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Oscillation Characteristics of a 400 GHz Band Frequency Tunable Gyrotron FU CW GIV

400 GHz 帯周波数連続可変ジャイロトロン FU CW GIVの発振特性

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At FIR center, Univ. Of Fukui, development of advanced sub-THz band gyrotrons is in progress. As a part of this, a frequency continuously tunable gyrotron, Gyrotron FU CW GIV, was developed. It oscillates in the 400 GHz band at the second harmonic cyclotron resonance frequency. The frequency tunability is achieved by operating it in the oscillation region of a gyro-backward wave oscillator (gyro-BWO). Continuous frequency variation around 3 GHz was obtained. In addition a Gaussian beam converted by the internal mode converter was successfully observed.

1. Introduction

Recently, gyrotrons are used in various studies of the material science, such as electron spin resonance (ESR) spectroscopy [1], sensitivity enhancement of nuclear magnetic resonance via dynamic nuclear polarization (DNP/NMR) [2, 3] and so on. In those applications, gyrotrons should have broadband frequency tunability with a required output power. At FIR center, University of Fukui, continuous frequency tunable tubes for 600 MHz DNP/NMR have been developed [4, 5]. In the design process of the gyrotrons, the theoretical consideration by using a self-consistent code [6] is started. The first gyrotron tube designed with this code is Gyrotron FU CW X [7, 8], which has no mode-convertor. Following it, a new tube equipped with an internal mode converter, gyrotron FU CW GIV, was developed as the fourth gyrotron of the Gyrotron FU CW G-series[REF]. It is expected that the application fields of the gyrotrons will be expanded by the realization of the gyrotrons combining both the functions of frequency tunability and Gaussian beam output.

2. Frequency tunability via gyro-BWO operation

The oscillation frequency of gyro-devices is determined by satisfying two conditions; the wave dispersion in the cavity waveguide and the resonance condition between electrons and the oscillation wave. They are written as

$$\omega = c\sqrt{k_\perp^2 + k_\parallel^2}, \qquad (1)$$

and

$$\omega = s\Omega_c + k_\parallel v_\parallel. \qquad (2)$$

Here, ω is the wave angular frequency, c is the speed of light, $k_\perp$ and $k_\parallel$ are perpendicular and parallel components of the wave number, respectively, s is resonance harmonic number, Ω_c is the cyclotron angular frequency ($\Omega_c = eB_c/m_e\gamma$), and $v_\parallel$ is the parallel component of the electron velocity. They are graphically indicated in Fig. 1. Oscillation occurs near a cross-point of the two curves. When the cavity magnetic field strength B_c is continuously changed, the cross-point continuously moves on the curve (1) so that the wave frequency will change. In the cold cavity model, the frequency has discrete values because only discrete values of $k_\parallel$ satisfying the boundary condition are permitted. However, in the case taking account of electron contributions, continuous change of $k_\parallel$ is permitted in the region of $k_\parallel < 0$ [9], i.e. the gyro-BWO region.

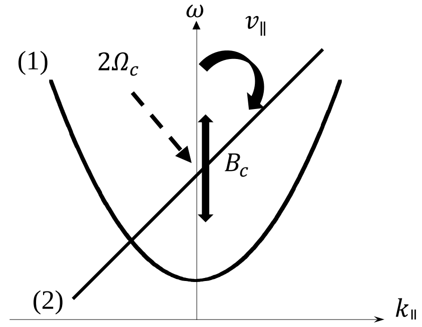

Fig1. Determination of the wave frequency.

Thus, the wave frequency can change continuously. The frequency change is also achieved by changing $v_{\parallel}$.

3. Gyrotron FU CW GIV

Gyrotron FU CW GIV with an internal mode converter was designed as a second harmonic gyrotron with more than 1 GHz tunable range in the 400 GHz frequency band. The shape of the cavity is that of the normal gyrotron having a straight cylindrical section with a diameter of 5.962 mm and a rather long length of 35 mm, and accompanied with the up- and down-tapers at the both ends of the straight section. It was designed on the basis of the theoretical calculations with the self-consistent code. In the calculations with this code, the wave frequency is almost continuously varied for changing the cavity magnetic field strength, but stepwise change in frequency appears in some places, where the axial index number of the electric field profile is changed [8].

4. Experimental results

Oscillation characteristics of Gyrotron FU CW GIV was examined. The wave frequency was measured with a heterodyne receiver system with changing B_c. The result is shown in Fig. 2. The frequency around $B_c = 7.18$ T is almost constant, because it the normal gyrotron operation is expected. As B_c increases, the measured frequency increases. It changes almost continuously. However, small stepwise change is also observed in some places. In addition, multi-frequency branches were observed around $B_c = 7.25$ T. For the larger B_c, the changing rate of the frequency against B_c increases. As the result, a frequency tunable band of about 3 GHz was obtained.

The radiated beam pattern was measured with an IR camera. The result is shown in Fig.3. The pattern with an on-axis peak was obtained as expected.

5. Summary

A frequency tunable gyrotron in the 400 GHz band was developed. In the frequency measurement, frequency tunability of around 3 GHz was achieved by changing the cavity magnetic field strength. In addition, it was confirmed that the beam radiated from the gyrotron window has a Gaussian shape.

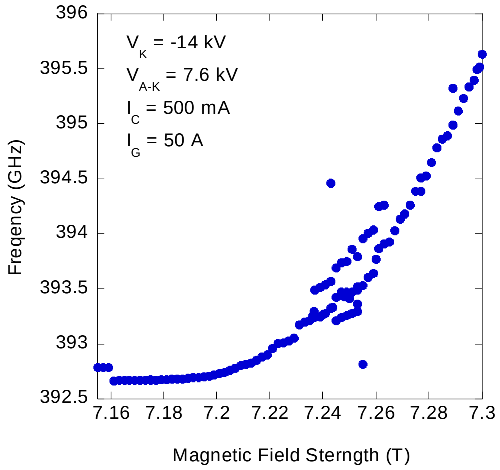

Fig.2 Dependence of measured oscillation frequency on the cavity magnetic field strength.

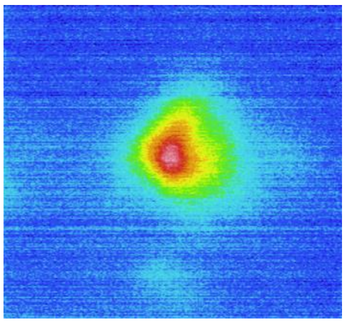

Fig.3 Measured pattern of the radiation beam.

References

[1] T. Tatsukawa *et al.*, 19th Int. Conf. on IRMMW, 395 (1994).

[2] T. Idehara *et al.*, J Infrared Milli Terahz Waves **31**, 775 (2010).

[3] A. C. Torrezan *et al.*, IEEE Trans. Terahz Sci. Tech. **58**, 2777 (2011).

[4] T. Idehara *et al.*, Int. J. Infrared Milli Waves **31**, 763 (2010).

[5] T. Idehara *et al.*, Int. J. Infrared Milli Waves **31**, 775 (2010).

[6] O. Dumbrajs et al., Jpn. J. Appl. Phys. **51**, 126601 (2012).

[7] Y .Yamaguchi et al., 38th Int. Conf. on IRMMW-THz, Mo Pl-53 (2013).

[8] Y .Yamaguchi et al., Proc. of 5th IW-FIRT, p.69 (2014).

[9] Y. Tatematsu et al., Phys. Plasmas **21**, 083113 (2014).