INFLUENCES OF THE INNER-CONDUCTOR ON MICROWAVE CHARACTERISTICS IN AN L-BAND RELATIVISTIC BACKWARD-WAVE OSCILLATOR *

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Abstract

The influences of the inner-conductor on microwave characteristics in an L-band relativistic backward-wave oscillator (RBWO) are investigated theoretically and experimentally. The numerical results show that the resonance frequency decreases obviously with the increase in the inner-conductor radius. To verify the above conclusions, an L-band coaxial RBWO is investigated in detail with particle-in-cell (PIC) code. It is shown that the frequency is lowered from 1.63 GHz to 1.51 GHz when the inner-conductor radius increases from 0.5 cm to 2.5 cm. And the efficiency varies in the range of 35.4-27.7%. Furthermore, experiments are carried out at the Torch-01 accelerator. When the diode voltage is 887.6 kV and the current is 7.65 kA, the radiated microwave with frequency of 1.61 GHz, power of 2.13 GW and efficiency of 31.3% is generated. It is found that the frequency decreases from 1.64 GHz to 1.58 GHz when the inner-conductor radius increases from 0.5 cm to 1.5 cm. And the efficiency varies in the range of 31.3-29.8%.

INTRODUCTION

Recently, considerable attention has been paid to development of the relativistic backward wave oscillator (RBWO), which is known to be an efficient high power microwave (HPM) source. [1–5] Since the first RBWO was developed in 1970, there have been many reports on RBWOs operating in the high frequency regime (S-band, X-band, and millimeter wave), [6–11] but discussions on low operation band (L- and P-bands) are scanty. The main reason is that the dimension of the low operation band RBWO is so large that it is difficult to manipulate in experiments. It should be mentioned that the HPM sources with frequency less than 2 GHz still have very important applications in both military and industrial fields. Naturally, the investigation on the compact L-band RBWO is of great interest to the HPM field.

The correlative researches show that the quasi transverse electromagnetic (quasi-TEM) mode has no cutoff frequency in a coaxial slow-wave structure (SWS).[12–14] Thus, the radius of the coaxial SWS can be obviously smaller than that of the noncoaxial SWS. The low operation band RBWO with coaxial SWS can be very compact and convenient for practical applications. Moreover, the peculiarities of the coaxial SWS are that the introduction of the inner conductor can increase the space-charge limiting current, then the interaction efficiency, and the coupling impedance is larger than that in the noncoaxial SWS.

In the previous work, [15, 16] the L-band RBWO with coaxial SWS is investigated and fabricated, as shown in Fig. 1. Compared with the conventional RBWO, there are the coaxial SWS and the coaxial extractor structure at the end of the SWS section. The coaxial SWS and the coaxial extractor structure are designed to reduce the size, realize the mode selection, and increase the efficiency of the device. [12, 13] This paper presents the influences of the inner-conductor on microwave characteristics in the L-band RBWO.

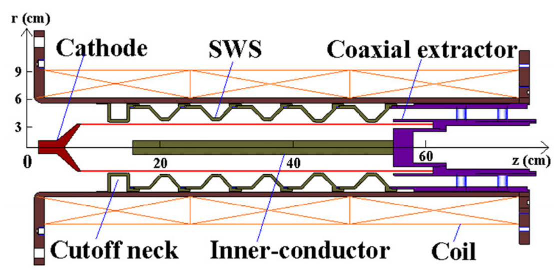

Figure 1: Schematic of the L-band RBWO.

NUMERICAL CALCULATION

The resonance frequency of the coaxial SWS is calculated by using the electromagnetic software. Figure 2 shows the electrical field distribution of the π mode of the quasi-TEM wave. Its resonance frequency is 1.67 GHz when the inner-conductor radius is 1.5 cm. Meanwhile, the relationship between the radius of inner-conductor and the resonance frequency is analyzed in detail as shown in Fig. 3. The curve marked by empty circles stands for the numerical results. It shows that the resonance frequency decreases obviously with the increase of the inner-conductor radius.

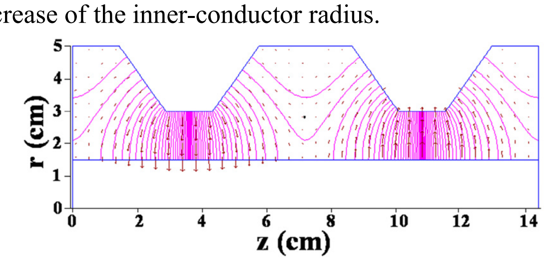

Figure 2: Electric field distribution for π mode of the quasi-TEM wave in the coaxial SWS.

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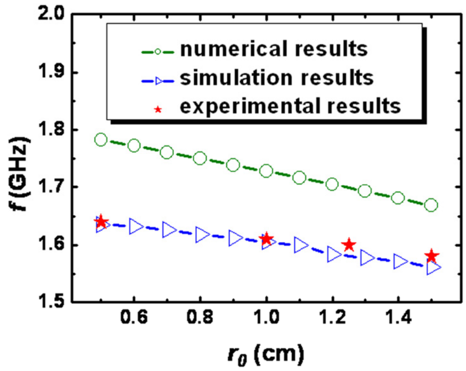


Figure 3: Microwave frequency vs the inner-conductor radius.

PARTICLE SIMULATION

In order to validate the numerical results, a compact L-band RBWO is investigated and optimized in detail with particle-in-cell (PIC) methods (KARAT code), whose models are illustrated in Fig. 4. In simulation, the inner and outer conductors are connected with the perfect metal, which ensures that the inner and outer conductors share the same potential and eliminates the effects of the direct component. A special dielectric employed ahead of the perfect metal absorbs the rf pulse generating from the beam-wave interaction.

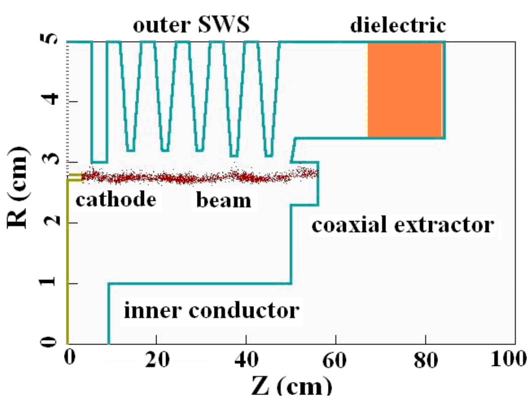


Figure 4: Model for the L-band RBWO.

Detail results of the L-band RBWO are presented. The relationship between the radius of inner-conductor and the resonance frequency is analyzed in detail as shown in Fig. 3. The curve marked by empty triangles stands for the PIC simulation results, which is slightly lower than the numerical results with nonlinear effects of the electron beam. From Fig. 3, it is clear that the relationship between the radius of inner-conductor and the resonance frequency of the simulation results is in good agreement with the numerical results. Particularly, the maximum tuning bandwidth of 8% at a half power level (1.51–1.64 GHz) is achieved in simulation when the inner-conductor radius increases from 0.5 cm to 2.5 cm.

The relationship between the radius of inner-conductor and the efficiency is analyzed in detail as shown in Fig. 5. The curve marked by empty squares stands for the PIC simulation results. It is shown that the efficiency varies in the range of 35.4-27.7% when the inner-conductor radius increases from 0.5 cm to 2.5 cm.

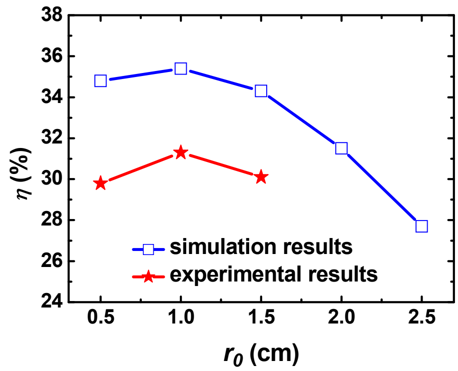


Figure 5: Efficiency vs the inner-conductor radius.

EXPERIMENTAL RESULTS

To verify the above analysis, we design and fabricate an L-band coaxial RBWO and investigated its performance. The experiment is carried out on the Torch-01 accelerator as shown in Fig.6. The diode voltage and the beam current are measured by a capacitance voltage divider and a Rogovsky coil, respectively. The radiated microwave power is measured using a calibrated rf-diode crystal detector placed 5 m away from the window of the output waveguide by integrating over the radiation pattern. The microwave frequency is measured directly by a Tektronix-DSA71254 oscilloscope.

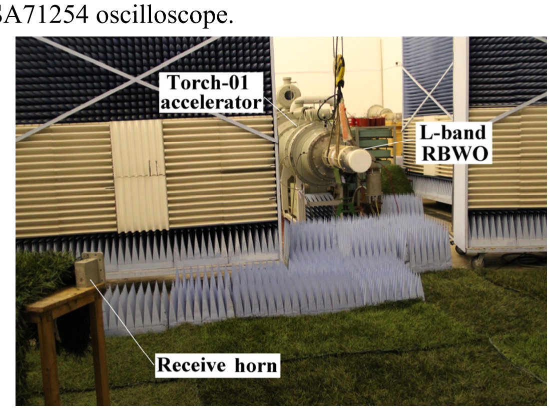
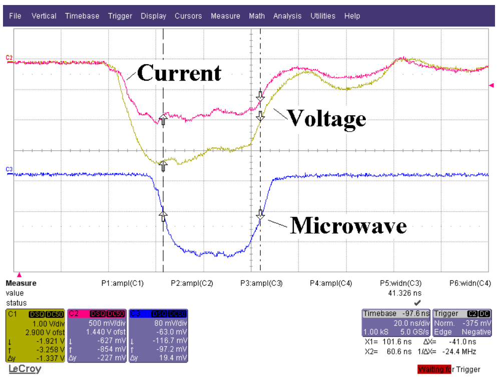
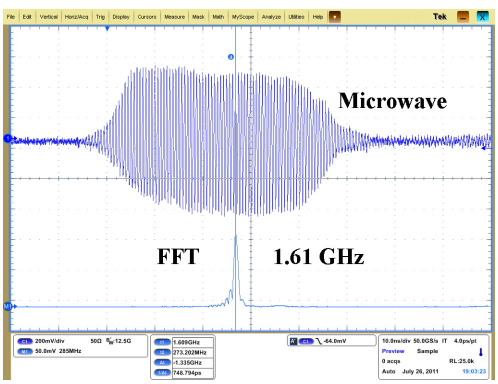


Figure 6: Scheme of microwave measurements.

When the diode voltage is 887.6 kV, the current is 7.65 kA and the guiding-magnetic field is 0.93 T, the radiated microwave with power of 2.13 GW and pulse duration of 41.3 ns is generated. Its efficiency is 31.3% and its main mode is TM_{01} mode. Figure 7 gives the microwave signal and the corresponding fast Fourier transform. Obviously, it can be seen that the generated microwave frequency remains approximately 1.61 GHz. The experimental frequency is close to the simulated frequency (1.60 GHz). The frequency discrepancy between the numerical and experimental results is approximately 0.1 GHz. For simplicity, we obtain the numerical results without the beam. The experimental results are measured when the space charge effects of the beam is considered adequately.



(a): Waveforms of voltage, beam current and microwave.



(b): Radiated microwave and its spectrum.

Figure 7: The typical measured waveforms.

Furthermore, we fabricate the inner-conductors with different radii. The tunable characteristics are studied in detail. It is found that the frequency decreases from 1.64 GHz to 1.58 GHz when the inner-conductor radius increases from 0.5 cm to 1.5 cm. The curve marked by solid stars in Fig. 3 shows the relationship between the radius of the inner-conductor and the resonance frequency of the experimental results, which is in good agreement with the simulation results. Thus, the frequency tuning within 4% is realized by mechanically altering the radius of the inner-conductor at a half power level.

The curve marked by solid stars in Fig. 5 shows the relationship between the radius of the inner-conductor and the efficiency of the experimental results, which is in good agreement with the simulation results.

SUMMARY AND CONCLUSION

This letter presents the influences of the inner-conductor on microwave characteristics in an L-band RBWO. The key effects of the inner-conductor contributing to the frequency and efficiency are investigated theoretically and experimentally. The numerical results show that the resonance frequency decreases obviously with the increase in the inner-conductor radius. To verify above conclusions, an L-band RBWO is investigated with PTC code. It is shown that the frequency is lowered from 1.63 GHz to 1.51 GHz when the inner-conductor radius increases from 0.5 cm to 2.5 cm. The efficiency varies in the range of 35.4-27.7%. In the experiments, it is found that the frequency decreases from 1.64 GHz to 1.58 GHz when the inner-conductor radius increases from 0.5 cm to 1.5 cm. The efficiency varies in the range of 35.4-27.7%. The experimental results are in good agreement with the theoretical results.

ACKNOWLEDGEMENTS

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