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Development of fundamental oscillation 400 GHz sealed-off gyrotron with continuous frequency tunablility
基本波発振による400GHz帯周波数連続可変ジャイロトロンの開発

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Gyrotron is required to enhance sensitivity of 600 MHz NMR spectroscopy for analysis of complex proteins structures. A fundamental oscillation 400 GHz range gyrotrons having boardband frequency tunability are being designed and developed in the University of Fukui. The sealed-off gyrotron has been newly developed to realize higher output power and more stable oscillation from results of a demountable tube type gyrotron. In preliminary experiments, the output power reached about 50 W, which exceeds that of the demountable tube type gyrotron.

1. Introduction

Gyrotrons are powerful sources in millimeter to sub-millimeter wavelength region. High frequency gyrotrons the frequency of which exceeds about 200 GHz are applied for plasma diagnostics, electromagnetic wave sintering, material sintering and biological sciences and medical treatment. In particular, high power irradiation of sub-millimeter wave is required to analyze the structures of proteins by nuclear magnetic resonance (NMR) spectroscopy [1]. The sensitivity of NMR spectroscopy for more complex proteins is too low and the analysis takes an immense amount of time. A dynamic nuclear polarization (DNP) method is expected to enhance the sensitivity [2]. The enhancement of DNP depends on the oscillation frequency of irradiation. The optimal frequencies are $f_{ESR} \pm f_{NMR}$, where f_{ESR} and f_{NMR} are frequencies of electron spin resonance (ESR) and NMR. The value of f_{ESR} is 394.6 GHz for 600 MHz DNP-NMR spectroscopy. Continuous tunability of frequency is required to obtain the optimum enhancement. Moreover, stability of radiation power is necessary. Objectives of this study are the development of the frequency tunable gyrotron for 600 MHz DNP-NMR spectroscopy and the operation test of the oscillation characteristics. In the university of Fukui, we have already developed a frequency tunable gyrotron which oscillated fundamental mode using a 15 T superconducting magnet [1]. This gyrotron was demountable type. The frequency tuning was ranged from 394.65 GHz to 395.27 GHz and the output power was ranged from 10 to 30 W [3].

2. Experimental setup

A new fundamental oscillation gyrotron has been developed to improve output power, the stability and CW operation. This gyrotron is of sealed-off type as shown in Fig.1 The vacuum pressure in a tube is kept under 10^{-6} Pa and the variation of the pressure is suppressed low. The liquid helium free 15 T superconducting magnet is used to excite a fundamental oscillation at 394.6 GHz. The room temperature bore of this magnet is 52 mm. The

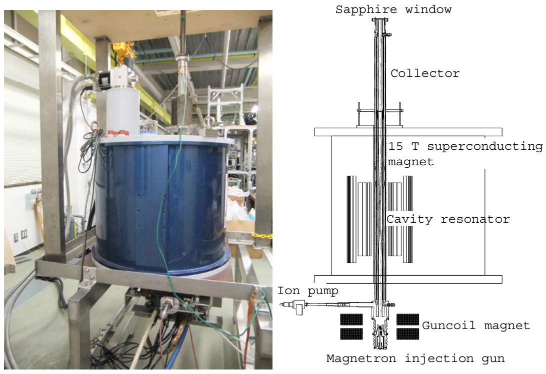

Fig.1 Sealed-off gyrotron (Gyrotron FU CW VIB) and a 15 T superconducting magnet.

operating mode was designed as $TE_{0,6,q}$ around the ESR frequency of 394.6 GHz. The index, q, stands for the axial mode number. The shape of the cavity resonator is a conventional cylindrical cavity with linear tapers on both end. The length and diameter of the cavity are 25.0 mm and 4.750 mm, respectively. Calculated Ohmic, diffractive and total quality factors are Q_Ω = 22375, Q_d = 77734 and Q_t = 17374. We can expect excitation of axial modes with q > 1 owing to the long cavity. In addition, a backward wave interaction with the electron beam will continuously cover the gap between neighboring axial modes without stopping radiation [4]. A magnetron injection gun is a triode type and the emitter diameter is 9.0 mm. Cathode voltage is up to 30 kV and the maximum beam current is 500 mA. The electron beam is injected in the 2nd electric field peak region (beam radius : 0.65 mm) of $TE_{0,6,q}$ mode at the cavity entrance by adjusting a gun coil magnet.

3. Preliminary experiment results

Figure 2 shows the oscillation signal, the output power and the calculated stating current as a function of magnetic field strength. The oscillation signal and output power were measured by a pyroelectric detector and a water load respectively. This operation condition is a cathode voltage V_k = 12 kV and an anode voltage V_a = 4.7 kV, a beam current I_b ~ 250 mA and the gun coil current I_g = -150 A. The peaks of radiation power correspond to minimums of the starting current for which the expected cavity modes are oscillated. Therefore, $TE_{0,6,1}$ mode was oscillated from B_c ~ 14.35 T. It is expected that the oscillation of $TE_{0,6,q}$ modes continued until B_c ~ 14.6 T without stopping radiation. The output power was about 30 W at q = 1 and the output powers were about 5 – 20 W in higher axial modes. The frequencies tuning is expected in this region and the oscillation frequencies will be measured very soon.

The dependencies of the output powers on the beam current and the voltage between the cathode and the anode were measured at B_c = 14.37 T. The output power linearly increased with increasing beam current, as shown in Fig.3. The maximum output power reached about 50 W. And the output powers increased gradually by increasing a pitch factor as a function of the voltage between the cathode and the anode as shown in Fig.4. The pitch factors were calculated by electron beam analysis code, EGUN [5]. Output power reached about 40 W in the region of pitch factor α ~ 2.0. The most suitable operating condition is being searched aiming at improvement of further output power.

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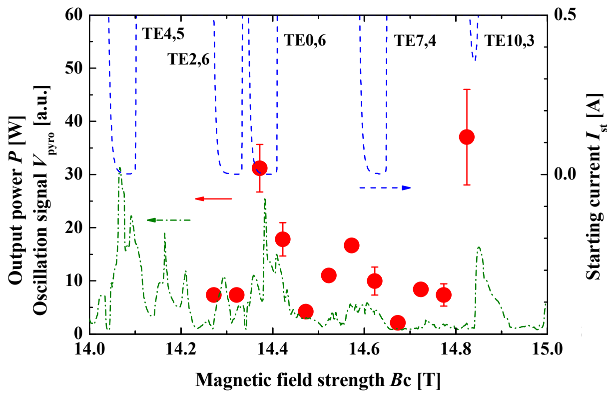

Fig.2 Oscillation signal, output power and calculated stating current as a function of magnetic field strength.

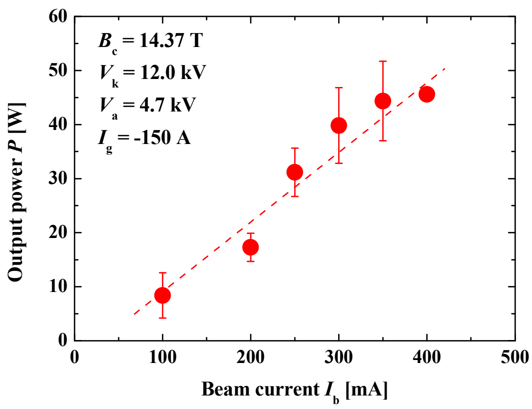

Fig.3 Output power as a function of beam current.

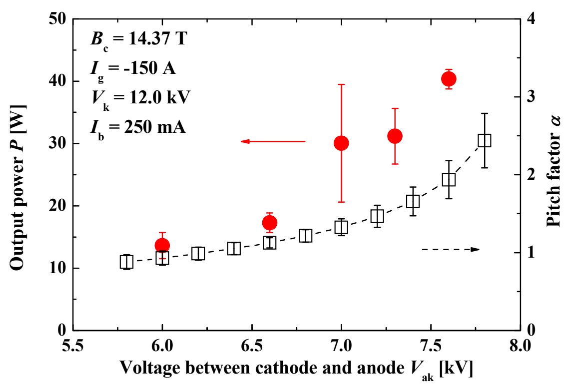

Fig.4 Output power and calculated pitch factor as a function of the voltage between cathode and anode.