CPC(HEP & NP), 2012, **36**(8): 753–755 Chinese Physics C Vol. 36, No. 8, Aug., 2012

Development of the relativistic backward wave oscillator with a permanent magnet

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Abstract: Firstly, an X-band relativistic backward wave oscillator with a low guiding magnetic field is simulated, whose output microwave power is 520 MW. Then, an experiment is carried out on an accelerator to investigate a relativistic backward wave oscillator with a permanent magnetic field whose strength is 0.46 T. When the energy of the electron is 630 keV and the current of the electron beam is 6.7 kA, a 15 ns width pulsed microwave with 510 MW output power at 8.0 GHz microwave frequency is achieved.

Key words: permanent magnet, relativistic backward wave oscillator, low magnetic field

PACS: 41.60.Bq **DOI:** 10.1088/1674-1137/36/8/012

1 Introduction

The relativistic backward wave oscillator (RBWO), which needs a high guiding magnetic field [1–4], is one of the most promising high power microwave generators. In order to achieve a higher energy efficiency and lower operational cost, it is necessary to lower the strength of the guiding magnetic field, so a permanent magnet is used to produce this guiding magnetic field. An RBWO with a permanent magnet, whose microwave output power is 510 MW at 8.0 GHz frequency, was developed by the Institute of Applied Electronics in 2011.

The simulated results of the RBWO with a low magnetic field are presented in Section 1. In Section 2, a newly designed permanent magnet is described. The experimental results carried out on an RBWO with a permanent magnet are shown in Section 3. Finally, a summary is given in Section 4.

2 Simulation of the RBWO with a low magnetic field

Based on the simulation with the PIC code KARAT [5], an RBWO with a low magnetic field is designed, whose slow wave structure (SWS) is divided into two sections by a drift tube [6]. When a relativistic electron beam (REB) travels through the first section of the SWS, its velocity is modulated. The velocity modulation is converted into density bunching gradually when the REB travels through the drift tube. Finally, the energy of the well-bunched REB is extracted in the second section of the SWS. There is a Bragg reflector on 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 the Q value of the device and decrease the strength of the guiding magnetic field (Fig. 1).

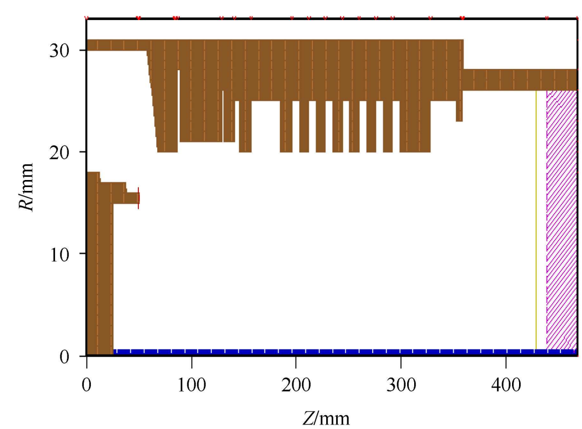

Fig. 1. Modal of the RBWO with a low magnetic field, where R and Z are radial scale and axial scale.

Received 19 October 2011

When the strength of the guiding magnetic field is 0.47 T, and the electron energy and beam current of the diode are 600 keV and 7.2 kA, a simulation result shows that the output microwave power with 520 MW at 7.9 GHz frequency is achieved (Fig. 2).

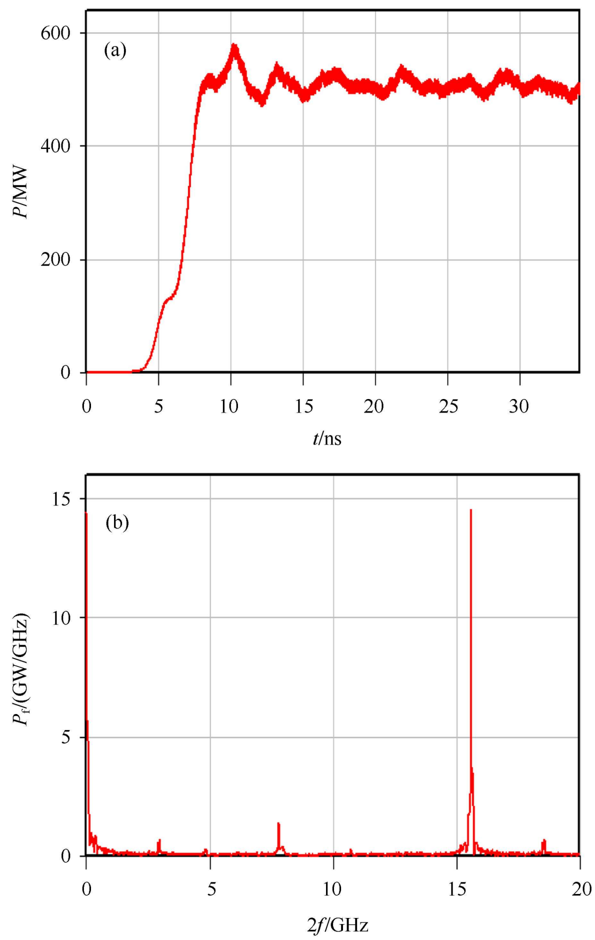

Fig. 2. The results of simulation. (a) The output microwave power; (b) Fast Fourier transform of the output microwave. Where f is frequency and P_{f} is power in the frequency domain.

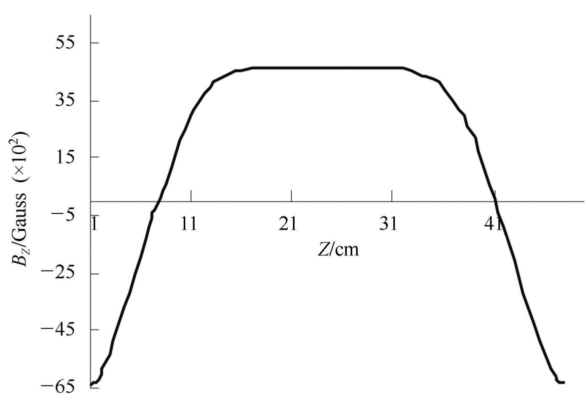

Fig. 3. Axial magnetic field distribution of the permanent magnet.

3 Development of the permanent magnet

According to the magnetic field used in the simulation, a permanent magnet with the inner radius of 3.5 cm and even magnetic field length of 22 cm at 0.46 T is developed (Fig. 3). This magnet is made of serval radially magnetized discs.The magnet's total length is 48 cm, the outer radius is 15 cm and the weight is 116 kg.

4 Experimental investigation of the RBWO with a permanent magnet

4.1 The description of the experimental system

The electron beam used in the experiment is generated by the high-current electron accelerator SU-450 which consists of a pulse generator, a switch and a high-current electron diode. The electron diode and the RBWO are immerged in the permanent magnetic field. The microwave with mode of TM_{01} is generated by the RBWO and a mode converter is used to convert the mode of the microwave from TM_{01} to TE_{11}. Finally, the microwave is radiated in air through an antenna.

4.2 The microwave frequency measurement

The heterodyne technique is used to obtain the microwave frequency. Attenuated by cable and attenuators, the radiated microwave received by a receiving antenna is mixed with an eigen signal in a mixer, which results in a heterodyne signal. The radiated microwave frequency can be deduced from the heterodyne signal.

Figure 4 shows the typical heterodyne signals when the eigen signals are different. From Fig. 4 we can acquire the output microwave frequency as 8.0 GHz.

4.3 The microwave mode

It is difficult to directly measure the mode of the microwave, but we can deduce it from the microwave power density pattern. The microwave power density pattern (Fig. 5) is measured at a distance of 1.75 m from the radiating antenna in the horizontal direction.

It is shown in Fig. 5 that the mode of the microwave is TE_{11}.

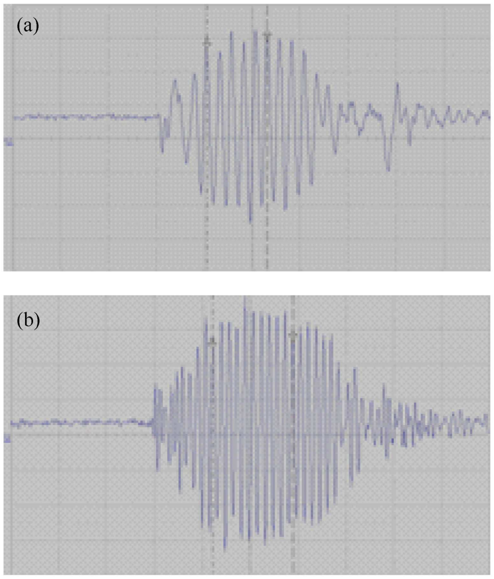

Fig. 4. (color online) Typical heterodyne signal. (a) when the eigen frequency is 7.6 GHz; (b) when the eigen frequency is 8.6 GHz.

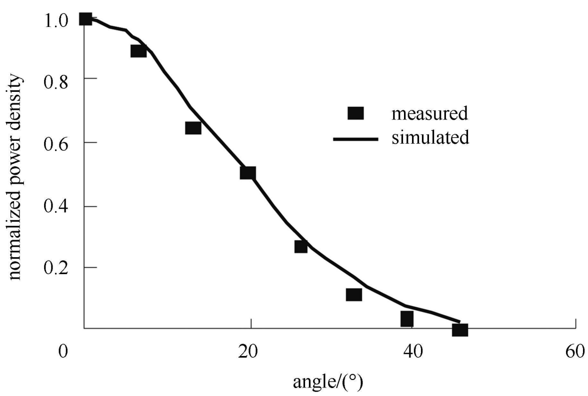

Fig. 5. The normalized power density pattern of radiation.

4.4 The output microwave power

The output microwave power is gained by integrating the power density in Fig. 5 into the whole space.

Figure 6 is the typical experimental waveform when the energy and the current of an annular electron beam, whose inner radius is 1.6 cm and thickness is 1 mm, are 630 kV and 6.7 kA respectively. A 15 ns width microwave with 510 MW output power is deduced from Fig. 5 and Fig. 6.

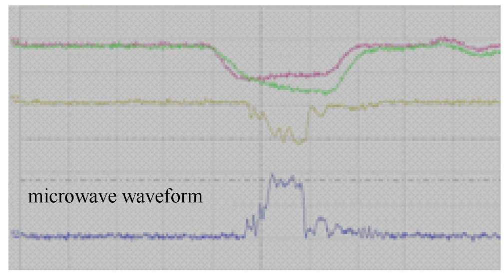

Fig. 6. (color online) Typical experimental waveform.

It is observed from Fig. 6 that there are some fluctuations on the waveform. This may be due to the low quality of the electron beam which is caused by the low strength of the permanent magnet.

5 Conclusion

The RBWO with a magnetic field strength of 0.46 T from a permanent magnet is developed. When the energy of the electron is 630 keV and the current of the electron beam is 6.7 kA, a 15 ns wide pulsed microwave with 510 MW output power at 8.0 GHz microwave frequency is achieved.

It is the first experiment in the world where a permanent magnet is used to produce the guiding magnetic field in an RBWO.

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