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Development of 28/35 GHz Dual-Frequency and 14 GHz Gyrotrons for Advanced Fusion Devices

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ABSTRACT

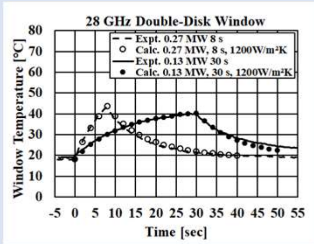
- **28/35 GHz dual-frequency gyrotron** (1.65 MW at 28 GHz has achieved)
  Cooling characteristics of a double-disk sapphire window were evaluated.
  Output power of 0.13MW with 30 s was demonstrated at 28 GHz.
  Comparing the experimental results with the calculated results, the capability of 0.4 MW CW at 28 GHz has been confirmed.
  Transmission efficiencies of the CW dummy load and plasma injection port were measured.
- Development of the **14 GHz gyrotron** which has difficulty issue with a high divergence RF beam is in progress.

BACKGROUND

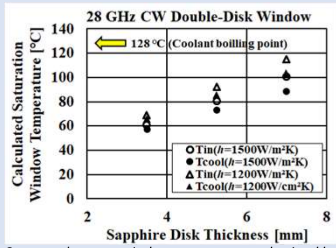
- The gyrotron is an effective and essential tool for ECH, ECCD and EBW.
- Currently, we are collaboratively developing MW-class gyrotrons, which encompass a wide frequency range (14–300 GHz), to be incorporated into existing and future fusion devices.
- In the relatively low-frequency region of 14–35 GHz, technical difficulties occur as compared with in high-frequency regions because of the long wavelength and large divergence of the RF beam.
- A 28 GHz gyrotron #1 (output power of 1.38 MW was achieved) was applied to the QUEST (Kyusyu University). An unprecedented electron-cyclotron driven plasma current of approximately 80 kA was non-inductively achieved via a 28 GHz injection
- New 28/35 GHz dual-frequency gyrotron for QUEST, NSTX-U, Heliotron J, and GAMMA 10/PDX, a non-saturated output power of 1.65 and 1.21 MW were observed at frequencies of 28.036 and 34.83 GHz, respectively.

Design parameters of Tsukuba gyrotrons

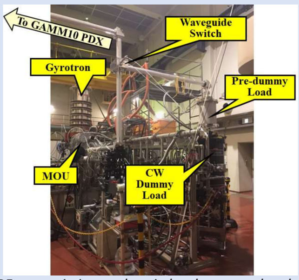
	14 GHz Gyrotron	28/35 GHz Dual-frequency Gyrotron		
Frequency	14 GHz	28 GHz		34.77 GHz
Output Power	> 1 MW	2 MW	0.4 MW	1 MW
Pulse Width	> 5 s	3 s	CW	3 s
Output Efficiency	35% (with CPD)	50% (with CPD)		
Beam Voltage	75–80 kV	80 kV	70 kV	80 kV
Beam Current	50 A	70 A	20 A	40 A
MIG	Triode	Triode		
Cavity Mode	$TE_{4,2}$	$TE_{8,5}$		$TE_{10,6}$
Output Mode	$HE_{1,1}$ Waveguide Mode	Gaussian-like		
Output Window	Sapphire Double Disk	Sapphire Double Disk		
Collector	Depressed Collector (CPD)	Depressed Collector (CPD)		
	Sweeping Coils	Sweeping Coils		



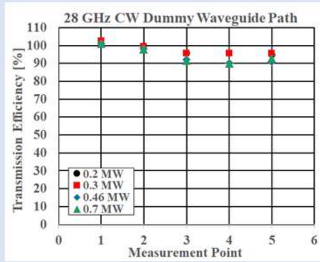
Measured and calculated window temperature dependencies on gyrotron operation time.



Saturated output window temperature obtained by calculation based on sapphire disk thickness.



RF transmission path switches between the plasma injection path and CW dummy load path.



Transmission efficiencies at each measurement point up to CW dummy load inlet (measurement point 5).

28/35 GHZ DUAL-FREQUENCY GYROTRON

Experimental Test for Demonstration of 0.4 MW CW Operation

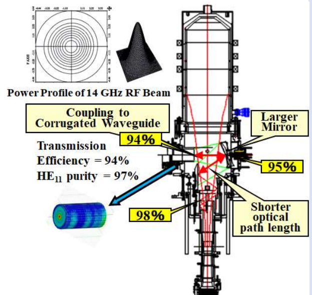
- Time evolutions of the output window temperatures of the gyrotron for the 28 GHz operation was measured by IR camera and calculated.
- In the 0.13 MW, 30 s operation, the measured window temperature increased during the operation period and tended to saturate at approximately 42 ℃.
- Heat transfer coefficient h from the sapphire disk to the coolant was estimated by comparing the calculated results and experimental measurements using three operation parameters (0.13 MW, 30 s; 0.22 MW, 10 s; and 0.27 MW, 8 s), and h was estimated to be 1200–1500 W/m^{2}K.
- When h was 1500 W/m^{2}K, T_{cool} for the 6.98 mm sapphire disk can be reduced (89 ℃). If only a 28 GHz oscillation gyrotron is considered without the 35 GHz oscillation, then the window thickness for frequency matching can be set to 3.49 mm. In this case, T_{cool} can be suppressed to 57 ℃. These results confirm the operation of a 0.4MW CW at 28 GHz is possible.
- The output power and pulse width were limited by the cooling water flow rate of the water load, collector, and power supply. the cooling system was reviewed and improved to demonstrate a 0.4 MW CW operation.
- A waveguide switch was newly introduced such that both the 0.4 MW CW gyrotron test and the GAMMA 10/PDX plasma experiment can be performed efficiently without disassembling and assembling the waveguides.
- The total transmission efficiency was approximately 95% and 70% at the CW dummy load inlet and plasma injection port, respectively.

Plasma Experiment at 28 GHz Using Dual-frequency Gyrotron

- Using this dual-frequency gyrotron, a 28 GHz fundamental ECH experiment was performed in the GAMMA10/PDX plasma. A high heat flux generation experiment to simulate edge localized modes (ELMs) was performed with a higher injection power of 0.55 MW (0.86 MW at the gyrotron output window) for 5 ms. The ECH experiment to produce higher density plasma was performed using a longer pulse width of 100 ms at a power of 0.25 MW.
- In the high-density plasma production experiment for simulating high density operation on the pilot GAMMA PDX-SC in University of Tsukuba, the line density increased with the pressure of the gas puff. This finding is useful for the ECH of the new project.

14 GHZ 1 MW GYROTRON

- For a 14 GHz RF beam with high divergence, a calculated transmission efficiency of 94% to the corrugated waveguide coupling position was initially obtained by introducing the design concept of the direct coupling by built-in waveguide and adjusting the mirror positions to minimize the RF transmission path.
- To optimize the output efficiency, a built-in corrugated waveguide design is in progress using a three-dimensional full-wave electromagnetic field simulator HFSS.
- Calculated mode purity of HE_{11} at the coupling position (aperture diameter of 88.9) is 97%. In addition to a linear corrugated waveguide, a conical or Gaussian profiled corrugated waveguide study is planned to taper down toward the diameter of 63.5 mm.



14 GHz gyrotron

CONCLUSION

- Comparing the experimental results with the calculated results, the capability of 0.4 MW with CW at 28 GHz has been confirmed.
- After demonstration of 0.13 MW 30 s, the cooling system and RF transmission system were reviewed and improved for the 0.4 MW CW operation of the gyrotron and plasma injection at GAMMA 10/PDX.
- Using dual-frequency gyrotron, ECH experiment was performed in the GAMMA10/PDX plasma. Useful results for the ECH in the pilot GAMMA PDX/SC which is being constructed were obtained.
- Manufacturing of the 14 GHz gyrotron parts is in progress along with the built-in corrugated waveguide design for optimizing the output efficienc.

ACKNOWLEDGEMENTS

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