8. Bilateral Collaboration Research Program

University of Tsukuba

Highlight

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

Divertor simulation experiments using large tandem mirror device (GAMMA 10/PDX) has been extensively performed and the highest heat-flux of 30 MW/m^2 far beyond the ITER relevant heat flux was achieved at the end-cell by superimposing a short pulse of ECH into the ICRF-heated plasma. Generation and characterization of detached plasma in the recently developed divertor simulation experimental module (D-module) have also progressed and the examination using various radiator gases showed that the Xe gas was most effective on electron cooling and generation of plasma detachment.

The first experimental test of new 28/35 GHz dual-frequency gyrotron (2 MW 3 s and 0.4 MW CW) being prepared for a number of present fusion devices (QUEST, NSTX-U, Heliotron J and GAMMA 10/PDX) was performed. The main mode oscillations were confirmed at the frequencies of 28.032–28.045 GHz and the output power of 1.25 MW was obtained at the beam current of 51.5 A with the output efficiency of 30.8%. For the development of diagnostics, the yttrium-aluminium-garnet (YAG)-Thomson scattering (TS) system has been constructed and the radial profiles of electron temperature and density at seven radial positions was successfully measured in a single laser shot at the central-cell of GAMMA 10/PDX.

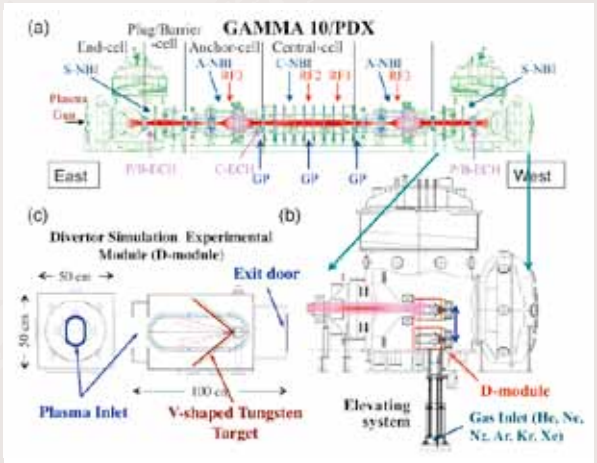

Fig. 1 (a) Schematic view of GAMMA 10/PDX, (b) divertor simulation experiment region in the west end-ell and (c) schematic view of D-module.

In the Plasma Research Center (PRC), University of Tsukuba, studies on boundary plasmas by making best use of the large tandem mirror GAMMA 10/PDX have been performed together with the development of high-power gyrotrons under the bilateral collaboration research program. Since FY2010 the number of the research subjects of the program in PRC continues to increase and in FY2016 a total of 28 subjects was accepted including the base subject. As shown in Fig. 1 GAMMA 10/PDX has open magnetic field configuration and improvement of the plasma confinement with potential formations has been demonstrated. By using the controllability of plasma parameters, divertor-simulation experiments at the end-cell region have been performed with strong ICRF and ECH systems. ICRF heating experiments in anchor regions and west barrier region were performed. In addition, the power transmission circuit of ICRF power amplifier was modified to drive two ICRF antennas for the central plasma heating. The obtained heating effect was equivalent to the standard one when the total powers were adjusted to the same. By using the ECH system in the plug/barrier cells, ITER relevant level heat flux of ~10 MW/m^2 at the end-cell has been obtained in an early stage of the collaboration research (2012). In Fig. 2 the heat flux measured at the end-mirror exit is plotted as a function of the ECH power. In autumn FY2016, installation of new antennae was completed in east and west plug ECH and we achieved the highest heat flux of 30 MW/m^2 by superimposing a short pulse of ECH into the ICRF-heated plasma. Recently, the divertor simulation experimental module (D-module) has been installed on the west end of the device. This module has a closed divertor structure and a V-shaped target plate made of tungsten. Several kinds of radiator gasses (N_2, Ne, Ar, Kr and Xe) are injected into D-module and detailed comparison in suppression performance of particle and heat fluxes and reduction of T_e showed that Xe was most effective on electron cooling and generation of plasma detachment.

The development of high power gyrotrons has also progressed. Figure 3 shows the summary of gyrotron development in Univ. Tsukuba. The first experimental test of new 28/35 GHz dual-frequency gyrotron (2 MW 3 s and 0.4 MW CW) for QUEST, NSTX-U, Heliotron J and GAMMA 10/PDX was performed. The main mode oscillations were confirmed at the frequencies of 28.032–28.045 GHz with a Gaussian-like beam. The output power of 1.25 MW was obtained at the beam current of 51.5 A with the output efficiency of 30.8%. The dependencies of the cavity magnetic field and anode voltage on the output power were measured at the output power of 1 MW. These characteristics were confirmed to be in their normal ranges. The total efficiency increased with the Collector Potential Depression (CPD) voltage and the maximum total efficiency of 50% was achieved. The oscillation in the 34.8 GHz mode was observed at the frequency of 34.82 GHz with a Gaussian-like beam. The design of the RF transmission system was confirmed to be correct. The output power and efficiency at the frequency of 34.8 GHz were 0.48 MW and 12.2%, respectively, for the beam voltage of 80 kV and the beam current of 49.3 A.

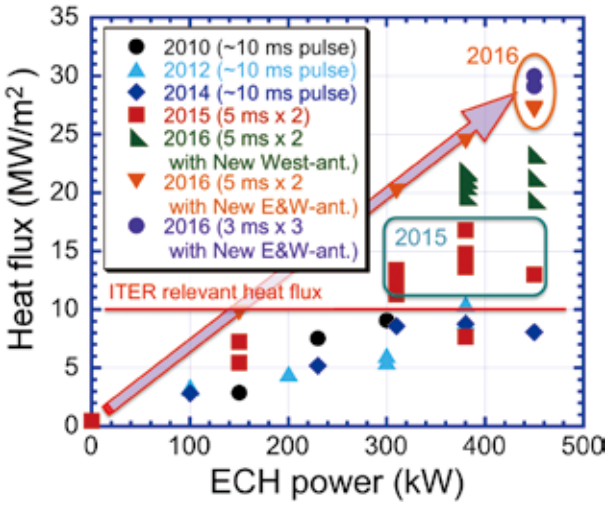

Fig. 2 ECH power dependence on the heat flux measured at the end-cell

In the tandem mirror GAMMA 10/PDX, the yttrium-aluminium-garnet (YAG)-Thomson scattering (TS) system has been constructed for electron temperature and density radial profiles. We can successfully measure the radial profiles of electron temperature and density at seven radial positions in a single laser shot in the central cell of GAMMA 10/PDX. By using the high-speed oscilloscopes and their data collection program, we can measure the time dependent electron temperatures and densities every 100 ms in a single plasma shot. Moreover, in order to increase the TS signal intensities, we have constructed a multi-pass TS system of the polarization-based system with image relaying optics. The clear multi-pass TS signals from first to eighth passing lasers through the plasma were successfully obtained. About the five times larger TS signal intensity was indicated. For the D-module experiments, we started to construct the end-TS system that contained a back scattered collection optics, a bundled optical fiber, and a filter-type polychromator.

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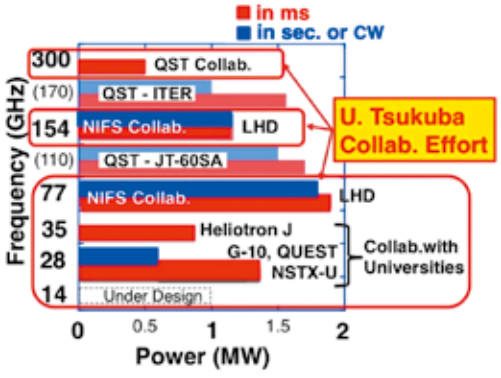

Fig. 3 Summary of the MW gyrotron development in Univ. of Tsukuba