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High efficiency X-band relativistic backward wave oscillator with non-uniform slow wave structures

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Abstract: Backward wave oscillators (BWOs) driven by intense relativistic electron beams are very efficient means of producing high-power microwaves. However, the efficiency of conventional BWO is lower than 30%. An X-band oversized BWO with non-uniform slow wave structure is designed to improve RF output characteristics. In particle-in-cell simulation, a high power microwave with a power of 8.0 GW and efficiency of 40% is obtained, compared with that of 30% obtained in a conventional relativistic BWO.

Key words: high power microwave, BWO, slow wave structure, non-uniform

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1 Introduction

In recent years, devices generating narrow-band high power microwaves (HPMs) have been widely developed [1]. Moreover, backward wave oscillators (BWOs) are one of the most promising HPM devices to produce high power coherent radiation in centimeter and millimeter wavelength regions [2, 3]. In order to increase the power handling capacity of the devices, the oversized BWO with a resonant reflector is used to reduce the RF field in the device since its cross section can be increased beyond the cutoff radius [4–7]. We have experimentally realized 6.0 GW output power with an efficiency of about 27.5% in the last year using uniform slow wave structure (SWS) (the experimental results are described in detail in Ref. [8]). Although the efficiency is relatively high compared with other types of HPM devices, it is generally lower than 30%, so more efforts should be given to the efficiency enhancement [9–11].

An X-band relativistic BWO with a power of 8.0 GW and efficiency of 40% is designed in this paper. In Section 2, we present a BWO model with a non-uniform SWS and a brief description of its working characteristics. In Section 3, the simulation results are given with the aid of particle-in-cell (PIC) simulation. Finally, some conclusions are given in Section 4.

2 Physics model

The structure of the X-band relativistic BWO is shown in Fig. 1. There are three main parts in the device: resonant reflector, drift tube and SWS. Mode selection is a key issue in the oversized BWO, and it can be realized by three methods. The first one is that the reflector is designed to ensure the reflection at working frequency while keeping the reflection of other frequencies relatively low. Meanwhile, the excited field in the reflector can modulate the electron beam which reduces the startup current of the working mode. The second one is that the length of the drift tube is designed to favor the interaction for the working mode and not for the other modes. The third one is that the SWS is tuned to maintain efficient beam-wave interaction.

Different from a conventional BWO, a two-section SWS is utilized to increase the efficiency of the device. When the electron beam traverses the device, it loses energy. In order to maintain a synchronous condition for efficient interaction, the phase velocity in SWS2

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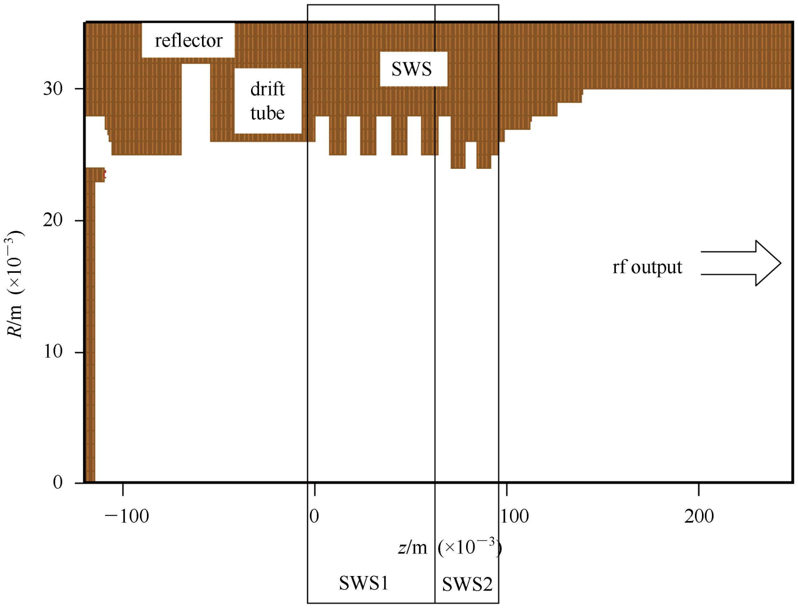

Fig. 1. The modified BWO structure.

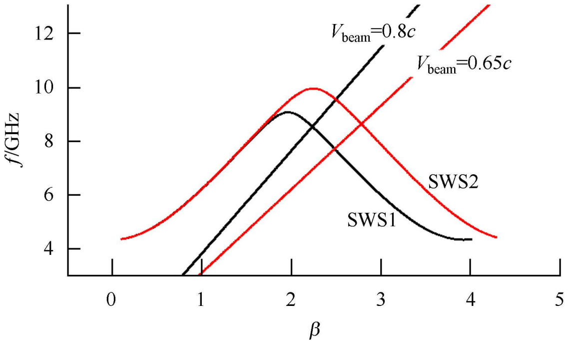

Fig. 2. Two SWSs' dispersion curves.

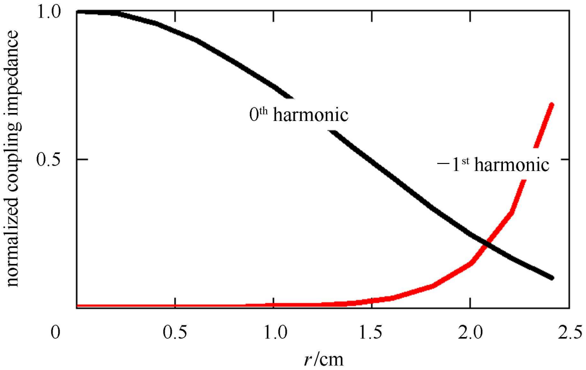

Fig. 3. Normalized coupling impedance of 0th harmonic and -1^{st} harmonic versus radius.

is decreased to match the average velocity of the decelerated electrons. This can be achieved by decreasing the disk period of the SWS2. As shown in Fig. 2, the synchronous velocity of the SWS2 is 0.65c, while that of the SWS1 is 0.8c. Besides that, the inner radius of the SWS2 is smaller than that of the SWS1, so the coupling impedance of the SWS2 is larger than that of the SWS1 since the beam is closer to the disk as shown in Fig. 3.

3 Simulation results

PIC simulation is used to investigate the physics of this tube. As shown in Fig. 4, the axial electric field amplitude in the SWS2 of the modified BWO is stronger than that in the conventional BWO. Meanwhile, the peak electric field interval in the SWS2 is smaller than that in the conventional BWO. Therefore, the field amplitude and field phase are all beneficial for the efficient energy exchange between the electron beam and the electromagnetic field. Fig. 5 is

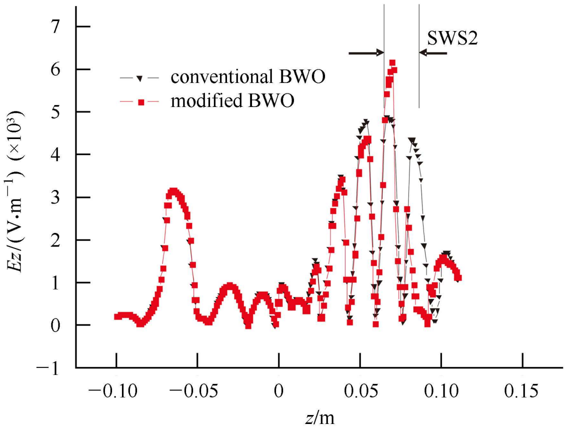

Fig. 4. The axial electric field amplitude distribution in the conventional BWO and the modified BWO.

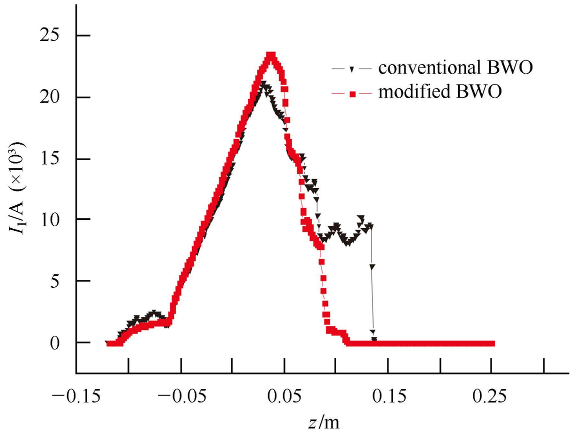

Fig. 5. Fundamental harmonic current versus z in the conventional BWO and the modified BWO.

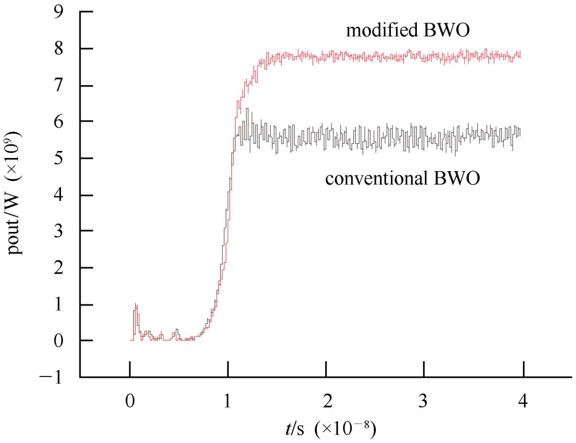

Fig. 6. RF output power in the conventional BWO and the modified BWO.

the fundamental harmonic current versus z; we can find that beam-to-wave conversion in the modified BWO is more adequate than that in the conventional BWO.

Figure 6 shows the output microwave power as a function of time. Here, the result obtained with the conventional BWO is compared with that obtained with the modified BWO. For the two cases, with the diode voltage of 1 MV and the diode current of 20 kA, the output microwave powers are 6.0 and 8.0 GW, giving the beam-to-wave conversion efficiencies of 30% and 40%, respectively. Note that the working frequency in the modified BWO is 8.48 GHz, which is slightly larger than that in the conventional BWO. This is because SWS2 increases the working frequency.

4 Conclusions

In this paper, we have presented an oversized X-band relativistic BWO with non-uniform SWS to improve the beam-wave synchronization and coupling. PIC simulation shows that a microwave with power of 8.0 GW and frequency of 8.48 GHz is obtained when the diode voltage is 1 MV and the diode current is 20 kA, and the conversion efficiency is 40%, compared with that of 30% obtained with the BWO using uniform SWS. An experiment will be carried out in the near future.

References

1 Benford J, Swegle J, Schamiloglu E. High Power Microwaves. Boston: Artech House, 1992

2 Carmel Y, Ivers J, Kribel R E, Nation J. Phys. Rev. Lett., 1974, **33**: 1278

3 Bugaev S P, Cherepenin V A, Kanavets V I, Klimov A I, Kopenkin A D, Koshelev V I, Popov V A, Slepkov A I. IEEE Trans. Plasma Sci., 1990, **18**: 525

4 Abe D K, Carmel Y, Miller S M, Bromborsky A, Levush B, Antonsen T M, Destler W W. IEEE Trans. Plasma Sci., 1998, **26**: 591

5 Gunin A V, Klimov A I, Korovin S D, Kurkan I K, Pegel I V, Polevin S D, Roitman A M, Rostov V V, Stepchenko A S, Totmeninov E M. IEEE Trans. Plasma Sci., 1998, **26**: 326

6 LI Z H. Appl. Phys. Lett., 2008, **92**: 054102

7 LI Z H, QI Y. Phys. Plasmas, 2008, **15**: 093104

8 MA Q S, LI Z H, LU C Z, WU Y, JU B Q, YU A M, SU C, JIN X. IEEE Trans. Plasma Sci., 2011, **39**: 1201

9 Moreland L D, Schamiloglu E, Lemke R W, Korovin S D, Rostov V V, Roitman A M, Hendricks K J, Spencer T A. IEEE Trans. Plasma Sci., 1994, **22**: 554

10 Levush B, Antonsen T M, Vlasov A N, Nusinovich G S, Miller S M, Carmel Y, Granatstein V L, Destler W W, Bromborsky A, Schlesiger C, Abe D K, Ludeking L. IEEE Trans. Plasma Sci., 1996, **24**: 843

11 XIAO R Z, CHEN C H, ZHANG X W, SUN J. J. Appl. Phys., 2009, **105**: 053306