializes in highly project-oriented cross-disciplinary studies. In addition to the individual study in each research section, “cooperation with scientists from different academic fields” is also an important key word for our institute since its establishment. We have been conducting a lot of collaborative activity with researchers from inside and outside of the institution and also with domestic and international colleagues; Joint Usage/Research Center (JURC) Program, collaboration works in the Laboratory for Complex Energy Processes, research projects with other universities and organizations, research/educational program with other department in Kyoto University, etc.

As an innovative concept for Advanced Energy, we have proposed a concept of “Zero-emission Energy (ZE)” since FY2010. This idea of ZE comes from the fruitful results of individual and collaborative researches including collaboration projects performed with a lot of member from relating departments in Kyoto University. Since FY2011, IAE has been qualified by the Ministry of Education, Culture, Sports, Science and Technology as Joint Usage/Research Center for Zero-emission Energy Research. This program supports about 90 collaboration subjects par a year, which are proposed by researchers from about 40 institutions except for IAE. On the other hand, the collaboration program in the Laboratory for Complex Energy Processes supports the cross-division and/or cross-section activities mainly for the IAE researchers, which are producing the seeds for advanced collaboration subjects in JURC for Zero-Emission Energy Research.

This annual report summarizes key activities in those IAE’s research for FY2015. Although this report is edited based on the research section, some results from the collaborative investigations are also included.

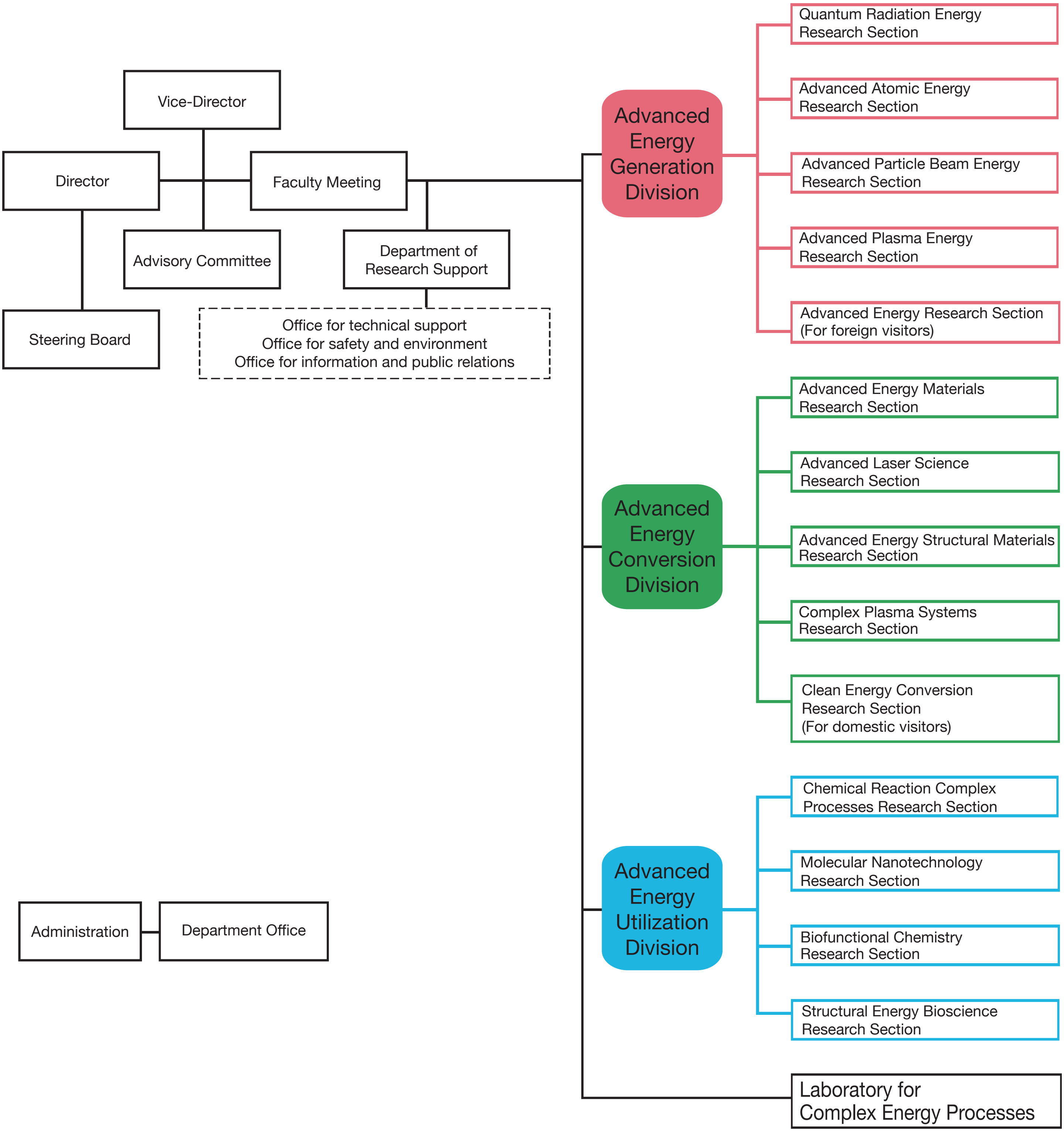
Due to the space limitation, unfortunately, the details of each study is not shown in the report. Please contact to each researcher for the details and for the possibility of future collaborations.

We would like to ask your continual support, guidance and cooperation for these activities. Thank you.

March 2016

Tohru MIZUUCHI
Director
Institute of Advanced Energy
Kyoto University

2. ORGANIZATION CHART



3. RESEARCH ACTIVITIES

3-1. TOPICS

Novel Silicon Carbide Composites with Particle Dispersion in Matrix

T. Hinoki, Associate Professor
(Advanced Energy Materials Research Section)

Silicon carbide (SiC) is one of very attractive engineering ceramics in particular for severe environment. Silicon carbide composites basically require weak fiber/matrix interphase like carbon (C) or boron nitride (BN). The interphase material and its thickness are keys to determine mechanical properties. However precise control of the interphase is the critical issue in particular for large scale production and affects material cost significantly. The objective of this work is to develop novel SiC composites without fiber/matrix interphase by applying particle dispersion in SiC matrix.

Silicon carbide composites were fabricated by CVI method and LPS method. Silicon carbide with C matrix was formed by mixture of SiC source gas and C source gas in CVI composites. Silicon carbide with BN matrix was formed by mixture of SiC powder and BN powder in LPS composites. Mechanical properties were characterized by tensile test and flexural test before and after exposure in air up to 1750C. Microstructures and fracture surfaces were characterized by FE-SEM.

Both SiC composites with C and with BN in matrix have uniform microstructure through thickness. They showed ductile fracture behavior with fiber pullouts. The tensile strength of 2D-CVI composites with C was approximately 260 MPa. The flexural strength of UD-LPS composites with BN was approximately 500 MPa. Scattering of mechanical properties for each sample was limited well. No significant degradation of tensile strength of the BN particle dispersion SiC composite wasn't observed following exposure up to 1500C in air. Oxidation of the composites were limited to near surface in particular for the fiber bundle region up to 1500C.

This accomplishment was introduced by Japanese newspaper, "NIKKAN KOGYO SHIMBUN" on July 30, 2015.

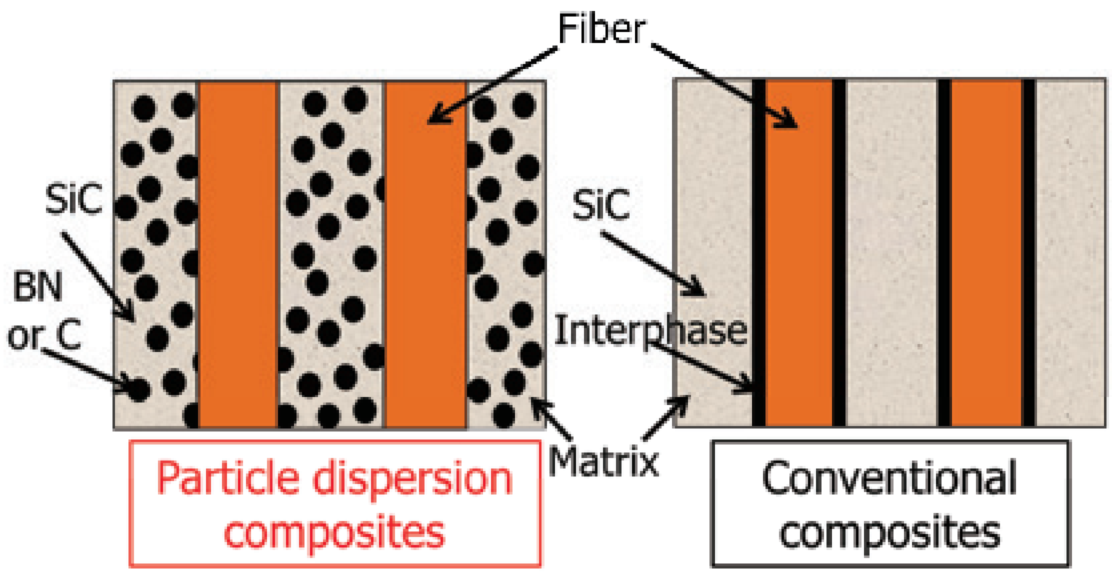


Fig. 1 Schematic illustration of the particle dispersion SiC composites and conventional SiC composites.

3-2. RESEARCH ACTIVITIES IN 2015

Quantum Radiation Energy Research Section

H. Ohgaki, Professor
T. Kii, Associate Professor
H. Zen, Assistant Professor
H. Farzaneh, Program-Specific Junior Associate Professor
(K. Miura, Specially Appointed Professor)
(J. Wannapeera, Researcher)
(J. Yan, Researcher)

1. Introduction

Coherent-radiation energy with wide wavelength tunability, high power and high efficiency is quite promising in the 21st century that is sometimes called the "era of light". The research in this section aims at developing the technology to generate new quantum-radiation energy and apply the radiation in various fields; atomic energy including plasma heating, energy transportation in the universe, material science, material synthesis, electronic device, medical and biological science, etc. Free-electron laser (FEL) is one of the powerful candidates for the new quantum radiation, and it is sometimes called the light source of next generation.

2. Free-electron Laser

FEL is regarded as a light source of the next generation because of its wide wavelength tunability where the conventional lasers cannot reach, potential high efficiency, and high power. However, the system is usually much larger and the cost is higher than conventional lasers. We are going to overcome these difficulties by exploiting an RF (radio-frequency) gun, an undulator, etc.

2.1 KU-FEL

The target wavelength of KU-FEL is MIR (Mid infra-red) regime, from 5 to 20 μm. The high power tunable IR laser will be used for basic researches on energy materials and systems. Figure 1 shows a schematic drawing of the KU-FEL system. The KU-FEL consists of a 4.5-cell thermionic RF gun, a 3-m travelling wave accelerator tube, a beam transport system, and a 1.8-m undulator and a 5-m optical resonator. The FEL device now can cover the wavelength range from 5 to 20 μm. The maximum macro-pulse energy which can provide is around 30 mJ in a 2-μs macro-pulse at the wavelength of 9 μm. The FEL is routinely operated and opened for internal and external users.

Another topic of KU-FEL development is introduction of photo-cathode RF gun, which enables us to generate higher peak power and wider tunable range MIR-FEL. Development of a UV-laser system for illuminating photo-cathode has been completed under collaboration with Dr. R. Kuroda, Researcher of AIST. In FY2014, we have achieved FEL lasing with photo-electron beam generated from LaB_6 cathode. Further study is undergoing to use this operation mode for user experiments.

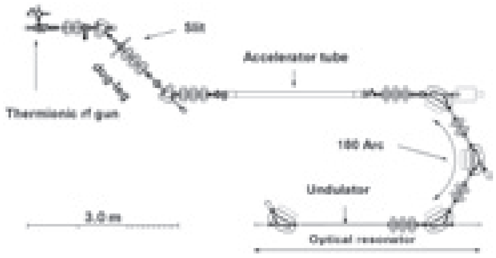


Fig. 1 Schematic drawing of the KU-FEL

2.2 MIR-FEL Application in the Energy Science

Mode-selective phonon excitation (MSPE) is important issue for the bulk solid material to develop the energy saving devices. In this fiscal year, MIR-FEL pump, visible pico-second laser probe experiment has been conducted. We found two components having different temporal feature. The origin of those two component is not clear and further study will be performed in next fiscal year.

2.3 Compact seeded THz-FEL Amplifier

A new compact terahertz radiation source is under construction. It consists of a 1.6-cell RF-gun, a solenoid magnet, a magnetic chicane bunch compressor, a triplet quadrupole magnet, a planar undulator, and a laser system for photocathode and seed THz light. The target wavelength is from 400 to 800 μm. Schematic view of the proposed system is shown in Fig 2.

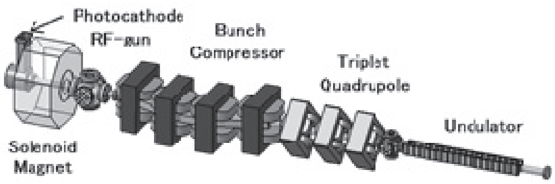


Fig. 2 Schematic view of the compact seeded THz-FEL.

In the first stage of the development, we will operate and investigate the performances of the system without seed THz light. The photocathode RF-gun is driven by 10 MW klystron, which is commonly used with KU-FEL. The magnetic chicane compress the electron bunch until the final bunch length is in a picosecond order. The ultra-short and high brightness electron beams are injected to the undulator with the number of periods of 10 and the period length of 7 cm. The undulator generate a high power THz radiation through a “Coherent Synchrotron Radiation” process. We expect to complete the construction and start the commissioning of the first stage system in 2016.

3. Bulk HTSC Staggered Array Undulator

An undulator or a wiggler with strong magnetic field will play an important role in future synchrotron light sources and free electron lasers. We constructed the bulk high critical temperature superconductor staggered array undulator (Bulk HTSC SAU) which can generate a stronger periodic field than that of conventional permanent magnet undulator. The Bulk HTSC SAU consists of stacked bulk high-Tc superconductors (HTSs) and a solenoid magnet which is used to magnetize the bulk HTSs as shown in Fig. 3.

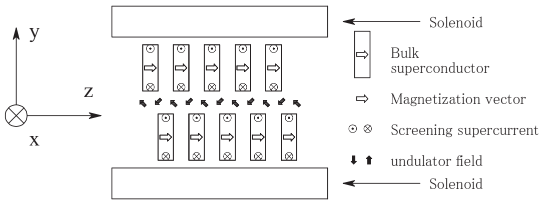


Fig. 3 Conceptual drawing of the bulk HTSC SAU and generation principle of the periodic undulator field using an induced supercurrent.

4. Isotope Imaging for Nuclear Security

A Nuclear Resonance Fluorescence (NRF) measurement is a powerful tool for investigation not only of the nuclear physics, but also of isotope identification inside the nuclear waste canisters. We have been developing an isotope imaging technique by using NRF. The absorption can be measured by sample material and “witness target”. A numerical study has been performed by using our revised version of GEANT4. As a result we can successfully reproduced the distribution of ^{238}U. Figure 4 shows a CT image of the normal CT method (atomic transmission), NRF CT (NRF absorption), and enhanced NRF CT which is deduced by the atomic transmission.

5. Japan-Thailand Project for Effective Use of Biomass Wastes as well as Low-rank Coals

Our section has organized a Japan-Thailand joint research project entitled “*Development of clean and efficient utilization of low rank coals and biomass by solvent treatment*” as one of the projects that are supported

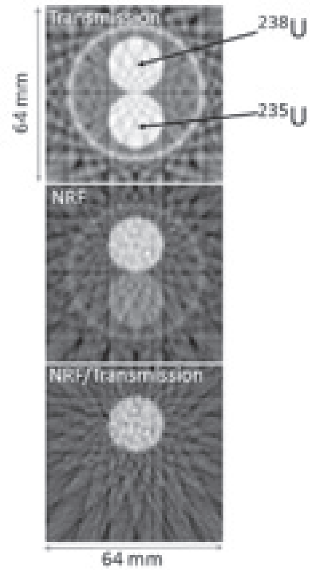


Fig. 4 Simulated CT images. Top figure depicts normal CT image of ^{235,238}U, the middle one is NRF CT image, and bottom one is enhanced NRF CT image. [Daito EMSES]

by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA) through the program called Science and Technology Research Partnership for Sustainable Development (SATREPS). More than 15 Japanese researchers from Kyoto University, Akita University, Central Research Institute for Electric Power Industry (CRIEPI), and Kobe Steel Co. Ltd and 12 Thai researchers from the Joint Graduate School of Energy and Environment at King Mongkut’s University of Technology Thonburi and PTT Public Company Limited are involved in the project.

Through 6 years of cooperation starting from 2013 we are to develop several technologies to convert biomass wastes as well as low rank coals into valuable products such as carbon fiber, biofuel, high quality solid fuel, etc. based on a novel degradative solvent extraction technology developed at Kyoto University. We have already shown that carbon fiber can be prepared from the Soluble prepared from a rice straw and that the Soluble can be a candidate of a new biofuel. The outputs from this project are expected to make global contribution in every perspective. Clean and efficient utilization of low rank coals as well as increased biomass utilization will reduce the CO_2 emission.

Acknowledgment

These works were partially supported by the Grant-in-Aid for Scientific Research B, the Grant-in-Aid for challenging Exploratory Research, the Grant-in-Aid for JSPS Fellows by the Ministry of Education, Culture, Sports, Science and Technology of Japan, and The Collaboration Program of the Laboratory for Complex Energy Processes, Institute of Advanced Energy, Kyoto University.

Collaboration Works

NSTDA（タイ），JASTIP、WP2，大垣英明

自然科学研究機構分子科学研究所・協力研究（UVSOR 利用を含む），BL1U における大強度ガンマ線発生と同位体イメージングへの応用，全炳俊（代表者），大垣英明，紀井俊輝，平義隆，早川岳人，静間俊行，加藤政博

Financial Support

1. Grant-in-Aid for Scientific Research

大垣英明，基盤研究（B），NRF を利用した同位体 3D イメージングに関する基礎研究

紀井俊輝，挑戦的萌芽研究，射出方向・エネルギー・エネルギー広がり可変の高輝度Ｘ線・ガンマ線ビーム発生法

全炳俊，若手研究（A），超短バンチ電子ビームを用いた新奇 THz 自由電子レーザ発生手法の研究

2. Others

大垣英明，科学技術振興機構，平成 27 年度「日本・アジア青少年サイエンス交流事業（さくらサイエンスプラン）」

大垣英明，科学技術振興機構，平成 27 年度日本・アジア青少年サイエンス交流事業

大垣英明，大学等連携支援事業（高エネ事業），光陰極高周波電子銃を用いた THz-FEL 開発とこれによる大学院学生の加速器教育

大垣英明，科学技術振興機構，日 ASEAN 科学技術イノベーション共同研究拠点－持続可能開発研究の推進－

大垣英明，研究拠点形成費等補助金（博士課程教育リーディングプログラム），京都大学大学院思修館

大垣英明，科学技術振興機構，さくらサイエンスプラン日本・アジア青少年サイエンス交流事業 A．科学技術交流活動コース中国科学技術大学

大垣英明，科学技術振興機構，さくらサイエンスプラン日本・アジア青少年サイエンス交流事業 B．共同研究活動コースヤンゴン大学

三浦孝一，国際協力機構，低品位炭とバイオマスのタイ国におけるクリーンで効率的な利用法を目指した溶剤改質法の開発プロジェクト

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Advanced Atomic Energy Research Section

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R. Kasada, Associate Professor
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1. Introduction

Future energy could not be discussed without solar. The major objective of the study in this section is to pursue advanced energy systems for the sustainable development under global environmental constraints. The studies described below are featured by not only the innovative technology of energy genera-tion, conversion and utilization systems. The attractiveness of the total energy system considered by the socio-economic analysis of future society and mar-kets in the global scale and the scope covering 21st century and beyond is reflected. Typically, we pro-pose a Zero-emission energy scenario based on fu-sion energy for biomass-based recycling system.

The major studies performed in our laboratory this fiscal year were as follows:

(1) Design of small and realistic biomass-fusion hybrid energy system
(2) Development of advanced fusion blanket and divertor with liquid LiPb and SiC composite for high temperature heat
(3) Conversion of waste biomass by endo-thermic reaction to generate hydrogen and liquid fuel
(4) Design and analysis of grid system for zero-emission electricity system
(5) Development of compact neutron beam using newly developed cylindrical discharge device.
(6) Analysis of radioactive impact of nuclides from fusion plants.
(7) Materials R&D for the above-mentioned issues

2. Feasibility analysis of vacuum sieve tray for tritium extraction in the HCLL test blanket system

This study describes the quantitative analysis for the design of a tritium extraction system that uses liquid PbLi droplets in vacuum (Vacuum Sieve Tray, VST), for application to the ITER helium-cooled lithium lead (HCLL) test blanket system (TBS). The parametric dependences of tritium extraction efficiency from the main geometrical features such as initial droplet velocity, nozzle head height, nozzle diameter, and flow rate are discussed. With nozzle diameters between 0.4 and 0.6 mm, extraction efficiency is estimated from 0.77 to 0.96 at the falling height of 0.5 m, with flow rate between 0.2 and 1.0 kg/s. The device has a height of 1.6 m, within the external dimensions of the HCLL Test Blanket Module (TBM), and no additional pumping power is required. The attained results are considered attractive not only for ITER, but also in view of the application of the VST concept as a candidate tritium extraction system for the European Union's demonstration fusion reactor (DEMO). The extraction efficiency of a single droplet column, which is the basis of the design analysis presented, has been validated experimentally with hydrogen. However, further experiments are required on an integrated system with size relevant to the proposed HCLL-TBS design to validate system-level effects, particularly regarding the desorption process in an array of multiple droplets.

[F. Okino, P. Calderoni, R. Kasada, S. Konishi, Fusion Engineering and Design, in press.]

3. Requirements for DEMO from the Aspect of Mitigation of Adverse Effects on the Electrical Grid

One of the most important missions of the next fusion plant, DEMO, will be electricity generation. However, there are significant envisioned problems for DEMO: its startup power and the reliability as a source of electricity. When designing DEMO, its compatibility with the electrical grid would be a critical requirement and a limitation. Typical DEMO designs require a few hundreds of MW of power when starting operation, primarily for magnetization of coils and plasma heating and current drive. In addition, unpredictable interruptions of output power due to plasma disruptions and other off-normal events also have to be considered. Since the percentage of renewables will be greater in the future, effects of these disturbances would be greater than currently envisioned. This study assessed the adverse effects of DEMO on the grid quantitatively through a simulation-based case study on Japanese power system of 2040.

The results indicated that when considerable percentage of renewables are installed, the power system would experience serious frequency deviations as large as 0.4 Hz, which is greater than the current tolerance, 0.2 Hz. DEMO installation would need an assessment as part of the power system, together with mitigation devices, to be connected to the grid as shown in Fig.1.

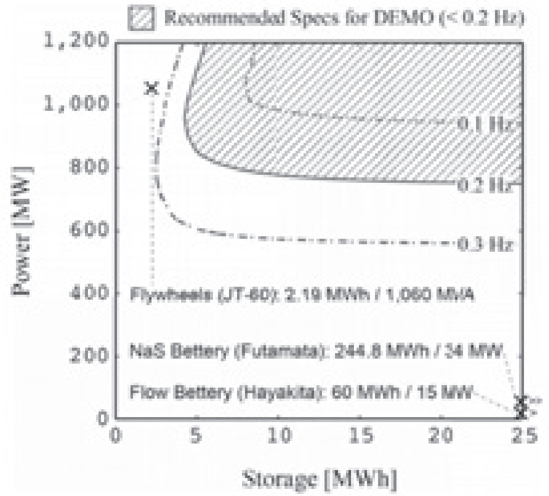

Fig. 1 Recommended battery specifications for DEMO.

[S. Takeda, Y. Yamamoto, R. Kasada, S. Sakurai, S. Konishi, Plasma and Fusion Research: Rapid Communications 10 (2015) 1205070]

4. Development of a system dynamics model for stock and flow of tritium in fusion power plant

Self-sufficiency of tritium fuel cycle (TFC) is essential for deuterium–tritium (D-T) fusion power plants (FPP) to achieve their steady-state operation. Furthermore external preparation of initial loading of tritium has been considered to be necessary for start-up of D-T fusion reactors. Beyond ITER, however, acquiring the initial loading of tritium may become an obstacle to start DEMO program in Japan because of no available commercial tritium. In order to mitigate supplier risk in a tritium supply chain, possible scenarios to start D-T FPP without the external tritium, so-called D-D start-up scenarios, have been proposed and analyzed. This study upgrades our SD-TFC model to analyze the stocks and flow of tritium in various FPP concepts. The D-D start-up scenario is examined for the two kinds of fusion power plants having different fusion power output 3 GW and 1.5 GW. Possible operating scenario to avoid excess stock of tritium is also discussed.

The main results are summarized as follows:

(1) SD-TFC simulations indicated that D-D start-up absolutely without initial loading of tritium is possible for both of the 3 GW and 1.5 GW FPP concept. Steady state full-power operation without initial loading of tritium needs ~ 50 day for the FPPs with TBR values of GDT = 1.1 and GDD = 0.67.

(2) Excess stock of tritium is generated by the steady state operation with the TBR over unity.

[R. Kasada, S. Kwon, S. Konishi, Y. Sakamoto, T. Yamanishi, K. Tobita, Fusion Engineering and Design 98-99 (2015) 1804-1807.]

5. Dynamic tensile properties of reduced-activation ferritic steel F82H for fusion reactor blanket structural material

Plasma disruption events will give large and transient electromagnetic forces on the structural materials of tokamak machines including ITER. It is obvious that strain-rate in the structural materials during plasma disruption events is a design-dependent and operation-dependent parameter. Assuming that plasma current of 16.7 MA linearly decreases in 30 ms, for example, Tanigawa et al. calculated the Eddy current distribution and subsequent electromagnetic forces in the DEMO blanket. If the blanket structure has a few millimeter thickness, estimated strain-rate during current plasma disruption event is ~ 0.1 s^{-1}. While available information of the structural design is limited, a possible strain-rate window of structural materials in fusion reactor is suggested in Fig. 2 which is based on the Lindholm diagram. Divertor components in magnetic fusion machines may receive high strain-rates due to short pulse thermal loading from edge localized mode (ELM). Solid wall of laser inertial fusion reactor may suffer from much higher strain-rates due to the pulse loading. These facts motivate high strain-rate testing to investigate the dynamic mechanical properties of fusion reactor materials. The present study shows first results of the dynamic tensile deformation behavior of RAF steel F82H.

We found strain-rate dependence of tensile properties of F82H BA07-heat by high-speed tensile testing at 296 and 423 K. Test results are summarized as bellows: (1) The result clearly shows higher strength for higher strain-rate condition. The activation volume analysis suggests a change of deformation mechanism at around 10–100 s^{-1}. (2) Higher strain-rate condition testing resulted in the higher uniform strain. In contrast, reduction of area indicates similar true fracture strain among the present strain-rate conditions. (3) Zerilli–Armstrong bcc model can predict dependence of yiled stress of F82H steel on temperature and strain-rate tested in the present study.

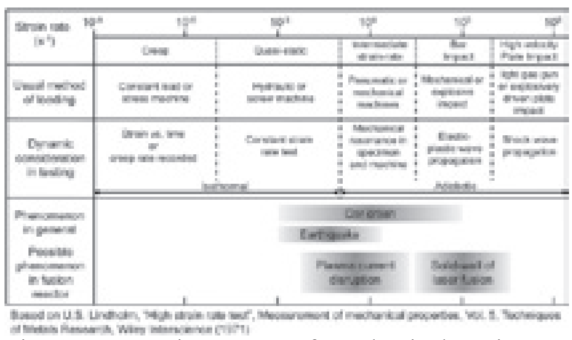

Fig. 2 Dynamic aspects of mechanical testing and related phenomenon in general and in fusion reactor.

[R. Kasada, D. Ishii, M. Ando, H. Tanigawa, M. Ohata, S. Konishi, Fusion Engineering and Design, 100 (2015) 146–151.]

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Advanced Particle Beam Energy Research Section

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1. Introduction

Advanced and innovative control methods for the collective behavior of charged particles are being developed in this research section to bring about enormous contributions to the human beings. Studies of nonlinear interactions between charged particles and electromagnetic fields are particularly emphasized. We focus on the following subjects; improvement and understanding of confinement and transport in fusion plasmas, development of heating and current drive systems using high power millimeter waves, development of advanced diagnostics in high temperature plasmas, development and application of compact and portable neutron/proton sources driven by fusion reaction, and production/diagnostics of highly brilliant relativistic electron beams for advanced light sources such as free electron laser.

2. Zero-dimensional model analysis of NBI plasma start-up

In stellarator/heliotron devices, plasma start-up using neutral beam injection (NBI) has been proposed to extend the operational range of magnetic field strength, which is useful for high β and toroidal magnetic field scaling experiments. In the Heliotron J device, plasma start-up by NBI has been done with the assistance of a seed plasma generated by non-resonant 2.45 GHz microwaves. A high density plasma is built up after starting the NB injection to the seed plasma with an additional gas puff, and here the seed plasma play an important role on the ionization process of fast neutrals originated from NBI.

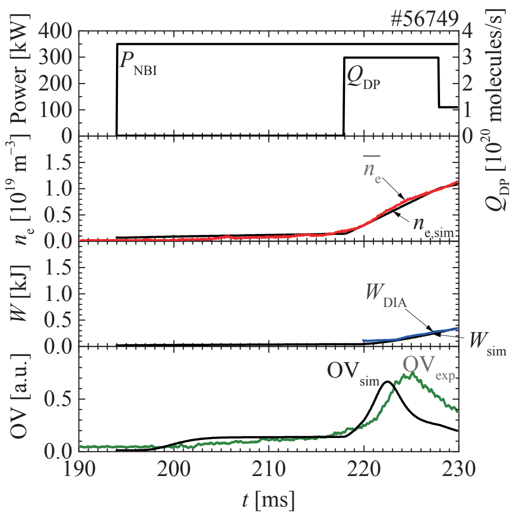

Fig. 1 Time evolutions of the NBI power and main gas puff, the electron density, the stored energy, and the OV emission (278 nm, $1s^22s3p \rightarrow 1s^22s3s$).

In order to investigate the physical processes of the NBI plasma start-up in Heliotron J, a zero-dimensional (0-D) model has been developed. The 0-D model comprises of four sets of time dependent equation: particle density equations for fast hydrogen ions from the NBI, particle density equations for neutrals (H_2, D_2, H, and D), particle density equations for ions (H_2^+, D_2^+, H^+, and D^+), and energy density equations for bulk electrons and ions.

Comparisons of simulation results with the experimental data are conducted to validate the 0-D model. Figure 1 shows the time evolutions of the NBI power and main gas puff, the electron density, the stored energy, and the OV emission. These simulation results provide good agreement with the experiment data in terms of not only the electron density but also the OV emission. The 0-D model analyses lead us to the conclusion that the dominant processes in Heliotron J are (i) production of fast hydrogen ions, (ii) electron heating, and (iii) the ionizations and dissociations of the main gas. A positive feedback loop of these processes results in successful build-up.

3. Density fluctuation measurement with two Ka-band microwave reflectometers in Heliotron J

Anomalous transport in fusion plasmas is believed to be caused by turbulent fluctuations. In order to measure density fluctuations in such high temperature plasmas, we have developed two reflectometer systems to measure density fluctuations in Heliotron J. Using the new reflectometers, fluctuation characteristics at the transition from L-mode (Low confinement

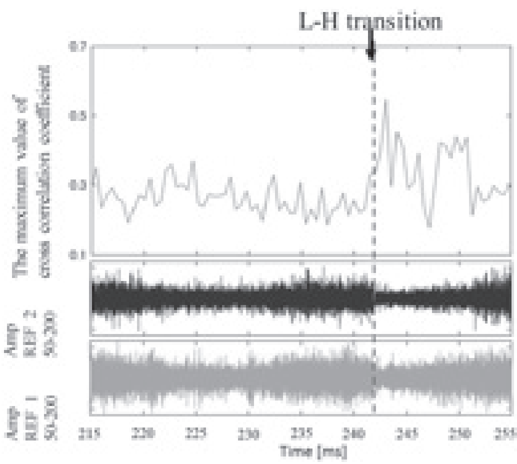

Fig. 2 The time evolution of cross correlation and fluctuation amplitude

mode) to H-mode (High confinement mode) has been investigated in high-density NBI heated plasmas with high-intense gas puffing. Figure 2 shows the time evolution of the cross-correlation of turbulence between density fluctuation at slightly different radial positions (top), and the fluctuation amplitudes measured with the reflectometer-1(middle) and reflectometer-2 systems (bottom). The fluctuation amplitude drastically decreases at the L-H transition, and the cross-correlation in radial direction increases after the transition with a time scale shorter than the energy confinement time.

4. Development of electrostatic probe for IEC plasma

Measurement of plasma parameters inside a cathode in IEC is an important issue to understand how fusion reaction process takes place. Several diagnostics have been used such as a Doppler shift spectroscopy and laser-induced fluorescence techniques for this purpose, but have a problem of low S/N ratio especially under low-pressure high-voltage operating conditions. To cope with this problem, a scheme using an electrostatic probe has been developed in this study. The problem in applying the probe to the IEC is that the operation condition be also limited under low-voltage, because a breakdown between cathode and probe easily occurs in such a high voltage condition if the probe is inserted into anode-cathode gap. To realize the measurement under such a high-voltage circumstance, we have replaced the cathode feedthrough rod by a tube, put the probe through the tube (see Fig. 3), the probe is grounded at the cathode itself to avoid the breakdown between the probe and the cathode. This new probe system was confirmed to work under high cathode voltage up to 55 kV. Floating potential profile inside the cathode was measured using this probe, which successfully revealed that the floating potential distribution inside the cathode, as shown in Fig.4.

5. Space charge effect on emittance reduction in electron gun

Emittance reduction is an important problem for next generation Synchrotron Radiation light source such as Energy Recovery Linac and Free Electron Laser. The emittance is influenced at the vicinity of cathode, where beam dynamics is dominated by space charge effect. Recently, it was discovered that emittance rises near cathode and subsequently decreases due to self-linearization force caused by space charge effect.

We have numerically investigated the transverse emittance and its dependence on parameters such as initial current density, accelerating field and the distance from the cathode. This investigation was performed assuming a model of ideal DC acceleration. Figure 5 shows dependency of emittance evolution on initial current density and accelerating field at cathode. We have also discussed the dependence of position of minimum emittance on perveance. Figure 6 shows a correlation of the position of minimal emittance to perveance, in the cases of two electron gun structures (SCSS, ideal DC gun). This position can be controlled by proper settings of operating parameters of electron injector. As a result, the emittance can be reduced by corresponding designing of preference.

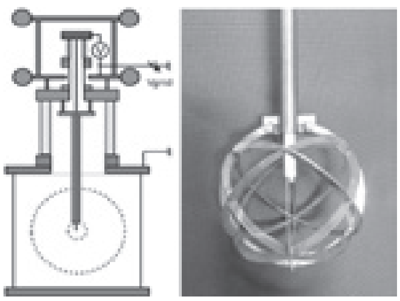

Fig. 3 Schematic illustration of the electrostatic probe system and the photo of the probe and the cathode.

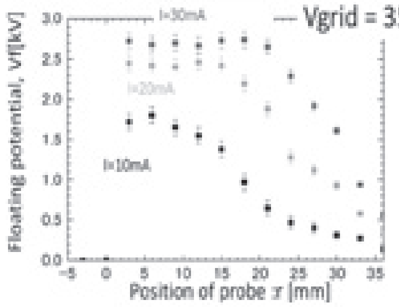

Fig. 4 Floating potential distribution inside the central gridded cathode.

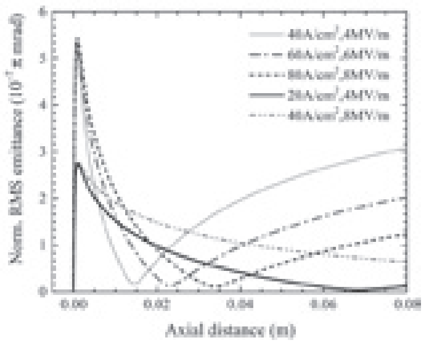

Fig. 5 Emittance evolution for different accelerating field and for current density.

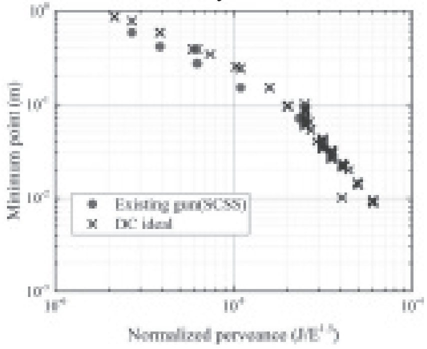

Fig. 6 Dependence of minimum point of emittance on normalized emittance.

Collaboration Works

Univ. Wisconsin（米国），Oak Ridge National Laboratory（米国），Max Plank Institute（ドイツ），Stuttgart Univ（ドイツ），CIEMAT（スペイン），Australian National Univ.,,（オーストラリア），Kharkov Institute（ウクライナ），Southwest Institute of Physics（中華人民共和国），ヘリカル型装置における SOL/ダイバータプラズマに関する研究，水内亨，長崎百伸，岡田浩之，小林進二，山本聡，南貴司

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Advanced Plasma Energy Research Section

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T. Minami, Associate Professor
S. Kobayashi, Assistant Professor

1. Introduction

The current subjects of this research section are to study the properties of high temperature plasmas in order to control and improve the plasma energy confinement from the physical viewpoint of nuclear fusion research. The experimental and theoretical investigations for the optimization of the helical-axis heliotron configuration are in progress under the collaboration with other groups of the international/national institutes and also groups of other universities under the auspices of the Collaboration Program of the Lab. Complex Energy Processes, IAE and the Collaborative Research Program of NIFS (National Institute for Fusion Science).

In this report, a remarkable result obtained in the Heliotron J experimental study in FY2015 is reported focusing on (1) rapid NBI plasma startup using pre-ionization method in Heliotron J and (2) Comparison of electron internal transport barrier formation between CHS and Heliotron J.

2. Rapid NBI plasma startup using pre-ionization method by non-resonant microwave injection

Plasma initiation by neutral beam injection (NBI) alone has been demonstrated in large Heliotron devices. However, in the case that the path-length of NBI is not long enough to initiate the plasma in a limited time, pre-ionization methods are effective in rapid plasma start-up and in reduction in heat load onto the armour tile of the NBI. In Heliotron J, the plasma start-up by NBI has been succeeded by the pre-ionization method using low power microwaves at a magnetic field range of 0.6-1.3 T [1] This study is done by the international collaboration research with Max-Planck-Institut für Plasmaphysik (IPP Greifswald, Germany).

Figure 1 shows the typical waveform of the plasma startup by NBI. The 2.45GHz microwave is launched 0.6 sec before NBI turn-on. In the experimental condition, there are no fundamental or higher harmonic resonances for the 2.45 GHz frequency. The ECE measurement shows the production of the high energy electrons by launching the 2.45 GHz microwave. The small amount of the additional gas puffing during the 2.45 GHz launch is effective to increase the seed-plasma density. The achieved seed-plasma density was $\bar{n}_e = 5\times10^{18}$ m^{-3} in maximum, being much higher than that of the 2.45 GHz O-mode cutoff (7.5×10^{16} m^{-3}). Stochastic acceleration model has been proposed to explain the generation of the high energetic electrons. After the NBI turn-on, the rapid (~10 ms) increase in $\bar{n}_e$ is found. An additional gas puff increased $\bar{n}_e$ to over 3×10^{19} m^{-3} in a few tens ms, which is almost comparable to the plasma initiation by 70GHz ECH.

The successful NBI plasma start-up depends on the seed-plasma density. A clear density threshold ($\bar{n}_e \sim 2\text{-}3\times10^{17}$ m^{-3}) is found to initiate the plasma by NBI. The magnetic field (or configuration characteristics of the high energy particle confinement), the microwave power and the gas pressure are the control parameters for the seed-plasma generation. The experimentally observed density threshold is consistent with a 0-dimensional numerical calculation which is newly developed for the Heliotron J experimental conditions [2]. The pre-ionization method and the obtained seed-plasma density developed in this study have a capability to realize the NBI plasma start-up in experimental devices which have perpendicular NBI such as W7-X operated in IPP Greifswald.

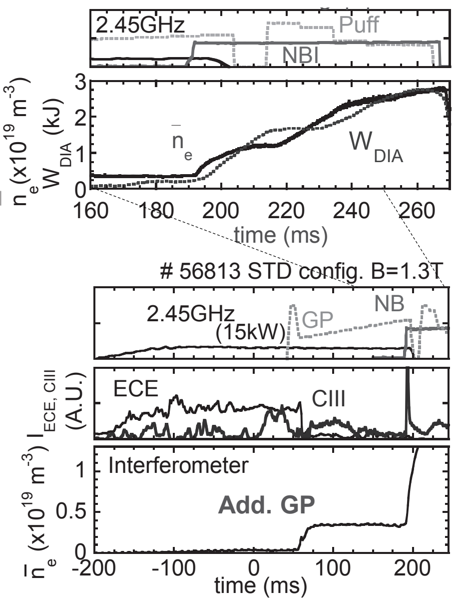

Fig. 1. Time evolution of heating (NBI and 2.45 GHz), gas puffing, $\bar{n}_e$, stored energy (W_{DIA}), ECE and CIII intensities obtained in NBI plasma startup discharges.

3. Comparison of electron internal transport barrier formation between CHS and Heliotron J

Comparative study of the electron internal transport barrier (eITB) formation is carried out between CHS and Heliotron J to investigate the effect of the magnetic configuration on the eITB formation[3][4]. The experiments have been performed on the standard magnetic configuration of both Heliotron J and CHS, and the magnetic field strength on the magnetic axis of Heliotron J is B_{ax} = 1.25 T, and that of CHS is B_{ax} = 0.88 T. The neoclassical transport of the helical plasma is characterized by the effective helical ripple (ε_{eff}), which characterize the helical 1/ν electron transport. The hypothesis of the eITB formation is that the eITB is easily formed in the larger ε_{eff}, magnetic configuration, because the access of the electron-root regime is easy as predicted by the neoclassical transport theory. The value of the ε_{eff} of Heliotron J is 2-10 times larger than that of CHS.

The plasma with eITB is produced by the ECR heating. The Heliotron J and CHS are equipped with 70GHz (Injected ECR power: P_{inj} ~ 120-330 kW) and 53GHZ (P_{inj} ~ 120-160 kW) gyrotrons, respectively. The single path absorption of the ECR heating is ~90% in both the experiments. Both the gyrotrons can heat exactly at the magnetic axis by focusing optics[3]. In some CHS experiments, the neutral beam (P_{inj} ~ 620 kW) is injected into the plasma, however, the characteristics of the eITB formation is not different from the ECR heating only plasma, because the deposited power of NBI to the electrons is smaller than the absorbed ECR power due to the low plasma density. The electron temperature and density profiles were measured with Nd:YAG laser Thomson scattering system using the same analysis procedure.

The typical electron and density profiles of Heliotron J and CHS with the eITB formation have same characteristics. When the eITB is formed, steep electron temperature gradient is created, and peaked temperature profiles are produced in the plasma core. On the other hand, the temperatures on the outside of the peaked profiles with and without eITB are almost equal in both the CHS and Heliotron J. The peaked electron temperature is formed by small reduction of the plasma density. However, both the results have the different electron density when the eITB is formed. The density (line averaged electron density (n_e^{ave}) ~ 1.2×10^{19} m^{-3}) of the Heliotron J is approximately two times larger than that (n_e^{ave} ~ 0.5×10^{19} m^{-3}) of the CHS[4]. Consequently, the plasma density regime in which eITB is formed is expanded in Heliotron J.

It is important to take account in the power difference between both the experiments, because the barrier formation depends on the ECR power. Figure 2 (a) shows $T_e(0)$ dependence on the injected ECR power that is normalized by the line averaged density[4]. In this figure, the closed and open circles show the Heliotron J and CHS results and the red and blue circles show the profiles with and without the peaked temperature, respectively. Although the threshold value of P_{inj}/n_e^{ave} for the barrier formation is almost equal in both the results, the larger $T_e(0)$ is achieved by the smaller P_{inj}/n_e^{ave} in Heliotron J compared to CHS.

Figure 2(b) shows $T_e(0)$ dependence on the electron collisionality normalized by the bounce frequency (ν_h*) at ρ = 0.2 [4]. The ν_h* is associated with the ion-root to electron-root transition. The ν_h* of the Heliotron J plasma easily reach the collision-less regime compared to CHS due to the larger ε_{eff}. This is because the bounce frequency is higher in Heliotron J due to the higher ε_{eff}. Accordingly, there is a possibility that eITB is easily formed in Heliotron J. However, the eITB formation is realized in higher collisionality in CHS compared to Heliotron J. It shows that the eITB formation is not dominated by the collisionality alone.

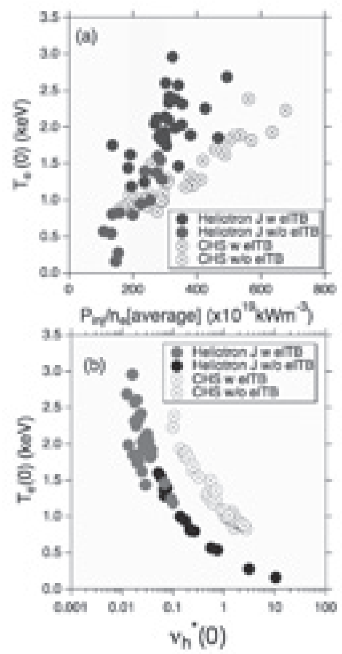

Fig. 2 Dependence on the P_{inj}/n_e^{ave} (a) and ν_h^* (b). Closed and open circles show Heliotron J and CHS results, red and blue circles show plasma with and without eITB, respectively.

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Collaboration Works

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Univ. Wisconsin（米国），Oak Ridge National Laboratory（米国），Max Plank Institute（ドイツ），Stuttgart Univ（ドイツ），CIEMAT（スペイン），Australian National Univ.（オーストラリア），Kharkov Institute（ウクライナ），Southwest Institute of Physics（中華人民共和国），ヘリカル型装置における SOL/ダイバータプラズマに関する研究，水内亨，長﨑百伸，岡田浩之，小林進二，山本聡，南貴司

Stuttgart University（ドイツ），CIEMAT（スペイン），ヘリカル磁場配位における乱流揺動研究，大島慎介，長﨑百伸，水内亨，岡田浩之，南貴司，小林進二，山本聡

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CIEMAT（スペイン），Kurchatov Institute（ロシア），ORNL（米国），低磁気シアヘリカル装置における高速イオン励起 MHD 不安定性に関する研究, 山本聡，小林進二，長﨑百伸，大島慎介，水内亨

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核融合科学研究所・双方向型共同研究，有限ビーム幅を考慮した電子バーンシュタイン波放射計測，長﨑百伸，水内亨，大島慎介，南貴司，山本聡，小林進二，岡田浩之

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2. Others

水内亨，自然科学研究機構核融合科学研究所，双方向型共同研究

水内亨，（株）日立製作所，京都大学エネルギー理工学研究所における核融合研究に対する助成

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Advanced Energy Research Section

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1. Summary

The author will present a personal perspective on oxide dispersion strengthened (ODS) steels development as the cladding materials for generation IV nuclear fission reactors including super-critical water cooled reactors, lead-bismuth eutectic cooled fast breeder reactors and sodium cooled fast breeder reactor etc., and for the accident tolerant fuels (ATF) of light water reactors.

2. Introduction

Since 2006, the author has been very lucky to work with Professor Akihiko Kimura, Institute of Advanced Energy, Kyoto University, on two ODS steels development programs. The first great program titled as "Research and Development of Corrosion Resistant Super-ODS Steels as the Cladding Materials of Advanced Nuclear Fission Reactors with High Efficiency" was entrusted to Kyoto University by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan with Professor Kimura as the principal investigator and the project period from 2005 to 2010. The second program titled as "Research and Development of ODS Ferritic Steel Fuel Cladding for Maintaining Fuel Integrity at the High Temperature Accident Conditions" entrusted by MEXT of Japan. The second program is still continuing now.

3. Generation IV Nuclear Fission Reactors

The goal of the program is to develop super-ODS steel as the fuel cladding materials of Generation IV Nuclear Fission Reactors with not only very good irradiation tolerance and creep resistance but also excellent compatibility with various coolants such as super-critical water, sodium and lead-bismuth eutectic etc. The achievements of the program are excellent in that the successfully developed Zr/Hf added Fe-Cr-Al ODS steel has very good performance as follows:

◆Superior high temperature strength and tensile ductility (RA = 59.8% at 973 K), indicating very good fracture toughness at high temperature;
◆Optimal creep resistance at 973 K: the creep rupture life is comparable to that of 12Cr-ODS steel;
◆ Extremely high corrosion resistance to supercritical pressurized water and lead-bismuth eutectic at high temperature (e.g., 973 K);
◆No susceptibility to thermal ageing embrittlement and stress corrosion cracking;
◆Very good resistance to irradiation damage;
◆ Oxides exhibiting outstanding irradiation tolerance and thermal stability;
◆Very good compatibility with U-Zr alloy.

The author has systematically studied the effect of various minor reactive elements and processing parameters on the structure and chemistry of corrosion-resistant ODS steels from micron scale to atomic scale. He has investigated the precipitation crystallography and solid phase transformation crystallography of complex oxides in depth. Moreover, he has successfully clarified the underlying mechanisms of the creep strengthening, irradiation tolerance and corrosion resistance of ODS steels. The significant insights obtained provide additional guidelines for developing novel type ODS alloys with improved performance.

4. Accident Tolerant Fuels of Light Water Reactor

The goal of the project is to develop Fe-Cr-Al ODS steel as the fuel cladding materials of Light Water Reactors. The main task of Kyoto University is to study the thermal aging behavior and phase separation mechanism of Fe-Cr-Al ODS steel. From Nov. 30 2015 to now, the author has systematically studied the effect of various elements and processing parameters on the thermal aging behavior and phase separation mechanism of newly-developed Fe-Cr-Al ODS steels. Moreover, the author has studied the structure and chemistry of newly-developed Fe-Cr-Al ODS steels from micron scale to atomic scale. He has investigated the precipitation crystallography and solid phase transformation crystallography of the complex oxides. The work is still going on.

Advanced Energy Research Section

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1. Introduction

In this report, the author describes a possible approach to investigate the impurity behavior in Heliotron J by means of passive spectroscopy.

Producing electricity using nuclear fusion in a controlled way is an exciting and challenging project that scientists and engineers have been pursuing for many decades. This project relies on the use of the huge energy, which is released by the exothermic fusion reactions of hydrogen isotope nuclei. In order to fuse them, nuclei should be confined and the repulsive inter-nuclei Coulomb force should be overcome by the thermal energy. Unlike in the sun and the stars where confinement is gravitational, fusion power plants will rely on either inertial (short intense lasers) or magnetic confinement. Research on both types of confinement made huge progresses and are still ongoing.

In this long way towards a fusion power plant realization, several technological and scientific challenges should be meet. These challenges are connected to many issues such as power exhaust and plasma control. In particular, physics of divertors and the elementary processes in the divertor include special interests, as they are one of the best scenarios allowing to comply with the heat load technological limit of 10 MW/m^2. In the present situation, spectroscopy can help characterizing divertors where the plasma-material interactions take place to produce impurity ions and where at the same time the impurity seeding can actively enhance the power exhaust.

2. Role of impurities in fusion plasma

In magnetic fusion devices, transport of impurity ions is regarded as a significant energy loss channel of heat and particles. In core region, accumulation of the heavy impurity, such as irons, leads to the decrease in the electron temperature due to the inelastic collision followed by the radiative transition as well as due to the bremsstrahlung. In the edge/divertor region, on the other hand, impurity ions can act as the preferable radiator to mitigate the heat load onto the plasma-facing materials.

For the devices equipped with divertor in which the additional gas can enhance the radiation loss, plasma can further be cooled and can be neutralized through volumetric recombination processes.

In the devices without divertor, like Heliotron J, even though it has a so-called "natural divertor" magnetic field configuration, impurities sputtered from the plasma-facing component can more easily be transported into the separatrix and accumulate in the core region.

Therefore monitoring the impurity is an important task to achieve the high-temperature core plasma. At the same time, since to a greater or less extent, the plasma cannot be free from the impurities, one can draw considerable information from the impurity radiation.

3. Impurity Behavior in Carbon-wall tokamak

For tokamaks whose walls and target plates are made of carbon materials, it has been found that the line radiation from C^{3+} ions is one of the dominant energy loss channels in the divertor region of such devices [1]. It is therefore important to determine the particle balance between the impurity emitters and their radiative power. Radiative power due to impurities can be determined from spectral line intensities provided both the electron density and temperature are known. These parameters have to be determined with a good accuracy and should be cross-checked with independent methods whenever it is possible.

Taking JT-60U tokamak (the major radius R = 3.4 m and the minor radius r = 1.0 m) having carbon wall and divertor plates for instance, usually a toroidally symmetric strong radiation forms under detachment conditions [1, 2]. The peak of this strong emission, which is due mainly to C^{3+} and C^{2+} ions, is observed in the region located between the inner divertor leg (plate) and the X-point, and moves towards the X-point. The phenomenon in which the radiation peak reaches the X-point is named here X-point MARFE (Multifaceted asymmetric radiation from the edge) formation.

In our previous research in JT- 60U, C III and C IV visible and VUV (vacuum ultraviolet) emission line spectra are simultaneously observed using both low- and high- resolution spectrometers.

High-resolution C IV (the principal quantum number n = 6 - 7; 772.6 nm) line spectra measured along several viewing chords covering an X-point MARFE under detachment conditions of JT-60U was analyzed for the purpose of spatial characterization of the divertor plasma.

The analysis of the spectral profile of the C IV n = 6 - 7 line requires the calculation of theoretical line profiles accounting for all the broadening mechanisms. As the considered line is emitted by C^{3+} ions in deuterium plasma in presence of a magnetic field, it is subject to Stark and Doppler broadenings as well as the Zeeman split and the instrumental function.

Calculation was made using a robust and fast line shape code known as PPP [3]. The PPP code was first developed for the calculation of profiles of lines emitted by ions in dense plasmas where the Stark broadening [4] is the main line broadening mechanisms.

The measured spectra, free from the Zeeman split, that is available by inserting a linear polarizer, was compared to calculated profiles and an excellent agreement has been found for the emission coming from a single layer in the case of peripheral viewing chords, as shown in Fig. 1 [5].

For viewing chords crossing the MARFE central parts, the spectra were able to be fitted to a plausible degree using a sum of two contributions from a low-density and a high-density layers.

4. Possible application to Heliotron J plasma

In Heliotron J having R = 1.2 m and $< r >$ = 0.25 m, although the plasma-facing component is mainly made by stainless steel, emission from carbon impurities is able to be observed both in visible and VUV regions. What is most concern though is that the electron density in Heliotron J is at least few times lower than that for the JT-60U, even the case aiming at the high-density operation (up to 0.6 - 1.0 $\times 10^{20}$ m^{-3}) [6]. Therefore, the stark broadening can be smaller.

When the brightest emission region is localized in two positions with different magnetic field in the viewing chord, evaluation of the Zeeman split can complicate the fitting procedure [7].

Fortunately in Heliotron J, there is a possible viewing chord along which the magnetic field strength is almost constant as shown in Fig. 2. In that case, one can get rid of the effect of the disturbance by multi-position Zeeman components.

Also, helium-seeding plasma can be produced for the purpose of applying the line intensity ratio method for He I based on the collisional radiative model. Helium atom spectra undergo Stark broadening in highly-excited quantum states [8, 9].

Therefore, the author would like to propose to install a high-resolution spectrometer to this port to observe the spectral line shape of light impurities, such as helium or carbon. Then, applicability of the Doppler and Stark components will be assessed.

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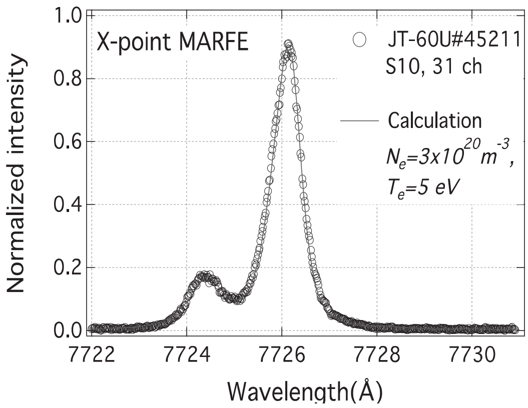

Figure 1 Comparison of the C IV n = 6 - 7 line spectrum along an edge viewing chord with a theoretical profile. A good agreement is found for a density of 3.0×10^{20} m^{-3} for $T = T_i = T_e$ = 5 eV. (taken from Fig. 3 in ref.[5])

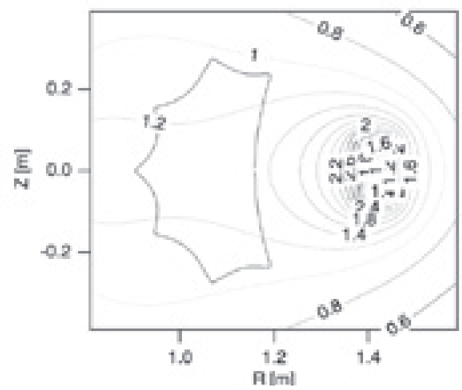

Figure 2 An example of the calculated magnetic field strength at a poloidal cross section of Heliotron J standard configuration. Number in the counters is in Tesla. Region with strong dense contours represents the L = 1 helical coil. Plasma boundary is indicated by the red-color bean shape. The viewing port yielding the constant Zeeman effect along the sightline is located around R ~ 0.8 in the mid-plane, Z = 0.

Advanced Energy Materials Research Section

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1. Introduction

We are working on basic and applied science of nano-materials from a viewpoint of optics and material science. Our research aims at exploring new physical and chemical phenomena leading to applications of novel nano-materials including carbon nanotubes, graphene related materials, and layered transition metal dichalcogenides for efficient utilization of light energy and development of future optoelectronic devices with ultra-low energy consumption. The Multi-Scale Testing and Evaluation Research Facility (MUSTER) is also used for development of new composite materials. Followings are main research achievements in the year of 2015.

2. Discovery of efficient upconversion photoluminescence of carbon nanotubes

We demonstrated that single-walled carbon nanotubes (SWNTs) exhibit bright near infrared photoluminescence (PL) under photoexcitation conditions in which the excitation photon energy is considerably smaller (>120 meV) than the emission photon energy. This anomalous phenomenon occurs efficiently under weak one-photon excitation conditions and does not result from common multi-photon excitation or anti-Stokes Raman processes. We conducted luminescence spectroscopy and imaging measurements on ensemble samples and individual nanotubes, and found that the spectral shape and peak position of the upconversion PL (UCPL) are nearly coincident with those of Stokes PL. The temperature dependence of the UCPL intensity suggests that phonon-assisted exciton upconversion processes enable the UCPL in SWNTs. The UCPL intensity was nearly independent of the excitation polarization angle with respect to the nanotube axis, indicating that extrinsic localized states lying below the intrinsic one-dimensional state function as intermediate states in the UCPL process. These findings may open new doors for energy harvesting, optoelectronics and deep-tissue photoluminescence imaging in the near-infrared optical range.

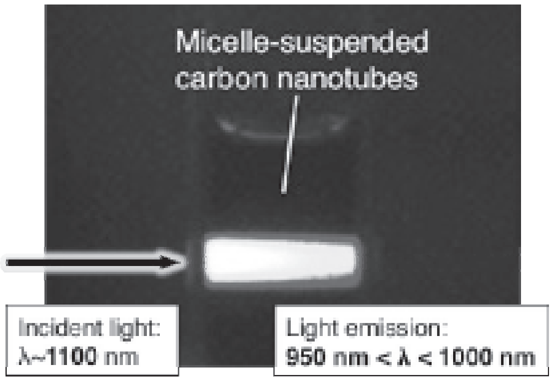

Fig. 1. Optical image showing UCPL from SWNTs dispersed in D_2O using surfactant excited by incident light of wavelength ~1100 nm. The photoemission image was selectively detected in the 950–1000 nm wavelength range using optical filters.

3. Enhanced photovoltaic performances of graphene/Si solar cells by insertion of a MoS_2 thin film

Transition-metal dichalcogenides such as MoS_2 exhibit great potential as active materials in optoelectronic devices because of their characteristic band structure. We demonstrated that the photovoltaic performances of graphene/Si Schottky junction solar cells are significantly improved by inserting a chemical vapor deposition-grown, large MoS_2 thin-film layer. This layer functions as an effective electron-blocking/hole-transporting layer. We also demonstrated that the photovoltaic properties are enhanced with the increasing number of graphene layers and the decreasing thickness of the MoS_2 layer. A high photovoltaic conversion efficiency of 11.1% was achieved with the optimized tri-layer-graphene/MoS_2/n-Si solar cell.

4. Observation of homogeneous linewidth broadening in monolayer transition metal dichalcogenide.

We performed spectroscopic studies of mechanically exfoliated monolayer $MoTe_2$ over a wide temperature range from 4.2 to 300 K. At a low temperature, the photoluminescence spectra for monolayer $MoTe_2$ showed two sharp peaks for excitons and charged excitons (trions). The homogeneous linewidth of the exciton peak broadened linearly as the temperature increased. This linear linewidth broadening was caused by acoustic-phonon scattering of the exciton, i.e., shortening of exciton dephasing. The broadening factor due to exciton–acoustic–phonon interactions was found to be 0.11 meV K^{-1}. This small value for the exciton–phonon coupling coefficient and the lack of a Stokes shift suggest that exciton–phonon interactions in monolayer $MoTe_2$ are in the weak coupling regime.

5. Observation of tunable electronic correlation effects in nanotube-light interactions

Electronicmany-body correlation effects in one-dimensional (1D) systems such as carbon nanotubes have been predicted to strongly modify the nature of photoexcited states. We directly probed this effect using broadband elastic light scattering from individual suspended carbon nanotubes under electrostatic gating conditions. We observe significant shifts in optical transition energies, as well as line broadening, as the carrier density is increased. The results demonstrate the role of screening of many-body electronic interactions on the different length scales, a feature inherent to quasi-1D systems.

6. Novel Silicon Carbide Composites with Particle Dispersion in Matrix

Silicon carbide (SiC) is one of very attractive engineering ceramics in particular for severe environment. Silicon carbide composites basically require weak fiber/matrix interphase like carbon (C) or boron nitride (BN). The interphase material and its thickness are keys to determine mechanical properties. However precise control of the interphase is the critical issue in particular for large scale production and affects material cost significantly. The objective of this work is to develop novel SiC composites without fiber/matrix interphase by applying particle dispersion in SiC matrix.

Silicon carbide composites were fabricated by CVI method and LPS method. Silicon carbide with C matrix was formed by mixture of SiC source gas and C source gas in CVI composites. Silicon carbide with BN matrix was formed by mixture of SiC powder and BN powder in LPS composites. Mechanical properties were characterized by tensile test and flexural test before and after exposure in air up to 1750C. Microstructures and fracture surfaces were characterized by FE-SEM.

Both SiC composites with C and with BN in matrix have uniform microstructure through thickness. They showed ductile fracture behavior with fiber pullouts. The tensile strength of 2D-CVI composites with C was approximately 260 MPa. The flexural strength of UD-LPS composites with BN was approximately 500 MPa. Scattering of mechanical properties for each sample was limited well. No significant degradation of tensile strength of the BN

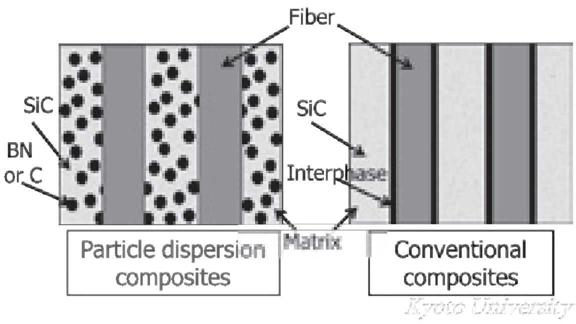

Fig. 2 schematic illustration of the particle dispersion SiC composites and conventional SiC composites.

particle dispersion SiC composite wasn't observed following exposure up to 1500C in air. Oxidation of the composites were limited to near surface in particular for the fiber bundle region up to 1500C.

7. Analytical analysis of the synchrobetatron resonant coupling mechanism

We had engaged in a laser cooling experiment of ion beam in Small Laser-equipped Storage Ring (S-LSR) at Advanced Research Center for Beam Science, Institute for Chemical Research. The synchrobetatron resonant coupling method was employed in S-LSR. Near the synchrobetatron resonant coupling point where the difference integer resonance condition was satisfied, an unexpected tune jump of the horizontal betatron tune had been observed. The synchrobetatron resonant coupling mechanism was analyzed analytically from the Hamiltonian for an orbiting particle to clarify the physics of the observed tune jump and the horizontal cooling mechanism of the beam. We apply this Hamiltonian method further to orbiting particles.

Collaboration Works

University of Bordeaux（フランス），単一ナノ物質における先端分光，松田一成

Oak Ridge National Laboratory（米国），TAITAN (Tritium,Irradiation and Thermofluid for America and Nippon) Task2-2 接合・被覆システムの健全性，檜木達也

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1. Grant-in-Aid for Scientific Research

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Advanced Laser Science Research Section

T. Nakajima, Associate Professor

1. Introduction

The main objective of our research is to develop the laser-related theory and experimental techniques to contribute to the efficient use of laser devices in energy science. Many different phenomena take place at the different laser wavelengths. At the x-ray wavelength, excitation of the core electron occurs, and the deep understanding and the efficient use of core-excitation can lead to the radiation amplification in the x-ray region. At the mid-infrared wavelength, structural change in crystalline polymers can be monitored in a time-dependent manner by tuning the mid-infrared laser to the structure-sensitive vibrational mode. At the visible wavelength region, plasmonic heating of metallic nanoparticles results in the formation of nanobubbles, which may be used as a nano-reactor to synthesize new functional materials.

2. Dynamics of core-excited states subject to the resonant x-ray and optical lasers

Although the study on the dynamics of core-excited states induced by short wavelength radiation has been attracting a lot of interests in recent years, a time-resolved detection of such processes was not possible, because the core-electron dynamics usually occur in an ultrafast time scale, which is far beyond the time-resolution of synchrotron radiation. However, the advent of x-ray free-electron lasers (XFELs) enables us to undertake the thorough study from both experimental and theoretical point of view. Upon creation of the core-excited state by a resonant x-ray pulse, the outer valence electron immediately fills up the vacancy in the inner-shell, and the excess energy coming out of this process results in the electron emission from the outer valence shell (resonant Auger process). Introduction of an additional optical laser may allow us to control the core-electron dynamics, which would manifest themselves in the Auger electron spectrum. Along this line, we have undertaken the theoretical study of resonant Auger process under the simultaneous action of x-ray and optical laser pulses.

Figure 1(a) shows the level scheme of Ne atom under study. It consists of the ground and two core-excited states. The ground state, $2p^6$, is resonantly coupled to the core-excited state, $1s^{-1}$ 3p at 867.1 eV, by the x-ray pulse (photon energy 867.1 eV). This core-excited state is further coupled to another core-excited state, $1s^{-1}$ 3s at 865.2 eV, by the optical pulse (photon energy 1.55 eV). Process (A) described in Fig. 1(a) is a two-photon ionization process into the continuum (Ne^+ $1s^{-1}$ at 870.1 eV + free electron) from $1s^{-1}$ 3p by the optical pulse, while process (B) are the one-photon ionization process from $1s^{-1}$ 3p and $1s^{-1}$ 3s by the x-ray pulse. The third process (C) depicted in Fig. 1 is the direct photoionization into the continuum, Ne^+ $2p^4$ 3p at 55.8 eV + free electron from the ground state by the x-ray pulse. Theoretical results are shown in Fig. 1(b). This figure clearly shows which processes, (A)-(C) in Fig. 1(a), contribute how much in the Auger electron spectra.

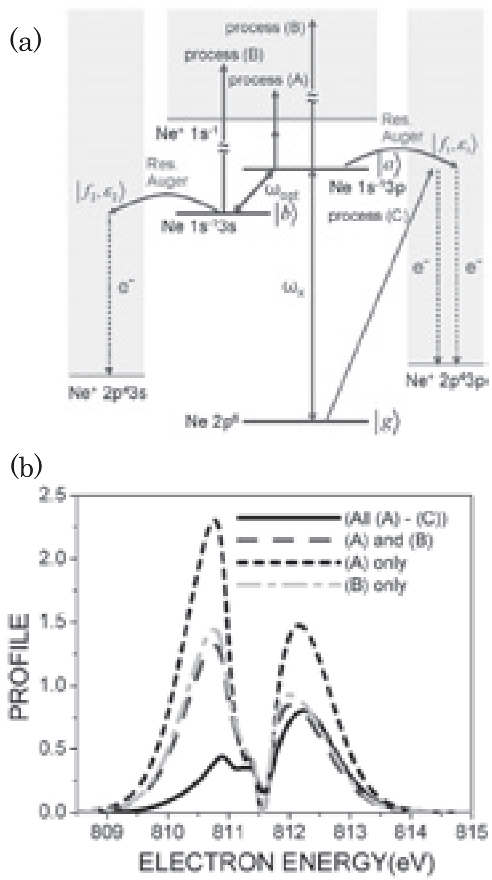

Fig. 1 (a) Level scheme. (b) Auger electron spectra under the simultaneous action of x-ray and optical pulses. Employed intensities of x-ray and optical pulses are $5x10^{18}$ and 10^{12} W/cm^2, respectively.

3. Real-time observation of structural change in crystalline polymer films using mid-infrared free-electron laser pulses

Polymer films are used in many different ways in these years, for instance, as a host material of nano-composite to dope nanoparticles, etc. for novel optical materials. However, most of the polymers that are currently used are an amorphous type. If crystalline-type polymers are used, instead, more functional materials may be realized, since they have additional degree of freedom such as the degree of crystallinity and its orientation. For the efficient fabrication of crystalline polymer films, it is essential to understand the time-dependent dynamics of structural change of crystalline polymers, from crystalline to amorphous and vice versa. This has never been studied in the past, since the conventional devices such as FTIR and XRD do not have time-resolution. Last year we started a project to develop the system for the real-time observation of structural change in crystalline polymer films. This is a time-resolved in-situ optical method, which enables us to detect the polymer structure during the fabrication of the films, if necessary.

Crystalline polymer films are now fabricated with a better method (solution-casting method) than the one (spin-coating method) we have employed last year. As a result, we are now able to carry out the systematic study to investigate the transmission change of the mid-infrared probe pulse by varying the time delay between the pump (for the heating) and probe (for the detection of structural change) pulses.

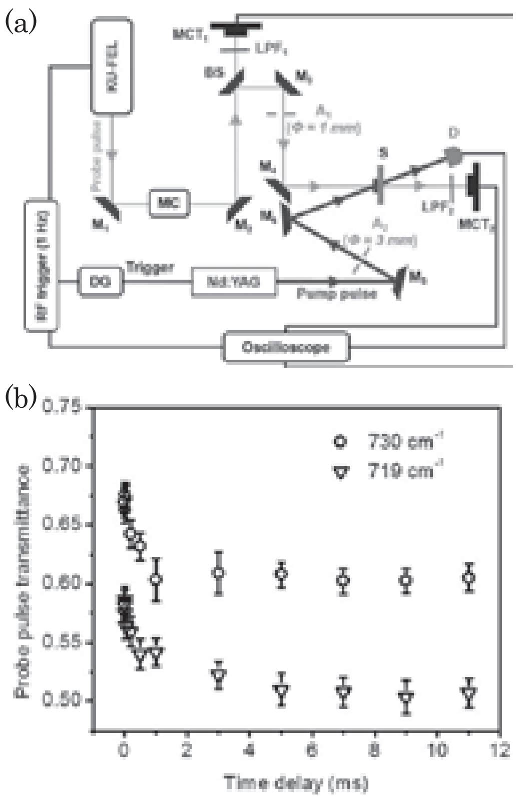

Fig. 2 (a) Experimental setup. (b) Transmittance of the mid-infrared probe pulses at 730 and 719 cm^{-1} as a function of time delay between the pump and probe pulses. The pump pulse fluence is 59 mJ/cm^2.

The experimental setup for the present study is shown in Fig. 2(a). It consists of a Nd:YAG laser as a pump pulse to heat the PE film and a mid-IR FEL to probe the transmission change through the PE film. To spectrally resolve the two absorption bands of PE at 719 and 730 cm^{-1}, the probe pulse goes through the monochromator to narrow the spectral width from ~20 cm^{-1} to ~5 cm^{-1}. The pump and probe pulses are synchronized with the RF trigger pulse as a master pulse through the delay generator. The diameters of the pump and probe pulses at the PE film are 3 and 1 mm, respectively, to ensure that the probe pulse irradiates the uniformly heated area on the film. Transmission of the probe pulse through the PE film is measured by a pair of mercury cadmium telluride (MCT) detectors with low-pass filters in front of them to block the scattered light of the pump pulse.

The transmission measurements are repeated many times by varying the time delay between the pump and probe pulses. The results are shown in Fig. 2(b). What we can learn from Fig. 2(b) is that the time for the laser-heated film to sufficiently cool down is about millisecond. This is in good agreement with the numerical solution of thermal diffusion equation for the film thickness of 2.5 μm. Another observation is that the time constants for the cooling appear to be different for the two different vibrational modes of the polymer at 719 and 730 cm^{-1}. This, however, cannot be true, since all vibrational modes of the polymer must have been well thermalized at this time scale. Our current understanding is that, it looks so, because Fig. 2(b) is a plot of probe pulse transmission as a function of time delay. If we manage to convert the probe pulse transmission into the film temperature, the two curves for the probe wavelength of 719 and 730 cm^{-1} should become identical, and we are working for it now.

4. Strange behavior in the growth of plasmonic nanobubbles

Interaction dynamics of laser pulses and nanoparticles are of great interest in recent years. In many cases, laser-nanoparticle interactions result in the formation of plasmonic nanobubbles, and the dynamics of nanoparticles and nanobubbles are inseparable. So far, very little attention has been paid to the number density. We have found that the growth of plasmonic nanobubbles strongly depend on the number density of nanoparticles in the solution. Very interestingly, this cannot be explained by the existing physical picture. Proposal of a new model is underway in our group.

Collaboration Works

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中国計量学院（中華人民共和国），アト秒パルスのキャラクタリゼーション，中嶋隆

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Advanced Energy Structural Materials Research Section

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1. Introduction

Materials R&D is essential for safe and efficient operation of advanced nuclear energy systems in the near future. This section takes up a mission of materials R & D for advanced nuclear energy, such as development of fusion blanket structural materials and fuel claddings of Gen-IV nuclear systems. Current main researches are as follows:

(1) Development of structural materials for fusion systems: Materials R&D is essential for realization of fusion energy. Among the issues for materials R&D for fusion application, we have been focusing on the development of radiation tolerant structural materials, which include reduced activation ferritic (RAF) steels and oxide dispersion strengthened (ODS) steels for fusion blanket. R&D of high Cr ODS steels has been performed as a national program to develop an innovative material with radiation tolerance, corrosion-resistance and high-temperature strength for advanced nuclear fission and fusion systems.

(2) Tungsten diverter R&D: Evaluation of feasibility of tungsten (W) diverter has been performed along with joining technology development of W/ODS steel joints by means of transient liquid phase bonding method. The application of ODS steels as structural components of W-diverter has been considered to be effective to reduce the temperature gradient between plasma facing material and coolant constituents.

(3) Multi-scale modeling: Tungsten (W) is proposed as one of the candidates for the first wall protection in fusion power plants. In irradiated tungsten at temperatures where vacancies can move, voids (vacancy clusters) are experimentally observed by transmission electron microscopy (TEM). Voids induce swelling, which leads to the dimensional changes of the material.

(4) Radiation damage mechanism of fission nuclear structural materials: For the sake of the highly efficient and safe operation of nuclear fission reactors, the mechanisms of irradiation embrittlement and stress corrosion cracking have been investigated. Small specimen test technique for evaluation of structural integrity has been developed towards extension of operation period of light water reactors.

2. Ion-irradiation effects on Tungsten (W)

W-armor of fusion divertor suffers damages caused by the high heat loading more than 20 MW/m^2 which may result in cracking of the armor during cooling to below about 773 K because of recrystallization embrittlement. Furthermore, it is considered that neutron irradiation enhances the embrittlement through irradiation hardening. Irradiation effects were investigated by means of ion-irradiation method using DuET/MUSTER facility.

Single-ion irradiations used 6.4 MeV Fe^{3+}. Dual-ion irradiation is used 6.4 MeV Fe^{3+} ions for displacement damage simultaneously with energy-degraded 1.0 MeV He^{+} ions. Radiation damage structures were examined by FE-TEM and so-called "void lattice" was found in the ion-irradiated W. Fig. 1 shows the void lattice formed in the recrystallized W irradiated with Fe^{3+} ion and energy-degraded 1.0 MeV He^{+} ions at 1273 K up to 3 dpa. Detailed TEM examinations revealed that the dislocation loops were interstitial type with a/2<111> Burgers vector, and the loops formed BCC lattice with a lattice parameter of 45 nm that was measured from the phots observed from <001>, <011> and <111>.

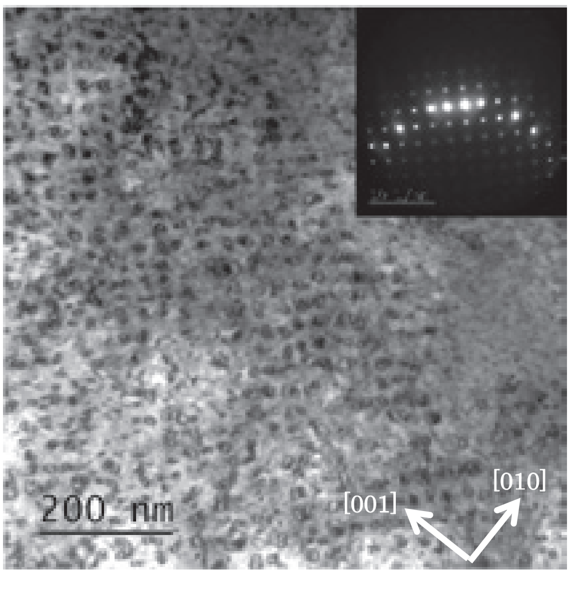

Fig. 1: Dislocation loop lattice found in W. Three dimentional self-ordering of I-type dislocation loops

Although the void lattice was observed in neutron irradiated W, the loop lattice had not been observed yet in the irradiated W. 3-Dimentional loop lattice formation could be a general behavior in materials under some adequate irradiate conditions, temperature, dpa and flux. Among then, the temperature plays a key role in the formation of loop lattice. At lower irradiation temperatures, as carried out in most irradiation experiments, the loops formed into one-dimensional aggregates. But when the irradiation temperature reaches to 1000 °C, the loop lattice is formed. The ion flux is also important in the loop lattice formation. As for the case of neutron irradiation at 1000 °C, only voids were formed. No loop lattice was found probably owing to the low flux in neutron irradiation experiments.

3. Helium effects on microstructural change in RAFM steel under irradiation: Reaction rate theory modeling

Reduced-activation-ferritic/martensitic (RAFM) steel is proposed as one of the candidates for blanket structural materials in a nuclear fusion reactor. Blanket structural materials suffer from 14 MeV high-energy-neutron bombardments, in which many types of point defect such as vacancies, self-interstitial atoms (SIAs) and helium gas atoms are produced by atomic displacement and nuclear transmutation. Those produced point defects thermally migrate and form defect clusters, e.g. interstitial type dislocation loops (I-loops), voids and helium bubbles. Such athermal lattice defects induce the microstructural change of a material, leading to the performance degradation and deformation. Especially, helium is known to enhance formation of voids, and promote void swelling and high temperature intergranular embrittlement; therefore, detailed investigation of the helium effects is necessary for the study of nuclear fusion materials.

In the present study, helium effects on the formation kinetics of I-loops and helium bubbles in RAFM steel during irradiation was numerically investigated by means of reaction rate theory (mean field cluster dynamics modeling), with focusing on the nucleation and growth processes of the defect clusters. The rate theory model employs the size and chemical composition dependence of thermal dissociation of point defects from defect clusters. In the calculations, the temperature and the production rate of Frenkel pairs are fixed to be T = 723 K and $P_V = 10^{-6}$ dpa/s, respectively. And then, only the production rate of helium atoms was changed into the following three cases: $P_{He} = 0$, 10^{-7} and 10^{-5} appmHe/s.

The calculation results show that helium effect on I-loop formation quite differs from that on bubble formation. As to I-loops, the loop formation hardly depends on the existence of helium, where the number density of I-loops is almost the same for the three cases of P_{He}. This is because helium atoms trapped in vacancies are easily emitted into the matrix due to the recombination between the vacancies and SIAs, which induces no pronounced increase or decrease of vacancies and SIAs in the matrix, leading to no remarkable impact on the I-loop nucleation. On the other hands, the bubble formation depends much on the existence of helium, in which the number density of bubbles for $P_{He} = 10^{-7}$ and 10^{-5} appmHe/s is much higher than that for $P_{He} = 0$. This is because helium atoms trapped in a bubble increase the vacancy binding energy, and suppress the vacancy dissociation from the bubble, resulting in a promotion of the bubble nucleation. And then, the helium effect on the promotion of bubble nucleation is very strong, even the number of helium atoms in a bubble is not so large.

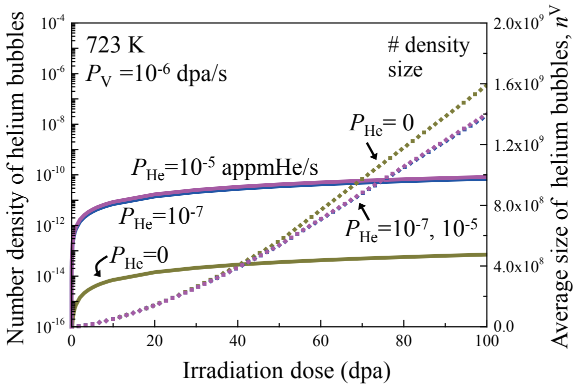

Fig. 2: Irradiation dose dependence of number density and size of helium bubbles at 723 K for $P_V = 10^{-6}$ dpa/s and the three cases: $P_{He} = 0$, 10^{-7} and 10^{-5} appmHe/s.

4. Irradiation effect in metals

Particle irradiation leads to the formation of oversaturated interstitials and vacancies. The behavior of the point defects is responsible for the evolution of the microstructure, which may cause degradation, (or development), of the mechanical properties of the material. Hence, the elucidation of the behavior of point defects is essential for understanding the mechanisms responsible for the changes in mechanical properties. In our study, the microstructure evolution under particle irradiation has been investigated experimentally and computationally by the ion accelerator (DuET), electron microscopies, the first principle, MD, and so on. One of the recent results is the following.

We have investigated the interaction between voids and dislocations, experimentally and computationally. The interaction to dislocations is different between faceted voids and spherical voids. Moreover, the interaction and the critical shear stress depend on the faceted plane and the distance from the center of voids.

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Complex Plasma Systems Research Section

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1. Introduction

Magnetic fusion has some key features which make it an attractive option in a future energy mix: (1) inherent safety features; (2) waste which will not be a burden for future generations; (3) no greenhouse gases; and (4) the capacity for large scale energy production. The required raw materials for the fuel are abundantly and widely available in the Earth. The combination of these features provides magnetic fusion the potential to make a substantial contribution to satisfying world energy demand later this century and beyond. The development of magnetic fusion as a commercial reactor of electricity requires the solution to the physics problems of plasma transport and magneto-hydrodynamics. The goal of the fusion plasma research is the discovery of a magnetic configuration that can efficiently confine a high density plasma at a high temperature for a sufficiently long confinement time to produce net thermonuclear power. The point is to deepen the understanding of fusion plasma dynamics and to create key innovative technologies to make magnetic fusion a practical energy source. This research section seeks to investigate the confinement optimization of high-temperature plasmas in the helical-axis heliotron line. For the experimental and theoretical investigation of this theme, the plasma device of Heliotron J has been operated to study the magnetic configuration effects of ”hot plasma” confinement in Heliotron J. In particular, heating and fuelling, confinement and diffusion mechanisms and their diagnostics are of great importance. Recent results of this section in FY2015 are as follows:

2. Upgrade of the high-throughput low dispersion visible spectrometer

Line intensity ratio of the atomic helium line has been used to determine electron density and temperature by comparing the measured line/population ratio to the calculation based on the collisional radiative model. This method has a merit in that the absolute spectral intensity calibration is unnecessary. On the other hand, wide range (*i.e.* low-dispersion) high-throughput multi-channel (along the entrance slit direction) spectrometer needs to be developed.
Atomic helium has many line spectra in visible/near ultraviolet region of 380 - 730 nm, and the bright ones are mainly for the transitions from the principal quantum number n = 3 and 4.

Atomic helium has many line spectra in visible/near ultraviolet region of 380 - 730 nm, and the bright ones are mainly for the transitions from the principal quantum number n = 3 and 4.

In this respect, we have developed a hand-build low-dispersion visible spectrometer for the measurement of the helium discharge plasma and the helium-seeded hydrogen plasma.

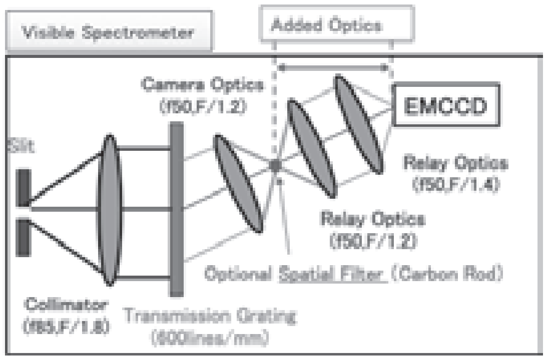

Fig. 1 Schematic illustrations of the hand-build visible spectrometer with Reighley-block type spatial filter.

In the early stage of the development, however, we found that when a strong emission saturated the detector dynamic range, measurement became irregular for the present imaging detector, EMCCD (electron multiplying charge-coupled device).

Therefore, in this fiscal year, we extended the spectrometer by attaching a 1:1 imaging optics, and we inserted the spatial filter, known as the Rayleigh-block, in the intermediate image plane, as show in Fig. 1. Up to now, we only concern about the strong Balmer-α line of deuterium/hydrogen at 656 nm, but the notch wavelength can be tuned by shifting the Rayleigh-block on the intermediate imaging plane.
The preliminary result for hydrogen plasma with additional helium puffing to show the effect of the Rayleigh-block is shown in Fig. 2. Note that the exposure time and the EM gain, etc. were set so as not

to saturate the Balmer-α signal. As one can see, Balmer-β line was considerably filtered out. It also means that one can increase the whole signal to enhance the signal to noise ratio for the weaker helium lines to increase the applicability and credibility of the line intensity method.

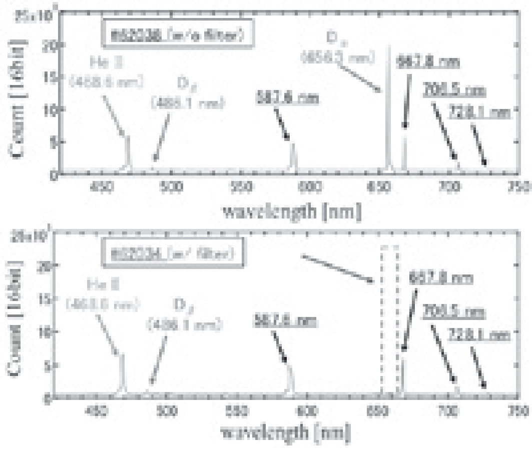

Fig. 2 Comparative example of the spectrum for helium-hydrogen plasma in Heliotron J in similar condition, obtained (a) without the Rayleigh-block filter and (b) with the filter. Exposure time was set to 7.7 ms.

3. Studies of lost fast ions caused by fast-ion-driven MHD instabilities

Lost fast ions induced by fast-ion-driven MHD instabilities such as energetic particle modes (EPMs) and toroidicity-induced Alfvén eigenmodes are observed in helical plasmas as well as tokamaks. In the Heliotron J plasma whose magnetic configuration is different from those of LHD and CHS, and is characterized by low magnetic shear, lost fast ions induced by EPMs are also observed in a Faraday-cup-type lost fast ion probe (FLIP).

The observed lost fast ions have an energy of E = 15~27 (keV) and pitch angle χ = 110~125 (deg.) and correspond to trapped ions. These experimental observations are different from a prediction based on a resonance condition between shear Alfven waves and fast ions. We numerically investigate the fast ion losses caused by a perturbed magnetic fluctuation of EPMs by using the Monte Carlo simulation code DELTA5D where we take into account actual information of beam deposition and reconstructed MHD equilibria of Heliotron J plasmas. We use the birth velocity and position of fast ions which are calculated by HFREYA code. A part of fast ion originated from NBI became a trapped ion even in tangential NBIs because Heliotron J has a helical-axis magnetic configuration. The perturbed magnetic field can be assumed as Gaussian profile based on the profile measurement of fluctuations obtained from soft X-ray and beam emission spectroscopy. The perturbed magnetic field is a transverse wave because of shear Alfven wave and has a frequency of 80 kHz which corresponds to the experimental result. Figure 3 shows the time evolution of the number of confined fast ions in the case of collision and collision-less, and dependence of width and amplitude of the perturbed magnetic field. Clear loss of the fast ions caused by perturbed magnetic field is observed when perturbed magnetic field has an ampilitude of $1x10^{-3}$. The result shows the amount of fast loss is also related to the mode width. Figure 4 shows that informations including the position and angle of lost fast ions in the condition of collision, perturbed magnetic filed with the amplitude of ~ $1x10^{-3}$ and the width of ρ = 0.2. The red square shows a passing ions which will have a trajectory of re-entering ions (confined ions). The blue square indicates transition and trapped ions. The FLIP exists ζ = 0.25 and θ = 0.75 of Boozer coordinate in Figure 4. The fast ion loss whose position corresponds to the FLIP only observed in the case of considering perturbed magnetic field. The experimentally observed fast ions losses caused by resonantly perturbed magnetic field can be numerically reproduced by the Monte Carlo simulations.

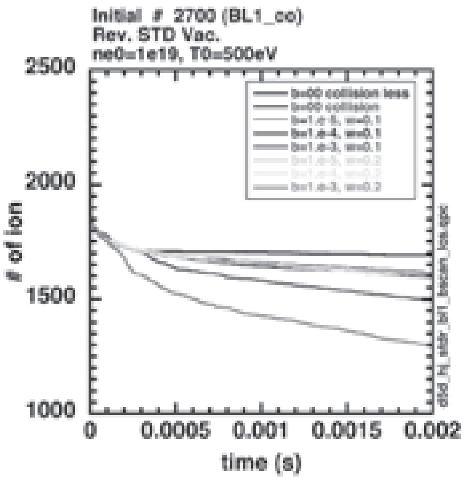

Fig. 3. Time evolution of confined fast ions with or without perturbed magnetic fields.

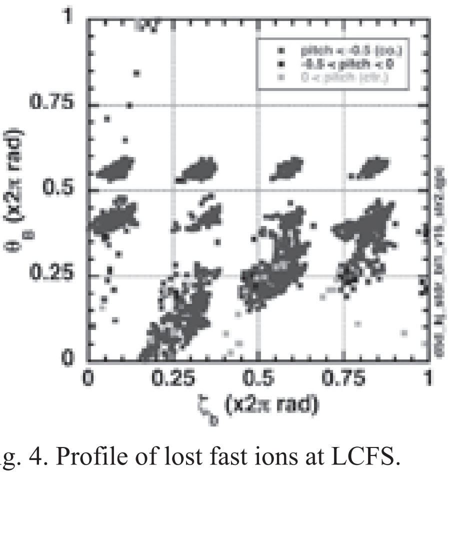

Fig. 4. Profile of lost fast ions at LCFS.

Collaboration Works

Univ. Wisconsin（米国），Oak Ridge National Laboratory（米国），Max Plank Institute（ドイツ），Stuttgart Univ（ドイツ），CIEMAT（スペイン），Australian National Univ.，（オーストラリア），Kharkov Institute（ウクライナ），Southwest Institute of Physics（中華人民共和国），ヘリカル型装置における SOL/ダイバータプラズマに関する研究，水内亨，長﨑百伸，岡田浩之，小林進二，山本聡，南貴司

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Clean Energy Conversion Research Section

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1. Summary

Aiming to establish sustainable society, advanced energy and electronic devices have been studied on the basis of high-performance carbon nanotube thin film technologies.

2. Introduction

Carbon nanotubes (CNTs) exhibit unique physical and chemical properties including high carrier mobility, excellent chemical and mechanical robustness. The good processability is also attractive, i.e., simple solution and transfer processes can realize high performance semiconductor/metallic CNT thin films on various kinds of materials such as semiconductors, polymers, glasses, and so on. This opens wide range of thin film applications from energy devices to wearable healthcare devices.

One of key technologies to enable the versatile electronics applications of CNTs is the thin film formation. The conductivity of a CNT thin film is dominated by the tube-to-tube junction resistance, i.e., the longer the CNTs and the lower the number of tube-to-tube junctions in a current pathway, the higher the conductivity. Contamination of CNTs may also contribute to higher tube-to-tube junction resistance. Recently, high-performance CNT thin films using long and clean CNTs have been realized by using floating-catalyst chemical vapor deposition (CVD). In this method, CNTs grown by the floating-catalyst CVD were collected by a membrane filter and then transferred onto an objective substrate as shown in Fig. 1. It has been demonstrated that the dry transfer process is quite easy and can form a CNT film quickly on various kinds of substrate such as plastic films, metal foils, and Si wafer. The performance, i.e., the sheet resistance and optical transmittance, is comparable to that of ITO deposited on plastic.

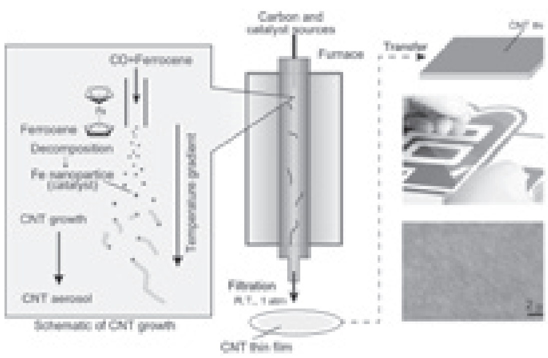

Figure 1 Formation of high-performance CNT thin film based on floating-catalyst CVD.

In this study, the applications of the CNT thin films for advanced energy devices and electronic devices have been investigated.

3. Transparent conductive film for solar cells

Transparent conductive films (TCFs) are widely used in most of flat-panel displays such as liquid crystal displays and recently in organic light-emitting diode displays and touch sensors, which have been fabricated on glass traditionally. Moreover, the demand of TCFs is increasing for emerging solar cell application.

Carbon nanotube (CNT) TCFs are attracting considerable attention because they potentially have excellent conductivity originating from the long mean free path of carriers, and they are also free from the resource and price fluctuation problems that sometimes arise for indium–tin–oxide (ITO) conventionally used as TCFs. The excellent processability of CNT films can realize ultimately low-cost manufacturing of TCFs based on non-vacuum and low-temperature processes.

Carbon nanotube-based solar cells have been extensively studied from the perspective of potential application. In this study, a significant improvement of the CNT/Si-based solar cells was demonstrated in the extensive collaboration with Prof. Kazunari Matsuda, by using the high-performance CNT TCFs and metal oxide layers for efficient carrier transport. The metal oxides also serve as an antireflection layer and an efficient carrier dopant, leading to a reduction in the loss of the incident solar light and an increase in the photocurrent, respectively. As a consequence, the photovoltaic performance of both p-single-walled carbon nanotube (SWNT)/n-Si and n-SWNT/p-Si heterojunction solar cells using MoOx and ZnO layers is improved, resulting in very high photovoltaic conversion efficiencies of 17.0 and 4.0%, respectively. These findings regarding the use of metal oxides as multifunctional layers suggest that metal oxide layers could improve the performance of various electronic devices based on carbon nanotubes.

4. Transparent, stretchable devices for wearable electronics

Flexible and stretchable electronics offer a wide variety of wearable electronics applications such as electronic-skins and healthcare/medical devices. Among various conductive materials for wearable electronics, CNT thin films are advantageous in flexibility/stretchability, and conductivity. In addition, CNT thin films can be used both as a channel material for high-performance transistors and as a metallic conductor for interconnections; i.e. integrated circuits can be constructed by using CNT thin films. In this study, the stretchable and transparent all-carbon devices have been realized, which can be attached directly to human skin.

The CNT thin-film transistors (TFTs) were realized on a stretchable substrate of poly(dimethylsiloxane) (PDMS). After the device fabrication was completed on a Si substrate, the devices were transferred on the PDMS substrate. The fabricated device is transparent and attachable to human body as can be seen in Fig. 2. The all-carbon devices provide a new possibility to realize wearable devices without feeling its existence.

The device exhibited excellent stretching ability; one-dimensional tensile strain test showed a small degradation in drain current as 8 % under the tensile strain of 20%. The device worked even for 40% tensile strain, and the drain current returned to the initial value when the strain was released.

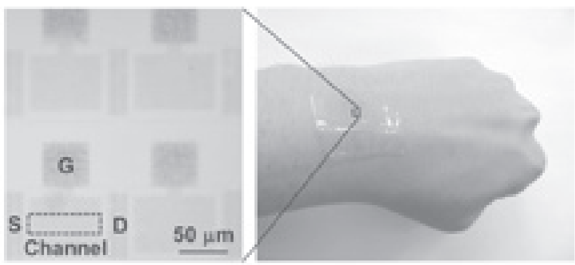

Figure 2 Transparent and stretchable all-carbon devices.

5. Flexible biosensors

Flexible biosensors are also attracting much attention because of the possibility to realize wearable healthcare devices. CNT thin films have excellent properties as a biosensor material such as high electron transfer rate, wide potential window, and good biocompatibility. In this work, high-performance flexible biosensors have been realized, based on a CNT thin film with clean surface.

The CNT electrochemical microelectrodes were fabricated on a PEN substrate by the dry transfer method and standard microfabrication process as shown in Fig. 3. To minimize the contamination of CNT surface due to photoresists, the CNT surface was covered with an oxide film during the fabrication process.

The electrochemical properties of CNT microelectrodes were characterized by cyclic voltammetry with $K_4[Fe(CN)_6]$. The results showed the well-defined sigmoidal voltammetric curves with the steady-state characteristic of ultramicroelectrode. The quartile potentials $|E_{3/4} - E_{1/4}|$ was 60 mV, close to the ideal value (59 mV), meaning that the fabricated CNT microelectrodes had high electron transfer rate. Electrodeposition of gold nanoparticles on electrode confirmed the in-plane uniformity in electrochemical activity of the CNT surface, especially after an activation process.

The detection of dopamine, a kind of neurotransmitter, was demonstrated with the CNT sensor. The CNT sensor exhibited good linearit in the detection of dopamine from 10 nM to 1 μM, covering the DA concentration in blood.

The stability in electrochemical property of the CNT electrode was investigated by detecting dopamine, with cyclic voltammetry repeatedly. Here, acceleration test was carried out with high concentration dopamine (~1000 times higher than the blood concentration). The shift in half height of oxidation potential was 23 mV after 10 consecutive measurements for the present CNT-based sensor, which was much smaller than that of commercial carbon fiber (67 mV) and Au (94 mV). These results demonstrated the good uniformity and stability of the present CNT-based biosensors.

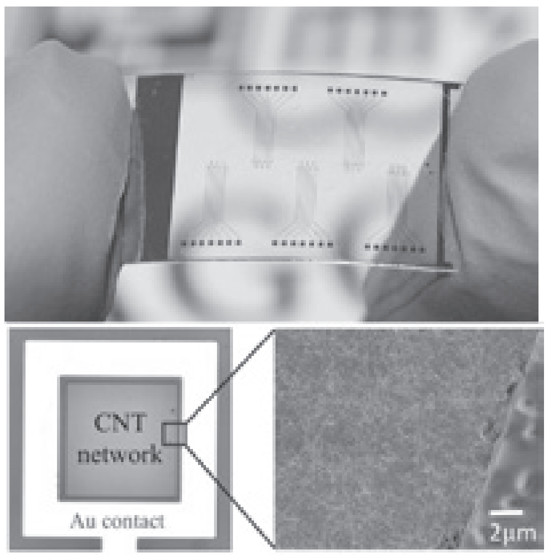

Figure 3 Flexible CNT-based biosensors. Photograph of a sample, micrograph of a device, and SEM image of CNT film.

Clean Energy Conversion Research Section

Hiroaki Yonemura, Visiting Associate Professor
(Kyushu University)

1. Summary

We reported that (1) the large enhancements of the photocurrents were observed at near-infrared wavelengths by localized surface plasmon resonance (LSPR) due to gold nanorod, (2) the fluorescence intensity due to upconversion based on triplet-triplet annihilation was enhanced by LSPR in the presence of silver nanoparticles, and (3) the remarkable increases in the photocurrents were observed when combining LSPR and magnetic field effects.

2. Introduction

Recently, photocurrent generation devices using organic compounds are expected to become the next generation of solar cells. However, most important issue is to improve the efficiency of photoelectric conversion. One of the methods for upgrading these devices is the use of LSPR induced by the coupling of the incident electric field with the free electrons in the metal nanoparticles [1-3]. Gold nanorods (AuNRs) possess two bands (visible and near-infrared regions) corresponding to transverse and longitudinal LSPR.

Photon upconversion based on sensitized triplet-triplet annihilation (TTA) (PUC-TTA) is a non-linear process involving multiple diffusion controlled triplet-triplet energy transfer steps, ultimately resulting in the generation of delayed fluorescence that is of higher energy than the incident light. The PUC-TTA have been attracting for application of low-intensity incoherent light such as sunlight in photovoltaics [4].

The mechanisms of photochemical reactions in the gas phase, the liquid phase, and the solid phase have been explained in terms of magnetic field effects (MFEs) on reaction kinetics or yields. The MFEs are expected to improve the efficiency of photoelectric conversion [5].

In this study, we reported the improvement of efficiency of photoelectric conversion using AuNR, the improvement of efficiency of PUC-TTA using LSPR toward the utilization of near-infrared region of sunlight, and the improvement of efficiency of photoelectric conversion using combination of MFEs and LSPR.

3. Enhancements of Photoelectric Conversion using AuNR

We examined the effects of enhanced electric fields resulting from LSPR of AuNR (longitudinal and transverse modes) on the photocurrents of copper phthalocyaninetetrasulfonic acid tetrasodium salt (CuPc)–AuNR composite films [6].

In CuPc–AuNR composite films and CuPc films, stable cathodic photocurrents were observed. The photocurrent action spectra of two samples (Figure 1) were in good agreement with the absorption spectrum of CuPc in methanol solution. The result strongly indicates that the photocurrents are attributable to the photoexcitation of CuPc.

It is noteworthy that the photocurrents in CuPc–AuNR composite films were larger than those in CuPc films (Figure 1). Furthermore, the relative enhancements of photocurrents increased with increasing of wavelength up to near-infrared region and the relative enhancements (1.5–2.5) at one Q band of CuPc in the longer wavelength (670–800 nm) were larger than those (1.0–1.5) at the other Q band of CuPc in the shorter wavelength (520–670 nm). The result strongly suggests that the local electric fields due to longitudinal LSPR of AuNR are stronger than those due to transverse LSPR of AuNR.

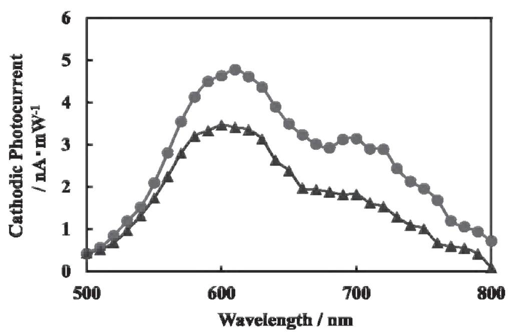

Figure 1 Photocurrent action spectra of CuPc film (▲) and CuPc–AuNR composite film (●).

4. Effects of Metal Manoparticles on PUC-TTA

Effects of silver nanoparticle (AgNP) and gold nanoparticle (AuNP) on PUC-TTA were examined in the system of platinum(II) octaethylporphyrin (PtOEP) and 9,10-dipheny lanthracene (DPA) [7].

The ITO electrodes immobilized with AgNPs and AuNPs were prepared by electrophoretic method. Samples were prepared by sandwiching the solution of PtOEP and DPA between glass and the ITO electrode modified with AgNPs or AuNPs. In the sandwich samples, the enhancements of upconversion fluorescence from DPA were observed in the presence of AgNP (Figure 2), while the quenching of the upconversion fluorescence in the presence of AuNPs.

The absorption bands due to Q-bands of PtOEP overlap the extinction due to the band of LSPR due to AgNP aggregates, while the emission bands of PtOEP overlap the extinction due to the band of LSPR due to AuNP aggregates. Therefore, the enhancements are most likely attributable to large electric fields due to LSPR of AgNP aggregates. The quenching is most likely attributable to nonradiative metallic quenching of AuNP.

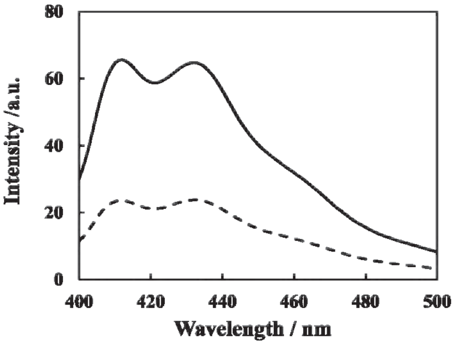

Figure 2 Steady-state upcoverted fluorescence spectra from DPA of one part with AgNP (solid line) and another part without AgNP (dashed line) in sandwich sample.

5. Effects of Magnetic and Plasmonic Fields on Photoelectric Conversion.

We examined the effects of magnetic and plasmonic fields on the photocurrents of donor-acceptor linked compound–metal nanoparticle (AgNP or AuNP) composite films [8,9].

Zinc-porphyrin–viologen linked compound containing six methylene group (ZnP(6)V)–AgNP or AuNP composite films were fabricated by combining electrostatic layer-by-layer adsorption and the Langmuir-Blodgett method [8]. The photocurrents of the ZnP(6)V–AgNP composite films are higher than those of the ZnP(6)V films and much higher than those of porphyrin derivative films without viologen moiety as a reference. The large increase in the photocurrents of the ZnP(6)V–AgNP composite films likely comes from a combination of LSPR from AgNPs and photoinduced intramolecular electron-transfer upon linking to a viologen moiety. Furthermore, the photocurrents of the ZnP(6)V–AgNP composite films and the ZnP(6)V films increase upon application of a magnetic field.

The MFEs were clearly observed for both ZnP(6)V–AgNP composite films and the ZnP(6)V films. Photocurrents increase with magnetic field under low magnetic fields ($B \leq 150$–300 mT) and are constant under high magnetic fields ($B > 150$–300 mT) (Figure 3). The MFEs can be explained by hyperfine coupling and spin-lattice relaxation mechanisms in radical pair mechanism. The magnitude of the MFEs in the ZnP(6)V–AgNP composite films is higher than that in the ZnP(6)V films. A remarkable increase in photocurrent for the ZnP(6)V–AgNP composite films was observed because of LSPR from the AgNPs in the presence of a magnetic field when compared with the ZnP(6)V films in the absence of a magnetic field. We also observed the similar results using ZnP(6)V–AuNP composite films [9].

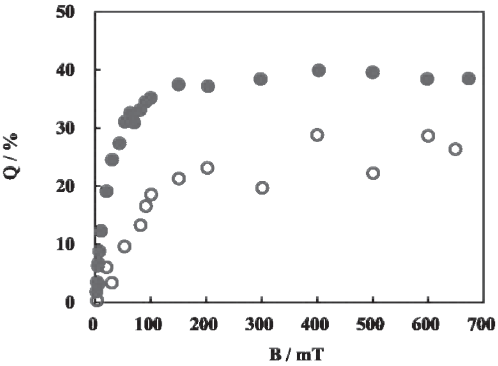

Figure 3 Magnetic field dependence of the Q values in AgNP/PEI/ZnP(6)V/ITO (●) and PEI/ZnP(6)V/ ITO (○).

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Chemical Reaction Complex Processes Research Section

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T. Kodaki, Associate Professor
X. Yang, Program-Specific Assistant Professor

1. Introduction

In this research section, we study on electrochemistry, materials science, genetic engineering and protein engineering. We also apply them to the development of efficient solar-grade silicon production process and the efficient utilization of bioenergy.

In this fiscal year, we have researched the development of a novel production process of solar-grade silicon and the highly efficient production of bioethanol.

2. Development of a Novel Production Process of Solar-grade Silicon Using Molten Salt Electrolysis

The global photovoltaic (PV) market has been growing rapidly in recent years. Up to now, the prevalent material for solar cells is silicon, particularly crystalline silicon. With the expansion of the PV market, the consumption of solar-grade silicon (SOG-Si; 6N purity) has also climbed dramatically. However, the conventional Siemens process has several disadvantages such as low productivity and high energy consumption. Thus, a novel, high-yielding and inexpensive process for SOG-Si production is required.

We have already demonstrated that solid SiO_2 can be directly reduced to solid Si by molten salt electrolysis. Using the contacting electrode method, SiO_2 is reduced to Si by electrolysis at the three-phase zone of SiO_2/molten salt/electrode via the reaction:

$$SiO_2\ (s) + 4e^- \rightarrow Si\ (s) + 2O^{2-}$$

By using this reaction, we proposed a new process for SOG-Si production in which high-purity SiO_2 granules were used as raw material. In the present study, the mechanism and kinetics for reduction of SiO_2 granules in molten $CaCl_2$ at 1123 K were investigated, and the purity of the obtained Si was evaluated.

The molten salt reactor was assembled in a vertical electric furnace. An Al_2O_3 crucible charged with $CaCl_2$ was set inside a SiO_2 vessel and heated to 1123 K in a dry Ar atmosphere. The working electrode was consisted of an Al_2O_3 tube with a graphite plate at the bottom. High-purity SiO_2 granules (0.10~0.25 mm) were charged in the Al_2O_3 tube. SiO_2 granules were electrolyzed potentiostatically at different potentials (0.6, 0.8, 1.0, and 1.2 V *vs* Ca^{2+}/Ca). The effects of electrolysis potential on reduction kinetics, current efficiency, morphology and purity of Si product during the electrolysis of SiO_2 granules were investigated.

Fig. 1 shows the cross-sections of the working electrodes after electrolysis for 20 min at different potentials. For each sample, a dark brown layer is observed above the graphite plate at the bottom, which grows up from the bottom as the electrolysis time increases. Formation of crystalline Si in this layer was confirmed by XRD and SEM/EDX analysis. The growth of the reduced layer is very slow at 1.2 V *vs* Ca^{2+}/Ca, while the growth is observed clearly in the other cases. The result suggests that a more negative potential is favorable for faster reduction. The rate-determining step for the electrochemical reduction of SiO_2 granules in molten $CaCl_2$ changes with time. At the initial stage of electrolysis, the electron transfer is the rate-determining step. At the later stage, the diffusion of O^{2-} ions in the reduced layer is the rate-determining step.

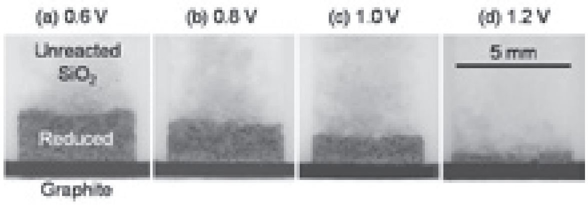

Fig. 1. Cross sections of the working electrodes after electrolysis for 20 min at different potentials.

Table 1 lists the concentrations of major impurities in the SiO_2 granules before electrolysis, in the recovered Si powder after electrolysis at different potentials (0.6 to 1.0 V *vs* Ca^{2+}/Ca) for 5 h and H_2O/HF leaching, and in the Si ingot after refining by directional solidification using the Si powder electrolyzed at 0.6 V *vs* Ca^{2+}/Ca. All samples were analyzed by GDMS. The result indicates that the impurities can be controlled at very low level. Directional solidification is effective to remove most metal impurities. Since the impurity concentrations in the Si powder are larger than in the original SiO_2 granules, $CaCl_2$ is considered to be the major source of the impurities which tend to enrich during electrolysis. The result indicates that a pre-electrolysis of molten $CaCl_2$ would be an effective approach to further lower down the impurity concentrations.

Table 1 Impurity concentrations analyzed by GDMS.

(ppm by weight)

	SiO_2	Si powder			Si ingot	Requirement for SOG-Si
		1.0 V	0.8 V	0.6 V		
B	<1	3.8	2.0	2.6	1.6	0.1-0.3
P	0.28	23	8.0	6.4	1.1	<0.1
Ca	<30	3000	4600	5800	7.8	<0.2
Al	3.3	930	700	600	33	<0.1
Ni	<0.1	24	23	35	0.13	<0.1
Fe	1.5	41	45	30	0.93	<0.1
Ag	<1	2.7	3.9	3.1	<0.1	<0.1
Ti	1.3	23	34	19	0.16	<0.1
Mg	0.24	18	20	21	<0.1	<0.1

3. Development of Highly Efficient Bioethanol Production Yeast Using Protein and Metabolic Engineering

Naturally occurring *Saccharomyces cerevisiae* strains have been used for industrial scale bioethanol production from hexose sugars. Furthermore, there is considerable research interest in the development of recombinant strains that can efficiently ferment both hexose and pentose sugars from lignocellulosic hydrolysates. Construction of efficient xylose-fermenting yeast *S. cerevisiae* has been subjected to large number of trials for improving ethanol productivity from mixture of glucose and xylose. In this study, the effects of overexpression of the genes involved in the non-oxidative pentose phosphate pathway (PPP) was investigated. It is well known that, in *S. cerevisiae*, the flux through the PPP is insufficient compared to other yeast species, most likely resulting in lower rates of xylose fermentation. Therefore, enhancement of the PPP in xylose-utilizing strains by the overproduction of non-oxidative PPP enzymes has been attempted to improve yeast growth on xylose as well as xylose consumption rate. A recombinant xylose-fermenting yeast *S. cerevisiae* was transformed with a plasmid containing the genes for non-oxidative PPP enzymes including transaldolase, transketolase, ribulose-5-phosphate 3-epimerase and ribose-5-phosphate ketol-isomerase. Xylose consumption rate and ethanol production rate of this recombinant yeast were determined (Fig. 2). Both xylose consumption rate and ethanol production rate was shown to be enhanced by this recombinant yeast, compared to the wild type yeast and the control xylose-fermenting yeast.

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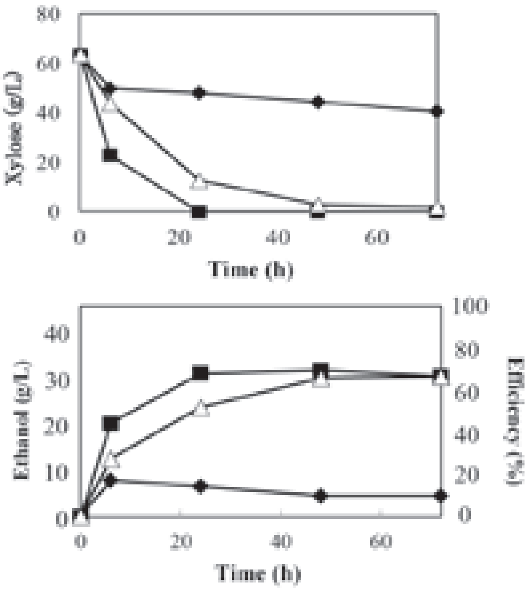

Fig. 2. Xylose consumption rate and ethanol production rate of the recombinant yeast. square; the recombinant yeast, rhomboid; wild type yeast, triangle; control xylose-fermenting yeast.

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Molecular Nanotechnology Research Section

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1. Introduction

Nanotechnology is essential for highly efficient energy use. Our group studies the basics of assembling small molecules into the advanced materials and devices in energy sector with high efficiency. We have already developed several unique techniques technique which are totally new molecular assembling techniques such as ‘electro-chemical Epitaxial Polymerization’ and ‘2-Zone Radical Polymerized Chemical Vapor Deposition (2Z RP-CVD)’ method which enable to produce molecular wires on metal surface from small molecules. By using these techniques, organic electronic devices such as Field-effect transistors and organic solar cells will be developed. Main research achievements in Molecular Nanotechnology Research section in 2015 are described below.

2. Synthesis of armchair-type graphene nanoribbon from unique precursor with 2-Zone RP-CVD technique

Graphene nanoribbons (GNRs) which have 1D stripes of graphene which have attracted much attention because of promising candidate for next generation semiconductors. These properties strongly depend on width and edge structure of them. Therefore, precisely controlled width and edge structure are required for desired properties. Bottom-up synthesis of GNR is a one of suitable method to satisfy these requirements because of definition of their edge structure and width by the shape of precursors. Atomically precise synthesis of armchair type GNRs have already been achieved under ultra-high vacuum (UHV) condition. However, given GNRs in this method were low yield and density was still low. Therefore, it was difficult to develop organic electronic devices with them.

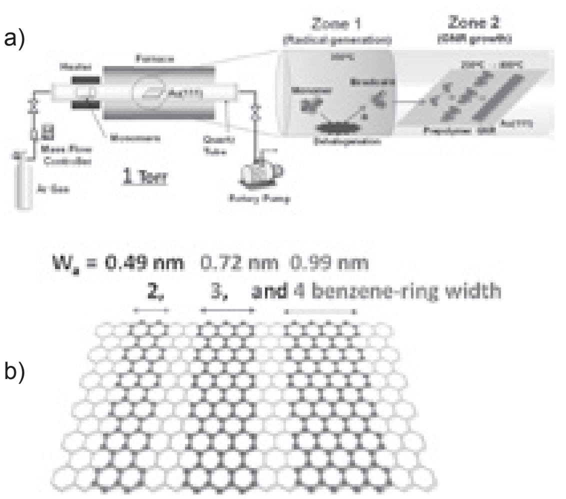

Fig. 1 Schematic illustrations of a) 2-zone RP-CVD instrument and b) synthesized graphene nanoribbons.

To develop devices, atomically precise synthesis of “multilayer GNRs,” isolation, and device fabrication are required. We have demonstrated bottom-up growth of multilayered GNR under low vacuum condition from halogenated polycyclic aromatic hydrocarbons by 2Z RP-CVD (Fig 1-a). Attractive features of this method originate from an independent temperature-control of radical-generation process (zone 1) and the growth process (zone 2). Au(111) on a glass or mica substrate was placed in a quartz tube as a reactor heated by an electric furnace (zone 2). The system was evacuated using a rotary pump with Ar gas flow, resulting in pressure of 1 Torr. Solid monomers placed on a quartz boat were vaporized by heating, followed by collision with the hot wall of the quartz tube (zone 1) heated at a temperature to produce biradicals by dehalogenation, to supply on substrate as a first stage, and to be radical-polymerized into prepolymers. Subsequently, the temperature was raised for conversion from the prepolymers to GNRs by dehydrogenation reaction as a second stage.

We found two important parameters for massive GNR-growth by RP-CVD. Only when the condition meets these requirements, an intense Raman signal from GNR was observed. The first requirement is cleaning of a quartz tube by immersion in concentrated nitric acid after heating at 1000 °C. The Raman intensity was enhanced markedly by cleaning processes compared with that of untreated tube. A second requirement is the side (vertical position) of Au(111) substrate placed in the quartz tube. Facing Au(111) side to the nearest surface of quartz tube gave more intense Raman intensity than that to the gas side. Organic biradicals produced from gaseous aromatic dibromide by thermal activation at cleaned hot wall of the reaction tube. The concentration of organic biradicals was dense at the confined space from near the wall. An atomically flat Au (111) metal surface was placed at the optimized space in a reaction tube, GNR prepolymer propagated and converted into GNR efficiently despite extremely low-vacuum (1 Torr) conditions. The utilization of the high-density biradicals is a remarkable benefit of 2-zone RP-CVD method. In fact, RP-CVD is applicable to the other monomers to produce GNR of different widths. We synthesized different width of armchair-type GNRs (A-GNR) with 2,3, and 4 benzene-ring width (Fig 1-b).

Additionally, obtained multilayered GNR films can be isolated from Au(111) surface. This is the first example of isolation of GNR material with an atomically well-ordered width prepared by bottom-up synthesis. GNR films could be transferred onto insulator surface. We achieved the first example of the measurement of nanogap electrode FET device of bottom-up synthesized GNR films by e-beam lithography technique.

3. Synthesis of Acene-type GNR with 2Z RP-CVD tequnique

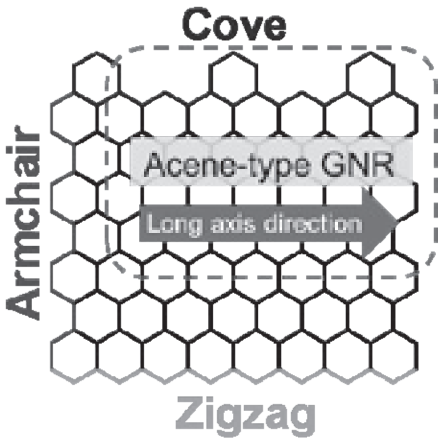

Fig. 2 Edge structure of GNR.

This method enables to produce not only arm-chair type GNRs but also various types of them with different precursors. Recently, we have succeeded in producing acene-type GNRs which have cove structure at the edge by using unique precursor which is easy to transform to be suitable for polymerization reaction on Au(111) surface (Fig. 2). Interestingly, produced prepolymers have chirality regardless of no chiral catalyst and chiral monomers. More surprisingly, prepolymers were chosen only one conformation from huge number of them which exist 10^{100} types of conformations at least on the Au(111). Additionally, only prepolymers which have suitable conformation on an Au surface were turned into acene-type GNRs by efficient stepwise intramolecular dehydrogenation reaction. It seems a kind of evolutionally growth in nature.

Acene-type GNRs produced by 2Z RP-CVD was characterized with scanning tunneling microscopy (STM) measured in air. Prepolymers prepared at 250 °C were densely-packed array of linear wire. The periodicity and width of wires correspond to 0.80 nm and 1.37 nm from cross section, respectively. The length of wires was up to 22.5 nm.

To study the GNR growth mechanism, heating temperature raised to 375 °C, 450 °C and 500 °C in step. The Sample annealed at 375 °C turned into partially fused prepolymer which is dehydrogenated at inner core and took place alternate monomer-units in chain. Sample annealed at 450 °C turned into wavy wires which have no periodicity at the edge of wires. These were estimated GNRs having defect. Finally, we could obtain the perfectly fused GNRs by annealed at 500 °C which have protrusions at edge of wires with periodical spacing 0.74 nm corresponding to the benzene rings of cove edge.

The band gap of GNR is inferred to depend on the edge structure and width. In previous report, we have succeeded in determined bandgaps of A-GNRs with 2, 3 and 4 benzene-ring width by using scanning tunneling spectroscopy (STS). Experimentally determined bandgaps were good agreement with theoretical prediction which was obtained using the first principle method with LDA. Additionally, we could determine bandgaps of acene-type GNRs this time, including prepolymer, partially fused prepolymer and defect GNR. These band gaps were good agreement with theoretical prediction.

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坂口浩司，新学術領域研究，表面重合した新規ナノ炭素細線の分子レベル電子計測

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Biofunctional Chemistry Research Section

T. Morii, Professor
E. Nakata, Junior Associate Professor
S. Nakano, Assistant Professor

1. Introduction

A transition to renewable energy technologies requires new chemistry to learn from nature. Nature has found fantastic solutions to convert solar energy to produce chemicals and to utilize them in the exceptionally efficient manners for almost 3 billion years. It is our challenge to understand the efficient bioenergetic processes of nature and to construct bio-inspired energy utilization systems. The research interests in our group focus on the design of biomacromolecules and their assemblies for molecular recognition, catalysis and signal transduction in water, the solvent of life. We take synthetic, organic chemical, biochemical and biophysical approaches to understand the biological molecular recognition and chemical reactions. Proteins and protein/nucleic acids assemblies are explored to realize biomimetic function of biological systems, such as visualization of cellular signals by fluorescent biosensors, directed self-assembly of peptides and proteins to build up nanobiomaterials, tailoring artificial receptors and enzymes based on the complex of RNA and a peptide or a protein, and reconstitution of the functional assemblies of receptors and enzymes on the nano architectures. Followings are main research achievements in fiscal year 2015.

2. Spatially organized enzymes drive cofactor-coupled cascade reactions.

In cellular enzyme cascades, efficient transport of an intermediate is often driven by confining free diffusion in a compartment of spatially organized enzymes. When the enzymes are in close proximity to each other upon compartmentalization in the cell, the formation of byproducts is substantially reduced, leading to high turnover and obstructive effects, such as inhibition of the final product, and unfavorable kinetics can be reduced. In the typical substrate channeling mechanism observed in nature, the intermediate from the first enzyme is transported directly to the second enzyme without diffusion to the bulk phase to maximize the efficiency of sequential reactions. When enzymes are positioned near enough to each other such that the intermediate produced by the first enzyme is processed efficiently by the second enzyme before diffusing in bulk solution, a proximity effect is expected to enhance the sequential reaction. In order to understand the role of the spatial organization of enzymes, enzyme cascade reactions have been studied in vitro or in cell by immobilizing enzymes on the scaffold, such as proteins, lipid bilayer, and nucleic acids. Though simulation studies indicated that the substrate channeling including proximity channeling would be observed within 1 nm of interenzyme distance, experimental results indicated that the enzyme cascade reactions were enhanced for the systems with the interenzyme distance of more than 1 nm. Thus, a question whether the efficient transport of an intermediate is governed by its simple diffusion or not remains to be clarified. Additionally, the mechanism of the intermediate transport between two enzymes would become more crucial when more than one molecule, such as the intermediate ad a cofactor, are involved in the efficient transport of reaction intemediates can be modeled. The definable nature of DNA nanostructures allows for the construction of a variety of spatially constrained enzyme assemblies, such as glucose oxidase/horseradish peroxidase or glucose-6-phsphate dehydrogenase/malic dehydrogenase, thus supporting their use as ideal scaffolds for this purpose. Site-specific attachment of enzymes on the DNA scaffold was mostly carried out by tethering of the enzymes through oligodeoxynucleotides (ODNs). One drawback of this method is that the activity of the enzymes attached to the ODNs tends to decrease compared with the activity of native enzymes. Therefore, to overcome this problem, we developed methods to use sequence-specific DNA-binding proteins, the zinc finger protein (zif268) and the basic leucine-zipper protein (GCN4), as adaptors to stably locate the enzymes at specific positions on the DNA origami scaffold. Our protein adaptor-based method successfully assembled the recombinant enzymes in high loading yields with control of the number of enzyme molecules and maintenance of the catalytic activities of enzymes.

We reported the construction of an artificial enzyme cascade based on the D-xylose metabolic pathway. D-xylose is a five-carbon aldose that can be metabolized into useful products by a variety of organisms. In addition to its biological significance, D-xylose is a major product of the hydrolysis of lignocellulosic biomass, which can be fermented to bioethanol or biohydrogen by bacteria, yeasts, and filamentous fungi.

Within the metabolic pathway of xylose, we have focused on the oxidoreductase pathway, also called the xylose reductase (XR)–xylitol dehydrogenase (XDH) pathway. In the artificially designed cascade, the first enzyme XR converts xylose into xylitol by consuming the cofactor NADH. The produced xylitol and NAD^+ are both simultaneously transported to the second enzyme XDH, which converts xylitol into xylulose by consuming NAD^+ to recycle the NADH cofactor. DNA origami was utilized as a scaffold to coassemble the enzymes XR and XDH in this artificial D-xylose metabolic pathway. The enzyme coassembly formed as designed through the protein-based adaptors, with variations in the interenzyme distance and defined numbers of enzyme molecules. We systematically evaluated the sequential reactions of xylose metabolism through the simultaneous bimolecular transport of xylitol and NAD^+ from XR to XDH with recycling of the cofactor NADH. The efficiency of the cascade reaction was highly dependent on the interenzyme distance between XR and XDH.

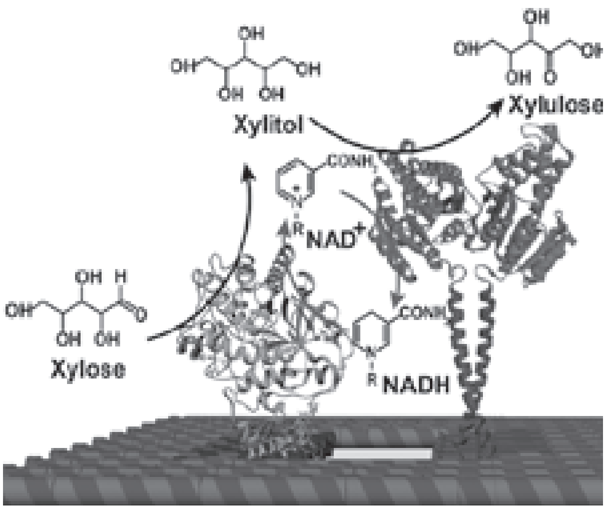

Figure 1 An artificial enzyme cascade based on the xylose metabolic pathway.

A sequential enzymatic reaction system based on the D-xylose metabolic pathway in the cavity of the DNA scaffold were designed and constructed. The first two enzymes in this pathway, XR and XDH, were located in the cavity of the DNA scaffold at predesigned positions in a distance-dependent manner. Our results showed that this reaction system, which localized the two enzymes in close proximity to facilitate transport of reaction intermediates, resulted in significantly higher yields of the product and allowed for recycling of cofactors. The efficiency of the cascade reaction with the biomolecular transport of xylitol and NAD^+ depended more on the interenzyme distance than that of the cascade reaction with unimolecular transport between two enzymes. By using our protein-adaptor-based method for efficient loading of the enzymes on the DNA scaffold and their volume analysis, the number of assembled enzymes was determined and controlled according to the number of adaptor binding sites. This advantage of our method would be useful to investigate further the effects of the ratio of enzymes within the cascade, which could be a critical factor in determining the enzyme cascade reaction. Our investigation helps further development of various scaffold-assisted assemblies of biologically important enzymes with predesigned patterns to achieve efficient natural or artificial enzymatic cascade reactions.

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Structural Energy Bioscience Research Section

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1. Introduction

We explore the way how biomolecules such as proteins (involving enzymes) and functional nucleic acids (DNA and RNA) work at atomic resolution based on structural biology with NMR. We determine both static and dynamical structures with the aid of our own development of the new methodology and elucidate the underlying mechanism of functions of these biomolecules. Structural biological approach is also applied to analyze components of wood biomass at atomic resolution. The analysis is useful to develop the way to extract energy and valuable materials that can be used as starting materials of various products from the wood biomass. Thus, we pursue to contribute to the paradigm shift from oil refinery to biorefinery.
Followings are main research achievements in the year of 2015.

2. Structural and functional analysis of wood degrading enzymes for better utilization of wood biomass

Major components of wood biomass are cellulose, hemicellulose, and lignin, among which cellulose has been used to produce bioenergy and biomaterials. Remaining two components, hemicellulose and lignin, also contain potentially useful chemical structural units, which can be converted into bioethanol, biomaterials, and medical chemicals. However, the rigidity and complexity of the structure of hemicellulose and lignin hinder their isolation from wood tissue. To obtain a tool to isolate hemicellulose and lignin by environmentally friendly, as well as physically and chemically mild treatments, we have been investigating the protein enzymes that are expressed in highly selective lignin-degrading white-rot fungi. Recently, our interests have been focused on three manganese peroxidases, short-, long-, and extra-long-MnPs, and a cellulase, that are thought to play major roles in lignin and/or hemicellulose degradation. In this fiscal year, we developed *E. coli* expression systems, by which each of the three MnPs can be obtained in soluble fraction. These MnPs were highly purified in two steps, Ni-affinity and size-exclusion column chromatography. Obtained MnPs were confirmed to coordinate iron-containing heme. We then demonstrated that these MnPs exert oxidase activity in the presence of hydrogen peroxide by 2,6-dimethoxyphenol-based assay. Currently, we are investigating their degradation activity against several lignin model compounds using NMR. Crystallization is also underway to solve their structure. On the other hand, we had previously expressed cellulase in *P. pastoris* in soluble fraction. This year, we established two step purification method using anion-exchange and phenyl column chromatography. Subsequently, we crystalized cellulase and collected X-ray diffraction data. Currently, optimization to obtain larger crystals and higher X-ray diffraction data so as to solve the structure is in progress.

3. Identification of the new LCC of wood biomass and development of accurate quantitation method

Major components of wood biomass, lignin and hemicellulose, are covalently linked through the lignin-carbohydrate complex (LCC). The exact chemical structure of LCC, however, has not been elucidated. By means of NMR analysis of natural wood biomass, we have identified the LCC of a α-ester bond for the first time (in collaboration with Prof. Watanabe and Dr. Nishimura of RISH, Kyoto Univ.). This finding is valuable to design a process to separate and purify each major component of wood biomass.

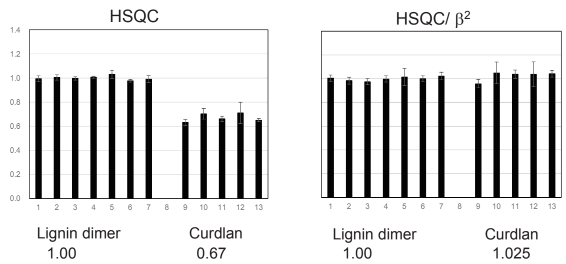

Fig. 1 New NMR method for accurate quantitation of components of wood biomass. (Left) Although a solution contains the same amounts of lignin and curdlan, HSQC underestimates the amount of a high molecular weight component, curdlan. (Right) When our method is applied, the amounts are the same for both components, as expected.

For the utilization of various components of wood biomass, it is a critical first step to know the amounts of each component. Although a HSQC spectrum of NMR has been widely used for the quantitation, obtained values suffer from skewing due to difference in molecular size and chemical structure of each component. By combining HSQC and another spectrum, TROSY, we have developed the NMR methodology to accurately quantify amounts of components. It is proved that this method can correct the skew of the quantitation and provide accurate amounts of each component (Fig. 1).

4. Real-time NMR analysis to investigate the sliding mechanism of an antiviral factor APOBEC 3G

A human antiviral factor APOBEC3G protein (A3G) is a cytidine deaminase that exerts antiviral activity by introducing mutations in the genes of infected retroviruses, such as HIV. Deamination activity of A3G is highly sequence specific, triplet repeat of cytidine (CCC) within single-stranded DNA (ssDNA) being converted into CCU. A3G reportedly deaminates a CCC that is located close to the 5' end of ssDNA more efficiently than ones that are less close to the 5' end (3'-->5' polarity). Previously, we developed an NMR method that can trace the deamination reaction by A3G in real-time and found that this 3'-->5' polarity is explained by nonspecific ssDNA-binding and sliding direction-dependent deamination activities of A3G. Last year, we used several ssDNAs containing modified nucleic acids as substrates and different salt concentrations of buffer conditions to investigate the nature of 3'-->5' polarity, and demonstrated that the phosphate backbone of ssDNA is important for sliding due to electrostatic intermolecular interaction between A3G and ssDNA. This year, we revealed that A3G's deaminase activity decreases as the pH increases in the range of pH 6.5-12.7, and moreover, 3'-->5' polarity increases as the pH decreases in the range of 6.5-8.0. These findings imply that A3G continues sliding without abortion at lower pH, while A3G dissociates from ssDNA during sliding at higher pH due to the weakened electrostatic interaction.

5. Structural and interaction analysis of promoter-associated non-coding RNA with TLS

Translocated in Liposarcoma (TLS) is an RNA/DNA binding protein that is involved in gene expression, maintenance of genomic integrity, miRNA processing, and so on. TLS binds to long non-coding RNA, promoter-associated non-coding RNA (pncRNA) which is transcribed from the 5' upstream region of *cyclin D1* (*CCND1*), inhibits the expression of *CCND1*. Our collaborator (Prof. Kurokawa, Saitama Med. Univ.) identified the sequence of the pncRNA. We have started structural and interaction study by NMR to elucidate the recognition mechanisms of pncRNA by TLS at atomic resolution. We determined the secondary structure of one of fragments (pncRNA-1) by NMR (Fig. 2). PncRNA-1 contains a stem loop structure in a 3'-region and a single strand in a 5'-region. Then, pncRNA-1 was divided into two fragments, the 5' end and the 3' end of pncRNA-1. The ^{1}H-^{15}N HSQC spectrum of TLS dramatically changed during the addition of the 5' end of pncRNA-1 (Fig. 2), but moderately changed of the 3' end of pncRNA-1. Thus, it was revealed that TLS interacts with the 5' end of pncRNA-1 more tightly than with the 3' end of pncRNA-1.

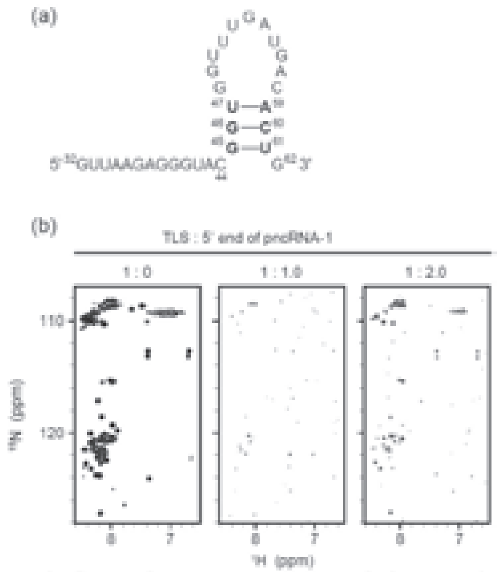

Fig. 2 Secondary structure and interaction of pncRNA-1 with TLS. (a) The secondary structure of pncRNA-1. (b) ^{1}H-^{15}N HSQC spectra of TLS in the course of titration with the 5' end of pncRNA-1, with the molar ratios of 1:0, 1:1, 1:2, respectively.

6. Determination of unusual structures of nucleic acids with unique activities

Unique modified nucleotides have attracted attention due to their high potential for many applications, including gene regulation, nucleic acid-based drugs and nanotechnology. DNA interstrand crosslinks are the primary mechanism for the cytotoxic activity of many clinical anti-cancer drugs. 4-amino-6-oxo-2-vinylpyrimidine (AOVP) derivative with an acyclic spacer can form crosslink with guanine or 8-oxoguanine. We determined the structure of the crosslink product between AOVP and 8-oxoguanine (in collaboration with Prof. Nagatsugi, Tohoku Univ.). The structural information provided novel insight into the development of DNA-based applications. We also identified the structure of a metal (M)-mediated base pair, 5-hydroxyuracil (U^{OH})-M-U^{OH}, by NMR (in collaboration with Prof. Shionoya, Tokyo Univ.). U^{OH} can form a Watson-Crick-type base pair with an adenine base. Thus, U^{OH} is expected to be applied for a bifacial nucleobase to construct metal-responsive DNA switches.

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Advanced Energy Utilization Division

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1. Introduction

The topoisomerase enzymes regulate the DNA topology such as overwinding or underwinding that arises due to the intertwined nature of the double helical structure of DNA.[1] These enzymes also play important role in replication, transcription, recombination, and chromosome condensation and segregation. During DNA replication and transcription, overwinding problem occurs. If it is not repaired, it eventually inhibits the ability of the enzymes involved in replication process. Topos control these DNA topological problems by transiently cleaving the phosphodiester bond, which generates a Topo-DNA cleavage complex. Once the winding problem is resolved, the enzyme-mediated DNA break is resealed. This process is critical for the healthy cells to survive and function normally, and failure to reseal the DNA break can ultimately lead to cell death. Topos are classified into two types based on the number of strands cleaved in one round of action: i) Type I: cuts one strand of DNA, topological changes happen, and then reanneal the cleaved strand; and ii) Type II: cuts both the strands of one DNA duplex, topological stress is released, and then reseals the cleaved strands. Both the types of Topos (in general) or the Topo-DNA cleavage complex (in particular) is of great interest as a potential target for the development of anticancer drugs.[2] In addition to the cleavage complex, various steps involved in the Topos function were also targeted by several anticancer drugs. Topos involve several step-by-step process in releasing the topological stress of DNAs. The typical steps in the enzyme reaction cycle are binding of Topo to DNA, ATP driven strand passage, strand cleavage by Topo, formation of Topo-DNA cleavage complex, religation of cleaved DNA, and catalytic cycle after DNA cleavage/enzyme turnover. Blocking any of these reaction steps would lead to the inhibition of the enzyme which culminate to cell death.

2. Formation of DNA catenane and analysis of topoisomerase IIα activity inside a DNA origami frame

In the current research work, I have utilized a "scaffolded DNA origami" structure as a novel scaffold for the preparation of topologically constrained catenane, and for the analysis of Topo reaction and drug screening. In 2006, "scaffolded DNA origami" method - the folding of DNA strand to create almost any arbitrary two- and three-dimensional nanostructures, was developed by Rothemund.[3] Since then it was successfully utilized for the nanopatterning of transition metals, nanoparticles, proteins, virus-like particles, and other functional components into deliberately designed arrangements.[4-11] It was also applied for the analysis of various reactions and functions at single-molecule level.[6] To the best of my knowledge, DNA origami nanostructures were not used for the screening of any drug molecule. Thus, by considering the potential of DNA origami, it is of great interest at the current situation to use these nanostructures for the formation of the topologically constrained DNA structure, analyze the function of DNA topology specific proteins such as Topo enzymes, and further to investigate the inhibition mechanism of the protein reactions by drug molecules.

As designed, the DNA origami frame is now successfully prepared. I have also inserted a catenane structure inside the origami frame which is

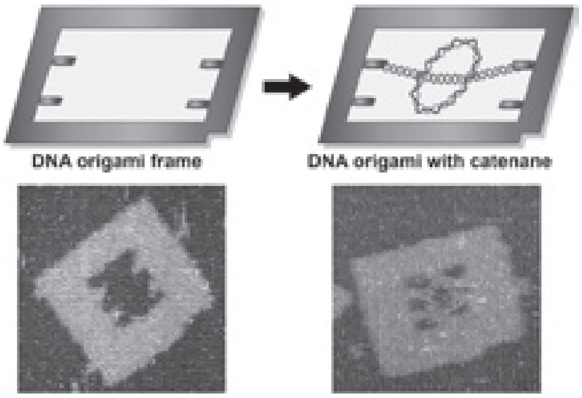

Figure 1. The schematic explanation of the DNA origami frame and the formation of DNA catenane inside the frame. AFM images of each case is given below the scheme. Image size: 175 × 175 nm.

characterized by the high-speed atomic force microscopy (Figure 1). However, the yield of the catenane inside the origami frame is too low. The optimization of the conditions for the formation and insertion of the catenane inside the DNA origami frame are now underway. Further, I have investigated the stability of the DNA origami frame and the catenane structure in the presence of various kinds of Topo inhibitors. Both the origami and the catenane are stable against the Topo inhibitors for several hours at room temperature. This indicated that the DNA origami based analysis of Topo inhibitors could be successfully carried out. After increasing the yield of the catenane inside the origami frame, the Topo reaction and the drug screening will be carried out.

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Laboratory for Complex Energy Processes Research Section

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1. Introduction

A. Theoretical Biophysics

A variety of self-assembling and ordering processes in biological systems, which occur at molecular levels, are sustaining life. Biopolymers, a great diversity of molecular and ionic species, or water is simply *material* when each of them is separately present. However, the complicated correlations among these material constituents can lead to *life*. We are elucidating those correlations, uncovering the mechanism of the biological self-assembly, and clarifying the roles of water by developing special theories based on statistical mechanics and morphometric thermodynamics. The achievements will provide important bases of nanobiotechnology. The current subjects are hydrophobic and hydrophilic hydrations, behavior of confined liquids, folding/unfolding mechanisms of proteins, molecular recognition, prediction of the native structure of a protein, enhancement of the thermal stability of membrane proteins, and functioning of ATP-driven proteins.

B. Plasma Physics

The major subjects are to study fast-ion confinement in plasma confinement devices and to investigate interactions between fast-ions and materials, such as a first wall and a vacuum vessel. The fast-ion confinement is a critical issue for the fusion reactor since the alpha particles produced in the D-T reaction should be utilized to heat plasma efficiently. The interactions between fast-ions and materials cause the impurity problem for the plasma energy confinement and the damage for the vessel or the first wall materials occurs. Fast-ion profile and velocity distribution are investigated using ion cyclotron range of frequency (ICRF) minority heating in Heliotron J with special emphasis on the effect of the toroidal ripple of magnetic field strength ('bumpiness'). Optimization of the ICRF heating is important for the three-dimensional magnetic configuration. We also investigate the effect of the position of the ion cyclotron resonance layer on the fast ion formation and confinement.

(A-1) Mechanism of one-to-many molecular recognition accompanying target-dependent structure formation: For the tumor suppressor p53 protein as an example [1]

The new type of molecular recognition, in which an intrinsically disordered region (IDR) of a protein binds to many different target proteins with target-dependent structure formation, is indispensable to the expression of life phenomena and also implicated in a number of diseases. According to the prevailing view, the physicochemical factors responsible for the binding are also target dependent. Here we consider an IDR of the tumor suppressor p53 protein, p53CTD, as an important example related to carcinogenesis and analyze its binding to four targets accompanying the formation of target-dependent structures (i.e., helix, sheet, and two different coils) using our statistical-mechanical method combined with molecular models for water. We find that all of the seemingly different binding processes are driven by a large gain of the translational, configurational entropy of water in the system. The gain originates from sufficiently high shape complementarity on the atomic level within the p53CTD-target interface. It is also required that the electrostatic complementarity be ensured as much as possible to compensate for the dehydration. Such complementarities are achieved in harmony with the portion of the target to which p53CTD binds, leading to a large diversity of structures of p53CTD formed upon binding: If they are not achievable, the binding does not occur. This finding is made possible only by calculating the changes in thermodynamic quantities upon binding and decomposing them into physically insightful components.

(A-2) On the physics of thermal-stability changes upon mutations of a protein [2]

It is of great interest from both scientific and practical viewpoints to theoretically predict the thermal-stability changes upon mutations of a protein. However, such a prediction is an intricate task. Up to now, significantly many approaches for the prediction have been reported in the literature. They always include parameters which are adjusted so that the prediction results can be best fitted to the experimental data for a sufficiently large set of proteins and mutations. The inclusion is necessitated to achieve satisfactorily high prediction performance. A problem is that the resulting values of the parameters are often physically meaningless, and the physicochemical factors governing the thermal-stability changes upon mutations are rather ambiguous. Here we develop a new measure of the thermal stability. Protein folding is accompanied by a large gain of water entropy (the entropic excluded-volume (EV) effect), loss of protein conformational entropy, and increase in enthalpy. The enthalpy increase originates primarily from the following: The energy increase due to the break of protein-water hydrogen bonds (HBs) upon folding cannot completely be cancelled out by the energy decrease brought by the formation of protein intramolecular HBs. We develop the measure on the basis of only these three factors and apply it to the prediction of the thermal-stability changes upon mutations. As a consequence, an approach toward the prediction is obtained. It is distinguished from the previously reported approaches in the following respects: The parameters adjusted in the manner mentioned above are not employed at all; and the entropic EV effect, which is ascribed to the translational displacement of water molecules coexisting with the protein in the system, is fully taken into account using a molecular model for water. Our approach is compared with one of the most popular approaches, FOLD-X, in terms of the prediction performance not only for single mutations but also for double, triple, and higher-fold (up to seven-fold) mutations. It is shown that on the whole our approach and FOLD-X exhibit almost the same performance despite that the latter uses the adjusting parameters. For multiple mutations, however, our approach is far superior to FOLD-X. Five multiple mutations for staphylococcal nuclease lead to highly enhanced stabilities, but we find that this high enhancement arises from the entropic EV effect. The neglect of this effect in FOLD-X is a principal reason for its ill success. A conclusion is that the three factors mentioned above play essential roles in elucidating the thermal-stability changes upon mutations.

(B-1) Study of Fast Ion Generation by Combination Heating of ICRF and NBI in Heliotron J [3]

The fast ion generation and confinement are studied by using ICRF minority heating (hydrogen minority and deuterium majority) for the simulation study of alpha particles, whose heating is essential for fusion reactors. In a three dimensional magnetic field device, Heliotron J (R_0 = 1.2 m, a = 0.1-0.2 m, $B_0 \leq$ 1.5 T), fast ion generation and confinement by ICRF minority heating are studied in combination with neutral beam injection (NBI) heating. Fast ions are measured using a charge-exchange neutral particle analyzer with ten channels for hydrogen.

The energy range is extended from the injection energy of the NBI beam, 25 keV, to 60 keV during the ICRF pulse in the newly attempted low-ε_t configuration and medium density operation (1x10^{19} m^{-3}). This configuration is better in the fast ion generation and confinement than the high bumpiness configuration which is the best among the bumpiness scan. Here, the toroidicity and the bumpiness normalized by the helicity for the low-ε_t and the high bumpiness configurations are (0.77, -1.04) and (0.86, -1.16) in Boozer coordinates, respectively. They are key parameters in 1/ν regime of helical devices. The low-ε_t configuration is expected to have good confinement from the neo-classical theory. The observed fast ions are limited up to 35 keV in the high bumpiness configuration for the same conditions. The particle flux is measured at the pitch angle of 52°. For the larger pitch angle (nearer to 90°), the high energy component becomes smaller. For example, the fast ions at the pitch angle of 62° in the high bumpiness are observed in the energy range below 20 keV during the ICRF pulse.

Using Monte-Carlo method with the experimental magnetic field and plasma parameters, the numerical calculation including orbit tracing, Coulomb collisions and ICRF acceleration is done in order to estimate the averaged behavior in whole torus for various configurations since the measurement area of the CX-NPA is limited. The test ions (protons) in the calculation, which represent the NBI particles, start at the middle point of the NB path in a plasma with the NB injection energy.

Injected ions with the mono energy collide with bulk particles in a plasma and are accelerated or decelerated by the ICRF wave, then, ions spread in velocity space. The particles in the calculation are summed up during 0.5 ms after 1.5 ms from the beginning because of the statistical reason. At this timing, the high energy tail is formed near 60 keV in the low-ε_t. The high energy tail is formed along 55° in pitch angle for the low-ε_t and 45° for the high bumpiness. The energy tail spread more toward the high energy region in the low-ε_t and its direction is relatively narrow in comparison with the high bumpiness. The experimental and calculation results are explained partially by the loss region of fast ions for these configurations. The loss region is located near 90° in pitch angle and high energy area. The area is larger for the high bumpiness configuration.

In this study, the fast ion generation and confinement using ICRF and NBI heating is performed in the two different magnetic field configurations in the medium density; (1) the fast ions are generated up to 60 keV from the NBI injection energy 25 keV, (2) the low-ε_t configuration is better in the fast ion generation and confinement in comparison with the high bumpiness configuration, (3) the numerical calculation using Monte-Carlo method shows that fast ions in the higher energy is observed in the low-ε_t configuration.

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Collaboration Works

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核融合科学研究所・双方向型共同研究，ヘリカル系プラズマにおけるアルヴェン固有モードに起因する高速イオン損失研究，山本聡，小林進二，大島慎介，岡田浩之，南貴司，長﨑百伸，水内亨

核融合科学研究所・双方向型共同研究，低磁気シアヘリオトロン配位における磁気島に対するプラズマ応答の研究，岡田浩之，水内亨，長﨑百伸，山本聡，小林進二，南貴司

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核融合科学研究所・双方向型共同研究，複合揺動計測によるヘリオトロン J の乱流構造解析，水内亨，長崎百伸，岡田浩之，南貴司，小林進二

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ADMIRE project
(Application of DuET and MUSTER for Industrial Research and Engineering)

S. Kondo, Program-Specific Associate Professor
W. Han, Program-Specific Assistant Professor

1. Introduction

The ADMIRE project (Application of DuET and MUSTER for Industrial Research and Engineering, current project leader; Prof. Kimura) is originally launched at IAE, Kyoto University in early 2006 as a MEXT supported program "Open Advanced Facilities Initiative for Innovation (Strategic Use by Industry)". Our primary objective is providing and sharing our resources, such as laboratory equipment, scientific knowledge, and the corresponding techniques, to private companies for encouraging their innovation. The representative facilities, DuET & MUSTER, were historically dedicated for the research on energy science and technology, with the special emphasis on fusion reactor materials R&Ds. Due to this reason many of nuclear material relevant subjects are continuously running from the beginning of the ADMIRE. The current project, however, is flexible to accept any new ideas from the industries and ventures for supporting their R&D efforts, in so far as they are innovative. Indeed, most subjects currently running are not related to the nuclear applications, but related to advanced energy- and/or nano-science. Note that many inputs from these exciting new research fields drastically stimulate our original work.

2. Activities with DuET (Dual-Beam Irradiation Facility for Energy Science and Technology)

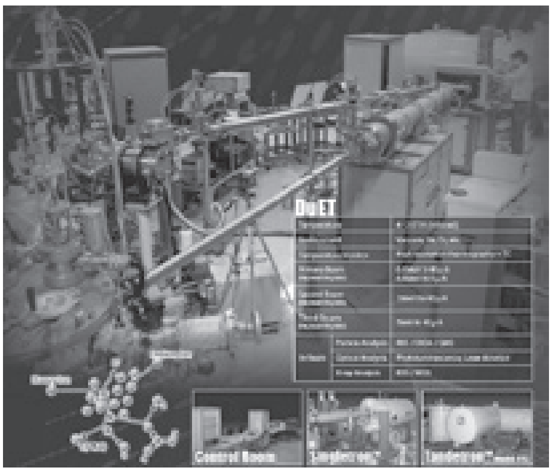

Fig. 1 Summary of the DuET facility set-up.

As an important part of fusion material research, evaluation of radiation damage in materials has been emphasized more than three decades. Under the current situation with no 14 MeV neutron irradiation facilities available for materials research, the Multiple Beams–Materials Interaction Research Facility has to have a very important role in many years to come. In order to obtain fundamental understandings of the radiation damage in fusion materials, as the dynamic material behavior under severe environments in advanced energy systems, such as fusion reactors, fission reactors, a Multiple Beams–Material Interaction Research Facility (DuET facility: Fig. 1) has been constructed at the IAE in 1998. The facility consists of a 1.7 MV tandem accelerator system with a pair of ion sources (a cesium sputter type heavy ion source and a duo-plasmatron type light ion source), a 1.0 MV single-end accelerator system with a light ion source and three target stations.

Testing by ion-irradiation is extremely useful to R&D of the nuclear materials because the flux “or damage rate” is extremely high (and it is easily controllable!) and conditions are accurate comparing to the testing in research reactors. Thus, many advanced materials, such as silicon carbide, tungsten alloys, and nuclear grade graphite, pro-vided by multiple commercial companies were tested within the ADMIRE framework. For example, the dimensional change of the graphite materials during irradiation have been unclear because of the difficulty of the testing due to the high porosity. However, our developed methods (WO2014034829 A1) successfully revealed a unique irradiation effects observed in those materials, such as the anisotropic dimensional change.

The creation of the functional materials, such as gradient materials, by implanting the specific ions on the materials is the other side of DuET work. Unfortunately, the detail of most topics cannot be introduced here because of the fixed-term classified contract between the ADMIRE and companies. However, those works help us to create new idea for the DuET application.

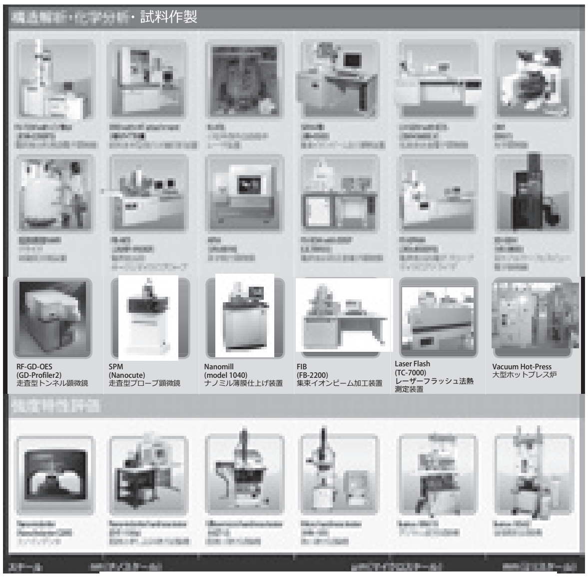

Fig. 2 Summary of the MUSTER equipment (selected).

3. Activities with MUSTER (Multi-scale testing and evaluation research) facility

Various analytical devices and mechanical testing machines are participated in the MUSTER facility; each covers different time-scale and/or time-scale range, respectively. Especially for the ADMIRE related work, an analysis of thin foils, coating materials, nanosized particles, and the control of nanoscale textures seem to be the key words of the recent users' demands. Two powerful analytical systems, KU-FEL (Kyoto University mid-infrared free electron laser facility managed by Prof. Ohgaki, Quantum Radiation Energy Section, Advanced Energy Generation Division, IAE) and NMR (three high-sensitive NMR systems managed by Prof. Katahira, Advanced Energy Utilization Division, Advanced Energy Utilization Division, IAE), have perticipated in the MUSTER in early 2013. Some upgrading and expanding of the MUSTER equipments, such as the instllation of new soft-XRD detector, high-resolution-TEM CCD camera, and GD-OES were achevived as well in 2013 to satisfy a recent user need. The latest available resources can be found in ADMIRE official site (http://admire.iae.kyoto-u.ac.jp).

Offering the right device for the right research objective is one of our key missions in addition to the technical advices for the device operation. One can say these analytical devices are the essential for most ADMIRE subjects, currently 24 subjects are running, where the percentage of operating time for the ADMIRE related work is more than 40% (averaged, JAN 2016) of the total hours of use. Some have strong connection to the DuET experiments because the ion irradiation typically modify the atomic-scale structure. Some of ADMIRE subjects, such as the microstructural analysis of the grain boundary diffusion in neodymium magnet, led to the collaboration research with IAE, and those were presented at conferences and published in scientific journals by our faculty stuff.

The followings are the key analytical electron microscopies of the MUSTER.

• Field Emission Transmission Electron Microscope (JEOL JEM-2200FS): This is designed for both high resolution TEM/STEM and analytical microscopy with a 200 kV field emission gun. Point and line resolutions are 0.23 nm and 0.1 nm, respectively. The attachments or analytical methods which can be utilized are EDX, EELS, HAADF, Z-contrast imaging, etc.

• Field Emission Scanning Electron Microscope (Zeiss ULTRA55): This is a field emission scanning electron microscope (FE-SEM) incorporating a cold cathode field emission gun. Voltage range is from 0.5 kV to 30 kV. The resolution is 1 nm at 15 kV. The attachments are EDX and EBSD.

4. People

Human resources are the most important assets of the ADMIRE project. The followings are the members providing direct supports for all subjects currently running (MAR 2015, faculty professors are excluded in the following list).

- Hideki Matsui, Ph. D., Specially Appointed Professor, Liaison officer.
- Reine Sakamoto, (Assistant Administrative Staff).
- Okinobu Hashitomi (IAE Technical Staff), Administrator of DuET accelerators.
- Takamasa Ohmura (IAE Technical Staff), Administrator of MUSTER facility and more.
- Yasunori Hayashi (Program-Specific Researcher)
- Yoosung Ha, Ph. D. (Program-Specific Researcher)

Financial Support

Others

檜木達也，近藤創介，日本原子力研究開発機構，SiC/SiC 複合材料の照射下強度予測のための SiC の動的照射特性評価

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藪内聖皓，韓文妥，木村晃彦，皆藤威二，鳥丸忠彦，林重成，大野直子，鵜飼重治，事故時高温条件での燃料健全性確保のための ODS フェライト鋼燃料被覆管の研究開発(2)(4)イオン照射影響評価，日本原子力学会 2016 年春の年会，東北大学川内キャンパス，2016.3.26-28

3-3. AWARD

Outstanding Presentation Awards of the Cryogenics and Superconductivity Society of Japan (CSSJ) 2015

Quantum Radiation Energy Research Section
Toshiteru Kii (Associate Professor)

Cryogenics and Superconductivity Society of Japan (CSSJ) was established as a public interest incorporated association on April 1, 2011. The society was originally established as Cryogenic Association of Japan established in 1966.

In the 90st meeting held in Fukushima, I presented a work on “Design study of magnetic field distribution control by using bulk HTS array” and I received the outstanding presentation award. (Fig. 1)

Bulk high-temperature superconductors (HTS) have a large potential for various application because current density in the bulk HTS is very high. However, main application of the bulk HTS is simple strong magnet. In the presentation, I introduced new approach to design complicated magnetic field distribution using bulk HTS array.

Fig. 1 Photograph of certificate of commendation and medal for outstanding presentation award of CSSJ 2015.

5th Best Presentation Award of the Japan Society of Infrared Science and Technology (JSIR)

Quantum Radiation Energy Research Section
Heishun Zen (Assistant Professor)

The Japan Society of Infrared Science and Technology (JSIR) was founded in 1991 for development of science, technology and application of infrared region (0.8 μm to several millimeter) light. Annual meetings have been held every year.

In the 25th annual meeting held in Chubu University, I presented a work on “Development of Mid-Infrared Free Electron Laser at Institute of Advanced Energy, Kyoto University,” as a poster presentation and I received the best presentation award of this annual meeting. Figure 1 is the photograph of the commemorative shield which I received from JSIR.

In this poster presentation, brief introduction, development history, configuration, present performance and some example of application experiments of mid-infrared free electron laser developed in our institute were presented.

Fig. 1: Photograph of the commemorative shield of 5th Best Presentation Award of the Japan Society of Infrared Science and Technology.

Presentation Awards of the 12th Annual Meeting of Particle Accelerator Society of Japan (PASJ)

Quantum Radiation Energy Research Section
Heishun Zen (Assistant Professor)

The Particle Accelerator Society of Japan was founded in 2004 as a domestic scientific society of researchers and technicians working on particle accelerators and related topics. Annual meetings have been held every year.

In the 12th annual meeting held in Tsuruga, I presented a work on “Multi-bunch photoelectron beam generation from LaB_6 cathode in an RF gun and its utilization to MIR-FEL oscillation,” and I received the presentation award of this annual meeting.

A mid-infrared Free Electron Laser (FEL) named Kyoto University FEL (KU-FEL) has been developed in our institute. A RF gun with thermionic cathode made by LaB_6 has been used as its electron source. Thanks to the continuous efforts, KU-FEL can provide intense mid-infrared laser beam in wide wavelength range, from 5 to 20 μm. However, because of limitation of electron bunch charge, the peak power of FEL is less than 10 MW and not sufficient for some nonlinear spectroscopic applications.

In this work, in order to increase the peak power of the FEL, we irradiate multi-bunch UV laser to generate photoelectron and to obtain electron beam with much higher bunch charge from the cathode. As the result, the bunch charge was increased from 50 to 150 pC by the photoelectron generation. The generated multi-bunch photoelectron beam (150 pC, 120 bunches) has been used for FEL lasing. The FEL micro-pulse energy has been increased from 2 to 13 μJ. In this condition, the peak power was expected to be about 20 MW.

Atomic Energy Society of Japan Kansai Chapter Award.

Advanced Atomic Energy Research Section
Shutaro Takeda (D2)

The Atomic Energy Society of Japan was founded in 1959 and is the only organization in Japan that aims to contribute towards progress in the development of atomic energy by seeking academic and technological advances pertaining to the peaceful use of atomic energy. Kansai chapter of AESJ holds young researchers’ workshop annually.

In the 11th Kansai Chapter AESJ Young Researchers’ Workshop, Takeda presented a work on the limitation of fusion power plant installation to future power grids, and received the Kansai Chapter Award (Encouragement Award).

Selected as Key Scientific Article by Renewable Energy Global Innovations.

Advanced Atomic Energy Research Section
Shutaro Takeda (D2)

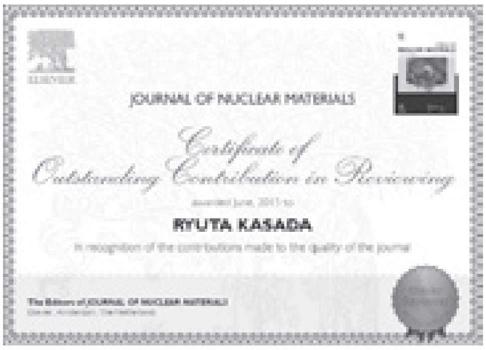
Renewable Energy Global Innovations series is a Canadian based company established in 2007 to ensure that the results of excellent renewable energy research are rapidly disseminated throughout the world, in a fashion that conveys their significance for advancing scientific knowledge and developing innovative technologies for the benefit of man kind.

In Feb. 2016's issue of REGI, his paper on Fusion Enginnering and Design, "Limitation of Fusion Power Plant Installation on Future Power Grids under the Effect of Renewable and Nuclear Power Sources" (2015) was featured as Key Scientific Articles.

Outstanding reviewer for Journal of Nuclear Materials, Elsevier

Advanced Atomic Energy Research Section
Ryuta Kasada (Associate Professor)

The Journal of Nuclear Materials publishes high quality papers in materials research for fission reactors, fusion reactors, and similar environments including radiation areas of charged particle accelerators. Kasada was awarded this status on June 2015 as he is within the top 10th percentile of reviewers for the Journal, in terms of the number of manuscript reviews completed in the last two years. For Journal of Nuclear Materials, this meant a minimum of 5 reviews in two years. Scientific Articles.



Outstanding reviewer for Fusion Engineering and Design, Elsevier

Advanced Atomic Energy Research Section
Ryuta Kasada (Associate Professor)

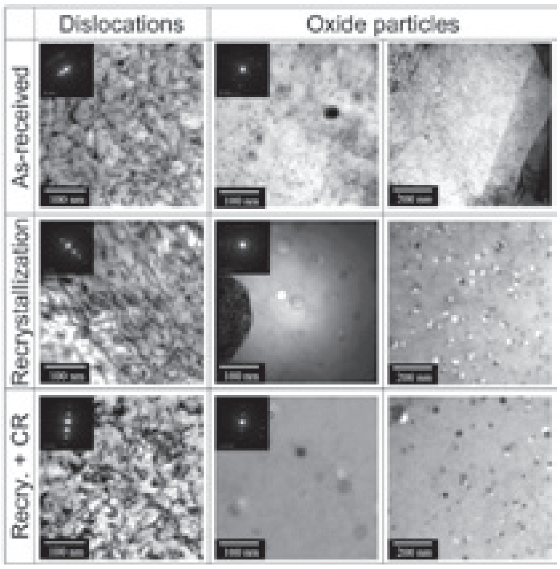
The Fusion Engineering and Design publishes papers about experiments (both plasma and technology), theory, models, methods, and designs in areas relating to technology, engineering, and applied science aspects of magnetic and inertial fusion energy. Kasada was awarded this status as he is within the top 10th percentile of reviewers for the Journal, in terms of the number of manuscript reviews completed in the last two years. For Fusion Engineering and Design, this meant a minimum of 7 reviews in two years.

Encouragement award of Atomic Energy Society of Japan in 2015

Advanced Energy Structural Materials Research Section
Yoosung Ha (Researcher)

The Atomic Energy Society of Japan (AESJ) energetically pursues human welfare and sustainable development while conserving global and local environments through the atomic energy research, development, utilization, and education, under the principle of information disclosure with maintaining a harmonious relationship with society and securing nuclear safety.

This award was offered for the comprehensive study on the effects of ion-irradiation on the oxide dispersion strengthened (ODS) steels as a part of R&D of the nuclear structural materials. Microstructure observation by transmission electron microscope (TEM) revealed that the irradiation hardening was due to formation of dislocation loops in high density (Fig. 1). This study contributed to understanding the mechanism of irradiation embrittlement of ODS steels.



Student Poster Session Good Idea Award in the Atomic Energy Society of Japan

Advanced Energy Structural Materials Research Section
Toshiki Nakasuji (D1)

The Atomic Energy Society of Japan was founded in 1959 as the only organization in Japan that aims to contribute towards progress in the development of atomic energy by seeking academic and technological advances pertaining to the peaceful use of atomic energy. In the 2015 Annual Spring Meeting held at Ibaraki University, Mr. Nakasuji made a good presentation on their effort on “Theoretical evaluation of microstructural change in metal under various irradiation conditions”, and received the Student Poster Session Award for their valuable unique ideas. His research activities was encouraged to be more enhanced.

Student Session Outstanding Achievement Award in the Japan Society of Maintenology

Advanced Energy Structural Materials Research Section
Toshiki Nakasuji (D1)

The Japan Society of Maintenology was founded in 2003 to establish “Maintenology” of nuclear power plants, other complex artifacts, and the natural environments, emerged by collecting a wide variety of information and knowledge of engineering, technology, natural science, sociology, and so on. Mr. Nakasuji made both oral and poster presentations at the 2015 Annual Meeting on the advanced maintenance methodology of nuclear fission reactor vessel. He was given the Student Session Award for their excellent theoretical investigations and his research activities was largely encouraged.

Young scientists poster award and TAIYO NIPPON SANSO award in the 54th Annual Meeting of the NMR Society of Japan.

Structural Energy Bioscience Research Section
Keisuke Kamba (D3)

The NMR Society of Japan was founded in 1961 to provide the opportunity for presentation and exchange of information related to NMR study, which includes function, structure, interaction and dynamics of biomolecules such as protein, as well as NMR technology, and so on. The 54th annual meeting of this society was held in Chiba, Japan.

In the 54th annual meeting, I presented our latest work entitled "Novel aspects of real-time NMR methods –New findings in anti-viral protein APOBEC3G concerning sequence-recognition and sliding on the DNA, and its involvement in epigenetics–". Human APOBEC3G (A3G) is an anti-viral factor that destroys HIV infection by deaminating cytosine (C) into uracil (U) within the viral cDNA. Although the structures of several constructs of A3G in its free form were determined, the mechanism of the interaction between A3G and single-stranded DNA (ssDNA) are yet to be elucidated. We previously developed a real-time NMR method that can monitor A3G's deamination reaction involving sliding along DNA. Here, we present new findings obtained by this method. Firstly, we have shown that A3G recognizes 5 consecutive nucleotides of ssDNA. Secondly, the electrostatic interaction between A3G and the phosphate backbone of ssDNA turns out to be the key for sliding. Finally, we have applied this method to 5-methylcytosine (5mC), an epigenetic marker, or 5-hydroxymethylcytosine (5hmC) containing ssDNA and demonstrated for the first time that A3G can deaminate 5mC.

4. JOINT USAGE/RESEARCH PROGRAM

Joint Usage/Research Center Program
“Zero-Emission Energy Research”

It is an urgent task to find out the best solutions against the energy and environmental problem for ensuring the sustainable society on the earth. The new energy system for this purpose has to be an environmentally friendly or ecological one. Here, we should consider not only the energy sources but also the efficiency in the each phase of energy usage. The former should have good quality and enough quantity. The latter should be considered including the so-called “three Rs (Reduce, Reuse and Recycle)” in the energy system;

- Reduce of energy consumption, environmental pollutant such as greenhouse gas, waste-heat, hazardous waste, etc.
- Reuse of waste heat/energy, etc.
- Recycle of fuel, etc.

In order to realize them, only the extension of the present technology is not enough. Interdisciplinary studies with innovative ideas are indispensable to realize the energy system for next generation.

We propose a new concept of Zero-Emission Energy as a typical model of Advanced Energy. IAE Zero-Emission Energy Research aims at the realization of environmentally friendly energy system for sustainable society with minimum emission of environmental pollutants and with maximum utilization of energy and resources.

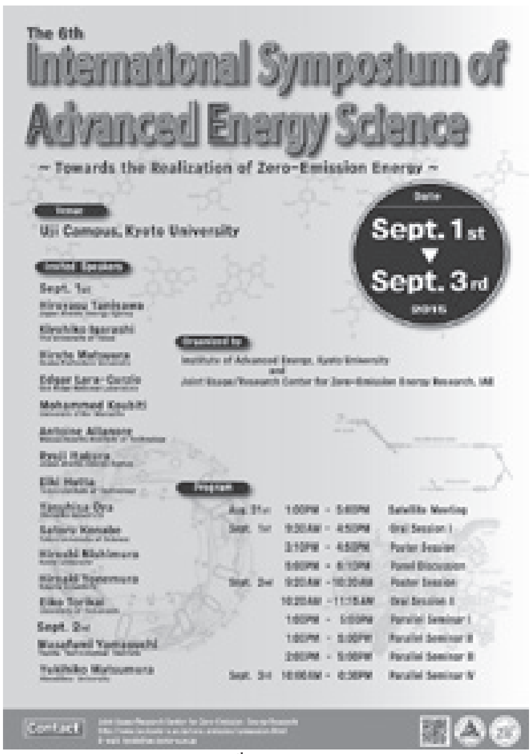


Fig. 1 Poster of the 6th International Symposium

Since FY 2011, we have operated a project, “Joint Usage/Research Program on Zero-Emission Energy”, which is the program authorized by the MEXT. Here, we aim to (1) promote interdisciplinary joint usage/research studies for Zero-Emission Energy Science & Technology, (2) promote education & practical training for young researchers and (3) explore future horizon of Advanced Energy System for sustainable development. IAE provides many unique & attractive facilities for the Joint Usage/Research not only in the field of advanced plasma & quantum energy but also in the field of photonics & energy nano-science for energy research.

Many researchers have participated in this program. In FY 2015, Joint Usage/Research collaborations of total 91 subjects (including one workshop) on Zero-Emission Energy were performed with more than 428 visiting participants from 34 all-Japan Universities and Institutions including graduate/undergraduate students. The results of these collaborations are summarized in a report “IAE Joint Usage/Research Program on Zero-Emission Energy 2015. (in Japanese)” Some of them were reported and discussed in a Research Summary Meeting of FY2015 held at Uji Campus on March 7, 2016. If you have interest to this collection, please contact to the Office of Zero-Emission Energy Research.

In addition to the Joint Usage/Research collaborations, we organized "the 6th International Symposium of Advanced Energy Science ~ Contribution to Zero-Emission Energy ~” on September 1 – 3, 2015 at Uji Obaku Plaza, Kyoto University (Fig. 1). This symposium consists of plenary and poster sessions, panel discussions and parallel seminars. About 270 scientists and students including three foreign and five domestic invited speakers were participated in the symposium. In addition, several informal seminars and/or internship on Zero-Emission Energy were also organized. (http://www.iae.kyoto-u.ac.jp/zero_emission/calendar2015.html)

We are also operating “Zero-Emission Energy Network” to share the knowledge of Advanced Energy and Zero-Emission Energy with researchers in the fields of energy science and technology, since world-wide activities for Zero-Emission Energy Research are indispensable for the realization of sustainable society.

List of Zero-Emission Energy Joint Usage/Research Subjects in FY 2015

(Subject, Principal Researcher, IAE Key Person)

Hydrogen isotope retention behavior for heavy ion implanted tungsten under higher temperature
Y. Oya, T. Hinoki

Effects of Magnetic Field and Metal Nanoparticles on Photocurrents of Dye-Metal Nanoparticle Composite Films
H. Yonemura, H. Sakaguchi

High value-added biomass originated from a bacterium often found in activated sludge
M. Takeda, M. Katahira

Design and development of functional organic materials for energy conservation-directed light-emitting devices
M. Shimizu, H. Sakaguchi

Unraveling the optical properties of atomic layers by microscopic spectroscopy
Y. Miyata, Y. Miyauchi

Development of hybrid nanofiber for enzymatic and photocatalytic transformations of carbon dioxide to alcohol
N. Tanaka, T. Morii

Mode-selective phonone excitation in wide-bandgap semiconductor by mid-infrared free-electron-laser
K. Hachiya, H. Ohgaki

Photo-Energy Conversion System Based on DNA and Photo responsible Dye Conjugation
K. Yamana, T. Morii

NMR analysis of supramolecular structure of lignin in cell wall for advanced biomass utilization: Relationship between incorporation of p-hydroxyphenyl unit and lignin structure
K. Fukushima, M. Katahira

Development of anode/electrolyte interface for advanced Na-ion battery
H. Sakaguchi, T. Nohira

Development of novel energy production processes in atomic layered materials
S. Konabe, K. Matsuda

Hydrogen isotope permeation behavior of ceramic coatings irradiated by heavy ions under higher temperature
T. Chikada, K. Yabuuchi

Mechanism of Radiation Resistance of Advanced Tungsten Alloys
A. Hasegawa, A. Kimura

R&D of First-wall Component for Fusion Reactor Using Explosion Welding
K. Hokamoto, R. Kasada

Design of nanoscale structures embedded into two-dimensional atomic layered materials for innovation of novel photovoltaic systems
S. Okada, K. Matsuda

Influence of high temperature irradiation on hydrogen isotope retention and permeation in first wall and divertor materials for fusion reactors
Y. Hatano, T. Hinoki

Mechanical properties of fusion reactor materials, tungsten and reduced activation ferritic/martensitic steels (F82H), under high strain rate loading.
H. Lee, R. Kasada

Optimization of a high particle and high temperature loading experiment system using the ion beam test stand, and experiment of a fusion diverter system II
Y. Yamamoto, S. Konishi

Experimental evaluation of the stability of point defect clusters under irradiation
H. Kinoshita, A. Kimura

Dynamics of Self-Organization to Helical-Axis Reversed-Field Pinch and Its Control for Plasma Performance Improvement
S. Masamune, T. Mizuuchi

Development of New Neutron Detection Method with IEC Device and TMFD Detector
T. Misawa, K. Masuda

Effects of Damage and Helium Generation Rates on Bubbles/Voids Formation in Fusion Reactor Structural Materials
T. Yamamoto, A. Kimura

Mechanical properties of dissimilar bonding between low-activation ferritic steel and ODS steel
T. Nagasaka, A. Kimura

Development of FP corrosion-resistrained cladding materials in fast reactor application
K. Fukumoto, A. Kimura

Development of rechargeable zinc-air batteries

based on surface-induced phase transition of electrolyte solutions within nanoporous electrodes
K. Fukami, M. Kinoshita

Effects of Interactions between Algae and Bacteria on Material Cycling in Lake Biwa
Y. Shimizu, M. Katahira

Hydrogen isotope behavior under complex fusion irradiation environment
Y. Ueda, A. Kimura

High-Fluence Irradiation Behavior of Reduced Activation Fusion Reactor Materials
H. Tanigawa, T. Hinoki

Structural analysis of lignin by ultra-high sensitivity NMR for biorefinary
T. Watanabe, M. Katahira

Characterization of Oxide Dispersion Strengthened Reduced Activation Ferritic/Martensitic Steel for DEMO Fusion Reactor
M. Ando, A. Kimura

Evaluation of ion irradiated Ni-based oxide dispersion strengthened (ODS) alloys for Gen. IV nuclear reactors
S. Ukai, A. Kimura

Damage Formation Mechanism of Tungsten under Repetitive and Pulsed High-Heat Load Conditions (Part 4)
K. Ezato, A. Kimura

Study on Fatigue Life Evaluation Method of SiC/SiC Composite
S. Nogami, T. Hinoki

NMR analyses of RNA-peptide complexes for the development of biomolecules which regulate gene expression
T. Sakamoto, T. Nagata

Theoretical Analysis on Natural Convection Heat Transfer from Vertical Rod Bundles in Liquid Sodium
K. Hata, T. Mizuuchi

Measurement of active radicals produced by atmospheric pressure plasma jet in the gas-liquid interface
H. Matsuura, S. Kado

Control of the growth of the neuron by cell ahesive peptide nanofiber for development of artificial neural circuit
T. Waku, T. Morii

Study of electron bunch length by measuring coherent synchrotron radiation with narrow-band detectors
N. Sei, H. Ohgaki

Highly efficient photochemical reactions induced by optimal laser pulses
Y. Ohtsuki, T. Nakajima

Correleration between dierectric constant change of glass substrate after ion irradiation and LSPR wavelength
T. Shibayama, T. Hinoki

Development of the site-directed RNA mutagenesis for regulating an energy production in the cell
M. Fukuda, T. Morii

Structural study of the mechanism of signal transduction in eukaryotic translation initiation factor complex.
E. Obayashi, T. Nagata

Clustering of metal binding proteins on local membrane domain towards the development of a rare or toxic metal recovery system
M. Mori, T. Morii

Heavy irradiation effect of Fe-based composite materials with a high thermal conductivity
N. Hashimoto, A. Kimura

Analysis of radiation induced nano-clustesr in Fe based structural alloys
H. Watanabe, A. Kimura

Mechanical characterization of cellulose nanofiber reinforced resin composite materials by nanoindentation
Y. Tsujii, R. Kasada

Design of artificial enzymes targeting RNA in a sequence-specific manner
M. Imanishi, T. Morii

Rural Electrification by Renewable Energy in Sarawak, Malaysia
W. Hew, H. Ohgaki

Study of liquid metal embrittlement on SiC materials for high efficiency heat exchanger
C. Park, S. Konishi

A fluorescent probe for imaging of energy metabolism in cells
S. Sato, T. Morii

Development of the zero-emission energy oriented

boron neutron capture agents having tumor-selectivity and diagnosability.
Y. Uto, E. Nakata

Development of ultrasound-enhanced cell-internalization method
A. Harada, E. Nakata

Advanced measurement for high energy particle in three-dimensional magnetic configuration
Y. Nakashima, S. Kobayashi

Phase measurement of vacuum-ultraviolet pulse and control of electronic states
R. Itakura, T. Nakajima

Development of Organic-Inorganic Hybrid Film toward High-Performance Organic Thin-Film Solar Cells
T. Akiyama, H. Sakaguchi

Structural studies on hierarchical molecular architectures created in microfluidic device
M. Numata, E. Nakata

Development of novel aptamers that confer stable guanine-quadruplex structures.
M. Hagihara, T. Morii

Effect of Hydrogen on Mechanical Properties in Tungsten
K. Sato, A. Kimura

Modeling/simulation of irradiation parameter dependence on microstructural change in RAFM steel
Y. Watanabe, K. Morishita

Development and Microstructure Control of Composite Materials for High Thermal Conductivity
G. Sasaki, T. Hinoki

Development of newly design-conceptural SiC-based composites under multiple environments
K. Shimoda, T. Hinoki

Flow analysis from a nozzle for SMBI
N. Nishino, T. Mizuuchi

Comparative study of Negative Triangular Tokamak and Helical II (ITG/TEM structure and flow shear)
M. Kikuchi, K. Nagasaki

Simultaneous measurements of electron cyclotron emission signals at two toroidal positions in torus plasmas
Y. Yoshimura, K. Nagasaki

Big data analysis of dynamic behavior of plasma measured with microwave reflectometry
S. Inagaki, K. Nagasaki

Development of single-electron irradiation technique for microscopic track structure study
Y. Uozumi, H. Ohgaki

Radiation effects on properties of plasma facing materials in fusion reactor
K. Tokunaga, A. Kimura

Development of a radiative transfer code in Heliotron J
H. Kawazome, T. Mizuuchi

A study of the irradiation characteristics of advanced vanadium alloys for fusion reactors
T. Miyazawa, R. Kasada

Developing Social Decision-making System for Renewable energy and Nuclear Power Generation.
H. Iwakiri, K. Morishita

Study of nonlinear dynamics and structure formation of turbulence in helical plasmas
A. Ishizawa, S. Kobayashi

Development of multi-channel spectroscopic system for turbulence measurement
A. Fujisawa, S. Ohshima

Study of ballooning mode using high-speed soft X-ray camera in Heliotron J
Y. Takemura, S. Yamamoto

Study on vapor shielding effect of the fusion wall materials during plasma irradiation
K. Ibano, S. Konishi

Plasma Fluctuation Diagnostics with Digital Imaging Technique
M. Irie, T. Mizuuchi

Biochemical functional analysis of small proteins encoded in the noncoding regions of the human genome
Y. Aizawa, T. Morii

Probing the intrinsic electrical and optical properties of high-quality atomic layers with microscopic spectroscopy
R. Kitaura, K. Matsuda

Effects of helium on dimensional stability and microstructure of Hi-Nicalon Type-S SiC fiber

K. Ozawa， T. Hinoki

Radiation effects of dual ion beam irradiated SA-Tyrannohex all fiber SiC compoiste and single crystal 3C-SiC.
J. Kai， T. Hinoki

NMR study on chemical property of natural organic matter
T. Sasaki， M. Katahira

Supramolecular assembling regulation of bacterial cell division protein FtsZ
A. Onoda， E. Nakata

Evaluation of mechanical properties of electrodeposited Al-W alloy films
M. Miyake， R. Kasada

Boundary diagnostics using field corresponding double probe and rf heating in Heliotron J
K. Uehara， T. Mizuuchi

Nanostructure formation on solid surfaces with few-cycle laser pulses
G. Miyaji， K. Matsuda

Study of carbon-based materials and bio photoreaction using infrared free electron laser
K. Nakao， H. Ohgaki

Statistical analysis on edge turbulence fluctuation data in a toroidal plasma
Y. Nagashima， S. Ohshima

Development og a small molecule that has affinity to RNA G-quadruplex
Y. Katsuda， T. Morii

Physical property analysis of the late blooming phase governing the engineering lifetime of pressure vessel steels of light water reactor
Y. Matsukawa， K. Yabuuchi

Mode-selective phonon excitation in 2D material by mid-infrared free electron laser
K. Yoshida， H. Ohgaki

Study of Deuterium Retention Property of Heavy Ions Beam Irradiated Tungsten Using Compact Divertor Plasma Simulator for Hot Laboratory
M. Yajima， T. Hinoki

Workshop on Modeling and Simulation of Fusion Reactor Engineering Design and Materials Development
K. Tobita， K. Morishita

5. COLLABORATION WORKS IN THE LABORATORY FOR COMPLEX ENERGY PROCESSES

Collaboration Works in The Laboratory for Complex Energy Processes

1. Introduction

The laboratory was established for research on advanced processes of energy production, conversion and application. Resource and energy problems as well as global warming problems become very serious in recent years. We have to concentrate all our knowledge and wisdom to find solutions to these problems. From such a viewpoint, the research targets of the laboratory should be focused on two specific fields, (i) "advanced studies of science and technology on plasma energy and quantum energy" and (ii) "innovative studies of nano-bio functional materials for power generation". Therefore, two sections (A2 and A3 mentioned below) are founded. In addition, a section of promotion for international collaborative research arranges and promotes international and domestic research collaborations.

In order to perform the research objectives of the Institute of Advanced Energy, it is essentially necessary to organize the cooperative research program with much close connection between related research fields in the institute. The laboratory takes charge of organizing and promoting the cooperative research project as a center of research activity in the Institute. The research staffs in the institute participate in specific projects to carry out their subjects. The scientists of other faculties in Kyoto University can also participate in the cooperative project to enhance the progress of research and educational activities. The laboratory also manages various functions such as symposium and seminar for related topics on energy field. The cooperative research activities will be published in a publication edited in the laboratory at the end of the year.

A1 Section of Promotion for International Collaborative Research

This section promotes international collaborative research on advanced energy to lead the field of energy science and technology as an international pioneer. Collaborative researches between the institute and domestic/international organizations are supported towards realization of advanced energy systems as practical applications with contributions to human society. This section also promotes personal exchange, cooperative research activities and multi-lateral collaborative research with industries. Establishment of infrastructure and human resource development are supported for execution of collaborative R&D activities on advanced energy.

A2 Section of Promotion for Advanced Plasma and Quantum Energy

This section promotes studies on advanced plasmas and quantum energy for realizing future energy systems, integrating plasma energy science and advanced energy material research. In particular, based on the results obtained in our related group, we aim at extending the research fields and contributing to human society by utilizing the existing key devices such as Heliotron J, DuET, MUSTER and inertial electrostatic confinement (IEC) device, which have been developed in IAE.

A3 Section of Promotion for Photon and Energy Nano-Science Research

This section promotes studies on photon and energy nano-science for realizing next generation renewable energy system. In particular, functional nano- and bio-materials to utilize solar energy and bio-energy are studied by unifying laser science, nano-technology, and bio-technology. We aim at extending our research fields by utilizing the existing devices such as System for Creation and Functional Analysis of Catalytic Materials, SEMs, SPM, Solar Simulator, TW fs laser, MIR-FEL and so on

B Cooperative use of facilities and equipment

Facilities and equipment of the laboratory are provided to researches cooperated for the scientists in the university.

2. The cooperative research program

A brief summary of the cooperative research subjects carried out in FY2015 are shown next pages, which were proposed by researchers of IAE and selected by the program committee of the Laboratory.

The collaboration works in the Laboratory for Complex Energy Processes are consist of two categories of “Kiban (基盤)” and “Shorei, Kikaku-Chosa (奨励, 企画・調査)” cooperative researches. The former means a program to promote leading research themes of the institute projects, which are proposed by the each chair of the research sections of the Laboratory. The latter means a program to promote seeds research with respect to the institute projects and to promote the organization of seminar or symposium. Every researcher of IAE can make proposal to this category.

As a result, the research themes of 22 were applied and applications of 22 were accepted after the approval by a steering committee of the laboratory. The number of research subjects is listed in Table 1 according to the project categories.

Table 1 Number of the accepted research subjects according to the standard project theme

The whole sum 22

		category A			B	total
		A1	A2	A3		
Kiban	inside	1	1	1	0	3
	outside	0	0	0	0	0
Shorei/Kikaku-Chosa	inside	4	9	6	0	19
	outside	0	0	0	0	0

"inside" or "outside" : Number

The individual research subjects are as follows

Kiban A1

"International Collaborative Research on Advanced Energy Science"
- H. Ohgaki and Staff Researcher of IAE (Kyoto Univ.),
- J. Qika (Univ. Sci. Tech. China),
- P. Kaung (Univ. Yangon),
- Y. U.Jeong (Korea Atom. Energy Res. Inst.),
- D. Wang (Shanghai Inst. App. Phy.),
- M. Abdrahim (Univ. Malaya),
- B. Funtamasan (King Mongkuts Univ. Tech. Thanburi),
- P. Pinpathomrat (Rajamangala Univ. Tech. Thanyaburi),
- H. Saptadi (Univ. Gaja Mada),
- L.K. Ping (National Univ. Singapore)

Kiban A2

"Development of Advanced Plasma and Quantum Energy Studies"
- K. Nagasaki, R. Kasada, S. Ohshima, K. Yabuuchi, S. Konishi, A. Kimura, T. Minami, H. Okada, S. Kobayashi, S. Yamamoto, T. Mizuuchi, S. Konoshima (Inst. Adv. Energy, Kyoto Univ.)
- Y. Nakamura, N. Kenmochi, Y. Ohtani, L. Xiangun (Grad. Sch. of Energy Sci., Kyoto Univ.)
-

Kiban A3

"Research on establishment of Photo-Energy Nano Science"
- H. Sakaguchi and Researchers of Photo-Energy Nano-Science (Inst. Adv. Energy, Kyoto Univ.)

Shorei/Kikaku-Chosa A1

"International Collaboration Research on Plasma Production Using Microwaves"
- K. Nagasaki, S. Yamamoto, K. Masuda, S. Ohshima, K. Sakamoto, T. Mizuuchi, T. Minami, H. Okada, S. Kado, S. Kobayashi, S. Konoshima (Inst. Ad. Energy, Kyoto Univ.)
- T. Stange, N. Marushchenko, H. Laqua (Max Plank Inst., Germany)
- E. Ascasibar, A. Cappa (CIEMAT, Spain)
- F. Volpe (Columbia University, USA)
- Y. Yoshimura (National Inst. Fusion Sci.)
- Y. Nakamura, K. Hada (Grad. Sch. Energy Sci., Kyoto Univ.)

"US-Japan Collaborative Research Ion-irradiation Effects on Materials"
- A. Kimura, K. Morishita, T Hinoki, R. Kasada, K. Yabuuchi, W. Han, S. Kondo (Inst. Ad. Energy, Kyoto Univ.)
- G. Was, G. Jiao, S. Taller (Univ. Michigan, USA)
- S Maloy (LANL. USA)
- B. Weber (Univ. Tennessee, USA)
- S. Tumey (LLNL, USA)
- M. Toloczko (PNNL, USA)
- T. Shibayama, N. Hashimoto (Hokkaido Univ.)
- A. Hasegawa, K. Nagai (Tohoku Univ.)
- N. Sekimura (Univ. Tokyo)
- T. Muroga (National Inst. Fusion Sci.)
- H. Watanabe (Res. Inst. App. Mech. Kyushu Univ.)
- H. Tanigawa (JAEA)

"Developing a mathematical model for construction of nuclear safety agreement between nuclear experts and the general public."
- K. Morishita, R. Xianoyong (Inst. Adv. Energy, Kyoto Univ.)
- H. Iwakiri (Dep. Education, Univ. Ryukyu)
- Y. Yamamoto (Inst. Nuclear Safety System)
- N. Murayoshi (Grad. Sch. Energy Sci., Kyoto Univ.)

"International cooperative activity for developments in plasma density fluctuation measurement systems"
- S. Kobayashi, S. Ohshima, T. Mizuuchi, S. Yamamoto, H. Okada, T. Minami,

K. Nagasaki, S. Konoshima (Inst. Adv. Energy, Kyoto Univ.)
- C. Deng, D.T. Anderson (Univ. Wisconsin-Madison, USA)
- G. Weir (JSPS)
- S. Torsten (Max-Plank Institute for Plasma Physics)
- L. Hyunyong (Korea Adv. Inst. Sci. Tech.)
- Y. Suzuki, K. Nagaoka, T. Ohishi, S. Okamura, K. Mukai (National Inst. Fusion Sci.)
- Y. Nakashima (Univ. Tsukuba)
- S. Murakami (Dep. Nucl. Eng., Kyoto Univ.)
- Y. Nakamura (Grad. Sch. Energy Sci., Kyoto Univ.)

Shorei/Kikaku-Chosa A2

"Development of reduced activation ferritic/martensitic steels to improve the tolerance to the irradiation damage"
- K. Yabuuchi, A. Kimura (Inst. Adv. Energy, Kyoto Univ.)

"Development of scintillator type lost fast ion probe in Heliotron J"
- S. Yamamoto, K. Nagasaki, S. Kobayashi, T. Mizuuchi, H. Okada, S. Kado, T. Minami, S. Ohshima, S. Konoshima (Inst. Adv. Energy, Kyoto Univ.)

"Measurement of the impurity line spectra in Heliotron J for the plasma diagnostics"
- S. Kado, H. Okada, S. Yamamoto, T. Mizuuchi, K. Nagasaki, T. Minami, S. Ohshima, S. Kobayashi, S. Konoshima (Inst. Adv. Energy, Kyoto Univ.)
- Y. Nakamura (Grad. Sch. Energy Sci., Kyoto Univ.)

"Study on Prompt Gamma-Ray Analysis for Development of Delivery Agents for Neutron Capture Therapy"
- K. Masuda, E. Nakata (Inst. Adv. Energy, Kyoto Univ.),
- Y. Uto, M. Nakamura (Grad. Sch. Tokushima Univ.)

"Challenge to super thermal conductive materials by dispersion of liquid-gas phase in metal-matrix"
- R. Kasada, S. Konishi (Inst. Adv. Energy, Kyoto Univ.)
- R. Ishira, K. Aoki (Grad. Sch. Tokushima Univ.)

"Study of isotope effect realization on improved confinement mode for advanced helical plasma"
- T. Minami, T. Mizuuchi, S. Kado, H. Okada, S, Kobayashi, S. Yamamoto, S. Ohshima, S. Konoshima (Inst. Adv. Energy, Kyoto Univ.)
- K. Tanaka (National Inst. Fusion Sci.)

"Advanced maintenance technology for nuclear energy systems"
- K. Morishita (Inst. Adv. Energy, Kyoto Univ.)
- H. Nakamura, D. Kato (National Inst. Fusion Sci.)
- M. Miyamoto (Interdisciplinary Faculty of Sci. Eng., Shimane Univ.)
- H. Iwakiri (Dep. Education, Univ. Ryukyu)
- Y. Kaneta (Akita National Coll. Tech.)
- Y. Watanabe (JAEA)
- X. Qui (Kyoto Univ. Res. Reactor Inst.)
- T. Nakasuji (Grad. Sch. Energy Sci., Kyoto Univ.)

"Development and application of fluctuation analysis technique using analytic signal"
- S. Ohshima, T. Mizuuchi, S. Kobayashi, H. Okada, K. Nagasaki, S. Yamamoto, S. Konoshima, G. Weir (Inst. Adv. Energy, Kyoto Univ.)

"Study of fast-ion confinement and ion heating in non-axisymmetric magnetic field by using ICRF heating"
- S. Kobayashi, S. Yamamoto, T. Minami, S. Ohshima, T. Mizuuchi, K. Nagasaki, S. Kado (Inst. Adv. Energy, Kyoto Univ.)
- T. Mutoh (National Institute for Fusion Science)
- Y. Nakashima (Univ. Tsukuba)
- N. Nishino (Grad. Sch. Eng., Hiroshima Univ.)
- Y. Nakamura (rad. Sch. Energy Sci., Kyoto Univ.)

Shorei/Kikaku-Chosa A3

"Analysis of structure-function relationships on wood degrading enzymes for better utilization of woody biomass"
- T. Nagata, M. Katahira, T. Morii, T. Kodaki, E. Nakata (Inst. Adv. Energy, Kyoto Univ.)

"Characterization of Pulse Property of Mid-Infrared Laser under the Photocathode Operation of KU-FEL"
- H. Zen, T. Nakajima, H. Ohgaki, K. Masuda, T. Kii (Inst. Adv. Energy, Kyoto Univ.)

"Development of a highly efficient bioethanol production yeast by genetic engineering"
- T. Kodaki (Inst. Adv. Energy, Kyoto Univ.)
- S.M.R. Khattab (Microbial Biotech. at Botany and Microbiology Dep., Al Azhar Univ., Assiut Branch)

“Development of Compact THz-FEL System”

- H. Ohgaki, K. Masuda, T. Kii, H. Zen (Inst. Adv. Energy, Kyoto Univ.)
- S. Suphakul (Grad. Sch. Energy Sci., Kyoto Univ.)
- K. Damminsek (Chaingmai Univ.)

“Development of the Methodology to Construct the High-efficient Material Conversion System on DNA Nanostructure”

- E. Nakata, T. Morii, T. Kodaki, M. Saimura (Inst. Adv. Energy, Kyoto Univ.)

“Analysis of the biomolecular energetics and intermediates involved in the G-quadruplex formation using DNA nanostructure”

- A. Rajendran, T. Morii, E. Nakata, S. Nakano, M. Katahira, T. Nagata, M. Saimura (Inst. Adv. Energy, Kyoto Univ.)

THE LABORATORY SEMINARS

Laboratory Seminars

The Laboratory promotes topical academic seminars in order to strengthen the research activities in each research section and to enhance the mutual cooperation among a lot of academic fields. The Laboratory also had a symposium on April 8, 2016 for discussions of the cooperative research results in FY2015.

In FY2015, six topical seminars were held with following themes.

1. Topical Seminars

(1) **July 7, 2015**

K. Nagaoka,
"Physics experiment on structure formation and transport in turbulence–beyond plasma physics – "
National Institute for Fusion Science

(2) July 6, 2015

H. Tay Lin
"Advanced Ceramics for Clean and Efficient Energy Technologies"
Guangdong University of Technology, China

(3) July 28, 2015

K. Hiramatsu,
"Risk assessment and safety education",
Environmental Safety Management Center, Kyoto University

(4) August 13, 2015

M. Hammond,
"RNA-based Fluorescent Biosensors for Visualizing Enzyme Reactions in Vivo"
University of California, Berkeley, USA

(5) January 27, 2016

G. Tynan,
"Plasma-materials Interaction research needs for next-step fusion energy research"
University of California, San Diego, USA

(6) February 3, 2016

Y. Ohno,
"Carbon nanotube electronics"
Institute of Materials and Systems for Sustainability, Nagoya University

6. PROJECTS WITH OTHER UNIVERSITIES AND ORGANIZATIONS

Innovative strategy for highly efficient utilization of solar energy "Exploring novel principles for highly efficient utilization of solar energy"

The MEXT special budget project in its second year pursued three main research topics including efficient conversion of solar energy to electricity, production of solar fuels, and efficient conversion of biomasses to useful chemicals.

Efficient conversion of solar energy to electricity

Prof. Matsuda's group studied development of a novel strategy for light energy utilization in his research entitled "Toward efficient light energy applications using novel nano-materials." Recent studies for development of novel solar light energy utilization using nano-carbon materials (carbon nanotube and graphene oxide) were discussed. As an introduction, the fundamental aspect of nano-materials and their potential application for the solar light energy utilization were introduced. Then, he presented about considerably improvement of photovoltaic performance in carbon nanotube/Si heterojunction solar cell. The high photovoltaic conversion efficiency of 17% was realized by our new strategy using efficient hole transport layer. This result is a key achievement toward the utilization solar light energy.

Prof. Sakka studied optics of solar cell surfaces in his research "Colloidal particle uptake into growing metal thin film electrode at a liquid-liquid interface." For the utilization of silicon as a photoelectrode, It is well known that monodisperse polystyrene particles form two-dimensional arrayed structures at an oil/water interface with a large interparticle distances due to the large electrostatic repulsion. We have shown that this structure could be taken into an electrodeposited metal thin film growing at the interface. Interaction between the thin-film electrode and nearby particles, which is a key to clarifying this phenomenon, was discussed.

Prof. Sagawa's group studied the principle of hybrid solar cells by his research entitled "Band Alignment of Organic and Inorganic Materials for Hybrid Solar Cells." Chalcopyrite structures of $(AgIn)xZn_2(1-x)S_2$ with 3 different amounts of Zn (x = 0.6, 0.8, and 1.0) having their crystallite sizes ranged from 2 nm to 6 nm were prepared and applied for hybrid organic-inorganic solar cells with 3-hexylthiophene (P3HT). Varying the Zn ratio and/or substitution of the ligand from oleylamine to pyridine is enabled to adjust the bandgaps to that of P3HT.

Prof. Nohira's group developed new processes for the production of solar-grade silicon by molten salt electrolysis. With the aim of developing a new production process for the solar-grade silicon, we have investigated the electrochemical reduction of SiO_2 granules in molten CaC_{l2}. We have clarified the reaction mechanism and kinetics. We have also investigated the electrode position of Si from molten KF–KCl as an alternative method to prepare the crystalline Si substrate for photovoltaics.

Prof. Ohgaki's group carried out a research on “Study on phonon excitation in energy materials by MIR-FEL" at Institute of Advanced Energy, Kyoto University. The group has directly demonstrated mode-selective phonon excitation by mid-infrared free electron laser (MIR-FEL) with anti-Stokes Raman scattering spectroscopy. As the next step, to clarify the dynamics of a phonon selectively excited by a MIR laser (KU-FEL), we developed a phonon dynamics measurement system consisted of a pico-second laser and MIR-FEL (KU-FEL).

Production of solar fuels

Prof. Morii's group studied on the sequential enzymatic reaction by spatially arranged enzymes. Protein-based adapters were utilized to locate the individual enzyme molecules to defined addresses on the molecular switchboard. This strategy enables the reconstitution of natural enzyme cascades outside the cell to realize an artificial photosynthesis system made by biomolecules.

Prof. Sakaguchi's group reported the synthesis of graphene nanoribbon (GNR), which was predicted to behave as semiconductor in the research of " Evolutionary growth of graphene nanoribbons." His group demonstrated large-scale growth of all types of armchair-edged GNRs (3p, 3p+1, and 3p+2; p is defined as the number of carbon atoms along the width) on Au(111) even in extremely low-vacuum conditions using our newly developed method, radical-polymerized chemical vapor deposition (RP-CVD). Armchair-edged GNRs with a width of 2, 3, or 4 benzene rings, grown on a large scale, can form the isolated films, which can be used to characterize the experimentally unknown width-dependent band gap and can also be used to fabricate devices such as field effect transistors (FETs) and photoconductive devices.

Efficient conversion of biomasses to useful chemicals

Wood biomasses are produced by solar energy. Therefore, development of new bio-refinery methods also contributes on exploring novel principles for highly efficient utilization of solar energy. Although NMR is recognized as one of the most powerful tool to achieve this and is widely used in many fields, variation in a molecular size of components distorts quantitation due to size-dependent decay of magnetization. Prof. Katahira’s group studied lignin-carbohydrate complex (LCC) by NMR. Three major components of wood biomass are cellulose, hemicellulose and lignin. It is critical to identify the mode of the lignin-carbohydrate (LC) linkage for efficient utilization of wood biomass. The key information was obtained by NMR on the basis of long-range HMBC correlations. 3D HSQC-TOCSY gave further information. Thus, the presence of the benzyl ether LC linkage was clearly demonstrated.

Bidirectional Collaborative Research Program on Heliotron J

Since 2004, the Heliotron J group at Kyoto University has joined the Bilateral Collaboration Research program proposed by an inter-university research institute, National Institute for Fusion Science (NIFS). Under this program, the facilities in relating research institutes or centers of universities is open to researchers throughout Japan as a joint-use program of NIFS. The purpose of this program is to extend the activities of nuclear fusion research at universities by promoting collaborative research activities for comprehensive understanding of toroidal plasma physics.

The main objective of the research in our group is to improve the confinement and stability performance for advanced helical magnetic configurations such as the helical-axis heliotron, Heliotron J. Six key topics for the collaboration research are picked up in FY2015; (1) confinement improvement by magnetic configuration control and related plasma self-organization physics, (2) ECH/EBW heating physics, (3) NBI plasma formation with assistance of microwaves and high-beta plasma confinement (4) boundary plasma control, (5) instability suppression by magnetic configuration control, (6) toroidal plasma current control. The some results are described below. An annual report for all of the collaboration subjects in this program are published by NIFS.

Study of three-dimensional magnetic field configuration effects on the electron internal transport barrier (eITB) [1]: The eITB is considered to play an important role for the helical plasma confinement improvement. In Heliotron J, the eITB phenomena are observed in ECH plasmas, where the radial gradient of electron temperature T_e becomes large at a radial position. This gradient substantially depends on the line-averaged electron density $\bar{n}_e$. The T_e gradient near $\rho = 0.1$ of the normalized minor radius clearly increases for $\bar{n}_e \leq 1.2\times10^{19}\,m^{-3}$ under the ECH power of ~ 0.33 MW. The similar phenomenon was observed in other helical devices with different configurations such as CHS in NIFS, however, the gradient is not so large and the gradient change is observed at a larger ρ value in CHS. In a high electron temperature helical plasma, eITB is considered to be driven through the large radial electric field formation due to the transition to the "electron root" in the neo-classical transport. This experiment in Heliotron J give a good chance to understand the three-dimensional magnetic field effects on eITB.

Fast plasma production using neutral beam injection (NBI) heating with assistance of none-resonant micro waves [2]: The plasma production only with NBI heating has been demonstrated in LHD and W7-AS, where the beam path length of NB is long enough. On the other hand, the pre-ionization is very useful in the case of short beam path length in the plasma or quick production requirement. In Heliotron J, a pre-ionization method with a low-power (< 20 kW) 2.45 GHz microwave injection scheme successfully accelerates the sound start-up of NBI plasma for the magnetic field strength from 0.6 T to 1.3 T. The ECE measurement confirms the production of high energy electrons by the microwaves. Controlling the gas-fueling and NBI timing effectively increases electron density up to $0.45\times10^{19}\,m^{-3}$ in the pre-ionization phase. Further gas puffing in a later timing of NBI pulse easily increases electron density more than $1.0\times10^{19}\,m^{-3}$. This procedure has a critical electron density of $2\text{-}3\times10^{17}\,m^{-3}$ in the pre-ionization plasma produced only by the micro waves.

Fast ion generation using combination heating of ion cyclotron range of frequencies (ICRF) and NBI [3]: Since "self-heating of plasma" by alpha particles is essential for fusion reactors, the study on the behavior of high energy ions is important. The fast ion generation and confinement are studied by using ICRF minority heating (H minority and D majority) and NBI heating. The energy range is extended from the injection energy of the NBI beam (25 keV) to 60 keV during the ICRF pulse for a medium density operation ($1\times10^{19}\,m^{-3}$) in the low-ε_t configuration. This configuration is suitable for the fast ion generation and confinement from the viewpoint of neo-classical theory than that in the high bumpiness configuration, which shows the best performance in the bumpiness scan experiments. The observed fast ions in the high bumpiness configuration are limited up to 35 keV for the same heating conditions. The Monte-Carlo calculation also shows that the larger high energy tail in the ion energy distribution is formed in the low-ε_t configuration.

References

[1] T. Minami, et al., "3D magnetic field effect on electron internal transport barrier in Heliotron J", 20th International Stellarator/Heliotron Workshop (ISHW), Greifswald, Germany, 5-9 Oct., 2015, S1-I4.

[2] S. Kobayashi, et al., "Rapid NBI plasma initiation using pre-ionization method by non-resonant microwave injection in Heliotron J", ibid., S3-O2

[3] H. Okada, et al., "Magnetic field optimization study for fast ions generated by ICRF heating in Heliotron J", ibid., P2S3-36.

Application of DuET and MUSTER for Industrial Research and Engineering (The ADMIRE Project)

1. Introduction

The ADMIRE Project at the Institute of Advanced Energy (IAE), Kyoto University is one of the MEXT (Ministry of Education, Culture, Sports, Science and Technology of Japan) -supported programs "*Project for Creation of Research Platforms and Sharing of Advanced Research Infrastructure*" to provide private companies with utilization of experimental facilities and expertise of IAE, Kyoto University. The DuET Facility i.e. dual beam ion accelerator system with a dedicated specimen irradiation stage, and the MUSTER Facilities consisting of high-performance TEM, SEM, FIB, EPMA, Auger, etc. are included in this program. Technical guidance to operate experimental equipment and consulting on the experimental results is also offered to the users. In the "Trial use mode" the users can use these facilities free of charge for a limited time period.

2. Project details

The ADMIRE Project was launched in 2006. The DuET and MUSTER are two of the representing facilities in the IAE dedicated for the research of energy science and technology, with the special emphasis on fusion and fission reactor materials R&Ds. The ADMIRE Project aims to provide the private industries with the research resources of IAE. Research topics accepted by the ADMIRE Project are NOT restricted to fission or fusion reactor materials, nor energy science and technology. We welcome proposals from a variety of fields all over the world.

The ADMIRE Project has four modes of facility use: a) Trial use mode, b) Charged use mode-X (exclusive use of data), c) Charged use mode-N (non-exclusive use of data), and d) Collaborative use.

a) Trial use mode

In this mode, users are allowed to utilize the ADMIRE facilities free of charge for six months for the MUSTER facilities or twelve months for the DuET facilities. The term may be repeated once if requested and approved. The only obligation of the user is to submit a short report at the end of the term. If the user requests to postpone the immediate dissemination of the outcome in order to secure its IPR, a moratorium up to two years may be given.

b) Charged use mode-X (exclusive use of data)

This mode is programmed for those users who have strong interests on the intellectual property rights to be obtained through the ADMIRE utilization. There is no obligation to submit reports, etc. to the ADMIRE. The subject title and the name of the user may be kept undisclosed if the user so requests.

DuET, the dual-ion beam irradiation facility

c) Charged use mode-N (non-exclusive use of data)

This mode is similar to the mode-X but is different only in that submission of a report is obligatory. The charge rate for facility use is lower compared to the mode-X.

d) Collaborative use

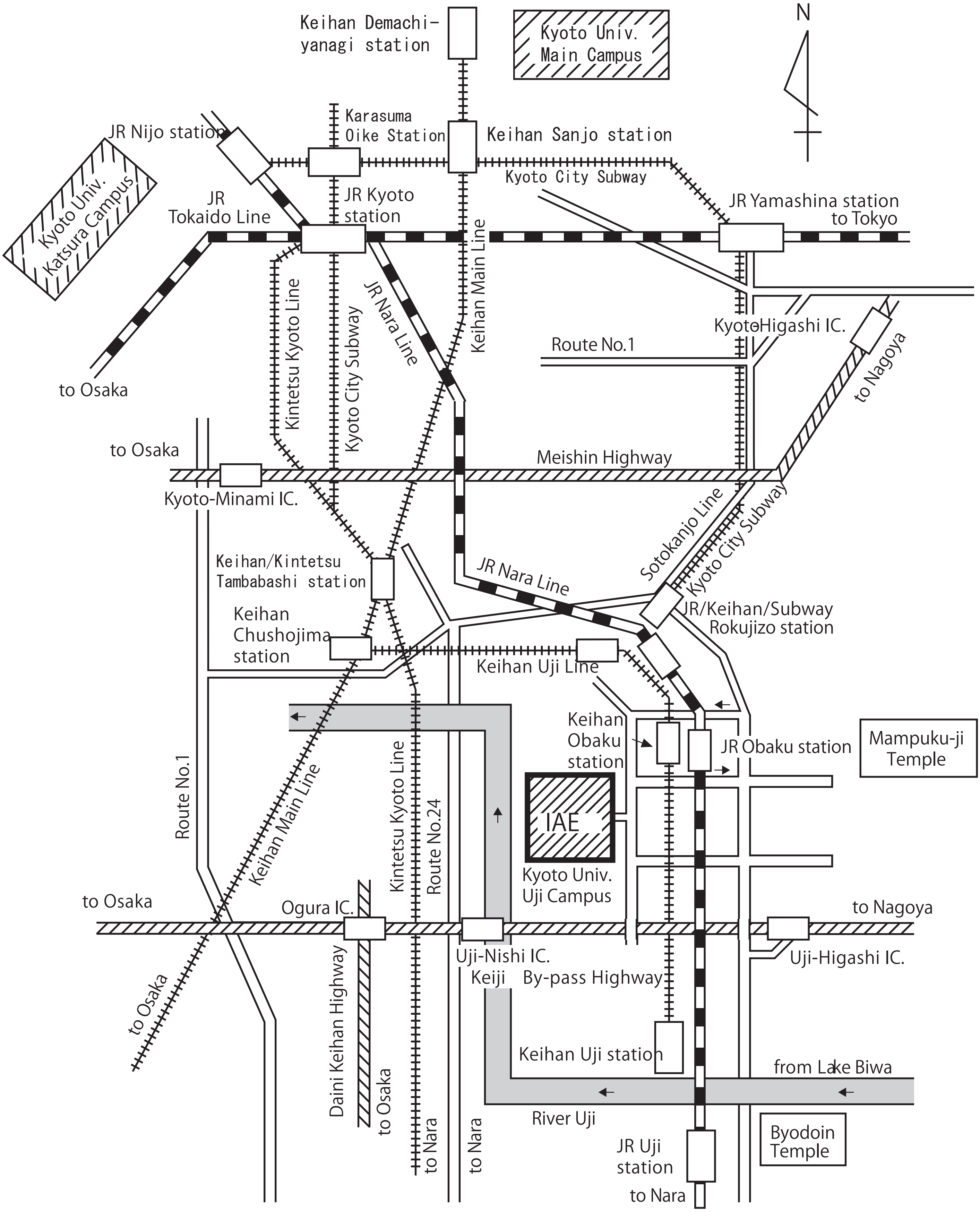
This mode is similar to the standard collaborative research conducted jointly by private companies and university staff under a contract to which both parties agreed. This is not just utilization of the facility but full collaboration on specific subjects.

3. Benefits for companies

- Rapid progress of products development by use of high performance equipment
- Reduction of expenditure for equipment
- Rapid exploration of new idea
- Training of equipment operation and consulting on experimental results are available

for details, please visit our website at:
http://admire.iae.kyoto-u.ac.jp/

7. HOW TO GET TO THE IAE



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