7. Bilateral Collaboration Research

The purpose of the Bilateral Collaboration Research Program (BCRP) is to enforce the activities of nuclear fusion research in the universities by using their middle-size experimental facilities of the specific university research centers as the joint-use facilities for all university researchers in Japan. The current program involves five university research centers as follows:

- Plasma Research Center, University of Tsukuba
- Laboratory of Complex Energy Process, Institute of Advanced Energy, Kyoto University
- Institute of Laser Engineering, Osaka University
- Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University
- Hydrogen Isotope Research Center, University of Toyama

In the BCRP, each research center can have its own collaboration programs, using its main facility. Researchers at other universities can visit the research center and carry out their own collaboration research there, as if the facility belongs to NIFS. That is, all these activities are supported financially by NIFS for the research subjects in the BCRP. The BCRP subjects are subscribed to from all over Japan every year as one of the four frameworks of the NIFS collaboration program. The collaboration research committee, which is organized under the administrative board of NIFS, examines and selects the subjects.

(S. Sakakibara)

Osaka University

FAST IGNITION OF SUPER HIGH-DENSE PLASMAS

Laser-driven inertial confinement fusion by the Fast Ignition (FI) scheme has been intensively studied as the FIREX-1 project at the Institute of Laser Engineering, Osaka University. The researches consist of target fabrication, laser development, fundamental and integrated implosion experiments, simulation technology and reactor target design, and reactor technology development. In FY2020, the following progress was made through Bilateral Collaboration Research Program with NIFS and other collaborators from universities and institutes (NIFS12KUGK057 as the base project).

Fundamental and Integrated Plasma Experiments

For the fast ignition of the inertial confinement fusion, we have developed several novel schemes, namely, stable generation of high-density core plasma using a solid ball fusion fuel, realization of an ultra-high contrast heating laser using a plasma mirror, low mean-kinetic energy beam of fast electrons, and focusing of the laser-accelerated electron beam using laser-driven strong magnetic field and self-generated magnetic field. The average energy of the electron beam accelerated by the heating laser must be kept as low as possible to achieve efficient heating. We have developed a high-contrast heating laser by introducing a plasma mirror into a kilojoule-class laser system. The average energy was reduced by about 80% as shown in Fig. 1, and the heating efficiency was improved by a factor of two compared with the previous experiments. We have shown that the pulse contrast is essentially important for plasma heating.

In the current fast ignition experiment, an external magnetic field using a laser driven coil is used. However, this method may not be suitable for realization of the laser fusion energy, which requires repetition rates of 10 Hz or higher. We have started experiments on guiding of the electron beams using a self-generated magnetic field formed spontaneously by the laser-accelerated electron beam itself.

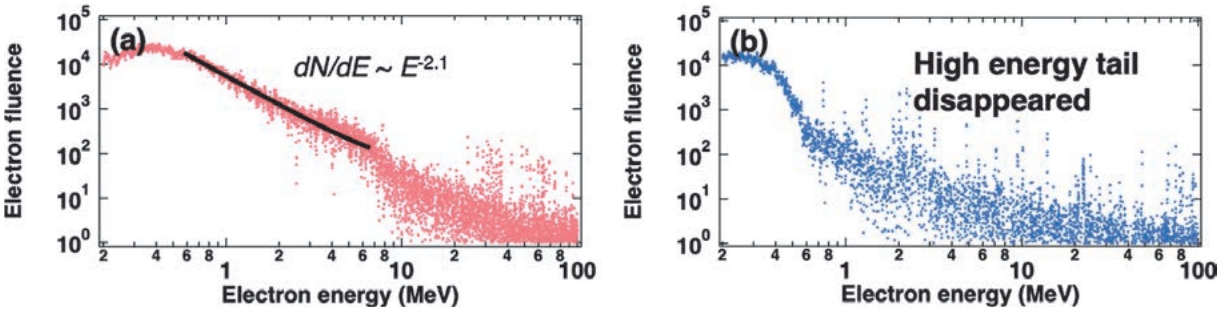

Fig. 1　Difference of electron energy distribution with (right) and without (left) a plasma mirror.

Target Fabrication

The low dense materials have been developed for laser fusion targets. In this year, the bromine (Br) doped trimethylolpropane trimethacrylate (TMPT) was developed, since Br doping to target materials is considered to be useful for suppression of the Rayleigh-Taylor instability. The Br-doped TMPT were fabricated by co-polymerization of *p*-Bromostyrene and TMPT. After gelation, the co-polymer was dried by the supercritical carbon dioxide method. Figure 2 shows SEM images of the TMPT and the Br doped TMPT. The concentration of Br can be controlled up to 20 wt%. The spherical shaping was also successfully performed.

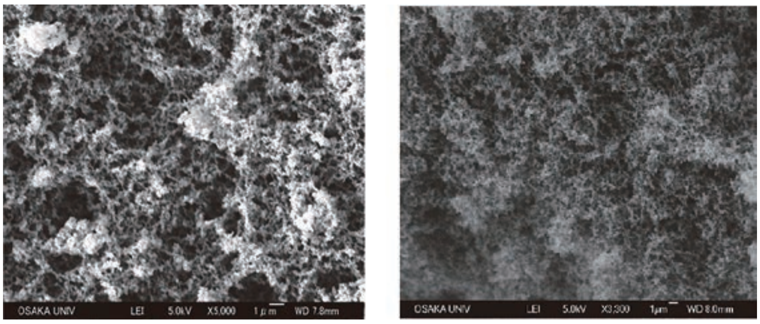

Fig. 2 SEM images of TMPT (left) and Br-doped TMPT (right).

Theory and Simulation of heating and ignition design

Heating of the dense plasmas by relativistic-intensity lasers has been considered to be effective in heating the core plasma by drag heating, resistive heating, and diffusive heating. The LFEX laser can maintain the heating surface at electron temperatures of 10 keV or higher and drive thermal diffusion with keV temperature as confirmed with simulations (Fig. 3). It can be seen that the core center is heated to a pressure above PPa. Energy conversion ratio from the laser energy to the core plasma is more than 15%. These results were published in Physical Review Letters [1].

Based on these results, we designed an ignition-scale experiment. The density of the imploded core was assumed to be 300 g/cc, and the heating laser was assumed to be 2ω light of 200 kJ/20 ps. All the heating processes and the radiation losses were taken into account in the calculation. The results are shown in Figs. 3 (d) and 3 (e). The maximum density of 300 g/cc set at 100 μm was heated to over 5 keV with the arrival of the thermal diffusion front at about 20 ps. From the calculation results, it is expected that the ignition temperature can be achieved by heating with 200 kJ 2ω light at about 20 ps.

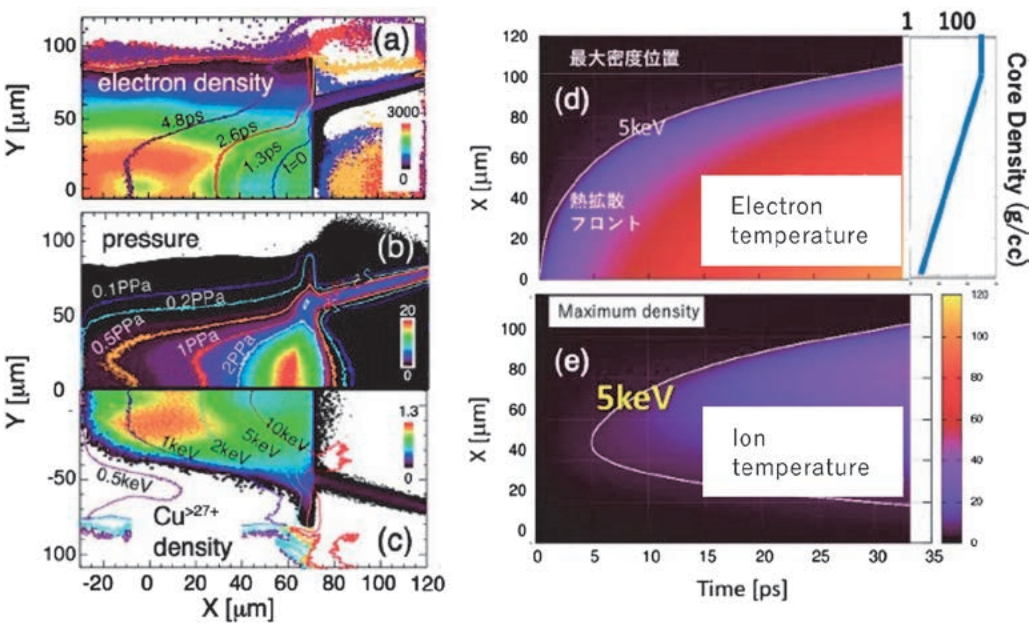

Fig. 3 Simulation of the FIREX experiment by the PICLS code. (a), (b) and (c) Results of the heating calculations for the ignition scale experiment. (d) Time evolution of the electron temperature. (e) Time evolution of the ion temperature.

Improvement of GXII and LFEX laser system

Replacement of various old devices by controllable devices on network has started for remote control of Gekko-XII (GXII) laser system. Based on a reconstructed timing chart of the whole system, a timing controller and a digital-controllable fiber oscillator have been renewed this year. The remote control of the oscillator has been implemented on September 2020 and already operated for many experiments.

In LFEX laser, a pulse energy and a spectral shape of a laser pulse from the front end have been improved by installing a fiber system instead of the conventional solid system for pulse stretching, amplification and spectral shaping. The concerned deterioration of a pulse intensity contrast due to introduction of the fiber system did not appear resulting in high contrast of 10^{10} as shown in Fig. 4.

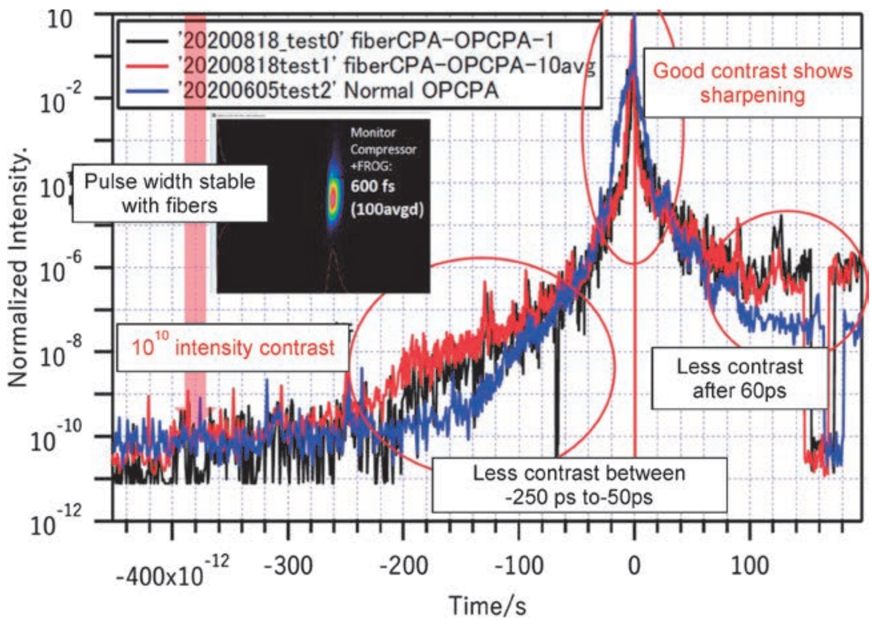

Fig. 4 Pulse intensity contrast measured with a third-order autocorrelator.

Individual Collaborations

In parallel to the main base project, 16 other collaborations by individual researchers including three from abroad as described below have been performed. Those were on electron-driven fast ignition (5 collaborations), ion-driven fast ignition (2), alternative scheme of laser-driven inertial fusion (3), implosion hydrodynamics (2), diagnostics of high-temperature and high-density plasmas (3), and reactor technology (1). 7 were projects continued from the previous year(s) and 9 were newly accepted in FY2020.

[1] K. Matsuo *et al.*, Phys. Rev. Lett. **124**, 035001 (2020).

(R. Kodama, H. Shiraga, S. Fujioka, K. Yamanoi, K. Shigemori, Y. Sentoku, and J. Kawanaka)

University of Tsukuba

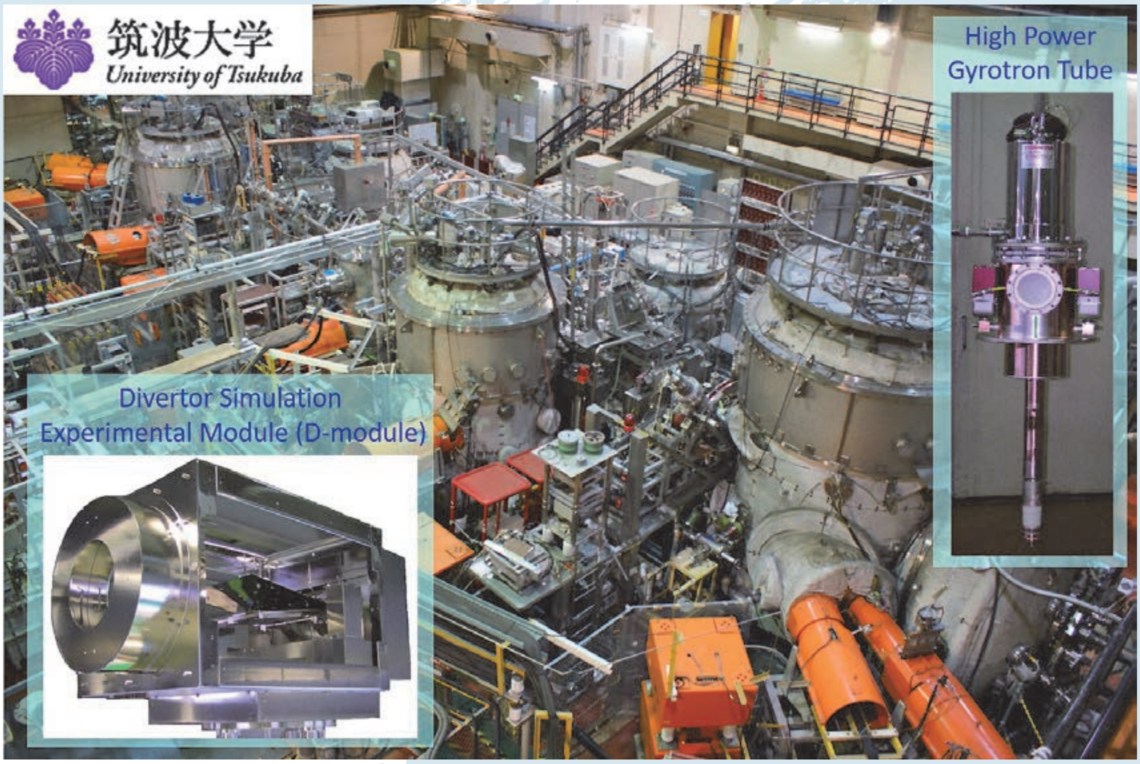

Fig. 1 Bird's eye view of GAMMA 10/PDX.

Highlight

Study of boundary plasmas by making use of open magnetic field configuration and development in high power gyrotrons towards the DEMO project

In the Plasma Research Center, University of Tsukuba, studies of boundary plasma and development of high-power gyrotrons have been performed under the bilateral collaboration research program. The GAMMA 10/PDX (Fig. 1) is the world's largest tandem mirror device and has many plasma production/heating devices. By using a divertor simulation experimental module (D-module), shown in lower left of Fig. 1, which is installed at the west end region of the GAMMA 10/PDX, hydrogen recycling and plasma detachment have been extensively studied. The effective plasma detachment is clearly shown by the additional N_2 + H_2 gas injection into the D-module. As a ratio of the amount of N_2 gas to H_2 gas injection increases, the electron density and ion flux decrease more, indicating that nitrogen-induced molecular activated recombination efficiently contributes to the plasma detachment. Besides, enhancement of hydrogen recycling due to increase in the target temperature has been studied. A test of a new 28/35 GHz dual-frequency gyrotron has been carried out. The new linear plasma device with superconducting coils is designed and under construction to contribute to the DEMO divertor design.

In the Plasma Research Center, University of Tsukuba, studies of boundary plasma and development of high-power gyrotrons have been performed under the bilateral collaboration research program. In FY2020, 26 subjects including the base subject were accepted and produced a number of excellent results.

Effects of a combination of N_2 and H_2 gas-puff on the plasma detachment have been investigated. Figure 2 shows time evolution of pressure inside the D-module, electron temperature, density and ion flux in the cases of hydrogen gas-puff only and a combination of hydrogen and nitrogen gas-puff. It is found that as a ratio of the amount of N_2 gas to H_2 gas injection increases, the electron density and ion flux decrease more. The ratio of H_α line intensity to H_β line intensity, which is a good monitor of hydrogen activated molecular recombination (especially in the dissociative attachment process), is lower in the case of a combined gas-puff of hydrogen and nitrogen gases than hydrogen gas-puff only, suggesting processes of nitrogen-induced molecular activated recombination suppress the dissociative attachment process.

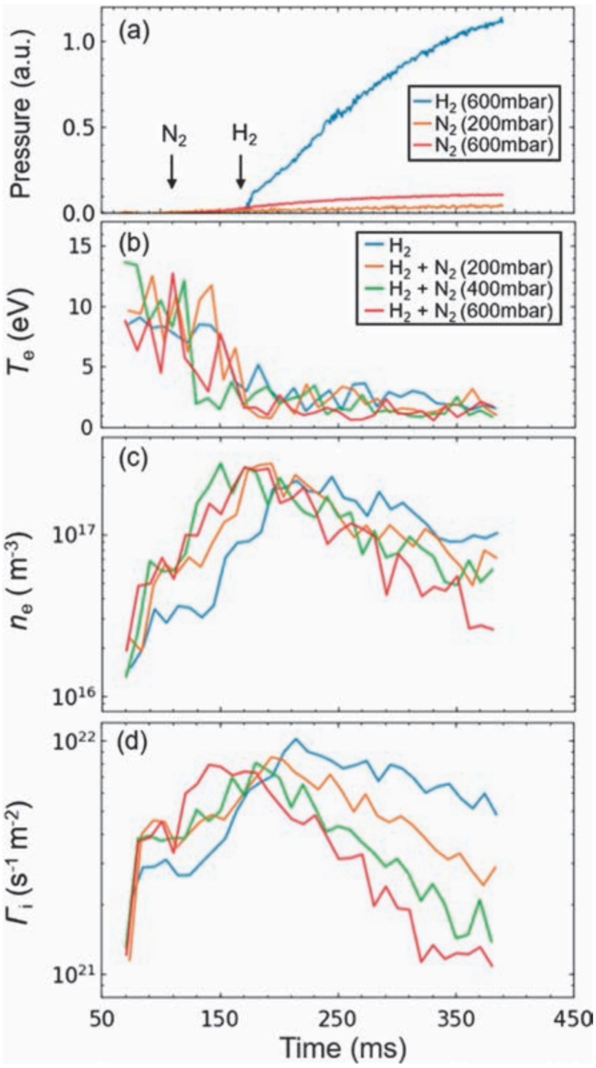

Fig. 2 Time evolution of (a) pressure inside the D-module, (b) electron temperature, (c) electron density, and (d) ion flux. The plenum pressure of hydrogen is fixed at 600 mbar.

An effect of increasing the temperature of a tungsten target on hydrogen recycling has been studied. So far, enhancement of hydrogen recycling has been shown in the case of a high temperature target. Here, an effect of gas-puff on the recycling enhancement is studied. When the gas-puff is done, the electron temperature decreases more and the electron density increases more in the case of a high temperature target, compared to room temperature. However, there is no difference in the electron densities in the cases of high and room temperature targets. It is found that hydrogen recycling is enhanced due to the high temperature target when the amount of gas-puff is smaller than a certain value. When gas-puff exceeds a certain value, plasma seems to be detached.

An experimental test of a 28/35 GHz dual-frequency gyrotron has been carried out to achieve 0.4 MW CW at 28 GHz. In FY 2020, a cooling system was improved to suppress the temperature increase of cooling water at the collector up to 30°C in a 0.4 MW CW operation.

(M. Sakamoto)

Kyoto University

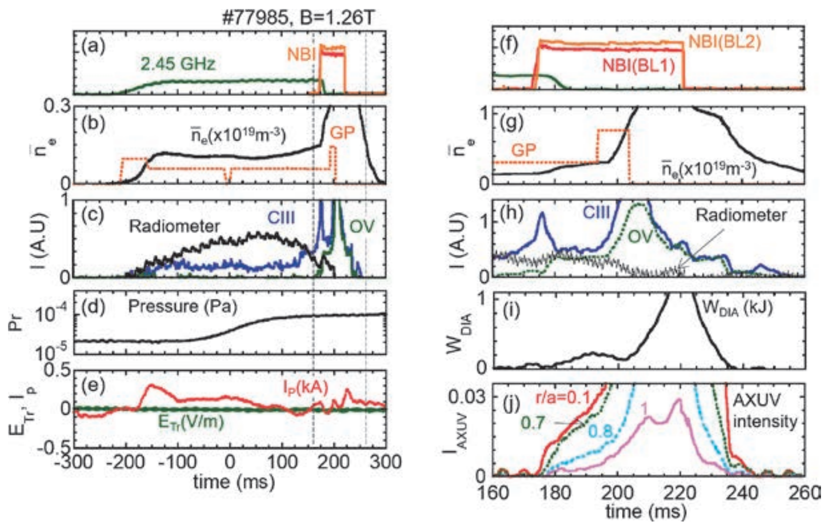

Fig. 1 Time evolution of plasma parameters in an NBI start-up plasma of Heliotron J assisted by non-resonant microwave heating. (a)–(e) in the pre-ionization by non-resonant microwave launch and (f)–(j) for the main plasma formation by NBI. The time response of the neutral gas pressure is in the order of 0.1 s.

Highlight

Study of NBI plasma start-up assisted by seed-plasma generation using non-resonant microwave heating:

Robust and reliable plasma start-up is an important topic not only in Tokamak but also in Stellarator/Heliotron (S/H) devices. In S/H configurations, since plasma pressure modifies the poloidal symmetry, development of operation scenario for high-β plasmas is required to study the β-effect on the confinement and transport. The plasma is often produced by electron cyclotron heating (ECH), and this heating scheme limits the operational magnetic field due to the resonance condition. To resolve this problem, a start-up technique using a high energy neutral beam injection (NBI) has been developed in some devices. However, experimental devices with large major radius and higher magnetic field strength are preferable for the plasma start-up by NBI alone. In order to mitigate this condition, we have developed a production method by use of non-resonant 2.45 GHz microwave, which enables us to realize the NBI plasma start-up even in the conditions of low NBI power (> 0.3 MW), low acceleration voltage (< 30 kV) and small device size (~1 m). Generation of relativistic electrons, which should be essential to produce the plasmas, has been confirmed experimentally with synchrotron radiation and hard X-ray emission measurements. A 0-D model analysis shows that the seed plasma has an important role in the rapid start-up. The physical processes of the rapid NBI start-up are as follows: (1) the beam ions are produced sufficiently to heat electrons by the collisions with the seed plasmas, (2) the electron heating promotes the dissociation and ionization of the deuterium molecules, molecular ions and atoms, and (3) the increase in electron density produces fast ions and heat electrons. In the successful start-up cases, the processes have a positive feedback loop, resulting that the electron temperature exceeds radiation barrier for low Z impurities. Since the beam fueling is not so effective to increase the electron density, an additional gas fueling with proper timing is required to ramp up the density under the condition that the seed plasma density is low. The key point for successful plasma start-up in the low NBI power condition is to produce the beam ions by the collisions with the seed plasmas to heat the background electrons sufficiently in the early phase of the beam injection. The pre-ionization technique developed in this study will be useful to realize the NBI plasma start-up in the low absorption power case such as the perpendicular or deuterium NBI.

Research Topics from Bilateral Collaboration Program in Heliotron J

The main objectives of the research in the Heliotron J device under this Bilateral Collaboration Program are to experimentally and theoretically investigate the transport and stability of fusion plasma in advanced helical-field, and to improve the plasma performance through advanced helical-field control. Picked up in FY2020 are the following seven key topics; (1) studies of plasma confinement improvement and related plasma self-organization through advanced helical magnetic field control, (2) study of plasma profile, plasma flow, and plasma current control for the confinement improvement, (3) study of fluctuation-structure formation and its control in plasma core region and peripheral region, (4) investigation of MHD instabilities of energetic particle modes and their control, (5) extension of high-density operation region, (6) optimization of particle supply and heating scenario, and (7) empirical research of new experimental methods and analysis methods.

Effect of magnetic configurations on energy confinement and formation of plasma structure:
The Heliotron J device has a feature of high freedom in confinement magnetic configuration. In the configuration control experiments, we have extended the bumpiness (toroidal mirror ratio) parameter in the magnetic field spectrum from the conventional low-, medium (standard)- and high-bumpiness configurations to an ultra-high-bumpiness configuration. We have measured the electron density and temperature profiles with a Nd:YAG Thomson scattering diagnostic. The injection angle and magnetic field strength are adjusted to have on-axis ECH heating, and the electron density is kept $1–1.2\times10^{19}$ m^{-3}. The experiments have confirmed that the stored energy measured with a diamagnetic loop is the highest at the standard configuration, while the plasma profile depends on the magnetic configuration. The hollowness of the electron density profile is stronger as the bumpiness decreases. The reason may be the effect of trapped particles on radial particle transport. According to the TRAVIS ray tracing code, the ratio of the trapped electrons to the passing ones, produced by ECH is higher at a higher bumpiness configuration. Although the higher bumpiness causes a higher trapped particle population, the radial particle transport may be reduced through the bumpiness effect, resulting that the density profile is flatter.

Bumpiness dependence of electron confinement, and temperature and density distributions:
Electron internal transport barrier (e-ITB) is observed at on-axis ECH in helical plasmas. The ECH generates a radial electric field, which is determined by neoclassical transport, forming a large electron temperature gradient with the reduction in thermal transport coefficient. This phenomenon has been observed in many helical devices. On the other hand, in NBI plasmas, an ion internal transport is observed under some conditions, while no e-ITB is observed without ECH. In the Heliotron J device, we, for the first time, have observed an e-ITB in an NBI plasma without ECH. The NBI is injected tangentially in the co- and counter-directions. When a high intense gas puffing (HIGP) is applied to the NBI plasma, the electron density and stored energy increases, and the increase rate changes 20 msec after HIGP. In the core region, $r/a < 0.3$, the Te gradient changes, and the central Te increases up to 0.6 keV, which is typically 0.2 keV in conventional NBI plasmas. The ne profile is not flat but peaked after the HIGP. A multi-channel AXUV diagnostic shows that the core intensity increases after the HIGP, and it is kept low at the edge region, indicating that the profile shape changes into a peaked one during the improvement phase.

Many research topics have been made progress on with collaborative researchers under Bilateral Collaboration Program in the Heliotron J project. The magnetic field configuration research including formation of a rational surface at the edge region is advanced, and the local fluctuation measurement is prepared by introducing a new beam emission spectroscopy, a Doppler reflectometer, and an upgraded Langmuir probe. A 0.7-mmϕ pellet injector has been under operation for high-density plasmas. A laser blow-off system for the impurity transport measurement, and a multi-path Thomson scattering system for the high reliability measurement will be available soon. We will make effort to extend the plasma operation region to comprehend plasma self-organization and control instabilities according to the confinement field optimization.

(K. Nagasaki)

Kyushu University

Research activities on QUEST in FY2020

We will summarize the activities of the Advanced Fusion Research Center, Research Institute for Applied Mechanics at Kyushu University during April 2020 – March 2021. The QUEST experiments were executed during 6th June – 28th Aug. (2020 Spring/Summer; shot no 42539–43470) and 9th Sep. – 5th Mar. (2020 Autumn/Winter; shot no 43471–45925). The main topics of the QUEST experiments in FY2020 are listed below.

1) Two 6 h discharges were achieved after modification of the center stack cover from the stainless steel type 316L, coated by atmospheric plasma spray tungsten (APS-W), bent in line with the circumference of the center stack, to more than 200 panels made of stainless steel type 316L. The center stack cover panels were cooled down by water-cooling channels. Wall stored hydrogen into the center stack panels was increased and wall pumping capability was significantly enhanced. Consequently, one 6h discharge could be obtained. The other was assisted by water-cooling of the hot wall located on the top side. The cooling down was executed during the discharge and clear recovery of wall pumping capability was observed.
2) The dependence of plasma current and electron temperature on a refractive index along the toroidal direction of the injected electron cyclotron wave (N//) was experimentally confirmed. The wave could be absorbed at higher harmonic electron cyclotron resonance. The presence of energetic electrons gave rise to enhancement of the wave absorption and efficiently drove plasma current in the case of high N//. While the wave was efficiently coupled with bulk electrons in the case of low N// and consequently high electron temperature could be achieved.
3) Radial distribution of atomic hydrogen flux to the walls, F, in steady-state discharges with inboard limiter configuration is measured using a reciprocate PdCu permeation probe for the first time. The F drops from 7.7×10^{16} H/m^2/s in front of the radiation shield to a non-zero level of 4.3×10^{16} H/m^2/s, inside the vacuum port.
4) The drift of the integrated signal of the magnetic sensor is the one of the most serious problems for a steady state tokamak operation.
   The procedure compensating the integrated magnetic sensor signal with hall sensors has been developing based on the Cauchy condition surface method for equilibrium reconstruction of the QUEST long operation.
5) A CW 28 GHz is finally assembled. The output power of 400 kW is expected in the CW operation. It will be used in long-pulse discharges on plasma-wall interaction studies, as well as RF ramp-up of the tokamak plasma.
6) The use of liquid metals as the divertor surface materials has been receiving attention in the magnetic fusion community over the past two decades. The present work is intended to investigate the effect of forced convection on the behavior of heat transport in liquid metals such as GaInSn, safe to handle in a laboratory experiment. Data indicate that the convection induced by a JxB electromagnetic force can significantly increase the heat transport coefficient. However, it is also true that the effect of Joule heating can warm up the liquid metal. In the next fiscal year, the magnetic field will be increased so that the Joule heating effect can be controlled.
7) A large electrode system which can withstand high heat flux by water cooling during steady state tokamak operations at QUEST has been developed for edge voltage biasing experiments and scrape-off layer plasma measurement. Preliminary SOL measurements using the system succeeded in detecting locally the bulk electron temperature, intermittent dynamics of the high energy electron flux, and coherent and broadband fluctuation spectra of the floating potential during SSTOs.
8) A high-field side biased electrode configuration successfully initiated discharges in the injector region after the deployment of a new gas injection manifold that directed gas directly towards a cylindrical electrode attached to the electrode plate. There were some indications of the toroidal current persisting after the CHI

discharge was over. These results are encouraging for a planned upgrade, which involves lowering the cylindrical electrode structure closer to the CHI injector coil and further improvements to the gas injection system.

9) The design of the HIBP has been initiated to investigate heat and particle transport in core plasmas under controlling particle recycling. The ion species of the probe beam is cesium and the required beam energy is less than 60 keV for the toroidal magnetic field strength of 0.25 T. The observable area covers the upper half of the poloidal cross-section of plasmas.

10) To develop the high temperature first wall with tungsten (W) armour for the QUEST, the Advanced Multi-Step Brazing (AMSB) was applied to fabricate the prototype joint structure of W armour with a thickness of 0.254 mm and the stainless steel (SUS) substrate, in which the oxide dispersion strengthened copper alloy (ODS-Cu) with a thickness of 1 mm was inserted between W and SUS as an intermediate material. The staggered joint structure of W/ODS-Cu/SUS was successfully obtained by AMSB. Each joint interface showed no sign of exfoliations and macro defects. The hydrogen retention properties will be confirmed in the 2021 fiscal year.

11) A magnetic probe that is suitably designed for measuring ECH generated plasma at QUEST has been examined to investigate magnetic phenomena during plasma equilibration and various plasma instabilities. The growth of flux during current ramp-up was detected by the probe, in which a vertical shift of the current with flux perturbation was also observed in the measurement data.

12) A layered material with tungsten coating and a substrate of type 316 stainless steel was prepared by hot rolling. Small samples prepared from the rolled sheet were installed and exposed to plasma in the 2020 spring/summer experimental campaign of QUEST. No thick deposition layer was formed on the plasma-exposed surfaces of the samples. However, impurities such as oxygen and carbon were found around scratch marks formed by the rolling. Surface finishing seems to be important for controlling plasma-surface interaction of a rolled material.

13) Increasing the operation days of the Thomson scattering system was an important issue to be solved. Two members of joined the Thomson scattering team, and they contributed to the operation, the calibration and the analysis. As a result, the plasma measurement days increased from 15 days in AY2019 to more than 40 days in AY2020. Remote participation from the University of Tokyo was tested using a VPN, in which monitors and windows necessary for the operation and analysis were shared successfully.
A laser beam position monitor system was tested and the best optical configuration was found.

14) On CT injection at QUEST, a new drift tube, inside of which is a CT guiding tube made of OFC-Cu, has been prepared to improve CT transport and fueling efficiency. The performance of the Cu tube was numerically verified, resulting in substantial improvement. A verification experiment has been also planned to be carried out with a small size plasma gun at Univ. Hyogo.

15) In order to apply the framework developed for a carbon divertor in the LHD to QUEST, we implemented the tungsten EAM potential developed by L.-F. Wang *et. al.* (L. F. Wang, *et. al.*, J. Phys. Condens. Matter 29, 435401 (2017)) into the hydrogen recycling model. The developed model was employed to estimate the release time of hydrogen atoms and molecules from the tungsten wall. The simulation results show that, similar to carbon walls, the release of molecular hydrogen takes longer than the release as atoms.

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Yuji Hatano (University of Toyama) 12)
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Seiki Saito (NIFS) 15)

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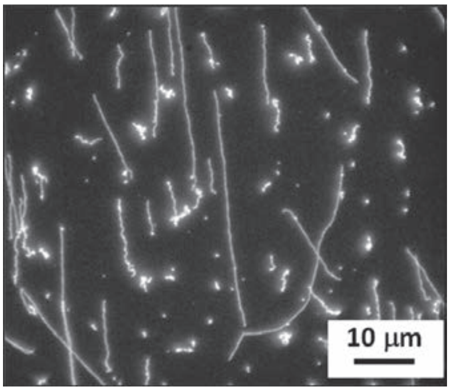

Fig. 1 Fluorescence image of genome-sized DNA molecules of T4 GT7 bacteriophage. The rate of double strand breaks was evaluated by measuring the change in the lengths of DNA molecules after immersion in tritiated water.

Highlight

Research Activities in Hydrogen Isotope Research Center, Organization for Promotion of Research, University of Toyama

A simple experimental system to examine the rate of double strand breaks (DSBs) of genome-sized DNA molecules in tritiated water under well-controlled conditions was established for the validation of computer simulation on interactions of biomolecules and ionizing radiation. No noticeable irradiation effects were observed at a tritium (T) concentration of 1300 Bq/cm^3, indicating that the effects of β-ray irradiation were far smaller than those of oxidation and/or thermal motion at the low dose rate (43 μGy/h). Radiation-induced DSBs were clearly recognizable at high T concentrations of 4.0–5.2 MBq/cm^3. The dependence of the DSB rate on water temperature and DNA concentration was examined by using the high concentration tritiated water.

[*Double-strand breaks in a genome-sized DNA caused by beta-ray under cellular environment (T. Kenmotsu, Doshisha U.)*]

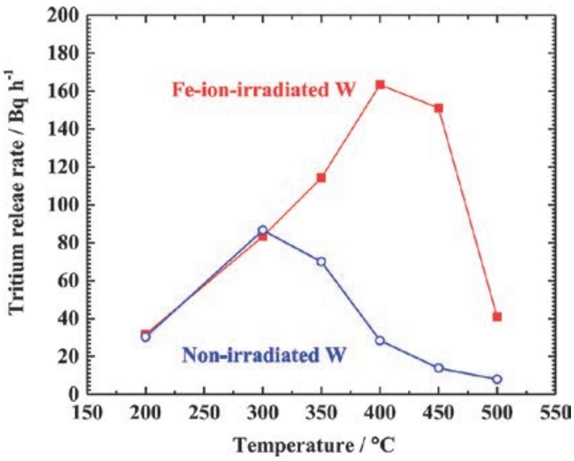

Fig. 2 Tritium release rate from W sample damaged with 6.4 MeV Fe ions to 0.5 dpa and non-irradiated W sample during heating under Ar gas flow.

Tritium Transport in Fusion Reactor Materials: Development of T removal technique from plasma-facing materials (PFMs) after the service in a fusion reactor is important for safe and cost-effective disposal. Lattice defects induced by neutron irradiation in tungsten (W) act as traps against hydrogen isotopes. Hence, it is important to understand the influence of radiation-induced defects on T removal efficiency. For this purpose, T release from a W sample irradiated with heavy ions was examined in this study. A plate of W was irradiated with 6.4 MeV Fe ions to 0.5 displacement per atom (dpa) at the damage peak at 500 °C, using the accelerator DuET at Kyoto University to simulate neutron irradiation effects. The depth of the damaged zone was about 1.1 μm. The irradiated and non-irradiated samples were exposed to DT mixture gas (4% T) at 500 °C. Then, the sample was heated under Ar gas flow sequentially to 200–500 °C. The released T was collected in water bubblers and its amount was evaluated using a liquid scintillation counter. Non-destructive depth profiling of T was performed using β-ray induced X-ray spectrometry and Monte Carlo simulation, considering generation and attenuation of X-rays in the sample and Ar gas. The fraction of hydrogen isotopes to W in the damaged zone reached ([D]+[T])/[W] = 7×10^{-4}, while that in the non-irradiated sample was ~10^{-7}. As shown in Fig. 2, the detrapping rate of T from irradiated W was comparable with that of the non-irradiated sample, indicating that the detrapping of T from radiation-induced defects was negligibly small at 250 and 300 °C. The significant T release from the damaged zone started at 400 °C. A sharp concentration gradient of T was developed in the damaged zone during T release, indicating the rate of T release was controlled by a diffusion process under the trapping effects. The majority of T was released not as HT but as HTO via isotope exchange with moisture in Ar gas. In addition, T permeation experiments through a metallic wall from and to high temperature, high pressure water was started to examine T transport to coolant water in a future fusion reactor.

Other experimental studies performed in the Hydrogen Isotope Research Center in the fiscal year 2020 are the followings:

- *Hydrogen isotope transport through plasma modified fusion reactor materials* (H. T. Lee, Osaka U.);
- *High temperature and high flux irradiation effect on hydrogen isotope retention in damaged W* (Y. Oya, Shizuoka U.);
- *Hydrogen isotope exchange on metallic plasma facing walls* (N. Ashikawa, NIFS);
- *Tritium retention on facing materials modified by plasma wall interactions* (K. Tokunaga, Kyushu U.);
- *Synergistic effects of bulk helium and damages on hydrogen isotope retention behaviors in plasma facing materials* (F. Sun, Shizuoka U.);
- *Application of GD-OES analysis to efficient grasping major controlling factors of complicate PWI in high-temperature plasma confinement devices* (N. Yoshida, Kyushu U.);
- *Evaluation of hydrogen isotope retention and release of SiC and SiC/SiC composite* (H. Kishimoto, Muroran Inst. Technol.);
- *Gamma-ray irradiation effect on hydrogen isotopes at fusion material surfaces* (T. Chikada, Shizuoka U.);
- *Suppression of tritium permeation in metals by laser-doping of impurities* (Y. Nobuta, Hokkaido U.); and
- *Development of high concentration tritium heavy water and monitoring of the concentration* (Y. Arikwa, Osaka U.).

(Y. Hatano, University of Toyama)