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Institute of Advanced Energy
Kyoto University

ANNUAL REPORT

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京都大学エネルギー理工学研究所

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Kyoto University

Gokasho, Uji, Kyoto 611-0011
Japan

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FOREWORD

The Institute continues to thrive through the first midterm period (2004–2009) under the new system (conversion of national universities to independent corporate entities). Efforts have yielded fruitful results in the advanced energy science and technology fields of plasma systems, bioenergy, lasers, quantum energy, and much more. Research activities and external funding are all sound.

In 2008, two significant programs were initiated: a new CREST (Core Research for Evolutional Science and Technology, JST) project involving novel solar cells, and the Global COE program "Toward CO_2 Zero-Emission Energy System" (2008–2012) started with the cooperation of the Graduate School of Energy Science and other two institutions after successful completion of the 21st COE program (2002–2006). The Asian CORE Program (JSPS; Advanced Energy Science with China and Korea) is now the successor of the Core University Program (JSPS; Energy Science and Engineering with Seoul National University, 1998–2007). In addition, antiseismic reinforcement work on the main building is underway and continues through 2010.

We are now developing plans for the second midterm period, which starts in 2010, based on our results and activities in the first period. Intensifying worldwide concern regarding energy supplies and global warming drives our efforts, and energy issues demand urgent priority. We shall renew our efforts in the upcoming period, through research and education on advanced energy science and technology, to cope with these critical issues and contribute to the benefit of future generations.

It is our great pleasure to issue this Annual Report. We hope that it provides you with a good understanding of the activities of the Institute of Advanced Energy, Kyoto University.

March 2009

（署名）

Yukio H. OGATA
Director
Institute of Advanced Energy
Kyoto University

3. BRIEF HISTORY OF THE INSTITUTE OF ADVANCED ENERGY

The Institute, established in 1971 as the Institute of Atomic Energy, was renamed on May 11, 1996, to the Institute of Advanced Energy upon its consolidation with the Plasma Physics Laboratory. The new name represents its current research interests in advanced, socially acceptable energy systems across the domains of energy generation, conversion, and utilization.

The Institute's precursor was founded in 1941 as the Engineering Research Institute with the objective of pursuing synthetic engineering studies through cooperation with specialists in different fields. Since 1971, the Institute has studied the peaceful application of atomic energy and has performed fundamental research into nuclear engineering. The renaming in 1996 reflects the Institute's recent expansion into new fields such as systems engineering for social and environmental energy systems, advanced energy conversion in quantum engineering, physico-chemistry, and materials science.

In 2002, the Institute joined the Kyoto University 21st Century COE program "Establishment of COE on Sustainable Energy System," with the university's Graduate School of Energy Science and Radio Science Center for Space and Atmosphere. The program was completed successfully in FY 2006. An extension of the program, the International New Energy Cooperative Organization, is in the planning stage. Further changes were also made in response to the FY 2004 structural reforms in the national universities with the aim of introducing various innovative new systems.

The Institute provides research opportunities in advanced energy science, engineering, and related fields. Institute professors lecture in their specialized fields to students of the Graduate School of Energy Science. Graduate students prepare masters or doctoral theses at the Institute under professorial guidance. The educational activities of the staff are described in their respective sections.

The Institute is located on the Uji campus of the university about 20 km south of Kyoto city. Additional facilities for research on advanced materials, advanced chemistry, magnetoplasma, plasma direct energy conversion, plasma physics, and fusion engineering are located in various buildings on the campus.

The Institute publishes the following:

(1) Annual Report of the Institute of Advanced Energy, Kyoto University (in English)

(2) Research Report of the Institute of Advanced Energy, Kyoto University (occasionally in English)

(3) Newsletter of the Institute of Advanced Energy, Kyoto University (three issues a year, in Japanese)

The Institute consists of three main research divisions (listed below), each containing four research sections, an attached laboratory, and two visiting staff research sections. All are encouraged to collaborate with one another to most effectively address the critical energy-related interdisciplinary issues facing us today and in the years to come.

I. ADVANCED ENERGY GENERATION DIVISION

(for the study of advanced, socially acceptable methods for generating energy)

(a) Quantum Radiation Energy Research Section

(b) Advanced Atomic Energy Research Section

(c) Advanced Particle Beam Energy Research Section

(d) Advanced Plasma Energy Research Section

(e) Advanced Energy Research Section (foreign visiting professor)

II. ADVANCED ENERGY CONVERSION DIVISION

(for the study of efficient, effective methods for converting energy)

(a) Energy Conversion Processes Research Section

(b) Advanced Laser Science Research Section

(c) Advanced Energy Storage Research Section

(d) Complex Plasma System Research Section

(e) Clean Energy Research Section (domestic visiting professor and associate professor)

III. ADVANCED ENERGY UTILIZATION DIVISION

(for study of high-performance processes for utilizing energy)

(a) Chemical Reaction Complex Processes Research Section

(b) Molecular Assemblies Design Research Section

(c) Biofunctional Science Research Section

(d) Bioenergetics Research Section

IV. LABORATORY FOR COMPLEX ENERGY PROCESSES

(for the promotion of equipment design, software development, and collaboration with domestic and foreign institutions to advance the study of energy generation, conversion, and utilization)

4-2. RESEARCH ACTIVITIES IN 2008

Quantum Radiation Energy Research Section

H. Ohgaki, Professor
T. Kii, Associate Professor
(Y. U. Jeong, Guest Professor)
(T. Sonobe GCOE Assistant Professor)

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. KU-FEL: MIR Free-electron Laser facility

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, energy recovering system, undulator, etc.

2.1 KU-FEL

The KU-FEL is designed to achieve FEL lasing in MIR (Mid infra-red) regime, from 4 to 13 µm. The tunable IR laser will be used for basic research on photoenergy materials and systems, such as high-efficiency solar cells, energy conversion in bio materials. The KU-FEL consists of a 4.5 cell thermionic RF gun, 3 m travelling wave accelerator structure, beam transport system, and a Halbach type undulator of 1.6 m and an optical resonator. Fig. 1 shows a schematic drawing of the system. Development of the compact FEL system has been completed in the Laboratory for Photon and Charged Particle Research.

2.2 Power saturation

The first lasing experiment has been achieved with the electron beam of 25 MeV and the undulator gap of 25.5 mm in Mar. 2008. Although we successfully observed FEL amplification at wavelength of 12.4 µm, peak strength of the MIR laser was about 50 times larger than the spontaneous radiation. The small output power compared to the numerical estimation was ascribed to energy fluctuation in the electron beam macropulse owing mainly to the beam

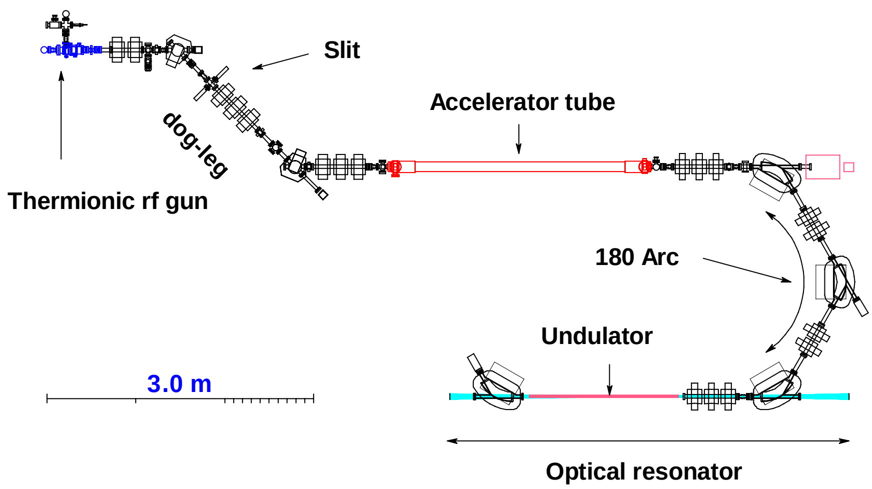

Fig. 1 Schematic drawing of the KU-FEL

loading effect. In order to increase the output power of the FEL, we tried to compensate the beam loading effect by improving RF system of the KU-FEL linac system. As the results, beam energy was stabilized in the macropulse and the effective macropulse duration was extended and the FEL output power was increased. The power saturation of the FEL was successfully obtained at wavelength of 13.2 μm in May 2008. Temporal evolution of the FEL output is shown in fig. 2. Optical beam properties of the FEL and the electron beam parameter under the power saturation condition are listed in Table 1 and 2 respectively.

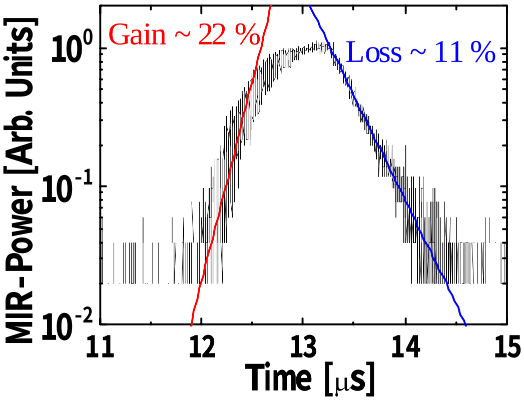

Fig. 2 Temporal evolution of the FEL output.

Table 1 Optical parameter of the KU-FEL

Wavelength λ	13.2 μm
Bandwidth σ_λ/λ	0.8 %
Average power	4.6 mJ
Peak power *	2.9 MW

*Pulse duration of 650 fs is assumed.

Table 2 Electron beam parameter in the saturation experiment

Energy E_e	24.0 MeV
Energy spread σ_E/E_e	0.8%
Bunch length	2 ps (rms)
Macropulse length	5.5 μs
Average current	115 mA

2.3 Optical beam transport system

In order to start user experiments, optical beam transport system is required. A nitrogen displaceable transport system was designed and installed. The transport system consists of a beam expander and beam ducts as shown in figs 3 and 4 respectively. Conical FEL beam is converted to parallel beam by the spherical mirror and transported to the experimental hall through a water-vapor free optical transport line.

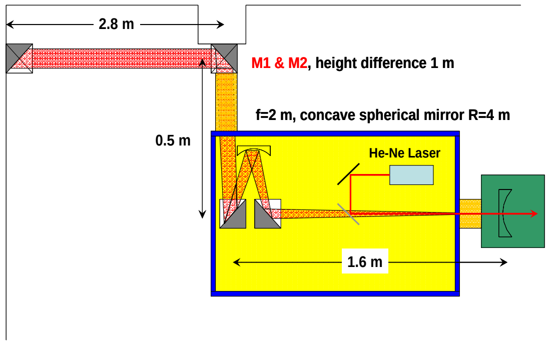

Fig. 3. Schematic drawing of the beam expander consisting of a concave spherical mirror and two flat mirrors.

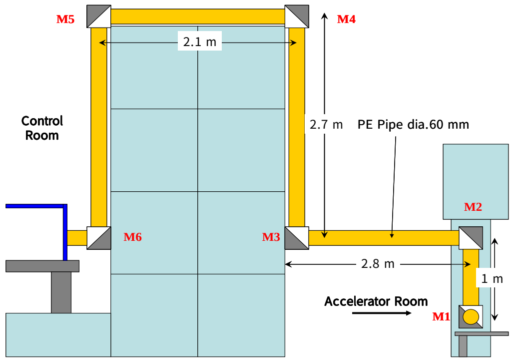

Fig. 4. A schematic drawing of the FEL beam transport. The FEL output is transported from the accelerator room to the control room using flat mirrors and nitrogen displaceable piles.

3. Conclusion

We have successfully developed a MIR-FEL facility "KU-FEL" consisting of an S-band thermionic RF gun, a 3 m accelerator tube and a planer undulator. Upgrade of the RF system of the KU-FEL was made in order to reduce the energy fluctuation due to beam loading effect. After the upgrade, FEL power saturation at 13.2 μm was successfully obtained in May 2008. An optical beam transport was also developed for future researches on photoenergy science.

The new quantum-radiation energy from a compact accelerator will accelerate research in advanced energy science.

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Advanced Atomic Energy Research Section

S. Konishi, Professor
Y. Yamamoto, Associate Professor
Y. Takeuchi, Assistant Professor

1. Introduction

The major objective of the study in this field is to research fusion technology as an advanced energy for sustainable growth under global environmental constraints. The studies described below are featured by the consideration between technical possibility of better suitable energy generation, conversion and utilization systems of fusion with advanced technology, and socio-economic analysis of future society and markets that actually requires and utilizes such energy.

The major studies are as follows:

(1)Assessment of fusion energy and energy system design

(2)Study of the compact neutron beam using newly developed cylindrical discharge device.

(3)Study of advanced fusion reactor blanket with liquid LiPb and SiC composite for early realization and high temperature output, including fundamental SiC and LiPb studies.

(4)Development of Intermediate Heat Exchanger for advanced nuclear energy with SiC composite.

(5)Hydrogen production from biomass using high temperature heat from fusion reactor

To design and develop energy system based on the biomass- fusion concept to provide hydrogen and fuels with high temperature blanket is one of the target. Generation and application of compact fusion neutron beam is another subject to pursue. :

2. Assessment and design of fusion energy system

The highlight of this study in 2008 is a proposal of biomass-fusion hybrid concept that enables early fusion energy demonstration with small device and reduced plasma requirement. Based on the previous studies of hydrogen production from biomass, it was proved that biomass can be converted to fuel at high efficiency. Combining this process , fusion energy can be converted to fuel at the efficiency of 270%, that makes total energy output by small fusion plant positive. This will also contribute to the recycling society that does not require fossil fuel by using recycled biomass with fusion energy as shown in the fig.1. The potential market for fuel is known to be larger than that of electricity. By the known Fischer-Tropsch Synthesis technology, H2-CO mixture can

Fig. 1 Future recycling society with fusion-biomass hybrid system.

easily be converted to artificial oil, such as diesel, kelosene or jet fuel. This fuel form can be commercially deployed as a substitute of fossil fuel by the existing social infrastructure while releases no carbon dioxide due to the carbon-neutral nature of the waste biomass.

With this concept, we proposed Biomass-Fusion hybrid DEMO concept. This fusion energy conversion process for production of commercial fuel significantly relaxes the requirement of plasma energy multiplication factor Q for the meaningful fusion power demonstration (below 10). Pulsed, and/or driven burning plasma may also demonstrate energy production ratio over unity. It implies that plasma parameters similar to that of ITER with the near future technology can demonstrate fusion energy production that will eventually replace fossil fuel while emitting virtually no carbon dioxide without any resource constraints. The advantage of this plant concept can be understood as "Non-nuclear Hybrid" that enables fusion DEMO with low Q and small major radius machine, but does not involve fissile materials.

Another interesting result obtained in the fusion energy assessment study was long term behavior of tritium released from fusion facilities. We suggest tritium will be accumulated in the environment, and although it will be within the limit, large area will be contaminated with detectable level of tritium that mainly causes injestion dose. Location near the ocean will have a significant effect to reduce this tritium level because of the isotopic dilution effect.

3. Study of advanced fusion reactor blanket

Blanket concepts based on the combination of LiPb, SiC and helium are of particular interests for high efficiency blankets applied in many DEMO reactor blanket designs. It is expected to be feasible in near term targets such as ITER/TBM, and by staged development strategy it would eventually achieve high operating temperature for DEMO, that is expected to have better performance beyond current fission reactors are operated.. We proposed to use the cooling panel made of SiC composite, that can actively cool and thus achieves controlled isolation between LiPb and ferritic steel. This technique can be used for the high temperature ceramic heat exchanger, that is necessary to transfer from the primary high temperature LiPb coolant to the secondary media, used for the energy utilization such as high efficiency generation or hydrogen production at above 900 degree C.

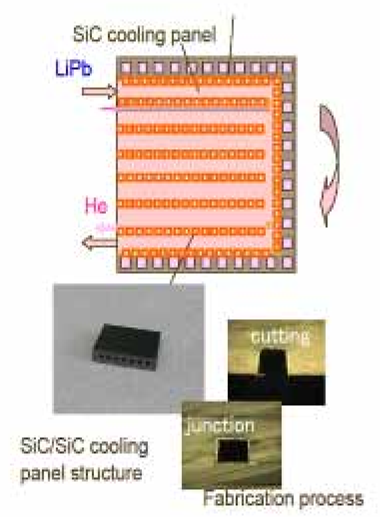

Fig.2. Concept of the high temperature SiC-LiPb blanket.

Fabrication of SiC/SiC cooling panel shows the feasibility of fine structure for helium flow channel. High temperature LiPb loop is operational above 900 degree C for experiments on heat transfer, material compatibility, MHD pressure drop, and hydrogen transport. Independent experiments also show hydrogen behavior in SiC materials and the information on chemical equilibrium with LiPb. We measured permeation of hydrogen isotopes through hydrogen composite as well as raw materials powder and fibers, and found various permeation paths such as bulk, grain boundary and other phases such as additives or carbon coating on fiber make different consequences.

The numerical simulations on neutronics and thermal hydraulics are also conducted to optimize the designs. It was found to be possible to satisfy tritium breeding ratio and temperature distribution to provide high temperature heat while maintaining structural material temperature within a considerably broad design window. It should be noted when the thermal insulation is effective, to obtain higher temperature of LiPb is even easier than the cases of passive insulation with FCIs.

4. Development of advanced intermediate heat exchanger

Under a sponsorship of the MEXT and a contract with JST, we have been developing a compact intermediate heat exchanger made of SiC/SiC composite as a collaboration with JAEA since 2006. This program aims at an intermediate heat exchanger to be used at the operation temperature above 900 degree C, with various coolants such as helium gas, other gases, water vapor or liquid metal. Pressure difference between primary and secondary sides of the heat exchanger could be 10MPa so that high temperature gas reactor (HTGR) that is currently has a direct cycle generation system could have a secondary turbine generation system that will have cleaner medium under regular industrial standard.

In our development, approximately 10 cm square scale model of the heat exchanger was made and tested in a dual high temperature loop of He and liquid metal to demonstrate the heat exchange capacity of 1KW order as shown in the fig.3.

Fig.3. heat exchanger tested in a He-LiPb loop.

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Advanced Particle Beam Energy Research Section

K. Nagasaki, Professor
K. Masuda, Associate Professor

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 followings; improvement and understanding of confinement and transport in fusion plasmas, development of heating and current drive systems using high power millimeter waves, development and application of compact and portable neutron/proton sources driven by fusion plasmas, production and diagnostics of highly brilliant relativistic electron beams for advanced light sources such as free electron lasers.

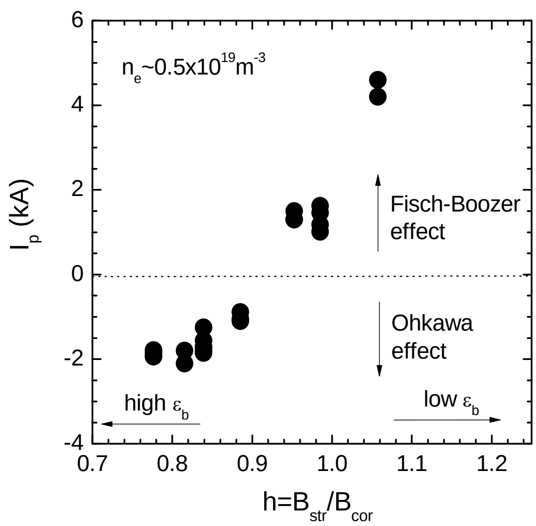
2. Effect of magnetic configuration on ECCD in Heliotron J

Non-inductive current has an important role on realization of high performance plasmas and sustainment of steady state plasmas in toroidal fusion devices. In stellarator/heliotron (S/H) systems, no Ohmic current is required for equilibrium since the confinement magnetic field is generated by external coils. However, it is known that non-inductive current flows as well as in tokamaks. Finite plasma pressure drives bootstrap current, and tangential neutral beam injection (NBI) generates so called Ohkawa current, which modifies rotational transform profile, resulting that the equilibrium and stability is affected.

Electron cyclotron current drive (ECCD) is recognized as a useful scheme for stabilizing magnetohydrodynamic (MHD) instabilities and analyzing heat and particle transport. In S/H systems, ECCD is expected as a useful scheme to avoid dangerous rational surface by cancelling the bootstrap current particularly in low shear devices. Figure 1 shows the measured toroidal current as a function of the magnetic field ripple at n_e=0.5×10^{19} m^{-3}. Here the positive sign of the current corresponds to the direction determined by the Fisch-Boozer effect. The Ohkawa effect, on the other hand, drives the current in the negative direction. The EC driven current flows in the Fisch-Boozer direction when the EC power is deposited at the ripple top position. As the EC power is deposited at the deeper ripple bottom position, the EC driven current goes to zero, and then changes its flowing direction.

Recent international collaboration research on ECCD in Heliotron J, TJ-II and CHS has shown that the maximum EC current amount is a few kA in all the devices, and the ECCD efficiency is similar, ζ=0.03-0.05. Although the magnetic field structure is different among the devices, the EC current amount is a few kA in all the devices, and the ECCD efficiency is the same order within a factor of 2. Rather low efficiency compared to tokamaks may be due to the strong Ohkawa effect enhanced by the magnetic ripple. Although such an ECCD efficiency is about 10 times lower than that in tokamak device, it is comparable to the bootstrap current and NBCD current, suggesting that the ECCD is applicable for cancellation of other non-inductive current, thus tailoring the rotational transform profile.

In current EC launching system, an unfocused Gaussian beam is injected to the Heliotron J vacuum chamber with fixed angles. In order to improve the controllability of power deposition and ECCD, a new launching is being developed by introducing a focusing mirror and a steerable mirror. The toroidal injection angle is estimated from -11 to 19 degree for standard magnetic configuration, corresponding that the refrac-



tive index $N_{||}$ ranges from 0.6 to -0.3. A quasi-optical theory shows that the beam radius is about 30 mm at magnetic axis, smaller than the plasma radius, a=170 mm, suggesting that the power can be deposited in more localized area. ECCD experiment using the new launching system will be performed in the next experimental campaign.

3. Diagnostics of D-D and D-^{3}He Reactions in IEC

An inertial electrostatic confinement (IEC) fusion device basically consists of a spherical anode filled with D_2 or mixture of D_2 and ^{3}He fuel gases, and a highly transparent central cathode grid at a high negative potential. Ions produced between the spherical electrodes, e.g. by a glow discharge, and accelerated toward the center undergo D-D and D-^{3}He fusion reactions. Of particular interest, protons from D-^{3}He reactions are highly energetic and can potentially be used to produce radioisotopes for medical use and to generate mono-energetic γ-rays for versatile uses such as security inspection, though the proton production rate achieved so far is 2-5 order lower than the requirements for practical uses. As neutron sources, the IEC devices provide near-term applications with such advantages over conventional sources as long lifetime, dc operation capability, easy operation not requiring an expert operator, and safety without radioactive isotope, while a higher neutron yield is needed for extending their applications.

In IEC research aimed at drastically enhanced neutron/proton yields, understanding the spatial distribution of fusion reactions is one of the most intensive interests. Possible fusion paths are; (i) beam-beam collisions, i.e. collisions between ions accelerated towards the cathode, which are most preferable and are expected to be localized at a converged core within the transparent cathode, (ii) beam-gas collisions taking place anywhere in the entire volume of the device which are also preferable in viewpoints of a high power input capability and a long lifetime owing to the use of 'gas' target instead of a solid target in accelerator-driven sources, (iii) cathode grid surface, i.e. D and ^{3}He trapped in the grid wire hit by the beams, and (iv) anode wall surface hit by fast neutrals originating from charge exchange processes.

Though the volumetric fusion reactions, i.e. beam-gas collisions, have been expected to dominate over the other fusion paths, recent experimental D-D neutron yield dependences on the anode temperature strongly indicate a considerable contribution on the anode wall surface. Meanwhile D-D proton measurements by the use of eclipse disk scanning indicated a negligible anode wall contribution and a dominant volume source on the contrary. A diagnostic system for determining spatial distributions is thus needed to be developed to understand these results and to explore fractions of fusion paths and their dependence on operating conditions.

For this purpose, we have introduced a Si diode proton detector (solid state detector: SSD) with a movable collimator mask (see Fig. 2), and a reconstruction algorithm based on Most Likelihood-Expectation Maximization (ML-EM) method to determine spatial distributions of proton birthplaces. A preliminary result in Fig. 3 shows (i) more than 99 % D-^{3}He fraction on the cathode surface, (ii) comparable on-cathode and volumetric fractions for D-D, and (iii) D-D proton yield in the anode grid and chamber vicinities, which agree with what early experiments have implied except for the significant D-D fraction on the cathode surface in the present study. Further study is planned to confirm these results.

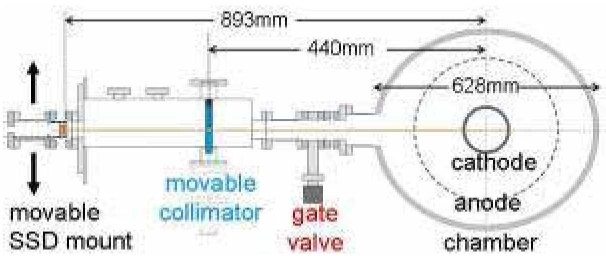


Fig. 2. A cross-sectional layout of spherical anode and cathode grids installed inside a vacuum chamber, a collimator whose aperture is 12 mmϕ, and an SSD set in a linearly movable mount.

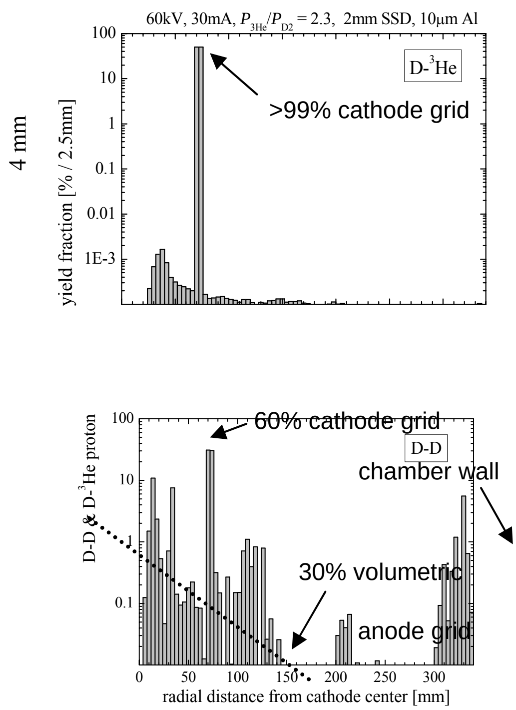


Fig. 3. Reconstructed distributions of D-^{3}He and D-D proton yields (fractions in 4-mm thick spherical hulls), with V = –60 kV, I = 30 mA and P_{3He} / P_{D2} = 2.3.

Collaboration Works

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核融合科学研究所、「高ベータプラズマにおける MHD 平衡、安定性及び輸送特性に関する研究」、長崎百伸

核融合科学研究所、「中性子検出器較正用小型 D-D 中性子源の高性能化」、増田開、長崎百伸

核融合科学研究所、「大電力定常ミリ波伝送システムの真空化」、長崎百伸

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Advanced Plasma Energy Research Section

T. Mizuuchi, Professor
T, Minami, Associate Professor （Jan. 1, 2009 ~）
S. Kitajima, Lecturer
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 the 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, we describe some results obtained in the Heliotron J experiment in FY2008 focusing on (1) the thermal energy confinement with regard to the effect of the bumpy magnetic field (bumpiness), being a toroidal mirror ratio, and (2) the effects of energetic-ion-driven MHD activities on the energetic ion transport for neutral beam injection (NBI) plasmas of Heliotron J.

2. Thermal Energy Confinement in NBI plasmas [a]

The control of the magnetic field by adjusting its Fourier components is one of the ways to achieve good energy and particle confinement in heliotron/stellarator configurations. In Heliotron J, a helical-axis heliotron device, the importance of the bumpiness $\varepsilon_b = B_{04}/B_{00}$ on the collision-less transport has been predicted theoretically. Here, B_{mn} is the Fourier component of the field strength with m/n mode numbers in the Boozer co-ordinate system. The bumpiness has a role to reduce the $\nabla\boldsymbol{B}$ drift by aligning the mod-B_{min} contour with the magnetic surface. In this study, we selected three ε_b configurations of high (ε_b = 0.15), medium (0.06) and low (0.02) at r/a = 2/3 (see Fig. 1) by changing the current ratio of two sets of toroidal coils. The standard configuration of Heliotron J corresponds to the medium ε_b. The magnetic axis position ($\langle R_{ax}\rangle$ = 1.2 m), the plasma volume (≈ 0.7 m^3), the edge rotational transform (≈ 0.56) of three configurations are kept constant.

Figure 2(a) shows the experimentally obtained energy confinement time (τ_E^{DIA}) as a function of the absorbed NBI power (P_{abs}) in the three ε_b configurations. The hydrogen neutral beam of counter direction is injected into the deuterium plasmas after the initial plasma production by 70 GHz ECH. These data were obtained at the line-averaged electron density at 2×10^{19} m^{-3}. The energy confinement time is deduced using the formula, $\tau_E^{DIA} = (W_{dia} - W_{beam})/P_{abs}$, where W_{dia}, W_{beam} and P_{abs} are the experimentally obtained plasma stored energy, beam component of the stored energy estimated from the beam absorption calculation and the absorbed NBI power, respectively. The numerical calculation of the beam absorption shows the beam component in the stored energy is less than 7%. The energy confinement time in the high- and medium-ε_b configurations is clearly higher than that in the low ε_b case. The

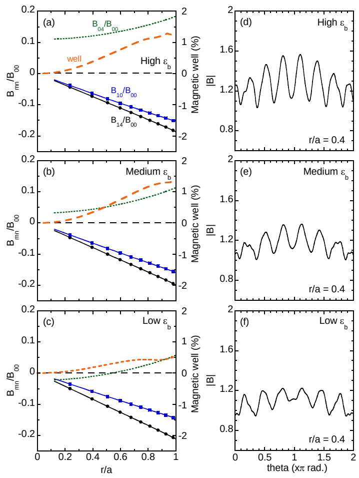

Fig. 1. (a)-(c) Radial profile of magnetic well, helicity, toroidicity and bumpiness in Boozer coordinate systems and (d)-(f) field strength along the field line in the three ε_b configurations.

[a] This work was also supported by Grants-in-Aid for Young Scientists (A) (20686061).

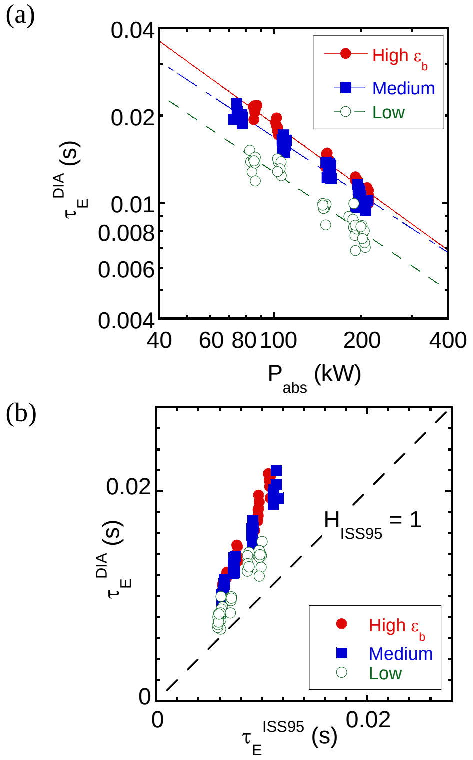

Fig. 2 Experimentally obtained energy confinement time as a function of (a) NBI absorption power, and (b) International Stellarator Scaling law ISS95.

difference in τ_E^{DIA} between the high- and medium-ε_b configurations is small, but τ_E^{DIA} of high bumpiness case is about 5% longer than that of the medium-ε_b configuration on average.

Since these data were obtained at the constant density condition, the dependence of the energy confinement time on the heating power can be investigated. As shown in Fig. 2(a), τ_E^{DIA} is proportional to $P_{abs}^{-0.72}$, $P_{abs}^{-0.66}$ and $P_{abs}^{-0.68}$ for the high-, medium- and low-ε_b cases, respectively. The observed power dependence is almost similar to that of International Stellarator Scaling law ISS95, where $\tau_E^{ISS95} \propto P^{-0.59}$.

Figure 2(b) shows the comparison of the energy confinement time between experimentally obtained one τ_E^{DIA} and ISS95 scaling value τ_E^{ISS95}. In the present experimental conditions, the electron collisionality is in the plateau regime. The enhancement factor of the energy confinement to the scaling ($H_{ISS95} = \tau_E^{DIA}/\tau_E^{ISS95}$) is about 1.8, 1.7 in the high and medium ε_b configurations, respectively, which is higher than the low-ε_b case of 1.4. These results suggest that the high and medium-ε_b configurations have better confinement characteristics for bulk plasma than that for the low-ε_b configuration in these experimental conditions.

3. Energetic-ion-driven MHD activities

Interaction of fast ions with MHD activities is one of the most important issues in burning plasma physics, because it may decreases α-particle heating efficiency. In low-magnetic-shear helical devices, global Alfvén eigenmode (GAE) is a candidate of most unstable modes when fast ion pressure becomes fairly high. GAEs have been observed at several magnetic configurations in NBI plasmas of Heliotron J, however, strong bursting GAE has not been observed in low-ε_b configuration.

In order to investigate the ion transport in detail, a Hybrid Directional Langmuir probe (HDLP) system is installed under the collaboration research with NIFS. HDLP can measure the co- and counter-directed ion fluxes separately using pairs of probe tips. This system can control the radial position, poloidal and rotation angles simultaneously to detect the spatial distribution of fast ions and to align the probe-tip pairs with the magnetic field line.

Figure 3 shows the time evolution of the bursting GAE observed in NBI and ECH plasma. The frequency of GAE chirped down quickly from 70 kHz to 40 kHz. The co-directed ion flux synchronized with GAE burst was observed and its amount was sensitive to the burst amplitude. On the contrary, the response of the counter-going ion flux to GAE burst was weak. Then the co-going ion flux of fast ions is considered as a resonant convective oscillation. These results indicate that the influence of GAE on the energetic ion confinement should be taken into account for further optimization of the helical-axis heliotron configuration toward fusion reactor.

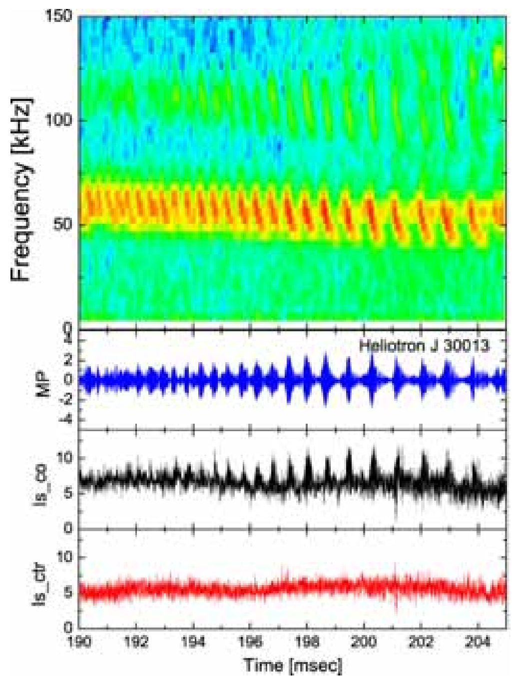

Fig. 3 The contour map of the power spectrum by magnetic fluctuation and filtered waveform, co- and counter-directed ion currents (Is_co and Is_ctr) measured by HDLP at r/a= 0.9.

Collaboration Works

Univ. Wisconsin（米国）、Oak Ridge National Laboratory（米国）、Max Plank Institute（ドイツ）、Provence Univ.（フランス）、CIEMAT（スペイン）、Australian National Univ.（オーストラリア）、Kharkov Institute（ウクライナ）、Kurchatov Institute（ロシア）、Southwest Institute of Physics、「先進ヘリカルにおける改善閉じ込めの研究」、佐野史道、水内亨、岡田浩之、南貴司、小林進二、山本聡、D. Anderson, J.H. Harris, F. Wagner, S. Benkadda, E. Ascasibar, C. Hidalgo, A. Fernandez, A. Cappa, V. Tribaldos, B. Blackwell, H. Punzmann, D. Pretty, V. Chechkin, V. Pankratov, V. Zhuravlev, Chen Wei

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Advanced Energy Research Section

Young Uk Jeong, Foreign Visiting Professor
(Principal Researcher, Quantum Optics Division, Korea Atomic Energy Research Institute,
Daejeon, Rep. of Korea)

1. Introduction

Generation and application of intense radiation and high-energy particles to the nuclear energy are main research topics of my laboratory in Korea Atomic Energy Research Institute (KAERI). The common interest on the quantum radiation energy research has drawn decade-long collaboration between Institute of Advanced Energy (IAE) and KAERI. Based on the close collaborations, I was hosted by Prof. Hideaki Ohgaki at the Institute of Advanced Energy. During my visiting period from May 1 to July 31 of 2008, collaboration researches on lasing experiment of the Kyoto University Free Electron Laser (KU-FEL) and preliminary design of a compact terahertz (THz) FEL, seminars and discussions including cooperation on laser-induced high-energy particle generation, have been performed mainly at the Uji campus of Kyoto University and partly at other institutions of Japan.

2. Outline of the collaboration researches on FEL

The first lasing of the KU-FEL was successfully demonstrated at the wavelength of 12.4 μm on March 31, 2008. I could participate in the experiments on lasing optimization of the mid-infrared FEL and measurement of the FEL output characteristics. Also design study on a compact THz FEL had been performed based on the common interest to the potent applications of THz science and technology. Followings are summaries of the cooperative researches on FEL.

a. Lasing experiment of the KU-FEL

The KU-FEL has unique feature of its thermionic radio frequency (RF) gun with the beam loading compensation by modulating klystron gain. The FEL performance is closely related on the current and energy characteristics of electron beam from the gun. The thermionic RF gun has remarkable advantages in size and brightness. To overcome the transient increase of beam loading during the electron macropulse, RF amplitude and phase were controlled to decrease the energy spread and phase fluctuation of the electron beam to be less than 0.5% of the central energy and 2 degrees, respectively. With the successful control of the gun parameters and electron beam trajectory, the KU-FEL could increase its output power up to the saturation level. The amplification ratio of the saturated power to the spontaneous emission was more than 10^6. Also, FEL power stability depending on FEL cavity detuning length was measured for various conditions of the FEL and environment, such as temperature stability of the air and waters of the facility.

b. Measurement of the KU-FEL output parameters

Main parameters of the FEL output characteristics, such as power, gain/loss, spectrum, micropulse duration, and spatial distribution have been successfully measured during a short period of 1-2 months with the concentrative and outstanding ability of the KU-FEL team. The macropulse energy of the saturated FEL beam was measured to be more than 5 mJ by a calibrated pyroelectric energy detector. If we assume the micropulse duration to be less than 1 ps, the FEL micropulse power was estimated to be more than 1 MW. Measurement of the FEL micropulse duration was performed by a Michelson-type interferometer with the linear auto-correlation method. If we assume full temporal coherency of the FEL micropulses, the measured micropulse duration was less than 1 ps.

From the measured waveform of the FEL macropulse power, incremental gain and loss of the radiation round-trip in the FEL oscillator were estimated to be 20% and 4%, respectively. Power spectra of the FEL output were measured by a grating spectrometer. The measured spectral width of the FEL was approximately 200 nm. The value and the pulse duration show the relation of Fourier-transform limit. The spatial distribution of the FEL output was measured by 2-D scanning of the single-cell detectors and by an IR 2-D camera. The KU-FEL shows a ultra-short, intense and efficient MIR source for the advanced applications of energy, bio-medical and material sciences.

c. Design of a transport MIR beamline for the KU-FEL

A transport beamline for the MIR radiation from the KU-FEL facility room to the control room was designed for introducing the MIR radiation to the shielded experimental space. The optics consists of 6 mirror boxes and 6 pipes, which can be feed by N_2 gas for reducing the water vapor concentration. The MIR radiation was designed to be collimated by a concave spherical mirror, M2. The main parameters of the MIR beamline are as follows:

- Total length : 13-14 m,
- Beam divergence from a outcoupling hole : 10 mrad,
- Beam size (Airy disk diameter) at M2 mirror : ~20 mm,
- Beam size after transportation : 20-30 mm.

d. Preliminary design of a compact THz FEL

Preliminary design of a compact THz FEL was performed for two compact electron sources of a RF gun and microtron. The energy of the electron beam was determined to be 4 MeV for both electron sources. The main differences of the electron beam parameter between the RF gun and microtron were macropulse current and energy spread. The lasing conditions and undulator parameters were compared for both electron beams. The target of the design was to get a 1-W class compact FEL operating in the tunable wavelength range from 0.5 to 2 THz for real-time security inspection at airports, public organizations, and companies.

3. Seminars and discussions

Seminars were presented at Kyoto University (Uji campus), the University of Tokyo (Tokai campus), and JAEA (Tokai). The seminars spanned a range of topics, including:

• Application of THz technology to bio science and overview of KAERI THz FEL activities.

• Generation of high-energy particles and radiation from relativistic plasma induced by intense laser pulses.

I have visited laboratories in AIST (Tsukuba), JAEA (Tokai and Nara), the University of Tokyo (Tokai), and Institute of Chemical Research of Kyoto University for cooperative discussions on following fields;

• Laser acceleration of high-energy electron beam by using a table-top terawatt laser system.

• Compton-back scattering between short-pulse electron beam and terawatt laser pulses.

• Efficient generation of high-energy protons and ions from metal and plastic thin targets irradiated by a intense laser pulses.

• Application of a high average power FEL for nuclear industry.

• Development of a compact laser-driven proton accelerator for cancer therapy.

4. Plans for future collaboration

Due to the strong overlap in interest on quantum radiation energy research between Kyoto University and KAERI, we are sure to continue the collaborations based on the Asian CUP program. We expect further collaborations on following fields:

• Characterization and stabilization of the MIR FEL.

• Application of the MIR FEL to advanced energy sciences.

• Development of a seeded THz FEL with a superconducting undulator.

• Application of the laser-induced high-energy particles and radiation to the nuclear sciences.

Advanced Energy Research Section

Ya-Ming Hou, Foreign Visiting Professor
(Professor, Department of Biochemistry and Molecular Biology, Thomas Jefferson University, Philadelphia, USA)

1. Introduction

I was a visiting professor in the laboratory of Professor Takashi Morii at the Institute for Advanced Energy, Kyoto University, from July 2 to September 4, 2008. My scholarly activities included daily interactions with the students and staff in Professor Morii's group, attending weekly group meetings with the Morii group, giving lectures and seminars at Kyoto University and other locations throughout Japan. I also carried out collaborative research with the students and staff in the Morii lab.

2. Daily interactions with the students and staff of the Morii's group

During my time of visit, Dr. Morii's group consisted of senior staff, Ph.D. graduate students, and master graduate students. These are highly motivated and dedicated researchers who work hard and aspire to succeed. I had frequent conversation with each of these researchers, usually on topics of their work and their academic life. For example, from my conversation with Kazu, I was very interested in his work on synthetic chemistry, on methanogenesis, and on RNA sensors. From my conversation with Tora, I was interested in his clever design and selection of RNA aptamers. From my conversation with Shun, I was interested in his chemical mapping studies of active RNA aptamers that bind and distinguish among small molecular ligands, such as ATP from GTP. I also enjoyed my conversation with Inoue about his education background and I learned from him about HPLC analysis. With Reiko and Saori, I tried to encourage their studies and to build their self-confidence as female researchers in the competitive academic life in Japan. I appraised Hiromi's work ethics and unwavering intensity. I admired Sago's organization skills and his leadership ability on the lab outing. I had interesting conversation with Nobu about the expressive styles in English and in Japanese. I received critical help from Endo about using computers in the Japanese language, and I appreciated the cultural help from Tan on using the Japanese-Chinese newspaper. My interactions with these researchers occurred throughout the day, sometimes initiated from my desire to understand them and to learn how to work around the lab and on the streets. Sometimes the interactions were initiated from their side to learn about my research and my experience in Kyoto. These interactions can go on through meals and well into late evening hours. I enjoyed my interactions with them and I treasured the interactions as my greatest success in Kyoto.

3. Weekly group meetings

I attended the weekly group meetings of the Morii lab in Dr. Morii's office. The meeting alternates between the RNA and sensor topics. Each group meeting has 3-4 presenters, who prepared a written summary of their work and gave an oral presentation of the summary in English. I appreciated their extra work to translate their work from Japanese to English for me. In turn, I helped to correct their oral English and contributed to the discussion of their work. I was able to read the Chinese characters in their written reports and this skill helped our mutual communication. Overall, I was most impressed with the serious attitude the students demonstrated in their group meeting presentation. Many of them would stay overnight to prepare a good presentation and many of them took the time to practice their oral skill. I enjoyed my discussion with them immensely.

4. Seminars

I gave one seminar to the Morii group and another one to the joint meeting of the Morii lab and Sugiyama lab. I also gave a seminar to the lab of Dr. Hiroaki Suga in Tokyo University, one to the lab of Dr. Kozo Tomita in the Institute of Biological Resources and Functions in National Institute of Advanced Industrial Science and Technology, and one to the lab of Dr. Osamu Nureki of Institute of Medical Science in University of Tokyo. The topics focus on the mechanism of protein synthesis and, in particular, the kinetics of synthesis of aminoacyl-tRNA, and how it is integrated into the rate of protein synthesis. Notably, the synthesis of aminoacyl-tRNA is catalyzed by aminoacyl-tRNA synthetases, which is the reaction that determines the matching of an amino acid with a trinucleotide sequence of the genetic code. The emphasis on the kinetics of synthesis of aminoacyl-tRNA is to address the specificity of aminoacylation and the supply of aminoacyl-tRNA for the ribosome, which is the rate-determining step of cell growth. Another topic is on the maturation of the tRNA 3' end with the synthesis of the CCA sequence, which provides the site for tRNA aminoacylation. The importance of the CCA synthesis activity, which is catalyzed by the CCA enzyme, is the ability to act as a quality control step to eliminate backbone damaged tRNA from further processing or participating in the ribosome machinery. Both topics are important for understanding the decoding mechanism of cellular life.

5. Collaborative research

I performed collaborative research in Dr. Morii's lab in two areas that are of common interest. One area is chemical synthesis of RNA molecules that are conjugated with an amino acid. The goal is to use these amino acid-carrying RNA molecules to join with the sequence of a tRNA so as to create an aminoacyl-tRNA with the option of a specific amino acid group attached at the terminal end. Such chemically synthesized aminoacyl-tRNAs will have the greatest utility in the study of the mechanism of decoding on the ribosome. The natural synthesis is limited in two reasons. First, the yield is usually in the range of 20-30% due to the necessity to use tRNA transcripts that are prepared by in vitro transcription, rather than the native tRNAs that are difficult to purify from cells to homogeneity. However, while tRNA transcripts are easy to prepare, they lack the modified nucleotides that are commonly present in the native tRNA and as such they are less efficient to produce high yield of the aminoacylation product. Second, the natural synthesis of aminoacyl-tRNAs cannot generate modified amino acid moieties, which will be useful for genetic engineering purposes and for mechanistic probes. Neither is the natural synthesis able to create mis-matched aminoacyl-tRNAs, which will be useful to test the mechanism of ribosome specificity. In contrast, the chemical synthesis method is not limited to these problems and thus offers a much higher versatility for studies on the ribosome and greater promises for new insights into the mechanism of the ribosome specificity.

The second area of collaborative research is the development of chemical resins that can specifically bind to cysteinyl-tRNA. The interest in cys-tRNA is because the kinetic mechanism for synthesis of cys-tRNA is well characterized in my lab at USA, thus providing a solid framework to study the reactions downstream of its synthesis. In the ribosome protein synthesis machinery, the downstream reactions of synthesis of an aminoacyl-tRNA include the interaction of the aminoacyl-tRNA with the elongation factor Tu and entry of the aminoacyl-tRNA to the ribosome. These are important reactions that deliver the charged aminoacyl-tRNA to the ribosome for protein synthesis. We are interested in using cys-tRNA as a model system to study the kinetics of these downstream reactions. Because the synthesis of cys-tRNA by the cysteine-specific enzyme is not stoichiometric, this prompted the development of new resins that can specifically bind to cys-tRNA and separate it away from the uncharged tRNA. Taking advantage of the expertise of the Morii lab, we have created synthetic new chemical resins that are conjugated with thiol groups, which serve to specifically interact with the thiol of cys-tRNA. The unique feature of the new synthetic resin is the presence of a 12-residue-carbon linker that servers to separate the highly negative charges of tRNA molecules from repulsion of each other. Preliminary studies of the new resin indicate high promise for successful purification of cys-tRNA.

6. Plans for further collaboration

Another common interest between our group at Thomas Jefferson University and the Morii group is the mechanism of methanogenesis, the process to produce methane from reduction of carbon dioxide. Because methane is a clean energy source, the methanogenesis process is highly significant given the current energy crisis and the concern for the environmental survival. Our lab is interested in addressing the protein synthesis mechanism of the primary methane-producing organism, the *Methanococcus* species, and we have focused on the enzymology of a few key enzymes in the species. Our focus is on understanding the efficiency of their reactions, which will be critical to the biogenesis of the methaonogensis process. We have invited the graduate student Reiko Sakaguchi of the Morii lab to join our lab as a postdoc fellow once she receives her Ph.D. degree. This is both a cultural and scientific exchange, which is aimed at continuing our collaboration beyond my visit of two months in Kyoto, and promoting productive cross-cultural fertilization in advanced energy research.

Advanced Energy Research Section

Boyd D. Blackwell, Foreign Visiting Professor
(Director, National Plasma Fusion Research Facility, Australian National University, Canberra, Australia)

1. Introduction

From late December 2008 until the end of March 2009, I was hosted at the Institute of Advanced Energy. This continues a collaboration with Heliotron group on data mining of magneto hydrodynamic (MHD) instability data on Heliotron J, and on a comparative study of that device and one in Australia, the H-1 Heliac. I also gave an Institute seminar, some Heliotron group seminars, presented papers at Conferences, prepared a joint proposal for an Australian Research Grant, and advised graduate students informally and at weekly meetings.

2. Research

Alfvén eigenmodes (AEs) were recently discovered in the H-1 flexible heliac [i], the centrepiece of the H-1NF Major National Research Facility located at the Australian National University. These modes are an interesting variant of spatial "resonances" of the torsional Alfvén wave bounded by, and propagating within, a toroidally confined, magnetised plasma. Two features set them apart from Alfven waves that have been thoroughly investigated– the peculiar dependence of Alfven velocity on minor radius, and the (unfortunate) close match between the velocity of fusion-born alpha particles and the Alfven phase velocity, that enables strong wave-particle interactions. Understanding this tightly coupled dynamical interaction that can cause mode destabilization and loss of alpha confinement, remains one of the key unresolved physics issues facing the fusion community[ii]. If not controlled, Alfvén eigenmodes can effectively expel these 3.5MeV alpha particles from the reactor, creating a critical problem[iii] for sustaining the fusion "burn" which relies on effective confinement of those fusion products.

The modes observed in H-1 are clearly *not* excited by fusion alphas, but are very similar, and are more likely excited by other species with similar velocities, such as electrons or very energetic ions. H-1 has low shear (spatial derivative of magnetic field twist), and great configurational flexibility. In addition, the unique magnetic-coil-in-tank H-1 design provides for almost unhindered measurement access to the plasma.

Kyoto University's Heliotron J[iv] stellarator is an optimised advanced helical axis device, the latest in the famous "Heliotron" line. Equipped with neutral beam injectors and high power heating systems, the plasma conditions approach those encountered in a fusion reactor. The neutral beams are an ideal source of fast ions to simulate the fusion alpha particles which excite these AEs, and so the observations of activity in that device more accurately resemble fusion plasma phenomena. The flexibility of H-1, the closer approach to fusion conditions of Heliotron J and the unique measurement systems developed at both sites constitute a formidable experimental resource with excellent potential to improve understanding of these modes.

Our data mining technique was developed at the ANU in collaboration with my student Dr. David Pretty, and involves the representation of fluctuations in multichannel signals in a space defined by the phase difference between the individual channels, and utilisation of a clustering algorithm on this space to locate distinct classes of fluctuation[v]. The classes of fluctuation are defined by their phase structure, and can be mapped to the physical nature of the instabilities. In 2008, our data mining technique was applied as a proof of principle to the most recent 4000 shots in the database of Heliotron J.

The current project successfully interfaced a completely rewritten, open source version (the "PYFUSION" code) to the Heliotron data system. I have produced extensive preprocessed databases of the last several years of Heliotron-J MHD data, and more abbreviated databases of all years of operation. I have extended the preprocessing to capture the very fast transients characteristic of the "energetic particle mode" instability, in which kinetic energy quickly escapes from the plasma, and produces a "chirped" frequency signature. The self testing facility of python enhances reliability and accuracy of results, and the self-documenting feature makes the code easier to understand and use. Simple one line commands or operation of more user-friendly "Graphical User Interfaces" allow powerful searches to be made for different classes of phenomena. Work is well underway on the cross-checking of results from this process with previously analyzed data, both published and unpublished, and will continue to with the production of a paper on scans in rotational transform. This will then provide a basis for the extraction of new features from the database. Work on a comprehensive parameter scan of the MHD activity leading to another publication will be continued.

3. Conference Papers

I acted as Deputy Chair of the Japan Australia Workshop on Plasma Diagnostics in February and presented a paper in the opening session on my collaborative work "Comparative study of Configurational Effects and Alfven Range activity in
H-1 and Heliotron-J". With Australian funding, I represented stellarators in general in a paper presented at the 3rd International Meeting On Frontiers Of Physics in Malaysia in January, and gave a seminar "Progress in International Fusion Research" including our joint work at the University of CyberJaya in Kuala Lumpur.

4. Seminars, Grant Proposals and Interactions

I presented an Institute seminar, on Plasma Research in Australia, and new energy initiatives at the Australian National University, and Heliotron group seminars on magnetic island effects on plasma, and MHD data analysis. I prepared a proposal to the Australian Research Council under the "Discovery Projects" scheme which has just been expanded to enhance international collaborative research. This included a joint experimental program on Alfven Eigenmode research using the unique features of our two helical axis devices; in particular the precise control of rotational transform on H-1, and the improved confinement and multiple heating systems and energetic particle sources of Heliotron-J. A second proposal was based on an extension of the data mining work. I advised graduate students both informally and at weekly meetings especially in the final weeks leading up to the Master of Engineering thesis submission deadline.

5. Plans for further collaborative research

The strong overlap of research interests, the complimentarily of plasma devices and seeds of ideas germinated during this visit will ensure future successful collaborations, such as the grant proposal described earlier. In particular, the technique has been adopted at the CIEMAT institute in Madrid for analysis of results from the TJ-II stellarator, and Dr. Yamamoto has begun work with researchers on the NIFS LHD device, the "flagship" of the international stellarator program, on extending this project to some MHD data from that device. Interest from other lines of fusion research devices has been indicated. Finally, ideas for another Japan-Australian Workshop, to complement the long-running and successful "Diagnostics" series, are being discussed with leading researchers at this institute, NIFS and in Australia.

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Advanced Energy Research Section

Igor M. Pankratov, Foreign Visiting Professor
(Institute of Plasma Physics, National Science Center
"Kharkov Institute of Physics and Technology", Kharkov, Ukraine)

1. Introduction

During the period January through March of 2009 I was Visiting Professor of Institute of Advanced Energy from Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology" (Kharkov, Ukraine).

My Institute of Plasma Physics NSC "KIPT" and Institute of Advanced Energy have a long term and fruitful collaboration in the investigation of the high temperature plasma confinement in the Uragan-3M torsatron (Kharkov) and in Heliotron E, Heliotron J devices (Kyoto University). Recent joint results (Dr. V. Chechkin and Prof. T. Mizuuchi with colleagues) are well known in the world thermonuclear community. I was invited in the frame of this collaboration.

My activities included seminars at IAE, attendance at NIFS Workshop and collaborative research in Heliotron J.

2. Seminars and lectures

In the IAE seminar I presented recent Uragan-3M torsatron results. In report "Outflow of fast ions to the helical divertor of the U-3M torsatron" the fast ions energy distribution measurements in diverter flows in symmetrical poloidal cross-section in several magnetic field periods were shown. These experimental results qualitatively confirm the assumption on a determining contribution of fast ion loss to the divertor plasma fluxes up-down asymmetry in a heliotron/torsatron [1].

In report "Influence of fast ion losses on ETB formation in the U-3M torsatron" the time evolution of U-3M RF discharges with spontaneous L-H and L-H-like transitions was shown. The role of fast ion losses in the radial electric field bifurcation and ETB formation was discussed.

In my lecture the interaction of an external helical magnetic perturbation (with poloidal number *m* and toroidal number *n*) with edge plasma was discussed, when this perturbation is resonant on the magnetic surface where $\iota(r_{res})/2\pi = n/m$.

In the first part of my lecture "Penetration of an external low frequency helical perturbation into a tokamak edge plasma" it was shown that strong plasma response (induced helical current near resonant magnetic surface) occurs when the fast rotation of plasma and perturbation relative to each other takes place [2,3]. The induced current modifies magnetic islands; additional plasma transport across magnetic surfaces may arise. The same phenomenon may take place in Heliotron J.

In the second part "ELMs suppression" the new approach was presented that may explain the influence of a resonant external magnetic helical perturbation on ballooning modes.

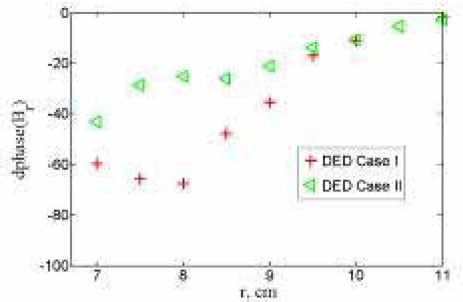
3. Collaborative research in Heliotron J

During my visit I had studied recent Heliotron J and TU-Heliac experiments in detail. A shift of diverted plasma position during a discharge was observed in the standard (STD) configuration of Heliotron J. In this configuration magnetic islands of n=4/m=7 (like magnetic island divertor) surround the last closed flux surface (LCFS). The observed shift was the order of a few cm, which was measured by using the divertor probe array and fast-camera image monitoring system [4]. In these experiments the hydrogen beam injected into deuterium plasma. In this situation in NBI phase it may be expect the formation of strong radial electric field till the order of 100V/cm that will to rotate plasma [5].

The edge plasma parameters in the Heliotron J experiment [4] were approximately the same as in the HYBTOK-II tokamak (Nagoya University), where the plasma response on an external helical magnetic perturbation was investigated [6] (see Fig.1). More over, the magnetic probe measurements in HYBTOK-II qualitatively coincide with my theoretical predictions (see Fig.2).

My theoretical consideration shows that the plasma response phenomenon may explain a shift of diverted plasma position in the Heliotron J experiment [4].

The radial electric field control was possible by electrode biasing during the L-H transition experiment in the Heliotron J with using of the hot cathode of Tohoku University [7]. My proposition was to combine this L-H experiment with the investigation of the divertor plasma behavior to monitor the plasma flux position outside LCFS. The comparison of a plasma transport during the L-H transition is also possible in this case.



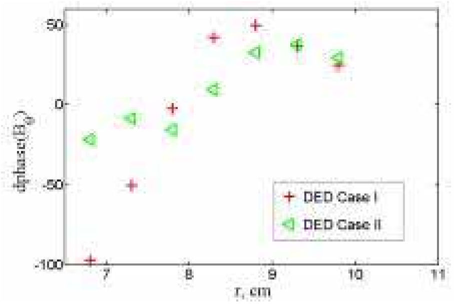


Fig.1. Profiles of phase changes (degrees) of magnetic field $B_{r,\theta}$ perturbations in HYBTOK-II [6]. These changes are the result of a plasma response.

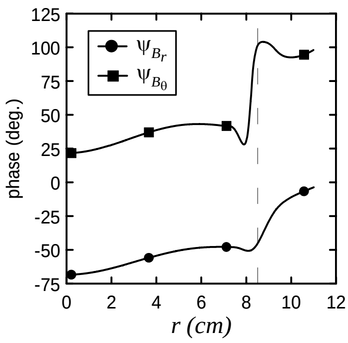


Fig.2.Calculated phase profiles with plasma response taking into account.

In our experiments for ECH-only discharges, the low density ($n \sim 10^{12} cm^{-3}$) hydrogen plasma production and heating was performed by using the 2.45 GHz, 4 kW generator at low magnetic field B≈800 G. The electron temperature was T_e ~20 eV. It was expected that the equilibrium plasma current was lacking in this experiment. The driven frequency that causes the plasma response was only Doppler shift due to the plasma rotation. The estimated edge radial electric field was not so large, the order of (0.1-0.4) V/cm, hence, expected driven frequency was (10-40) kHz.

The position of plasma flux outside LCFS was monitored by using the divertor Langmuir probe array only. The position of the array was not being best for considered magnetic configuration: only six probes it was possible to use. The position of the biasing electrode in plasma also was not being best for the strong radial electric field formation near LCFS.

The profile changes of a diverted plasma density along probe array were observed that was related with the voltage and current changes of the biasing electrode. The induced helical current near LCFS because of a plasma rotation may be responsible for these profile changes (plasma shift).

The biasing experiments to obtain more detailed profile data of the edge plasma position shift should be continued in Heliotron J.

4. Plans for further collaborative research

The investigation of the divertor plasma behavior is important not only for Heliotron J, but also for LHD (local island divertor regime) and W-7X (magnetic island divertor) devices.

We are planning further collaborative research:

(i) series of Heliotron J biasing experiments with plasma parameter profiles measurements and detail interpretation for the investigation of the edge magnetic island plasma behavior for the field topology of the STD configuration at low magnetic field will be carried out;

(ii) moveable magnetic probe measurements near the edge resonant magnetic surface $\iota(r_{res})/2\pi = 4/7$ with detail interpretation also are planned.

The plasma response also it is necessary to take into account in the Tohoku University experiment [8], where rotating magnetic islands driven by an external perturbation fields were investigated.

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Advanced Energy Materials Research Section

A. Kohyama, Professor
T. Hinoki, Associate Professor
H. Kishimoto, Assistant Professor

1. Introduction

The importance of the materials development for advanced energy systems including nuclear fusion and fission reactors has been rapidly growing in these years and expected to be emphasized in the coming years and the upcoming century. The mission of the Advanced Energy Materials Research Section at the Advanced Energy Conversion Division is to develop advanced energy materials to be used in advanced energy systems with the emphasis on advanced energy conversion systems. The research section is unfolding unique and extensive researches in the fields of functional and structural materials development as well as playing important roles in national and international programs for R & D of energy materials.

2. Development of advanced SiC/SiC composites for nuclear energy systems

Advanced nuclear energy systems, such as gas cooled fast reactor (GFR), very high temperature reactor (VHTR) and fusion reactor are potential candidates for sustainable energy systems in the future. In order to realize these attractive energy systems, materials must be responsible to keep their performance under very severe environment including high-temperature, high energy neutron bombardment and surrounding coolants and fuels. Because of fiber-reinforcement, silicon carbide fiber-reinforced silicon carbide matrix (SiC/SiC) composites are more damage tolerant to mechanical and thermal loading (thermal shock) and have the capability for larger components than their SiC monolithic form. Also in comparison to the best high-temperature metallic alloys, SiC/SiC composites are lower density and thermal expansion, and have the potential for displaying excellent high-temperature thermo-mechanical properties under high energy neutron bombardment.

Nano-Infiltration and Transient Eutectic-phase (NITE) process is the first successful application of liquid phase sintering (LPS) for matrix densification of SiC/SiC composites. The matrix in NITE-SiC/SiC consists of well-crystallized SiC grains with small remnants of the metal oxide sintering additives. Such polycrystalline SiC matrix suggests excellent radiation resistance of the NITE SiC/SiC composites similar to that of chemically vaporized SiC/SiC composites (CVI-SiC/SiC). The differences of properties between NITE and CVI composites are mainly caused by their matrix porosities, the NITE composites are less porosity than the CVI composites. A heat flux capacity of NITE-SiC/SiC is superior in the candidates of first wall materials for fusion reactor, so that it is expected that NITE composite has an excellent figure of merit against the thermal stresses. Satisfactory results for reducing the leakage of helium gas as a coolant gas in the reactor are also reported.

3. Development of evaluation methods for Advanced SiC/SiC Composites at elevated temperatures

For the application and design of SiC/SiC composites, various testing methods for different fracture mode have been required. Our research group has made efforts to develop various evaluation methods such as monotonic tensile and inter-laminar shear/tensile strengths. Double-notched specimen (DNS) test and diametral compression tests were conducted in order to clarify the inter-laminar shear/tensile properties of NITE SiC/SiC composites at high temperatures. The DNS and the diametral compression tests were conducted at 298-1573K, in air, Ar and Ar+O_2 atmospheres.

The credibility of diametral compression test was confirmed at ambient temperature by comparing trans-thickness tensile test normalized in ASTM C1468. Inter-laminar shear/tensile strengths increased at 1573K. This reason may be due to the relaxation of residual stress by mismatch of thermal expansion coefficient (CTE). At an elevated temperature in Ar+O_2, PyC interface was deteriorated and inter-laminar shear/tensile strengths decreased.

4. Engineering research on joining of materials for nuclear energy systems

The important issues to use SiC/SiC composites for industry are the developments of joining and coating techniques. For SiC or SiC/SiC composites joining, our joint technique using SiC has an advantage at the high temperature due to the very limited CTE mismatch. Monolithic SiC and NITE-SiC/SiC composites are successfully joined applying NITE process. The joined SiC materials show stronger than that joined by the other conventional joining processes.

Fundamental study of interface of dissimilar joints or metal coated SiC materials are ongoing in parallel with the engineering developments. Tungsten is an appropriate material for the dissimilar joint and coating with SiC because of the similar CTE with SiC. NITE SiC/SiC composites have excellent resistance against high temperature and high pressure, thus, the hot-press joining is being developed. The hot-pressing is performed over 1000 °C in Ar gas flow environment. A tungsten plate or tungsten powder are put on a SiC plate and consolidated by hot-pressing. SEM investigation show that the reaction zone between tungsten and SiC grew up with the hot-pressing temperature and time. The reaction zone is investigated W-Si, this zone seems to determine the share strength of joined materials.

The techniques to bond SiC and SiC/SiC composite to general purpose construction materials, stainless steel, are also developing for the expansion of practical applications. Two step joining method is being developed for SiC and steel. The first step is joining of SiC to W or W alloy by diffusion bonding based on the joining technique previously developed for SiC and W, followed by joining of SiC/W to stainless steel (SUS430) with intermediate materials which inserted to reduce the residual stress in the joints. The preliminary results indicate that the joining of SiC to steel is possible by the proposed procedure.

5. Modeling of microstructural evolution in β-SiC under irradiation

Lattice defects produced and accumulated in a material under irradiation cause the microstructural changes and affect the material properties. In order to analyze the atomistic behavior and understand the kinetics of defects, some energetic parameters such as defect formation energies and migration energies are necessary. However, even basic properties of SiC materials have been unknown.

Formation energies and stable configurations of self-interstitial atom (SIA) clusters in β-SiC are calculated using a classical molecular dynamics (MD) method using Gao-Weber potential based on the Brenner potential formalism. The properties of SIA clusters with various sizes and composition of silicon (Si) and carbon (C) interstitials are studied in the MD simulations of 1000 unit cells. Temperature condition is started at elevated temperature and reduced to 0 K during the calculation to obtain the total energy.

From these formation energies of SIA-clusters, binding energy of an SIA to SIA-clusters can be obtained. Defect energies such as the binding energies are very important to investigate formation kinetics of defect clusters.

6. Irradiation effects on tensile and interfacial properties of advanced SiC/SiC composites

In order to identify the effects of neutron irradiation on tensile and interfacial properties of advanced SiC/SiC composites, cyclic tensile tests were conducted and the hysteresis loop analysis method was applied for the investigation. Neutron irradiation was performed at JOYO (Oarai, Ibaraki). Nominal fluence and irradiation temperature were 3.1×10^{25}n/m^2 at 740^{o}C and 1.2×10^{26}n/m^2 at 750^{o}C. The ultimate tensile strength and proportional limit stress of composites in both conditions showed excellent irradiation resistance. The hysteresis loop analysis indicated that the sliding stress at fiber/matrix interfaces was not changed after irradiation to 3.1×10^{25}n/m^2 at 740^{o}C, whereas it was significantly reduced by 1.2×10^{26} n/m^2 at 750 ^{o}C for both composites.

7. Development of Nondestructive test method for NITE-SiC and SiC/SiC composite materials

The practical use of SiC ceramic materials has been limited, because of the lack of nondestructive investigation method under pre- and in- service environments. It is required to develop a higher reliability nondestructive test method for SiC and SiC/SiC composite materials.

In our group, the defects detection capability of ultrasonic test methods (C-Scan method and Pulse-echo reflection method) on NITE-SiC ceramics has been investigated. Monolithic NITE-SiC specimens with various sizes of artificial defects were prepared and examined by ultrasonic C-Scan method and pulse echo reflection method with the frequency condition of 10, 25 and 50 MHz. Also, the detection limit of 25 and 50MHz was investigated about 100 and 200 um, respectively. It was determined from the wavelengths.

8. Influence of inclusions on low cycle fatigue properties of reduced activation ferritic/martensitic steels

Reduced activation ferritic/martensitic steels (RAFs), such as F82H, are promising structure materials for ITER test blanket modules (TBMs) and a fusion DEMO reactor. The fatigue properties of RAFs depend on various material factors such as the distributed inclusion, surface morphology and so on. Therefore, the investigation of type of inclusion and these effects on low cycle fatigue (LCF) properties would be essential. The LCF lifetime was increased with decreasing the number density of total inclusions. Two types of inclusions, the complex inclusion consisted of Al_2O_3 and TaO_x, and the simple inclusion of TaO_x, were observed by SEM. It was found that a crack initiation was caused by the separation of the relative weak interface between the matrix and an inclusion. The crack initiation from the Ta-oxide site in a Al_2O_3-TaOx complex inclusion is much extensive than that in the simple inclusions. It can be surmised from these results that the primary reason for the reduction of the LCF property of F82H-IEA heat steel is the existence of complex inclusion with Al_2O_3-TaOx complex inclusions.

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Advanced Laser Science Research Section

K. Miyazaki, Professor
T. Nakajima, Associate Professor
K. Hata, Assistant Professor
G. Miyaji, Assistant Professor

1. Introduction

Our research interest is focused on the development of advanced lasers and their applications to the study of ultrafast, strong-field interactions with atoms, molecules and solid surfaces, aiming at the goal of demonstrating potential abilities of coherent radiation sources for future science and technology. The laser development is concerned with the generation of femtosecond (fs), high-intensity laser pulses and with coherent extreme-ultraviolet sources. Applications of laser technology include the development of materials control and nano-processing.

2. High-intensity ultrashort pulse lasers

A high-intensity 40-fs Ti:sapphire laser system shown in Fig. 1 is a principal experimental apparatus in our Section. The laser system using the chirped-pulse amplification (CPA) technique produces a peak power of 1 TW (40 mJ in 40 fs) at the center wavelength of 800 nm. This system includes a frequency conversion apparatus to extend the fs output to the blue and ultraviolet regions of spectrum. The peak power is 0.2 TW in 60 fs at 400 nm and 20 GW in 140 fs at 267 nm.

Another Ti:sapphire laser system was developed for the purposes of advanced material processing, which produces 100-fs, 800-nm pulses with a well- defined intensity distribution and good temporal characteristics. Also a new laser system is under development to produce high-intensity 10 fs pulses.

Fig. 1. High-intensity, 40-fs Ti:sapphire laser system.

3. High-order harmonic generation from aligned molecules

New fields of science and technology have been opened with high-intensity, ultrashort-pulse lasers. Important research subjects are asscociated with nonperturbative nonlinear interactions of intense laser pulses with atoms and molecules. One of them is the high-order harmonic generation (HHG) from nonadiabatically aligned molecules. The fs laser-induced molecular alignment provides a promising approach to control nonlinear processes in molecular gases. We have demonstrated that HHG provides a sensitive way to probe the dynamic alignment of molecules, and the characteristic harmonic signal in time and frequency domains clearly reveals coherence in the rotational wave packet.

Collaborating with a theoretician's group of Bielefeld University, we have recently developed a theory to describe the HHG from coherently-rotating molecules, while there has been no reliable quantum mechanical theory to describe the HHG from aligning molecules. The validity of this theory was confirmed by the experimental study of dynamic behaviors of angle dependent harmonic signals for N_2 and O_2. The experiment employs a pump-probe technique using 40-fs laser pulses, where the pump forms a rotational wave- packet that leads to transient molecular alignment and its revivals, and the delayed probe pulse generates high harmonic radiation from molecules. We have measured the high-harmonic signals as a function of the angle α between the pump and probe polarization directions, noting that α is different from the angle θ between the molecular axis and the field direction.

The results are in excellent agreement with those calculated using the recently developed theory, representing the characteristic properties predicted for the angle-dependent harmonic generation. Figure 2(a)

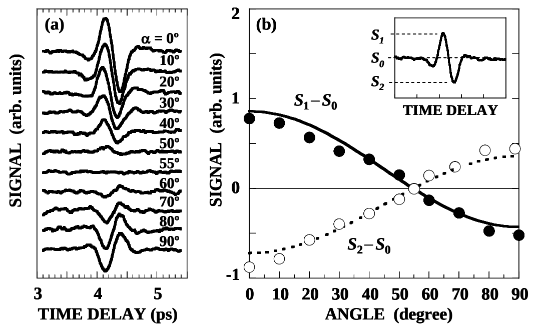

Fig.2. (a)Time-dependent 19th harmonic signals around the half revival time for different α, and (b) the signal modulations as a function of α, where the solid and dotted lines represent the calculated results.

shows an example of α-dependent harmonic signals observed around the half revival time. The signal modulations are plotted as a function of α in Fig. 2(b), where the solid and dotted lines represent the modulations calculated with the theory developed. The calculation is demonstrated to agree well with the experimental, where no signal modulation is observed at the critical angle $\alpha_c = \arctan\sqrt{2} \sim 55°$, as predicted by the theory.

The same experiment was done for O_2 molecules, and the calculated signals also provided an excellent agreement with the experimental.

We have shown that the nonlinear process of HHG can be applied to the measurement of molecular rotational temperature in a thin supersonic gas beam, since our theory is able to reproduce well the rotational distribution in a rotational wave packet. The rotational temperature of molecules was accurately derived with high spatial and temporal resolutions from the Fourier spectra of time-dependent signals. The validity of method was successfully tested for an expanding flow of N_2 beam.

4. Nanoprocessing with fs laser pulses

During the last two decades, intense fs laser pulses have been demonstrated to be extremely effective for high energy-density excitation of solid surfaces and resulting precision processing of materials. This is due to the fact that the ultrafast interaction can minimize undesirable thermal and mechanical effects on target materials. In such laser-material interactions, spatial resolution is usually limited to the order of laser wavelength λ_0 due to the diffraction limit. Despite this limitation, several years ago we have found that fs laser pulses are able to form *periodic nanostructures* on hard thin films such as diamond-like carbon (DLC) and TiN. The observed size of structures was much smaller than λ_0, i.e., in a range of $\lambda_0/10$ - $\lambda_0/5$. The characteristic properties of nanostructuring have been studied as functions of laser parameters. The results have shown that the nanostructure is usually produced with multiple laser pulses at *low fluence* around the single-pulse ablation threshold, where the periodic structures have their wave vectors parallel to the laser *E*-field, and the structure size tends to be proportional to λ_0 used. For the development of laser nano-processing, a comprehensive and/or versatile physical model is strongly required to illustrate the interaction process for nanostructuring.

In a recent experiment for DLC, we found that the nanostructure formation is initiated on the swelled surface of which bonding structure is changed from DLC to glassy carbon (GC). The subsequent experiment using patterned targets has clearly demonstrated that the ablation to create the nanostructure is preferentially induced with the help of *local field* or *near field* enhanced on the stripe with a high curvature. The local field generation accounts for the initiation of nanoscale ablation at low fluence around the ablation threshold and its polarization dependence.

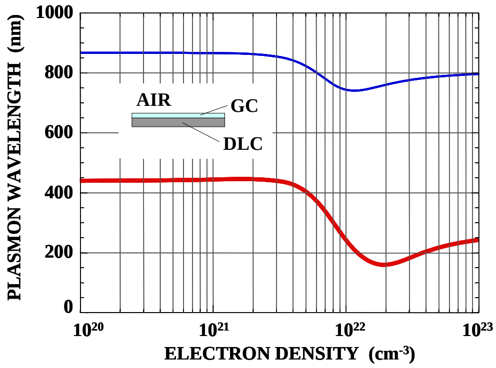

Fig. 3. Plasmon wavelength calculated as a function of electron density for the GC/DLC interface (lower) and for the air/GC (upper).

The other problem is the origin of *nanoscale periodicity* produced on solid surfaces. Observing the initial stage of nanostructuring, we ascribed it to the periodic enhancement of local fields through the excitation of *surface plasmon polaritons* (SPPs) in surface layer.

Figure 3 shows the SPP wavelength λ_{sp} calculated as a function of electron density N_e in the GC/DLC and air/GC interfaces. The estimated value of N_e for efficient energy absorption is 0.7 – 6 x 10^{22} cm^{-3}, which leads to λ_{sp} = 150 – 340 nm for the GC/DLC interface, whereas λ_{sp} for the air/GC is of the order of λ_0. The local nanoscale ablation should be initiated at a period $d \sim \lambda_{sp}/2$ with the help of local fields enhanced periodically with SPPs. The periodicity d = 75 – 170 nm calculated for the GC/DLC interface is in good agreement with the observed size of nanostructure. The validity of the above physical picture is now under investigation by applying it to the other materials such as TiN and Si.

5. Theoretical study of ultrafast laser-matter interactions

We have shown that the delay-dependence of high-order harmonics and above-threshold ionization under the two-color field is different, and successfully explained the difference using the classical analysis. Moreover, we have shown that our theoretical results on the resonance enhancement of the two-color two-photon ATI spectra of He by harmonic pulses agree well with the recent experimental results.

6. Transient critical heat fluxes of cooled water flow

The swirl tubes with twisted- tape inserts have been shown to provide considerable enhancement of critical heat flux. This enhancement is due most likely to the reduction of laminar boundary layer thickness on the heated surface of test tube.

Collaboration Works

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Advanced Energy Storage Research Section

A. Kimura, Professor
K. Morishita, Associate Professor
R. Kasada, Assistant Professor

1. Introduction

Efficient energy conversion and storage are great concerns for sound human life in the near future. This section takes up a mission of materials R & D for advanced nuclear energy conversion and storage, such as development of fusion blanket structural materials and fuel clad materials for high burn-up operation of light water reactors. The main issues are as follows:

(1) ODS steels for the advanced nuclear energy systems: Cladding material development is essential for realization of highly efficient high burn-up operation of next generation nuclear systems, where high performance is required for the materials, that is, high strength at elevated temperature, high resistance to corrosion and high resistance to irradiation. Oxide dispersion strengthening (ODS) ferritic steels are considered to be most adequate for the cladding material because of their high strength at elevated temperature. From fiscal year 2005, our research group has begun a research project “R&D of Super ODS steels for the Advanced Nuclear Energy Systems” in MEXT Innovative Nuclear Research and Development Program.

(2) Multi-scale modeling of fusion blanket structural materials: Reduced activation ferritic steels (RAFS) and SiC/SiC composite are the promising candidates for fusion structural materials for future fusion reactors where structural materials are expected to suffer sever highe-energy particle irradiation. The multi-scale modeling approach is very useful to understand and predict the degradation.

(3) Lifetime evaluation 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. From fiscal year 2007, our research group has begun a METI project concerning “program”.

2. Super ODS Steels R&D for Fuel Cladding of Next Generation Nuclear Systems

In this work, “Super ODS steel” that has better corrosion resistance than well-known 9Cr-ODS steel, has been developed for application to cladding of a variety of next generation nuclear systems.

Alloy design study suggests that 14-16Cr plus 4Al is necessary to keep corrosion resistance in SCPW and to suppress a severe aging embrittlement. Especially, the addition of Al is very effective to increase corrosion resistance of 16Cr-ODS steels in SCPW and in LBE. However, the addition of Al remarkably decreases the tensile strength because of the oxide particles dispersion morphology change. An effort was made to reduce and increase the size and the number density of the nano-scaled oxide particles, respectively, which was realized by the addition of Hf or Zr. The positive effects of Hf or Zr addition is superior to the negative effects of Al addition on high temperature strength. The Zr addition is more recommended than Hf addition in terms of neutron absorption or efficiency.

16Cr-4Al ODS steels were highly resistant to ion irradiation up to 150 dpa. Helium bubble growth and segregation at grain boundaries were suppressed by oxide particles dispersion. It is considered that the nano-sized oxide dispersion resulted in the increase in the phase stability that is essential for good material performance under irradiations.

Cladding pipes have been successfully fabricated by using Super-ODS candidate materials, as shown in Fig. 1. Further long-term experiments, such as neutron irradiation experiments, creep tests and long-period corrosion and aging tests, are necessary to assess performance of high-Cr ODS steels as fuel cladding of advanced nuclear systems with high efficiency and high burn-up.

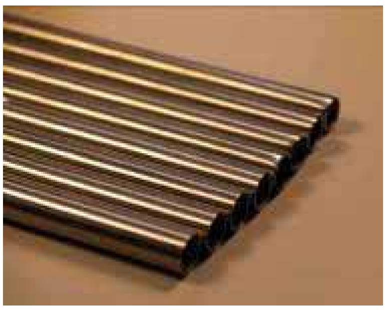

Fig. 1 Super-ODS cladding pipes.

3. Computational modeling of the nucleation and growth process of vacancy clusters in *β*-SiC during irradiation

SiC/SiC composites are one of promising candidates for the blanket structural material of fusion reactors, because of high stability at high temperature. Microstructural changes in the material during irradiation have been reported in literatures, where voids are observed by the transmission electron microscopy (TEM) when irradiation temperature is greater than about 1273 K. This temperature range for void formation in *β*-SiC is much greater than those in other materials proposed as the blanket structural material. As a first step towards constructing a model for simulating microstructural evolution in *β*-SiC during irradiation, the formation and binding energies of vacancy clusters in *β*-SiC were evaluated as a function of the size, vacancy composition, and vacancy configuration of clusters.

Molecular dynamics and molecular static calculations have been performed using the empirical many-body interatomic potential to obtain the formation and binding energies of relaxed configuration of vacancy clusters in *β*-SiC, which are necessary when the nucleation and growth process of clusters is investigated. The formation energy of vacancy clusters in *β*-SiC depends on the size, vacancy composition, and vacancy configuration of clusters. When the size and vacancy composition of clusters are given, the vacancy configuration of clusters with the lowest formation energy is primarily given so as to take the smallest number of dangling bonds. Especially when the fraction of the number of silicon vacancies to the number of carbon vacancies in clusters is quite high or quite low, the formation property of antisite defects in clusters becomes a key factor to determine the stable configuration of clusters.

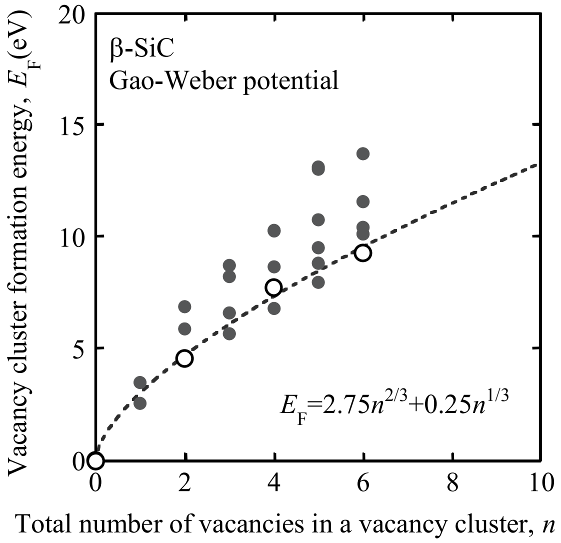

Fig. 2 The lowest formation energy of vacancy clusters in *β*-SiC as a function of cluster size, $n=n_V^{Si}+n_V^{C}$, where n_V^{Si} and n_V^{C} are the numbers of silicon- and carbon-vacancies in a cluster. The open and closed circles indicate clusters with $n_V^{Si}/n_V^{C}=1$ and with $n_V^{Si}/n_V^{C}\neq 1$, respectively..

4. Development of nano- and micro-composite particle coating for Pb-Bi cooled fast reactor

From fiscal year 2006 to 2008, our research group was carrying out **"**Development of nano- and micro-composite particle coating for Pb-Bi cooled fast reactor**"** in a MEXT Innovative Nuclear Research and Development Program for young scientists. Corrosion-resistant Al_2O_3 coating for structural materials of Pb-Bi cooled fast reactor has been successfully developed by applying sol-gel processing using aluminum nitrate solution containing nano- & micro-α-Al2O3 powders and so on. A new conventional device to evaluate the corrosion behavior of the coating in Pb-Bi quickly by using rotating specimens was also newly developed as shown in Fig. 3. These developments will contribute to not only the next generation fission reactor systems but also fusion reactor blanket systems using Li-Pb.

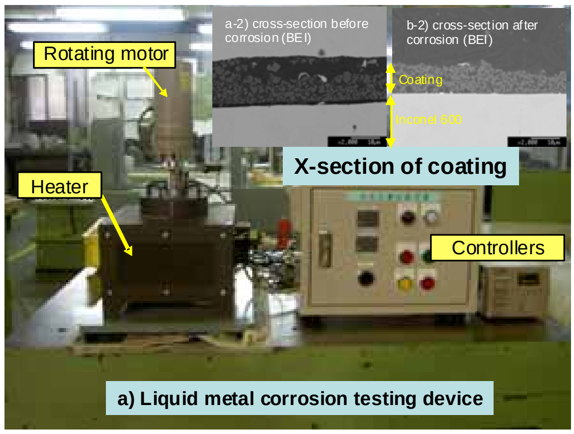

Fig. 3 a) developed liquid corrosion testing device before installing into a glove box, b, c) cross-sectional view of coating before and after LBE corrosion test.

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Complex Plasma Systems Research Section

F. Sano, Professor
K. Hanatani, Associate Professor
S. Yamamoto, Assistant Professor

1. Introduction

The development of magnetic fusion as a commercial power reactor requires the magnetic configuration that can efficiently confine high density plasmas at high temperature for sufficiently long confinement time to produce net thermonuclear power. This research section seeks to investigate the confinement optimization of high temperature plasmas in the helical-axis heliotron line. For the experimental and theoretical investigation of this theme, the magnetically confined plasma device of Heliotron J has been operated at the Laboratory for Complex Energy Processes since FY2000 to study the magnetic configuration effects of confinement with special regard to the improved bulk plasma confinement regime, H-mode, the bumpiness effects of the high-energy particle confinement, the non-inductive plasma current properties, and MHD activities. With regard to these experimental studies, the detailed theoretical and numerical simulation studies have also been carried out.

2. Studies of MHD instability on Heliotron J plasmas using data mining techniques

Data mining techniques based on statistics, pattern recognition, artificial intelligence and information technology have been used in the areas of distribution and finance for business, and bio-informatics, astronomy and geology for science. Data mining techniques can extract new information because they are able to automatically pick out patterns in large amounts of high-dimensional data. We applied a data mining technique to analyze the fluctuation signals within a large database in order to identify MHD instability on Heliotron J plasmas. Moreover, the entry of information about MHD instability classifications into a database enables us to exactly and quickly investigates the characteristics of MHD stability through parameter studies. We analyzed 3786 plasma discharges (shot) including all of 14 magnetic probe data. We used 1024 data points which were used for the short time segments (Δt~1ms). The size of database with multiple data points per time interval exceeds 2.5 million data points. Fig. 1 shows nine clusters, which are well defined by the data mining technique using the expectation maximization (EM) algorithm. The frequency of MHD instabilities in each cluster shown in Fig. 1 is in the range of frequencies f = 20 ~ 150 kHz which are close to the frequency of shear Alfvén continua. Fig. 2 shows the phase differences between each magnetic probe for each cluster shown in Fig. 1 calculated using the fast Fourier transform (FFT). The plot numbers in Fig. 2 corresponds to those in Fig. 1. The estimated poloidal mode number m for each cluster is indicated in Fig. 2. To investigate why the observed high frequency mode propagates in the different two directions, we searched the magnetic field strength in the database. As a result of comparison between cluster in Fig. 2 and database of magnetic field strength, almost all of observed modes propagate in the diamagnetic drift direction of ions. The energetic-ion-driven MHD instabilities propagate in the diamagnetic drift direction of ions. The advantage of data mining technique is that it is easy to investigate

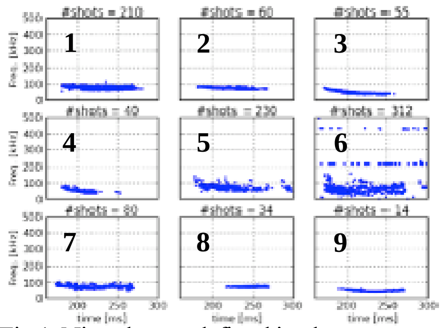

Fig.1. Nine clusters defined in phase space

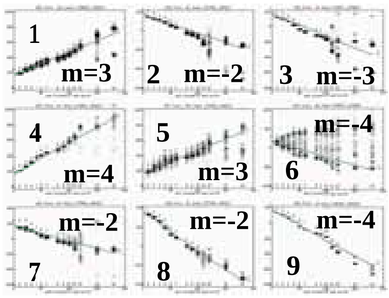

Fig. 2. Phase difference of magnetic signals

the characteristics of the observed MHD instability through the parameter study. Parameter studies using database related to the energetic ion characteristics and plasma parameters such as the energetic ion velocity and electron density showed that the observed MHD instabilities in the nine clusters are energetic-ion-driven MHD instabilities destabilized by the co-flowing energetic ions.

3. Langevin Equation for Guiding Center Motion and its Application to Neoclassical Transport Theory

Neoclassical transport in toroidal plasmas was studied [1, 2] by formulating the Langevin equation for guiding center motion in the framework of statistical mechanics. To ensure the diffusive nature of a stochastic process, the dynamics of test particles is expressed in terms of the Langevin equation with the assumption of sufficiently small radial orbit width. The transport coefficients are evaluated by the time integration of auto- and cross-correlation functions for each pair of time-reversal expressions of microscopic fluxes. As a test of this method, the neoclassical viscosity coefficients are calculated numerically and are shown to agree with analytical formulas.

The Langevin equation is used to describe the transport processes in a system close to thermal equilibrium. An advantage of the Langevin-type description is that it can be easily simulated using a quasi-random number generator. The Monte Carlo methods have been extensively used in the stellarator/heliotron research, in particular, to estimate radial diffusion in the long mean-free-path regime, which gives the irreducible minimum of the transport level in a toroidal configuration. The calculation of parallel transport such as bootstrap currents is also important for predicting the noninductive currents, which are observed in experiments.

Mathematically, the Langevin equation is an example of stochastic differential equations (SDEs). When we consider a stochastic variable $X(t)$ in a Gaussian random process with t, a time variable, the evolution of $X(t)$ can be written in terms of SDEs by $dX(t) = a(X; t)\, dt + b(X; t)\, dW(t)$ where $a(X; t)$ is the deterministic part of test particle motion, while $b(X; t)$ denotes the random acceleration with the standard Wiener process $W(t)$. In most cases, we need not solve exact trajectories of test particles. Instead, the Wiener increments $dW(t)$ are expressed by relatively simple random variables, such as the two-point or uniform ones as approximations of the Wiener increments. The transport theory in such a stochastic system can be treated quantitatively by the correlation-function method. The transport coefficients are then calculated from the time-integration of correlation function between microscopic fluxes carried by each particle. This is known as the Green-Kubo formula. In the linear response theory of stochastic process, this approach is valid in a variety of transport phenomena, provided that the evolution of a system is dominated by Gaussian probability distributions. In this work, we proposed a new method for computing neoclassical transport matrix using the Langevin equation and correlation function. Although it is not easy to calculate the correlation function in general, the neoclassical ordering enables us to evaluate it as a function of magnetic surface label.

In summary, we derived the Langevin equation for guiding center motion and developed the method for computing neoclassical transport using the correlation function method. As noted, the neoclassical ordering is important to ensure the local and diffusive nature of the transport. Owing to this assumption, the explicit calculation of correlation functions becomes possible. As a specific example, we evaluated the neoclassical viscosity coefficients, which are then used in the moment-equation method for obtaining the viscosity-flow relation. We showed [1, 2] that the viscosity coefficients could be calculated by the correlation-function method, which is based not on the kinetic but on the stochastic approach using the Langevin equation. In future work, the method will be used to investigate the effect of radial electric field and also be applied to realistic toroidal MHD equilibria.

4. Optimization of helical-axis heliotron.

In order to improve the magnetic configuration of helical-axis heliotron which has simple l=1 helical coil and can confine steady state plasma, we try to optimize the magnetic configuration of Heliotron J using stellarator optimizer "STELLOPT" suite. In this study, we mainly target on particle confinement of both thermal and energetic particle. First of all, we explored the possibilities to optimize the magnetic configuration of Heliotron J using modulation of Fourier harmonics of last closed flux surface, that is fixed boundary optimization. The way to improve the bulk particle confinement is to minimize the differences of contour of the second adiabatic invariant J and B minimum with magnetic flux surface. Fig. 3 shows the well alignment B minimum which represented the particle confinement of deeply trapped particle with magnetic flux surfaces in the optimized configuration. As a result of this study, optimized magnetic configuration has clear quasi-omnigenous structure, which has a well combination with three Fourier components of toroidal, helical and mirror ripple.

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Clean Energy Conversion Research Section

Mitsuru Kikuchi, Visiting Professor
(Japan Atomic Energy Agency)

1. Introduction

Fusion is one of clean energy options. Realization of fusion energy requires magnetic confinement of high temperature plasma in closed magnetic configuration. Tow major configurations are "Tokamak" adopted in ITER and "Helical" adopted in LHD (Japan) and Wendelstein-7X (Germany). Right now, Tokamak showed an excellent plasma confinement capability, leading to the construction of Tokamak type experimental reactor ITER in Cadarache. However, tokamak needs extensive effort to realize steady-state operation, while helical system is intrinsically steady-state. In this work, I have tried to describe progress of steady state tokamak research towards the contribution to realize low carbon society in the end of this century.

2. Fusion Energy [1], [2]

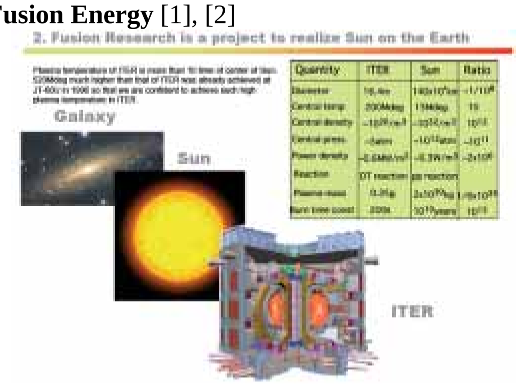

Figure 1 ITER, Sun and Galaxy

Fusion is a project to realize Sun on the earth. Plasma temperature of ITER is more than 10 time of center of Sun. 520Mdeg much higher than that of ITER was already achieved at JT-60U in 1996. So we are confident to achieve such high temperature in ITER.

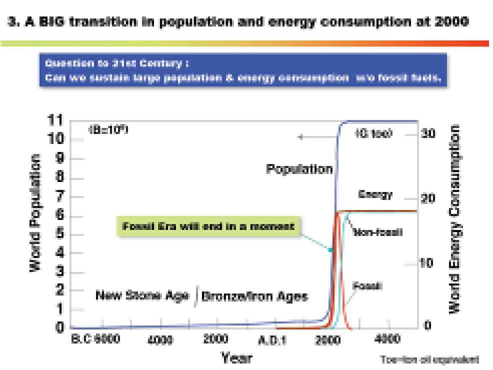

Figure 2 a big transition in population and energy consumption between last and present millenniums

Present human culture is blessed by the large-scale energy consumption, especially from fossil fuels. But, fossil fuel era is very short if we see the time scale of millennium as seen in Figure 2.

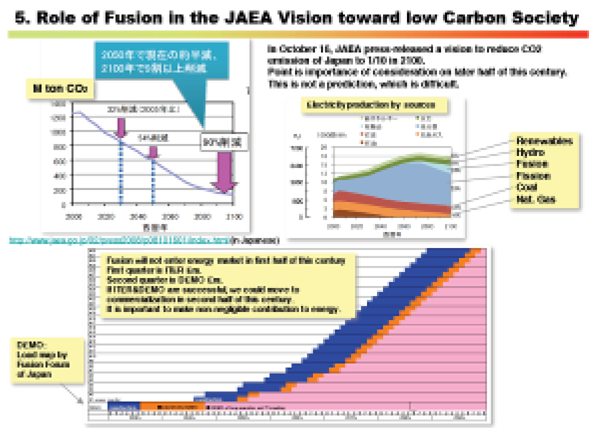

Figure 3 Strategy to realize 90% reduction of CO_2 emission in 2100 with good contribution from fusion.

Office of Strategy Research of JAEA (Director : M. Murakami) established Year 2100 Atomic vision – proposal towards low-carbon society, and press released on Oct. 16, 2008 [3], in which Fusion plays a meaningful role as seen in Figure 3 [4].

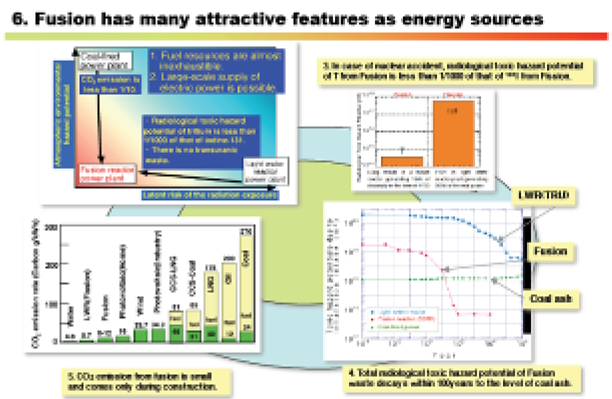

Figure 4 Attractive features of fusion

Fusion has many advantages as energy source such as low Carbon emission, comparatively lower radiological hazard potential, quicker decay of radio activities [5] as shown in Figure 4.

3. Steady State Tokamak Research

Reactor concept has been established based on the bootstrap current experiments in JT-60 in 1990 [6]. Since then, significant efforts were made to establish physics basis of steady state operation of Tokamak [7],[8],[9].

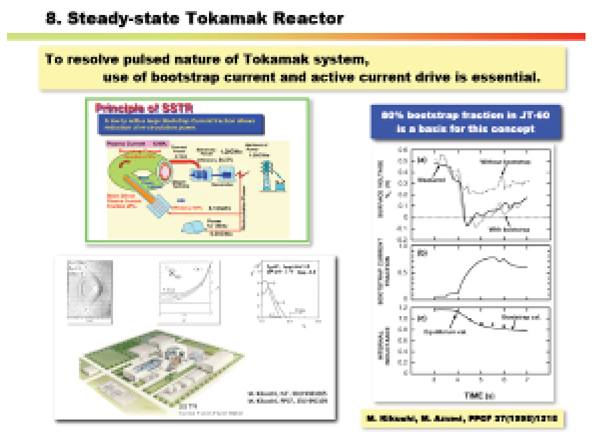

Figure 5 SSTR Concept and physical basis from JT-60

During this research, a unique structure formation "Current Hole" was observed in JT-60 [10] as seen in Figure 6. This current hole is suitable for enhancing bootstrap current and also vertical plasma elongation to increase edge safety factor.

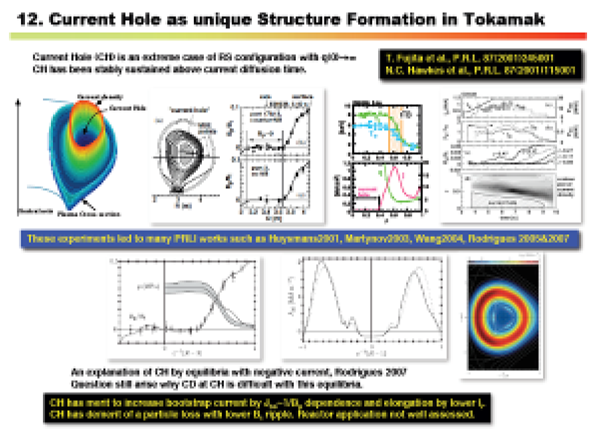

Figure 6 Current hole in JT-60 and possible explanation

So-called Internal Transport Barrier (ITB) was observed in JT-60 and the measurement of the radial correlation shows long correlation length in L-mode and short correlation length with ITB, which is consistent with the picture of Self-Organized Criticality (SOC) for L-mode and ITB as local relaxation of SOC.

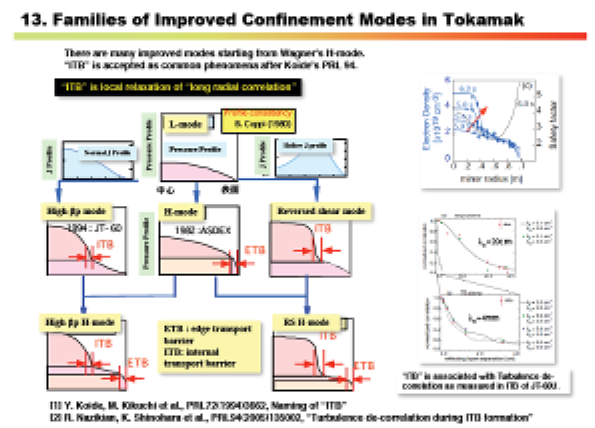

Figure 7 Families of Improved Confinement Modes and ITB in Tokamak

To achieve reasonably high power density for the reactor, high pressure operation above no-wall limit should be stably maintained as assumed in SSTR. RWM (Resistive Wall Mode) should be stabilized by stopping the slipping of the plasma against RWM. This has been achieved with small toroidal rotation in 2007[11].

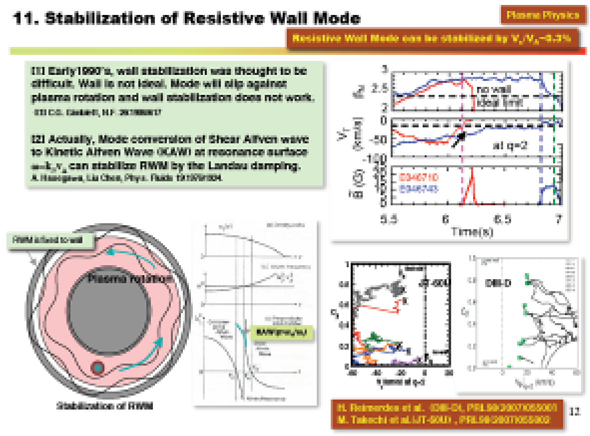

Figure 8 Demonstration of RWM stabilization in JT-60 as necessary condition for SSTR.

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Clean Energy Conversion Research Section

Shinichiro Kado, Visiting Associate Professor
(The University of Tokyo)

Proposal of the Beam Emission Spectroscopy (BES) System on Heliotron J

1. Introduction

It has widely been recognized in the magnetically confined plasmas research that the steep gradient of the density or temperature is a measure of good particle/energy confinement. In addition, the gradient of plasma parameter itself can be a free energy to drive a turbulent fluctuation-induced particle and energy fluxes. Therefore, the diagnostics that can simultaneously measure both the gradient and fluctuations are demanded.

A beam emission spectroscopy (BES) is considered to satisfy such requirement. The BES has originally been developed in tokamak in late 1980's for the long wavelength fluctuations [1]. Its capability of the imaging diagnostics for the turbulence has been particularly drawn attention to for the study of the zonal flow [2]. Recently the BES was first applied to a helical confinement system, CHS (Compact Helical System) in NIFS, by the authors [3, 4] and investigated the relationship between the local density gradient and a peculiar coherent MHD fluctuation having higher harmonics frequencies [5-8]. Effectiveness of the fast measurement of the edge density gradient was proved in identifying the edge transport barrier (ETB) formation [9].

In this study, the applicability of the BES system to Heliotron-J is evaluated for the study of the fluctuations and transport in a helical-axis configuration.

2. Diagnostic Principle of BES

A beam emission spectroscopy (BES) system measures emission from the collisionally excited neutral atoms of a high energy beam injected to the plasma (denoted as “beam emission”). The dominant excitation process depends on the beam energy:

$$n_e n_{b1} \sigma_{eff} v_b \equiv n_e n_{b1} < \sigma_{e,13} |v_b - v_e| > + n_i n_{b1} < \sigma_{i,13} |v_b - v_i| >$$

were n_e, n_i and n_{b1} denote the densities of electron, ion and ground state beam ion, respectively, while v_e, v_i and v_{b1} denote the velocities of them, respectively. < > represents the average procedure assuming the Boltzmann temperature. Since the velocity of the thermal ions is small compared to that of electron and beam, so that it is negligible. Therefore, the effective excitation cross section of the hydrogen beam atom from ground to n = 3 state, $\sigma_{eff,13}$, usable for the detection of Balmer alpha beam emission, where n is the principal quantum number, can be written as:

$$\sigma_{eff,13}(v_b, T_e) = \frac{< \sigma_{e,13} |v_b - v_e| >}{v_b} + \sigma_{i,13}$$

The result of the calculation is shown in Fig. 1. pNBI and nNBI denote the typical beam energy for the positive and negative ion source systems of the neutral beam injection (NBI), respectively. Because the acceleration energy of the NBI in the Heliotron J is around 30 kV, the beam atom undergoes both the electron and ion impact excitation processes from n = 1 to 3 state.

3. Consideration of the Observation Port

The intensity of the beam emission represents the local electron and ion densities. Therefore, the multi-point measurement system yields the density profiles under some assumptions of calibration and beam attenuation, while the spatio-temporal evolution yields the fluctuation power spectra with respect to frequency and wavenumber.

The beam emission can be distinguished from the bulk plasma emission by taking advantage of Doppler shift. Larger angle (< 90 degrees) between the normal line of the beam on the mid-plane and the viewing chord is preferable in the conventional case.

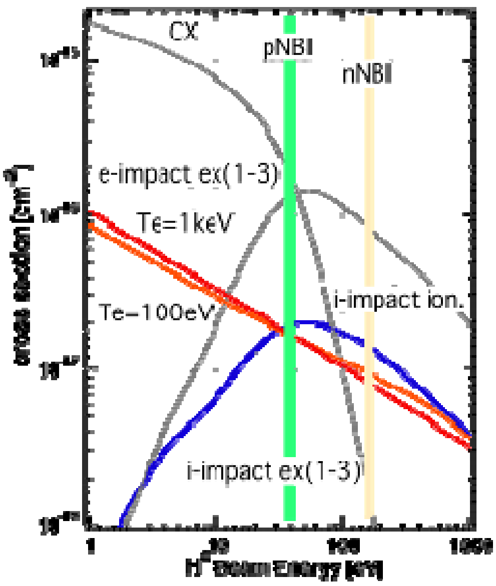

Fig.1 Cross sections of the atomic processes relevant to the BES diagnostics for the Balmer-alpha beam emission.

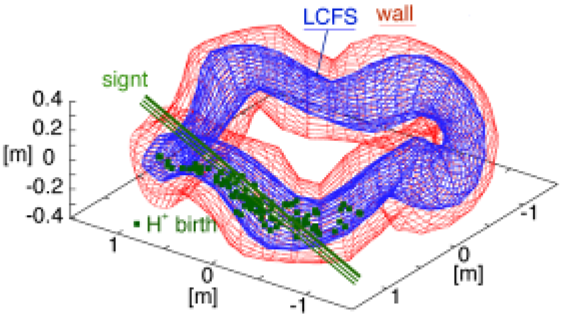

Fig.2 Schematic views of the Heliotron J magnetic flux surface and chamber wall. Birth points of the beam ions (reduced for the visibility) and the possible viewing chords when one intends to keep spatial resolution of the BES system are drawn.

In addition, variation of the sightlines in the position with respect to the flux surface passing across the beam corresponds to the effective spatial resolution. Thus, in the BES system on CHS, the location of the object lens was designed such that the viewing chords are as tangent as possible to the magnetic axis. This could be realized by inserting a observation port deeply into the vacuum chamber (see Fig. 1 in ref. [3]).

In the helical-axis heliotron devices (the pole *l* and the pitch *m* are 1 and 4, respectively for the Heliotron J), however, the situation was more challenging. The up-down periodicity of 4 along the toroidal direction makes the large part of the flux surface intersect the mid-plane, loosing the spatial resolution from the conventional horizontal view. It seemed, at first, impossible to yield spatial resolution.

However, we have found that when one views down from the upper point in the vacuum chamber where viewing lines become parallel to the plasma between the one pitch, namely from the rising top to the falling bottom, one can avoid the spread of radial localization of the viewing flux surface. An example of the viewing chord are shown in Fig. 2 together with the birth points of the hydrogen beam ions calculated using a HFREYA code [10]. Observation from the #2.5O port in the upper side of the chamber and the full-energy component of the pNBI of the beam line BL2 of a horizontal port having 1.2 degree in beam divergence, 27 kV in the acceleration voltage, and the electron density n_e = 2x 10^{19} m^{-3} were used for the calculation. Since the dependence of ionization and excitation cross-sections on the beam energy is similar, it can also be used as the birth points of the exited beam atoms for BES.

Fig. 3 shows the distribution of events with which the ionization of the beam atoms occurs within the viewing spot 10 mm in diameter and 20 degree in depression angle for different sight lines in Fig. 2.

One can see that the birth points for their viewing chords distribute along the flat part in the average minor radius confirming the beam emission from the same flux surface can be observed in the present geometry.

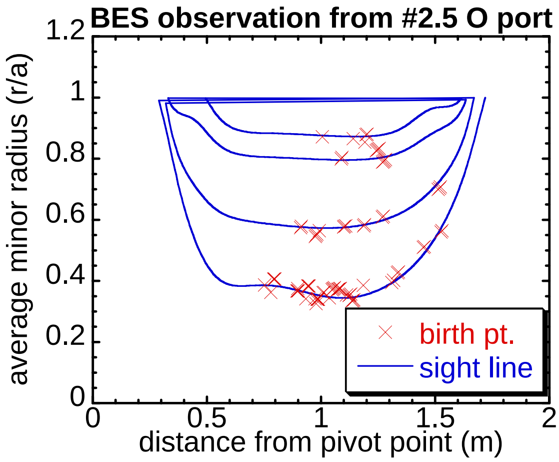

Fig.3 Location of the birth points and the sight lines in Fig. 2 represented in the average minor radius. The horizontal axis is the distance from the datum point for the viewing chords near the observation port #2.5O.

The implementation of the BES system on Heliotron J will be planned soon.

I acknowledge S. Kobayashi for the collaboration in this work.

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Chemical Reaction Complex Processes Research Section

Y. H. Ogata, Professor
T. Sakka, Associate Professor
K. Fukami, Assistant Professor

1. Introduction

Major research activities of this section are in the field of fabrication and characterization of various surface structures. Especially, photo-energy conversion properties are the subject of great interest. We utilize electrochemical processes and laser spectroscopic techniques to perform research in this subject.

In this academic year we have performed research work on the mechanism of the macroporous silicon formation, copper filling into mesoporous silicon, medium-sized porous silicon rugate structure, laser diffraction of particle monolayer, and application of laser ablation emission spectroscopy to *in situ* underwater alloy composition analysis. Some details are given below.

2. Ordered macropore formation in pre-patterned p-type silicon

Porous silicon is formed by anodization of silicon in HF solution. For highly resistive silicon, macropores are formed in the pore size range from 50 nm to 10 μm. If ordered pre-etch pits are prepared on silicon prior to the etching, an ordered macropore is formed. Such an ordered macropore is useful in the field of electronics, photonics, MEMS and so on. Although the mechanism of macropore formation has been discussed, there are many unclear points about the ordering and disordering of macropores etched from a pre-patterned substrate.

In the present work, the effects of pre-etch pit size and applied current density were studied. The results suggest that the electric field formed in silicon affects the formation of an ordered macropore. On the basis of ordered macropore formation, we succeeded in the formation of an ordered silicon nano-wire by selective dissolution of pore walls.

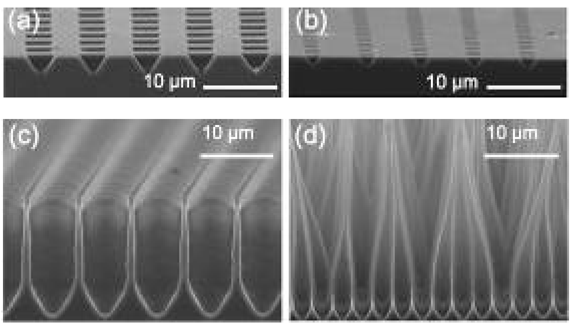

Fig. 2-1 (a) and (b) show the ordered pre-etch patterns with different sizes. (c) A cross-sectional SEM image of an ordered macropore. The etching was preformed using the substrate shown in (a). (d) A cross-sectional SEM image of silicon nano-wires. The nanowires were formed by control of applied current leading to the selective dissolution of the pore walls.

3. Filling of mesoporous silicon with copper by electrodeposition and its numerical simulation

The filling of nano-sized pores or trenches by electrodeposition of copper is an important issue for nano-electronics. The utilization of mesoporous silicon as template for electrodeposition is one of the promising approaches for nano-wiring.

In the present work, the filling of mesopores having the pores with 40 nm in diameter was carried out by electrodeposition of copper. The experimental results indicate that the mesopores are continuously filled from the bottom to the opening as shown in Fig. 3-1. However, the mesopores were not continuously filled, but many copper particles were deposited when deposition current was increased from −5 to −10 μA or the pore depth was increased from 4 to 8 μm. In order to understand the filling mechanism, the numerical simulation was also carried out. The simulation results suggested that discontinuous filling with copper particles was caused by diffusion-limited deposition at −10 μA and by plugging at the pore openings using mespores with 8 μm in depth.

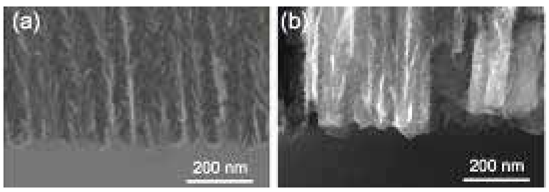

Fig. 3-1 Cross-sectional SEM images of mesoporous silicon (a) and that after filling with copper by electrodeposition (b).

4. Multi-layered porous silicon for vapor-sensing

A porous silicon multilayer prepared by sinusoidally modulating current density during anodization of silicon in HF solution produces a kind of 1-D photonic structure. The spectral peak position is a strong function of the average refractive indices of the layers, and the shift

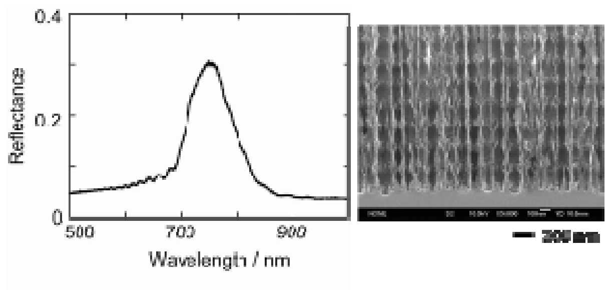

Fig. 4-1 Reflectance spectrum of a medium-sized porous rugate filter prepared by anodization of heavily doped silicon, and the SEM cross-sectional image.

when exposed in vapors provides a sensitive method for the detection of condensable vapors. A compromise in the pore size is indispensable to avoid the low sensitivity and poor optical properties of the resulting filters. The pores have to be large enough to allow molecules to enter but small enough to preserve a large specific surface area to ensure high sensitivity.

We prepared porous silicon rugate filters, the refractive index of which varies sinusoidally in the structure, with different pore sizes that can be used for sensing molecules having different sizes and investigated their optical properties. Mesoporous silicon rugate filters can be easily prepared on heavily-doped silicon. However, microporous silicon rugate filters need a modulation of current function. The sinusoidal modulation of current density over a wide range produces a deformed refractive index profile in the structure. Modification of the sinusoidal current signal is necessary to achieve an accurate microporous filter. Addition of oxidizing agent and surfactant to dilute HF solution produces a porous rugate filter with an average pore size of 100 nm (medium-sized) on heavily doped silicon (Fig. 4-1). In conclusion, the preparations of rugate structures with micro- and medium-sized pores are possible, but the preparations are not very easy compared with the preparation of the structure with mesopores.

5. Laser diffraction measurement of arrayed particle monolayer

Two-dimensional (2D) array of monodisperse spherical particles can be used as a template for fabrication of various ordered structures. For example, by evaporating a metal into interstitials of such particle monolayer, periodically-holed two-dimensional metal film can be obtained. Such a structure works as a photo-functional surface due to the excitation of surface plasmon polariton. The 2D array of the microspheres can be formed by self-assembly from the dispersion solution (Fig. 5-1), meaning that the cost of the fabrication can be very low. However, it is hard to obtain large whole area being single domain due to very weak capillary force between the particles during evaporation of the solvent. To investigate the optimum condition for large single domain formation, *in situ* structure monitoring is useful.

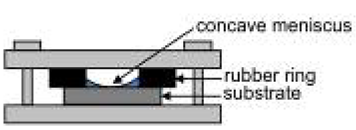

Fig. 5-1 Setup for the formation of 2D array of monodisperse spherical polystylene particles (3.21 μm in diameter) from their dispersion solution by vaporization of solvent from a concave meniscus surface.

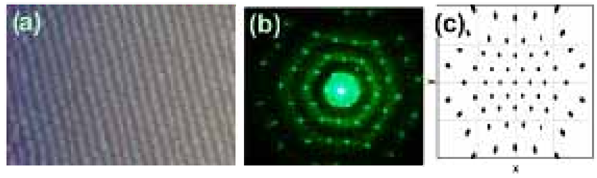

Fig. 5-2 Ordered monolayer of polystyrene microsphere on a glass substrate. (a) optical microscope image, (b) laser diffraction pattern on a plane screen, and (c) simulation of the laser diffraction pattern by projecting the Laue function to x-y plane.

In the present work, laser diffraction pattern was measured for the particle array, and compared with the simulation using a diffraction theory as used for x-ray analysis. The results show that experiment and simulation agree well with the 2D hexagonal packing structure. Next step on this subject is to enable the identification of disordered structures, which is necessary for the monitoring of the structure formation from disordered structure to ordered one.

6. Emission spectroscopy of laser ablation plume: composition analysis of a target in water

Previously, we have shown that laser ablation by a long ns pulse, such as 100 ns or longer, gives clear atomic lines in the emission spectra even in water. This enables *in situ* surface elemental analysis of solid materials in liquid.

In the present work we measured emission spectra of ablation atoms by the irradiation of Cu65/Zn35 binary alloys in water with a 150-ns pulse. Fig. 6-1 shows the Cu/Zn ratio obtained by the emission spectra as well as that obtained by ICP analysis of the residual water after the irradiation. The former is obtained as the best-fit parameter by fitting theoretical spectra to experiments, and is significantly low compared with the target composition, while the latter is comparable. This suggests that the whole ablation event fairly keeps the stoichiometry of the target, while the emission region does not reflect the stoichiometry, and that a calibration is necessary for quantitative analysis.

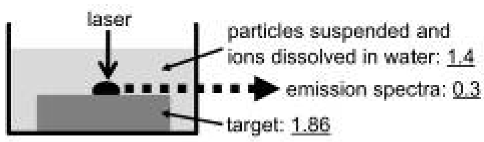

Fig. 6-1 Cu/Zn ratios obtained by ICP analysis of residual water and from atomic emission lines. The ratio obtained by emission spectroscopy is extremely low compared with the original composition of the target.

Collaboration Works

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尾形幸生、基盤研究(B)、「センサーへの応用を目指すルゲート型多孔質シリコン多層構造の形成」

作花哲夫、基盤研究(B)、「電気化学的析出プロセスのその場元素モニタリングの新しい方法」

深見一弘、若手研究スタートアップ、「多孔質シリコンへの導電性高分子膜の電解重合によるマイクロタスの作成」

2. Others
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Molecular Assemblies Design Research Section

S. Yoshikawa, Professor
T. Sagawa, Associate Professor
Y. Suzuki, Assistant Professor
Y. Kobuke, Visiting Professor

1. Introduction

Development of novel photovoltaic devices and/or systems is one of the promising strategies for new system with solar energy. For the sake of construction of efficient photoelectric conversion system, utilization of self-organized molecular assembly and fabrication of novel one- or two-dimensional nanomaterials of metal oxides or conductive polymers, such as nanotubes, nanowires, and/or nanosheets are studied in this research section. Particularly, we are developing highly efficient organic solar cells, such as organic thin-film solar cell and dye-sensitized solar cell (DSC), as well as highly active photocatalyst to realize sustainable energy systems based on next-generation solar technologies. Followings are main research achievements in the year of 2008.

2. 1D- and 2D-nanostructured conductive materials of organic and/or inorganic hybrid to improve the conversion efficiency in polymer solar cells

Previously, we succeeded in fabrication of highly efficient organic solar cell by inserting TiO_x layer between Al electrode and active layer [S.Y. *et. al*., *Appl. Phys. Lett*., 2007, *90*(16), 163517/1-3]. Based on the time-resolved photophysical analysis, we confirmed that the introduction of TiO_x layer into the device was effective to elongate the life-

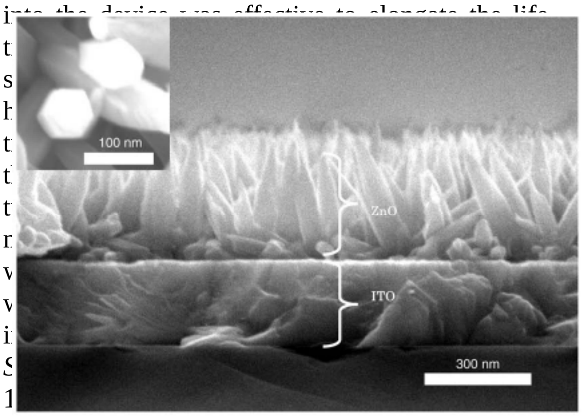


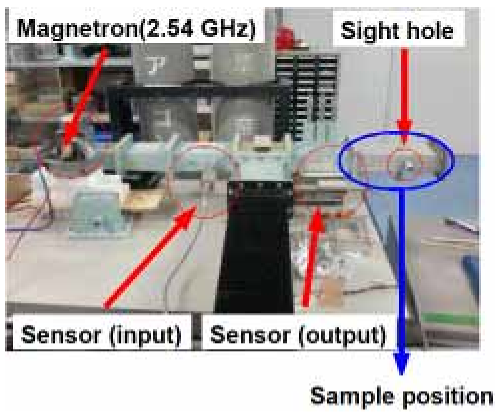
Fig. 1 SEM cross sectional image of ZnO nanorod arrays on the ITO substrate. Inset shows the top view image (T.S., S.Y. et. al., *Solid-State Electronics*, **2009**, *53*, 176-180).

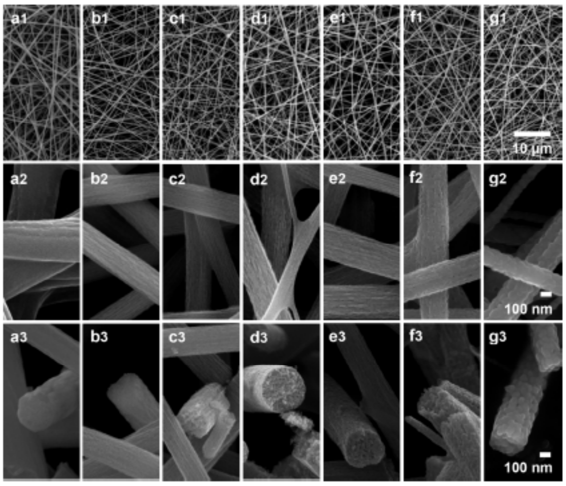
176-180]. Application of such nanoarrays of ZnO and TiO_2 for DSC was also investigated [T.S., S.Y. *et. al*., *J. Crystal Growth*, 2009, *311*, 757-759]. Morphologically control of the active layer by irradiation of single mode microwave (Fig. 2) was newly established and revealed that this strategy is homogeneous and selective.

Newly prepared oligoZnporphyrin showed excellent absorption characteristics of visible light and was or ganized into a porphyrin-fullerene composite by pyridyl to Zn coordination (by Y. K.).

This research was partially supported by New Energy and Industrial Technology Development Organization (NEDO) from the Ministry of Economy, Trade and Industry (METI) as R&D for Next Generation PV System: Research and development of high-efficient organic thin-film solar cell with supra-hierarchical nano-structure (FY2006-FY2009) to S.Y., T.S., and Y.K. Core Research of Evolutional Science & Technology (CREST) from Japan Science Technology Agency (JST) as Development of polymer hybrid cell (FY2008-FY2010) to S.Y. and T.S. supported this research partially.

3. Photocatalytic evolution of hydrogen with





the anatase phase and the observed increase in the size of the crystalline domains. These nanofibers were utilized as photocatalyst for hydrogen evolution. The nanofiber photocatalyst calcined at 450˚C showed the highest activity among the TiO_2 tested such as ones prepared by hydrothermal method and anatase nanoparticles (Ishihara ST-01). These results indicate that 1D electrospun nanofibers with highly aligned bundled nanofibrils are beneficial for enhancement of the crystallinity, large surface area, and higher photocatalytic activity.

4 Titanate Nanowire Thin Films by Spray Layer-by-Layer Assembly Method

Hydrogen titanate nanowires were prepared by hydrothermal method in 10 M NaOH followed by ion-exchanging process. Titanate nanowire thin films were successfully obtained by spray Layer-by-Layer (spray LbL) method within a short time. Due to the good dispersion state of the nanowires in an aqueous suspension and their linear morphology, titanate nanowires effectively adsorbed on the glass substrate. As a reference, TiO_2-anatase nanoparticle thin films were also prepared by spray-LbL method. This work was supported by MEXT, Japan (Grant-in-Aid for Science Research No. 19685020 For Young Scientist: Category A).

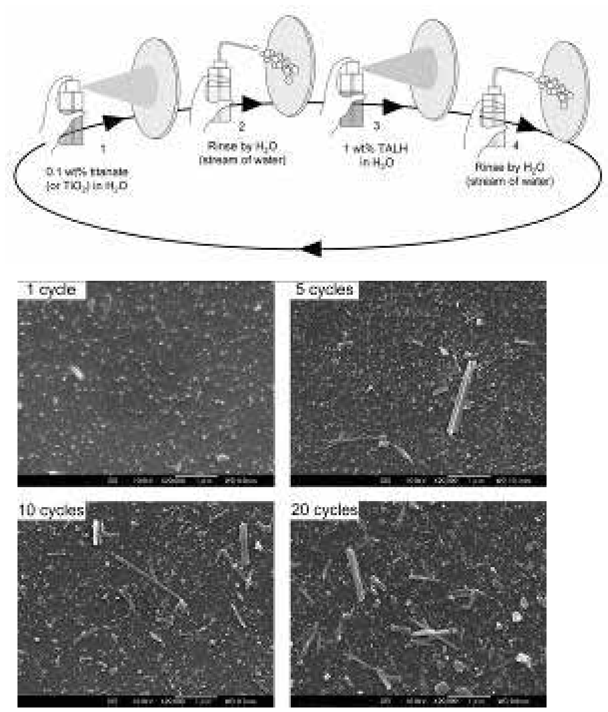


Fig. 4 Preparation and Microstructure of titanate-nanowire thin films prepared by splay-LbL method (the scale bars are 1 μm). (Y. Suzuki et al., *J. Ceram. Soc. Jpn*., **2009**, *117*(3), 381-384).

Collaboration Works

大阪大学、大阪市立工業研究所、新日本石油、京都大学化学研究所、京都大学大学院工学研究科、「超階層ナノ構造を有する高効率有機薄膜太陽電池の研究開発」、吉川暹、佐川尚、小夫家芳明

Financial Support

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吉川暹、受託研究（科学技術振興機構)、「高分子ハイブリッドセルの開発」

吉川暹、奨学寄付金（株式会社カネカ)、「エネルギー理工学研究所分子集合体設計研究分野への研究助成」

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Biofunctional Science Research Section

T. Morii, Professor
K. Tainaka, 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. Design and application of miniature proteins and functional protein/nucleic acids assemblies are explored to target and to chemically transform biologically important molecules in water, the solvent of life. Followings are main research achievements in the year of 2008.

2. Context-Dependent Fluorescence Detection of a Phosphorylated Tyrosine Residue by a Ribonucleopeptide

Tools for selective recognition and sensing of specific phosphorylated tyrosine residues on the protein surface are essential for understanding signal transduction cascades in the cell. A stable complex of RNA and peptide, a ribonucleopeptide (RNP), provides effective approaches to tailor RNP receptors and fluorescent RNP sensors for small molecules. *In vitro* selection of an RNA-derived pool of RNP afforded RNP receptors specific for a phosphotyrosine residue within a defined amino-acid sequence Gly-Tyr-Ser-Arg. The RNP receptor for the specific phosphotyrosine residue was successfully converted to a fluorescent RNP sensor for sequence-specific recognition of a phosphorylated tyrosine by screening a pool of fluorescent phosphotyrosine-binding RNPs generated by a combination of the RNA subunits of phosphotyrosine-binding RNPs and various fluorophore-modified peptide subunits. The phosphotyrosine-binding RNP receptor and fluorescent RNP sensor constructed from the RNP receptor not only discriminated phosphotyrosine against tyrosine, phosphoserine, or phosphothreonine, but also showed specific recognition of amino acid residues surrounding the phosphotyrosine residue. A fluorescent RNP sensor for one of the tyrosine phosphorylation sites of p100 coactivator showed a binding affinity to the target site 95-fold higher than the other tyrosine phosphorylation site. The fluorescent RNP sensor has an ability to function as a specific fluorescent sensor for the phosphorylated tyrosine residue within a defined amino-acid sequence in HeLa cell extracts.

3. Charge-Pairing Mechanism of Phosphorylation Effect upon Amyloid Fibrillation of Human Tau Core Peptide

Phosphorylation of a fibrillogenic protein, human tau, is believed to play crucial roles in the pathogenesis of Alzheimer's disease. For elucidating molecular mechanisms of the phosphorylation effect on tau fibrillation, we synthesized a peptide, VQIVY310K (PHF6) and its phosphorylated derivative (PHF6pY). PHF6 is a partial peptide surrounding a plausible *in vivo* phosphorylation site Tyr310 and forms amyloid-type fibrils similar to those generated by full-length tau. Fibrillation of PHF6 and PHF6pY were studied by spectroscopic and microscopic methods, and the critical

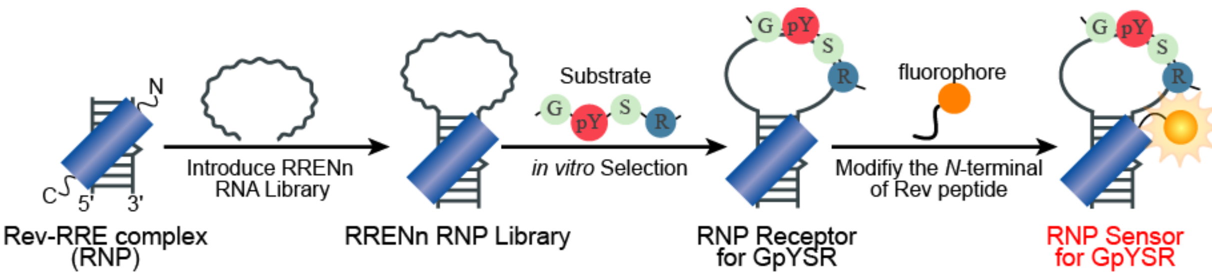

Figure 1. Strategy to obtain RNP fluorescent sensors specific for a phosphotyrosine-containing amino acid sequence GpYSR. Combination of the RNA subunit of the GpYSR-binding RNP and a fluorophore-modified Rev peptide provided a GpYSR RNP fluorescent sensor.

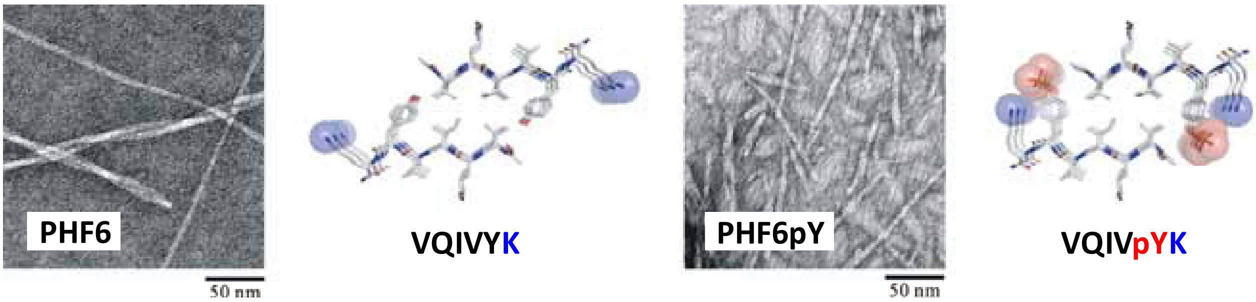

Figure 2. TEM images and of amyloid-type fibers of PHF6 and PHF6pY, and hypothetical structures of amyloid-type fibrils formed by PHF6 and PHF6pY at neutral pH. Blue color and red color indicate positively charged sites of Lys, and negatively charged sites of phosphate groups, respectively.

concentration of the fibrillation was determined for comparing the fibril stability. The results showed that the phosphorylation strongly influenced the fibrillation propensity of PHF6 by changing its dependency on pH and ionic strength. On the basis of the observations, we suggested that charged sites on the phosphate group and its electrostatic pairing with the neighboring charged residues were physical origins of the phosphorylation effect. To verify this charge-pairing mechanism, we conducted experiments using a series of PHF6 derivatives with non-native charge distributions. The electrostatic interaction in an intermolecular mode was also demonstrated by the system composed of two different peptide species, which found that fibrillation of nonphosphorylated PHF6 was drastically enhanced when a trace amount of phosphorylated PHF6 molecules coexisted. A simulation analysis utilizing crystal coordinates of the PHF6 fibril was also performed for interpreting the experimental results in a molecular level. The present study using the model peptide system gave us a microscopically insightful view on the roles of tau phosphorylation in amyloid-related diseases.

4. Novel *in vivo* Biosensors for IP_4 Reveal Temporal IP_4 Dynamics Inside Cells

The signaling cascades to link extracellular messengers to intracellular Ca^{2+} mobilization are regulated by the second messenger D-*myo*-inositol-1,4,5-trisphosphate (IP_3). A direct metabolite of IP_3, D-*myo*-inositol-1,3,4,5-tetrakisphosphate (IP_4), is also believed to be a pivotal second messenger in cellular signal transduction due to the close relevance to chromatin remodeling, modulation of IP_3 levels, Ca^{2+} mobilization, and immune cell development though the physiological function for IP_4 remains unclear. Conventional *ex situ* methods such as HPLC are not suitable to visualize a detailed picture of intracellular IP_4 mobilization in the individual live cells. The real time detection of temporal and spatial dynamics of Ca^{2+} influx and IP_3 has accelerated understanding of their function in cellular signaling events. We fabricated novel fluorescent biosensors for IP_4 that enable a real-time monitoring of IP_4 mobilization in mammalian cells. Optimally designed fluorescent sensors based on GRP1 PH domain exhibited appropriate affinities to IP_4 and detectable fluorescence responses upon target binding, in addition to the remarkable selectivity for IP_4 over other inositol phosphates. Expression of the genetically-encoded biosensors sometimes perturbs the intracellular dynamics of target ligands. The IP_4 sensors were homogeneously introduced into cytosol without greatly affecting the molecular geography of inositol phosphates in intact cells by controlling the loading conditions. The *in vivo* IP_4 sensors in combination of other biosensors would realize simultaneous monitoring of the *bona fide* behavior of multiple cellular second messengers in the single-cell, which is currently underway in our laboratory.

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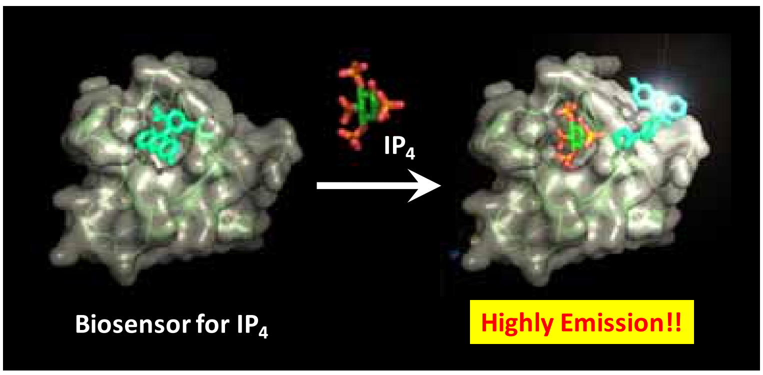

Figure 3. A schematic illustration shows the structure of biosensor for IP_4 based on GRP1 PH domain and biosensor-IP_4 complex. This biosensor exhibits a highly fluorescent emission in response to IP_4 binding.

Collaboration Works

ウェイン州立大学（米国)、「機能性 RNA 素子の開発」、森井孝、C.S. Chow

京都大学工学研究科、「細胞内シグナル伝達分子動態の解明」、森井孝、森泰生

福井大学医学部、「タンパク質による繊維凝集体形成」、森井孝、今野卓

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Bioenergy Research Section

K. Makino, Professor
T. Kodaki, Associate Professor

1. Introduction

Our research section seeks to develop environmentally clean and efficient reaction systems by means of chemically or biologically manipulated systems suitable for energy production. For the development of such a process by learning from biological systems, it is essential to understand complex network of biological signal transductions and mechanism of chemical transformations in the system. Following aspects have been investigated to establish the fundamental basis that would emerge a new technology for the energy-efficient utilization of ubiquitous environmental resources.

2. Efficient Bioethanol Production from Woody Biomass by Yeast Transformed with Protein Engineered Enzyme

Xylose is one of the major fermentable sugars present in lignocellulosic biomass, the second most abundant carbohydrate polymer in nature after glucose. The efficient fermentation of xylose is required to develop economically viable processes for producing biofuels such as ethanol from biomass. Although a few xylosefermenting yeasts are found in nature, *Saccharomyces cerevisiae* is used universally for industrial ethanol production because of its ability to produce high concentrations of ethanol and high inherent ethanol tolerance. However, native *S. cerevisiae* can not ferment xylose, so engineering *S. cerevisiae* for xylose utilization has focused on adapting the xylose metabolic pathway from the xylose-utilizing yeast *Pichia stipitis*. In this organism, xylose is converted to xylulose by two oxidoreductases: xylose is initially reduced to xylitol by NAD(P)H-linked xylose reductase (XR), and then xylitol is oxidized to xylulose by NAD^+-linked xylitol dehydrogenase (XDH). Although *S. cerevisiae* transformed with native XR and XDH genes from *P. stipitis* (referred to as PsXR and PsXDH, respectively), its ethanol production was not sufficient for application in the industrial bioprocess. One of the main reasons is the unfavourable excretion of xylitol, which may be due to intracellular redox imbalance caused by the different coenzyme specificity between XR and XDH. Therefore, modifying the coenzyme specificity of XR and/or XDH by protein engineering is one of the attractive challenges for achieving efficient ethanol fermentation from xylose using *S. cerevisiae*. We used the unique $NADP^+$(H)-dependent sorbitol dehydrogenase as a reference enzyme and achieved complete reversal of coenzyme specificity toward $NADP^+$. Furthermore, when the novel $NADP^+$-dependent XDH mutant was co-expressed with PsXR in *S. cerevisiae* cells, effective ethanol fermentation and a reduction in xylitol excretion were found, probably due to maintenance of the intracellular redox balance.

In this fiscal year, we focused on the effect(s) of mutated NADH-preferring PsXR in fermentation. The R276H and K270R/N272D mutants were improved 52- and 146-fold, respectively, in the ratio of NADH/NADPH in catalytic efficiency compared with the wild-type (WT), which was due to decrease of kcat with NADPH in the R276H mutant and increase of Km with NADPH in the K270R/N272D mutant. The most positive effect on xylose fermentation to ethanol was found by using the Y-R276H strain, expressing PsXR R276H mutant and PsXDH WT: 20% increase of ethanol production and 52% decrease of xylitol excretion, compared with the Y-WT strain expressing PsXR WT and PsXDH WT (Fig. 1). Measurement of intracellular coenzyme concentrations suggested that maintenance of the $NADPH/NADP^+$ and $NADH/NAD^+$ ratios is important for efficient ethanol fermentation from xylose by recombinant *S. cerevisiae.*

3. Biochemical and Biophysical Properties of Oxanine in DNA Strands

Oxanine (Oxa) has been considered as a unique lesion since we firstly reported in 1996 that Oxa is generated as one of the main deamination products from guanine (Gua) by nitric oxide (NO) or nitrous acid (HNO_2)-induced nitrosative oxidation. It was demonstrated that Oxa is formed together with xanthine (Xan) with the molar ratio of 1:3 when 2'-deoxyguanosine (dGuo) or DNA is treated with NO or in weakly acidic HNO_2.

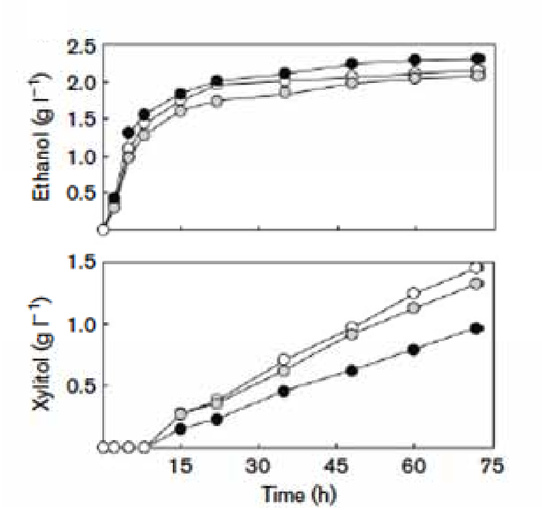

Fig. 1. Ethanol fermentation by recombinant *S. cerevisiae* in minimal medium supplemented with glucose (5 g l^{-1}) and xylose (15 g l^{-1}). (a) Ethanol (top) and xylitol (bottom) production profiles during batch fermentation in a shake flask by Y-WT (white), R276H (black) and K270R/N272D (grey).

Once Oxa is produced in DNA sequence, Oxa exists for a long time due to the stable N-glycosidc bond between the base and sugar moieties of its nucleoside, deoxyoxanosine (dOxo). It was found that Oxa is incorporated opposite cytosine (Cyt, C) and thymine (Thy, T) in the DNA polymerase chain elongation and also that Oxa in template DNA can induce mis-incorporation of Thy opposite Oxa during the DNA replication. Since Oxa produced in DNA sequence could induce severe genotoxic and cytotoxic damages, for instance GC to AT transversion mutagenesis, the biological repairing mechanism for Oxa has been expected. However, it was reported that the general base-excision repairing (BER) systems are not effective for repairing Oxa in DNA strands. Moreover, Oxa mediates DNA-protein cross-link (DPC) with some BER enzymes or DNA-binding proteins. It is more plausible that in the case of Oxa-repairing, the nucleotide excision and recombination repair (NER) system would play a more effective role by excising the Oxa-mediated DPC product.

In this fiscal year, to show the more-detailed biochemical and biophysical properties of Oxa in DNA strands, we investigated structural properties by circular dichroism (CD) spectroscopy, melting temperature (Tm) measurements and NMR spectroscopy, and enzymatic responses of polynucleotide kinase (PNK), alkaline phosphatase, ligase and restriction endonucleases. For analyzing the structural characteristics of Oxa in DNA strands, several DNA oligomers (11 mer) were synthesized; 5'-GTGAC O(orG) CACTG-3', and their complementary sequences 5'-CAGTG C(orT) GTCAC-3'. The CD analysis revealed no difference in whole solution structures of DNA duplexes irrespective of base-paring types such as O:C or O:T in DNA strands as well as G:C or G:T. In the case of Tm analysis, the order of DNA duplex stability was observed to be GC >> O:C ~ G:T > O:T in DNA strands. These DNA duplexes were also subjected to NMR analysis and their structures were assigned by 1H NMR and 13C NMR. The NMR data showed that the conformations of Oxa-containing DNA duplex are basically B-type. These structural analyses indicated that Oxa makes base-pairing and stacking in the DNA duplex and therefore does not cause any severe distortion in the whole DNA structure.

For analyzing enzymatic response of Oxa in DNA strands, several DNA oligomers were synthesized; 5'-O(orG) CCATTCCTGATTCTAAGTG-3' (20 mer) for PNK, alkaline phosphatase and ligase, and 5'-GAGTGCGGC O(orG)AATTC [or AO(orG)ATCT or AAO(orG)CTT] GCGGCTCAG-3' (24 mer) for EcoR I, Bgl II and Hind III, respectively. When Oxa-ODN was testified as substrates for PNK, alkaline phosphatase and DNA ligase, the enzymatic functions were not affected by Oxa in DNA strands largely. It was also determined that restriction endonucleases (EcoRI, BglII, HindIII) recognize and cleave the specific base-sequence even when Gua was substituted by Oxa in the sequence. These enzymatic results imply a high possibility that Oxa could be considered as Gua in DNA strands, especially, in terms of molecular and biological recognition.

Here, we prepared several chemically-synthesized Oxa-ODNs and performed biophysical and biochemical analyses for revealing structural properties and enzymatic responses of Oxa in DNA strands. These analyses indicated that Oxa makes base-pairing and stacking in the DNA duplex and therefore does not cause any severe distortion in the whole DNA structure. Oxa in DNA strands was also found to be recognized as Gua by DNA-relevant enzymes, even by specific-sequence reognizing enzymes, indicative of inducing severe genotoxic and cytotoxic problems. These results will be helpful for elucidating more-detailed biological mechanism of Oxa, especially, specific repairing system and DPC phenomena.

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渡邉誠也、若手研究(B)、「酵母を用いたＬーアラビノースからエタノールへの高効率変換系の確立」

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Laboratory for Complex Energy Processes Section

M. Kinoshita, Professor
H. Okada, Associate Professor

1. Introduction

A. Theoretical Biophysics

A variety of self-assembling and ordering processes in biological systems, which occur at molecular levels, are sustaining life. Examples of such processes are protein folding, protein traffic, molecular recognition, aggregation of protein molecules forming ordered and often symmetrical quarterly structure, and lipid-membrane formation. 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 biotechnology and nanotechnology. The current subjects are investigations on the hydrophobic effect, molecular mechanisms of folding and unfolding of proteins, molecular recognition, prediction of the native structure of a protein, and mechanism of amyloid-fibril formation.

B. Plasma Physics

The major subjects concerned with plasma physics in this section 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 confinement and the damage for the vessel or the first wall materials.

Fast-ion velocity distribution is investigated using ICRF minority heating in Heliotron J with special emphasis on the effect of the toroidal ripple of magnetic field strength (‘bumpiness’). Observed fast-ions depend on the bumpiness and the largest energy flux was measured in the high bumpy configuration at the specific pitch angle. In the medium and low bumpy configurations, such fast-ions were not observed.

(A-1) Pressure effect on structures formed by entropically driven self-assembly

Our picture is that protein folding and ordered association of proteins are driven by the solvent entropy: At low pressures, the structures almost minimizing the excluded volume (EV) generated for solvent particles are stabilized. Such structures appear to be even more stabilized at high pressures. However, it is experimentally known that the native structure of a protein is unfolded and the ordered aggregates are dissolved by applying high pressures. This initially puzzling result can also be elucidated in terms of the solvent entropy: We have developed a general theoretical framework of pressure effects on the structures formed by the self-assembly of solute molecules immersed in solvent [1,2].

The basic physics is in the phenomenon that when a large hard-sphere solute is immersed in small hard spheres forming the solvent, the small hard spheres are enriched near the solute and this enrichment becomes greater as the pressure increases. “Attractive interaction” is entropically induced between the solute surface and solvent particles, and many solvent particles are driven to contact the solute surface. The attractive interaction becomes higher with rising pressure. The formation of the enriched layer itself causes an entropic loss because the translational movement of solvent particles within the layer, in particular, that of those in contact with the solute surface, is somewhat restricted: An entropic loss occurs at the solute-solvent pair correlation level. However, the solvent crowding (i.e., the restriction of the translational movement of a solvent molecule by the other solvent molecules) well outside the layer is largely reduced: An entropic gain occurs at the solute-solvent-solvent triplet and higher-order correlation levels. The attractive interaction induced between the solute surface and solvent particles originates from the triplet and higher-order correlations. The key quantity is the net solvent-entropy gain arising from the loss at the pair correlation level and the gain at the triplet and higher-order correlation levels. The density profile of solvent particles around the solute is determined so that the key quantity can be maximized.

The above results are applicable to a complex solute whose structure is changeable using the morphometric approach combined with the integral equation theory. The structure stabilized, which maximizes the key quantity, is dependent on the pressure. Though at low pressures a structure almost minimizing its EV is stabilized, at high pressures a structure with the largest possible ASA together with the EV kept sufficiently small is more favored.

(A-2) Microscopic mechanism of cold denaturation of a protein

The temperature dependence of the hydrophobicity of nonpolar groups provides an important clue to the microscopic mechanism. We have analyzed the terms in ΔS_V and ΔU_V which are determined by the EV and by the ASA and the surface curvature (SC), respectively. At low temperatures, the ordered structure with enhanced hydrogen bonds of water molecules is formed near nonpolar groups. The enhancement becomes more important for unfolded structures with larger ASA. At low temperatures, the unfolded structures are relatively more destabilized in respect of the ASA- and SC-dependent term of ΔS_V but more stabilized in respect of the ASA- and SC-dependent term of ΔU_V. Interestingly, the destabilization and the stabilization, which are both quite large, are almost cancelled out: The formation of the ordered structure itself cannot be the driving force in cold denaturation.

At low temperatures, both the native structure and unfolded structures are less hydrophobic in the sense that $\mu/(k_B T)$ (μ is the hydration free energy) is significantly reduced. However, the reduction is greater for a structure with larger EV, and the EV-dependent term in ΔS_V plays an essential role. The EV-dependent term can further be decomposed into the protein-water pair correlation component in the Asakura-Oosawa and the protein-water-water triplet and higher-order correlation component. We have found that the latter component is responsible for the reduction: The translational-entropy effect arising from the water in the system, by which the native structure is stabilized relative to the unfolded structures, is considerably less powerful when the temperature is lowered, leading to cold denaturation [3].

(B-1). Dependence of the Fast-Ion Temperature on the Bumpy Field Component

The effect of the magnetic configuration on the fast-ion confinement is one of the most important issues in helical devices. Fast-ion confinement is studied using ion cyclotron range of frequencies (ICRF) heating in the minority heating scheme in Heliotron J [4,5,6], a low-shear helical-axis heliotron (R_0=1.2 m, a=0.1-0.2 m, $B_0 \leq 1.5$ T). The effect of the bumpiness, which is the toroidal field ripple, on fast-ion confinement and heating efficiency are discussed in the previous papers [7,8,9]. The good confinement of fast ions and the high efficiency of ICRF heating in the high bumpy case are reported. Here, the pitch angle dependence of energy spectra for three bumpy cases as velocity distribution is measured for the first time, then, the fast ions up to 34 keV are observed during ICRF heating in Heliotron J. The configurations used in this study are as follows; the bumpiness (B_{04}/B_{00}, where B_{04} is the bumpy component and B_{00} is the averaged magnetic field strength) are 0.15 (high) and 0.06 (medium, the standard configuration) at ρ=0.67. Here, ρ is the normalized minor radius.

Two ICRF loop antennas are installed on the low-field side of Helitoron J. Each antenna is fed by an independent transmitter. This section corresponds to the corner section of a Heliotron J plasma, where the mod-B surface has a tokamak-like structure. The ICRF wave is radiated from the antenna to target plasmas generated by a 70-GHz ECH. The power of ECH is from 300 to 350 kW. For keeping the ECH resonance position constant, the magnetic field strength adjusted to be constant in the ECH injection position. Therefore, the magnetic strength in the poloidal cross section of the ICRF antenna is changed for each bumpy configuration. The frequency is adjusted so that the resonance layer is positioned near the magnetic axis: 23.2 MHz for the high bumpiness and 19 MHz for the medium and low bumpy cases. An ICRF pulse is injected into an ECH target plasma where $T_i(0)$=0.2 keV, $T_e(0)$=0.8 keV and $\bar{n}_e$ =0.4x10^{19} m^{-3}. ICRF injection power is in the range from 250 kW to 300 kW. The minority heating mode is selected to generate fast ions with deuterium as the majority species and hydrogen as the minority.

In high bumpy case, the ion flux is observed up to 34 keV at the pitch angle of 120 deg. Such high energy particles cannot be observed in the medium and low bumpy configurations. The angle where the highest tail is observed is about 30 deg from the perpendicular direction to the magnetic field. Toward 90 deg, the tail component decreases. The tail decreases from the angle of 120 deg as the pitch angle increases as well, since there is no acceleration mechanism in the parallel direction to the magnetic field. In the medium and low bumpy cases, there is no fast ion observed over 15 keV. The dependence of the energy spectrum on the pitch angle is also different from that in the high bumpy case. In the range from 108 deg to 121 deg, the slope of energy spectrum is almost constant and the high energy fluxes are observed compared with the cases of 125 deg and 127 deg. Then, the slope becomes steeper in the angles of 125 deg and 127 deg. In the low bumpy case, the energy spectra at the pitch angles of 108 and 113 are almost same. Then, the slope becomes steeper continuously with the pitch angle. The dependences of the velocity distributions on pitch angle have different characteristic for three bumpy cases. Among them, the high bumpy case is recognized as the most preferable configuration for the fast ion formation and confinement in ICRF minority scheme.

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4-3. NEW RESEARCH FACILITIES

Quantum Radiation Energy Research Section

Free-electron Laser facility – KU-FEL

A tunable and coherent light source in the MIR (mid-infrared) range is useful tool for a research on molecular dynamics, designing a functional material, which are key techniques for "sustainable energy science".

We have developed an FEL (Free-Electron Laser) facility "KU-FEL" (Kyoto University FEL) as a key facility for the R&D of the future energy systems. The FEL system has been constructed in the Laboratory for Photon and Charged Particle Research, Institute of Advanced Energy, Kyoto University. The FEL system consists of an S-band 4.5 cell thermionic RF gun driven by a 10 MW klystron, a 3 m travelling wave accelerator structure driven by a 20 MW klystron, beam transport system, a Halbach type undulator of 1.6 m, and an optical resonator. Fig. 1 shows a schematic drawing of the system. The FEL wavelength of from 4 to 13 μm is expected with electron-beam energy of from 20 to 40 MeV.

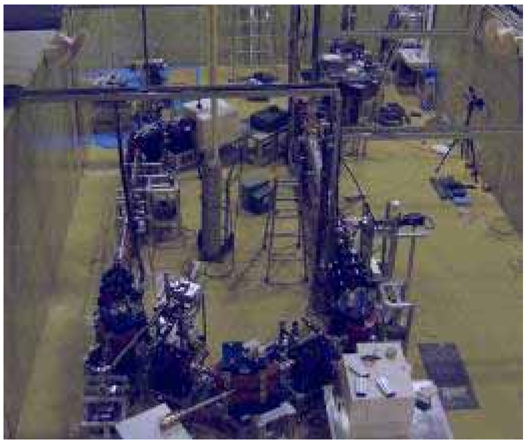
Power saturation of the FEL at wavelength of 13.2 μm was achieved in May 2008. Typical optical properties are shown in table 1. An optical beam transport system was also developed. The transport system consists of a beam expander which converts conical FEL beam to parallel beam and nitrogen displaceable beam ducts which avoid optical absorption by water vapor.

User experiments which use wavelength tunable and high-power MIR FEL will be started in 2009.

Table 1 Optical parameter of the KU-FEL

Wavelength λ	13.2 μm
Bandwidth σ_λ/λ	0.8 %
Average power	4.6 mJ
Peak power *	2.9 MW

*Pulse duration of 650 fs is assumed.



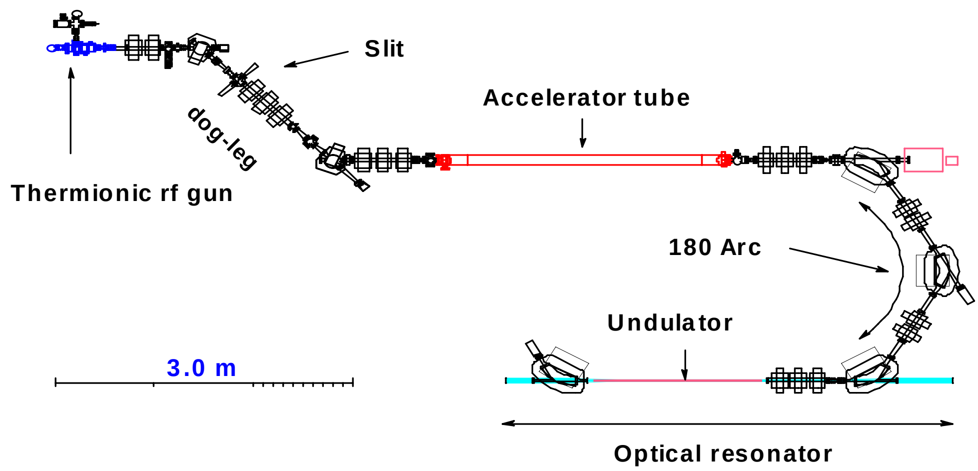


Figure 1: Layout of KU-FEL system

F-7000 Fluorescence Spectrophotometer, Hitachi High-Technologies

Figure 1. F-7000 Fluorescence Spectrophotometer

Compact system capable of performing many new functions such as sensitivity (S/N 800: RMS) and ultra high-speed (60,000 nm/min) at the highest level of its class. The application of fluorophotometry has been expanded to various fields such as industrial materials, in areas such as organic electroluminescence and liquid crystals; environment-related areas, such as water quality analysis; pharmaceutical manufacturing, such as the synthesis and development of a fluorescence reagent; and to biotechnology-related areas, such as intracellular calcium concentration measurement.

REX-250 Mercury Light Source, Asahi Spectra

Figure 2. REX-250 Mercury Light Source

REX-250, 250W mercury light source, is the perfect illuminator with complete heat blocking design, using an originally designed mirror module (UV or VIS). The REX-250 gets more compact and improves its portability, still remaining all useful functions such as a mirror module, filter wheel, ND variable control, timed shutter, and remote control.

IX-81 Mortorized Inverted System Microscope, Olympus

As new fluorochromes are developed and new methods of light excitation and manipulation become more popular for live cell experiments, more and more researchers will require the use of low phototoxicity near-IR wavelengths in addition to the conventional visible spectrum. Olympus has equipped its IX2 series microscopes with the new UIS2 optical system precisely to meet those demands. With its high S/N ratio, its compensation for chromatic aberration over a much wider wavelength range and its flat, high transmittance , this new system sets a new world standard of fluorescence performance — efficiently detecting even faint fluorescence signals without damaging the cell, and optimizing multi-color observation. Delivering unprecedented image quality over a super wide light spectrum, the IX2 inverted system microscope will be your live cell instrument of choice now and in the future.

C9100-13 ImagEM (EM-CCD Camera), Hamamatsu Photonics

The ImagEM camera is a newly developed back-thinned electron multiplier CCD camera. This new generation camera incorporates the latest Hamamatsu engineering and technology to provide a high speed readout rate of 32 frames per second at full spatial resolution and 16 bit digitization. Features include maximum QE over 90 % and cooling performance down to −90ºC to minimize noises. The ImagEM includes two selectable readout modes for applications such as real time imaging of low light fluorescence and ultra low light luminescence detection.

Figure 3. IX-81 Mortorized Inverted System Microscope equipped with ImagEM (EM-CCD Camera)

4-4. STUDENT AWARDS

Oral presentation award
The 88th Spring Meeting of The Chemical Society of Japan

(Biofunctional Chemistry, Biotechnology Section)

Biofunctional Science Research Section
Hironori Hayashi (D2)

The Spring Meeting of the Chemical Society of Japan is held every year at the end of March, which is the end of the academic/fiscal year in Japan. This meeting attracts more than 8,000 participants each year, and is among the largest scientific meetings in Japan. In the 88^{th} Spring Meeting, I presented a part of my doctoral work on the development of a rational approach for designing fluorescent ribonucleopeptide (RNP) sensors.

Fluorescent biosensors are crucial tools to facilitate sensitive detection of small molecules. However, construction of fluorescent biosensors with desired characteristics, that is, detection wavelengths and concentration ranges for ligand detection, from macromolecular receptors is not a straightforward task. Previously, we reported a modular strategy for constructing fluorescent ATP sensors from ribonucleopeptide (RNP) complexes. These RNP sensors had a variety of emission wavelengths and/or responding ligand concentration ranges. However, simultaneous optimization for their fluorescence responses and affinity to target molecule is still a difficult task. Here we report a design strategy to optimize the response of fluorescent RNP sensors based on the secondary structural analyses of ATP-binding RNPs.

To determine the relationship between the secondary structure and fluorescent characteristics of RNP sensors, we analyzed the secondary structure of RNA subunits of ATP-binding RNP sensors. Consequently, we have discovered that the ATP-binding RNP sensors with large fluorescent response tend to contain interior loop between the RRE resion and ATP-binding domain, and to display low fluorescence intensity in the absence of ATP. Indeed, fluorescence response of the other RNP sensor lacking interior loop was enhanced by the insertion of interior loop. This result suggests that use of the secondary structural elements would allow a rational functional design of RNP.

Award for Encouragement of Research in Materials Science The Materials Research Society of Japan

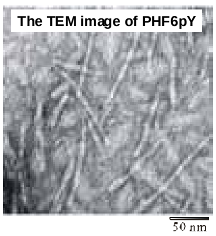
Biofunctional Science Research Section
Masafumi Inoue (D3)

The Material Research Society was founded in 1989 for the purpose of promoting academic, engineering research and application of advanced materials via interdisciplinary exchanges among materials scientists and engineers. The IUMRS International Conference in Asia 2008 (IUMRS-ICA2008) was held on December 9 to 13 at Nagoya, organized by Materials Research Society of Japan (MRS-J), and supported by the MRS regional societies in Asia. The IUMRS-ICA, which will be held every year from this conference, features new materials research from not only Asia but also around the world.

In the IUMRS-ICA2008, I presented a part of my doctoral study on the phosphorylation effect for the amyloid fibrillization of human tau protein derived peptide. Phosphorylation of a fibrillogenic protein, human tau, is believed to play crucial roles in the pathogenesis of Alzheimer's disease. To elucidate a molecular mechanism of the tau fibrillation that was controlled by the phosphorylation, we have synthesized a peptide, VQIVY310K (PHF6) and its phosphorylated derivative (PHF6pY). PHF6 is derived from a partial amino acid sequence surrounding a plausible *in vivo* phosphorylation site Tyr310 and forms amyloid-type fibrils similar to those generated by full-length tau.

Fibrillation of PHF6 and PHF6pY were studied by spectroscopic and microscopic methods, and the critical concentration of the fibrillation was determined to evaluate the fibril stability. The results showed that the phosphorylation of the Tyr residue strongly affected the fibrillation propensity of PHF6 by changing its dependency on pH and ionic strength. On the basis of the observations, we suggested that charged sites on the phosphate group and its electrostatic pairing with the neighboring charged residues were physical origins of the phosphorylation effect (Fig. 1).

These nanofibrils will be applicable for functional materials because functional groups can be introduced on the surface of fibril by using the phosphate-binding tag.



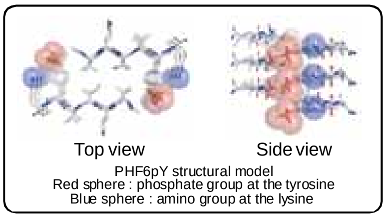


Fig. 1. Nanofibrils of PHF6pY peptide
Left : TEM image, Right : Structutal model

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. 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 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.

Research activities have been directed mainly toward the following cooperative projects as the principle research subject of the institute.

A1 Interdisciplinary Field of Plasma Energy

The scientific and technological researches on advanced plasma energy system aim at the development of a frontier field "complex plasma energy systems research" based on plasma, hydrogen and material sciences. This field includes the basic research on advanced plasma energy related to the plasma confinement improvement, the effective transport of heat and particle fluxes, the system construction for hydrogen fuel cycle, the basic study on POP of advanced divertor, the control of plasma surface interaction and the development of materials under extremely severe environment, application of plasma energy based on plasma basic research, and advanced fission energy research.

A2 Interdisciplinary Field of Bioenergy

Researches in this field include development of highly efficient material/energy-transformation systems on the basis of bio-nano-technologies and biomimetic approaches and elucidation, improvement, and utilization of the biological processes. The environmental aspects associated with the energy utilization are also studied in this field.

A3 Interdisciplinary Field of Photon and Quantum Energy

This specially-promoted field includes researches for extending advanced functions peculiar to photon, quantum and related materials, studies of fundamentals and /or technology for generating new functions of the energy, and interdisciplinary studies using the energy functions aiming at the creation of a new field of science and technology.

B. Cooperative use of facilities and equipments

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

2. The cooperative research project consists of (a) a specific program for "Promotion of a priority project" and (b) a standard program.

(a) A specific program was not planned in this year.

(b) Summary of the standard cooperative research subjects carried out in the year of 2008.

A public collection of cooperative research application was carried out, in this year, for a program which consits of 3 group 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 56 were applied and applications of 53 were accepted after the approval by a steering committee of the laboratory. The number of research subjects are 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 53

		category A			B	total
		A1	A2	A3		
Kibann	inside	1	1	1	0	3
*1	outside	0	0	0	0	0
Syorei	inside	8	6	6	0	20
*2	outside	17	4	4	3	28
Kikaku	inside	2	0	0	0	2
-chosa *3	outside	0	0	0	0	0

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

The individual research subjects are as follows, *1, *2 and *3 mean the "Kiban", "Syorei" and "Kikaku-chosa' cooperative research theme, respectively,

The individual Research subjects are as follows.

A1

"On Beam –Beam Colliding Fusion Reactions in Inertial Electrostatic Confinement in Low-Pressure High-Current Regime"

(1) K.Masuda, K.Nagasaki, Y.Yamamoto
(2) M.Ohnishi, H.Osawa, N.Miyashita, K.Kitagawa
(3) E.Hotta, K.Tomiyasu, K.Yokoyama,
(4) T.Nakagawa, T.Kajiwara
(5) K.Noborio
(1) Institute of Advanced Energy, Kyoto University
(2) Faculty of Engineering Science, Kansai University
(3) Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology
(4) Graduate School of Energy Science, Kyoto University
(5) Institute of Sustainability Science, Kyoto University

"Experimental Studies of the Cylindrical Discharge Type Fusion Neutron Source –Study of Long Line Source2- "

(1) Y.Yamamoto, Y.Takeuchi, S.Konishi
(2) K.Noborio
(3) A.Ishidou, T.Kanagae
(1) Institute of Advanced Energy, Kyoto University
(2) Institute of Sustainability Science, Kyoto University
(3) Graduate School of Energy Science, Kyoto University

"Electron Cyclotron Current Drive in Toroidal Devices"

(1) K.Nagasaki, K.Masuda, T.Mizuuchi, S.Kobayashi, K.Sakamoto, K.Hanatani, H.Okada, S.Yamamoto
(2) K.Kondo, Y.Nakamura
(3) Y.Yoshimura, G.Motojima
(4) N.Marushchenko
(5) A.Fernandez, A.Cappa
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) National Institute for Fusion Science
(4) Max Planck Institute, Germany
(5) CIEMAT, Spain

"Study of SMBI Effects on HeliotronJ Plasma"

(1) T.Mizuuchi
(2) CHEN Wei
(1) Institute of Advanced Energy, Kyoto University
(2) South Western Institute of Physics

"Effect of Bumpy Magnetic Field on Global Energy Confinement in NBI Plasmas of HeliotronJ"

(1) S.Kobayashi, T.Mizuuchi, K.Nagasaki, F.Sano, H.Okada, S.Yamamoto, K.Hanatani, S.Konoshima, T.Minami, K.Toushi
(2) S.Murakami
(3) Y.Nakamura, K.Kondo, S.Watanabe, K.Mukai, K.Hosaka, Y.Kowada, S.Mihara
(4) Y.Suzuki, K.Nagaoka, Y.Takeiri, M.Yokoyama
(5) Y.Nakashima
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Engineering, Kyoto University
(3) Graduate School of Energy Science, Kyoto University
(4) National Institute for Fusion Science
(5) Plasma Research Center, University of Tsukuba

"Research of Radiation Damages on Yttrium Oxides"

(1) H.Kishimoto
(2) A.Kohyama, T.Hinoki, K.Shimoda
(3) T.Koyanagi
(1) Department of Materials Science and Engineering, Muroran Institute of Technology

(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Energy Science, Kyoto University

"Subcooled Boiling Heat Transfer for Turbulent Flow of Water in a Short Vertical Tube at High Liquid Reynolds Number"
(1) K.Hata
(2) K.Fukuda
(3) S.Masuzaki
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Maritime Sciences, Kobe University
(3) National Institute for Fusion Science

"Theory & Modeling Study of Fusion Plasma-Material Interaction"
(1) K.Morishita, A.Kohyama, K.Hanatani
(2) Y.Watanabe
(3) H.Iwakiri
(4) D.Kato
(5) Y.Kaneta
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) Faculty of Education, University of the Ryukyus
(4) National Institute for Fusion Science
(5) School of Engineering, The University of Tokyo

"Confinement Improvement Studies of Advanced Helical Systems"
(1) F.Sano, T.Mizuuchi, K.Nagasaki, K.Hanatani, H.Okada, S.Kobayashi, S.Yamamoto, T.Minami
(2) K.Kondo, Y.Kishimoto, Y.Nakamura, S.Watanabe, K.Mukai, A.Matsuyama
(3) T.Mutoh, S.Okamura, K.Ida, K.Toi, Y.Takeiri, H.Iguchi, A.Fujisawa, S.Nishimura, Y.Yoshimura, M.Isobe, C.Suzuki, K.Nagaoka, M.Yokoyama, O.Yamagishi, T.Akiyama, Y.Suzuki
(4) S.Murakami
(5) N.Nishino
(6) T.Fukuda
(7) Y.Nakashima
(8) A.Isayama, N.Oyama
(1) Institute of Advanced Energy, Kyoto University
(2) Graduate School of Energy Science, Kyoto University
(3) National Institute for Fusion Science
(4) Graduate School of Engineering, Kyoto University
(5) Graduate School of Engineering, Hiroshima Universuty
(6) Graduate School of Engineering, Osaka University
(7) Plasma Research Center, University of Tsukuba
(8) Japan Atomic Energy Agency

"Study of Fast Ion Velocity Distribution Using ICRF Heating in HeliotronJ Plasmas"
(1) H.Okada, S.Kobayashi, S.Yamamoto, T.Mizuuchi, K.Nagasaki, F.Sano, K.Hanatani
(2) K.Kondo, 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) Plasma Research Center, University of Tsukuba
(5) Graduate School of Engineering, Hiroshima University

"Simultaneous Measurements by Two ECE Detector Sets in Heliotron-J"
(1) Y.Yoshimura, S.Okamura, S.Kubo, T.Shimozuma, H.Igami, H.Takahashi
(2) K.Nagasaki, F.Sano, T.Mizuuchi, H.Okada, S.Kobayashi
(3) K.Mukai
(1) National Institute for Fusion Science
(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Energy Science, Kyoto University

"Study of Spectrum Line Profiles in HeliotronJ"
(1) K.Kondo, Y.Kowada, Y.Nakamura
(2) F.Sano, T.Mizuuchi, K.Nagasaki, H.Okada, K.Hanatani, S.Kobayashi, S.Yamamoto, S.Konoshima
(1) Graduate School of Energy Science, Kyoto University
(2) Institute of Advanced Energy, Kyoto University

"Production of Over-Dense Plasma Using Long-Wavelength Microwaves in HeliotronJ"
(1) K.Toi, R.Ikeda
(2) S.Yamamoto, K.Nagasaki, T.Mizuuchi
(1) National Institute for Fusion Science
(2) Institute of Advanced Energy, Kyoto University

"High-Precision Monte-Carlo Simulation for Neutral Particle Transport Analysis in Non-Axisymmetric System"
(1) Y.Nakashima
(2) Y.Higashizono
(3) S.Kobayashi, T.Mizuuchi, F.Sano, K.Nagasaki, H.Okada, S.Yamamoto, K.Hanatani
(4) K.Kondo, Y.Nakamura, K.Hosaka
(1) Plasma Research Center, University of Tsukuba
(2) Japan Society for the Promotion of Science
(3) Institute of Advanced Energy, Kyoto University
(4) Graduate School of Energy Science, Kyoto University

“Development of Ion Flow Measurement System”

(1) N.Nishino
(2) T.Izuka, T.Hirooka, T.Mio, T.Takeuchi, A.Tashiro
(3) K.Kondo
(4) F.Sano, T.Mizuuchi, H.Okada, K.Nagasaki, S.Kobayashi
(1) Graduate School of Engineering , Hiroshima University
(2) Faculty of Engineering, Hiroshima University
(3) Graduate School of Energy Science, Kyoto University
(4) Institute of Advanced Energy, Kyoto University

“Effects of Surface Structure Characteristics of Wetted Materials Against Liquid Pb-17Li on Ultrasonic Transmission at the Interface”

(1) T.Kunugi, Y.Ueki
(2) T.Hinoki, K.Shimoda
(3) T.Yokomine
(4) M.Hirabayashi, A.Arakuni
(1) Graduate School of Engineering, Kyoto University
(2) Institute of Advanced Energy, Kyoto University
(3) Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
(4) Japan Atomic Energy Agency

“Evaluation of SiC and W Coated SiC as Plasma Facing Materials”

(1) Y.Ueda, Y.Tsuji, Y.Ohtsuka
(2) T.Hinoki, A.Kohyama
(1) Graduate School of Engineering, Osaka University
(2) Institute of Advanced Energy, Kyoto University

“High-Fluence Irradiation Behavior of Reduced Activation Fusion Reactor Materials”

(1) H.Tanigawa, M.Ando
(2) A.Kohyama, T.Hinoki, R.Kasada
(1) Japan Atomic Energy Agency
(2) Institute of Advanced Energy, Kyoto University

“He Ion irradiation Effects on Mechanical Properties of SiC and W Joining Interface”

(1) T.Shibayama, S.Watanabe
(2) T.Hinoki, A.Kohyama
(3) H.Kishimoto
(1) Center for Advanced Research of Energy Conversion Materials, Hokkaido University
(2) Institute of Advanced Energy, Kyoto University
(3) Department of Materials Science and Engineering, Muroran Institute of Technology

“Relations Between Compositions of Constituent Materials for SiC/SiC Composite and Their Electrical and Thermal Conductivities”

(1) T.Tanaka, T.Muroga
(2) A.Kohyama, T.Hinoki
(3) T.Ikeda
(1) National Institute for Fusion Science
(2) Institute of Advanced Energy, Kyoto University
(3) The Institute of Scientific and Industrial Research, Osaka University

“Evaluation on Shear Strength for Joints of Fusion Blankets Using a Miniature Specimen”

(1) T.Nozawa, H.Tanigawa
(2) A.Kohyama
(3) Hun Chae JUNG
(4) H.Ogiwara,
(1) Japan Atomic Energy Agency
(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Energy Science, Kyoto University
(4) Graduate School of Engineering, Osaka University

“Interaction of Helium and Defects in Metals”

(1) Qiu Xu,T.Yoshiie
(2) K.Morishita
(1) Kyoto University Research Reactor Institute
(2) Institute of Advanced Energy, Kyoto University

“Investigation of Irradiation Effects on Solid Materials with Complicated Crystal Structure”

(1) H.Iwakiri
(2) K.Morishita
(3) N.Yoshida
(1) Faculty of Education, University of the Ryukyus
(2) Institute of Advanced Energy, Kyoto University
(3) Research Institute for Applied Mechanics, Kyushu University

“Effects of Additive Element on Dynamical Behavior of Helium in Ferritic Steels”

(1) M.Miyamoto, K.Ono
(2) K.Morishita
(1) Interdisciplinary Faculty of Science and Engineering, Shimane University
(2) Institute of Advanced Energy, Kyoto University

“Theoretical Simulations for irradiated Materials Based on First Principles Method”

(1) Y.Kaneta, Chen Ying
(2) A.Kohyama, K.Moroshita
(3) Y.Watanabe
(1) School of Engineering, The University of Tokyo
(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Energy Science, Kyoto University

“First Principle and Thermodynamics Study on Point Defects in Fusion Reactor Materials”

(1) D.Kato
(2) K.Morishita

(1) *National Institute for Fusion Science*
(2) *Institute of Advanced Energy, Kyoto University*

"Confinement Improvement in Helical Systems"
(1) T.Mizuuchi
(2) S.Kitajima
(3) M.Yokoyama, R.Sakamoto
(4) Y.Kishimoto
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Faculty of Engineering, Tohoku University*
(3) *National Institute for Fusion Science*
(4) *Graduate School of Energy Science, Kyoto University*

"Workshop on the Multiscale Modeling of Radiation Damage Processes in Fusion Materials"
(1) K.Morishita, A.Kohyama, A.Kimura
(2) N.Sakaguchi
(3) Y.Kaneta, Chen Ying
(4) D.Kato, T.Muroga
(5) Y.Watanabe, J.Yoshimatsu
(6) Qiu Xu, T.Yoshiie
(7) M.Miyamoto
(8) N.Yoshida
(9) H.Iwakiri
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Center for Advanced Research of Energy Conversion Materials, Hokkaido University*
(3) *Graduate School of Engineering, The University of Tokyo*
(4) *National Institute for Fusion Science*
(5) *Graduate School of Energy Science, Kyoto University*
(6) *Kyoto University Research Reactor Institute*
(7) *Interdisciplinary Faculty of Science and Engineering, Shimane University*
(8) *Research Institute for Applied Mechanics, Kyushu University*
(9) *Faculty of Education, University of the Ryukyus*

A2
"Development of the Artifical Reductase Driven by Solar Energy"
(1) K.Tainaka, T.Morii
(2) N.Fujieda, M.Hukuda
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Kyoto University Pioneering Research Unit for Next Generation*

"Immobilization of Enzymes into Porous Silicon with Highly Controlled Pore Sizes"
(1) K.Fukami, T.Sakka, Y.H.Ogata
(2) T.Yamauchi
(3) Y.Suzuki
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Graduate School of Science and Technology, Niigata University*
(3) *Uyemura & Co.,Ltd.*

"Conductive Polymer Nanofibers for Organic Photovoltaics"
(1) S.Yoshikawa, T.Sagawa
(2) Surawut CHUANGCHOTE
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Graduate School of Energy Science, Kyoto University*

"Highly Efficient Production of Hydrogen by Using Photobioreactor with TiO_2 Photocatalyst and Hydrogenase"
(1) T.Sagawa, S.Yoshikawa
(2) Y.Sako
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Graduate School of Agriculture, Kyoto University*

"Construction of Functional RNA-Protein Complexes"
(1) T.Morii,K.Tainaka
(2) M.Fukuda, N.Fujieda
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Kyoto University Pioneering Research Unit for Next Generation*

"Development of Energy- and Material- Recycling Systems by the Biological Functions"
(1) K.Makino, S.Watanabe, Pack Seung Pil, T.Kodaki
(2) K.Tajima
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Kyoto Institute of Technology*

"Development of a Highly Efficient Bioethanol Production Yeast"
(1) T.Kodaki, K.Makino, S.Watanabe, Pack Seung Pil
(2) R.Ogawa
(1) *Institute of Advanced Energy, Kyoto University*
(2) *School of Medicine, Toyama Medical and Pharmaceutical University*

"Energies of (111) Twist Boundaries in Si"
(1) A.Otsuki
(2) K.N.Ishihara
(1) *Institute of Advanced Energy, Kyoto University*
(2) *Graduate School of Energy Science, Kyoto University*

"Photocurrent Generation Devices Using Nucleic Acid Derivatives"
(1) K.Yamana
(2) T.Morii
(1) *Graduate School of Engineering, University of Hyogo*
(2) *Institute of Advanced Energy, Kyoto University*

"Development of Methods for Dynamic Analysis of Nano-Scale Aggregation Processes of Disease-Related Peptides"

(1) S.Konno

(2) T.Morii

(1) Faculty of Medical Sciences, University of Fukui

(2) Institute of Advanced Energy, Kyoto University

"Structure-Based Design of Maniature Methane Monooxygenase Hydroxylase"

(1) N.Fujieda, M.Fukuda

(2) T.Morii, K.Tainaka

(1) Kyoto University Pioneering Research Unit for Next Generation

(2) Institute of Advanced Energy, Kyoto University

A3

"Studies on Stable Lasing in KU-FEL"

(1) H.Ohgaki, K.Masuda, T.Kii

(2) Heishun ZEN, K.Higashimura, R.Kinjo

(1) Institute of Advanced Energy, Kyoto University

(2) Graduate School of Energy Science, Kyoto University

"Study on the Electron Beam Energy Compensation in KU-FEL"

(1) H.Ohgaki, K.Masuda, T.Kii

(2) Heishun Zen, K.Higashimura, R.Kinjo

(1) Institute of Advanced Energy, Kyoto University

(2) Graduate School of Energy Science, Kyoto University

"Effect of Irradiation of Bulk Superconducting Magnet"

(1) T.Kii, H.Ohgaki, K.Masuda

(2) Heishun Zen, K.Higashimura, R.Kinjo

(1) Institute of Advanced Energy, Kyoto University

(2) Graduate School of Energy Science, Kyoto University

"Performance Improvement of KU-FEL RF Gun by Use of RF Triode Structure(Ⅲ)"

(1) K.Masuda, H.Ohgaki, T.Kii

(2) Heishun Zen, K.Higashimura, R.Kinjo

(1) Institute of Advanced Energy, Kyoto University

(2) Graduate School of Energy Science, Kyoto University

"High-Order Harmonic Generation by the Train of Mid-Infrared Laser Pulses"

(1) T.Nakajima, H.Ohgaki, T.Sakka, Chengpu Liu

(1) Institute of Advanced Energy, Kyoto University

"Investigation of Ultrafast Surface Excitation Process with Cycle Pulses"

(1) G.Miyaji, K.Miyazaki

(2) N.Yasumaru

(3) Alexander E.KAPLAN

(1) Institute of Advanced Energy, Kyoto University

(2) Fukui National College of Technology

(3) Johns Hopkins University

"New Method for the Analysis of the Emission Spectra from the Species Ablated by Liquid-Phase Laser Ablation"

(1) T.Sakka, T.Nakajima, K.Fukami, Y.H.Ogata

(2) T.Sasaki

(3) Y.Suzuki

(4) H.Yamagata

(1) Institute of Advanced Energy, Kyoto University

(2) National Institute of Advanced Industrial Science and Technology

(3) Uyemura & Co.,Ltd.

(4) Graduate School of Energy Science, Kyoto University

"**On the Frontier Study of Atomic Interaction Processes Involving Relativistic Electrons"**

(1) A.Itoh, H.Tsuchida, M.Imai

(2) H.Ohgaki, T.Kii, K.Masuda

(1) Graduate School of Engineering, Kyoto University

(2) Institute of Advanced Energy, Kyoto University

"Study on Generation of Bremsstrahlung Radiation from Electron Linac at Kyoto Univ."

(1) T.Shizuma

(2) H.Ohgaki, K.Masuda, T.Kii

(3) Heishun Zen, K.Higashimura, R.Kinjo

(1) Japan Atomic Energy Agency

(2) Institute of Advanced Energy, Kyoto University

(3) Graduate School of Energy Science, Kyoto University

"Preparation of Colloidal Solutions of High-Purity Monodispersed Noble Metal Nanoparticle Using Laser Ablation in Liquid Media"

(1) T.Sasaki

(2) T.sakka

(1) *National Institute of Advanced Industrial Science and Technology*

(2) *Institute of Advanced Energy, Kyoto University*

"C-N Bond Cleavage of Non-Activated Aliphatic Amines by Means of Mid-IR Pulse Laser Irradiation"

(1) K.Fugami

(2) T.Sakka

(1) *Graduate School of Engineering, Gunma University*

(2) *Institute of Advanced Energy, Kyoto University*

B

"Study of Scintillation Efficiency Universal Curves for Crystals"

(1) Y.Uozumi, G.Wakabayashi
(2) M.Imamura, Y.Koba, T.Nagasaki
(3) H.Ohgaki, T.Kii
(1) Faculty of Engineering, Kyushu University
(2) Graduate School of Engineering, Kyushu University
(3) Institute of Advanced Energy, Kyoto University

"Development of Single-Electron Irradiation Technique for Microscopic Truck Structure Study"

(1) G.Wakabayashi, Y.Uozumi
(2) H.Ohgaki, T.Kii
(3) M.Imamura, Y.Koba, K.Kiyohara
(1) Faculty of Engineering, Kyushu University
(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Engineering, Kyushu University

"Development of Landmine Detection System with D-D Neutron Source by Measuring Radiations from Landmine"

(1) T.Misawa, Cheolho PYEON
(2) K.Masuda
(3) Y.Takahashi, T.Yagi
(1) Kyoto University Research Reactor Institute
(2) Institute of Advanced Energy, Kyoto University
(3) Graduate School of Energy Science, 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 2008 three regular meetings and the annual meeting for the cooperative research results were held with following theme.

1. The regular meeting

The 1st Meeting, January 9, 2008

清水　洋「液晶性有機半導体とその薄膜デバイス応用」

Y.Shimizu, "Applications for thin-film devices with liquid crystalline organic semiconductors", *National Institute of Advanced Industrial Science and Technology*

The 2nd Meeting, March 4, 2008

佐々木毅「産業技術総合研究所　ナノテクノロジー・材料・製造分野の研究戦略」

T.Sasaki, "Research strategy of nanotechnology, materials, and manufacturing in AIST", *National Institute of Advanced Industrial Science and Technology*

The 3rd Meeting, March 23, 2008

Boyd Blackwell「オーストラリアにおけるプラズマ/核融合研究の概要とオーストラリア国立大学の先進エネルギー研究グループの紹介」

Boyd Blackwell "Overview of plasma/fusion research in Australia and energy research group of the Australian National University(ANU).", *The Australian National University*

2. The Annual Meeting for the Cooperative Research Results, May 1, 2008

増田　開「慣性静電閉じ込め核融合におけるビーム対ビーム衝突核融合反応」

K.Masuda, "On Beam –Beam Colliding Fusion Reactions in Inertial Electrostatic Confinement in Low-Pressure High-Current Regime", *Institute of Advanced Energy, Kyoto University*

岡田浩之「イオンサイクロトロン周波数帯加熱を用いたヘリオトロンＪプラズマ中の高速イオンの速度分布研究」

H.Okada, "Study of Fast Ion Velocity Distribution Using ICRF Heating in HeliotronJ Plasmas", *Institute of Advanced Energy, Kyoto University*

池田亮介「ヘリオトロンＪにおける長波長マイクロ波を用いた遮断密度を超える高密度プラズマの生成」

R.Ikeda, "Production of Over-Dense Plasma Using Long-Wavelength Microwaves in HeliotronJ", *National Institute for Fusion Science*

田井中一貴「太陽光エネルギー駆動型人工レダクターゼの開発」

K.Tainaka, "Development of the Artifical Reductase Driven by Solar Energy", *Institute of Advanced Energy, Kyoto University*

小瀧　努「高効率バイオエタノール生産酵母の開発」

T.Kodaki, "Development of a Highly Efficient Bioethanol Production Yeast", *Institute of Advanced Energy, Kyoto University*

佐川　尚「酸化チタン光触媒と好熱性ヒドロゲナーゼを固定化したフォトバイオリアクターによる高効率水素生産」

T.Sagawa, "Highly Efficient Production of Hydrogen by Using Photobioreactor with TiO_2 Photocatalyst and Hydrogenase", *Institute of Advanced Energy, Kyoto University*

大垣英明「KU-FEL のレーザー発振の安定化に関する研究」

H.Ohgaki, "Studies on Stable Lasing in KU-FEL", *Institute of Advanced Energy, Kyoto University*

伊藤秋男「相対論的電子ビームによる原子過程研究の新開拓」

A.Itoh, "On the Frontier Study of Atomic Interaction Processes Involving Relativistic Electrons", *Graduate School of Engineering, Kyoto University*

作花哲夫「液相レーザーアブレーションにおける放出種の発光スペクトルの新しい解析方法の検討」

T.Sakka, "New Method for the Analysis of the Emission Spectra from the Species Ablated by Liquid-Phase Laser Ablation", *Institute of Advanced Energy, Kyoto University*

6. PROJECTS WITH OTHER UNIVERSITIES AND ORGANIZATIONS

Asian CORE (Center Of Research and Education) program, 2008-2012

New program Asian CORE (Center Of Research and Education) for the "Advanced Energy Science" between Japan, Korea and China was granted by the JSPS (Japan Society for the Promotion of Science) and 5 year collaboration between Japan, Korea and China has started. In this program, Japan and core institutes in Asian nations will establish the network of research and education by the extensive collaboration of mutually equal contribution, in the advanced and important field of sciences. The Institute of Advanced Energy is assigned as a hub institute in Japan to represent universities and research institutes, with Prof. Yukio Ogata as the representative and Prof. Satoshi Konishi as the Program Coordinator. Counterparts are Prof. Hangyu Joo in Seoul National University in Korea and Prof. Kan Wang in Tsinghua University in China Figure 1 shows the concept of the framework of this program.

Advanced energy science and technology are of common interests in these countries where industrial application of energy is extensive. This program

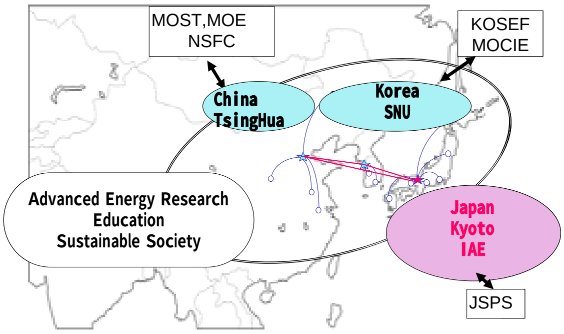


Fig.1 Concept of the newly approved Asian CORE Program.

supports the exchanges of scientists and students in the field of advanced energy research, for collaboration, workshops and other research activities. Particular emphasize of this program is on education, and assignment of students and seminars or schools will be planned and eventually provide leading young researchers in the energy field.

This program is operated by equal contribution basis, and it requires "matching fund" from counterpart countries, and Korea and China have different types of funding to send and accept approximately same level of exchanges as shown in the Fig.2.

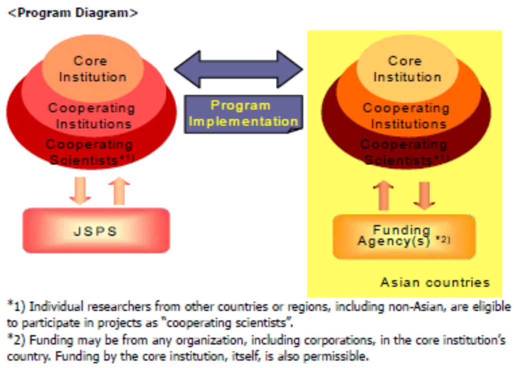


Fig.2 The structure of the Asian CORE Programs under the JSPS.

In the fiscal year 2008, we focused our effort to establish the organization of the collaboration. Seven workshops were held to coordinate the collaboration and possible technical areas were identified. Total 45 visitors went to Korea, and 21 to China. At the end of the year, steering committee meeting was held in Tsinghua University and 5 technical areas were agreed for the future collaboration as follows.

Task 1 Advanced Nuclear Energy Systems: liquid metal technology, high temperature nuclear energy conversion, neutronics, and fusion technology.

Task 2 Fusion Plasma Science: plasma physics, simulation and theory, heating and current drive, diagnostics and plasma wall interaction.

Task 3 Bioenergy: Synthesis of biofuel from biomass materials and energy production systems.

Task 4 Advanced Energy Materials: nuclear materials for high temperature use, ODS and ceramics, irradiation, and microscopy.

Task 5 Application of Quantum Radiation: electron beam, accelerator technology, free electron laser, tera hertz wave and its application.

From the fiscal year 2009, Activities will be planned on the above five research field.

Global COE Program “Energy Science in the Age of Global Warming – Toward CO2 Zero-emission Energy System-”

The 4th IPCC report in 2007 evaluated as almost certainly adverse the impact of greenhouse gasses on global warming. Consequently, the implementation of effective early measures to mitigate global warming, and the planning of policies to stabilize CO2 concentrations in the long-term have become an urgent global issue. Today could well be called the age in which ultimate solutions for the problems of global warming need to be planned. In order to solve the problem of global warming ultimately, it is necessary to make breakthroughs by promoting further research and to present scenarios that achieve zero CO2 emission energy systems by 2100 without dependence upon fossil fuels. Further, it is also necessary to train policymakers and leading researchers who can propose policies and create technologies to implement these scenarios. They can play leading roles not only in Japan but also across the world.

At this critical junction in the human being, Kyoto University Graduate School of Energy Science, Institute of Advanced Energy, Department of Nuclear Engineering, and Research Reactor Institute have been jointly granted as a Global COE Program on “Energy Science in the Age of Global Warming – Toward CO2 Zero-emission Energy System - “ to establish the global center of excellences toward pursuing an energy and environmental issues by Ministry of Education, Culture, Sports, Science and Technology (MEXT)(2008 – 2013).

The present COE will provide new approaches for the education-and-research on energy science as an international COE of Energy Science under the Age of Global Warming. The objective is to perform the research toward the realization of zero CO2 emission system in a scientific/technological as well as a policy-making manner through the coherent research and development of renewable energy, advanced nuclear energy, and the timely assessment of research progress based on what is actually needed from the public.

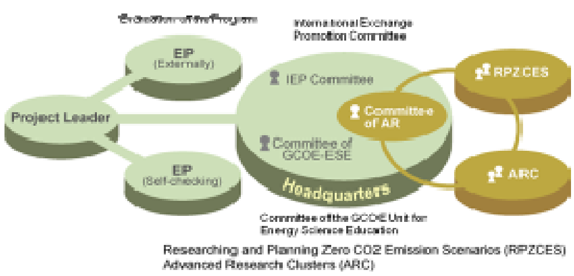


Fig.1 The structure of the G-COE Program.

Establishing “COE Unit for Energy Science Education” as a core of the present COE, coherent research and development of Zero CO2 emission scenario and advanced research as well as evaluations of program will be pursued. Scenario research/planning group will prescribe energy supply and demand scenarios toward a zero CO2 emission system. The advanced research cluster will systematize analysis, evaluation, planning, and system design based on the technological and social aspects of new energy systems such as solar energy, bio-energy, and advanced nuclear technologies. Evaluation on teaching, graduating student career and research results will be carried by self-check as well as external committee, of which will be reflected in this COE program. Figure 2 shows a schematic diagram of the research and planning of the G-COE program.

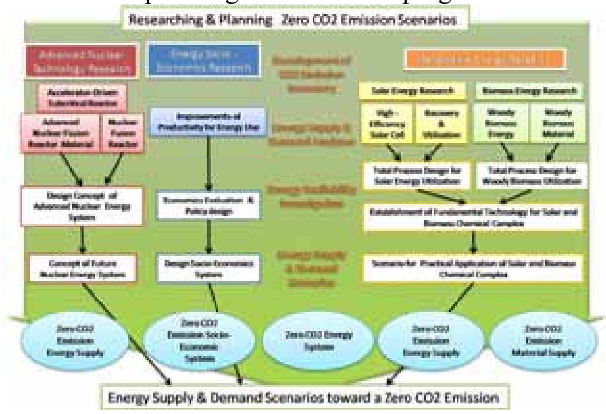
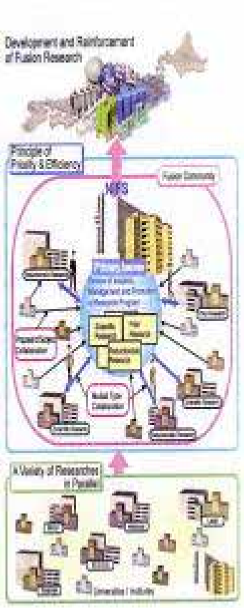


Fig.2 Schematic diagram of G-COE research & planning.

COE Unit for Energy Science Education will develop the human resources on the philosophy of “well-balanced interdisciplinary and international outlooks”. We will select and provide financial aid to excellent students from the four departments of the Graduate School of Energy Science and the Department of Nuclear Engineering, and organize an international think tank by employing outstanding researchers worldwide as assistant professors (tenure track) and post-doctoral researchers to create zero CO2 emission energy scenarios on a global scale.

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. It was also noted in the report that the university researchers should contribute to the studies of important issues in nuclear fusion research, such as (i) the function of electrostatic potential on plasma confinement, (ii) high beta plasma physics, (iii) optimum magnetic configuration for plasma confinement, (iv) steady-state plasma generation, and so on. NIFS was requested to play a leading role in these studies as the inter-university institute.



In the past collaborative programs of NIFS, university researchers came to NIFS and joined the research activity at NIFS. But in this program, the opposite movement of researchers became possible, that is, NIFS researchers can go to the universities. Hence a more efficient use of resources in both facilities became possible and the synergetic effect was expected.

The current program involves four major university research centers; Plasma Research Center, University of Tsukuba; Laboratory for Complex Energy Processes, Institute of Advanced Energy, Kyoto University; Institute of Laser Engineering, Osaka University; Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University. In this collaborative program, the researchers of those four research centers and of those of NIFS can move back and forth to each other to work on the same research subject. In addition, each research center can have its own collaborative programs with use of its major facility so that the researchers of other universities can join as if the facility belongs to NIFS. All these activities are supported financially as the research subjects of the NIFS bidirectional collaborative research program.

The collaboration between the Heliotron J group and other university groups such as the LHD group at NIFS has been continued during these 20 years. After the establishment of this collaborative program, both research activities have been highly stimulated, for example, from the viewpoints of adopted research subjects and research participants to understand machine-independent torus plasma physics through a systematic and exhaustive investigation. 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. The five topics for the collaboration research are selected; (1) the database construction for plasma confinement, (2) the plasma structure formation accompanying with the confinement transition, (3) ECCD and EBW heating, (4) the production and confinement of high energy particles, and (5) the theoretical analysis of helical configuration optimization. These studies are now progressing very favorably.

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

1. Introduction

ADMIRE PROJECT at Institute of Advanced Energy (IAE) in Kyoto University is a MEXT supported program "Open Advanced Facilities Initiative for Innovation (Strategic Use by Industry)" for 5 years to delivery of science and technology from Kyoto University to companies. ADMIRE provides and supports companies to utilize advanced facilities, such as DuET and MUSTER, IAE, Kyoto University for acceleration of cooperative research and developments among industries and IAE-Kyoto University. ADMIRE PROJECT provides services to utilize the equipments such as TEM, SEM and ion accelerators with free of charge for maximum 2 years.

2. Project details

Application of DuET and MUSTER for Industrial Research and Engineering (ADMIRE) PROJECT launched in 2006 and continues for 5 years funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of JAPAN. DuET and MUSTER are representing facilities in Institute of Advanced Energy (IAE) at Kyoto University dedicated for the research of energy science and technology, with the special emphasis on fusion and fission materials R & Ds. ADMIRE PROJECT aims to deliver the research resources of IAE to public. Thus, programs to be approved are NOT restricted within fission and fusion materials, nor energy science and technology. We expect many proposals from varieties of fields all over the world. Users can use the facilities with free of charge. ADMIRE PROJECT has two areas of proposal;

Strategic Use for Energy Science and Technology

This area is progressed under the sub-title of “Production and Conservation of Materials for Energy Equipments” for the collaboration research of applicants and IAE faculties. Main scope of this area is to contribute to the innovation and conservation of whole energy systems from small thermoelectric elements to huge generating stations of thermal, solar, fission and fusion etc. The period of use in this area is one year, and optionally extension of one more year. The intellectual intelligence relates to ADMIRE PROJECT is treated along the Intellectual Property Policy of Kyoto University as same as usual Industry-KyotoUniversity collaboration.

Innovative Application for Industrial Users

This area is flexible to accept any new ideas from industries for supporting their efforts to make progress. Applicants are able to choose collaboration or simple utilization of the facilities. The collaboration is handled under the standard Industry-Kyoto University collaboration procedure. The simple utilization of the facilities is available for companies having seeds of new products or very basic R & Ds. The simple utilization (non-collaborative utilization) is allowed for the applicant to hold all the Intellectual Properties from the activities. ADMIRE project nor IAE never demands right of Intellectual Property arising from the activities for the case of simple utilization. The Project provides services for contributing innovation of science and technology. The period of use in this area is 6 months, and optionally extension of 6 months will be available.

The invitation of the application will be made 2 times annually at spring and autumn. All users need to make report of the activity at the end of each program to MEXT. The report is open to the public. However, under special circumstances, the report might be waived maximum for 2 years for the protection of Intellectual Property. Also, the title and the content of the activity may be classified upon the request of the applicant.

3. Benefits for companies

- Rapid progress of products development by use of high performance equipments.
- Reduction of expenditure for equipments.
- Rapid investigation of new idea.
- Use of very expensive equipments.
- Access to excellent faculties and research resources at IAE.

Figure 1: DuET Facility

7. IAE RESEARCH REPORT

IAE-RR-2009　100
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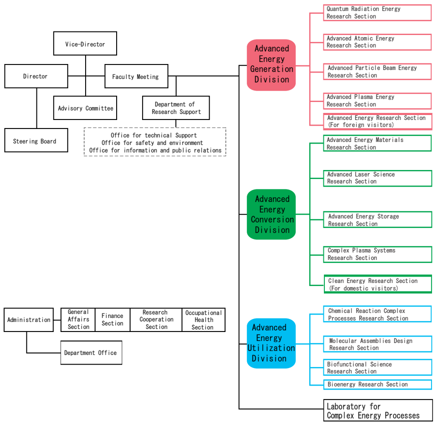

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京都大学エネルギー理工学研究所

〒611-0011 京都府宇治市五ヶ庄
TEL：0774-38-3400
FAX：0774-38-3411
http：//www.iae.kyoto-u.ac.jp