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Development of a high frequency gyrotron with an internal mode convertor
モード変換器内蔵高周波数ジャイロトロンの開発

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Gyrotron FU CW GII has been developed in Research Center for Development of Far-Infrarred Region, University of Fukui (FIR FU). It is the second gyrotron with an internal mode convertor, developed in FIR FU. It operates at 393 GHz at the second harmonic resonance. Measured output power was 74 W. An almost linearly polarized Gaussian-like beam was successfully delivered from the vacuum window. In addition, fundamental resonance oscillations with more than one hundred W output power were observed in the frequency range of 200 GHz. This gyrotron will be a power source radiating useful Gaussian-like beams with two different frequency bands around 200 and 400 GHz.

1. Introduction

In FIR FU, a lot of high-frequency gyrotrons have been developed as sources in the millimeter and sub-millimeter wave range. However, they were a linear type with axial output coupling. In this type of gyrotron, the electromagnetic wave which oscillates in the cavity resonator transmits to the top window through the waveguide, maintaining the complex spatial structure of the field (so-called, circular waveguide mode) and radiates through the window with the same structure. Such a beam is unsuitable as a power source for various applications. Then we have started development of another type of gyrotrons with an internal quasi-optical mode convertor. Our first gyrotron of such a kind is Gyrotron FU CW GI [1], which operates at the fundamental cyclotron resonance with a frequency of 203 GHz. The measured maximum power was 0.5 kW. The results have been reported at annual meetings of the plasma-fusion society of Japan and the physical society of Japan. The second gyrotron of this type has been developed. It is called Gyrotron FU CW GII. The designed frequency is 394.6 GHz, corresponding to the ESR frequency for 600 MHz DNP-NMR.

2. Gyrotron FU CW II

The photograph of Gyrotron FU CW GII is shown in Fig. 1. It is installed on an 8T superconducting magnet. It is a sealed-off type gyrotron. Selection of the oscillation mode and design of the cavity dimension were carefully carried out. As the oscillation mode, $TE_{8,3}$ mode has been selected. Although it has a competing mode $TE_{3,5}$, it can oscillate as long as the electron incident radius is properly set. Cavity radius and length were determined to 2.15 and 17 mm, respectively. An existing electron gun with 4.5 mm cathode radius is reused. A quasi-optical mode convertor consists of a conventional helical cut waveguide and four mirrors.

A radiation pattern of the power launched from the gyrotron window was measured as shown in Fig. 2. A circular pattern was observed. Polarization measurement of this beam was carried out. Wave signal intensity through a polarizer, consisting of metal wires, was observed with a pyro-electric detector. Figure 3 shows the signal intensity against

Fig. 1 Gyrotron FU CW GII

the rotation angle of the polarizer, θ, where θ is the angle between the wire direction and the vertical line. The dependence of the observed signal on θ agrees with $\cos^2\theta$. This guarantees the polarization is almost linear. The direction of the electric field is horizontal in Fig. 2.

Operation test was carried out for some range of the magnetic field strength B at the cavity. Signal intensity measured with a power-meter which is usually used for infrared lasers is shown in Fig. 4. A peak around B = 7.2 T represents the signal of $TE_{8,3}$ mode. There appear several signals from other cavity modes. The measured frequencies corresponding to the four peaks in Fig. 4 are 189.1, 393.4, 398.9, and 205.6 GHz, respectively. Based on the measured frequencies, oscillation modes have been identified as $TE_{1,3}$, $TE_{8,3}$, $TE_{1,6}$ and $TE_{4,2}$, respectively, as labeled in Fig. 4. $TE_{8,3}$ and $TE_{1,6}$ modes operate at second harmonic and $TE_{1,3}$ and $TE_{4,2}$ at fundamental. In spite that the internal convertor has been designed for the co-rotating $TE_{8,3}$ mode, circular radiation patterns are observed for all of these modes. In particular, the wave beam of $TE_{4,2}$ is radiated through the almost center position of the window. We showed that the beam direction is related with the quantity m/χ'_{mn} of the cavity mode, where m is the azimuthal number and χ'_{mn} is n-th zero of $J'_m(z)$. The values of m/χ'_{mn} for $TE_{8,3}$ and $TE_{4,2}$ are 0.45 and 0.43, respectively. Thus the present result agrees with the previous observation [2].

Radiation power from the window was evaluated with a water load. The maximum observed power was 74, 140 and 110 W for $TE_{8,3}$, $TE_{4,2}$ and $TE_{1,3}$ modes, respectively. The operation cathode voltage and the beam current are around -18 kV and 0.5 A, respectively. It is reasonably to consider that the actual powers radiated from the window are higher than these measured values because we neglected the heat capacity of the water vessel and assuming that all the power was absorbed by the water load. Since the cavity length has been optimized for the second harmonic oscillation, the efficiency of power conversion is lower for fundamental oscillations. However, the power of the fundamental modes exceeds 100 W. Thus, this gyrotron can radiate useful Gaussian-like beams with two different frequencies around 200 and 400 GHz. Much higher powers are expected if we use electron guns specially optimized for the gyrotron.

3. Summary

We have developed Gyrotron FU CW GII, our second gyrotron with the internal mode convertor. It radiates a circular shaped beam with 100 W output power. This gyrotron can be used as a radiation source with two different frequency bands around 200 and 400 GHz.

References

[1] Y. Tatematsu, Y. Yamaguchi, T. Idehara et al: Proc. 36th IRMMW-THz, Th2A.5 (2011) .
[2] Y. Tatematsu, T. Saito, T. Ozeki, S, Hashimoto, Proc. 35th IRMMW-THz, We-P.14 (2010).

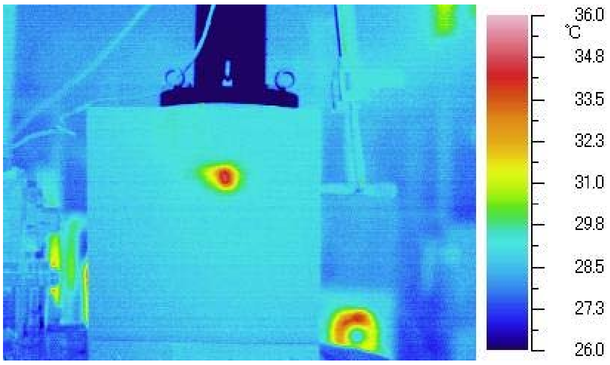

Fig.2. Radiation pattern from FU CW GII measured with an IR camera.

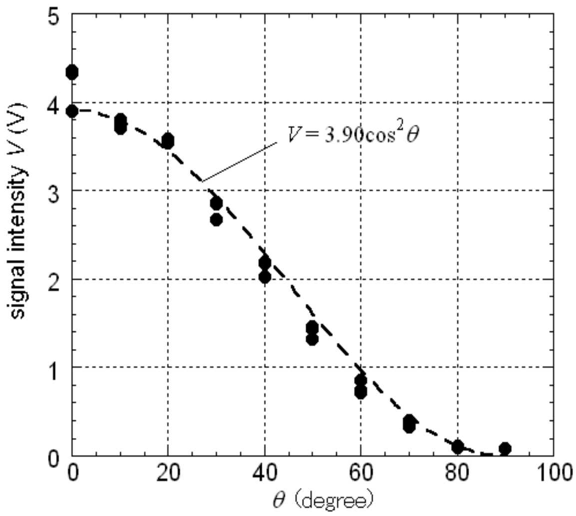

Fig.3. Polarization measurement of the radiation beam. Signal intensity was observed with a pyro-electric detector through a polarizer, whose wire direction rotates by θ.

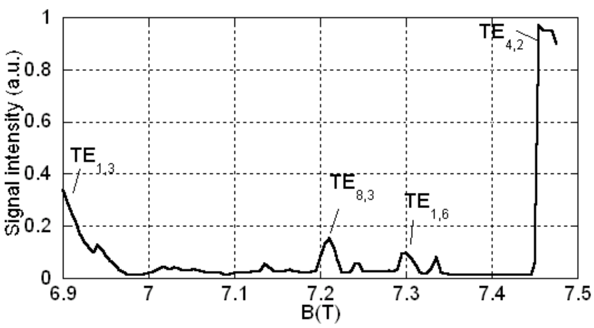

Fig.4. Measured signal intensity at the window. Attached labels indicate oscillation modes in the cavity.