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# Ultra-wideband BWO with waveguide loaded grating

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**Abstract**. This paper presents a solution for a tunable broadband terahertz radiation source, which can be realized by a newly designed BWO (Backward Wave Oscillator) using slow-wave structure with dual waveguide-loaded gratings. Gratings in two rows of the same height operate in different frequency ranges. Additionally, the signal-to-noise ratio within the operating frequency has been dramatically improved by placing a lossy material at the end of the waveguide. The operating frequency of the double gratings alternate from 185.63 GHz to 239.6 GHz and 244.08 GHz to 291.93 GHz accordingly. Ultimately, the relative bandwidth of the whole device reaches 41.7%.

## 1. Introduction

With the development of electromagnetic technology, terahertz waves have been widely used in biomedicine, non-destructive imaging, near-field imaging, space detection, etc. Terahertz scattering scanning near-field optical microscopy (s-SNOM) system has been a successful commercialized terahertz detection method. The signal source typically uses TDS, for it has an excellent large size of bandwidth, whilst the output power merely results in microwatts. Numerous materials have more pronounced absorption properties in the terahertz band, constraining the system’s performance in specific scenarios. It is thus necessary to use high-power radiation sources in the system to break the material limitations. Solid-state devices have certain advantages at low frequency, yet are not proper enough in the higher terahertz bands. However, various devices generating high-power terahertz coherent radiation, however inevitably encounter several problems, such as being too large to handle, or hard to adjust. Vacuum electronics have been the optimal solution for miniaturization and high power in the lower terahertz band. It is regarded as the highest bandwidth performance of the return oscillator in vacuum electronics, which perfectly accommodates the specific demands of s-SNOM. That is why we design and propose an ultra-wideband BWO for the system.

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The research on BWO is mainly divided into following two aspects. The first is to overcome processing technology limitation through innovating new structures. The second is to improve output and bandwidth performance of the device by tuning traditional structure. The proposal of waveguide-loaded gratings and sinusoidal waveguides adds more options to interaction structures. The experiment shows that those structures used in BWO greatly have improved the operating bandwidth and output performance [1].

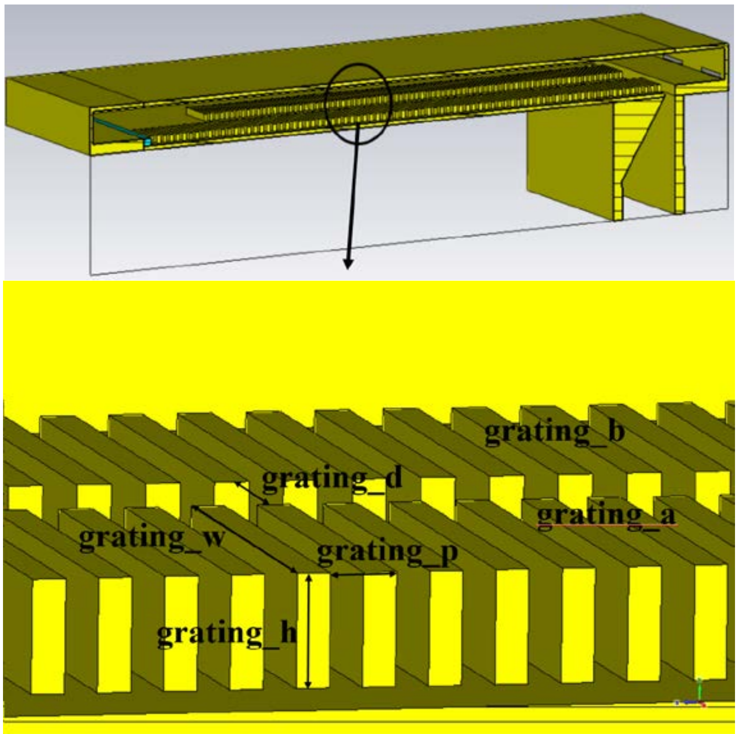


Fig. 1. Schematic diagram of waveguide loaded grating structure and local enlarged view.

For the purpose of improving efficiency and bandwidth, studies have been researched to adjust interaction structure, emission of electron beam, the concept of taper and clinotron. Subsequent researches use lossy material to increase bandwidth property of BWO. The method of achieving power synthesis through multiple electron beams to improve output capability has also been experimentally verified. For some scenarios that require a high-power pulsed source, a pseudo-spark electron beam source is used, which not only reduces the size and start-up time, but also greatly increases pulsed power of BWO [2]. There are also many attempts to process high-frequency structures. Diamond has good thermal conductivity, vacuum compatibility, low dielectric loss and resistance to stress deformation, so it is used as a substrate to support the gold micro-spiral structure to process a 650GHz biplane interdigitated BWO [3]. In order to solve the problem of larger volume of Backward-Wave Oscillator in the wave band at lower frequency, metamaterials are applied to it. On the basis of ensuring performance, the overall size of the period is greatly reduced.

## 2. Results and discussions

With the increase of the operating frequency of the vacuum electron device, the size of the interaction structure has been reduced, and higher requirements on the processing and assembly technology have been put forward. Therefore, a relatively simple waveguide loaded plane gratings structure was adopted in the structural design. As shown in Fig.1, the main components of the slow-wave system were a rectangular waveguide, two rows of plane gratings, a piece of lossy material, and a unilateral gradual output structure. The waveguide and coupling output structure were in relatively large size, while the high-frequency structure was simple. There was no difficulty in processing and assembly. Modern mechanical processing technology could fully meet the needs.

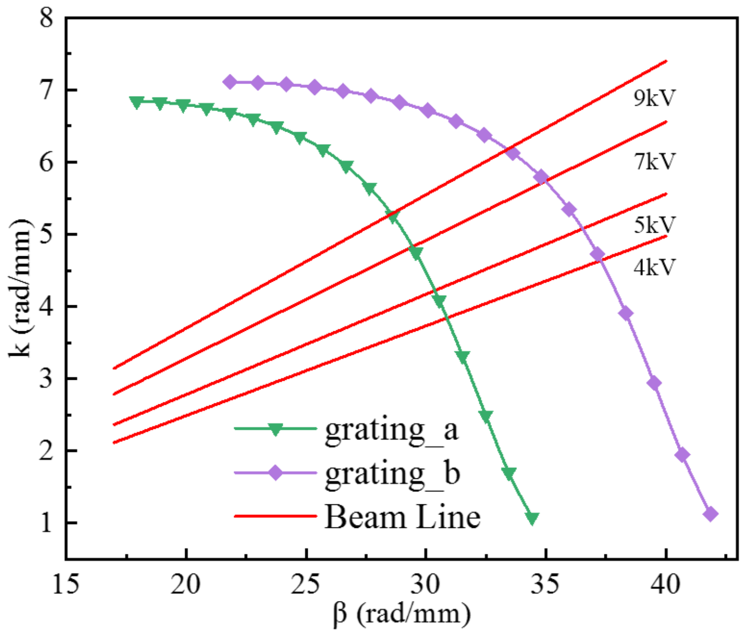


Fig. 2. Dispersion relation of grating_a and grating_b

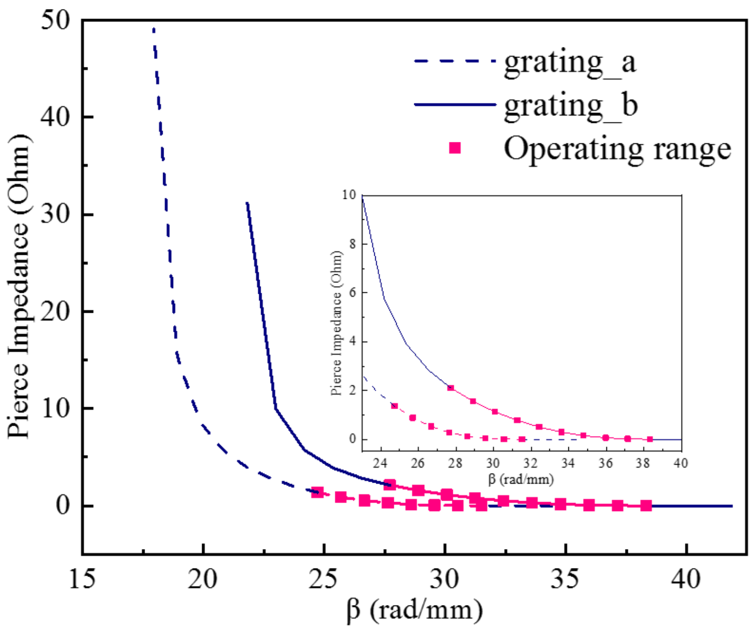


Fig. 3. Pierce Impedance of two gratings varies with β

It is well acknowledged that the intersection point frequency of the electron beam with the dispersion curve changes following the variation of the electron beam voltage. The Pierce Impedance is affected at the same time. When the Pierce Impedance deviates from the center frequency, the electron beam has insufficient modulation or excessive modulation, resulting in the decreased power and bandwidth. Hence, optimizing Pierce Impedance within the operating voltage range works

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effectively to expand the bandwidth of BWO, and the parameter does not change drastically within a specific phase shift interval. In the terahertz band, the structural size of the device has been dramatically reduced, and the design of the output structure is particularly critical. While the interaction structure has a broader bandwidth, a higher-bandwidth output coupling structure is also needed to match the output signal.

To realize broadband BWO, we placed the intersection of beamline and dispersion curve in the backward-wave region with a large slope. In this interval, the Pierce Impedance changed little, and a large frequency change could be obtained by fine-tuning the voltage of the electron beam, which made it easier to increase the bandwidth. The plane grating structure had the same phase shift condition as other interaction structures. However, the smaller Pierce Impedance facilitated the increase of the device bandwidth. As shown in Fig.2 these two groups of optimized grating structure parameters could generate 0.186-0.291THz signals under 4-9kV beam voltage. It can be seen from Fig.3 that the Pierce Impedance remained stable with the phase shift in the operating range.

## 3. Conclusion

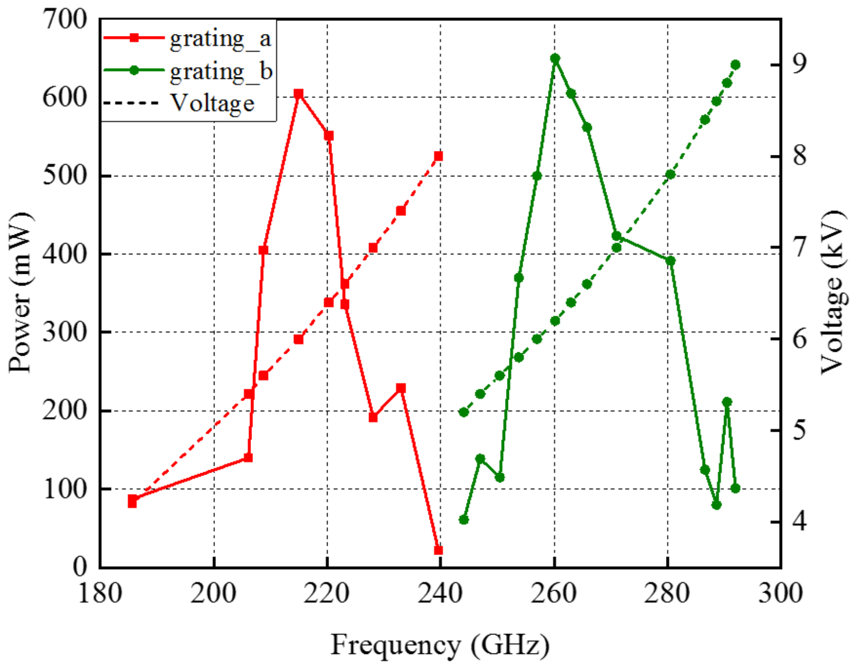


Fig. 4 The relationship between output power, frequency and voltage of electronic beam

The 60A/cm$^2$ electron beam was used in the bandwidth simulation. The bandwidth simulation of the structure with the above determined parameters obtains the following results. The grating_a can output signal from 185.63GHz to 239.6GHz by changing the voltage from 4.2kV to 8kV. The output frequency changes from 244.08GHz to 291.93GHz by means of changing the beam voltage of the grating_b from 5.2kV to 9kV. The power is almost all in the order of hundreds of mill watt. The output power of different grating is shown in Fig.4. It can be seen from the dispersion relation that the slope of grating_a is larger than grating_b, and the mode isolation is large. In the case of the same electron beam voltage difference, grating_a can output a signal with a larger frequency difference than grating_b. Therefore, under the condition that the frequency range of the two rows of gratings is 50 GHz, the voltage adjustment range required by grating_a is smaller than that of grating_b.

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