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Development of a high power sub-THz pulse gyrotron
サブテラヘルツ帯の高出力パルスジャイロトロンの開発

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We are developing a high power sub terahertz gyrotron for application as a power source of Collective Thomson scattering (CTS) diagnostics of fusion plasmas, especially of LHD high density plasmas. The frequency is in the 400 GHz band and the target output power is 100 kW. An output power of 56kW was obtained at a frequency 387.8GHz using the second harmonic oscillation. In order to achieve much higher output power, the oscillation mode has been changed to that with a higher coupling coefficient. As a result, an output power of 83 kW has been so far obtained. In addition, we have been designed a 300 GHz gyrotron with the fundamental oscillation. A design calculation predicts more than 200 kW. It will be equipped with an internal mode converter.

1. Background

FIR-FU has proved high power 400 GHz band gyrotron oscillation at second harmonic resonance. So far the maximum power has attained to 56 kW at 387.8 GHz, with the cathode voltage of 60 kV, and the beam current of 9 A. The oscillation mode was identified as the $TE_{1,8}$ mode from frequency measurement.

However, the output power is lower than 100 kW as the objective power. Then, we have adopted tow means to realize much higher power.

2. Means for obtaining a higher output power

Two means for obtaining a high output power are as follows.

The first mean is to increase the cathode voltage V_k to suppress deterioration of the quality of the electron beam. The maximum value of V_k at which we can operate has increased from 60 kV to 65 kV by improving the switching element of the power supply.

The second means is to change the oscillation mode from the $TE_{1,8}$ mode to the $TE_{17,2}$ mode the coupling coefficient C_{RB} of which is two times as high as that of the $TE_{1,8}$ mode. In fact, a mode competition calculation predicts a higher oscillation power by using the $TE_{17,2}$ mode. However, modification of the electron gun is necessary corresponding to the mode change. The beam radius R_b at which C_{RB} has the maximum value is 2.09 mm in the cavity of the present design. It is slightly larger than that for the $TE_{1,8}$ mode. Then, the radius of the emission belt R_k was increased from 14 mm to 15 mm to meet the following relation between R_b and R_k,

$$R_b = R_k\sqrt{\frac{B_k}{B_c}},$$

where B_k and B_c are the cathode magnetic field and the cavity magnetic field, respectively.

3. Experimental result (cathode voltage 65 kV)

The output power increased by increasing V_k to 65kV. The maximum power reached 62 kW at the beam current of 11 A. The oscillation efficiency is 8.7 %. Figure1 plots the maximum power obtained at each beam current. A decrease in power still exists.

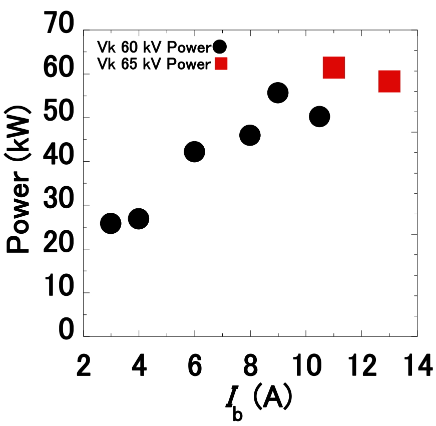

Fig.1. Maximum power for each beam current is plotted.

The oscillation frequency was measured by using a heterodyne receiver system. The measured frequency of 387.8 GHz is almost equal to 388.2 GHz, the resonant frequency of the $TE_{1,8}$ mode, and we identified the oscillation mode as the $TE_{1,8}$ mode. The small frequency difference about 0.4 GHz is due to manufacturing error of about 2.5μm.

4. Experimental result (mode change)

Figure 2 shows the beam current dependence of the output power obtained after modification of the electron gun. The maximum output power of 83 kW as a new power record was obtained at 10 A. The output power slightly decreases at the beam current larger than 10 A. This is likely due to deterioration of the beam quality at large Ib.

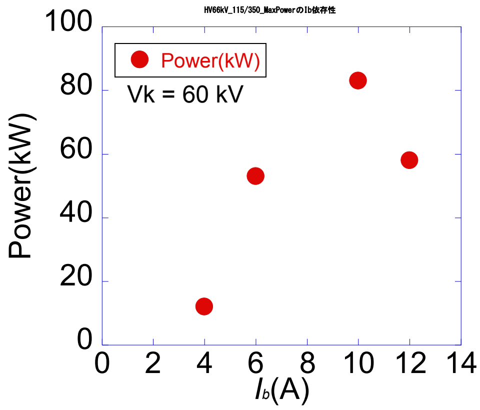

Fig.2 Maximum power is plotted for each beam current.

The oscillation frequency was measured with a Fabry-Perot interferometer. Figure 3 indicates a waveform of the interferometer. It proves no oscillation of fundamental modes. The measured frequency is 388.8 GHz. The design frequency of the $TE_{17,2}$ mode is 389.3 GHz. The measured frequency is again slightly less than the design value. Then, the oscillation mode was identified as the $TE_{17,2}$ mode

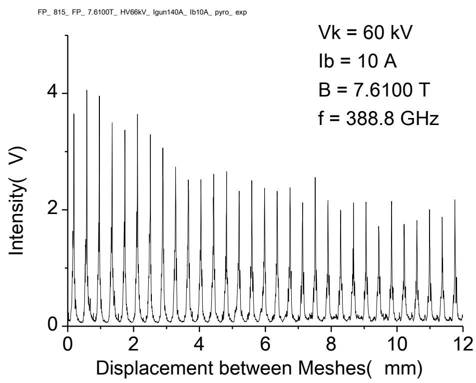

Fig.3 An example of the waveform obtained with a Fabry-Perot interferometer.

The oscillation efficiency at 83 kW with V_k of 60 kV and the beam current of 10 A is 13.8 %.

Oscillation of only second harmonic mode was not obtained with V_k of 65 kV. At this voltage, simultaneous oscillation of the fundamental $TE_{4,3}$ mode was observed in a wide operation range.

5. Design of a 300 GHz fundamental harmonic gyrotron

We designed 300 GHz fundamental harmonic gyrotron, in parallel with experiments using the second harmonic oscillation. In order to obtain fundamental oscillation of 300 GHz, a new liquid He free 12 T superconducting magnet will be installed. The $TE_{14,2}$ mode was selected. The design parameters are frequency 295 GHz, the cavity radius is 3.40 mm, the cavity length is 9 mm, and the beam radius is 2.42 mm.

Figure 3 shows the oscillation power calculated with the mode competition code. The calculation predicts that shows that the $TE_{14,2}$ mode oscillates alone and the output power is larger than 200 kW. Oscillation power stays larger than 200 kW for a possible change in R_b.

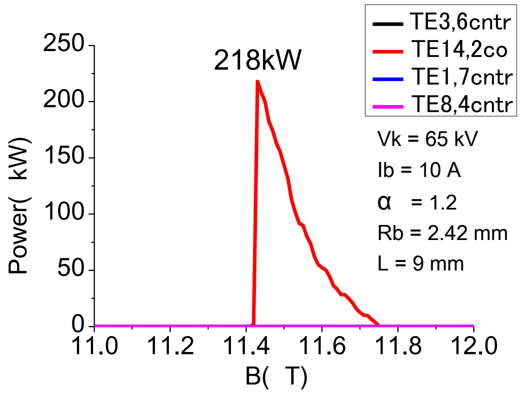

Fig.4 Power calculation with the mode competition code.

6. Summary

High power second harmonic gyrotron oscillation has been obtained. The recorded power was 62 kW at 387.8 GHz with the $TE_{1,8}$ mode. For realization of further higher power with the $TE_{17,2}$ mode, the electron gun was modified. The recorded power with this mode has so far been 83 kW at 388.8 GHz. In this experiment, we have achieved a new record in the sub terahertz region.

As another way getting higher power, a fundamental harmonic gyrotron with a 12 T magnet has been designed. An output power of 200 kW class can be expected.

References

[1] T. Saito et al., : 15th Int. Sym. on LASER-AIDED PLASMA DIAGNOSTICS, Korea, 2011, T11.