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S band radial beam coaxial grating backward wave oscillator*

Wang Zhanliang[1,2]， Wang Huanyu[1]， He Ziyuan[3]， Lu Zhigang[1]， Gong Huarong[1]， Wang Shaomeng[1]， Gong Yubin[1]

（1. *School of Electronic Science and Engineering*, *University of Electronic Science and Technology of China*, *Chengdu* 610054, *China*;

2. *Science and Technology on Low-Light-Level Night Vision Laboratory*, *Xi'an* 710000, *China*;

3. *Shenzhen Institute for Advanced Study*, *University of Electronic Science and Technology of China*, *Shenzhen* 518000, *China*）

Abstract: High power microwave devices are investigated extensively, because of their potential applications, such as advanced radars, electromagnetic warfare systems. However, low efficiency, enormous volume, huge weight and short lifetime limit their applications. In this paper, a coaxial grating slow wave structure backward wave oscillator (BWO) driven by radial beam is proposed. The focusing system is eliminated in the particle in cell simulation, which can reduce the volume and the power loss in practice. The lifetime of the BWO can also be improved with the thermionic radial beam cathode instead of the explosive emission cathode. After optimization, the BWO driven by 460 kV, 6 kA radial beam can produce 1.2 GW at frequency 3.8 GHz, with the efficiency of 43.5%.

Key words: radial electron beam, back wave oscillator, high power microwave

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High power microwave devices have been paid a lot of attention because of their potential applications, such as: advance radars, electromagnetic warfare systems, plasma chemistry reactors, material processing instruments, medical/biomedical research instruments[1-8]. At present, significant progresses have been made in this field. Many laboratories, institutes and universities around the world have obtained GW class HPM radiation[5-13]. However, the low efficiency, the short lifetime and the enormous volume of the HPM devices limit their applications. To extend the lifetime and reduce the volume, HPM devices should operate at high efficiency without focusing systems and explosive emission cathodes. Current HPM devices, such as conventional RBWO[6-10, 14-15] and RKO[5, 12-13, 16-17], Vircator[18- 19], MILO[20], can't satisfy the requirements. In this paper, a radial beam coaxial grating BWO which satisfies the above requirement is proposed. The structure is described in detail in section 1, the PIC simulation is presented in Section 2, and section 3 gives a brief conclusion.

1 Structure of the radial beam coaxial BWO

The cross section of the coaxial grating BWO is shown in Fig.1. The BWO looks like a disk with a cover, and there are some coaxial gratings etched on the cover, which slow down the EM wave [21-22]. A radial electron beam is injected into the center of the BWO from the outside edge as shown in Fig.1. After the beam wave interaction in the "disk" device, the HPM radiation is produced and extracted from the coaxial output port on the cover, which is located at the first grating.

The dispersion relation of the coaxial grating SWS can't be written easily as conventional "O" shape BWOs because of the radial structure [21]. Nonetheless, the eigen modes of the BWO can be analyzed by CST software, as shown in Fig.2. In Fig.2, the electric field distributions of the symmetric modes, whose corresponding frequencies are 1.05 GHz, 2.11 GHz, 2.92 GHz, 3.3 GHz, 3.8 GHz respectively, are shown. The dispersion relation is described in Fig.3 as that of the conventional "O" shape BWOs.

2 PIC simulation of the BWO

The PIC simulation of the BWO is carried out by CST Particle studio [11,19,23]. The parameters are provided in Table 1. The output power is 1.2 GW and the operating frequency is 3.8 GHz, as shown in Fig.4. The result shows that the BWO is operating in the π mode. Almost all the particles lost energy at the center of the BWO as shown in Fig.5.

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Corresponding author: Wang Zhanliang, 46969449@qq.com。

To improve the stability, extend the BWO lifetime and reduce the volume, two optimizations are made. First, because of the low current density of the radial beam, the BWO does not require the focusing system in the simulation, which can reduce the volume and the power loss in practice.

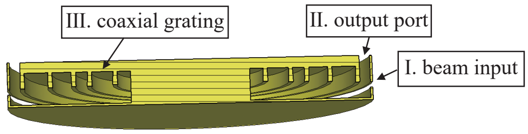

Fig. 1 Cross section of the BWO

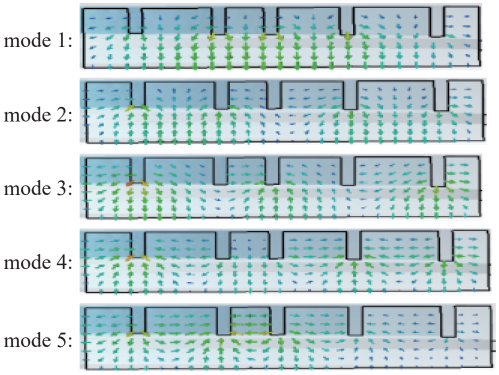

Fig. 2 Electric field of the modes

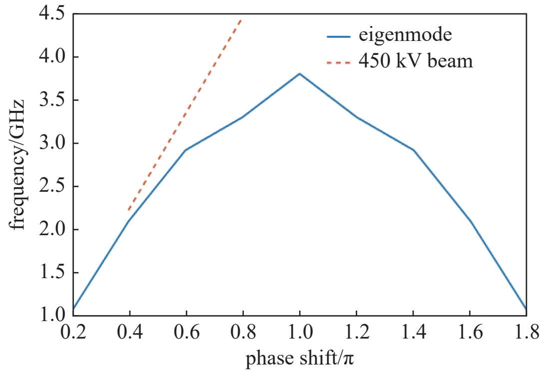

Fig. 3 Dispersion relation of the BWO

Table 1 Parameters for the PIC simulation

voltage of the sheet beam, U/kV	current of the sheet beam, I/kA	thickness of the beam, S_{beam}/mm	magnetic field, B/T	thickness of the BWO, H/mm	outer radius of the BWO, R_{out}/mm	inner radius of the BWO, R_{in}/mm	radius of the first grating, R_1/mm	radius of the second grating, R_2/mm	radius of the third grating, R_3/mm	radius of the fourth grating, R_4/mm	radius of the fifth grating, R_5/mm	depth of the grating, D/mm
460	6	5	0	30	180	60	166	140	115	100	75	12.5

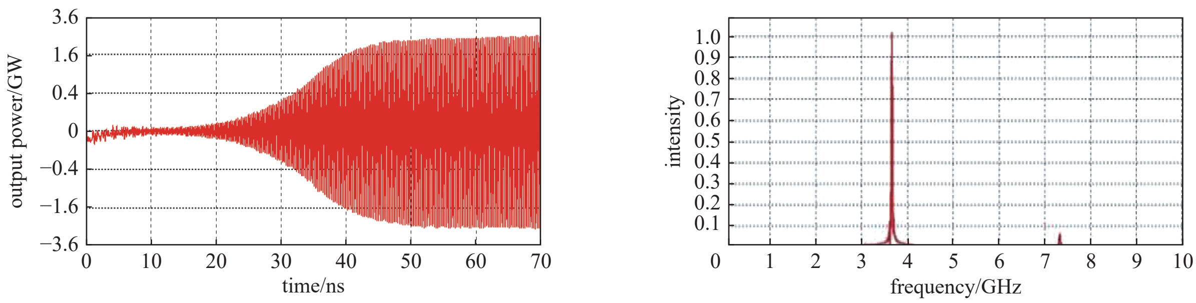

Fig. 4 Output power and corresponding frequency

Second, to improve the stability and the lifetime, a thermionic radial beam cathode instead of an explosive emission cathode is used in the BWO, because the lower beam current density can be achieved by the thermionic cathode [24-25]. A radial beam gun is designed, whose cross section is shown in Fig.6. The radial beam gun is transformed from the convenient pencil beam guns with the same cross section profile. The cathode is a ring located between the upper and the lower focus electrodes. The particles are emitted from the inner face of the ring cathode. The parameters of the gun are provided in Table 2. The beam current density of the BWO is 112 A/cm^2.

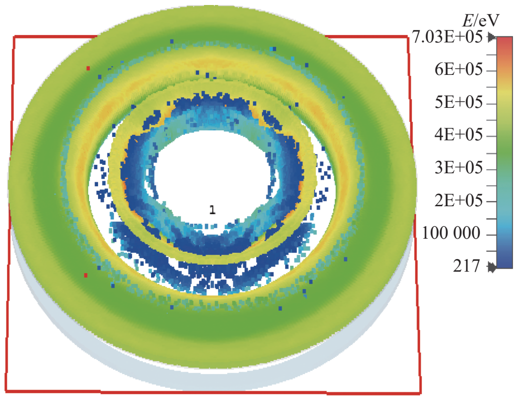

Fig. 5 Particle view of the BWO

The tracking simulation shows that the radial beam gun is with 17∶5 beam compression. Accordingly, the beam current density at the cathode surface (about 33 A/cm^2) can be achieved by the conventional thermionic cathodes with long lifetime and high stability, which have been used for many years in the modern

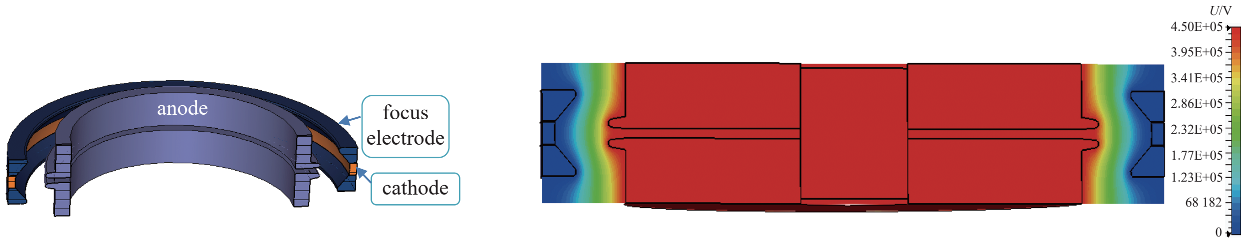

Fig. 6 Structure and potential of the radial beam gun

Table 2 Parameters of the radial beam gun

voltage of the cathode, U_c/kV	voltage of the focus, U_f/kV	voltage of the anode, U_a/V	thickness of the cathode, T_c/mm	radius of the cathode, R_c/mm	thickness of the focus, T_f/mm	inner radius of the focus, R_f/mm	radius of the anode, R_a/mm
−460	−460	0	17	209	23	197	180

vacuum electronic devices (VEDs) .

To radiate the output power, a small sized Vlasov antenna is designed, as shown in Fig.7 [1,8,23]. The antenna transforms the TEM mode to the TM_{01} mode and radiates the output power. The parameters of the antenna are shown in Table 3. The gain of the antenna is shown in Fig.8.

The BWO is designed as shown in Fig.9. It is expected to manufacture the BWO and carry out the test in the near future.

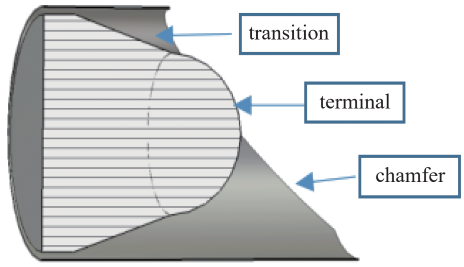

Fig. 7 Cut view of the Vlasov antenna

Table 3 Parameters of the Vlasov antenna

length of the transition, Z_t/mm	radius of the terminal, R_t/mm	length of the antenna, L_a/mm	corner cut of the antenna C_c/(°)
−150	110	450	45

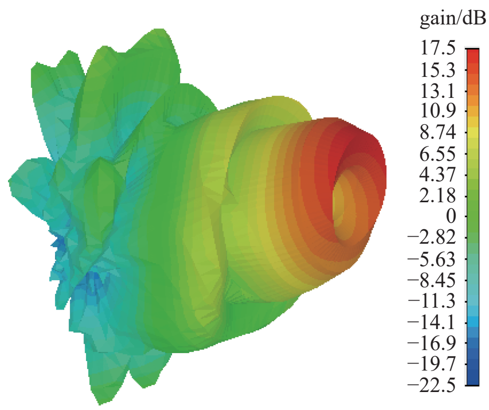

Fig. 8 Gain of the Vlasov antenna

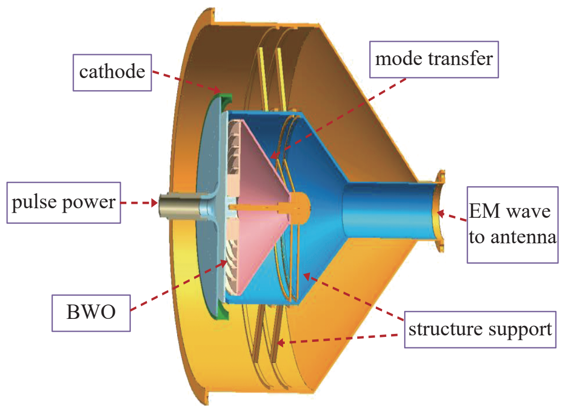

Fig. 9 BWO structure for test

3 Summary and conclusion

A high power radial beam coaxial grating BWO is proposed in this paper. Driven by a radial electron beam (460 kV, 6 kA), the BWO can produce 1.2 GW microwave at frequency 3.8 GHz, corresponding to the efficiency of 43.5%. The simulation does not require the focusing system, which can reduce the volume and the power loss in future. A thermionic radial beam gun is designed to improve the stability and the lifetime. The Vlasov antenna with the maximum gain 17.5 dB is used to radiate the output power.

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S 波段径向注同轴槽振荡器

王战亮[1,2]，　王环宇[1]，　何子远[3]，　路志刚[1]，　巩华荣[1]，　王少萌[1]，　宫玉彬[1]

（1. 电子科技大学 电子科学与工程学院，成都 610054；　2. 微光夜视国家重点实验室，西安 710000；
3. 电子科技大学 深圳高等研究院，广东 深圳 518000）

摘　要：高功率微波器件在雷达、电子对抗等方面具有重要的应用潜力，因此得到广泛的关注。然而，庞大的体积和重量，以及较低的效率和较短的寿命，严重限制了高功率微波的应用范围。提出了一种径向电子注驱动的同轴槽振荡器，该振荡器无需聚焦系统，从而能够大幅度减少体积和耗能。采用由外向内的径向电子注，阴极电流密度低，可以采用热阴极替代爆炸发射阴极，从而提高器件寿命。PIC 仿真中，采用 460 kV，6 kA 径向电子注能够在 3.8 GHz 产生 1.2 GW 的输出，对应效率 43.5%。

关键词：径向电子注；返波振荡器；高功率微波