Investigation of a 0.2-THz magnetron using 3D particle simulation

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Abstract: The results of a 3D particle simulation of a 0.2-*THz* cold cathode magnetron are presented. It is operated at first order backward spatial harmonic of a π/2-1 mode. The saturated output power is calculated as 2.8 *kW* with 13.6 *kV* anode voltage and 0.944 *T* magnetic field.

Keywords: Magnetron, THz oscillator, High power, Vacuum tubes.

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I. Introduction

Magnetrons, the earliest member of the vacuum tube family of devices, are rarely reported in THz band for the following reasons [1]. Firstly, the cavity dimensions are proportional to the wavelength, so the anode cavity and the mode separation straps are difficult to fabricate in THz band. Secondly, the back-bombarding current in this small cavity is so intense that the life time of the traditional thermal cathode becomes too short for practical applications.

Spatial harmonic magnetrons (SHMs), which were first proposed in 1956, offer a possible solution to the issues associated with strapped cavity [2]. They use either the first order backward spatial harmonic of the π/2 mode or a neighboring mode. This method of operation allows the SHMs to be operated with lower voltage and lower magnetic field. And they also exhibit good mode separation without the need for anode straps.

To tackle the issue of cathode life time, recently cold cathodes have been used to replace the traditional thermal cathode. These cathodes use the back- bombardment to generate the necessary space charge for the magnetron to operate. Indeed, an auxiliary cathode is required to generate the primary current, as shown in Figure 1. Cold cathode has extended the magnetron life time sufficiently for practical applications [3].

The aim of this work is to characterize the operation of a 0.2 *THz* SHM with cold cathode operating at the first backward space harmonic of π/2-1 mode, using CST Particle Studio. A comparison of a SHM and a conventional magnetron (CM) is given in Table 1.

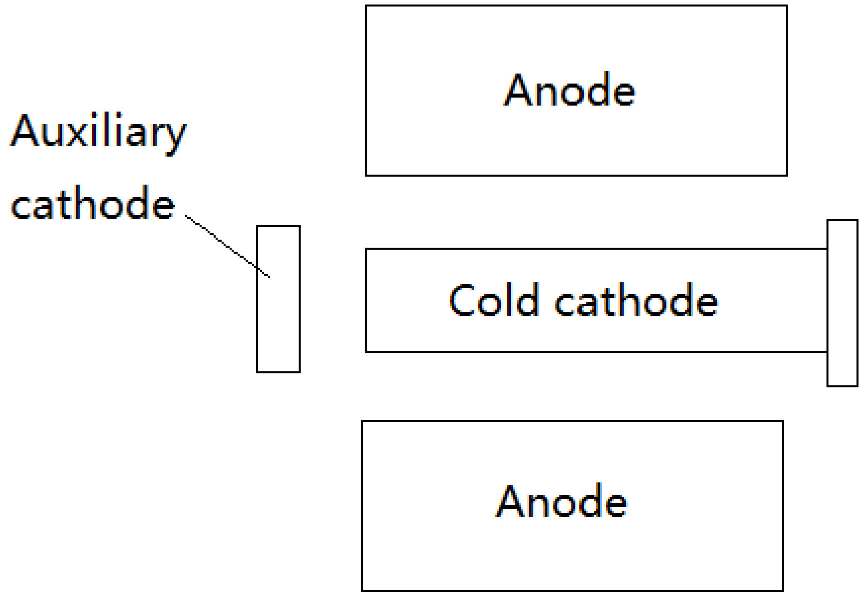


Fig. 1 Schematic of the cold cathode

Tab. 1 Comparison of CM and SHM

	CM	SHM
Operating mode	fundamental π mode	first backward spatial harmonic of $\pi/2$ mode or its neighboring one
Mode separation technic	straps or rising sun	without additional mode separation structures
Cathode	thermal	cold cathode
Voltage	U	U/4 to U/2
Magnetic field	B	B/4 to B/2

II. Simulation

A 40-vane SHM model is shown in Figure 2. It consists of a platinum cold cathode, an unstrapped anode, and a coupler with WR4 output waveguide.

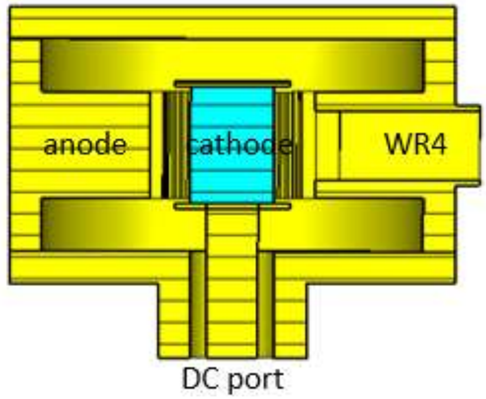
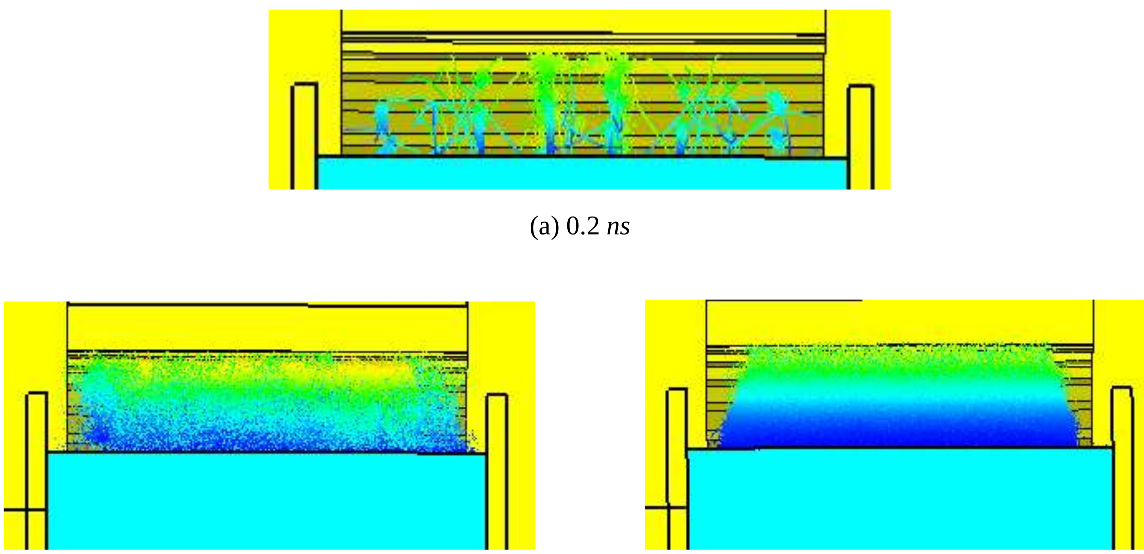


Fig. 2 0.2 *THz* 40-vane SHM model

An exact simulation with the auxiliary thermal cathode, as shown in Figure 1, is complicated and time consuming. As the auxiliary cathode is only required to initialize the emission of the cold cathode, to simplify the model, the auxiliary cathode will not be included in this model. Instead, the secondary emission will be initialized with a small primary current specified on the surface of the cold cathode see Figure 3 (a).



(a) 0.2 *ns*

(b) 2 *ns* (c) 15 *ns*

Fig. 3 Time evolution of the electron clouds

This small initial current is sufficient to initiate an avalanche process resulting in the rapid growth of the secondary emission current as shown in Figure 3 (a-c) and Figure 5 0-5 *ns*. After about 6 *ns*, the emission from the cold cathode surface has stabilized and 31 electron spokes appear near the anode surface which can be seen in Figure 4. This number of spokes agrees with the mode of operation of the SHM (k=/n+mN/, where k is the spoke number, n is the mode number, m is the order of the spatial harmonic and N is the number of the cavity). For this model, n=9, m= -1, N=40.

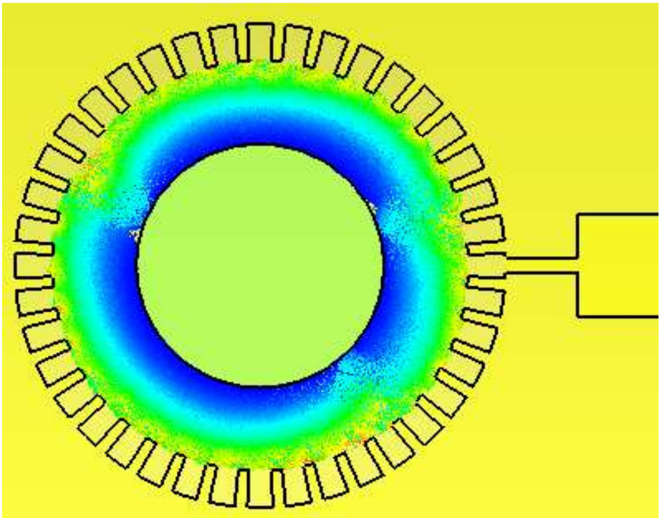


Fig. 4 Electron distribution at 18 ns

The amplitude of the output voltage measured at the centerline of the WR4 waveguide and its corresponding oscillation frequency obtained by Fourier transform are presented in Figure 5. While, Table 2 lists some key characteristics of this simulation.

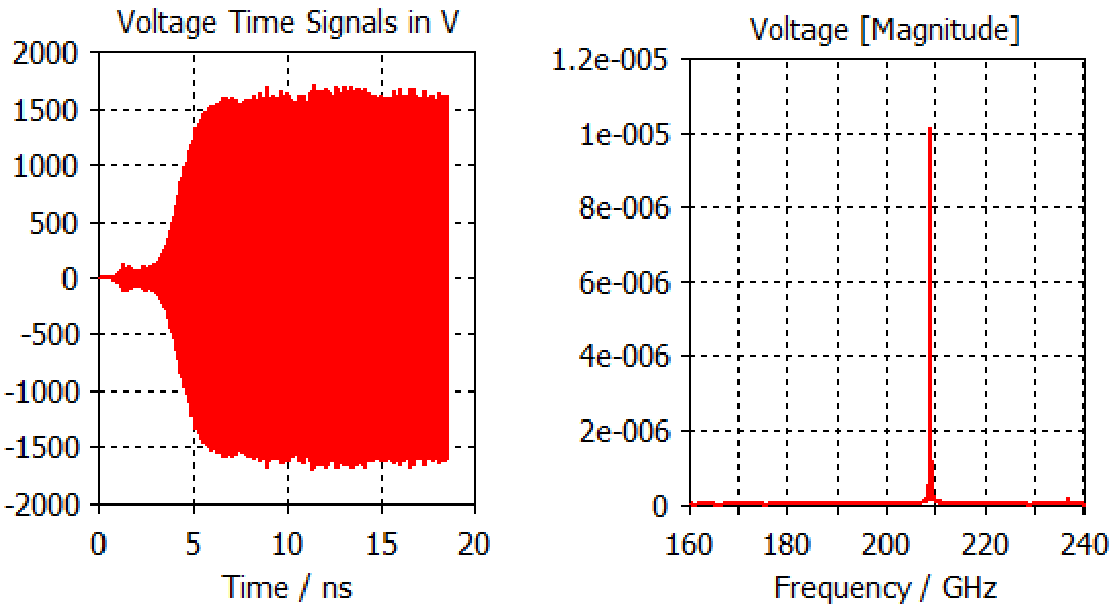


Fig. 5 Output voltage and oscillation frequency

Tab. 2 Some characteristics of the simulation model

Number of side resonators	40
Anode diameter	2.6 *mm*
Frequency	209 *GHz*
Out power	2.8 *kW*
Voltage	13.6 *kV*
Anode current	15 *A*
Magnetic field	0.944 *T*
Operating mode	π/2-1 mode

III. Discussion

In SHMs, the amplitude of the fundamental harmonic is much greater than the amplitude of the spatial harmonic. The spatial harmonic is further from the cathode and closer to the anode, so that electrons emitted from the cathode are affected by the fundamental harmonic. This is evident in Figure 4, where it can be seen that the electron distribution is non-periodic around the cavity. Thus, using a single mode approximation, as is done when analyzing a conventional magnetron, is unsuitable for analyzing the operation of SHM. In this simulation, all harmonics are included and so the operation of SHM is accurately depicted. The simulation results agree well with published experimental and qualitative results [4, 5]. Anode cavity is fabricated by 0.05 *mm* diameter wire cut and the corners of the side resonator are rounded rather than square, as simulated. Contrast the simulation profile in Figure 4 with a photograph of a real resonator in Figure 6. To examine the effect of this, a model where the bottom corners are rounded was studied as well. The measured frequency shows that there is about 5.2 *GHz* frequency shift due to the fabrication tolerance.

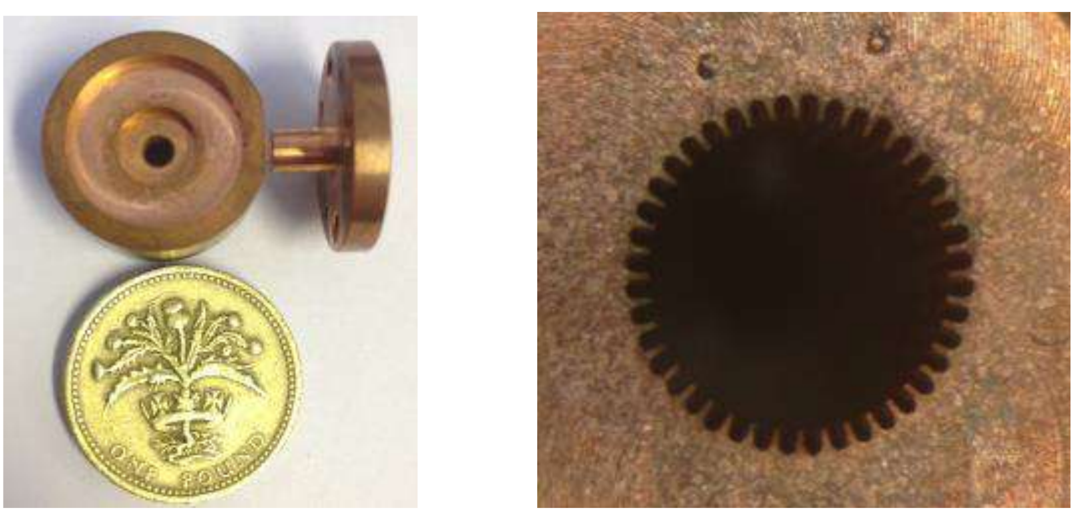


Fig. 6 Photograph of anode cavity

IV. Conclusion

This work details a successful particle simulation of a spatial harmonic magnetron in the low THz frequency range. The predicted output power of >1 *kW* can be achieved when fabrication tolerance, and vacuum window losses, etc. are considered. And the required 0.944 *T* magnetic field can be realized by permanent magnet. This indicates that SHM with a cold cathode is an attractive candidate for the development of high-power compact terahertz oscillator.

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