Developing A 0.33-THz Broadband Pulse Gyrotron

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***Abstract*—This paper reports our progress of developing a 0.33-THz gyrotron which is based on a compact pulse magnet and can generate broadband coherent THz radiation with bandwidth exceeding 10 GHz and peak power about 2 kW. The design and fabrication of the key components are addressed in detail, including strong-field magnet, pre-bunched cavity, broadband Quasi-Optical mode converter, and Brewster window. The terahertz gyrotron with kilowatt level high power, broadband capability, and compact configuration is the key to high-power terahertz research.**

I. INTRODUCTION

EFFICIENT THz radiation is challenging to be generated either by traditional electronic devices or photonic devices. As a result, the so-called *THz gap* appears on the spectrum due to lack of matured THz radiators and related detection technique [1]-[3]. This paper reports our progress of developing a high power THz source, namely a pulse-magnet mini-gyrotron. Fig. 1 shows the configuration of the THz gyrotron. The length of tube is limted to 45 cm. A compact pulse magnet with field strength up to 15 T is adopted to replace traditional superconducting magnet, and simultaneously the pulse magnet provides a time-varying magnetic field to tune the electron cyclotron frequency. A pre-bunched traveling-wave interaction circuit is employed for electron cyclotron maser operation and generates broadband spectrum THz radiation [4], [5]. In order to transfer the waveguide mode into free-space Gaussian beam, a broadband Quasi-Optical mode converter is specially developed, which is potential to achieve efficiency higher than 80% in the bandwidth between 310 GHz – 340 GHz. THz Brewster is developed to guide out the generated broadband THz power. The design and fabrication of these key components will be addressed in detail in this paper.

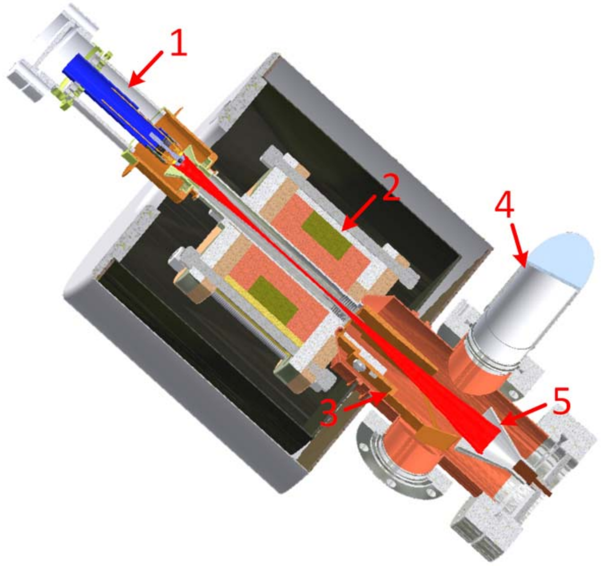
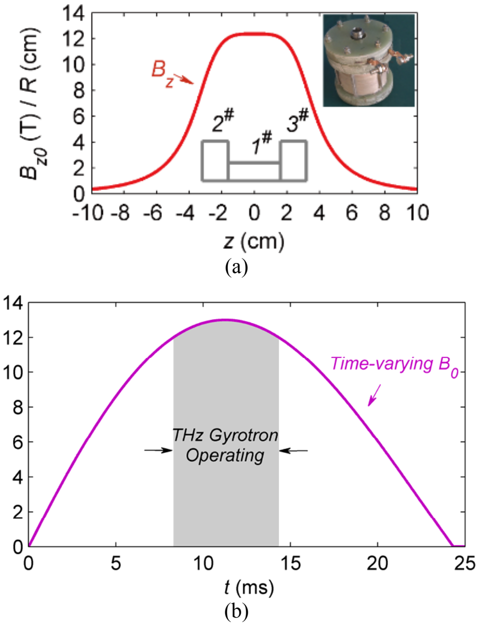


Fig. 1 The configuration of the mini-THz gyrotron. 1 indicates the single-anode electron gun, 2 pulse magnet, 3 broadband QO converter system, 4 Brewster window, and 5 collector.

II. STRONG-FIELD PULSE MAGNET

A strong field pulse magnet has been developed for the THz gyrotron operation. As shown in Fig. 2(a), the magnet consists of three coils and generates a flat field region with length of 3.5 cm in the cavity region. The highest peak field strength of 15 T is measured. A time varying magnetic field optimized for THz gyrotron operation is shown in Fig. 2(b). The total duration of the pulse magnet is about 25 ms. A consider part of the magnetic field pulse with duration of 6.0 ms and field changing between $B_0 = 12T - 13T$ can be used for gyrotron operation. Traditional pulse gyrotron uses a constant magnetic field with very short time-domain duration. It makes the utilization rate of the pulse magnetic power supply extremely low. In our scheme, a preliminary estimation indicates about half of the gyrotron power can be employed to maintain strong magnetic field for THz gyrotron operation. In other words, the utilization rate of the pulse magnet energy for gyrotron operation is as high as about 50% which is at least two orders of magnitude higher than traditional pulse magnet gyrotron experiment.



(a)

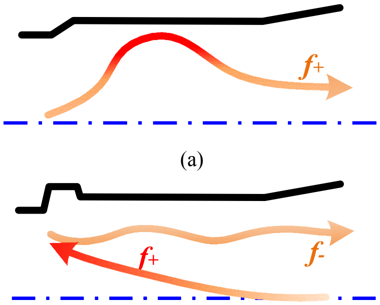
(b)

Fig. 2 (a) The magnetic field profile and coil configuration and (b) the measured time-varying magnetic field of the pulse magnet.

The pulse magnet provides time-varying magnetic field and leads to slowly variation of electron cycling frequency in gyrotron, which is potential to excite broadband THz-wave radiation. Broadband THz radiation with duration exceeding 6ms and kilowatt peak power in each pulse provides strong support for THz coherent detection, imaging application, or bio-THz interaction applications.

III. PRE-BUNCHED INTERACTION CIRCUIT

Frequency-tuning THz-wave power is especially attractive for advanced THz applications, for example, coherent detection, THz ESR, DNP-NMR, and so on. Fig. 3(a) shows a conventional open cavity for gyrotron interaction. The open cavity circuit is with high-Q mode and can excite electromagnetic wave on fixed frequency or limited tunable bandwidth. Especially, during frequency-tuning application, the tunable gyrotron based on open cavity constantly turns into chaotic oscillation and generates non-coherent radiation. Fig. 3(b) shows a new gyrotron circuit, namely, a broadband pre-bunched interaction circuit [4], where gyrotron can operates under either gyromonotron condition or gyrotron backward-wave condition [5]. When the cylindrical waveguide TE62 mode is chosen as the operating mode, the tunable bandwidth of the pulse gyrotron is shown in Fig. 4. The peak power about 2 kW and magnetic field controlled bandwidth exceeding 10 GHz is achievable. Systematic investigation on the multi-mode competition and time-varying characteristic of the gyrotron controlled by pulse magnetic field has been carried out, and results will be published in another independent journal paper. Single mode operation with radiation power about 1.0 kW–2.5 kW between 0.328 THz–0.338 THz with pulse duration about 6.0 ms can be realized.



(a)

(b)

Fig. 3 (a) A conventional open cavity circuit, and (b) a pre-bunched broadband interaction circuit.

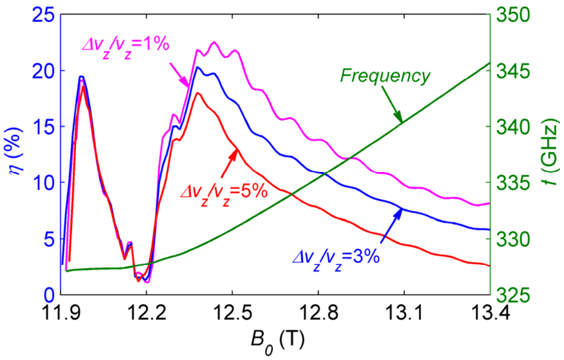


Fig. 4 The frequency-domain tunable bandwidth of the 0.33 THz pulse gyrotron, assuming electron beam with voltage of 20 kV and current of 0.5 A.

IV. THZ BREWSTER WINDOW

In order to transfer the waveguide TE62 mode into free-space Guassian beam, a broadband Quasi-Optical mode converter is developed, as previously reported in Ref. [6],[7]. Further more, a broadband window to guide out the THz radiation power out of the tube is also a critical component of the system. The Brewster window is capable of full-band transmission, which makes Brewster window the most favorable candidate of the broadband gyrotron. Two different Brewster windows based on distinctive materials, namely, Al2O3 and BeO, are successfully developed. Fig. 5 shows one of the Brewster window chip welded with kovar alloy. Either argon arc welding or braze welding can be employed to weld the window chip to the tube.

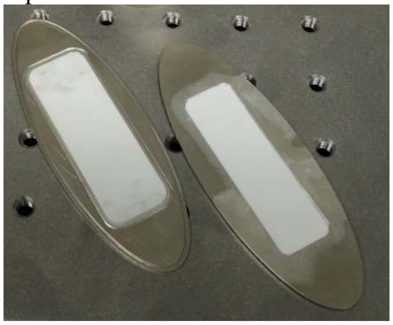


Fig. 5 The window chip of the THz Brewster window.

V. CONCLUSION

The key components of developing a novel broadband THz gyrotron are reported here. The compact pulse magnet is used to replace traditional superconducting magnet which greatly reduces the system cost and volume. The overall length of mini-THz gyrotron integrated with internal QO mode converter, pulse gyrotron and Brewster window is limited to 45 cm. The pulse magnet also provides time-varying magnetic field strength to tune the gyrotron radiation frequency. Broadband coherent radiation between 0.328 THz–0.338 THz peak power about 1.0 kW–2.5 kW and radiation pulse about 6 ms is possible. Broadband pulse THz mini-Gyrotron would become a key to advanced high-power THz research and applications.

ACKNOWLEDGEMENTS

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