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Simulation of the relativistic backward wave oscillator with a sinusoidal guiding magnetic field

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Abstract A simulation is carried out to investigate a relativistic backward wave oscillator (RBWO) with a sinusoidal guiding magnetic field. In the numerical simulation, a microwave output power of 1.33 GW at 9.57 GHz microwave frequency with 33% conversion efficiency is achieved. It is a significant attempt which is helpful for developing a practical high power microwave (HPM) source guided by a permanent magnetic field.

Key words HPM, RBWO, sinusoidal guiding magnetic field

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1 Introduction

The relativistic backward wave oscillator (RBWO), which needs a high guiding magnetic field, is one of the most promising high power microwave (HPM) generators. To achieve a higher energy efficiency and lower the operational cost, it is necessary to reduce the strength of the guiding magnetic field[1—4], so as to investigate the RBWO with a periodic permanent magnetic field (PPM).

The article consists of three parts. The model of the RBWO is described in section 2. The RBWO with a sinusoidal PPM is simulated in section 3. The conclusion is given in section 4.

2 Description of the model of the RBWO

Based on theoretical analysis in Ref. [5], the fundamental parameters of the BWO are chosen approximately as follows: 1) the average radius of the slow wave structure (SWS) $r_\mathrm{a} = 1.65$ cm; 2) the depth of SWS $d = 0.3$ cm; 3) the corrugation period of SWS $L = 1.6$ cm. The SWS of the BWO is divided into two sections by a drift tube. When a relativistic electron beam (REB) travels through the first section of SWS, its velocity is modulated. Its velocity modulation is gradually converted into density bunching when REB travels through the drift tube. At last, the energy of the well-bunched REB is extracted in the second section of the SWS. There is a Bragg reflector at the beginning of the SWS which is used to completely reflect the backward wave. There is also a reflector at the end of the SWS, which is used to partially reflect the forward wave so as to increase Q of the device and decrease the strength of the guiding magnetic field.

Then, the parameters are elaborately rectified with the PIC code KARAT[6] to obtain an optimized RBWO (Fig. 1).

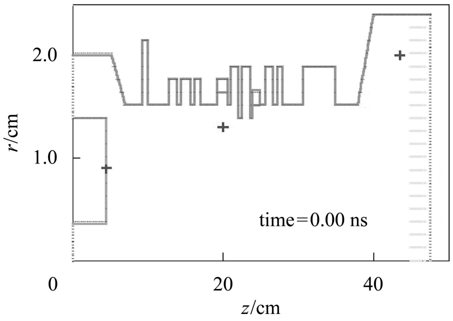

Fig. 1. Model of the RBWO.

3 Simulation of a RBWO with a sinusoidal guiding magnetic field

3.1 The sinusoidal guiding magnetic field

The magnetic field is necessary to guide the

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electron to travel through the SWS in the RBWO. The magnetic field used in the simulation is a sinusoidal magnetic field whose strength is 0.68 T and period is 4.6 cm.

3.2 Usages of dielectrics

To gain higher output microwave power, the velocity of the electron must be slower than the phase velocity of the microwave in the second section of the SWS. So dielectrics with dielectric capacities of 3.5 and 4 are filled in the first and the fourth cavities to lower the phase velocity.

3.3 Relationship between the output microwave power and the location of the cathode

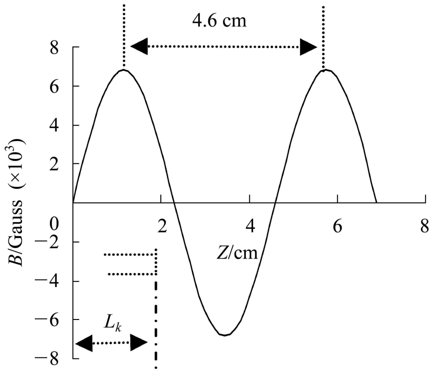

Fig. 2. Location of the cathode, L_k.

Because of $\left(\frac{r}{r_k}\right)^2=\frac{B_k}{B}$ (r_k is the radius of the cathode and B_k is the strength of the magnetic field on the location of the cathode), the shape of the electron beam varies with the location of the cathode immersed in the sinusoidal magnetic field (Fig. 2). Therefore, the output microwave power also varies with the location of the cathode.

Figure 3 shows the simulated relationship between the output microwave power and the location of the cathode, L_k. The simulated microwave frequency is 9.57 GHz.

As shown in this figure, the optimal location of the cathode is $L_k=0.3$ cm.

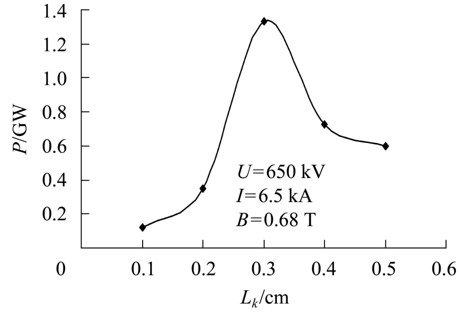

Fig. 3. Relationship between the output microwave power and L_k.

3.4 Relationship between the output microwave and the period of the magnetic field

From theoretical analysis we know that not only the power but also the frequency of the output microwave are influenced by the period of the sinusoidal magnetic field. The simulated results are shown in Fig. 4, which indicates that the optimal period of the magnetic field is 4.6 cm.

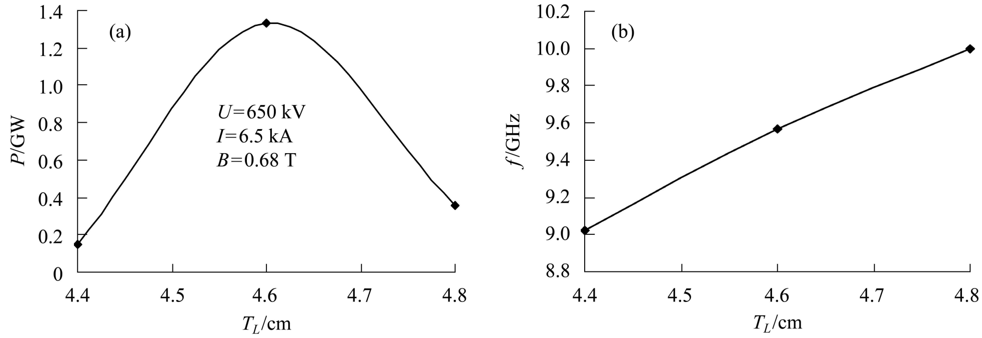

Fig. 4. (a) Relationship between the output power and the period of the magnetic field. (b) Relationship between frequency and the period of the magnetic.

3.5 Influence of the electron energy on the output microwave power

To obtain the biggest output microwave power, the electron must have an appropriate energy. Otherwise the conversion efficiency between the electron and the microwave lowers and the output microwave power diminishes (Fig. 5(a)). Simultaneously, the microwave frequency is influenced by the electron energy (Fig. 5(b)).

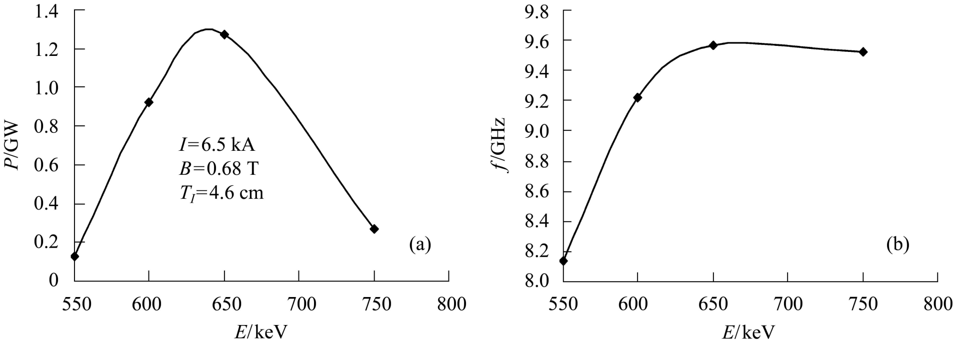

Fig. 5. (a) Relationship between the output power and the electron energy. (b) Relationship between frequency and the electron energy.

3.6 Influence of the beam current on the output microwave power

The electron beam current is one of the factors which influences the conversion efficiency. The biggest output microwave power obtainable under the given guiding magnetic field (0.68 T) and electron energy (650 keV) needs a special beam current of 6.5 kA (Fig. 6).

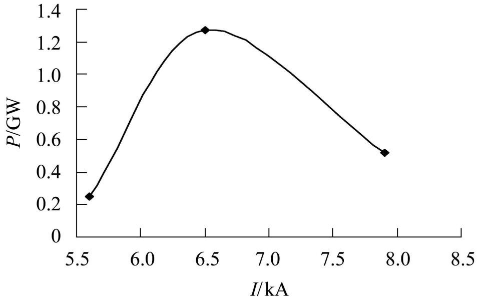

Fig. 6. Relationship between the output power and the beam current.

In Fig. 6, it can be seen that the output microwave power as a function of the beam current goes through a maximum. First, it increases because the total beam energy increases with the current. Then, because of the reflection of the electrons, a further continuous increase of the beam current leads to a decrease of the output microwave power.

3.7 Simulated results

For a period and strength of the sinusoidal guiding magnetic field of 4.6 cm and 0.68 T and for electron energy of 740 keV and beam current of the diode of 6.5 kA, we obtain the following results:

1) Modulated current. As shown in Fig. 7, when the electrons travel through the first section of the SWS, they are modulated and the modulated current reaches the maximum at the end. When the electrons travel through the second section of the SWS, the modulated current decreases.

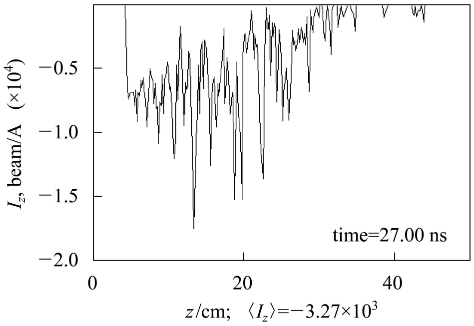

Fig. 7. Modulated current.

2) Output microwave power. Fig. 8 shows the waveform of the microwave with an output power of 1.33 GW and a conversion efficiency of 33%.

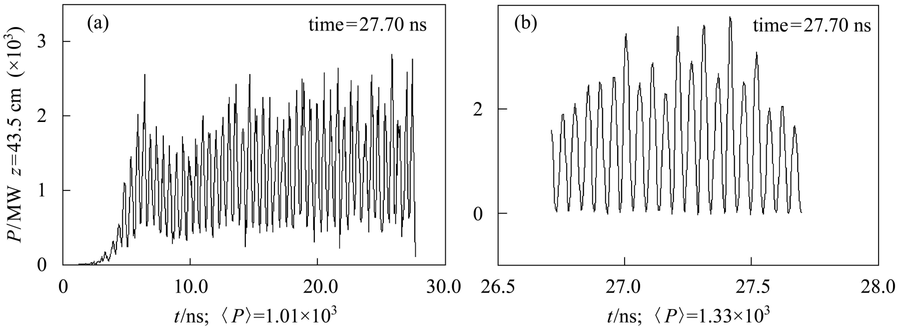

Fig. 8. (a) Output power varying with time, (b) instantaneous output.

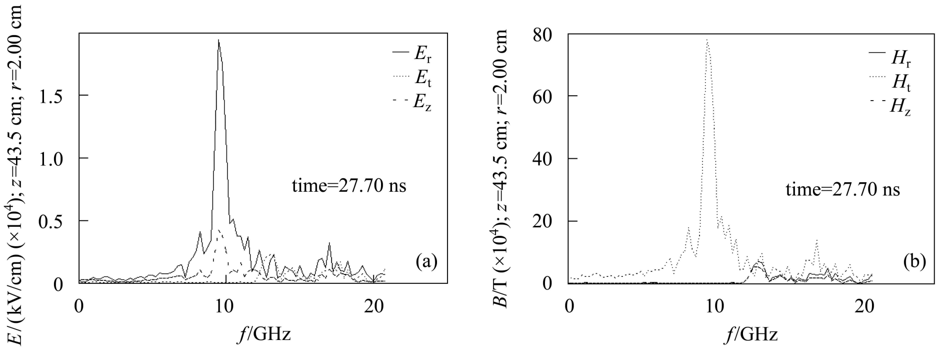

Fig. 9. (a) FFT of the electric field of the microwave. (b) FFT of the magnetic field.

3) Microwave frequency and mode. It can be seen from fast fourier transform (FFT) of the microwave (Fig. 9) that:

(1) The microwave frequency is 9.57 GHz;

(2) The microwave mode is TM_{01}.

4 Conclusion

A RBWO with a sinusoidal guiding magnetic field is simulated. For a period and strength of the sinusoidal guiding magnetic field of 4.6 cm and 0.68 T and electron energy of 740 keV and beam current of the diode of 6.5 kA, a microwave output power of 1.33 GW at 9.57 GHz microwave frequency with 33% conversion efficiency is achieved.

This is a significant attempt which is helpful for developing a practical HPM source guided by a permanent magnetic field.

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