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Institute of Advanced Energy
Kyoto University

ANNUAL REPORT 2013

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

ANNUAL REPORT

2013

Institute of Advanced Energy
Kyoto University

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CONTENTS

FOREWORD

Since it was launched in May 1996, the Institute of Advanced Energy (IAE) has pursued research aimed at the development of energy science and the creation of advanced technology that drives it. This work, which is outstanding both in terms of environmental harmony and social acceptance, is conducted by 3 divisions and 14 research sections (including two with guest researchers) that engage in research on energy generation, conversion, and advancement, as well as the Laboratory for Complex Energy Processes, which specializes in highly project-oriented cross-disciplinary R&D. Under the new university operation guidelines that took effect when the institute became a National University Corporation in 2004, IAE pursued its first six-year medium-term plan (2004-2009) and associated goals. In the current academic year (2013) IAE is entering the second half of its second medium-term plan and goals (2010-2015).

IAE is leveraging its track record and strengths as a research institute to focus on “advanced plasma and quantum energy” and “photon and energy nano-science” as fields of vital importance. It is devoted to R&D on nuclear fusion and advanced atomic energy, for which these disciplines serve as a scientific foundation, on distributed energy sources, typified by sunlight and biological systems, and on the advanced materials and effective energy utilization systems that support these technologies.

Since AY2011, IAE has been recognized by the Ministry of Education, Culture, Sports, Science and Technology as a Joint Usage/Research Center for Zero-Emission Energy Research (2011-2017) and has been functioning for three years. In the current academic year, IAE is undergoing an interim assessment and this research center was evaluated as “increasing its research performance in a wide range of fields, from scientific fundamentals to technological application in advanced energy.” In the coming years we plan to ramp up our efforts in the areas of zero-emission energy research and community formation.

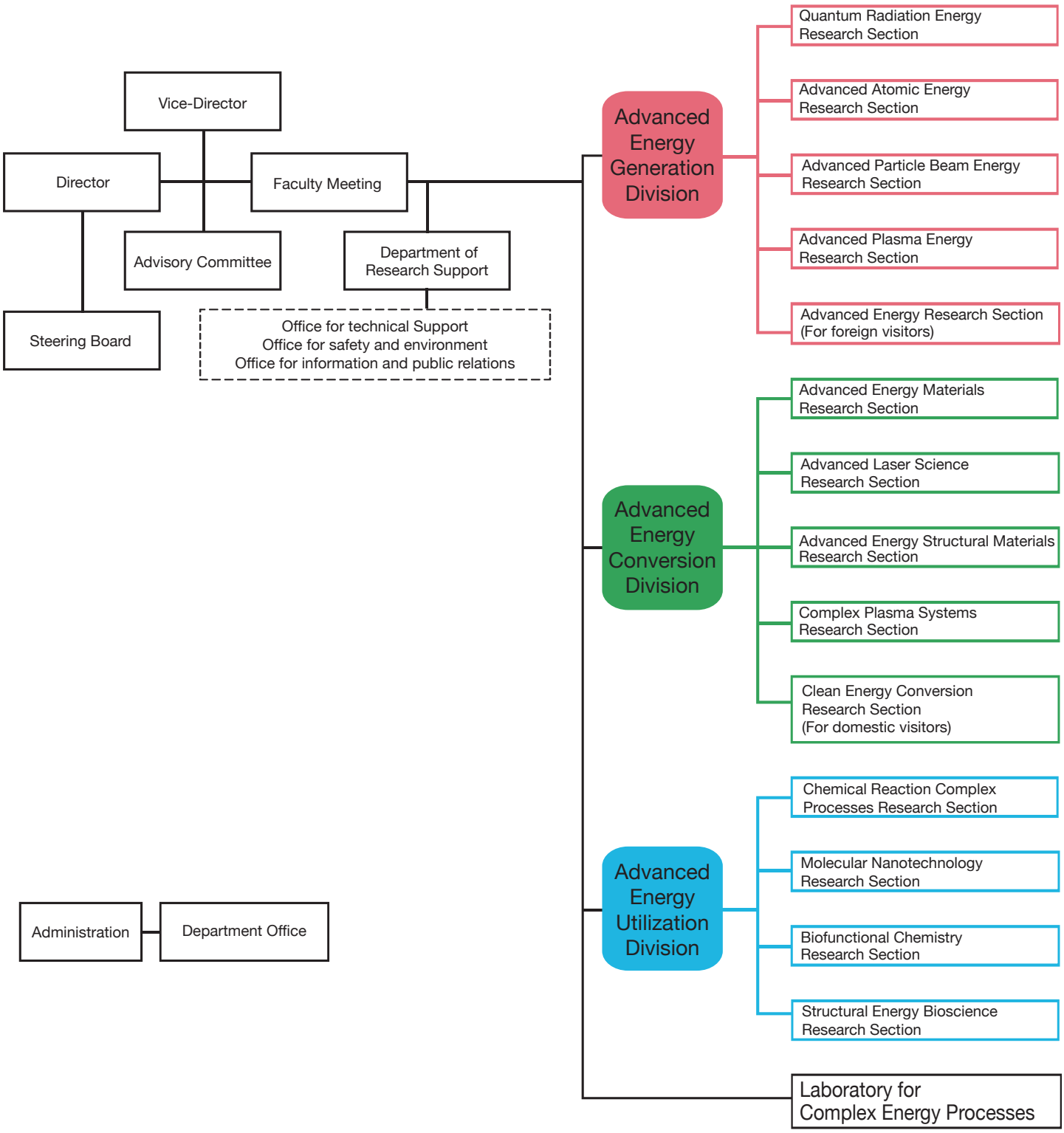
This academic year, IAE was also approved for the development of “innovative strategy for highly efficient utilization of solar energy” (by the Ministry of Education, Culture, Sports, Science and Technology: 2013-2018), with the expectation of advancing energy research based on new bio, optical, and nano-technologies. Furthermore, in addition to pursuing research on boosting the performance of nuclear fusion plasma and on technology for the recovery and utilization of nuclear fusion energy, through a bidirectional collaborative research program with the National Institute for Fusion Science, the “Promotion program of cooperation between industries and universities/national institutes by using advanced facilities” (2013-2018: Ministry of Education, Culture, Sports, Science and Technology) was started, in which IAE is actively performing joint research through industry-government-academia partnerships.

This year’s report summarizes the IAE’s research findings for the year. Three years have now passed since the Great East Japan Earthquake of March 2011, and amidst the persistent effort toward recovery by the Japanese government and people, the role and responsibility of universities have become even more important. Recognizing this, Kyoto University is working hard on a variety of fronts, to redefine its mission as a university, to formulate educational reforms and innovations, and to promote greater internationalization. In view of this, IAE feels a strong sense of social responsibility, to keep striving, harder than ever, as a key organization for energy research.

March 2014

Yasuaki KISHIMOTO
Director
Institute of Advanced Energy
Kyoto University

2. ORGANIZATION CHART



3. RESEARCH ACTIVITIES

3-1. RESEARCH ACTIVITIES IN 2013

Quantum Radiation Energy Research Section

H. Ohgaki, Professor
T. Kii, Associate Professor
H. Zen, Assistant Professor
(T. Hori, Specially Appointed Professor)
(K. Miura, Specially Appointed Professor)
(Izuru Daito, Researcher)
(Janewit Wannapeera, 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 energy recovering system, 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 tunable IR laser will be used for basic researches on energy materials and systems, such as high-efficiency solar cells, energy conversion in bio materials. 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 an optical resonator.

We have installed the 1.8-m undulator as the replacement of a 1.6-m undulator which has been used for FEL lasing. At the same time, the optical resonator mirrors have also been replaced with new ones for smaller optical loss and higher gain. Then the predicted tunable range of KU-FEL was at least 5-16 μm. After some effort to obtain good operational condition, we achieve the tunable range of 5-20 μm.

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 an UV-laser system for illuminating photo-cathode has been started under collaboration with Dr. R. Kuroda, Researcher of AIST. In this fiscal year, generation of enough high UV-laser power has been achieved and first multi-bunch photo-electron beam was generated from LaB_6 cathode. The amount of electron in one electron bunch is not sufficient for driving FEL. Therefore, further adjustment is required and will be performed in next year.

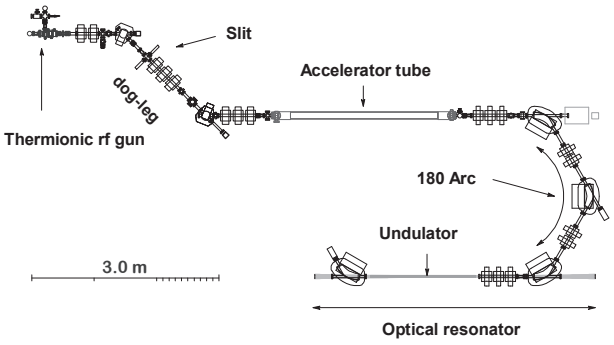


Fig. 1 Schematic drawing of the KU-FEL

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. A mid-infrared (MIR) pulse laser is suggested as a tool for MSPE. However, MSPE by a MIR pulse laser has not been demonstrated directly. Therefore, the direct demonstration of MSPE by a MIR pulse laser was conducted via anti-Stokes Raman scattering measurements of 6H-silicon carbide (SiC). A MIR free electron laser (KU-FEL : MIR-FEL) was used as a MIR pulse laser. Irradiation of SiC with MIR-FEL and a Nd-YAG laser at 14K produced a peak where the Raman shift corresponds to a photon energy of 119 meV (970

cm^{-1} : 10.4 μm) as shown in Fig. 2. This phenomenon is induced by MSPE through the irradiation of MIR-FEL, whose photon energy corresponds to the photon-absorption of a particular phonon mode. Herein, MSPE by a MIR pulse laser on 6H-SiC was demonstrated directly by anti-Stokes Raman scattering spectroscopy.

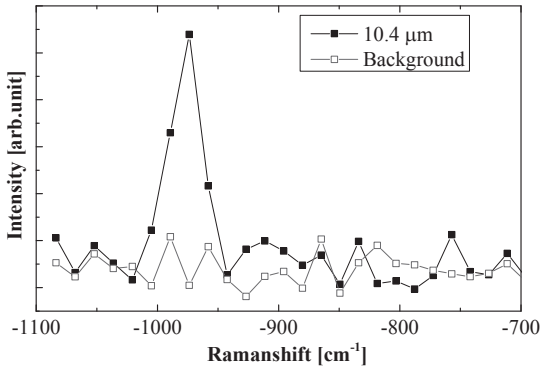


Fig. 2 Anti-Stokes Raman scattering spectra with and without MIR-FEL (10.4 μm) irradiation at 14 K.

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 proposed the bulk high critical temperature superconductor staggered array undulator (Bulk HTSC SAU) in order to generate a strong periodic field. 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.

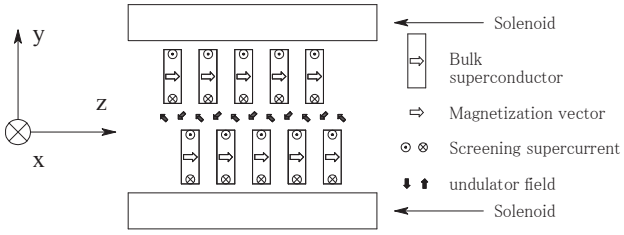


Fig. 3 Conceptual drawing of the bulk HTSC SAU and generation principle of the periodic undulator field using an induced current.

We have constructed the prototype of the undulator which consists of 12 pieces of GdBaCuO bulk superconductor and a superconducting solenoid. At the condition of λ_u = 10 mm, gap = 4 mm, and $T_{operation}$ = 6 K, the undulator field B_0 of 0.85 T have been achieved. The demonstrated field strength is stronger than the limit of the conventional undulator using permanent magnet.

4. Non-destructive Isotope Detection using NRF

A Nuclear Resonance Fluorescence (NRF) measurement is a powerful tool for investigation not only of the nuclear physics, but also of isotope detection for the homeland security such as a nondestructive measurement of containers at airports or harbors, detection or identification of special nuclear materials (SNM). The required performances of the detector used in the NRF facility are high energy resolution, high full energy efficiency, and high counting rate. $LaBr_3$(Ce) scintillator is a strong candidate to meet these requirements because of its superior energy resolution and high counting rates. We have constructed a 8 $LaBr_3$(Ce) detector array consisted of 1.5 inches in diameter and 3 inches in length. The performance of the array detector has been examined in the HIγS facility in Duke University, North Caronia. We successfully obtained NRF signal from ^{235}U target in 1.733 MeV resonance level by using the array detector.

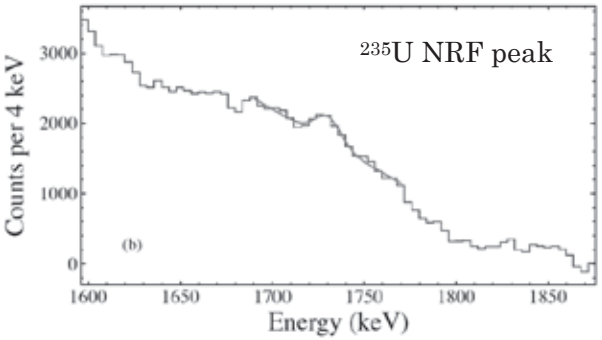


Fig. 4 Spectrum of the NRF measurement in ^{235}U by using $LaBr_3$(Ce) scintillator array detector.

Acknowledgment

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吉田恭平，特別研究員奨励費，中赤外自由電子レーザーによる選択的格子振動励起の検証と電子状態への影響

2. Others

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大垣英明，新日鐵住金（株），改質炭の二次熱分解挙動の研究

大垣英明，新日鐵住金（株），低品位鉄鉱石と低品位炭素資源からの公還元性・高ガス化反応性鉄鉱石・炭材コンポジットの製造

大垣英明，政府開発援助ユネスコ活動費補助金，カンボジアにおける持続可能な発展のためのエネルギー科学教育の推進

大垣英明，先導的創造科学技術開発費補助金，安全・安心な社会のための犯罪・テロ対策技術等実用化プログラムガンマ線による核物質非破壊検知システム

大垣英明，大学改革推進等補助金（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

三浦孝一，NEDO 共同研究（新日鐵住金），低品位鉄鉱石と低品位炭素資源からの高還元性・高ガス化反応性鉄鉱石・炭材コンポジットの製造

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三浦孝一，（独）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
Y. Takeuchi, Assistant Professor

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 generation, conversion and utilization systems. The atractiveness of the total energy system considered by the socio-economic analysis of future society and markets 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 fusion 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 endothermic reaction to generate hydrogen and liquid fuel
(4) Design and analysis of DC microgrid 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. High-performance divertor system design for advanced fusion reactor

The target surface of divertor takes high heat flux from plasma in fusion reactor. Removal of heat generated on the surface of divertor is one of the most difficult problems that should be solved for realization of fusion reactor. Besides, high temperature heat transfer medium should be collected for the efficient utilization of energy. This study analyzed thermal conduction behavior of composite material for the application to the divertor target. Steady state analysis was conducted using finite element method. Fiber with circular cross section is arranged into matrix regularly or irregularly to express actually produced specimen. Mesh size of each model was 1μm, and directions of fiber to thermal conduction are 0, 45, 90 and degree, respectively. Uniform heat flux is applied to the top surface of each model, and temperature of the bottom surface in each model, is assumed to be controlled at 600°C, assuming a large capacity coolant at the stable temperature is fed to the surface. In the steady state, temperature on top surface of each model was measured 1μm apart. Thermal conductivity of each model was evaluated by average of the temperature. From results of analysis, calculated thermal conductivity of the composite was enhanced almost proportionally to volume fraction of fiber when heat flux and fiber are parallel. However, heat conduction was found to be affected by direction, distribution and arrangement of fiber. Heat conduction in the composite was found to be rather complicated and simple equation could not express it.

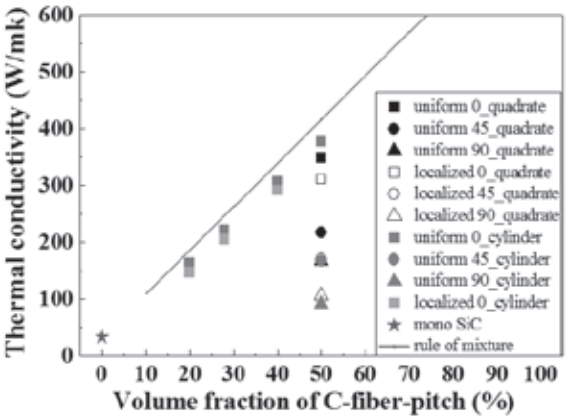

Fig. 1 Thermal conductivity of composite consisting of C-fiber (pitch) and SiC according to volume fraction of fiber.

3. Operation scenario of DT fusion plant without external initial tritium

Although tritium as DT nuclear fusion fuel exists about 20 kg in the world, the most of tritium will be burned and disappear after ITER operation. Now, Darlington plant in Canada and Wolsong plant in South Korea are merely available commercial source

of tritium, which extracts tritium from heavy water reactor. When other DT fusion project will be started, the quantity of tritium will be insufficient. Therefore, in order to launch DT fusion project after ITER, the proposal of management plan could be a critical issue for tritium fuel reservation. It is widely believed that initial loading of tritium is inevitable for fusion plants.

We have proposed a scenario to obtain initial tritium to reach steady state DT operation by DD commissioning phase of the fusion plant. By the DD reaction, resulted T and neutron that produces T in the breeding blanket will be accumulated. A neutronics of LiPb liquid blanket with 90% enriched lithium-6 was evaluated with neutron transport code MCNP-5.14 using FENDL-2.1 data libraries. System dynamics code STELLA was used for the analysis of tritium system and the scenario of the breeding. As the result, calculated local tritium breeding ratio in the blanket is 1.14 by DT neutron and 0.80 by DD neutron. The required extension period of DD commissioning operation without initial tritium is estimated closely 124 days, depending on the coverage and inventory. These results reveal that launching DT fusion projects without initial tritium is possible with additional DD operation period to obtain extra tritium to start up DT operation.

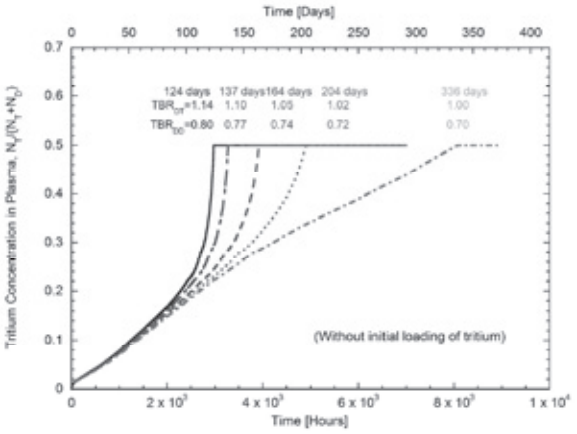

Fig. 2 Time-evolution of tritium concentration in plasma without initial loading against the different TBR.

4. Study on flow instability for feasibility of a thin liquid film first wall

This study proposes a probability of the evaporated gas that agitates a growing instability wave in a thin liquid film first wall. The liquid first wall was considered to be in vacuum and the effect of the ambient gas was neglected but the evaporated gas by the high energy fluxes is a probable cause of unstable wave agitation. The criterion is approximately expressed by the density ratio (Q_2) and the Weber number (We) as $Q_2 \times We^{0.5} \approx 5 \times 10^{-4}$. Performed indirect experimental supported this criterion. For a case study of liquid Pb-17Li film with a velocity of 10 m/s, the evaporated gas pressure must be below 6.2×10^3 Pa to maintain stable conditions. By recent study, this pressure is generated at 1600 K temperature and it is believed to be attainable by the energy fluxes on the first wall. This result is so far not confirmed so the full verification by experimental is to be performed.

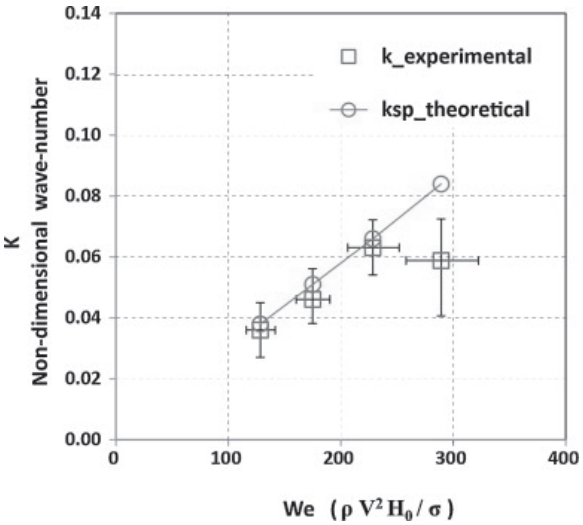

Fig. 3 The observed largest amplitude wave number k (□) as a function of Weber number (We). The theoretically predicted largest amplitude wave number ksp (○) is also plotted. At We < 230, the observed results agree with the theory. At We = 290, the observed results deviate from the theory. A shift to another wave mode is predicted to occur between 230 and 290, due to the decreasing growth time constant.

5. Neutronics and pumping power analyses on the Tokamak reactor for the fusion-biomass hybrid concept

A concern for the small power reactor including a fusion-biomass combined concept is the coolant pumping power which may significantly decreases the apparent energy outcome. Thus pressure loss and corresponding pumping power were studied for a designed Tokamak reactor: GNOME. First, 3-D Monte-Carlo neutron transport analysis for the reactor model with dual-coolant blankets was taken in order to simulate the tritium breeding ability and the distribution of nuclear heat. Considering calculated concentration of nuclear heat on the in-board blankets, pressure loss of the liquid LiPb at coolant pipes due to MHD and friction forces was analyzed as a function of fusion power. It was found that as the fusion power increases, the pressure loss and corresponding pumping power exponentially increase. Consequently, the proportion of the pumping power to the fusion power increases as the fusion power increases. In case of ~360 MW fusion power operation, pumping power required for in-board cooling pipes was estimated as 1~1% of the fusion power.

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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. Main research subjects are now focused on the following; 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 plasmas and production/diagnostics of highly brilliant relativistic electron beams for advanced light sources such as free electron lasers.

2. ECRH Assisted Plasma Start-Up in JT-60SA Superconducting Tokamak

In superconducting tokamaks, inductive toroidal electric field applied for plasma production is limited generally in the lower range of 0.3-0.5 $V \cdot m^{-1}$, which makes stable plasma start-up difficult. The method of electron cyclotron resonance heating (ECRH) assist has been proposed to realize stable plasma start-up and demonstrated successful result on JT-60U, DIII-D, and KSTAR. Recently, the method is also planned to apply to the start-up of JT-60SA superconducting tokamak plasma where the device is now under construction in JAEA. The main purposes of this study are to understand the physical mechanism in the initial plasma start-up phase and to examine conditions for reliable start-up in JT-60SA.

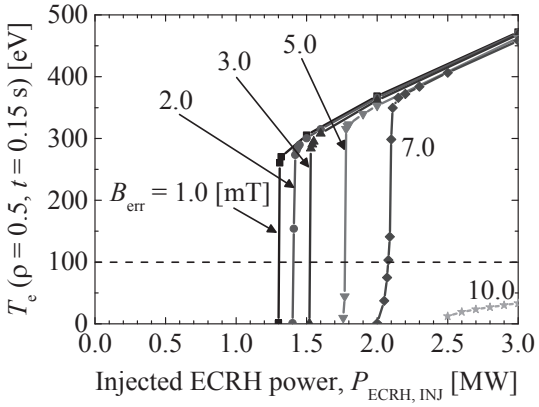

Fig. 1 Dependence of electron temperature on injected ECRH power in the cases of different error field of 1.0-10.0 mT.

In order to investigate the 2nd harmonic X-mode ECRH assisted start-up in JT-60SA, we have developed a one-dimensional (1-D) model including the five transport equations: energy transport equations for electrons and ions, particle transport equations for electrons and hydrogen atoms, and toroidal current equation, which are solved for a cylindrically-symmetrical plasma. Figure 1 shows the dependence of the electron temperature at ρ = 0.5 and t = 0.15 s on injected ECRH power in the cases of different error filed of 1.0-10.0 mT and here the initial neutral density is assumed to be $n_H = 3.0 \times 10^{18}$ m^{-3} at t = 0.0 sec. The calculation result shows that (i) a minimum power threshold of ECRH exists to start up plasmas, for example, the power of more than 1 MW is required even in the case of lowest error field of ~ 1 mT, and that (ii) the maximum limit of acceptable error field ($B_{err} \geq 10$ mT) is observed, at which plasma start-up becomes impossible within feasible power range of ECRH. The error field in JT-60SA is predicted to be 5-10 mT, and therefore the device requires the error field correction coils, which is expected to reduce error field to less than 1mT.

3. Numerical Study on Electron Beam Properties in Triode Type Thermionic RF Gun

In order to mitigate back-bombardment effect caused by back-streaming electrons in conventional thermionic RF guns, which leads to limitation of macro pulse duration, we are developing a triode type thermionic RF gun. It consists of an existing 4.5-cell thermionic RF gun used in KU-FEL(Kyoto University Free Electron Laser) and an additional small coaxial cavity which is to be fed with a separate RF source from the main 4.5 cells with the relative amplitude and RF phase difference controlled (see Fig.

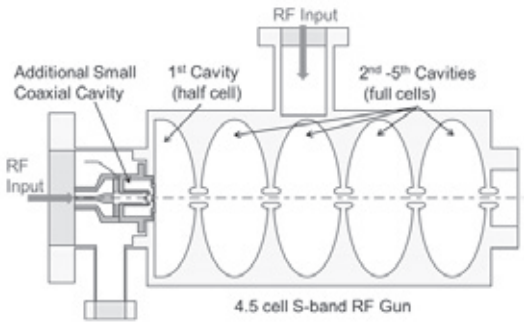

Fig. 2 Triode type thermionic RF gun.

2). Fabrication has been completed and experimental proof-of-concept is planned in near future. In this study, we investigated electron beam properties on operational parameters by using a 2-D particle-in-cell simulation code, KUBLAI.

Table 1 shows simulation results of peak currents I_{peak} and back-bombardment powers P_{back} in the triode RF gun, which is normalized to that of the conventional RF gun in different cavity voltages 20kV, 30kV and 40kV. Here, the phase difference ϕ in RF between the coaxial cavity and the main 4 and 5 cell cavities was chosen to obtain the highest peak current. I_{peak}. It is found that more than 90% of P_{back} can be reduced in all the cases, and ten times larger current I_{peak} than that of the conventional RF gun can be obtained in the cases of higher voltage at 30 and 40 kV.

Consequently, we conclude that more than 30 kV of V_{c} is needed in order to obtain a significant enhancement in I_{peak}.

Currently the coaxial cavity was fabricated and successfully tested at high power. The cavity testing with electron beam will be performed in near future.

Table 1 Beam properties as simulation result

V_{c} [kV]	20	30	40
ϕ [degree]	168	153	140
normalized P_{back}	0.036	0.082	0.093
I_{peak} [A]	90	400	490

4. Development of pulsed DD-IEC neutron source for non-destructive nuclear materials detector

Inertial Electrostatic Confinement Fusion (IECF) has been studied as a compact neutron source, which accelerates ions produced by glow discharge toward the hollow cathode with the static electric field. Non-destructive detection of nuclear materials is one of its potential applications, which is expected to prevent nuclear terrorism. We have developed a pulsed D-D IEC device for this purpose, and measured the pulse shapes of discharge current and applied voltage.

It is found that the glow discharge starts up after a delay of tens μsec with respect to the pulsed voltage as seen in Fig. 3. The influences of the applied cathode voltage and the operating pressure on the discharge start-up delay time was investigated. Figure 3 shows that the delay time tends to decrease with an increase of the operating gas pressure and the applied voltage. This results from the facts that (i) as the operating gas pressure is higher, the ionization takes place more frequently, and (ii) the reaction cross sections of ion impact ionization are increased by the increase of energy of ions.

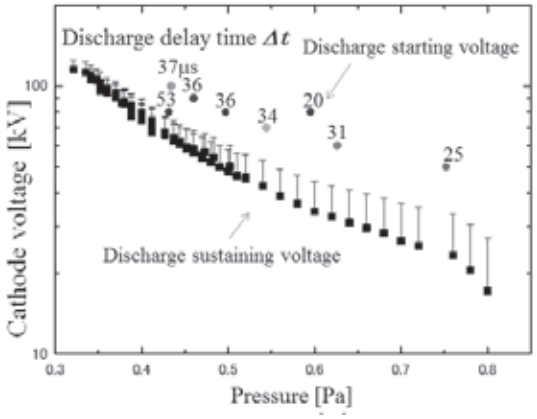

Fig. 3 Influences of charging voltage and operating pressure on discharge delay time.

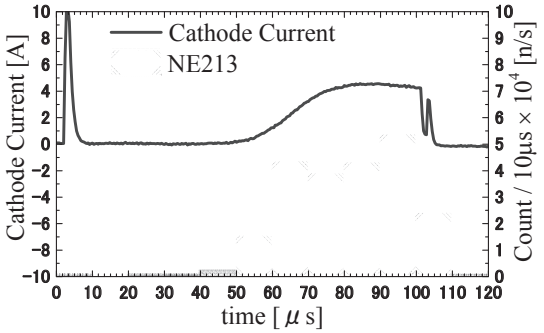

Fig. 4 Counts of generated pulse neutron measured with using an organic liquid scintillator and cathode current of the IEC device.

The pulse shape of neutron count rate by using an organic liquid scintillator (NE213) was also measured with the time interval of 10μsec. Figure 4 shows that a pulsed flux of fast neutrons is produced successfully corresponding to the pulse shape of the cathode current. The peak neutron count rate was about 50,000 counts per 10 μsec. This result implies that we can measure at a shorter time interval to obtain more detailed shape of pulse neutron flux.

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，佐野史道，水内亨，長﨑百伸，岡田浩之，小林進二，山本聡，南貴司

西南物理研究所（中華人民共和国）、IPP, Greifswald（ドイツ）、University of Wisconsin（米国），反射計を用いた電子密度分布・揺動解析，長﨑百伸

IPP, Greifswald（ドイツ），電子サイクロトロン電流駆動の理論解析，長﨑百伸

AUN（オーストラリア），データマイニングを用いた MHD 安定性解析，山本聡、長﨑百伸、佐野史道

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、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡

Stuttgart Univ.、CIEMAT（スペイン），先進閉じ込め配位，長﨑百伸、大島慎介、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡

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、佐野史道

Nuclear Physics Department, Applied Physics Laboratory, V.G. Khlopin Radium Institute（ロシア），Low-background Spectroscopic Position-Sensitive Neutron, Detection of Nuclear Materials in Cargo Containers，増田開

核融合科学研究所, 電子サイクロトロン電流駆動の物理と回転変換制御，長﨑百伸

核融合科学研究所, 先進ヘリカルによるプラズマ構造形成・不安定制御と閉じ込め磁場最適化の研究，佐野史道、水内亨、長﨑百伸、中村祐司、岡田浩之、南貴司、門信一郎、小林進二、山本聡、大島慎介、L. Zang、釼持尚輝、史楠、木島滋

核融合科学研究所, 高性能核融合プラズマ閉じ込め理工学の深化に向けた先進ヘリカル研究の現状と展望, 水内亨、鈴木康浩、大島慎介、山本聡、北島純男、上杉喜彦、岸本泰明、中村祐司、政宗貞男、中嶋洋輔、田中仁、岡村昇一、田中謙治、横山雅之

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核融合科学研究所, ダイバータープラズマにおける熱流束に関する実験的研究（ヘリオトロン J における周辺プラズマの揺動と熱輸送の計測），水内亨、岡田浩之、小林進二、大島慎介

核融合科学研究所, ヘリオトロン J におけるビーム放射分光法による密度揺動の空間分布計測, 水内亨、門信一郎、岡田浩之、小林進二、大島慎介

核融合科学研究所, 高速カメラを主体とした周辺乱流計測と乱流物理の解明-Helical Heliotron 磁場装置 Heliotron J での乱流計測-，佐野史道、水内亨、長﨑百伸、岡田浩之、南貴司、小林進二、山本聡、大島慎介

核融合科学研究所, ヘリオトロン J 装置における ICRF 加熱を用いた高速イオン閉じ込めの磁場最適化研究，佐野史道、水内亨、長﨑百伸、岡田浩之、南貴司、小林進二、山本聡、大島慎介

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核融合科学研究所, 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, 佐野史道、水内亨、長﨑百伸、岡田浩之、南貴司、小林進二、山本聡

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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 institute and also groups of other universities/institutes under the auspices of the Collaboration Program of the Lab. Complex Energy Processes, IAE, the Collaborative Research Program of NIFS (National Institute for Fusion Science), etc.

In this report, a remarkable result obtained in the Heliotron J experimental study in FY2013 is reported focusing on (1) a new operation regime for high density plasma and (2) development in the Nd:YAG Thomson scattering diagnostics in Heliotron J

2. Development of a new operation regime for high-density plasma in Heliotron J[1]

In magnetically confined plasmas, optimization of particle fuelling is an important subject to achieve high performance plasmas. Recently, we have obtained a high density plasma more than $1x10^{20}$ m^{-3} by a short-pulsed high intensity gas puffing (HIGP) method. In this section, we present the experimental result of the high density plasma operation by HIGP. The confinement characteristics and the behaviour of the hydrogen recycling in the high density plasma experiments are described.

Figure 1 shows the waveform of a high density plasma discharge using the HIGP method, which was obtained in the NBI heated plasmas in the configuration with lower toroidal magnetic ripple component (low ε_t). The co and counter NBs were injected at the port through power of 0.4 and 0.7MW, respectively. An HIGP, several times higher than that for the normal one with short period (10-20ms), was applied from t=210 ms. In this period, small degradation of the stored energy was observed. The response to the Hα/Dα intensity near GP almost corresponds to the quantity of fuelling by GP, while the strong reduction in the Hα/Dα intensity far from GP was observed at t=238ms in accordance with an increase in the edge AXUV intensity. After that, the stored energy reached a maximum value, which corresponds to the diamagnetic beta of 0.8%.

The radial profiles of the electron temperature (T_e), the electron density (n_e), the ion temperature (T_i) and the Hα/Dα intensity ($I_{H\alpha/D\alpha}$) are plotted in Figs. 2(a)-(b) before (t=210ms), just after (232ms) and 20ms after (242ms) HIGP. Due to HIGP, n_e at the core region increased twice from t=210ms to 232ms, while the change in T_e was small. At t=242ms, T_e and T_i in the peripheral region increased remarkable, then the increase in the stored energy was mainly due to the increase in the edge temperatures. At the timing of t=242ms, the maximum density around $1x10^{20}m^{-3}$ was observed in the core region. The Hα/Dα intensity decreased about 50% from t=232ms to 242ms, while its profile shape did not change significantly. Since the change in n_e was small between the two timings, this phenomenon indicates the reduction in the hydrogen density in the plasma after HIGP.

Now, we are applying the transport code into Heliotron J plasma and the energy and momentum transport will be discussed near future taking the neutral effect at the peripheral region into account.

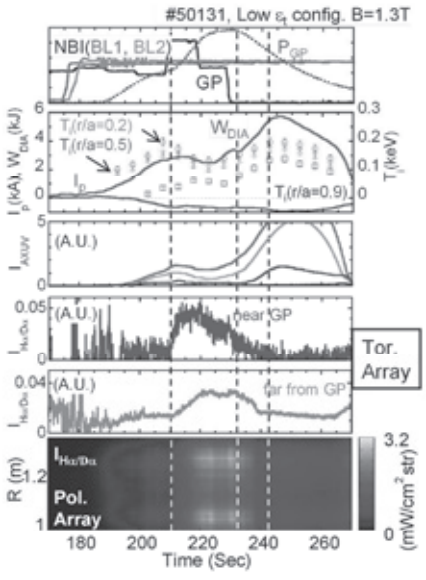

Fig. 1 Time evolution of heating/fueling, stored energy (W_{DIA}), toroidal current (I_p), ion temepreture, AXUV intensity (I_{AXUV}) and Hα/Dα line emission intensity ($I_{H\alpha}$).

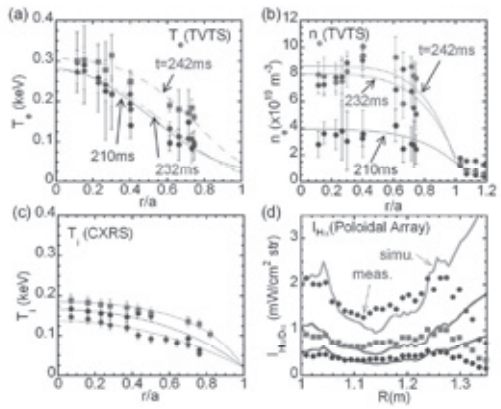

Fig. 2 Radial profile of (a) T_e, (b) n_e, (c) T_i and (d) Hα/Dα intensity before (t=210ms), during (232ms) and after (242ms) HIGP.

3. Time evolution measurement for a high performance plasma profile with the Nd:YAG Thomson scattering diagnostics

The precise time evolution measurements of plasma density and temperature profiles are required to investigate transport physics of the high performance plasma. Therefore, we have developed an Nd:YAG laser Thomson scattering system with high time and spatial resolution [2].

The system employs two Nd:YAG lasers of 550 mJ (oscillation frequency: 50 Hz) and has 25 measurement points with a spatial resolution of ~10 mm in a radial direction. A laser timing controller, which provides high time-resolution for the Thomson scattering system, has been developed to precisely control the injection timing of the laser pulses to a plasma discharge [3]. A new designed carbon beam dumper, which has a conical hole structure, attenuates the laser beam after passing through the plasma. Scattered light is collected by a large concave mirror (D = 800 mm, f/1.31) with a solid angle of ~ 50 mstr and guided to a set of interference filter polychromators through optical fiber bundles. The polychromators are installed temperature compensator bias circuits for each APD to keep constant sensitivity for changes in APD temperature.

In the last experimental campaign, we have completed the installation of the Nd:YAG Thomson scattering system on the Heliotron J and successfully measured the time evolution of scattered light from the plasma. The system achieved its designed performance of a high S/N ratio (~400) of scattered and background light even for low density $\bar{n}_e \sim 0.5\times10^{19}$ m^{-3} plasmas.

After the initial check of the system, we have applied it to the high performance plasma experiments. Figure 3 shows the results of the time evolution of Te profiles for the high performance plasma. The plasma was sustained by neutral beam injection (NBI) heating at the port-through power of 0.5MW. High intensity gas-puff fueling (HIGP) was carried out from 220ms to 230ms. As shown in figure 3(a), the plasma density is rapidly increased after the fueling, and the plasma stored energy is also increased after the slight reduction just after the HIGP. The profiles that is measured with the Nd:YAG Thomson scattering system is shown in figure 3(b). The time evolution measurement shows that the peripheral plasma is temporarily cooled just after the HIGP. After that, the electron temperature increases again mainly around the peripheral region and this may contribute the increase of the stored energy larger than before the HIGP. The time evolution measurements have a good agreement with the line averaged density and the stored energy, Therefore, these results suggest a possibility of the confinement improvement by the HIGP in the peripheral region.

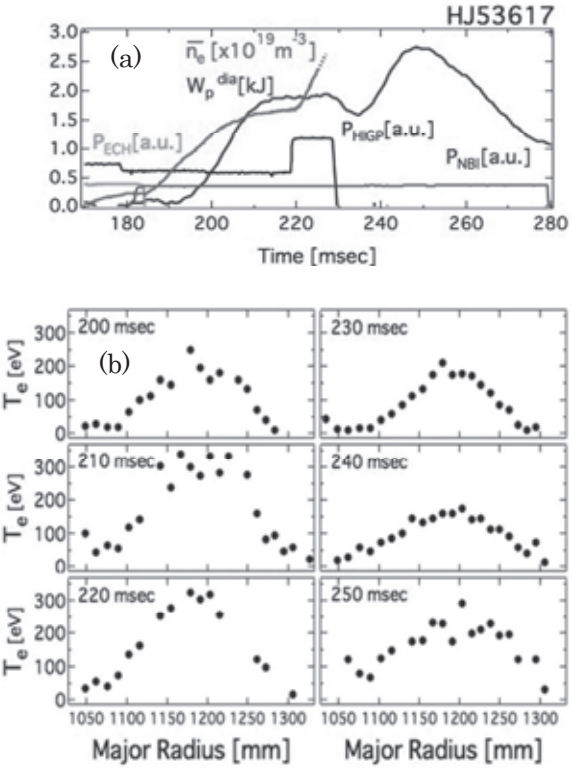

Fig. 3 (a) Time traces of line averaged density $(\bar{n}_e)$, plasma stored energy (W_p) and timings of ECH, NBI and HIGP. (b) Time evolution of T_e profiles of NBI-sustained high performance plasma.

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Collaboration Works

西南物理研究所（中華人民共和国)、CEIMAT（スペイン)，SMBI 法の応用，水内亨、他ヘリオトロングループ

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，佐野史道，水内亨、長﨑百伸、岡田浩之、小林進二、山本聡、南貴司、門信一郎

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、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡、門信一郎

Stuttgart Univ.、CIEMAT（スペイン)，先進閉じ込め配位，長﨑百伸、大島慎介、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡、門信一郎

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、佐野史道、岡田浩之、南貴司、門信一郎

PPPL（米国)，低磁気シアヘリカルプラズマにおける高速イオンの異常輸送ならびに損失機構に関する研究，山本聡、小林進二、佐野史道、他ヘリオトロングループ

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核融合科学研究所, トロイダル系閉じ込め装置における密度分布の動的挙動に係わる物理機構の解明と比較研究，佐野史道、水内亨、長﨑百伸、岡田浩之、南貴司、小林進二

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核融合科学研究所, ヘリオトロン J 装置における機械振動自己補正型干渉計の設計検討，水内亨、長﨑百伸、岡田浩之、南貴司、門信一郎、大島慎介

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Advanced Energy Research Section

Youngjoo Kwon, Foreign Visiting Professor
(Associate Professor, College of Pharmacy and Graduate School of Pharmaceutical Sciences, Seoul, Korea)

1. Introduction

I have known Professor Takashi Morii since 2006 through my previous stay at Uji campus of Kyoto University. In the year of 2006 I was invited by Institute of Chemical Research to spend one month and performed some experiments to determine the structures of relatively complex bioactive small molecules using nuclear magnetic resonance (NMR) spectrometer in the Professor Uesugi laboratory. Professor Morii allowed me to use NMR and related Unix-based molecular dynamic calculation programs without any restrictions. Also both of us are currently members of Asian Chemical Biology Initiative Program, Professor Morii invited me to spend three months at Institute of Advanced Energy, Kyoto University. I was impressed by well-funded research infrastructure in the previous visit, therefore I gladly accepted his invitation and commenced the visit on April 1, 2013 which could not be more perfect time for a foreigner to enjoy the cherry-blossom season of Kyoto and Japanese out-door cultural activities. I was greatly impressed this time that Uji campus has been quite upgraded with nice renovation and further well-established research infrastructure. I worked in the Morii laboratory learning about DNA origami technology and applying it to the development of a selective topoisomerase IIα inhibitor. It was a great experience for me to work under the guidance of Professor Morii and to exchange and discuss about our interest of collaboration with his graduate students, postdoc, assistant professor (Dr. Shun Nagano) and instructor (Dr. Eigi Nakata).

2. Exchanges for Future Scientific Cooperation

I had opportunity to give two presentations during my stay in Japan which were about the usage of chemical tools to understand/define multimodal calpain functions and roles in pathogenesis of diverse diseases and to develop isoform-specific topoisomerase IIα inhibitor with less DNA toxicity for the application of chemotherapeutic agents. I was hosted by Professor Shiroh Futaki in the Institute of Chemical Biology and Graduate School of Pharmaceutical Sciences. After the seminar, I had a chance to discuss with Dr. Futaki and colleagues about his research field including functions and applications of cell penetrating peptide as well as 6-year education status of Kyoto University which was adopted earlier than ours. With these experience, I had the opportunity to engage in organizing PI meetings between Colleges of Pharmacy of Ewha Womans University and Kyoto University to be held annually and alternately in Japan and Korea. We are planning to invite five professors of Colleges of Pharmacy of Kyoto University for three days, Jun 27 ~ 29, 2014. We will have a closed PI-meeting for the promotion of scientific collaborations in future.

I attended many Uesugi group laboratory meetings during which I participated in rich scientific discussions with members of his team. Professor Uesugi's research is somewhat similar to my own background in chemical biology, so these meetings were extremely important for me to extend and exchange knowledge and expertise. I also regularly participated in the laboratory meetings of Professor Morii, whose work in DNA origami research area is well-recognized. I stayed in the laboratory with Professor Morii's student rather than in the visiting scholar office which allowed me to work closely with group members and to have often open discussion about diverse topics including science, history and philosophy. That was one of the most enriching experiences during my stay in Japan. My interactions with his research group led to an opportunity for my students, Hyun Jung Woo and Ye-Jin Jung to visit the laboratories of Professors Morii and Uesugi for one month from February 10 to March 10, 2014. I also engaged in organizing an international teaching program with well-known foreign scholars for graduate students at our college of Ewha, then I invited Professors Morii and Uesugi who will teach our graduate students for a week coming this winter and next year summer semester, respectively.

3. Initiation of Collaboration

Closely discussing with Professor Morii and Drs. Nakata and Nagano about their expertise on nanomaterial such as DNA orgami, RNA aptamers, and synthetic fluorescence probes and my research interest, we came up to generate a small project of

"visual in-situ assessment of topoisomerase IIα inhibitors using DNA origami containing double-stranded DNA catenane". One of my research project was to clarify the mode of action of topoisomerase inhibitors which is an important strategy to develop topoisomerase IIα isomer-specific inhibitor with less side effects than non-specific inhibitors called topoisomerase poison. The Morii lab has explored nano architectures including protein/nucleic acids assemblies, RNA aptamer and DNA origami for the implementation of biomimetic function of biological systems. Working with Dr. Eigi Nakata, we designed 3-well DNA origami with DNA catenane encoding topoisomerase IIα cleavage site and non-cleavage site in each well. Since (1) DNA origami has been widely applied to sensing, catalysis, and device fabrication, and (2) the typical method to measure topoisomerase inhibitory activity of compounds with ethidium bromide staining is not reliable and cannot differentiate in which state of mode of action is interfered by compound for inhibiting topoisomerase IIα enzymatic activity. It is noteworthy to develop 3-well DNA origami consisting of no catenane, possessing catenane with topoisomerase IIα cleavage site and non-cleavage site, respectively and to utilize it to visualize topoisomerase IIα enzymatic activity at the same time. This is the first trial as far as we know. By the end of my three-month stay, we were successful to make 3-well DNA origami containing catenanes. After my departure, my graduate student, Hyun Jung Woo visited for one month and continued this project under guidance of Drs. Nakata and Nagano. She optimized the condition to make DNA origami with catenane and evaluated its formation with high-speed high-resolution AFM and agarose gel electrophoresis. The evaluation of topoisomerase IIα enzymatic activity and enzyme inhibitory activity of compound is remained for further future collaboration between both laboratories of Professor Morii and mine.

4. Activities for Experiencing Japanese Culture

Since the members of Professor Morii's lab are very nice and working hard and I enjoyed spending long time every day in the lab with them. It was possible for me to get the wonderful scientific experience as well as to experience many wonderful Japanese cultural activities in and around Kyoto with members especially Tamura san (Ph.D. candidate student) and Dr. Nagano (Assistant Professor). During golden week, my husband, Professor Younghwa Na visited me and we explored the city of Kyoto to the fullest extent as possible. The Kyoto city is rich in Japanese heritage. This time it was possible for us to see the inside of Kyoto Palace. The most enjoyable part of my husband's and my experiences was when Professor Morii and his wife invited us in a nice traditional Japanese sushi restaurant which only the local people know and not the foreigner or visitors.

5. Summary

My time spent in the laboratory of Professor Morii at Institute of Advance Energy was extremely rewarding scientifically and personally which can be explained with this phrase; a joy of doing science (in fact I quote the words of Professor Morii. Ha Ha!!) I was impressed by the quality of scientific achievement performed in the laboratory of Professor Morii and other faculty members at the IAE and mostly by the morals of Professor Morii as a senior professor and scientist.

Advanced Energy Research Section

Zhongping Yao, Foreign Visiting Associate Professor
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The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong)

1. Introduction

I knew Professor Takashi Morii in the Asian Chemical Biology Initiative events and was very delighted to have the opportunity to visit his group in Institute of Advanced Energy (IAE), Kyoto University for three months (1st July – 30th September 2013). This is the first time for me and my family to visit Japan and it is a wonderful experience for all of us.

2. Scientific Exchange and Collaboration

IAE is located at the Uji campus of Kyoto University, a peaceful and beautiful campus that is ideal for research. In addition to IAE, there are some other institutes such as Institute for Chemical Research, Disaster Prevention Research Institute, Research Institute for Sustainable Humanosphere in the Uji campus. The researches in these institutes are much related to the environment and living in Japan. I can see that Japan has made a lot of efforts and obtained significant achievements in these respects.

Research in Prof. Morii's group focuses on understanding, design and assembly of biomacromolecules for energy conversion, a field that is very different from my background in developing and applying mass spectrometry to address fundamental and applied problems. This thus provides a good opportunity for me to learn new subjects and understand more about general methodology in research. I regularly attended the group meetings in Prof. Morii's group. This is a universal group, having members from different countries including local, Vietnam, Malaysia and Italy. Group members presented project progress and literature review each week. They are talented, hard-working and prepared well for the presentations. What much impressed me was that the projects and the literatures were discussed in details during the meetings, and the supervisors gave comments to every detail of the experiments and the results. These were not very common in the group meetings I attended before in the research groups in USA, UK and Hong Kong. I visited Prof. Uesugi's group and Prof. Futaki's group in Institute for Chemical Research at the Uji campus as well. Both of the groups also have such regular group meeting. I think this is a good tradition and good training to the students. I also believe that preservation and paying attention to details are important characters for the success of scientific research in Japan.

During my stay, I tried to help the group to make more use of the mass spectrometry facilities in the institute, particularly using them to qualitatively and quantitatively analyze enzymes and their binding with ligands. I delivered a seminar on my research in Hong Kong at Uji campus with audiences from IAE and Institute for Chemical Research. I was very pleased that the seminar was well received and the questions from and discussions with the audiences were quite enlightening to me. I also visited University of Yamanashi and gave a talk in Prof. Kenzo Hiraoka's group, a group with research interest in ambient mass spectrometry. The visit has led to a PhD in his group coming to join my group as a postdoctoral researcher.

3. Cultural Experience

Kyoto is a city full of history and cultural heritages. My wife, Chanrou, three children, Yuanyue, Hanying and Hanhua, and I were able to visit most places nearby. Those scenes are always well maintained and we enjoyed the peaceful feeling when we visited them. The three children also attended local elementary school and kindergarten respectively for one week, giving them a very different education experience. The children enjoyed playing with their classmates and children of other staff of the Kyoto University. We were very impressed by many things in Japan, for example, the queuing habits, well-scheduled transportations, garbage recycling, delicately designed toilets. We appreciated the kindness and friendly manner of the

teachers, staff and colleagues, which made our stay joyful.

4. Summary

This is an unforgettable experience for me and my family. It opens a new door for us and provides new possibilities for further interactions in the future. We acknowledge Prof. Morii for providing such an opportunity and his group members and the staff at Kyoto University who helped us a lot during our visit.

Advanced Energy Research Section

Sik Lok Lam, Foreign Visiting Associate Professor
(Associate Professor,
Department of Chemistry,
The Chinese University of Hong Kong)

1. Summary

This article provides a review on the academic and research activities that I was involved in during my 3-month visit in Prof. Masato Katahira's Laboratory in IAE from November 1, 2013 to January 31, 2014. These include (i) working on a research project related to structural studies of cross-linked DNA oligonucleotides, (ii) participating in the weekly laboratory briefings and seminars, (iii) attending the International Symposium of Nucleic Acid Conference, and (iv) giving a research talk in IAE.

2. Research Project on Cross-Linked DNA Oligonucleotides

During the visiting period, I participated in a research project related to the solution structure studies of a covalently cross-linked DNA duplex using high-resolution nuclear magnetic resonance (NMR) spectroscopy. This was a collaborative project between Prof. Katahira and Prof. Fumi Nagatsugi from Tohoku University. Therefore, I had many opportunities to interact and discuss with members in Prof. Katahira's laboratory, including Drs. Takashi Nagata and Tsukasa Mashima. I also had an opportunity to present and discuss the project results with Prof. Nagatsugi during her one-day visit to our laboratory.

As synthetic oligonucleotides can artificially inhibit gene expression by binding specifically to target genes in a sequence-specific manner, improving the stability of these binding complexes can help to improve the inhibitory effects. Therefore, creating a covalent bond via cross-linking reactions between complementary DNA strands becomes an important means of improving the stability of the binding complex. In addition, cross-linking reactions have the potential to lead to site-directed mutagenesis. As a consequence, Prof. Nagatsugi's research group has recently developed the use of a reactive base, namely, 4-amino-6-oxo-2-vinylpyrimidine (AOVPY) in the cross-linking reactions with a DNA strand containing an 8-oxo-guanine (8-oxoG) base. Through the purification using high performance liquid chromatography (HPLC) and gel electrophoresis, a single major elution peak and migration band was obtained, respectively, suggesting the cross-linking reaction between two complementary 13-nt DNA strands was successful. Yet, the exact chemical structure of the cross-linked product was not known as there were three potential sites on 8-oxoG, including the N1 nitrogen, N2 nitrogen and O8 oxygen sites which could possibly lead to the N1-, N2- and O8-linked products, respectively. Therefore, the main aim of this project was to determine the chemical structure of the cross-linked DNA product in order to better understand the reaction mechanism between AOVPY and 8-oxoG.

As the molecular weights of the three possible cross-linked products were so close, the results from mass spectrometry did not provide sufficient information for characterizing the chemical structure of the cross-linked product. Crystallization of the reaction product had not been successful which made NMR became the most appropriate tool to determine the chemical structure. Preliminary optimization of sample condition and NMR data acquistion had been acquired by Dr. Mashima. Then, I was first involved in the spectral analysis of the collected NMR data. Surprisingly, the results showed two sets of NMR signals, and I decided to carry out additional variable temperature and diffusion NMR experiments and confirmed the presence of two products in the cross-linking reaction.

Subsequent NMR resonance assignment and spectral analysis were complicated by the overlap of two sets of signals and the lack of non-labile proton signal from 8-oxoG. Yet with the help from the chemical shift prediction methods developed from my laboratory, I was able to differentiate the two sets of signals and completed the sequential assignments of the full-length 13-nt duplexes, which were so critical towards the successful determination of the chemical structures of these cross-linked products. Then, I conducted further NMR experiments and was successful in analyzing the spectral features, leading to the identification of the N2-linked product.

Through rigorous discussion and exchange of views on literature results, we were ultimately able to identify the other one was the N1-linked product, concluding the cross-linking reaction occurs via two different pathways at equal chance. These results provide important insights towards the understanding of the cross-linking reactions which will advance the development of DNA oligonucleotides as an effective agent to inhibit gene expression.

3. Laboratory Briefings and Seminars

Every week, I would attend two regular group meetings. On Monday, there was a briefing at noon in which two to four students would give a brief presentation (~5-10 min) on the progress of their research projects. With such a time schedule, each student would have a chance to update their research progress and bring up issues related to their projects once every three weeks. All briefings were presented in English and these provided valuable opportunities for students to practice their spoken English. Through questioning after each of their presentations, I got to know more about how well each student was doing. One good thing about the noon time arrangement was that we usually would have lunch together right after the briefings. As a result, I could continue to discuss more with students in an informal and more relaxing manner. Sometimes, we would continue discussion on their research projects after lunch. The materials that we discussed could range from the long term goal of the project down to the details of how the NMR sample was treated right before data acquisition.

The second group meeting was usually arranged at 4 pm on Wednesday in which one student would give a more formal research seminar on their research project. With this arrangement, each student would be required to give a research seminar once every three to four months. This was an appropriate length of time for students to organize their results and present them nicely. After the research seminar, there would be journal article presentations in which one to two students would present one to two recent literatures related to their research projects. The journal presentation indeed was good to students as they could keep track of new findings and learned how scientific problems were solved by other laboratories.

4. International Symposium of Nucleic Acid Conference

In addition to the academic and research and activities within IAE, I also attended the 40th International Symposium on Nucleic Acid Chemistry at Kanagawa University in Yokohama during November 13-15, 2013. The three-day symposium was composed of invited lectures, oral presentations and poster presentations. The invited lectures were all about frontier works on various aspects of nucleic acids and they were delivered by experts from different parts of the world.

For the oral presentations, the majority of speakers were from local institutes, providing a clear picture to all participants about the excellent advancement of nucleic acids research in Japan. In particular, some of these good oral presentations were given by postdocs or graduate students, allowing them to gain valuable experience in presenting results and exchanging of ideas in international conference. Among the presenters, Yudai Yamaoki, a second year doctoral student from Prof. Katahira's laboratory, gave an interesting talk titled "Dual-quadruplex forming ribozyme distinctly switches on its activity in response to K^+".

For the poster presentations, they were organized in two 1.5-hour sections in two afternoons. Unexpectedly, these two sections indeed were the busiest moment for almost everybody, no matter whether you were presenting or asking questions about the posters. The discussion and exchange atmosphere was the most enthusiastic one that I had come across. When I was trying to ask someone a question about his or her poster, I usually had to wait in line for a while before I could talk to the presenter. Among these posters, Dr. Mashima, a postdoc from Prof. Katahira's laboratory, presented his work on "Origin of the anti-prion activity of quadruplex" received one of the best poster presentation awards.

There was also a very special event in this symposium, which was the exchange meeting in the evening of the second day. This was a valuable moment for exchange and discussion in an informal and relaxing environment. I had the opportunities to meet and talk to other students from other research laboratories. I was also lucky to meet Prof. Ichiro Hirao from RIKEN and got to know his story of discovering the unusually stable DNA GAA-loop about 20 years ago.

5. Research Seminar

On January 23, 2014, I gave a research seminar titled "From DNA chemical shifts to structures and infidelity of DNA replication" in IAE. This seminar provided a summary of the efforts that my research laboratory at The Chinese University of Hong Kong had been made in the past decade in advancing the use of chemical shifts in solution structure studies of DNAs and the application of NMR spectroscopy to better understand the origin of mutations during DNA replication. Some examples on applying predicted chemical shifts to facilitate the resonance assignments of the cross-linked DNA oligonucleotides were also given.

6. Acknowledgements

I would like to express my sincere thanks to Prof. Katahira, his colleagues, and all members of his laboratory. I was very grateful to their great hospitality during my visit.

Synthesis of Noble Metal Nanocrystals with Controllable Shapes via Seed-mediated Growth Process

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1. Introduction

During the past several decades, noble metal nanocrystals have received ever increasing interest owing to their unique physicochemical properties and promising applications in photonics, catalysis, electronics, sensing, energy, and biomedical research. Since the physicochemical properties (e.g., catalytic, electronic, optical, and magnetic properties) of the noble metal nanocrystals are greatly affected by their morphologies, sizes, and structures, tremendous efforts have been devoted to the synthesis of noble metal nanocrystals with controlled shapes to tailor their properties and thus performance in various applications.

Among all the reported syntheses, chemical reduction of a metal precursor in solution (either aqueous or organic solution) by a reductant has been considered as one of the most versatile and productive routes to generate noble metal nanocrystals with well-defined and controllable shapes. In general, two major steps are involved in a synthesis, including the nucleation and growth. The nucleation takes place at the very beginning of a synthesis, during which precursor molecules are reduced to elemental atoms that will serve as building blocks for the formation of nanocrystals. Once the concentration of the atoms in the reaction system has reached the point of supersaturation, small clusters will start to appear through aggregation of these atoms. On account of the autocatalytic effect of these clusters as well as their extremely high surface energy, they will further evolve into seeds and serve as active sites for the subsequent deposition of newly formed atoms. Continuous growth of the seeds results in the generation of metal nanocrystals as final products.

It should be noticed that in a one-pot synthesis, new nuclei and seeds might form throughout the reaction, leading to broad distributions in size and shape of the resultant nanocrystals. To improve the controllability of the synthesis as well as the uniformity of products, a two-step strategy, known as seed-mediated growth, has emerged as one of the most effective and powerful routes to control the synthesis of noble metal nanocrystals. The major advantage of this strategy is that the synthesis has been divided into two separate steps, which contain the formation of seeds, and growth of the as-prepared seeds. Each of these two steps can be precisely and independently manipulated by using different reaction systems, without worrying about the possible interference of these two processes. Furthermore, the undesired formation of new seeds during the growth step, a major concern and problem in a one-pot method, can be effectively eliminated by means of an expedient introduction of sufficient amount of seeds under well-controlled reaction conditions. Therefore, seed-mediated growth provides a facile and versatile route to the synthesis of noble metal nanocrystals with well-defined shapes and controllable sizes.

2. Pd Nanocrystals

Pd nanocrystals, which have been widely used as a versatile catalyst for many chemical processes including petroleum cracking, hydrogenation, dehydrogenation, and Suzuki, Heck, Stille, or other coupling reactions in organic chemistry, has drawn great attention in recent years. Thanks to the efforts of many research groups, Pd nanocrystals with a variety of shapes have been developed. However, most of these syntheses were based upon polyol reduction, and it is still a challenge to synthesize Pd nanocrystals with various controllable shapes in aqueous solution by simply using one single reaction system.

In our recent study, we developed a facile and green route to the synthesis of 3 nm single-crystal Pd seeds with a narrow size distribution, which can be used as active sites for the growth of Pd nanocrystals with various controlled morphologies and sizes. The synthesis of Pd seeds involved the reduction of H_2PdCl_4 by L-ascorbic acid in an aqueous solution at the boiling temperature in the presence of poly(vinyl pyrrolidone) and citric acid. We systematically investigated the effects of various reaction parameters on the reduction rate of the Pd precursor, and thus the final size, size distribution, and morphology of the resultant Pd seeds, including the reaction temperature, reducing power of the reductant, and capping agent.

The as-obtained ultra-small Pd seeds were then evaluated for the synthesis of Pd nanocrystals with controllable shapes in an aqueous solution via seed-mediated growth process. Thanks to the coordination effect of Br^- ions with Pd^{2+} ions and

their selective capping effect for the Pd {100} facets, Pd nanocrystals with various distinct shapes can be conveniently obtained by simply modulating the concentration of KBr in the growth solution, as shown in Figure 1. In addition, the size of resultant Pd nanocrystals can also be readily modulated by controlling the concentration of Pd seeds involved in the growth.

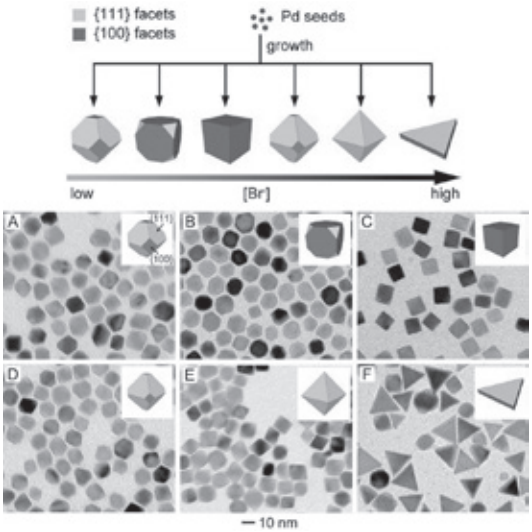

Figure 1. Pd nanocrystals with various shapes synthesized via seed-mediated growth by controlling the concentration of KBr in the growth solution.

Compared with the synthesis of Pd nanocrystals with a specific morphology by using conventional polyol method on the basis of a one-pot procedure, it is more convenient to control both the shape and size of the resultant Pd nanocrystals. In addition to the homogeneous growth, these ultra-small Pd seeds can also be extended into other metallic systems, especially for the growth of metal nanocrystals with sizes in the sub-10 nm regime.

3. Pd-Ag Bimetallic Nanocrystals

Bimetallic nanocrystals have received considerable interest owing to their remarkable properties that originate from the strong electronic coupling between the two metal components. The bimetallic nanocrystals can exhibit greatly enhanced physicochemical properties relative to their monometallic components. As a result, recent years have witnessed tremendous efforts devoted to the design, synthesis, and utilization of bimetallic nanocrystals with a variety of compositions. By controlling the reaction kinetics of the seed-mediated growth process, bimetallic nanocrystals with two different types of structures have been successfully developed: (i) dimer structure, where the second metal component selectively grows on one specific facet or along one certain direction of the seeds; (ii) core-shell structure, where the second metal component epitaxially grows on all facets of the seeds. Despite these successes with respect to the preparation of bimetallic nanocrystals with a variety of structures and combinations, it still remains a challenge to precisely control the growth mode and thus spatial distribution of the second metal on the surface of a nanocrystal seed.

In our recent work, we systematically studied the growth mode of Ag on Pd nanocrystal seeds in an effort to control the structures of the resultant Pd−Ag bimetallic nanocrystals. By carefully controlling different reaction parameters such as injection rate of $AgNO_3$ precursor, capping agent, reductant, and reaction temperature, we could deposit Ag on any number (from one to six) of the faces of a cubic Pd seed, leading to the formation of Pd−Ag bimetallic nanocrystals with various novel structures (Figure 2). We also evaluated the effects of different reaction parameters on the structure of final products. On the basis of a careful analysis of their TEM images, we also obtained a clear understanding of the spatial distributions of the elements in the resultant bimetallic nanocrystals. Significantly, we were able to identify the growth mode of Ag on Pd seeds according to the Moiré fringes that pinpoint the positions of the Pd seeds inside the bimetallic nanocrystals.

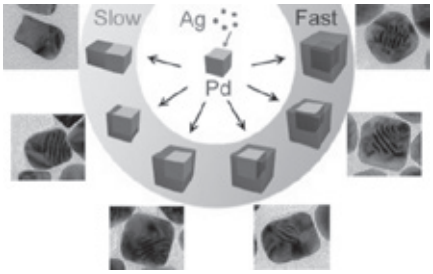

Figure 2. Pd-Ag bimetallic nanocrystals with various different structures synthesized via seed-mediated growth by controlling the reaction kinetics.

We further investigated the growth of Ag on other types of Pd seeds, including Pd nanocubes with different sizes and Pd octahedrons. As expected, Ag could also grow on a few or all the faces on these Pd nanocrystal seeds, depending on the reaction conditions involved. These results confirm that the structures of the resultant bimetallic nanocrystals could be conveniently manipulated by controlling the reaction conditions, not only for seeds enclosed by {100} facets but also for those enclosed by {111} facets. In addition, this strategy has also been successfully extended to other bimetallic system such as Pd-Au system to obtain similarly controllable nanostructures. This strategy for engineering the spatial distributions of elements in a bimetallic nanocrystal offers a novel and reliable approach to the fabrication of plasmonic nanostructures with enhanced sensing and surface-enhanced Raman scattering (SERS) capabilities, as well as enhanced catalytic property.

Advanced Energy Materials Research Section

K. Matsuda, Professor
T. Hinoki, Associate Professor
K. Jimbo, Assistant Professor

1. Introduction

We are investigating the scientific principle and applications of new materials including nano-materials for advanced energy science. In Avanced Energy Material Research section, the physical properties of nano-carbon materials (carbon nanotube, and graphene) by advanced optical spectroscopy and compositional ceramics (SiC) materials by multi-scale experiments for the material properties (MUSTER) are studied. Followings are main research achievements in the year of 2013.

1. Brightening of Excitons in Carbon Nanotubes on Dimensionality Modification

The low luminescence quantum yield of semiconducting carbon nanotubes, which is typically, at most, only a few percent for dispersed nanotubes, is deeply related to their one-dimensional nature. The balance between radiative and non-radiative relaxation rates (that is, the probability) of electron–hole bound states, termed excitons determines the nanotube luminescence quantum yield. Fast nonradiative decay, which dominates exciton recombination in nanotubes and results in their low luminescence quantum yield, is mainly caused by the quenching of one-dimensional mobile excitons due to the rapid collision between these excitons and local quencher states, which include nanotube defects and end sites. Efforts to improve the luminescence quantum yield by reducing the defect quenching of excitons have been reported. Conversely, if a local defect is not an exciton quencher but is luminescent by virtue of appropriate local electronic structures, the local state may function as a zero-dimension-like quantum state that captures mobile excitons and converts them to photons (as shown in Fig. 1) with a radiative relaxation rate possibly lying beyond that of intrinsic one-dimensional excitons. Therefore, one-dimensional nanotubes with luminescent, local zero-dimension-like states offer a unique opportunity for photophysical investigation of nearly ideal zero-dimensional–one-dimensional hybrid systems. Moreover, understanding the excitonic properties of these states can lead to the development of novel strategies for brightening nanotube excitons beyond the intrinsic limit for future photonics applications.

We found that the luminescence quantum yield of the excitons confined in the zero-dimension-like states generated by oxygen doping can be more than at least one order larger (~18%) than that of the intrinsic one-dimensional excitons (typically 1%), not only because of the reduced non-radiative decay pathways but also due to an enhanced radiative recombination probability beyond that of intrinsic one-dimensional excitons. Our findings are extendable to the realization of future nanoscale photonic devices including a near-infrared single-photon emitter operable at room temperature.

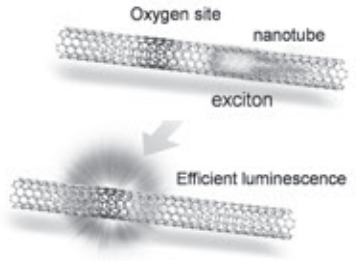

Figure 1. Schematic of efficient luminescence strategy for carbon nanotube.

2. Tunable Photoluminescence of Monolayer MoS_2 via Chemical Doping

Atomically thin transition-metal dichalcogenides (TMDs) have attracted a great deal of attention from the viewpoints of fundamental physics and various applications. Thin-layered TMDs, as novel two-dimensional materials, undergo remarkable changes in their electronic structures depending on the number of layers: from indirect-band gap bulk semiconductors to direct-band gap monolayer semiconductors. Monolayer MoS_2 (1L-MoS_2) have potential applications as novel two-dimensional direct-band gap semiconductors in various opto-electronic devices, such as low-electricityconsumption transistors, light-emitting devices, and solar cells. Moreover, 1L-MoS_2 is emerging as a novel platform for the study of "spintronics" or "valleytronics" because of its broken inversion symmetry, which gives rise to the coupling of spins and the valley degree of freedom in the momentum space.

Optically generated electron−hole pairs in

1L-MoS_2 form stable exciton states even at room temperature because of the extremely large Coulomb interactions in atomically thin two dimensional materials. The stable exciton plays an important role in the optical properties of 1L-MoS_2. Control of the carrier density is one effective method to modulate the optical properties of monolayer TMDs. The interplay between the exciton and charge carrier gives rise to the formation of a many-body bound state such as a charged exciton (trion), which provides additional pathways for controlling the optical properties of 1L-MoS_2.

We demonstrated that the photoluminescence (PL) properties of 1L-MoS_2 can be tuned via a solution-based chemical doping technique. The PL intensity of 1L-MoS_2 is drastically enhanced when p-type dopants cover its surface. This enhancement is understood as a consequence of switching the dominant PL process from the recombination of the negative trion to the recombination of the exciton under extraction of residual electrons in as-prepared 1L-MoS_2. In contrast, the PL intensity is reduced when 1L-MoS_2 is covered with n-type dopants. On the basis of these results, we confirmed that bidirectional control of the Fermi level of 1L-MoS_2 by chemical doping is possible and that this approach provides a great advantage in controlling the optical and electrical properties of thin-layered MoS_2.

3. Porous Silicon Carbide Composites for LWR Cladding

Silicon carbide is very attractive engineering ceramics in particular for high temperature use and nuclear application due to high temperature strength, oxygen resistance, chemical stability, low activation, radiation resistance and so on. Superior stability for steam to metal is critical motivation for LWR cladding application. However the application of silicon carbide ceramics is limited due to brittle feature. Silicon carbide composites have pseudo ductile behavior by debonding and sliding at fiber/matrix interface. However carbon at fiber/matrix interface is critical issue for oxidation by steam under sever accident condition. The objective of this work is to develop pseudo ductile porous silicon carbide ceramics by silicon carbide fiber reinforcement without carbon fiber/matrix interface.

The silicon carbide matrix was formed with carbon powder by liquid phase sintering method using sintering additives. The porous silicon carbide matrix was formed following decarburization process. The porosity in the matrix was controlled by the amount of carbon powder. Mechanical properties were characterized by three point flexural test. The specimens for three point flexural test were exposed in air at 1100C. The composites consisted with just silicon car-bide fiber and crystalline porous silicon carbide matrix without fiber/matrix interphase like carbon. Crystalline structure is requirement for nuclear application. The composites showed pseud-ductile behavior and complicated fracture behavior due to frictional stress at debonded fiber/matrix interface. Three point flexural strength was approximately 280 MPa for the material with 30 % porosity. Significant degradation wasn't observed following exposure at 1100C air condition. Silicon carbide composites require relatively weak fiber/matrix interface layer like carbon for pseud-ductile fracture behavior. The control of thickness and quality for the interface layer is very difficult, although it is the key to determine mechanical properties of the composites. The porous silicon carbide composites showed pseud-ductile behavior without the interface layer. It is easy to fabricate uniform material and reduce the material cost significantly. The carbon interface layer is the weakest link in some cases in particular for oxygen environment at high temperature. The porous material just consists with silicon carbide and applicable for various severe environment.

Porous SiC composites can't be used with current fuel pellet without coating due to lack of hermeticity. The recent microencapsulated fuels consisted with TRISO ceramics and SiC matrix can keep FP gas within fuels. Porous silicon carbide composite cladding can work with the microencapsulated fuels. Porous SiC composites were developed. The material has pseud-ductile behavior and applicable for structural material. It is different from brittle ceramics. The material doesn't require fiber/matrix interphase like carbon. It decrease material cost significantly. Productivity is also excellent compared to current silicon carbide composites. The material just consists with silicon carbide. Excellent resistance to high temperature oxygen and chemical corrosion is expected.

4. Laser Cooling of an Ion Beam in the Horizontal direction by Synchro-Betatron Resonance

K. Jimbo has engaged in a laser cooling experiment of ion beam at Small Laser-equipped Storage Ring. After we had succeeded to demonstrate energy transfer between the longitudinal and horizontal directions of a magnesium ion beam by synchro-betatron resonance to realize the horizontal cooling, this laser cooling experiment is temporarily halted. A much more powerful laser system is necessary to obtain a more convincing result and we are preparing for it.

According to the computer simulation, disappearance of peaks of synchrotron oscillation is expected when a beam turns to be space charge limited, which represents very cold state of ion beams. We have proposed a capability of detecting space charge limited state by observing such a frozen synchrotron oscillation.

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

Oak Ridge National Laboratory（米国），TAITAN (Tritium,Irradiation and Thermofluid for America and Nippon) Task2-3 動的変形挙動，檜木達也

Politecnico di Torino（イタリア）、Oak Ridge National Laboratory（米国），セラミックス材料の接合強度評価技術開発，檜木達也

Politecnico di Torino（イタリア），Mechanical and sealant joining of SiC/SiC composites for high temperature applications，檜木達也

Idaho National Laboratory（米国）、Idaho National Laboratory（米国）、Oak Ridge National Laboratory（米国），Accident Tolerant Fuels for LWRs Research and Development（CNWG），檜木達也

Oak Ridge National Laboratory（米国），原型炉プラズマ対向機器開発のための要素技術の工学的評価（Phenix），檜木達也

東北大学金属材料研究所, 原子力用セラミックス及びセラミックス複合材料の中性子照射効果, 檜木達也

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1. Grant-in-Aid for Scientific Research

松田一成，基盤(B)，ナノカーボン物質における量子制御とナノカーボン・フォトニクスの開拓

松田一成, 挑戦的萌芽研究，グラフェン量子ドットの創生と光電子変換機能の開拓

檜木達也, 挑戦的萌芽研究, セラミックス繊維強化高靭性タングステン材料の開発

宮内雄平，若手研究(A)，革新的光電デバイス応用に向けたカーボンナノチューブ量子多体効果の学理の開拓

毛利真一郎，基盤(C)，単原子層物質の励起子光物性の解明とその制御

小柳孝彰, 特別研究員奨励費, 残留応力解析を用いた SiC 基複合材料の中性子照射下強度のモデル化

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Advanced Laser Science Research Section

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K. Hata, Assistant Professor
G. Miyaji, Assistant Professor

1. Introduction

Our research interest is to theoretically as well as experimentally study the various kinds of laser-matter interactions in a time-dependent manner, where the laser wavelength can be in the mid-infrared, near-infrared, visible, ultraviolet, extreme ultraviolet, or even x-ray regions, and the target can be atoms/molecules, nanoparticles, thin films, materials with nanostructures, etc. Regardless of the choice of laser wavelength and the target, the objective of our research is to understand the coherent interaction of laser radiation with matters and finally to utilize them.

2. Efficient generation of atomic coherence under the presence of hyperfine structure

Knowing that the generation of high coherence is the key for the efficient nonlinear processes such as frequency-mixing, and the presence of substructures (such as hyperfine structure) in a system tends to prevent the generation of coherence, we have theoretically studied the generation of coherence in generalized two-level atoms with hyperfine structure by utilizing the detuning-induced stimulated Raman adiabatic passage (D-STIRAP). As expected, the degree of coherence between the ground and excited states cannot be as large as that for the ideal two-level atoms without hyperfine structure. However, we have found that the substantial degree of coherence can still be produced with small modulations, and the modulation period is essentially determined by the hyperfine splittings in the ground and excited states. As a specific example, we show in Fig. 1 the realistic result for the D_1 transition of Na with a Doppler broadening taken into account.

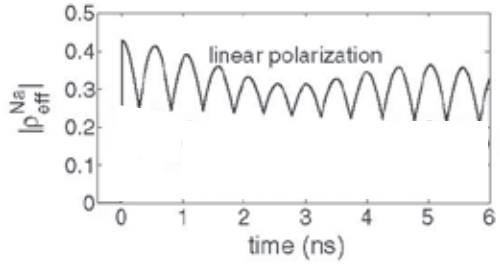

Fig. 1 Time evolution of the degree of coherence, |ρ|, for the linearly polarized pump pulse for the D_1 transition of Na.

3. Time-gating of KU-FEL by a plasma mirror

For some applications of FELs which require the time resolution, high peak intensity, etc., the time-gating and high focusability of FEL pulses without damaging a target would be very important. We have demonstrated that these two requirements for the KU-FEL pulses can be fulfilled with the aid of a plasma mirror. Figure 2(a) shows the experimental setup. A new feature in this study is the use of unusually long (nanosecond) switching pulses for the plasma mirror, since it is widely believed that the use of such long switching pulses results in the distortion of the wavefront and hence bad focusability of plasma-mirrored FEL pulses. Our results, however, clearly demonstrate that the plasma-mirrored FEL pulses have a good focusability, as ensured by the experimental observation of spectral broadening of FEL pulses by nonlinear effects. The effectiveness of the plasma-mirrored KU-FEL pulses is clear by comparing Figs. 2(b) and 2(c): Without the plasma

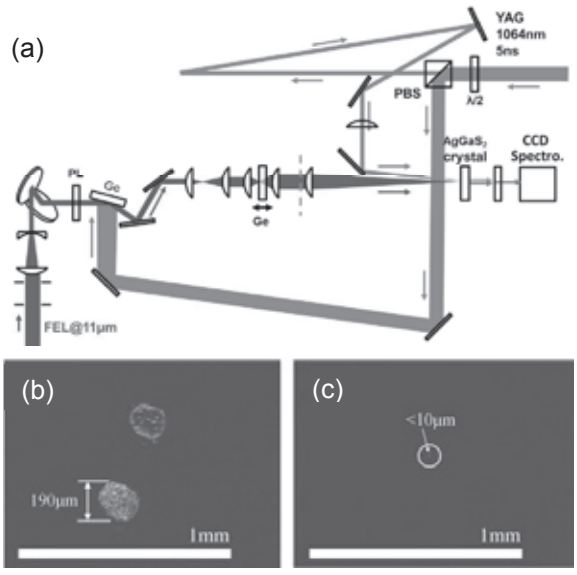

Fig. 2 (a) Experimental setup for the time-gating of KU-FEL pulses. (b) and (c) Microscope images of the target (Ge plate) after the irradiation of FEL pulses at 6 GW/cm^2 without the plasma mirror and at 60 GW/cm^2 with the plasma mirror.

mirror, the target (Ge plate) is very easily damaged by the irradiation of a single FEL macropulse (which contains ~4000 micropulses) at the peak intensity of 6 GW/cm^2, while the use of the plasma mirror enables us to reach the peak intensity as high as 60 GW/cm^2 without any obvious damage on the target after the irradiation of 3600 macropulses (each of which contains ~15 micropulses).

4. All-angle collimation of incident light in μ – near-zero metamaterials

Metamaterials (MMs) consist of structural units with a dimension smaller than the wavelength of the incident light, and they are of great interest for various purposes such as cloaking and super lens, etc. In this work we have employed the theory of inhomogeneous waves to study the transmission of light in μ-near-zero MMs, and found the effect of all-angle collimation of incident light, which means that the vector of energy flow in a wave transmitted to a μ-near-zero MM is perpendicular to the interface for any incident angles if an incident wave is s-polarized. To be more specific, we have considered the transmission of light in a negative-index MM in the spectral region with a permeability resonance, and demonstrated that all-angle collimation indeed takes place at the wavelength for which the real part of permeability is negligibly small, as shown around the incident wavelength of 740 nm in Fig. 3.

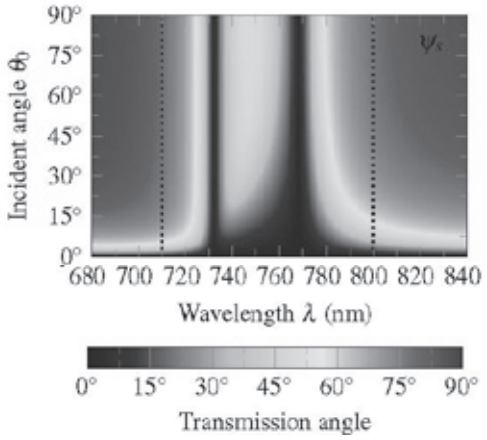

Fig. 3 Transmission angle for the s-polarized components of the Poynting vector as functions of incident wavelength and angle.

5. Fabrication of nanogratings with femtosecond laser pulses

Femtosecond (fs) laser ablation of solid surfaces has been observed to spontaneously form periodic nanostructures with a period much smaller than the employed laser wavelength. The formation of nanostructures strongly suggests potential applications of fs lasers to nano-processing of solid surfaces. The physical mechanism responsible for the nanostructuring and its control are essential for the generation of well-defined nanostructures, since the observed nanostructures have some inhomogeneity. Recently we have shown that the origin of nano-periodicity produced can be attributed to the periodically enhanced near-field through the surface plasmon polaritons excited with fs pulses. Based on this understanding, we have successfully fabricated a grating structure consisting of parallel stripes with a nano-period much smaller than the laser wavelength as shown in Fig. 4.

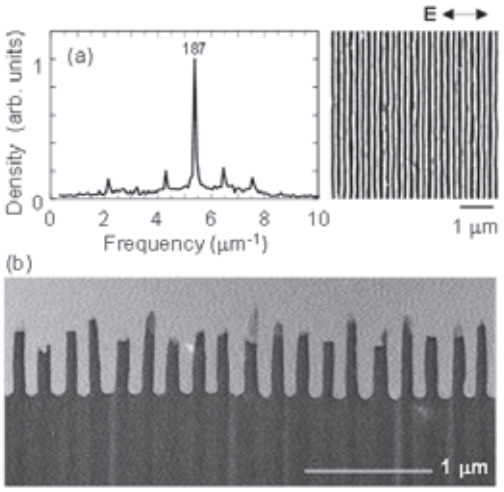

Fig. 4. (a) SEM image of GaN surface (right) and the frequency spectrum of periodic structure after irradiation of horizontally polarized fs pulses (left). The number in the spectrum indicates spatial period (nm). (b) Cross-sectional STEM image of GaN surface with nanogratings.

6. Experimental study on transient critical heat fluxes of subcooled water flow boiling in a sus304-circular tube

The flow transient critical heat fluxes (FT-CHFs) in a SUS304-circular tube caused by a rapid decrease in velocity from non-boiling regime are systematically measured under different conditions of initial flow velocities, initial heat fluxes, inlet liquid temperatures, outlet pressures, and decelerations caused by a rapid decrease in velocity by the experimental water loop comprised of a multistage canned-type circulation pump controlled by an inverter. The flow transient CHFs for SUS304-circular tube are compared with the steady-state CHF data for the empty vertical and horizontal SUS304-circular tubes and the calculated values. The influences of initial flow velocity, initial heat flux, and deceleration are investigated into details and the widely and precisely predictable correlations of CHF and flow velocity at the flow transient CHF for the circular tube is given based on the experimental data. The correlations can describe the flow velocity and the CHFs at the flow transient CHFs for SUS304-circular tube obtained in this work within ±20 % difference.

Collaboration Works

宇宙科学研究所（ルーマニア），高強度超短パルスレーザーによって誘起される非摂動相互作用の理論研究，中嶋隆

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

Johns Hopkins University（米国），フェムト秒レーザーによる表面ナノ構造生成過程のモデル構築，宮崎健創

University of Brawijaya（インドネシア），超短パルス高強度レーザーによる分子配向と高次高調波発生，宮崎健創

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1. Grant-in-Aid for Scientific Research

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宮地悟代，若手研究(A)，フェムト秒レーザーによる表面ナノ加工技術の開発

宮崎健創，新学術領域研究，レーザー励起ナノ界面プラズマの周期構造創成とプロセス応用

宮崎健創，基盤(B)，超短パルスレーザー励起ナノ構造生成のアト秒ダイナミクスとその応用

2. Others

畑幸一，（株）ES 研，エネルギー機能変換（レーザー科学）の研究助成

宮崎健創，（独）科学技術振興機構，フェムト秒レーザーによるナノ格子の大面積形成と微細化技術の開発

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Advanced Energy Structural Materials Research Section

A. Kimura, Professor
K. Morishita, Associate Professor
(W. Han, Researcher)

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. Development of advanced ferritic steels for fusion systems

Distribution and morphology of oxide particles were investigated to characterize factor controlling high performance of ODS steel. Effect of oxide particle on microstructure of ODS steel is observed by high resolution TEM. The oxide particles into ODS steel are very small and dispersed with high number density in matrix. Therefore, it plays a role in reinforcement and improves the mechanical properties of ferritic steels. Some nano-micro structure of fine grains formed caused by these oxide particles with pinning effect and retarded grain migration.

As result of TEM observation, Al-free ODS steel have oxide particle formed Ti-Y-O with 4nm, which is very small particle and 1.86 x 10^{22} m^{-3} of number density. This oxide particles are high thermo-dynamical stability, thus, it still remained high number density and small particle size comparatively, even after heated at 1400°C as shown Fig. 1 (b).

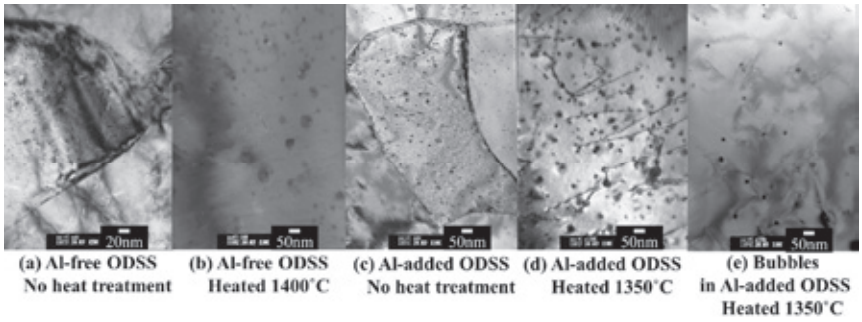

Fig. 1: Dispersion of oxide particles into ODS matrix

Al-added ODS steel is preferentially formed bigger oxide particle as Al-Y-O than Ti-Y-O, so it has lower mechanical properties. Zr component can add in ODS steel to remain dispersed fine oxide particle, also have high corrosion resistance with Al component. Although Zr component is added with small quantity, the oxide particles formed already bigger and lower number density than that of Al-free ODS steel before heat treatment (Fig. 1 (c)). Also, the particles are coarser after recrystallization, some bubbles are observed as shown Fig. 1 (e). It is suggested that grain is easy to migrate caused by restraint of pinning effect with big oxide particle and it can be occurred recrystallization. In case of adding Al, the mechanical properties are little reduced and anisotropy is more significant with good ductility, at the same time, it can acquire the good corrosion resistance and expect to economical effect of reduced recrystallize temperature. Therefore, Al-added ODS steel can use pragmatically in industry with improving lower mechanical properties.

3. Theoretical evaluation of oxidation rate of Zr

For pursuing the safety of nuclear light-water reactors, continuous efforts to keep the integrity of the plants should be made, which is so-called the ageing management. Plant aging is mainly occurred by material's degradation, which is caused by high energy neutron irradiation, high temperature, high pressure, high corrosion environment, cyclic loadings, and so on. In order to realize the sufficient and reasonable plant maintenance, the methodology to predict material's degradation should be established.

Zr alloys are used as the component material of fuel cladding in light-water reactors because of their low thermal neutron cross-section and good corrosion resistance. One of the main issues that threaten fuel the reliability of fuel claddings is oxidation phenomena occurred on their surface. ZrO_2 film preexists and further grows on the surface of Zr-alloy cladding material during plant operation. In literatures, the oxidation thickness is proportional to the *square* root of time above 1273K, which is consistent with the diffusion-controlled process. On the other hand, at a normal operating temperature of 573K, the oxidation thickness is proportional to the *cubic* root of time, which is inconsistent with the general diffusion-controlled process. It indicates that there may be some factors that suppress the diffusion rate of oxygen in ZrO_2 film at that temperature.

In this study, we have investigated the oxidation process of ZrO2 film at various temperatures from atomistic viewpoints. The change of formation and migration energies were evaluated as a function of compressive stress by first principle calculations using the SIESTA code. With the energies so obtianed, we have further evaluated the oxidation rate of Zr using the simple one-dimensional diffusion model, where an oxygen atom diffuses from the oxide surface to oxide/metal interface.

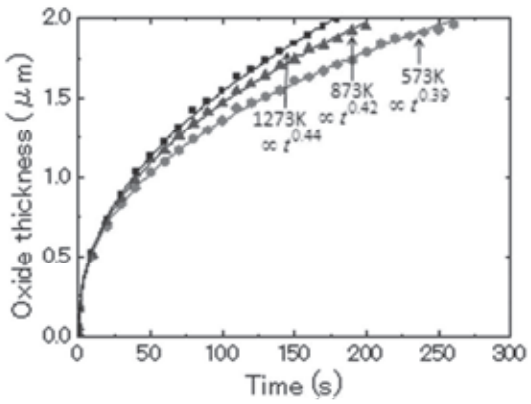

Fig. 2 Time evolution of oxide thickness at 573, 873 and 1273 K under compressive stress

By solving the diffusion equation, the time evolution of oxide thickness was obtained as shown in fig. 2. When the stress effect is considered, the growth rate of oxide layers decreases gradually; and finally, our calculation results qualitatively become consistent with experimental facts. Namely, the oxide thickness is proportional to the *cubic* root of time rather than the *square* root of time at normal operating temperature. At 1273K, on the other hand, the oxide thickness increases in approximately proportion to the *square* root of time, because the stress effect seems to be weak at higher temperature.

4. W-ODS steel joints for fusion divertor

The coupling of tungsten (W) and oxide dispersion strengthening steel (ODSS) is considered to be promising for fusion diverter component that consists of W and ODSS as a plasma facing material and structural material, respectively. Thus, the bonding technology R&D of these two materials is required. However, W cracks easily during bonding process, which is considered to be due to a large difference in coefficient of thermal expansion (CTE) between these two materials. Using ductile insert material is considered to reduce thermal stress. In our previous study, although the bonding using Fe amorphous foil resulted in the formation of good bonding interface, the thickness obtained was not large enough to reduce the thermal stress. In this study, we tried to reduce the thermal stress in W using pure iron or a simple steel as an insert material of diffusion bonding. As a result, we achieved a bonding strength of 280 MPa at room temperature as well as developing small specimen test technique using micro-3 bending specimens.

Collaboration Works

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Russian Research Center, Kurchatov Institute（ロシア），Irradiation effects on high Cr ODS steels，木村晃彦

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Bochvar Institut（ロシア），IAEA-CRP Pound robin test，木村晃彦

CIEMAT（スペイン），IAEA-CRP Pound robin test，木村晃彦

FEI STU（スロバキア），IAEA-CRP Pound robin test，木村晃彦

JRC European Commission- Petten, JRC-Institute for Energy and Transport，IAEA-CRP Pound robin test，木村晃彦

HZDR（ドイツ），IAEA-CRP Pound robin test，木村晃彦

KIT（ドイツ），IAEA-CRP Pound robin test，木村晃彦

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Complex Plasma Systems Research Section

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S. Yamamoto, Assistant Professor

1. Introduction

This research section seeks to investigate the confinement optimization of "hot" plasma in the helical-axis heliotron line. For the experimental and theoretical investigation of this theme, the plasma device of Heliotron J has been operated at the Laboratory for Complex Energy Processes since FY2000. Magnetic fusion by "hot" plasma as a commercial reactor of electricity has some key features which make it an attractive option in a future energy mix inherent safety features, waste which will not be a burden for future generations, no greenhouse gases and the capacity for large scale energy production. The development of magnetic fusion requires the solution to the physics problems of transport and magneto-hydrodynamics (MHD) of "hot" plasma. The goal of the hot 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 hot plasma dynamics and to create key innovative technology to make magnetic fusion a practical energy source. A topic of Heliotron J experiments in FY2013 was the new approach of high-density ($n_e > 10^{20}$ m^{-3}) plasma operation in the novel magnetic configuration where the lower toroidicity features prominently as compared with that of the standard configuration. To understand the relevant confinement physics, measurement results of plasma fluctuation, plasma rotation and fuelling particle behavior were studied with special regard to 3D currentless plasma optimization. The other topics such as comparative studies of parallel plasma flow of NBI plasmas between neoclassical theory and experiment, measurements of the structural change of plasma potential synchronized with energetic-ion-driven MHD and relating energetic ion loss diagnostics were also carried out. Upcoming experiments are planned to continue developing this high-density plasma performance as a candidate operation for advanced confinement of Heliotron J.

2. External control of energetic-ion-driven MHD instabilities by ECCD in Heliotron J plasmas

The energetic-ion-driven MHD instabilities such as Alfvén eigenmodes (AEs), which could enhance the transport and induce the loss of energetic ions such as alpha particles in a D-T fusion reactor, are being extensively studied in many toroidal plasmas. The methods to control the energetic-ion-driven MHD instabilities are required for the fusion reactor, but they have not been established yet. While several methods are proposed to control the modes, electron cyclotron heating / electron cyclotron current drive (ECH/ECCD) are ideal tools to control the modes since they can provide highly localized EC waves with a known location and good controllability. Since Heliotron J has low magnetic shear in vacuum and therefore the magnetic shear can be controlled by ECCD, we have investigated the effect of continuum damping, whose rate is related to the magnetic shear, on the mode.

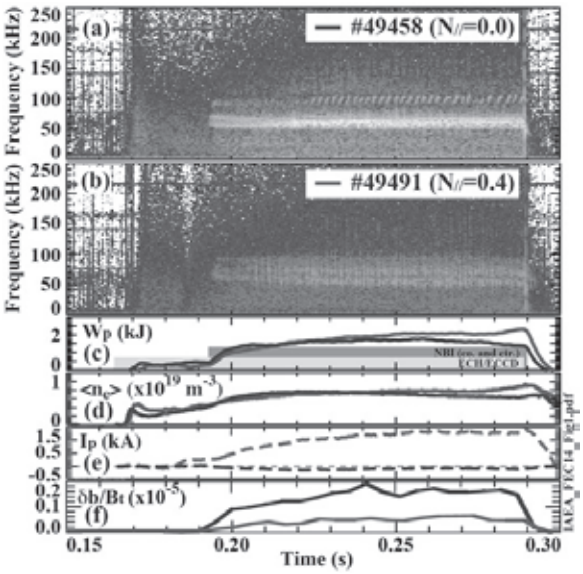

Fig. 1. Time evolution of typically observed EPMs in plasma (a) without ECCD and (b) with ECCD, and (c) plasma stored energy, (d) electron density, (e) plasma current and (f) amplitude of observed EPMs with m=2/n=1.

The observed MHD instabilities were identified as global AEs (GAEs) and energetic particle modes (EPMs) by comparing with shear Alfvén spectra in NBI-heated Heliotron J plasmas. In the low-density plasma ($\langle n_e \rangle \leq 1.0\text{x}10^{19}$ m^{-3}), EPMs

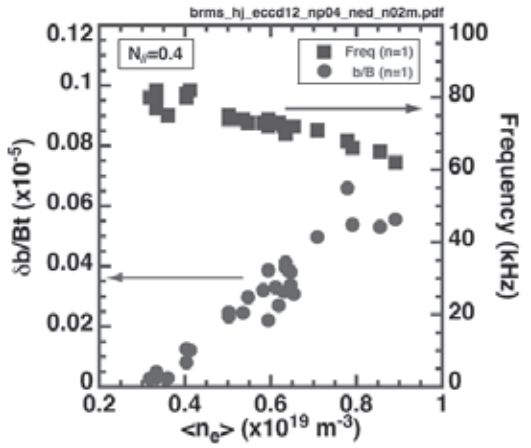

Fig. 2. Density dependence of amplitude and frequency of observed m=2/n=1 EPMs in NBI-heated Heliotron J plasmas.

only are observed. The bursting EPMs cause energetic ion loss from the confinement region under certain experimental conditions. Figure 1 (a) shows that typical observation of EPMs in low-density plasma heated by both ECH and NBIs. Purple curves in Figs. 1 (c)~(f) indicate time evolution of plasma stored energy, electron density, plasma current and amplitude of observed EPMs with m=2/n=1, respectively. Figure 2 shows the density dependence of frequency and amplitude of the observed EPMs with m=2/n=1. The frequency was not proportional to Alfvén velocity. Then this characteristic means that the observed modes are not AEs. EPMs are localized at the plasma edge region (r/a = 0.7~0.8) where the observed frequency of EPMs coincides with that of shear Alfvén continuum.

We attempted to control the observed EPMs by means of the magnetic shear modified by EC driven plasma current. It is expected that the continuum damping is the main damping mechanism of EPMs and that the continuum damping rate is related to the local magnetic shear. Typical observation of EPMs in the case of $N_{//}$ = 0.4 corresponding to ECCD case are shown in Fig. 1 (b). Electron and ion Landau damping, energetic ion beta were fixed in these experiments. Clear reduction of amplitude of the observed EPMs is shown in Fig. 1 (b). Plasma current I_p can be controlled in the range of -0.5 < I_p < 1.5 kA by ECCD by changing EC wave parallel refractive index $N_{//}$ from 0.0 to 0.5. The amplitude of the observed m=2/n=1 EPMs obviously decreased with an increasing local magnetic shear produced by EC driven current, as shown in Fig. 3. The EC driven plasma current profile estimated by TRAVIS code indicates that EC driven plasma current locally flows at the plasma core and enhances the magnetic shear at the plasma edge where EPMs are existed. We also observed that the effect of magnetic shear on the mode did not depend on its sign.

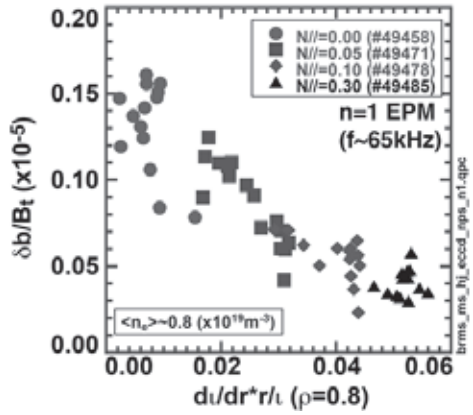

Fig. 3. Effect of magnetic shear induced by EC driven current on amplitude of observed m=2/n=1 EPMs.

3. Observation of energetic ion loss synchronized with bursting mode by Faraday-cup type lost ion probe (FLIP)

In order to clarify the mechanism of loss of the energetic ions caused by MHD instabilities, we have newly installed FLIP that can directly measure the lost ions just outside of last close flux surface. We have chosen the Faraday cup type detector, which can absolutely measure the ion flux corresponding to lost energetic ions. We observed the increasing of lost ion flux whose energy and pitch angle are in the range of $14 < E < 45$ keV and $48 < \chi < 60$ deg., respectively in FLIP. The change of lost ion flux was synchronized with the appearance of bursting EPMs, as shown in Fig. 4. The lost ion flux is proportional to the amplitude of the bursting EPMs. This means EPMs resonantly affected to the energetic ion orbit and lead to loss of energetic ion from confinement region.

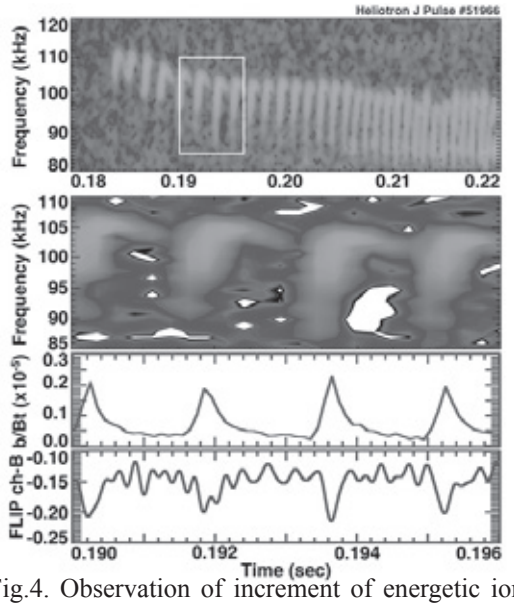

Fig.4. Observation of increment of energetic ion loss synchronized with bursting modes in NBI-heated Heliotron J plasmas.

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，佐野史道，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. Introduction

Peristaltic motion of electro-physiologically controlled organ (such as upper urinary tract, UUT; a peristaltic pump of urine) is so robust that partial damage at upper stream is automatically repaired with shifting an emerging point of the motion to the downward, and elongating the period of the contractions. An electrochemical circuit consisting of oscillatory and excitatory electrochemical oscillators can emulate this unidirectional and robust wave propagation by traveling current pulses through the network. For the evolution of the functions, the circuit demands critical two points; the decrease in the density of the oscillatory cells, the increase in the coupling strength of the excitatory matrix, but any spatial fine-tuning of the individual elements are not necessary. The demand for the coupling strength is spontaneously fulfilled by the biological boundary condition, i.e., the connection between kidney and UUT. The spatial decrease in the oscillatory cells is well harmonized with the cellular anatomical investigation in physiology.

2. Electrochemical Network

Here, we report a network consisting of two kinds of non-linear electrochemical oscillators (the oscillatory and the excitatory ones) is able to emulate the unidirectional and robust propagation of the traveling waves. The oscillator was consisted of iron anode and copper cathode dipped in an aqueous solution containing 1M sulfuric acid and 0.4M copper sulfate. In order to maintain quasi-polarographic condition for the iron electrode, the area of the copper cathode was 100 times larger than that of the iron anode (0.5 cm^2). Potential between the couple of the electrodes (E) was applied by a mulch-channel potential source, in which each channel was electrically isolated with isolation resistance over 1GΩ, i.e., each potential for the oscillator was equivalent to be supplied by independent batteries. Under E < 215 mV, a non-oscillating steady state (SS1) was observed with a constant current of 7.5 mA. In potential window; 215 mV < E < 245 mV, self-sustained relaxation oscillation appeared in the current. As increase in E, the amplitude of the current pulse as well as the period between them (T= 2π/ω) increased.

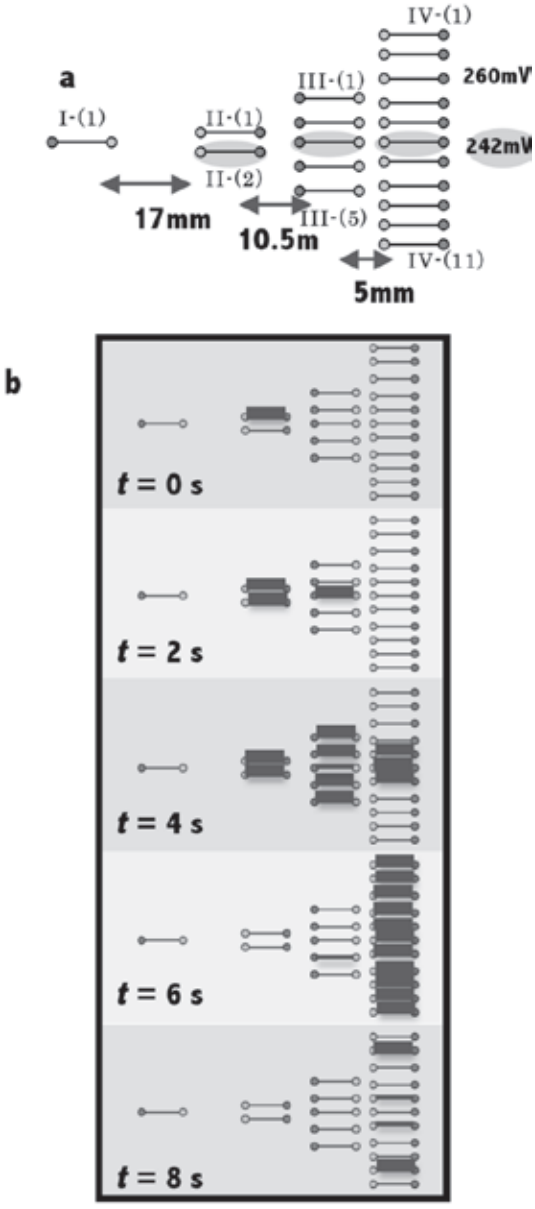

Figure 1 | Electrochemical circuit and current pulse propagation. (a) Architecture of the circuit consisting of oscillatory (pink ellipse, F_o = 0.05Hz) and excitatory oscillators. The single oscillator has iron anode (gray dot) and copper cathode (red dot). Applied potentials between the two electrodes were 260 and 242 mV for excitatory and oscillatory pairs, respectively. (b) Time evolution of the current pulses (blue bars) propagation.

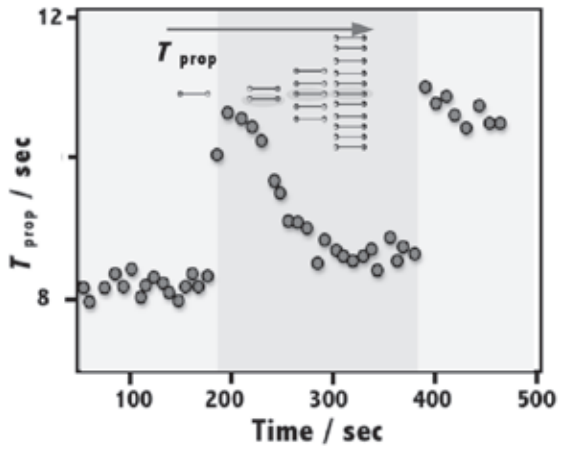

Figure 2| Staircase of propagating period (T_{prop}) of traveling pulses by sequential knock out of the self-sustained oscillators from upper stream.

In the electrolyte solution, while two self-sustained oscillators were linearly aligned with short distance (d) between the same polarities of the electrodes; iron-iron or copper-copper electrodes, both of the oscillators emitted the pulses at almost the same time (synchronization) but slight time difference was obvious between the synchronized pulses. The pulse from lower intrinsic frequency (the frequency under decoupled conditions) oscillator followed that from higher frequency one. This is "master and slave relationship" for the higher and the lower frequency oscillators, respectively. The synchronization has achieved not only with the oscillators pair having the same intrinsic frequencies ($F_1 = F_2$) but also with the pair having similar but different frequencies. The synchronization allowed the margin in the frequency difference, which was depend on d and $R_f = F_1/F_2$ (R_f ; the intrinsic frequency ratio between the coupled electrodes). We have reported the synchronization phase map as a function of R_f and d, and this phase map was considered as "Arnold's tongue" .

The electrochemical circuit emulating the robust and unidirectional wave propagation was shown in Figure 1a, which was segregated into 4 segments (I ~ IV), and distance between the segments decreased toward the down stream. The total number of the electrochemical nonlinear oscillators was 19 as shown form I-(1) to IV-(11). Oscillators covered by pink ellipses (II-(2), III-(3) and IV-(6)) were the oscillatory ones and others were the excitatory oscillators. The three self-sustained oscillators had the same applied potential, E = 242mV and F_o = 0.05Hz. All of the rest sixteen excitatory oscillators had the same potential, E = 260mV. The segments were coupled with same polarity, anode-anode (iron-iron; I-II and III-IV) and cathode-cathode (copper-copper; II-III), both of which were the excitatory coupling.

Time evolution of the propagation of the current pulse through the network was demonstrated in Figure 1b. This unidirectional propagation repeated periodically, and traveling period (T_{prop}) from the top (segment I) to the bottom in the network (segment IV) was 8s. After 20 cycles of steady and periodical propagations, the primary self-sustained oscillator located at the most upper stream (II-(2)) was set to be open circuit (knock out), and the oscillation of II-(2) was terminated. Starting point of the current pulse propagation shifted to the secondary self-sustained oscillator (III-(3)) and T_{prop} enlarged to 9 s through transient increase during 50 s. Likewise, once the secondary self-sustained oscillator (III-(3)) was terminated, the tertiary self-sustained oscillator (IV-(6)) behaved as the pace maker with T_{prop} = 10 s. In all of these cases, back propagation of the current pulse to the reverse direction (IV to I) was never observed.

The stepwise increase in T_{prop} by the sequential knock out of the self-sustained oscillators (II-(2) and III-(3)) presented in Figure 2. Thus, the network has successfully emulated three characteristics of UUT; (1) the unidirectional propagation of the traveling waves and (2) the self-repairing of the wave propagation against the partial damage, which was accompanied with (3) the increase in the propagation period (T_{prop}). Without any spatial dependent fine-tuning of E for the oscillatory and excitatory oscillators, the robust and unidirectional wave propagation was spontaneously emerged just by controlling the spatial geometry of these oscillators with accuracy in mm, which indicates the redundant spatial architecture was enough for the electrochemical circuit to accomplish the spatio-temporal functions.

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Clean Energy Conversion Research Section

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1. Introduction

These days the density region of Heliotron J is successfully expanded up to 5×10^{19} m^{-3} by development of a supersonic molecular beam injection (SMBI) [1]. For study in the new region, reliable plasma diagnostics are indispensable. Although a millimeter interferometer can measure the electron density precisely, it sometimes suffers from "fringe jump errors" and information of the electron density cannot be obtained in high density region. This is due to large beam refraction, which is proportional to roughly the squared wavelength, in a plasma. Hence a heterodyne interferometer with a HCN laser, whose wavelength is one order shorter than the millimeter wave, is developing on Heliotron J [2].

In this study, a dispersion interferometer [3] is proposed in addition to the conventional interferometers on Heliotron J. Since the dispersion interferometer is insensitive to mechanical vibrations, it does not need vibration compensation systems. This advantage also leads to the fringe-jump-less density measurement. When the phase shift measured with the interferometer is always smaller than one fringe (2π), the electron density can be uniquely determined from the phase shift. The smaller phase shift than one fringe is acceptable for the dispersion interferometer, because there is almost no phase error caused by the mechanical vibrations. In this way, the dispersion interferometer will be reliable density diagnostics equipment

2. Principle of dispersion interferometer

Figure 1 shows the basic optical setup of the dispersion interferometer. Laser light is injected into a nonlinear crystal to generate the second harmonic component. The probe beam is the mixture of the fundamental and the second harmonics components. Beam paths of the fundamental and the second harmonic components are almost the same, the mechanical vibrations are common. After passing through a plasma, the laser beam is injected into the nonlinear crystal again to generate another second harmonics. The fundamental component is cut by a filter and the interference signal between the two second harmonics is detected. The phases of the two second harmonics are as follows.

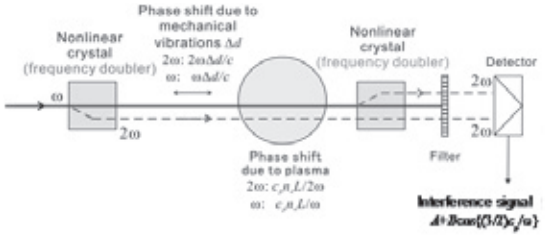

Fig.1 Optical setup of the dispersion interferometer

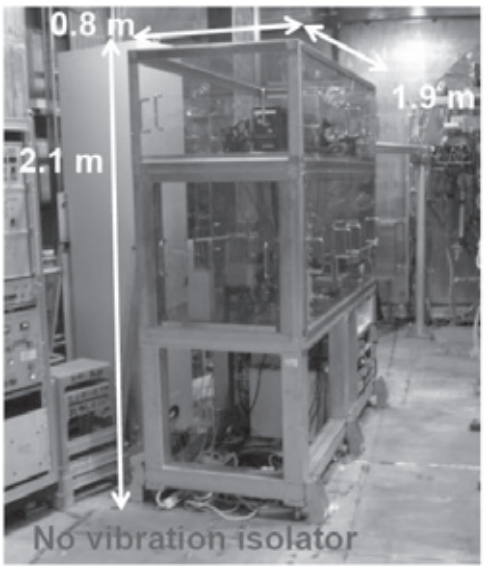

Fig.2: Photograph of the optical flame of the dispersion interferometer on LHD.

$$2(\omega t+\omega\Delta d/c+c_p\bar{n}_eL/\omega+\phi_1)\equiv\varphi_1$$

$$2\omega t+2\omega\Delta d/c+c_p\bar{n}_eL/(2\omega)+\phi_2\equiv\varphi_2$$

The phase of the interference signal is the subtraction of $\varphi_1-\varphi_2$. Since the vibration terms are common between φ_1 and φ_2, interference signal I becomes free from the mechanical vibration and depends on only the phase shift caused by a plasma $(3/2)c_p/\omega$, c_p is a constant and ω is the angular frequency of the laser light.

$$I=A+B\cos(\varphi_1-\varphi_2)$$
$$=A+B\cos\{(3/2)c_p/\omega\}$$
$$A=I_1+I_2,\ B=\sqrt{I_1I_2}$$
$$I_1,I_2:\text{detected intensity}$$

In this way, the dispersion interferometer is insensitive to the mechanical vibrations.

3. Dispersion interferometer on LHD

One of problems of the dispersion interferometer is a measurement error caused by variations of

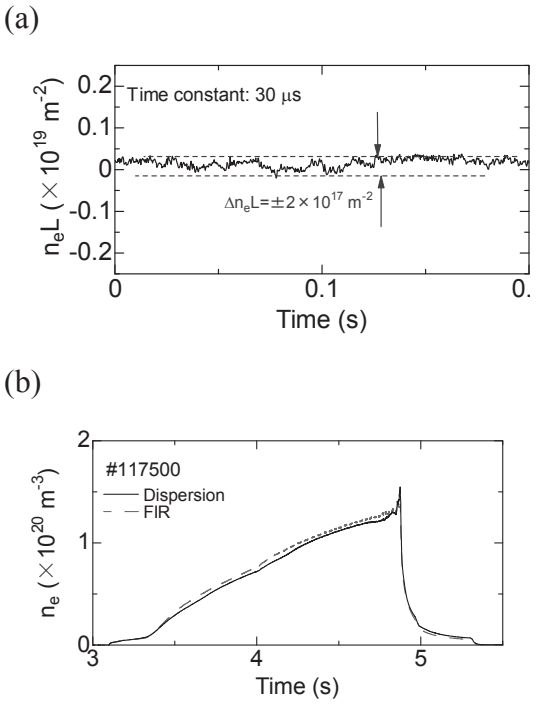

Fig.3: (a) Variations of the line-integrated electron density. (b) Comparison of the line-averaged electron density between the dispersion interferometer and the far infrared laser interferometer.

detected intensity. In order to resolve this problem, the phase modulation and the phase extraction method is introduced [4].

Figure 2 shows a photograph of the optical flame of the CO_2 laser dispersion interferometer installed on LHD. The dispersion interferometer is not equipped with a vibration isolation system. Despite large vibrations, the variations of the line-integrated density is 2×10^{17} m^{-2} with a time response of 30 μs as shown in Fig. 3(a). Figure 3(b) shows comparison between the dispersion interferometer and the existing far infrared laser interferometer. The line averaged electron density evaluated with the dispersion interferometer agrees with that with the far infrared laser interferometer.

4. Dispersion interferometer on Heliotron J

Figure 4 shows an example of the line of sight of the CO_2 laser dispersion interferometer on Heliotron J. Here, one plasma central chord and the same optical setup (the same density resolution) as that on LHD is supposed. The corner cube mirror is installed inside the vacuum vessel and the laser light has a double path in a plasma. The path length in the plasma is 0.6 m. Table 1 shows expected signal to noise ratios S/Ns for various electron densities. Even in the case of low density plasma with an electron density of 1×10^{19} m^{-3}, the S/N of 30 will be obtained.

Table 1 also shows the expected phase shifts. The

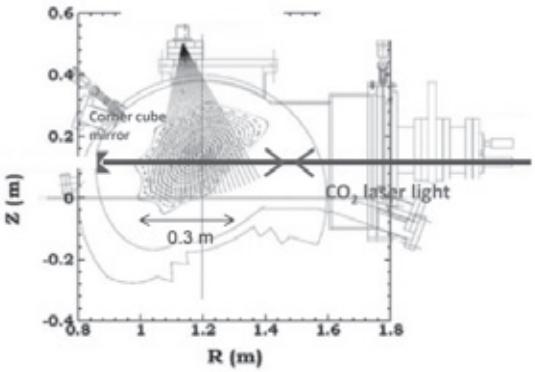

Fig.4: An example of the line of sight of the dispersion interferometer on Heliotron J.

Table 1: Expected signal to noise ratio S/N and phase shift in Heliotron J

n_e (m^{-3})	n_e L (m^{-3})	S/N	Phase shift (deg.)
1.0×10^{19}	6.0×10^{18}	30	15
3.3×10^{19}	2.0×10^{19}	100	50
1.0×10^{20}	6.0×10^{19}	300	150
2.3×10^{20}	1.4×10^{20}	700	360

electron density which causes a phase shift of 2π is 2.3×10^{20} m^{-3}. At least for a while the phase shift can be always regarded smaller than 2π and hence the electron density can be determined without fringe jump errors.

6. Summary

We have developed a dispersion interferometer on LHD, which is insensitive to the mechanical vibrations without fringe jump errors by selecting an appropriate wavelength of the laser source. The resolution of the line-integrated electron density is 2×10^{17} m^{-2} despite of the optical system without vibration isolation. The measured electron density is reasonable on LHD. Supposing that the same optical setup and the resolutions, a S/N of 30 will be obtained on Heliotron J even in the case of a low density plasma of 1×10^{19} m^{-3}. The expected phase shift of a CO_2 laser light is always smaller than one fringe on Heliotron J, there is no fringe jump error principally.

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Chemical Reaction Complex Processes Research Section

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K. Fukami, Assistant Professor

1. Introduction

In this research section, we studies on genetic engineering, protein engineering, surface science, and electrochemistry. We also apply them to efficient bioenergy utilization and design of highly efficient reaction processes.

In this fiscal year, we have investigated development of highly efficient bioethanol production, platinum deposition within nanoporous silicon and suppression of zinc dendrites for next generation rechargeable batteries.

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

Construction of efficient xylose-fermenting yeast *Saccharomyces cerevisiae* has been subjected to large number of trials for improving ethanol productivity from mixture of glucose and xylose that are widely distributed in lignocellulosic hydrolysates. In this study, genetically engineered *S. cerevisiae* overexpressing endogenous exclusively NADPH dependent aldose reductase, encoded by the *GRE3* gene, and endogenous xylulokinase with the mutated strictly $NADP^+$-dependent *Pichia stipitis* xylitol dehydrogenase was constructed and compared with the isogenic constructed reference strain expressing *P. stipitis* xylose reductase instead of the *GRE3* gene. As shown in Figure 2-1, the *GRE3* gene overexpressing strain increased ethanol production by 21.4 % compared with the reference strain, representing 42 g/g ethanol of total consumed sugars (85.7 % of the theoretical yield). Interestingly, rate of ethanol production by the *GRE3* gene overexpressing strain increased after glucose consumption where 39.5 g/g ethanol was produced in the presence of glucose and increased to 43.5 g/g ethanol after glucose consumption. Whereas the ethanol production rate decreased from 36.4 g/g to 32.9 g/g after glucose consumption in the reference strain. Furthermore, as shown in Figure 2-2, xylitol accumulation was diminished by 87.5 % representing 0.6 % of total sugars while the accumulation was 4.8 % of total sugars in the reference strain, probably due to effective regeneration of $NADPH/NADP^+$ cofactors by exclusively use of $NADPH/NADP^+$ between the *GRE3* gene product and the mutated strictly $NADP^+$ dependent *P. stipitis* xylitol dehydrogenase.

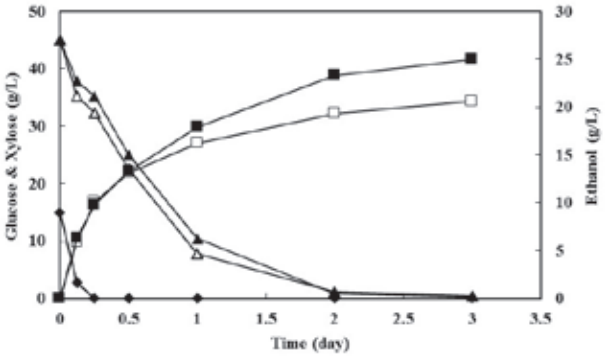

Fig. 2-1 Fermentation of the reference strain (open symbols) and *GRE3* overexpression strain (closed symbols). Xylose consumption (triangular symbols): Glucose consumption (rhomboid symbols) and Ethanol production (square symbols)

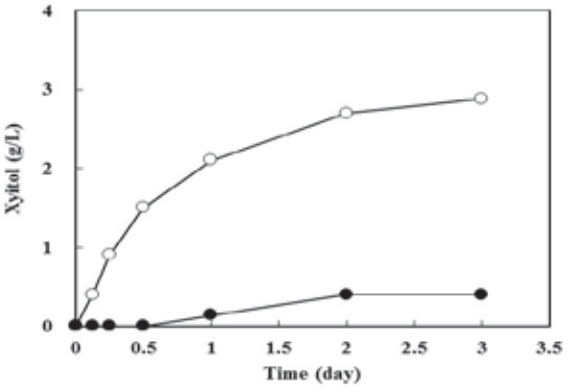

Fig. 2-2 Xylitol accumulation of the reference strain (open symbols) and *GRE3* overexpression strain (closed symbols).

3. Accelerated platinum electrochemical deposition in porous silicon: The effect of pore size

Porous silicon is a promising porous material which has a variety of advantages such as high specific surface area and controllability in pore size. The porous structure is very attractive in view of the utilization as template for nanostructure formation. Since porous silicon is a semi-conductive material, metals are possible to be electrochemically deposited within the matrix. However, the deposition process is a competitive process between the electron transfer at the surface and mass-transport. In this work, we have studied the effect of pore size on the platinum deposition within the pores.

Time developments of potential during the electrochemical deposition of platinum were measured with three different pore sizes, i.e., 4, 15, and 30 nm in diameter. Figure 3-1 shows the time developments of potential. On flat silicon, the potential increases monotonically, and reaches a steady value. In contrast, a potential plateau is observed when using porous silicon. This potential plateau is caused by the penetration of chemicals into pores. After the plateau, platinum was uniformly deposited within the porous layer. A surprising fact is that the duration of the plateau is much shorter in the smallest pores than the others. In general, chemicals diffuse into pores depending on the concentration gradient. The diffusion of platinum complex ions must be influenced by the pore morphology. The smaller the pore size is, the more difficult the diffusion of chemicals is. However, in the present study, the smallest pores enhance the penetration of chemicals into the pores. Thus, the mass-transfer in the nanopores is achieved not by diffusion but by another process.

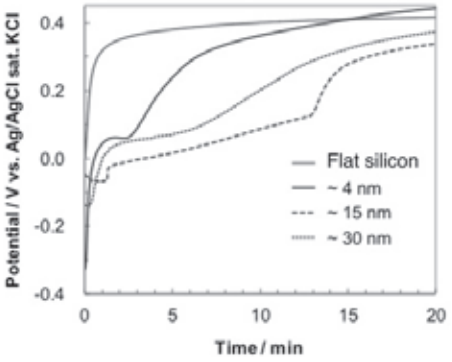

Fig. 3-1 Time developments of potential measured during the electrochemical deposition of platinum.

4. Suppression of dendritic growth in zinc electrodeposition using microporous silicon electrodes: The effect of coexisting cations

Rechargeable batteries are of great importance in the efficient utilization of energy. As a next generation batteries, negative electrodes consisting of metals are particularly attracted keen attention. This is because the energy density, which is possible to be stored in the battery, is much higher using metal electrode. However, dendritic crystal growth is known as a serious problem when using metal anode. Because dendrites often causes short circuit of batteries, they must be suppressed. We have shown that dendrites of zinc are possible to be suppressed using nanoporous electrodes. In this study, we have investigated the effect of coexisting cations in the solution for further efficient suppression of zinc dendrites.

Figure 4-1 shows the time developments of current efficiency for the deposition within nanoporous silicon electrodes. When the solution contains sodium cation, the efficiency is stable but not high enough. In the case of tetraethylammoniu cation, the efficiency reaches more than 95% in the initial stage. However it starts to decrease shortly. In contrast, the efficiency keeps ~95% when using the solution containing tetramethylammonium cation. Under such a high efficiency, dendrite formation on top of porous silicon was not observed. We believe that the utilization of nanoporous electrode for the suppression of dendrites during recharging batteries is a promising strategy for the next generation batteries based on metal negative electrodes.

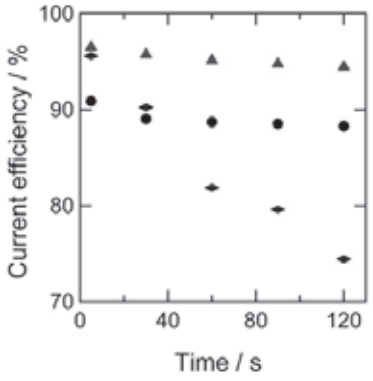

Fig. 4-1 Time developments of current efficiency for the zinc deposition (recharging). The plots by ▲, ◆, and ● show the efficiencies obtained using electrolyte solutions containing tetramethylammonium chloride, tetraethylammonium chloride, and sodium chloride, respectively.

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Molecular Nanotechnology Research Section

H. Sakaguchi, Professor
T. Kojima, Assitant Professor

1. Introduction

Nanotechnology is so important to produce the unprecedented materials for 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 developed 'Electrochemical Epitaxial Polymerization' technique which is a totally new molecular assembling technique of molecular wires on metal surface from single molecules. By the use of this technique, unprecedented materials for energy use will be developed. Organic electronic devices such as field effect transistors and solar cells will be studied. Followings are main research achievements in Molecular Nanotechnology Research section in the year of 2013.

2. Bottom-up massively produced graphene nanoribbons

Graphene nanoribbon (GNR) is a promising organic electronic material. GNR can work as a semiconductor with an atomically thinness and a sub-nanometer width. Atomically precise synthesis of monolayer GNR was achieved under an ultra-high vacuum condition. GNR growth reaction is required bond formation between monomers and conjugation expansion between connected monomers. Ultra-high vacuum (UHV) condition is required, because of short life times of aromatic biradical species. Highly reactive organic biradicals readily diminish by trapped with impurities under the reaction conditions. Only under UHV condition, biradicals reacted intermolecularly and afforded GNR precursor polymers.

To develop GNR 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 radical polymerized CVD. Poly (perianthracene) can be obtained under low vacuum condition (ca. 1 Torr) from 10,10'-dibromo-9,9'-bianthryl in an extremely cleaned quartz tube as a reactor. 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, and decreased concentrically. An atomically flat Au (111) metal surface was placed at the optimized space in a reaction tube, GNR prepolymer propagated efficiently. Further annealing process converted GNR prepolymer to conjugated GNR. The formation of poly (perianthracene) was confirmed by Raman spectrum. The reaction was applicable to the other organic monomers, for example, the narrowest GNR poly (perinaphthalene) was obtained from a mixture of 3,9-, and 3,10-dibromoperylenes. In our process, GNR propagation reaction proceeded efficiently. We obtained first example of multilayered GNRs by bottom-up synthesis. A multilayered GNR film 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 FET properties of bottom-up synthesized GNR films.

2. *2*-zoned radical-polymerized chemical vapor deposition (RP-CVD)

Attractive features of this method originate from an independent temperature-control of radical-generation process (zone 1) and the growth process (zone 2) to produce the biradical source for polymerization efficiently, leading to a high yield of GNR. Au(111) on a glass 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 in a quartz boat were vaporized by heating at 200–250 °C, 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 for 15 min, and to be radical-polymerized into prepolymers. Subsequently, the temperature was raised to 400 °C, and was maintained for 10 min as a second stage, for the prepolymers to be dehydrogenated into GNR. 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. These phenomena suggest that the biradicals formed from the evaporated monomers by the collision with the hot wall of reactor, are concentrated near the reactor surface. Placing the Au(111) substrate near the reactor surface, in which the high-density biradicals exist, is presumed as the reason for the high yield of GNR despite extremely low-vacuum (1 Torr) conditions. The utilization of the high-density biradicals is a remarkable benefit of RP-CVD.

3. STM studies of GNRs

GNR was characterized using STM measured in air. STM images of poly (perianthracene) GNR produced by RP-CVD showed a multilayered high-density array of linear wires. An intense Raman signal from the same sample was confirmed to originate from the massively grown multilayered GNR. The monolayer height corresponds to 0.22 nm from cross-sectional analysis of STM image. The GNR length is analyzed as up to 20 nm of the longest by a histogram from the STM image. To examine the GNR growth mechanism, the STM image of RP-CVD-grown sample at the first stage was measured. It shows a zigzag chain with spacing of each side corresponding to 0.82 nm, which shows good agreement with that of 0.85 nm for the alternate anthracene-ring in poly (anthrylene). These data suggest the mechanism of RP-CVD to be based on radical polymerization and dehydrogenation, in which the intermediate at the first stage corresponds to the prepolymer (poly (anthrylene)), followed by conversion to the poly (perianthracene) GNR at the second stage.

In fact, RP-CVD is applicable to the other monomers to produce GNR of different widths. When using monomers of mixtures containing 3,9-dibromoperylene and 3,10-dibromoperylene, the multilayered linear wires of poly (perinaphthalene) GNR, produced by RP-CVD, appeared in the STM images. The monolayer height was analyzed as 0.27 nm using cross-sectional analysis. A length histogram of the STM image of 100 nm^2 reveals that the length of poly (perinaphthalene) GNR is distributed up to 24 nm. Production of poly (perinaphthalene) GNR was also supported by Raman spectrum of the RP-CVD grown sample which showed identical peak-positions with those of the simulation. Although several reports to date have described the synthesis on poly (perinaphthalene) using CVD and pyrolysis from perylene-3,4,9,10-tetracarboxylic dianhydride, no direct evidence has been presented to visualize the wire structure. Moreover, physical properties such as band gaps and carrier mobilities have been unknown. The RP-CVD method has enabled clear visualization of the unknown structure of poly (perinaphthalene). The GNR growth mechanism was evaluated by measuring STM at the first stage. It clearly shows the existence of prepolymer and poly (perylenylene). Spacing at each line of image (1.75 nm) agrees with alternate spacing (1.7 nm) of the perylene rings in poly (perylenylene). Based on these data, the growth mechanism of poly (perinaphthalene) GNR was confirmed as polymerization of biradicals generated from monomers followed by dehydrogenation.

Poly(peritetracene) GNR with width of four benzene rings was produced when using 1,4-Bis(4-bromophenyl)-2,3,6,11-tetraphenyltripheny lene as a monomer. The multilayered linear wires of poly(peritetracene) GNR, produced by RP-CVD, appeared in the STM images. The monolayer height was analyzed as 0.27 nm using cross-sectional analysis. A length histogram of the STM image reveals that the length of poly(peritetracene) GNR is distributed up to 7 nm from the STM image. Production of poly (peritetracene) GNR was also supported by the Raman spectrum of the RP-CVD grown sample, which showed identical peak-positions with those of the simulation.

4. Band gaps of GNRs

The band gap of GNR is inferred to depend on the edge structure and width. Althoug there are some reports on the width dependence on the band gap, especially of armchair-edge type GNR, it has never been studied systematically. We measured the band gaps of our GNRs using scanning tunneling spectroscopy (STS). Present measurements experimentally established the band-gap value for the armchair-edged GNRs having sub-1 nm width. Experimental values are compared with the theoretical values obtained using the first-principles method with LDA. The reason for the deviation between experiments and theory might be the suitability of approximation used in theory.

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Biofunctional Chemistry Research Section

T. Morii, Professor
E. Nakata, Lecturer
S. Nakano, Assistant Professor

1. Introduction

The work in our research group takes synthetic, organic chemical, biochemical and biophysical approaches to understand the biological molecular recognition and chemical reactions. Rational design and functional evaluation of semi-synthetic miniature proteins, synthetic peptides and RNA/peptide assemblies enable precise recognition and fluorescence detection of biologically important molecules and in water, the solvent of life. Followings are main research achievements in fiscal year 2013.

2. Development of an adaptor to locate homodimeric proteins on DNA origami

Structural DNA nanotechnology, which includes DNA origami, enables the rapid production of self-assembled nanostructures. One of the key features of this technology is that fully addressable nanoarchitectures of various shapes and geometries are easily designed and constructed. By taking advantage of their addressable nature, DNA nanostructures have been used as scaffolds for the site-directed assembly of functional entities, such as small molecules and nanoparticles. As well as these functional entities, bio-macromolecules such as proteins and RNA-peptide (RNP) complex are a particularly interesting class of molecules to assemble because of their huge functional variability. In this year, we arranged enzymes and RNP sensors on DNA-origami and the function of these bio-molecules were confirmed on DNA-origami as the molecular switchboard.

We have developed that different locations within DNA-origami structures were site-specifically and orthogonally targeted by using sequence-specific DNA-binding proteins as an adaptor, and have demonstrated that adaptor-fused functional proteins were assembled at specific locations within DNA-origami structures. We have reported a basic-leucine zipper (bZIP) class of protein GCN4 as a new adaptor to expand the range of target DNA sequences. Based on the characteristics of GCN4 protein, GCN4 adaptor is suitable to arrange homo dimeric protein on DNA origami. Thus, a GCN4-fused homodimeric enzyme was arranged on molecular switchboard.

The GCN4 adaptor was applied for a homodimeric enzyme XDH. Conjugation of the GCN4 adaptor to the N-terminal of XDH afforded active adaptor-fused enzyme GCN4-XDH. The specific binding of GCN4-XDH on DNA origami was confirmed by AFM analyses. Furthermore, GCN4-XDH showed even higher activity than the wild type of XDH, and exhibited avid reactivity when assembled at the specific site of DNA origami.

Nature uses multiple proteins and/or enzymes in close proximity to efficiently carry out chemical reactions and signal transductions. Such assemblies of multiple proteins is now possible to design in vitro by using DNA-origami structures that have defined binding sites and various kinds of DNA binding adaptor-fused proteins.

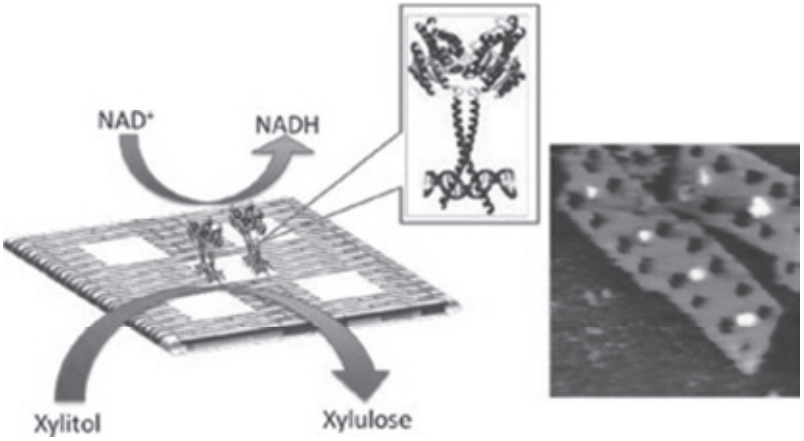
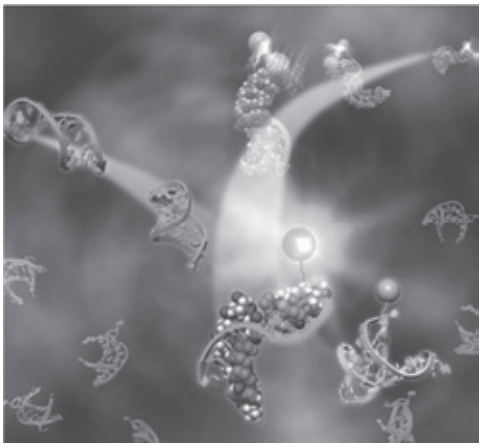


Figure 1. Assembly of GCN4-fused homo dimeric enzymes on the molecular switchboard.



3. A peptide nucleic acid heteroduplex probe discriminates a single-nucleotide difference in RNA

Sequence-selective detection of DNA and RNA is one of the fundamental techniques in molecular biology. In general, detection of target DNA or RNA sequences relies on the hybridization of the target sequence and its complementary oligonucleotide probe composed of either natural nucleic acids or their artificial equivalents. However, a major drawback in the hybridization technique for detecting single-stranded DNA (ssDNA) or ssRNA lies in the accuracy in discriminating a single-nucleotide difference in the target sequences. Several methods including the stringency clamping strategy have been developed to reduce nonselective hybridization of DNA or RNA probes by forming a stem--loop-type structure or by using a duplex-type probe with a fully matched strand or with a mismatch-containing strand, but there is room for further improvement. We have reported that a PNA heteroduplex with pseudocomplementary DNA or RNA effectively discriminates a single-nucleotide difference in ssDNA and/or ssRNA, and demonstrate that the pseudocomplementary PNA heteroduplex converted to a fluorescent probe can visualize a single-nucleotide difference in miRNA.

Selective discrimination of a single-nucleotide difference in single-stranded DNA or RNA remains a challenge with conventional DNA or RNA probes. A peptide nucleic acid (PNA)-derived probe, in which PNA forms a pseudocomplementary heteroduplex with inosine-containing DNA or RNA, effectively discriminates a single-nucleotide difference in a closely related group of sequences of single-stranded DNA and/or RNA. The pseudocomplementary PNA heteroduplex is easily converted to a fluorescent probe that distinctively detects a member of highly homologous let-7 microRNAs.

4. Latent fluorescent probe based on self-assembled fluorophore

We have developed a rational design strategy for latent fluorescent probe based on self-assembled fluorescent molecules in aqueous condition. This year, we focus to develop the latent ratiometric fluorescent pH probes by using SNARF derivatives as the scaffold. Analysis of the characteristics of SNARF derivatives with protected phenolic group allowed classification of the threshold between assembled and monomeric states according to the Hansch-Fujita hydrophobic parameters for a substituent inserted as a SNARF-OH phenolic-protecting group. The esterase-activated latent ratiometric fluorescent pH probe was designed and the intracellular application of the probe was demonstrated. Furthermore, the confirmation of the mechanism of penetration of cell membrane was demonstrated by using visualized self-assembled SNARF derivatives. We believe that the present strategy of designing a latent fluorescent probe has great potential for use in tissue or in vivo as a targeted cell-specific fluorescent probe.

These research projects were partly supported by a Grant-in-aid for Scientific Research from Ministry of Education, Science, Sports and Culture, Japan (No. 24121717, 25620131, 25248038 to T. M. and 24651150, 24107513 to E. N.) and by CREST, JST to T.M..

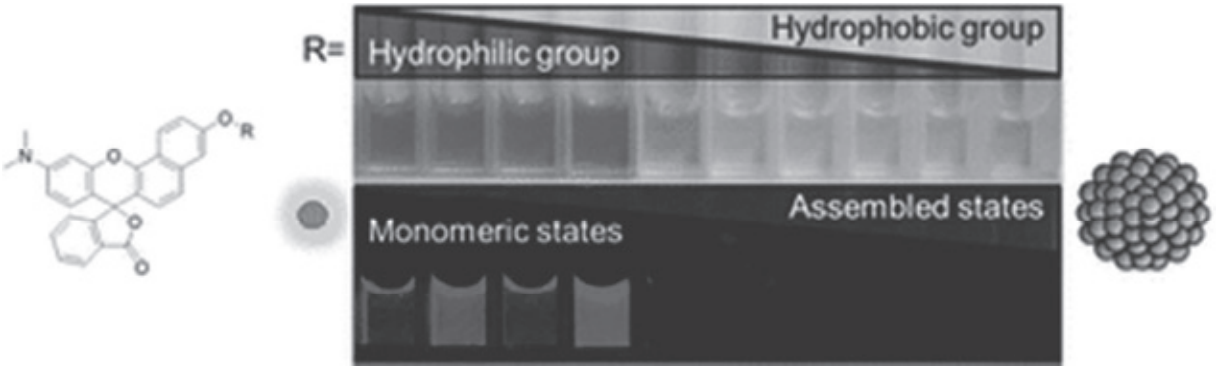


Figure 2. The novel strategy to design latent ratiometric fluorescent pH probes based on self-assembled fluorophore.

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森井孝，基盤(A)，タンパク質単分子配置による分子コンビナート構築原理の確立

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中田栄司，新学術領域研究，自己集合型ナノプローブによる細胞内酵素反応のリアルタイム解析

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Structural Energy Bioscience Research Section

M. Katahira, Professor
T. Nagata, Associate Professor

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 usefule to develope 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 2014.

2. Development of new methodology to investigate wood biomass with solution NMR

We have been developing new methodology to investigate wood biomass with solution NMR. This time we developed a method to correctly quantify amounts of various components involved in wood biomass sample at once. The intensity of a ^{1}H-^{13}C HSQC correlation peak of each component is usually used to quantify the amount. For a larger molecule, however, the magnetization is reduced during an INEPT transfer period of HSQC and thus the intensity of the HSQC peak is reduced, which results in skew of quantification. This is a serious problem, because wood biomass sample contains various components of a wide range of molecular weight. With an aid of the TROSY method, we developed a new method to calibrate the intensity loss during the INEPT period. Then, we successfully demonstrated that correct quantification is achieved with this correction for a mixture of various components with a molecular weight range of ca. 300-50000. This new methodology can give precise information in monitoring the amounts of various components during big-degradation of wood biomass.

3. Analysis of the substrate specificity of the antiviral factor APOBEC 3G by using real-time NMR

Human APOBEC3G protein (A3G) is an antiviral factor that disrupts HIV gene by introducing a significant level of mutations in the viral genome. A3G inactivates HIV by converting cytidene (C) into uridine (U) within the minus DNA strand, which was reverse-transcribed from RNA genome of HIV. Deamination activity of A3G is highly sequence specific, by which three base repeat of cytidine (CCC) within single-stranded DNA (ssNA) is converted into CCU then CUU, sequentially. Recently, it has been suggested that A3G may also target RNA as well as modified bases (5-methyl cytidine and 5-hydroxymethyl cytidine). We have developed an NMR method that can track the deamination reaction by A3G in real-time. The deamination activity of A3G against RNA and modified cytidines was analyzed quantitatively by using the real-time NMR method. Systematic DNA to RNA replacement of the nucleotide around target cytidine contributed to the elucidation of the recognition site by A3G. Based on the results, we found that recognition site of A3G deamination reaction is defined by both bases and sugars. Furthermore, A3G recognizes wider range of the nucleotides around target cytidine than as first thought.

4. Structural and functional analyses of Musashi1 involved in the maintenance of stem cell pluripotency

Musashi1 (Msi1) regulates the translation of target mRNAs and participates in the maintenance of cell 'stemness' and tumorigenesis. Msi1 binds to the 3'-untranslated region of *Numb* mRNA, which encodes Notch inhibitor, and suppresses initiation of its translation by competing with eIF4G for PABP binding. We have recently improved the preparation protocol of the second RNA-binding domain (RBD2) of Msi1, by which we have successfully [^{15}N, ^{13}C]-labeled it. We have then determined its 3D-structure by NMR. Additionally, we have performed NMR titration experiments, in which PABP was titrated to [^{15}N, ^{13}C] Msi1 RBD2. As a result, Msi1 RBD2 turned out to use its C-terminal region and α-helical surface to bind with PABP. On the other hand, we had previously shown that Msi1 RBD2 binds RNA on its β-sheet surface. Together, Msi1 RBD2 is now shown to bind to RNA and PABP at the same time (Fig. 1). Now, we have performed several

multidimensional triple resonance NMR experiments to determine the structure of Msi1 RBD2 in complex with RNA. Moreover, we are making PABP constructs that are suitable to determine the structure of Msi1 RBD2:PABP complex.

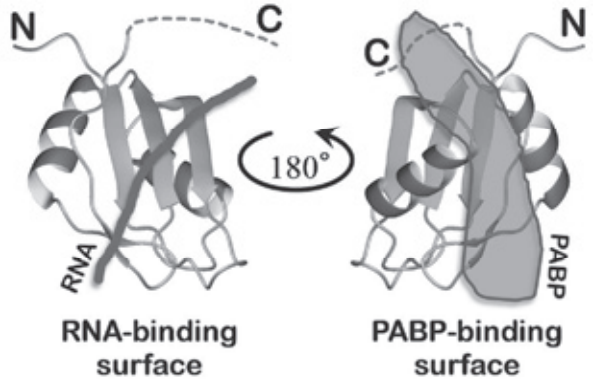

Fig. 1 Msi1 interacts with RNA on the β-sheet surface and PABP on the α-helix surface, respectively.

5. Development of intelligent enzyme that switches its activity in response to K^+

r(GGAGGAGGAGG), named as R11, changes from single-stranded elongated form into a compact quadruplex structure in response to K^+. In a hammerhead ribozyme, two portions of the catalytic core are linked with the stem and are located closely to exert the activity. We replaced this stem by R11 flanked with some linker residues. This chimeric RNA molecule, named as "quadruplex ribozyme (QR)" exhibits enhanced activity upon addition of K^+. To reduce an unwanted basal background activity and achieve the structural transformation without using heating-up and cooling-down procedure, we designed and introduced several complementary DNAs (Fig. 2). We found that the one, which is capable of forming an intramolecular quadruplex itself in the presence of K^+ fulfill our need. This QCS drastically repressed the basal activity of QR, by which an activity ratio with/without K^+ has reached as high as 16-fold. Since the intra- and extracellular K^+concentrations are very different, we will investigate this switching capability of QR-QCS in the cell system.

6. Analysis of the structure-function relationships on wood degrading enzymes for better utilization of woody biomass

Cellulose, hemicellulose, and lignin are the major components of wood. Cellulose has been used as a starting material to produce bioethanol and bioplastic. Other two components are also made of chemical structural units, which have potentials to be converted into bioethanol, biomaterials and medicine. However, the complexity of their structure in woody tissue hinders their isolation, as well as characterization of structure and function. To isolate lignin and hemicellulose in the native form so as to be able to use them as starting materials, we have begun to investigate the potentials of protein enzymes that are expressed in fungi that degrade wood. We have subcloned single genes of each cellulase and manganese peroxidase (MnP) of white-rot fungus (highly selective lignin-degrading fungus) that are thought to play major roles in lignin degradation. We have then succeeded to express cellulase in P. pastoris system and MnP in E. coli system. Optimization of the preparation procedure is underway. The further study is in progress to measure their activity, search for cofactors that enhance the activity, and solve the structure.

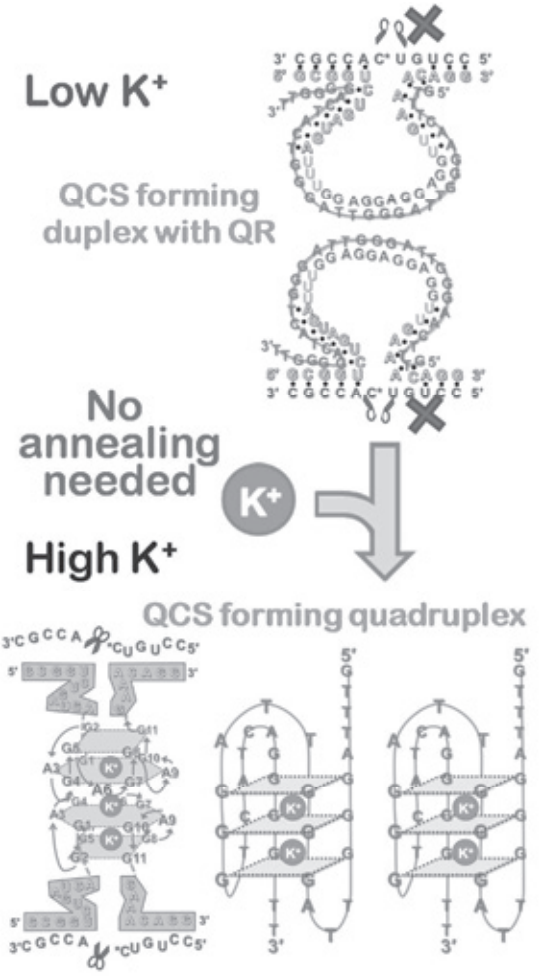

Fig. 2 QCS forms duplex with QR at low K^+ concentration and represses the basal activity of QR. At high K^+ concentration, QCS and QR dissociate and both form quadruplex structure, by which QR exerts ribozyme activity.

Collaboration Works

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Laboratory for Complex Energy Processes 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) Effects of sugars on the thermal stability of a protein [1]

In earlier works, we proposed a physical picture of thermal denaturation of proteins in which the measure of the thermal stability is defined as the solvent-entropy gain upon protein folding at 298 K normalized by the number of residues. A multipolar-model water was adopted as the solvent. The polyatomic structures of the folded and unfolded states of a protein were taken into account in the atomic detail. A larger value of the measure implies higher thermal stability. First, we show that the measure remains effective even when the model water is replaced by the hard-sphere solvent whose number density and molecular diameter are set at those of real water. The physical picture is then adapted to the elucidation of the effects of sugar addition on the thermal stability of a protein. The water-sugar solution is modeled as a binary mixture of hard spheres. The thermal stability is determined by a complex interplay of the diameter of sugar molecules d_C and the total packing fraction of the solution η: d_C is estimated from the volume per molecule in the sugar crystal, and η is calculated using the experimental data of the solution density. We find that the protein is more stabilized as the sucrose or glucose concentration becomes higher and the stabilization effect is stronger for sucrose than for glucose. These are in accord with the experimental results. Using an integral equation theory and the morphometric approach, we decompose the change in the measure upon sugar addition into two components originating from the protein-solvent pair and many-body correlations, respectively. Each component is further decomposed into the excluded-volume and solvent-accessible-surface terms. These decompositions give physical insights into the microscopic origin of the thermal-stability enhancement. The higher stability of the native state relative to that of the unfolded state is found to be attributable primarily to an increase in the solvent crowding caused by sugar addition. Due to the high hydrophilicity of sugar molecules, the addition of sugar by a larger amount or that with a larger molecular size leads to higher η, leading to the increased solvent crowding.

(A-2) Physics of multidrug efflux through a biomolecular complex [2]

Insertion and release of a solute into and from a vessel comprising biopolymers is a fundamental function in a biological system. A typical example is found in a multidrug efflux transporter. “Multidrug efflux” signifies that solutes such as drug molecules with diverse properties can be handled. In earlier works, we showed that the spatial distribution of the solute-vessel potential of mean force (PMF) induced by the solvent plays imperative roles in the

insertion/release process. The PMF can be decomposed into the energetic and entropic components. The entropic component, which originates from the translational displacement of solvent molecules, is rather insensitive to the solute-solvent and vessel inner surface-solvent affinities. This feature is not shared with the energetic component. When the vessel inner surface is neither solvophobic nor solvophilic, the solvents within the vessel cavity and in the bulk offer almost the same environment to any solute with solvophobicity or solvophilicity, and the energetic component becomes much smaller than the entropic component. Our idea is that the multidrug efflux can be realized if the insertion/release process is accomplished by the entropic component exhibiting the insensitivity to the solute properties. However, we have recently argued that the entropic release of the solute is not feasible as long as the vessel geometry is fixed. Here we consider a model of TolC, a cylindrical vessel possessing an entrance at one end and an exit at the other end for the solute. The spatial distribution of the PMF is calculated by employing the three-dimensional integral equation theory with rigid-body models in which the constituents interact only through hard-body potentials. Since the behavior of these models is purely entropic in origin, our analysis is focused on the entropic component. We show that the entropically inserted solute can be released by a continuous variation of the vessel geometry which forms a time-dependent entropic force continuing to accelerate the solute motion to the exit. Solutes with a wide range of sizes are entropically released using the same vessel-geometry variation. The results obtained are fairly general and also applicable to the efflux pump protein AcrB and ATP-binding cassette (ABC) transporter.

(B-1) Study of bumpiness and heating position effect on fast ions using ICRF minority heating in Heliotron J [3]

The fast ion confinement and ion heating efficiency is studied using ICRF minority heating. The better confinement in the high bumpiness and the localization of fast ions in the high-field side heating in the medium bumpiness are found in the experiment and simulation.

Fast ion velocity distribution is investigated using fast protons generated by ICRF minority heating in Heliotron J, a low-shear helical-axis heliotron (R_0 = 1.2 m, a = 0.1-0.2 m, $B_0 \leq$ 1.5 T). The fast ions are measured by a charge-exchange neutral particle energy analyzer (CX-NPA) installed at the opposite position in the toroidal angle to the ICRF antennas. The CX-NPA is positioned near the corner section of Heliotron J plasma. The experimental condition is as follows: the magnetic field strength is 1.25 T, the line-averaged electron density is 0.4×10^{19} m^{-3} and the ICRF power of 0.25–0.30 MW is injected into a target plasma produced by a 70-GHz ECH. The ion temperatures at the center of the ECH plasma are about 0.2 keV. The minority ratio is about 10%. Frequency of ICRF is 19 MHz or 23.2 MHz.

The high bumpiness among three bumpiness configurations was preferable for the fast ion confinement in the pitch angle scan experiment of the CX-NPA under the on-axis heating condition. In medium bumpiness, the two locations of cyclotron resonance layer were examined. The effective temperature, which is estimated from the slope of the energy spectrum between 1 keV and 7 keV, of the minority proton in on-axis heating was higher than that in the inner-side heating; however, the bulk deuteron temperature in on-axis heating was lower. It is not consistent with the heating scheme since most rf input power is absorbed by minority ions in our experimental condition. Fast ion's distribution is occasionally localized in real space and there is the loss region in velocity space in the high energy area. The result of fast ion observation should be analyzed including such effects and the configuration dependence of such effects should be clarified.

The two dimensional CX-NPA scan for the line of sight is performed for the three bumpiness configurations in on-axis heating condition. The scan region is from -2° to 12° for the horizontal angle and from -2° to 6° for the vertical angle. The toroidal position of the line of sight is changed in the horizontal angle scan as well as the pitch angle of the observed fast ions. The position of the line of sight in the oblique cross section is changed in the vertical angle scan. For the most angles, the effective temperature of fast minority ions and the bulk ion temperature in the high bumpiness are highest among three configurations. In the high bumpiness case only, the minority effective temperature profile is very peaked at -2° and 0° of horizontal angle. In the larger horizontal angle, the profile is relatively flat as in other two bumpinesses. For the bulk ion temperature profile, no such peaking is observed in all bumpinesses.

In this campaign, one antenna is used to clarify the effect of the heating position. The power level is from 150 kW to 200 kW. At the horizontal angle of 0°, vertical angle dependence of the fast ion distribution using the lower antenna is very large, whereas in the case of the upper antenna, the dependence is small comparing with the lower antenna case. To understand the experimental results, Monte Carlo code is developing to calculate the line-of-sight fast ion distribution.

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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，佐野史道，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、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡

Stuttgart Univ.、CIEMAT（スペイン），先進閉じ込め配位，長﨑百伸、大島慎介、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡

核融合科学研究所, 先進ヘリカルによるプラズマ構造形成・不安定制御と閉じ込め磁場最適化の研究，佐野史道、水内亨、長﨑百伸、中村祐司、岡田浩之、南貴司、門信一郎、小林進二、山本聡、大島慎介、ZANG Linge、釼持尚輝、史楠、木島滋

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

S. Kondo, 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 and the corresponding techniques, in areas of science and technology to private companies. 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 running in the beginning of the ADMIRE. The current project, however, is flexible to accept any new ideas from the industries 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 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)

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 clear understandings of 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.

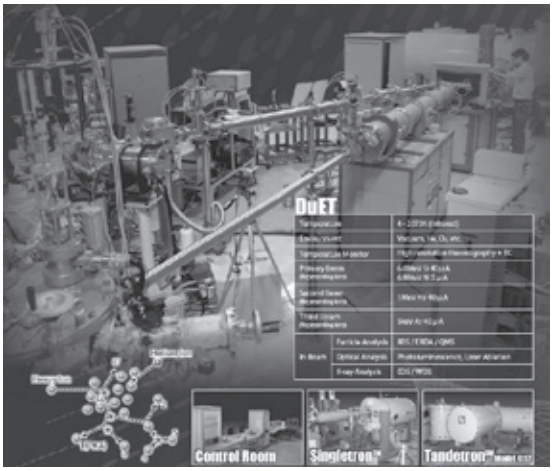

Fig. 1 Summary of the DuET facility set-up.

Testing by ion-irradiation is extremely useful to R&D of the nuclear materials because the flux “or damage rate” is very large (and it is easily controllable!) and conditions are accurate comparing to the testing in nuclear reactors. Thus, many advanced materials, such as silicon carbide and nuclear grade graphite, pro-vided by multiple commercial companies were tested within the ADMIRE framework. Although, we originally specialize in the irradiation study, some difficulties in testing the advanced materials, especially porous ceramic materials, were experienced. However, the developed methods (now the patent is pending, submitted in AUG 2012) successfully revealed a unique irradiation effects observed in those materials, such as the anisotropic dimensional change of the graphite materials, which were presented at the internal and international con-francs.

On the other side of the DuET work is the creation of the functional materials, such as gradient materials, by implanting the specific ions which is originally absent in the matrix constituents. Unfortunately, most topics cannot be discussed 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.

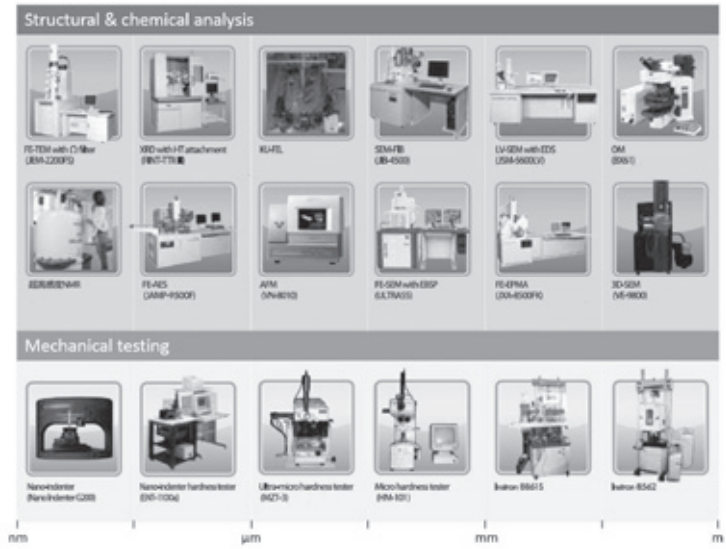

Fig. 2 Summary of the MUSTER equipment (selected).

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

Various analytical devices and mechanical testing machines are included in the MUSTER facility; each covers different 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 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 33 subjects are running, where the percentage of operating time for the ADMIRE related work is more than 50% (averaged, DEC 2013) 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 200kV 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 2014, faculty professors are excluded in the following list).

- Hideki Matsui, Ph. D., Specially Appointed Professor.
- Okinobu Hashitomi, Administrator of DuET accelerators.
- Takamasa Ohmura, Administrator of MUSTER facility.
- Je Hwanil, Ph. D., Program-Specific Researcher.
- Park ChangHo, Ph. D., Program-Specific Researcher.
- Han Wentuo, Ph. D., Program-Specific Researcher.
- Yasunori Hayashi, Program-Specific Researcher.
- Aya Kitamura, Technical Support Stuff.
- Reine Sakamoto, Secretary.

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3-2. AWARD

Student award in Institute of Advanced Energy

Quantum Radiation Energy Research Section
Kyohei Yoshida (D3)

I published a paper about mode-selective phonon excitation (MSPE). In this paper, MSPE of 6H-SiC by a mid-infrared pulse laser through anti-Stokes Raman scattering spectroscopy was demonstrated directly. MSPE is an important issue to develop energy saving devices because MSPE becomes a powerful tool for the study of ultrafast dynamics such as the electron-phonon interaction and the phonon-phonon interaction, which are significant factors for physical properties of those. The direct demonstration of MSPE of a solid material by a mid-infrared laser through anti-Stokes Raman scattering spectroscopy was conducted for the first time in the world.

Poster presentation award in 24th annual meeting of Association for Condensed Matter Photophysics.

Advanced Energy Materials Research Section
Naoto Akizuki (M2)

The Association for Condensed Matter Photophysics was founded in 1989 as a nonprofit, educational organization concerned with a broad range of phenomena relating to photophysics of condensed matter. The meetings have been held every year mainly in Kanasai area of Japan.

In the 24th annual meeting, I presented a work on excitation density dependence of photoluminescence spectra of excitons and trions (charged excitons) in hole-doped single-walled carbon nanotubes. I found that the photoluminescence intensity of trions exhibited a strong nonlinear saturation behavior as the excitation density increased, whereas that of excitons exhibited a weak sublinear behavior. I revealed that the strong photoluminescence saturation of trions is attributed to depletion of doped holes that are captured by excitons in the formation processes.

Excellent presenter awards in the 34th annual meeting of The Laser Society of Japan

Advanced Laser Science Research Section
Toshishige Inoue (M2)

Founded in 1973, The Laser Society of Japan (LSJ) is an international and domestic nonprofit association in the fundamental and industrial research relating to the laser and its application. The domestic annual meeting has been held every year.

In the 34th annual meeting in Fukuoka, I presented an experimental work on fundamental interaction process in nanograting formation on metal surfaces induced with femtosecond laser pulses.

2013 Young Researcher Award by Research Foundation for Opto-Science and Technology.

Advanced Energy Materials Research Section
Yuhei Miyauchi
(Specially Appointed Associate Professor)

The Research Foundation for Opto-Science and Technology was founded in 1988 as a public interest incorporated foundation for promoting development of science and technology of optics and photonics.

The award was given on my recent research achievements on optical properties and functionali-ties of carbon nanotubes.

Best Poster Award in 7th International Symposium on Nanomedicine

Biofunctional Chemistry Research Section
Eiji Nakata (Lecturer)

Japan Nanomedicine Society was founded in 2001 to give the broad fields' researchers who are interested in nanomedicine a chance to discuss and communicate about it. International symposium have been held every year mainly in Japan.

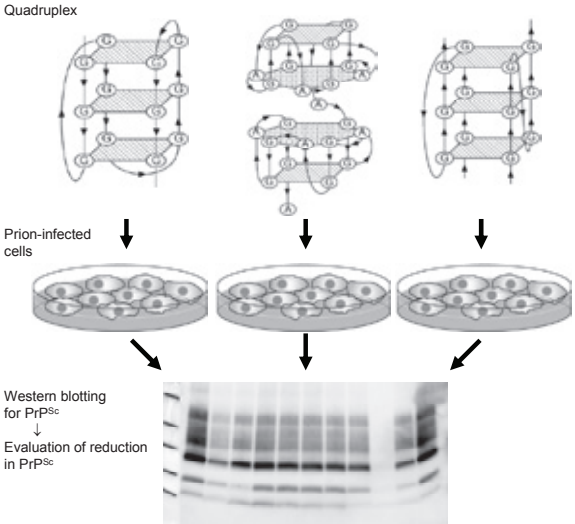
In the 7th international symposium, I presented the recent our research topics by following title, "A rational design strategy to design latent ratiometric fluorescent pH probes based on self-assembled SNARF derivatives". As well known, fluorescence imaging is one of the powerful techniques for continuous observation of dynamic intracellular processes of living cells. Fluorescent probes bearing a fluorescence switching property associated with a specific recognition or reaction of target biomolecule are therefore important for fluorescence imaging. Among them, the ratiometric fluorescent probe would generally offer an advantage over the intensity changing fluorescent probes not only test tube usage but also cellular application. Especially in the case of small molecules based ratiometric fluorescent probes, however, the initial fluorescence of the probe may prevent further intracellular application because the high background fluorescence of outside of cell must remain without washing operation. The latent ratiometric fluorescent probe which is defined as the probes to turn on inside cell via ester hydrolysis and to detect intracellular molecules including enzyme by ratiometric manner is possible to overcome the drawbacks. Therefore, the self-assembled SNARF derivatives recently we developed methodology (*Chem. Commun.*, 2010, **46**, 3526, and *RSC Adv.*, 2014, **4**, 348.) were used as the platform of the latent ratiometric fluorescent probes. The structure-activity relationship of the SNARF derivatives were explored and a rational design strategy for controlling self-assembled SNARF derivatives were developed. And the intracellular application of latent ratiometric fluorescent probe working as the intracellular pH indicator was discussed. The poster was well received, and even garnered a poster award.

The 40th International Symposium on Nucleic Acids Chemistry Outstanding Poster Award in 2013.

Structural Energy Bioscience Research Section
Tsukasa Mashima (Post-doc)

The international symposium on nucleic acids chemistry was founded in 1973 as an annual domestic meeting, and has become an international symposium in 2005. This symposium has contributed to development of the field of nucleic acids chemistry, as well as genetic technology, molecular biology, nanobiotechnology, and the therapeutic and diagnostic applications. The 40th symposium was held in Yokohama.

In the 40th symposium, I presented our latest work entitled "Origin of the anti-prion activity of quadruplex". Quadruplexes are higher-order nucleic acids structures formed from guanine rich sequences through hydrogen bonding between four guanine bases. We have recently found that the quadruplex structure of nucleic acids is responsible for anti-prion activity. In this symposium, I demonstrated that we have performed screening of the anti-prion activity among the nucleic acids that have distinct sequences and take on different topologies. Then, we have obtained a nucleic acid that was found to reduce the production of an abnormal prion protein (PrP^{Sc}) down to 10%. We estimated the 50% inhibitory concentration (IC_{50}) of the newly selected nucleic acid and it was around 100 nM. Judging from this low IC_{50} value, it is promising to develop an anti-prion drug derived from this nucleic acid.



Scheme of the screening for anti-prion nucleic acids. Nucleic acids folded into quadruplexes (upper) were added to prion-infected cells (middle). And then cells were lysed and analyzed by Western blotting for PrP^{Sc} (lower).

4. JOINT USAGE/RESEARCH PROGRAM

Joint Usage/Research Program "Zero-Emission Energy Research"

It is an urgent task to find out the best solutions against the energy and environmental problem for the sustainable development of human beings. 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 useful to realize three Rs 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 necessary to realize the energy system for next generation.

We propose a new ambitious concept of Zero-Emission 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.

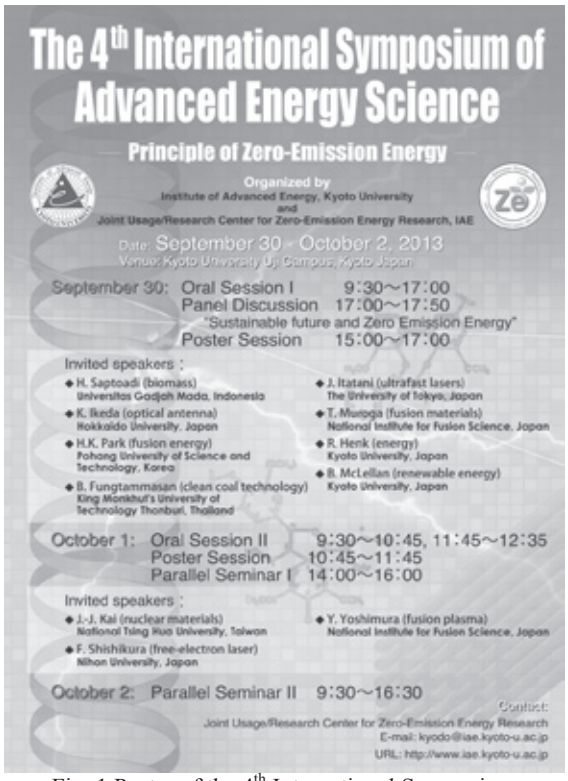


Fig. 1 Poster of the 4th International Symposium

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 new 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 research.

Many researchers have participated in this program. In FY 2013, Joint Usage/Research collaborations of total 78 subjects on Zero-Emission Energy were performed with more than 520 participants (~380 visitors) including graduate/undergraduate students from 38 all-Japan Universities and Institutions. The results of these collaborations are summarized in a report "IAE Joint Usage/Research Program on Zero-Emission Energy 2013." Some of them were presented and discussed in a Research Summary Session of FY2013 held at Uji Campus on March 5, 2014. If you have interest to this collection, please contact to the Office of Zero-Emission Energy Research (kyodo-office@iae.kyoto-u.ac.jp).

In addition to the Joint Usage/Research collaborations, we organized "the 4th International Symposium of Advanced Energy Science ~ Principle of Zero-emission Energy~" on September 30 – October 4, 2013 at Uji Obaku Plaza, Kyoto University (Fig. 1). This symposium consists of plenary and poster sessions, panel discussions and parallel seminars. About 220 scientists and students including six 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/calendar2013.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 2013

(Subject, Principal Researcher, IAE Key Person)

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

Phase stability in RAFM and ODS steels under ion irradiation
H. Abe, A. Kimura

Enzymatic conversion of carbon dioxide to methanol using biopolymer gel matrix
N. Tanaka, T. Morii

Structural determination of self-organizing glycoconjugates for development of high value-added biomass
M. Takeda, M. Katahira

R&D of high-resistant cladding materials in FBR against FP corrosion due to FCCI
K. Fukumoto, A. Kimura

Corrosion properties of Advanced Joints of Reduced Activation Ferritic/Martensitic Steel
T. Hirose, A. Kimura

Photo-Energy Conversion System Using DNA As a Carge Transporting Material
K. Yamana, T. Morii

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

Evaluation of radiation damages and helium effect on ODS ferritic steels
H. Sakasegawa, A. Kimura

NMR analysis of supramolecular structure of lignin and lignin-carbohydrate complex for advanced biomass utilization
K. Fukushima, M. Katahira

Tungsten material behavior under complex fusion irradiation environment
Y. Ueda, A. Kimura

Study on Gas Fueling and Pumping Systems for D-T Burning in Discharge Fusion Neutron Source
Y. Yamamoto, K. Masuda

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

Effect of He atoms in low-activation ferritic steel
H. Kinoshita, A. Kimura

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

Study on Mechanisms of Radiation Resistance of Advanced Tungsten Alloy
A. Hasegawa, A. Kimura

Effect of SFE on irradiation microstructure in Fe-Cr-Ni alloys
K. Yabuuchi, A. Kimura

Damage Formation Mechanism of Tungsten Under Repetitive and Pulsed High-Heat Load Conditions (Part 2)
K .Ezato, A. Kimura

Synergistic effects of displacement damage and tansmutant helium on the microstructure of fusion reactor structural materials and joints
T. Yamamoto, A. Kimura

Radiation induced hardening of pressure vessels steels due to ion irradiaton
H. Watanabe, A. Kimura

Development of the particle dispersion/precipitation strengthened Ni-base alloys as advanced nuclear materials and their evaluation of the microstructural behavior under irradiation
S. Ukai, A. Kimura

Studies on Helical Structure in Current-Carrying Toroidal Plasmas and Their Impact on Helical Plasma Research
S. Masamune, T. Mizuuchi

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

Study on photocatalytic film synthesis and biological CO2 fixing using infrared free electron laser
T. Sakae, H. Ohgaki

Property change on plasma facing materials for fusion reactor by high energy ion irradiation
K. Tokunaga, A. Kimura

Hybrid Solar Energy Research suitable for Rural Electrification
H.W. Ping, H. Ohgaki

Development of multi-pulse laser for energy enhancement of KU-FEL
R. Kuroda, H. Ohgaki

Development of Green Chemical Semiconductor Materials and Visible Light Response Photocatalyst by Dual-Beam Facility for Energy Science and Technology
K. Suzuki, A. Kimura

Improvement of mechanical, corrosion and irradiation properties of low activation vanadium alloys for fusion reactor
T. Nagasaka, A. Kimura

Multiple hydrogen trapping and thermal release at vacancies in high-fluence hydrogen plasma-tunsgten materials interaction
D. Kato, K. Morishita

Microstructure evolution of ion-irradiated oxide/nitride ceramics ～ Role of electronic excitation and selective displacement damage～
K. Yasuda, A. Kimura

Technology development of joining between nanostructured, toughened W-TiC and ODSS alloys for blanket structures
H. Kurishita, A. Kimura

Zero-emission energy system-challenge design and development of low-carbon boron tracedrugs for neutron dynamic therapy (NDT)
H. Hori, E. Nakata

Analysis of interaction between DNA and DNA binding domains of transcription activator-like effectors
M. Imanishi, T. Morii

NMR analysis of the interaction between an artificial RNA and a transcription factor
T. Sakamoto, T. Nagata

Design of functional protein nano-fiber and its application to the cell culture plate
N. Tanaka, T. Morii

R&D of Diverter Element for Fusion Reactor Using Explosion Welding
K. Hokamoto, R. Kasada

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

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

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

Studies on DNA Nanowire Transistor
K. Yamana, T. Morii

Transport analysis for high energy particles using numerical simulation codes in three-dimensional plasmas
Y. Nakashima, S. Kobayashi

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

Development of Radiation Detection Method Emitted from IEC Device
T. Misawa, K. Masuda

Porosification of semiconductor electrodes by electrochemical processes under dynamic self-organization
E. Tsuji, K. Fukami

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

Research on the production mechanism of cluster anions in laser ablation plasma for the development of functional materials
T. Kobayashi, T. Nakajima

Development and microstructure control of Composite Materials for High Thermal Conductivity
G. Sasaki, T. Hinoki

Creation of hierarchical self-assembling architectures in a microfluidic device
M. Numata, E. Nakata

Assembly of the rare metal binding protein on the DNA origami
Y. Mori, T. Morii

Development of Organic-Inorganic Hybrid Film toward High-Performance Organic Thin-Film Solar Cells

T. Akiyama, H. Sakaguchi
Comparative study of tokamak and helical viewed from heat and particle exhaust in fusion reactor
M. Kikuchi, K. Nagasaki

Development of iron-base composite materials with high thermal conductivity
N. Hashimoto, A. Kimura

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

Modeling of microstructural change in reduced activation ferritc/martensitic steel
Y. Watanabe, K. Morishita

Effects of Heavy Ion Irradiaion on Microstructure of Nuclear-grade Advanced SiC Fibers
K. Ozawa, T. Hinoki

Development of novel guanine-tethered antisennse probes
M. Hagihara, T. Morii

Effects of MeV order ion irradiation on nanostructure formation on novel metallic thin film/SiO2 glass substrate and correlation ship between nanostructure and its optical properties
T. Shibayama, T. Hinoki

Build-Up Strategy of ultra-thin carbon wire for Energy Conservation Devices
T. Nakae, H. Sakaguchi

Diagnostics of Plasma Turbulence by Using Micro-Wave
S. Inagaki, K. Nagasaki

Development of a steerable cylindrical millimeter wave launcher
H. Shidara, K. Nagasaki

Relation between a force vector acting on a solute in the vicinity of a surface and solvation structure around the solute
K. Amano, K. Fukami

Theoretical study on atomistic modeling for interactions between hydrogen/oxygen atoms and additive elements in zirconium alloys
Y. Kaneta, K. Morishita

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

Phase relaxation mechanism of excitons in doped carbon nanotubes
S. Konabe, K. Matsuda

Phase measurement of Vacuum-Ultraviolet pulse and control of electronic states
R. Itakura, T. Nakajima

Study of "zero-emission" molecules by time-resolved photoelectron spectroscopy with high harmonic pulses
T. Sekikawa, T. Nakajima

Investigation of methodology for Deliberative Polling based on science eduation to better reflect public opinion for nuclear power and other energy sources
H. Iwakiri, K. Morishita

Development of nano-scale assembly technique of multiple functional proteins
Y. Aizawa, T. Morii

Probing the intrinsic electrical and optical properties of high-quality graphene and carbon nanotubes by microscopic spectroscopy
R. Kitaura, K. Matsuda

Development of smart electronic devices using organic-inorganic composite materials with nano interface
T. Yamauchi, K. Fukami

Studies of visualization based on computer tomography of fluctuation in three dimensional high temperature plasmas
S. Ohdachi, S. Yamamoto

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

Detection of deuterium trapping site of deuterium-charged tungsten
K. Sato, A. Kimura

Unraveling the optical properties of individual carbon nanotubes by microscopic spectroscopy
Y. Miyata, K. Matsuda

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

Boudary diagnostics and rf heating in Heliotron J-III
K. Uehara, T. Mizuuchi

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 in 1996 simultaneously with the institute as an attached facility for research on advanced processes of energy production, conversion and application. On the other hand, resource and energy problems as well as global warming problems become very serious in recent years. We must concentrate all our knowledge and wisdom to find solutions to these problems. From such a viewpoint, the laboratory has been recognized again since FY2006 so that 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. 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 system 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 and MUSTER 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 field 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 project

Summary of the standard cooperative research subjects carried out in the year of 2013.

A public collection of cooperative research application was carried out, in this year, for a program which consists of three groups of “Kiban”, “Syorei” and “Kikaku-chosa” cooperative research. The “Kiban” cooperative research means a program to promote leading research themes of the institute projects. The “Syorei” cooperative research means a program to promote general research themes with respect to the institute projects. The “Kikaku-chosa” cooperative research means a program to promote the cooperative research through a seminar or symposium.

As a result, the research themes of 29 were applied and applications of 29 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 32

		category A			B	total
		A1	A2	A3		
Kibann	inside	1	1	1	0	3
	outside	0	0	0	0	0
Syorei/Kikaku-chosa	inside	6	10	8	0	24
	outside	1	0	0	1	2

"inside" or "outside" : Numbers applied by the inside or outside of the Institute

The individual research subjects are as follows.

A1

"International Collaborative Research on Advanced Biorefinery"

(1) B.J. Lee
(2) R. Norton
(3) M. Katahira , T. Morii, M. Kinoshita, T. Kodaki, E. Nakata, T. Nagata, T. Mashima, K. Kondo

(1) College of Pharmacy, Seoul Natl.Univ.
(2) Medical Chemistry, Monash Univ.
(3) Institute of Advanced Energy, Kyoto University

A2,

"Development of Advanced Plasma and Quantum Energy Studies"

(1) T. Mizuuchi, F. Sano, S. Konishi, K. Nagasaki, K. Morishita, K. Masuda, H. Okada, T. Minami, R. Kasada, S. Kado, U. Takeuchi, S. Kobayashi S. Yamamoto, S. Ohshima, S. Kondo, Shi Nan, S. Konoshima
(2) Y. Nakamura
(3) T. Akiyama, K. Tanaka, T. Kato
(4) T. Fukuda
(5) Y. Nakajima
(6) M. Ohnishi, Y. Yamamoto
(7) T. Iwakiri
(8) M. Miyamoto

(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) National Institute for Fusion Science
(4) Osaka University
(5) University Tukuba
(6) Kansai University
(7) University Ryukyu
(8) Shimane University

A3

"Research on establishment of Photo-Energy Nano Science"

(1) K. Matsuda, Member of Photo-Energy Nano-Science

(1) Institute of Advanced Energy, Kyoto University

A1

"Suppression of MHD Instabilities by Control of Rotational Transform"

(1) K. Nagasaki, S. Yamamoto, K. Masuda, S. Ohshima, K. Sakamoto, F. Sano, T. Mizuuchi, T. Minami, H. Okada, S. Kado, S. Kobayashi, S. Konoshima,
(2) Y. Nakamura
(3) Y. Yoshimura, G. Motojima, K. Mukai
(4) N. Marushchenko
(5) A. Cappa,
(6) F. Volpe

(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) National Institute for Fusion Science
(4) Max Plank Institute, Germany
(5) CIEMAT, Spain
(6) Columbia University USA

"Materials research for seeking advanced nuclear safety"

(1) K. Morishita, A. Kimura
(2) Y. Yamamoto, T. Nakasuji
(3) S. Ishino
(4) H. Abe
(5) H. Muta
(6) H. Iwakiri

(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) University of Tokyo
(4) School of Engineering, Tohoku University
(5) Graduate School of Engineering, Osaka University
(6) Dep. Education, University of Ryukyu

"Study on Tritium Flow in Fusion Reactor and Environment by System Dynamics"

(1) R. Kasada, S. Konishi, T. Shibata
(2) S. Kwon
(3) K. Noborio
(4) K. Ibano

(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) Toyama University
(4) University of Tokyo

“Energies of Coincidence Boundaries in Si (100) Twist Boundaries”

(1) K. Ishihara
(2) A. Ohtsuki
(1) Graduate School of Energy Science, Kyoto University
(2) Institute of Advanced Energy, Kyoto University

“Construction of high-efficient material conversion system on DNA nanostructure”

(1) E. Nakata, T. Morii, T. Kodaki, S. Nakano
(1) Institute of Advanced Energy, Kyoto University

“Development of a highly efficient bioethanol production yeast by genetic engineering”

(1) T. Kodaki, T. Nagata
(2) S. Sawayama
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Agriculture, Kyoto University

“Laser nanoprocessing on solid surfaces with femtosecond-laser-induced surface plasmon polaritons”

(1) G. Miyaji, K. Miyazaki
(2) A.E. Kaplan
(3) J. Reif
(1) Institute of Advanced Energy, Kyoto University
(2) Johns Hopkins University
(3) Brandenburgische Technische Univ.

A2

“Multiscale modelimg of material’s behavior under nuclear fusion condition”

(1) Y. Kaneta
(2) Y. Watanabe
(3) D. Kato
(4) S. Ohnuki
(5) M. Miyamoto
(6) X. Qui, T. Yoshiie
(7) Y. Yamamoto, T. Nakasuji
(8) K. Morishita, A. Kimura
(1) Akita National College of Technology Japan
(2) Japan Atomic Energy Agency
(3) National Institute for Fusion Science
(4) Graduate School of Engineering, Hokkaido University
(5) Interdisciplinary Faculty of Science and Engineering, Shimane University
(6) Kyoto University Research Reactor Institute
(7) Graduate School of Energy Science, Kyoto University
(8) Institute of Advanced Energy, Kyoto University

“Computational Study of Twisted-Tape-Induced Swirl Flow Heat Transfer and Pressure Drop in Vertical Circular Tubes with Various Twisted-Tape Inserts (Part3. Influence of Twist Ratio on Thickness of Conductive Sub-layer)

(1) K. Hata
(2) K. Hukuda
(3) T. Masuzaki
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Maritime Science, Kobe University
(3) National Institute for Fusion Science

“Development of Tow-dimensional Image Monitor for Diverted Plasma in Heliotron J”

(1) T. Mizuuchi, H. Okada, S. Kobayashi, S. Yamamoto, S. Ohshima
(1) Institute of Advanced Energy, Kyoto University

“Study of Mechanism of Ion Cyclotron Range of Frequency Heating of Plasma in a Non-Axisymmetic Magnetic Field”

(1) H. Okada, S. Kobayashi, S. Yamamoto, T. Minami, S. Ohshima, T. Mizuuchi, K. Nagasaki, F. Sano, S. Kado
(2) Y. Nakamura
(3) T. Mutoh
(4) Y. Nakashima
(5) N. Nishino
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) National Institute for Fusion Science
(4) Tsukuba University
(5) Graduate School of Engineering, Hiroshima University

“Development of multi-channel probes and analysis technique for visualization of edge turbulence”

(1) S. Ohshima, S. Yamamoto, S. Kobayashi, K. Nagasaki, F. Sano, T Mizuuchi, H. Okada, S. Nan, S. Konoshima,
(1) Institute of Advanced Energy, Kyoto University

“Development of High Speed Data Acquisition System to Increase Resolution of Nd;YAG Thomson Scattering Measurement”

(1) T. Minami,
(2) H. Funaba, K. Yamada, H. Nakanishi
(3) T. Hatae
(1) Institute of Advanced Energy, Kyoto University
(2) National Institute for Fusion Science
(3) Japan Atomic Energy Association

“Standardization and Verification of Lifetime Evaluation Method of W-Divertor Structural Component”

(1) A. Kimura, H. Wentuo, O. Hashitomi, T, Ohmura
(1) Institute of Advanced Energy, Kyoto University

“Study of high density plasma operation using novel fueling method and its transport characteristics”

(1) S. Kobayashi, T. Mizuuchi, F. Sano K. Nagasaki H. Okada, T. Minami, S. Yamamoto, S. Kado S. Konoshima,
(2) Y. Nakamura, M. Kirimoto, T. Harada
(3) Y. Nakashima
(4) Y. Suzuki, K. Nagaoka, Y. Takeiri, S. Okamura, K. Mukai,
(5) T. Ohishi
(6) S. Murakami,
(7) T. Estrada
(8) H. Lee
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) Tsukuba University
(4) National Institute for Fusion Science
(5) Faculty of Engineering, Nagoya University
(6) Graduate School of Engineering, Kyoto University
(7) CIEMAT, Spain
(8) Korea Advanced Institute of Science and Technology

“Studies of MHD equilibrium and stability in high beta plasmas of Heliotron J”

(1) S. Yamamoto, H. Okada, F. Sano, T. Minami, T. Mizuuchi, S. Kobayashi, K. Nagasaki, S. Kado, S. Ohshima, S. Konoshima S. Nan
(2) Y. Nakamura
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University

“Identification of the line spectra in Heliotron J for the plasma diagnostics”

(1) S. Kado, S. Yamamoto, H. Okada, F. Sano, T. Minami, T. Mizuuchi, S. Kobayashi, K. Nagasaki, S. Ohshima, S. Konoshima
(2) Y. Nakamura
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A3

“Isolation of KU-FEL pulses using plasma shutters”

(1) T. Nakajima, H. Zen, T. Kii, H. Ohgaki, X. Wang
(2) Y. Qin
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University

“Analysis of structure-function relationships on wood degrading enzymes for better utilization of woody biomass”

(1) T. Nagata, M. Katahira, T. Morii, T. Kodaki, E. Nakata
(1) Institute of Advanced Energy, Kyoto University

“Study on Photoelectron Emission Property of LaB_6 and CeB_6”

(1) H. Zen, H. Ohgaki, K. Masuda. T. Kii
(2) K. Okumura
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Engineering, Kyoto University

“Development of metal negative electrodes for next generation rechargeable batteries”

(1) K. Fukami,
(2) T. Sakka,
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Engineering, Kyoto University

“Development of wavelength scanning system for KU-FEL”

(1) T. Kii, H. Ohgaki, K. Masuda, H. Zen, E. Nakata
(1) Institute of Advanced Energy, Kyoto University

“Evaluation of Enzyme Activity for MIR Free Electron Laser irradiation”

(1) H. Ohgaki, T. Morii, T. Kii, E. Nakata, K. Masuda, H. Zen
(1) Institute of Advanced Energy, Kyoto University

“Basic Study on Compact THz-FEL System”

(1) H. Ohgaki, K. Masuda, T. Kii, H. Zen
(2) Y. Tsugamura
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University

“Feasibility study on high-power wavelength tunable THz pulse laser (I)”

(1) T. Kii, H. Ohgaki, K. Masuda, H. Zen
(1) Institute of Advanced Energy, Kyoto University

B

“Verification of selective phonon excitation by MIR-FEL”

(1) H. Hachiya, K. Yoshida
(2) H. Ohgaki, H. Zen
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(2) Institute of Advanced Energy, Kyoto University

SYMPOSIUM IN THE LABORATORY

Symposium
The symposium has been arranged in order to introduce the research activities in sections and to enhance the mutual cooperation among different fields. In 2013, three regular meetings and the annual meeting for the cooperative research results were held with following theme.

1. The regular meeting

(1) April 18, 2013

K. Matsuda, "Principle of optical science and its energy application based on nano-science -toward quantum green photonics-"
Institute of Advanced Energy, Kyoto University

(2) May 16, 2013

H. Sakaguchi, "Unprecedented fabrication process for carbon-based conjugated polymers ",
Institute of Advanced Energy, Kyoto University

(3) June 20, 2013

K. Nagasaki, "Highly elaborated utilization of electromagnetic waves for fusion plasma control "
Institute of Advanced Energy, Kyoto University

(4) July 25, 2013

H. Ohgaki, "Recent Topics of Quantum Radiation Beams"
Institute of Advanced Energy, Kyoto University

(5) September 19, 2013

M. Katahira, "Application of NMR in life- and green-innovation"
Institute of Advanced Energy, Kyoto University

(6) October 17, 2013

S, Konishi, "Biomass-Fusion Hybrid Concept and Sustainable Zero-Emission Energy System",
Institute of Advanced Energy, Kyoto University

(7) November 21, 2013

T. Morii, "Biological systems for efficient energy utilization: from a chemical point of view"
Institute of Advanced Energy, Kyoto University

(8) November 18, 2013

M. Preynas, "Experiments of Plasma Start-up and Wall conditioning using ECRH in preparation of Wendelstein7-X Operation."
Max-Planck-Institut fur Plasmaphysik, Greifswald

(9) November 25, 2013

B. Blackwell, "Recent results from the H-1 and the Australian Plasma Fusion Research Facility",
Plasma Research Laboratory, The Australian National University, Australian Plasma Fusion Research Facility

(10) December 20, 2013

S. Nakabayashi, "Electrochemical circuit that emulate robust physiological function"
Graduate School of Science and Engineering, Saitama University

(11) January 16, 2014

A. Kimura, "Material Performance under High Energy Particles Irradiation "R&D of Innovative Nuclear Materials"
Institute of Advanced Energy, Kyoto University

(12) February 7, 2014

M. Kinoshita, "A system comprising multiple material constituents is a treasure house of high-functioning－focusing on a biological system"
Institute of Advanced Energy, Kyoto University

(13) March 7, 2014

T. Mizuuchi, "Physics and Technology for High Temperature Plasma Control"
Institute of Advanced Energy, Kyoto University

2. The Annual Meeting for the Cooperative Research Results, April 4, 2014

(1) T. Mizuuchi, "Development of Advanced Plasma and Quantum Energy Studies",
Institute of Advanced Energy, Kyoto University

(2) S. Kobayashi, **"**Study of high density plasma operation using novel fueling method and its transport characteristics**"**

Institute of Advanced Energy, Kyoto University

(3) S. Yamamoto, **"**Studies of MHD equilibrium and stability in high beta plasmas of Heliotron J**"**
Institute of Advanced Energy, Kyoto University

(4) K. Matsuda, **"**Research on establishment of Photo-Energy Nano Science**"**
Institute of Advanced Energy, Kyoto University

(5) T. Nagata, **"**Analysis of structure-function relationships on wood degrading enzymes for better utilization of woody biomass**"**
Institute of Advanced Energy, Kyoto University

(6) T. Kii, **"**Development of wavelength scanning system for KU-FEL**"**
Institute of Advanced Energy, Kyoto University

(7) M. Katahira, **"**International Collaborative Research on Advanced Biorefinery**"**
Institute of Advanced Energy, Kyoto University

(8) T. Kodaki, **"**Development of a highly efficient bioethanol production yeast by genetic engineering**"**
Institute of Advanced Energy, Kyoto University

(9) R. Kasada, **"**Study on Tritium Flow in Fusion Reactor and Environment by System Dynamics**"**
Institute of Advanced Energy, Kyoto University

(10) S. Yoshikawa, **"**Research Center for Next Generation Photo-Voltaics of current**"**
Institute of Advanced Energy, Kyoto 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"

This interdisciplinary research project is aimed to uncover principles that govern highly efficient utilization of solar energy. Four research groups, each based on different disciplines of chemistry, biochemistry, physics and nanotechnology, simultaneously propel the cutting-edge research on the next generation photovoltaic cells, solar fuels, and biorefinery.

A symposium was held on Ocober 2, 2013 to promote mutual interactions between the research groups, which would incubate the original ideas, which stimulates creation of an innovative paradigm in solar energy utilization technology. Professor Takashi Morii opened the discussion with his lecture "Assembly of enzymes on molecular switchboards." DNA-origami structures are used as “molecular switchboards” to arrange enzymes and proteins with nanometer-scale precision. This strategy enables the reconstitution of natural enzyme cascades outside the cell, which is a necessary method to realize an artificial photosynthesis system made by biomolecules.

Professor Masato Katahira introduced a new aspect of bio-refinery research using wood biomass, which is produced by solar energy, entitled "Development and application of the methodology to investigate wood biomass by solution NMR." His methodology made it possible to identify and monitor the conversion of components of wood biomass at atomic resolution.

Professor Tetsuo Sakka discussed on the surface pattern formation by microparticles in his talk entitled "Two-dimensional self-assembled structure formed by the particles adsorbed at a liquid-liquid interface." His research focuses on highly controllable self-assembled particle layer formation at a liquid-liquid interface, where the particle structure is solely governed by the interparticle interaction. The method will be useful in designing the surface to properly scatter and diffract light to improve the efficiency of thin-film solar cells, the incident light must be trapped in the film.

Professor Hiroshi Sakaguchi inspired the audience by his talk of "One-dimensional carbon-based polymers for energy utilization." He has demonstrated Radical-polymerized Chemical Vapor Deposition (RPCVD) and Electrochemical Epitaxial Polymerization as bottom-up massive growth techniques of GNRs under normal condition. He has also succeeded in for the first time the synthesis of multilayered GNR, transfer onto insulator substrate and FET fabrication of bottom-up synthesized GNR. Electrochemical method to produce GNR under room temperature in metal-solution interface also has been demonstrated for the first time. These new techniques open the door to the device fabrication and unknown features of bottom-up fabricated GNRs.

Prof. Takashi Sagawa reported a cutting-edge research ongoing in his group by his talk of "Interface engineering of nanostructured ZnO/polymer for highly efficient hybrid solar cell" to discuss the potential and future utilization of solar cells.

A talk entitled "Development of novel light energy utilization using nano-carbon materials" by Professor Kazunari Matsuda emphasized a new concept for the development of novel light energy utilization using nano-carbon materials. Upon introducing the fundamental aspect of nano-materials and their potential application for the light energy, the topics of drastic improvement of luminescence quantum efficiency of carbon nanotubes toward the low energy consumption and efficient light emitters were discussed.

Professor Hideaki Ohgaki introduced the current status and future perspective of KUFEL, and his co-worker Kyohei Yoshida reported his recent study entitled “Experimental demonstration of mode-selective phonon excitation of 6H-SiC by a mid-infrared laser with anti-stokes Raman scattering spectroscopy." The results convinced all the participants a potential of MIR-FEL in the material science and that it could contribute to a development of zero-emission energy system.

Bidirectional Collaborative Research Program

Since 2004, the Heliotron J group at Kyoto University has joined the bidirectional collaborative research program of National Institute for Fusion Science (NIFS). The purpose of this program is to extend the activities of nuclear fusion research at universities in Japan after the Committee of the Science Subdivision under the Council for Science and Technology has decided to set up its master plan for Japanese fusion research and development by promoting collaborative research activities. This plan was summarized in the report "Policy for executing Japanese nuclear fusion research", where it was pointed out that continuous scientific research activities for comprehensive understanding of toroidal plasma physics are needed under the parameters which can be extrapolated to the fusion reactor.

The main objective of the research is to improve the confinement and stability performance for advanced helical magnetic configurations such as the helical-axis heliotron, Heliotron J. Six topics for the collaboration research for this FY are selected; (1) confinement improvement by controlling magnetic configuration and related plasma self-organization, (2) instability suppression by controlling magnetic configuration, (3) ECH/EBW heating physics, (4) toroidal current control, (5) fueling control and exhaust control of heat and particles, and (6) development of the FIR measurement system and so on. The results of several subjects are described below.

Study of high density plasma operation [1, 2]: To obtain high performance plasmas, the optimization study for gas-fuelling scenario has been carried out using supersonic molecular-beam injection (SMBI) and high-intensity gas-puff fuelling (HIGP) techniques in Heliotron J. The HIGP technique is effective to produce the electron density higher than 1×10^{20}m^{-3}. After stopping HIGP, increases in the ion/electron temperatures and the co-rotating toroidal rotation are simultaneously observed in the peripheral (r/a>0.7) region. At that time, the reduction in the density fluctuation at the edge region is also observed in accordance with the sudden drop of the Hα/Dα intensity. This type of high-density condition is achieved only in the low (ε_t) configuration. The neutral simulation is carried out for investigating high elongation effect of this configuration.

Stabilization of energetic-ion-driven MHD Mode by ECCD [3]: ECCD experiments have been made for stabilization of energetic-ion-driven MHD modes in Heliotron J. Theoretical analysis shows that an EC current of a few kA driven in the central region modifies the rotational transform profile from a shearless flat one into a high-shear one. ECCD has been applied to ECH+NBI plasmas in which AEs are excited by energetic ions. The EPM, an energetic-ion-driven MHD mode, has been fully stabilized by centrally localized second harmonic 70-GHz X-mode ECCD. In the magnetic configuration of $\iota/2\pi$ = 0.512 and 0.525, the EPM of 60-90 kHz is stabilized by the counter-ECCD which forms a positive magnetic shear. Since the mode is excited locally at r/a~0.6, the change in local magnetic shear contributes to the mode stabilization. The N|| scan indicates that the AE is stabilized when the magnetic shear exceeds a critical threshold. This tendency is consistent with the excitation theory of AEs.

Edge plasma behavior affected by energetic particle driven instabilities [4]: In Heliotron J, edge fluctuation has been studied using multiple Langmuir probes installed at different toroidal/poloidal sections. In low-density ECH plasma discharges with $n_e \sim 0.3\times10^{19}$ m^{-3}, a high correlation between floating potential signals measured with different probes was observed in the low frequency range less than 10 kHz. This fluctuation exhibits electrostatic characteristics. Radial structure of the fluctuation was investigated by fixing one probe inside LCFS and by scanning the other probe around LCFS in radial direction on a shot-to-shot basis. Clearly, the coherence is quite high ~0.95 inside LCFS in the low frequency range, and it quickly decreases outside LCFS. The phase difference in toroidal direction is almost zero in the observation range.

References

[1] S. Kobayashi, et al., "Experimental study of high density plasma operation in Heliotron J", 40th EPS, Espoo, Finland, 1-5 Jul. 2013, P1.148.
[2] T. Mizuuchi, et al., "Optimization of Fuelling Scenario for High Density Plasma in Heliotron J", Joint 19th ISHW and 16th IEA-RFP workshop, Padova, Italy, 16-20 Sep. 2013, K8.
[3] K. Nagasaki, et al., "Stabilization of energetic-ion-driven MHD Mode by ECCD in Heliotron J", Nucl. Fusion 53 (2013) 113041.
[4] S. Ohshima, et al., "Edge Plasma Behavior Affected by Energetic Particle Driven Instabilities in Heliotron J", Joint 19th ISHW and 16th IEA-RFP workshop, Padova, Italy, 16-20 Sep. 2013, O19.

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.

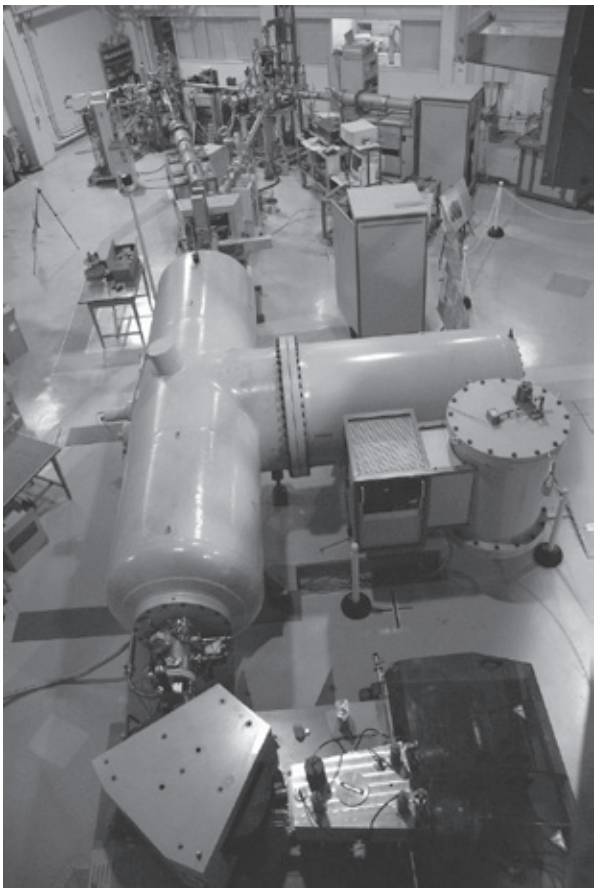
The ADMIRE Project has four modes of facility use: a) Trial use mode, b) Charged use mode-X (exclusive use of data), c) Charged use mode-N (non-exclusive use of data), and d) Collaborative use.

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

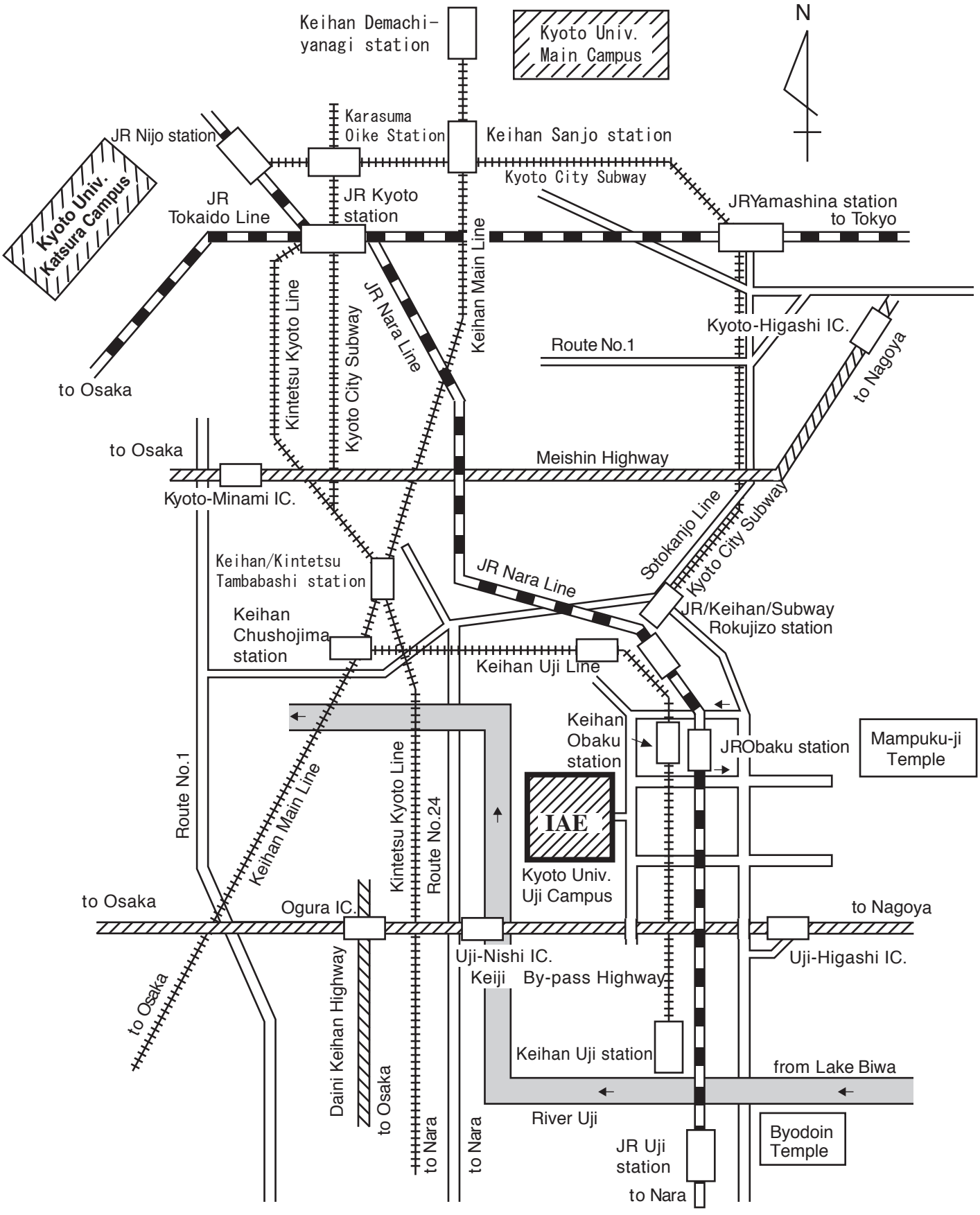
This mode is similar to the standard collaborative research conducted jointly by private companies and university staff under a contract to which both parties agreed. This is not just utilization of the facility but full collaboration on specific subjects.

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 IAE



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