Experimental Progress in High-Frequency Terahertz Gyrotrons

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ABSTRACT

Terahertz radiation sources have attracted significant attention due to their wide applications in high-resolution imaging, spectroscopy, and advanced communications. Gyrotrons, as high-power vacuum electronic devices, are ideal candidates for generating high-frequency, high-power terahertz radiation. This paper presents two recent advancements in THz gyrotron technology and experiments at Peking University: the development of terahertz harmonic gyrotrons based on superconducting magnets and experimental research on terahertz pulsed gyrotrons with high field pulsed magnets.

First, axis-encircling electron beams (also known as large orbit beams), characterized by their inherent mode-selection properties, can significantly reduce the mode spectral density in overmoded cavities [1]. This facilitates high-harmonic operation and enables the generation of high frequency terahertz radiation at relatively low magnetic fields. A magnetic cusp gun (MCG) with strong robustness in operating parameters produces a large orbit beam with extremely low velocity spread (as low as 0.4%) within a magnetic field range of 4–9 T, providing the foundation for continuous switching among multiple harmonics over a wide magnetic field range. Experimental results demonstrate that the developed large orbit gyrotron (LOG) can sequentially excite five different harmonic modes. The third harmonic achieved an output power of 0.68 kW at approximately 650 GHz, corresponding to an electronic efficiency of 2.16%. The good agreement between experiments and simulations validates the correctness of the design and the accuracy of the measurements.

Second, the gyrotron with high-field pulsed magnet provides another solution to meet the magnetic field requirements for high-frequency operation. The current mini-pulse-magnet platform can achieve a maximum field strength of up to 40 Tesla. Based on the fundamental harmonic interaction of the high-order whispering-gallery mode (WGM) $TE_{13,3}$ [2], terahertz radiation with millisecond-level pulse width and joule-level energy around 560 GHz is obtained. Moreover, the inherent time-varying properties of the pulsed magnetic field provides a natural path for achieving the high-efficiency operation in the hard-excitation region in every pulse, without the need for manual tuning [3]. The asymmetry of the operating range in the up-tuning and down-tuning semi-waveforms is also observed in the experiments, which is a direct manifestation hard-excitation-induced hysteresis.

In conclusion, the successful demonstration of multi-harmonic switching in LOGs and the exploitation of hard-excitation dynamics in pulsed systems provide critical insights for the future realization of high-power, stable, and frequency tunable THz radiation sources based on vacuum electronics.

References

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