# §6. 28GHz ECH Experiment and 14GHz, 28/35GHz Gyrotrons Development for Cooperation Study of SDC-plasma

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The final purpose of this collaborative program is the progress of the electron heating study such as the electron Bernstein wave (EBW) heating in super dense core (SDC) plasma. For the first step of this study, the Tsukuba 28 GHz 1 MW gyrotron was adapted to QUEST of Kyushu University and the plasma heating effect was demonstrated. The successful results were obtained that the over dense plasma production more than $1\times10^{18}\,\mathrm{m}^{-3}$ which was higher than cut-off density at 8.2 GHz and EC-driven plasma current of 60 kA in QUEST plasma experiment. The electron temperature was 80 eV[1].

In 2015 experiment, the first 28GHz 1 MW gyrotron developed for GAMMA 10/PDX was achieved the output power of 1.38MW as shown in Fig. 1 after the power supply was improved. Design study of a 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 has been completed[2] and bake-out and pinch-off of the gyrotron has finished in the end of April 2016. The first test start is scheduled in June 2016. This dual-frequency gyrotron has a sapphire double-disk window to enable CW operation. The structural cross-section of double-disk window is shown in Fig.2. A frequency characteristic of a double-disk window depends on the thickness (depends on manufacturing error) and permittivity (depends on frequency) of the sapphire disk and the fluorocarbon coolant (FC-3283). A frequency characteristic of a double-disk window can be adjusted by the thickness of fluorocarbon coolant. Before installing a double-disk window in dual-frequency gyrotron, we confirmed its dependence of reflective power on the coolant thickness by the cold test using gunn diode oscillator power (1 mW) and the hot test using the gyrotron output power (600 kW), as shown in Fig.3 and Fig.4 respectively. The absolute value differences of the reflectance in the cold test are the cause of the interference effect by the diverging incident waves or the reflection waves. In the hot test, the reflective power was less than 2 % at the coolant thickness of about 4 mm. The calculated absorbed power of double-disk window is less than 1 %. The best adjustment of the coolant thickness will be performed after installing in the dual-frequency gyrotron. In addition, uniform flow of coolant on the sapphire surface which is important to high cooling efficiency was confirmed. About the inlet and outlet structure of coolant, the 6×50 mm$^2$ rectangular structure was better than φ 6 pipe structure to obtain a uniform flow and a lower pressure loss. Until the CW operation test of dual-frequency gyrotron, the pressure loss of the cooling system will be reduced further. At the CW operation test, the window temperature will be measured with an IR camera. We hope that the construction of this 28 GHz 2 MW dual-frequency gyrotron contributes to the great measure of the collaborative studies of the ECH plasma experiment of QUEST, NSTX-U and Heliotron J as well as the GAMMA 10/PDX experiment.

In addition, the design study of 14 GHz gyrotron for GAMMA10/PDX and QUEST has been continued.

1) H. Idei, et al., in Proceedings of the 25th IAEA Fusion Energy Conf., (2014).
2) T. Kariya, et al. Nucl. Fusion 55 (2015) 093009.

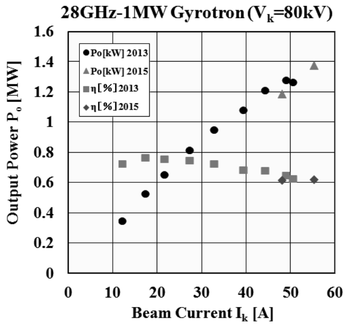


Fig.1 Beam current dependence of output power and efficiency with beam voltage of 80 kV.

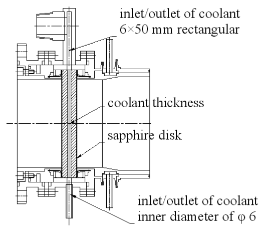


Fig.2 Structural cross-section of the double-disk window of the new 28/35 GHz dual-frequency gyrotron.

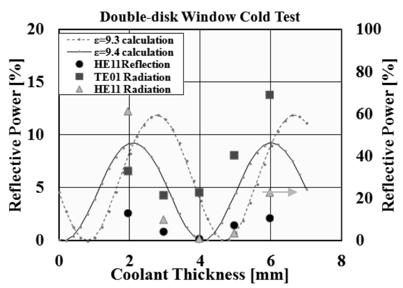


Fig.3 Reflective power dependences on coolant thickness using gunn diode oscillator power (1 mW) of the new dual-frequency gyrotron window.

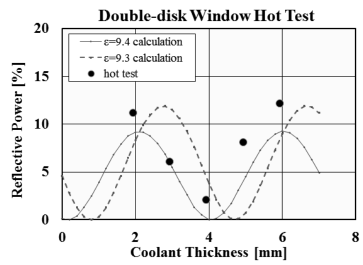


Fig.4 Hot test result of the reflective power dependences on coolant thickness using gyrotron power (600 kW).