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Study of Sub-Terahertz high power gyrotron for ECH&CD system of DEMO
原型炉用電子サイクロトロン加熱電流駆動システムに向けた大電力サブテラヘルツジャイロトロンの研究

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For the Electron cyclotron resonance heating and current drive (ECH&CD) system on DEMO reactor, the mm-wave of more than 200 GHz is expected. To increase the gyrotron frequency, extremely high-order oscillation mode should be adopted to suppress the Ohmic loss on the resonator wall to less than ~20 MW/m^2. Here, we designed and fabricated a 300 GHz gyrotron of $TE_{32,18}$ mode oscillation and started a short pulse experiment to investigate the oscillation characteristics of the high order mode at ~300 GHz. As a preliminary result, we demonstrated the power generation of ~0.5 MW at ~300 GHz oscillation at the oscillation mode of $TE_{32,18}$, and other modes.

1. Introduction

In the research and development of high power long pulse gyrotron for fusion application, 170 GHz has been the maximum frequency, which is required for the power source of ECH&CD system on ITER. On the R&D of ITER 1MW gyrotron, the stable, high-efficiency single-mode oscillation was demonstrated at the 1 MW-170 GHz with the operation modes $TE_{31,8}$ [1]. On the other hand, for the DEMO reactor, a high power CW gyrotron at the frequency f=200~300 GHz is expected to increase the current drive efficiency [2]. As the heat load by the Ohmic loss on the resonator wall increases roughly with $f^{2.5}$, the high-order oscillation mode is required to suppress the heat load to the acceptable level ~20 MW/m^2. In JAEA, a study of ~200 GHz is planned utilizing a prototype ITER gyrotron of $TE_{31,11}$ (170 GHz) mode. This gyrotron has a multi-frequency operation capability, i.e., the long pulse 203 GHz Gaussian beam power generation is possible by the excitation of $TE_{37,13}$ mode. Another activity toward the DEMO gyrotron is an investigation of the oscillation characteristics at ~300 GHz with the extremely high order mode. As an initial step of a "sub-Terahertz" gyrotron development that is capable of 300 GHz >0.5MW CW operation, we

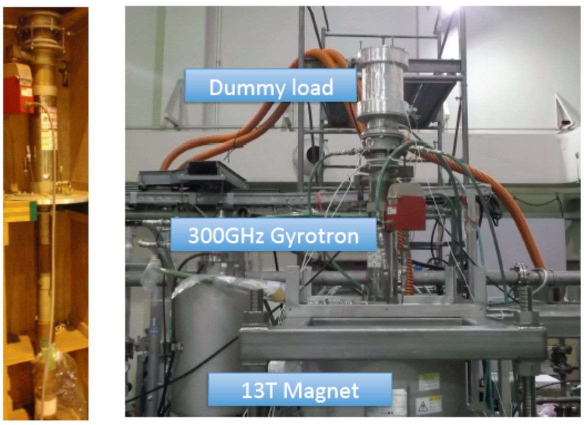

Fig.1 Picture of the gyrotron (left) and gyrotron test stand of University of Tsukuba (right).

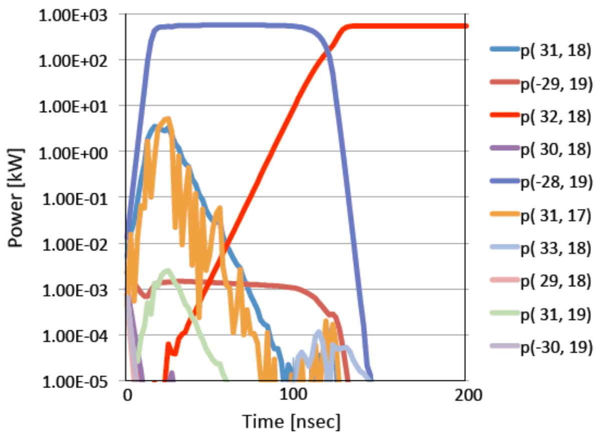

Fig.2 Simulation result of multi-mode oscillation. The target mode of $TE_{32,18}$ at 300 GHz and its neighbor modes are taken into account. Single mode excitation is realized after 130 ns. Here, beam energy 70 keV, beam current 30 A, pitch factor 1.2, cavity field 11.85 T, beam radius 5.6 mm are given.

designed and fabricated a short pulse gyrotron of $TE_{32,18}$ mode oscillation that output the power as the oscillation mode from the top of the gyrotron. The high power experiment was carried out on the gyrotron test stand of University of Tsukuba. In this paper, the design of the short pulse 300 GHz gyrotron and preliminary experimental results are reported.

2. Design and Experimental set-up

2.1 Short pulse gyrotron and experimental setup

A picture of the 300 GHz gyrotron is shown in Fig.1 (left). A height is ~2 m. The electron gun is diode type magnetron injection gun (MIG), and a diameter of an emitter is 74 mm. The resonator is a conventional open cavity. The diameter of the cavity is 31.6 mm, which corresponds to the 300 GHz oscillation with $TE_{32,18}$ mode. This mode is capable of 0.5 MW/300 GHz at CW operation. The distance from the emitter to the resonator is ~520 mm. The electron beam after the RF-beam interaction in the resonator proceeds along the magnetic field and absorbed at the collector. The mm-wave power is transmitted by the collector as the waveguide, and outputted at the oscillation mode through the sapphire window of 102 mm in diameter. A super-conducting magnet (SCM) is a 13 T liquid-He-free-magnet, which has a room temperature bore diameter of 110 mm. The 300 GHz gyrotron is inserted in the SCM. The beam radius at the cavity is adjusted by the magnetic field around the MIG using a normal conductor coil that is placed around the MIG. A dummy load is put on the top of the gyrotron to absorb and measure the output power.

2.2 Multi-mode simulation

Figure 2 is one example of the result of multi-mode simulation. The beam energy and current are 70 keV, 30 A, respectively, and a pitch factor of the electron beam is 1.2. By setting the cavity field 11.85T and the beam radius 5.6 mm, the single mode oscillation of $TE_{32,18}$ mode (300 GHz) is realized. Other competing modes are nonlinearly suppressed by the main mode. By changing the parameters, other modes dominate the oscillation.

3. Experimental results

Figure 3 is a result of the cavity field dependence of the output power P_o. The applied beam voltage is 80 kV, and the beam current is 36.8 A. Pulse duration is ~2 msec. The MIG field is optimized to oscillate the target mode. The power peak around I_m=110 A (12.0 T) corresponds to the $TE_{32,18}$ mode. The peak at around I_m~107.5A (~11.73 T) is lower adjacent mode ($TE_{31,18}$). In Fig.4, the beam current dependence of the output power is shown. The output power increases with the beam current, and 0.5 MW was obtained. It is a first demonstration of the 0.5 MW power output at 300 GHz using a CW relevant high order mode ($TE_{32,18}$).

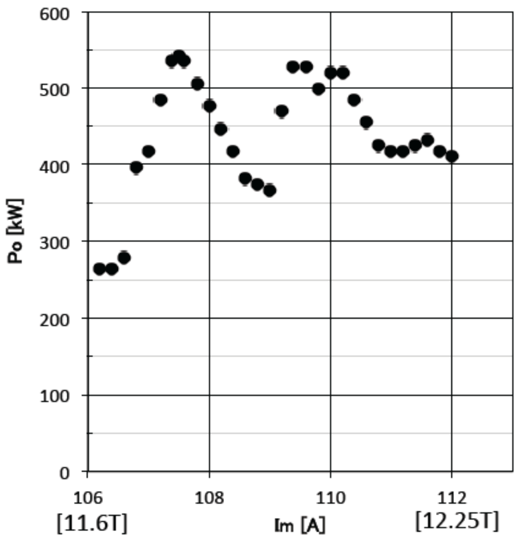

Fig.3 Output power vs. cavity field. Beam voltage 80 kV, beam current 36.8 A. The peak at Im~110 GHz corresponds to the 300 GHz oscillation.

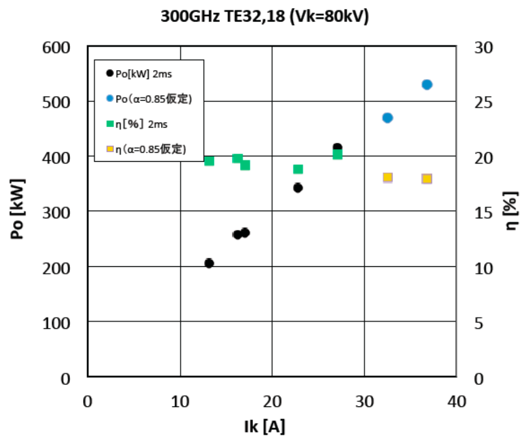

Fig.4 Output power of 300 GHz vs. beam current at $TE_{32,18}$ mode oscillation. Beam voltage is ~80 kV. Pulse duration is ~2msec.

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