Development of THz gyrotron using a 20 T superconducting magnet

K. Kosuga[1], T. Idehara[1], R. Ikeda[1], I. Ogawa[1], S. Mitsudo[1], T. Saito[1],
La Agusu[2] and M. Thumm[3]

[1]Research Center for Development of Far-Infrared Region, University of Fukui
Bunkyo 3-9-1, Fukui-shi 910-8507, Japan
[2]Haluoleo University
Gedung FMIPA Kampus Bumi Tridharma Anduonohu Kendari - Indonesia 93232
[3]Karlsruhe Institute of Technology, Association EURATOM-KIT[3]
Institut für Hochfrequenztechnik und Hlektronik Kaiserstr. 12, D-76131 Karlsruhe, Germany
kosuga@fir.u-fukui.ac.jp

Abstract

In the Research Center for Development of Far Infrared Region, many high frequency gyrotrons for high power technologies have been developed. In order to utilize gyrotrons as light sources in the THz region, we are carrying out the development of higher frequency gyrotrons. In the first THz-gyrotron experiment, we already obtained the result exceeding 1 THz radiation using a pulse magnet system [1]. However, this gyrotron is not convenient for application ~~to~~ in high power technologies, since it can only be used for short pulse operation and the repetition rate is very low. Therefore, we are developing a cw gyrotorn named Gutrotron FU CW III using a 20 T superconducting magnet. The design of the cavity is the same as the one installed in a pulse magnet gyrotron, the cavity radius and length are 1.95 mm and 10 mm, respectively.

1. Introduction

In THz and sub THz region, there are a lot of high power technologies, for example, plasma diagnostics, electron spin resonance (ESR) spectroscopy, application of Dynamic Nuclear Polarization (DNP) to Nuclear Magnetic Resonance (NMR) spectroscopy, new medical technology and so on. There are some radiation sources in this region, for example, BWOs, molecular lasers, free electron lasers to name a few [2]. However, the first two devices are not able to attain high power radiation and the last devices not convenient to apply in high power technologies because they are huge. On the other hand, Gyrotrons are the most suitable oscillators to obtain high power and high stable radiation in this region. Therefore, a number of gyrotrons in sub-THz region have been developed in the Research Center for Development of Far-Infrared Region (FIR FU). At present, we are developing a higher frequency gyrotron operating in THz region.

The first THz-gyrotron, with a 21.5 T pulse magnet, was already developed and succeeded in its first breakthrough experiment of 1 THz. A second harmonic operation was achieved at the frequency of 1.005 THz [2]. However, this gyrotron is not convenient for application in high power technologies, since it can operate ~~in~~ only in short pulse and the repetition rate is very low, only every 10 minutes.

In order to resolve these problems and achieve the application of gyrotrons to high power THz technologies, cw gyrotron series named Gyrotron FU CW Series is being developed in FIR FU.

2. Development of CW THz Gyrotron

The Gyrotron FU CW III was designed and constructed using a 20 T superconducting magnet. The bore diameter is 51 mm and the height is 1565 mm from the bottom to the top of the vessel. It was designed and constructed by JASTEC Co. The installed cavity has the same dimensions as the cavity of a pulse magnet gyrotron. The cavity radius and length are 1.95 mm and 10 mm, respectively (Fig.1). The designed cavity mode is $TE_{4,12}$ at the frequency of 1.013.66 THz by second harmonic operation [3].

Figure 2 shows the starting current calculation result of the fundamental and second harmonic operations as a function of the magnetic field intensity (the program of the starting current is made by Y. Tatematsu). The calculation parameters V_k (cathode voltage) is -21 kV, R_b (injection radiuses) is 0.343 mm (Fig. 2), and pitch factor is 1.2. In Fig. 2, the dashed lines are the fundamental operations and the solid lines are the second harmonic operations.

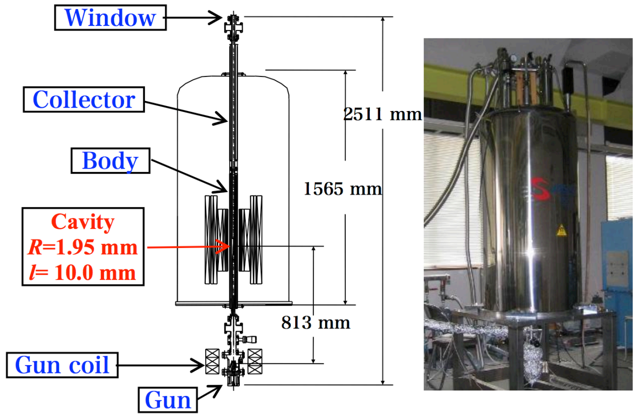

Fig 1. The cross section and exterior of Gyrotron FU CW III

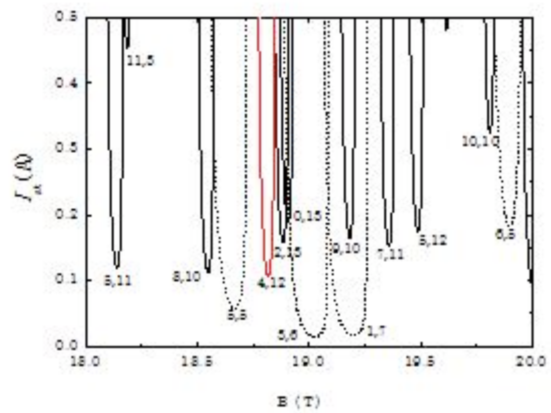

Fig.2 Starting current

Figure 3 shows the result of mode competition calculation taking into account $TE_{4,12}$, $TE_{2,12}$, $TE_{6,11}$ modes at second harmonic, and $TE_{3,6}$,$TE_{5,5}$ at fundamental. After 120 nsec, $TE_{4,12}$ mode is expected to radiate without mode competition with other modes.

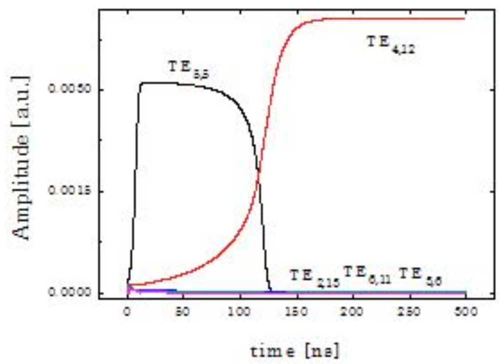

Fig.3 The result of mode competition calculation taking into account $TE_{4,12}$, $TE_{2,12}$, $TE_{6,11}$ modes at second harmonic, and $TE_{3,6}$,$TE_{5,5}$ at fundamental. Here V_k = -21 kV, R_{inj} = 0.343 mm, and α = 1.2 B = 18.75.

3. Result

Figure 4 shows the first experimental result that is the radiation power as a function of magnetic field intensity. The radiation power was measured by a pyro-electric detector through an aperture (high pass filter) of diameter 0.3 mm, resulting to a cutoff frequency of 586 GHz. In the field intensity region greater than 19 T, three radiation peaks were observed. These peaks or at least one peak is also expected in the second harmonic operation.

Figure 5 shows the measured and estimated frequencies for the observed radiations as a function of the magnetic field intensity. The triangular points show second harmonic operations and the circular points show fundamental operations. The oval area at the fundamental operation shows measured frequencies by a heterodyne system or a Fabry-Perot interferometer. The three signals above 19 T in the second harmonic operation (small oval area) are expected to achieve a breakthrough of 1 THz.

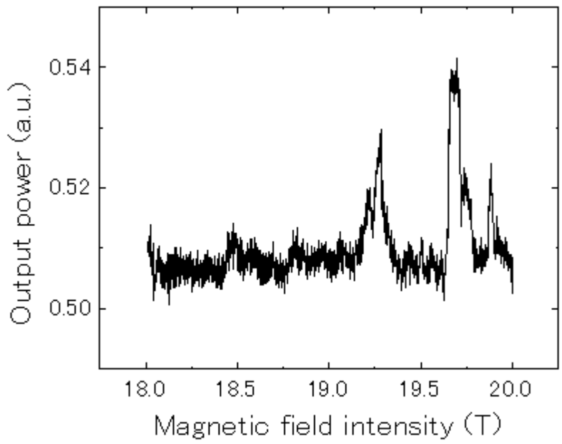

Fig.4 Radiation power by a pyro-electric detector with a high pass filter φ0.3 mm as a function of magnetic field intensity.

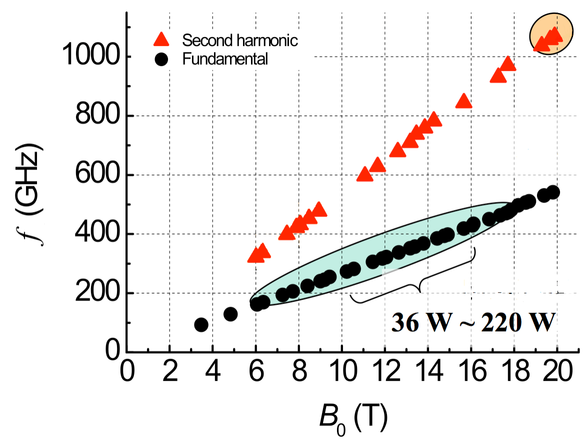

Fig.5 The measured and estimated frequencies as functions of magnetic field intensity.

4. Next plan

In order to utilize this new Gyrotron system for high power technologies, a Gaussian beam is desired for the transfer with high efficiency and irradiation to the sample with simple polarization.In order to obtain a high quality Gaussian beam, an output with high mode purity is required at the window. For the next step, we alreadydesigned and constructed a new resonator. The shape is illustrated in Fig. 6. The nonlinear up-taper is used in the new resonator.

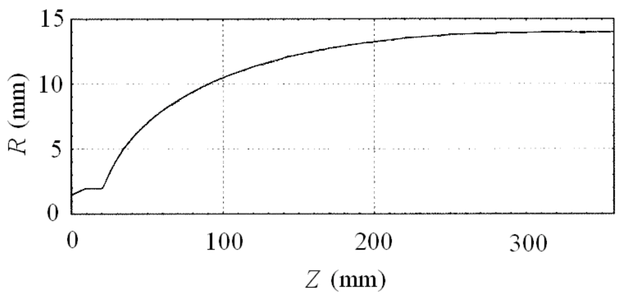

Fig.6 Nonlinear resonator geometry

The calculated mode purity at the end of the up-taper is higher 90 percent for several cavity modes, while it is around 50 percent for the resonator with a linear up-taper. Table 1 shows the results of the calculation on the mode purity of the new resonator for each mode. Here, fres is respective frequency, QD is diffraction Q, QΩ is Ohmic Q value, and Qtot is total Q value.

Table.1 Mode purity

mode m	p	harmonic	f_{res} (GHz)	mode purity (%)	Q_D	Q_Ω	Q_{tot}
1	6	1	440.99	99.44	9244	19195	6239
4	5	1	469.87	99.01	10721	19012	6855
5	5	1	503.61	99.71	12686	19361	7664
2	7	1	554.89	99.59	16058	21430	9179
3	8	2	668.36	99.33	26443	23418	12419
8	7	2	762.43	99.14	38558	23648	14658
5	9	2	816.99	99.19	48118	25619	16718
1	11	2	825.82	99.48	49578	26325	17195
4	10	2	859.04	98.89	56615	26524	18062
5	10	2	894.68	99.11	64401	26912	18980
10	9	2	987.90	97.49	93719	27050	20991
6	11	2	1007.67	98.01	101254	28487	22232
4	12	2	1013.66	98.37	104164	28919	22635
10	10	2	1067.07	97.85	127759	28375	23219

5. Summary

A THz CW operation gyrotron using a 20 T superconductor magnet named Gurotron FU CW III has been developed. The first experiment was carried out successfully. Several second harmonic operation powers were observed at the field intensity higher than 19.0 T. Theses radiation signals are expected to achieve a breakthrough of 1 THz. To obtain a high quality Gaussian beam, we already designed and constructed a new resonator. It is expected to obtain high mode purity for several cavity modes. The mode purity of the design mode $TE_{4,12}$ exceeds 98 % .

Reference

[1] T. Idehara, Int. J. Infrared Mili Waves 27, 319-331 (2006)

[2] La Agusu et al., Int. J. Infrared Milli Waves 28, 315-328 (2007).

[3] T. Idehara, et al., J. Plasma Fusion Res 8, 1508-1511 (2009)