THz Gyrotrons - FU CW Series for high power THz technologies

Toshitaka Idehara, Teruo Saito, Isamu Ogawa, Seitaro Mitsudo and Yoshinori Tatematsu
Research Center for Development of Far-Infrared Region, University of Fukui (FIR FU), Fukui 910-8507, Japan

Abstract- **Development and application of high power THz radiation sources – Gyrotron FU CW Series are presented. All of the gyrotrons included in the series operate in CW or long pulse modes. The series is now being developed and applied to high power THz technologies, for example, plasma diagnostics, DNP-NMR for protein research, etc. At the present. the series consists of four gyrotrons, Gyrotron FU CW I, II III and IV. Now, we are developing Gyrotron FU CW V for application to accurate measurement of energy level of positronium. Such activities concerning with development and applications of Gyrotron FU CW Series are presented.**

I. CW GYROTRON NEEDED FOR APPLICATIONS TO HIGH POWER THZ TECHNOLOGIES

ALMOST all gyrotrons developed until now operate in pulse mode. However, pulse operation is sometime not convenient for application to material processing, spectroscopy, new medical technology, etc. Because of such a reason, recently, we have begun to develop Gyrotron FU CW Series in FIR FU. At the present, we have developed four gyrotrons in sub-THz to THz frequency range. The first gyrotron FU CW I operates at 300 GHz in CW mode. The output power is around 2.3 kW at the fundamental operation of $TE_{22,8}$ cavity mode. The gyrotron is being used for material processing, for example, ceramics sintering. The second gyrotron FU CW II is frequency step tunable. The main designed mode is TE_{06} and the frequency is 394.6 GHz. The gyrotron is being used as a high power radiation source for DNP-NMR at 600 MHz. The third gyrotron FU CW III is frequency step tunable in sub-THz to THz region. By use of second harmonic operations, the gyrotron has achieved the breakthrough of 1 THz in CW operation mode. The fourth gyrotron FU CW IV has just begun to operate and achieved a frequency continuous tunability near 135 GHz by using a backward wave operation of several axial modes. In near future, we will develop gyrotrons FU CW V and VI for applications to accurate measurement of the difference between energy levels of positoronium and measurement of detailed structure of DNP-NMR at 600 MHz. Table 1 summarizes the specifications and applications of each gyrotron included in Gyrotron FU CW Series. Gyrotrons FU CW V, VI, VII and VIII are being developed for application to high power THz technologies.

II. SOME RESULTS OF GYROTRON FU CW SERIES

We have already developed Gyrotron FU CW I. The frequency is 300 GHz, output power 1.75 kW, the operation is complete CW. It is being applied for high frequency material processing. Following are introduced some recent results of Gyrotron FU CW II and III.

Gyrotron FU CW II[1)]

We have finished the construction of a next CW gyrotron, Gyrotron FU CW II and completed the operation test. Fig. 1 shows a cross section of the gyrotron.

The gyrotron consists of a 12 T He-free superconducting magnet, a demountable tube, a vacuum pump system and power supplies. The cavity is a simple cylindrical one whose diameter and length are 5.72 mm and 15 mm. The designed frequency is 394.6 GHz at the second harmonic operation of $TE_{2,6}$ cavity mode.

After completing the operation test, the gyrotron is being used for enhancement of NMR sensitivity by use of dynamic nuclear polarization (DNP). 394.6 GHz is corresponding to ESR frequency at the field intensity of 7.1 T. The frequency of proton NMR at the field is 600 MHz.

We have already succeeded to operate the gyrotron at many fundamental and second harmonic resonances. Cavity modes corresponding almost all radiations resulting from fundamental and second harmonic operations are identified. We have found the operation at the $TE_{0,6}$ cavity mode whose frequency measured by a heterodyn system is 394.4 GHz. It is a little bit lower frequency than the designed frequency. Fig. 2 shows radiation power observed near the field intensity of 7.2 T just after an output window as a function of magnetic field intensity.

Measured frequencies are distributed in the range from 61GHz to 209 GHz in the case of fundamental operations, while from 212 to 439 GHz in case of second harmonic operations. Measured output power of Gyrotron FU CW II are several 100 W at the fundamental and several 10 W at the second harmonics.

Table 1 Specification and application status of each gyrotron included in Gyrotron FU CW Series

Gyrotron	Freq. range	Output power	Maximum B	Applications
FU CW I	300 GHz	2.3 kW, CW	12 T	Material processing, New medical technology
FU CW II	110 – 440 GHz	20 – 200 W, CW	8 T	DNP-NMR at 600 MHz for protein research
FU CW IIA	203.7, 395.3 GHz	200W, 50 W, CW	9.2 T	DNP-NMR ar 300 MHz and 600 MHz
FU CW III	130 – 1,050 GHz	10 – 220 W, CW	20 T	High power THz Technologies
FU CW IV	134 – 139 GHz	5 – 60 W, CW	10 T	Measurement of detailed structure of DNP-NMR
FU CW V	203.4 GHz	100 – 200 W, CW	8 T	Accurate measurement positronium energy level
FU CW VI	393 – 396 GHz	50 – 100 W, CW	15 T	DNP-NMR at 600 MHz for protein research
FU CW VII	131.5 GHz	200 W, CW	8 T	DNP-NMR at 200 MHz for material science
FU CW VIII	100 -350 GHz	100 W, CW	8 T	XDMR experiment with high power THz radiation

978-1-4244-2120-6/08/$25.00©IEEE.

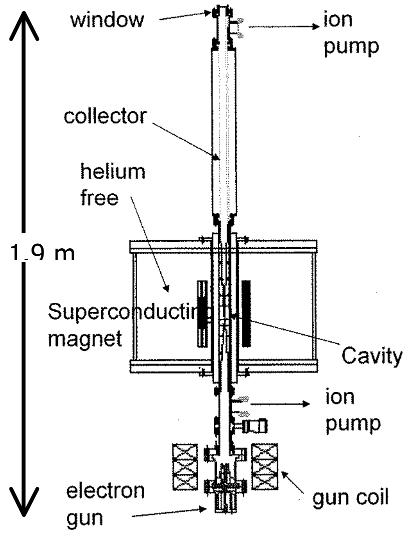

Fig. 1 The cross section of Gyrotron FU CW II

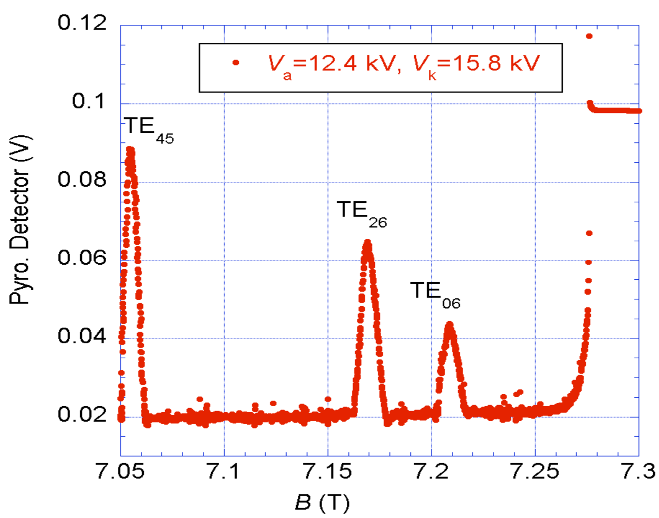

Fig. 2 Radiation power measured after an output window as a functions magnetic field near 7.2 T.

In Fig. 2, operations at the three second of TE_{54}, TE_{26} and TE_{06} modes and at a fundamental of TE_{23} mode are look very stable.

Gyrotron FU CW III [2)]

The third gyrotron, Gyrotron FU CW III with a 20 T superconducting magnet has already been constructed and the operation test has begun. In Table 1, main designed parameters of the gyrotron are shown. The gyrotron is optimized for the second harmonic operation of $TE_{4,12}$ at the frequency of 1013.7 GHz. The operation mode is complete CW. This gyrotron will achieve the breakthrough of 1 THz in CW operation. In addition, it is expected that many other cavity modes will be excited by adjusting the field intensity at the optimum value for each cavity mode. As the results, it will achieve frequency step tenability in wide range covering sub-THz to THz frequency region

Table 1 Specification of Gyrotron FU CW III

Total height from electron gun to the window: 2.4 m
Superconducting magnet :
Maximum magnetic field : 20 T
Inner bore : 50 mm
Cavity :Radius: 1.95 mm, Length : 10 mm,
Designed frequency : 1013.7 GHz at the second harmonic,
Main cavity mode : $TE_{4,12}$, Q-factor : 23720
Operation mode: Complete CW
Operating magnetic field: 19.1 T for : $TE_{4,12}$
Triode-type electron gun:
Cathode radius: 4.5 mm,
Maximum cathode current: 1 A,
Cathode voltage: 30 kV
Gun coil:
Maximum input current: 300 A,
Maximum magnetic field: 0.183 T

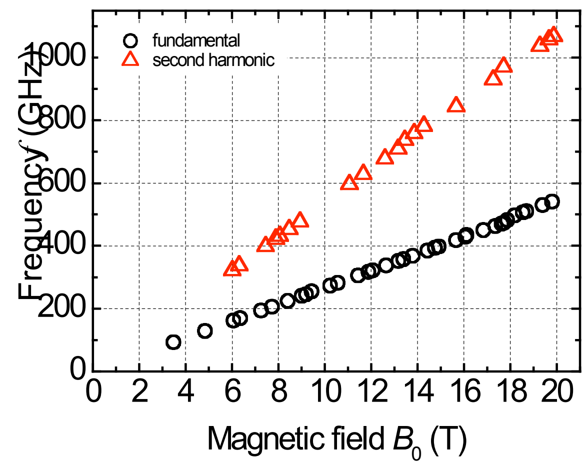

Fig. 3 Operation frequencies at both fundamental and second harmonic resonances. The breakthrough of 1 THz is achieved near the field intensity of 20 T in complete CW mode.

Fig 3 shows all frequencies observed up to the present are demonstrated as functions of magnetic field intensity. The gyrotron FU CW III has achieved the breakthrough of 1 THz near the field intensity of 20 T. The highest frequency is 1.08 THz. The output power is around 50 W. This is a new record of the high frequency operation of gyrotron.

In future, we are intending to apply our Gyrotron FU CW Series for many kind of high power THz technologies.

References

1) T. Idehara, I. Ogawa, La Agusu, T. Kanemaki, S. Mitsudo, T. Saito, T. Fujiwara, H. Takahashi, Development of 394.6 GHz CW gyrotron (Gyrotron FU CW II) for DNP/proton-NMR at 600 MHz, Int. J. Infrared and Millimeter Waves, **28**, 433-442 (2006).

2) La Agusu, T. Idehara, H. Mori, T. Saito, I. Ogawa, and S. Mitsudo, "Design of a CW THz gyrotron (Gyrotron FU CW III) using a 20 T superconducting magnet," Int. J. Infrared and Millimeter Waves, **28**, pp. 315-328 (2007).

978-1-4244-2120-6/08/$25.00©IEEE.