Simulation and Experimental Research of a Novel Vircator *

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A new configuration of an axially-extracted vircator with three resonant cavities is put forward and optimized by simulation with the PIC code. The output power of over 1 GW is obtained at around 4.1 GHz in the experiment, in agreement well with the PIC simulation results. The beam to wave power conversion efficiency is more than 6.6%.

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Virtual cathode oscillators (VCOs), usually taken as high-power microwave sources, have been studied for nearly four decades. They are one kind of the most promising high-power microwave sources because of their conceptual simplicity, high-output power capability, and operation frequency tunability.[1–3] However, it has a severe drawback of low efficiency. At present, it has been realized that microwave efficiency of VCOs depends strongly on the intensity of electromagnetic field around the virtual cathode,[4–7] so studies on vircators have been concentrated on the structure improvement to acquire enough electromagnetic field modulation for virtual cathodes.

In this Letter, we propose a novel configuration of VCOs, in which three resonant cavities are used. We test this new VCO configuration on the water accelerator named spark04 in our laboratory. Under the diode voltage of 630 kV, the diode current of 24 kA, high power microwave with output power 1 GW at frequency 4.1 GHz is obtained in the experiment.

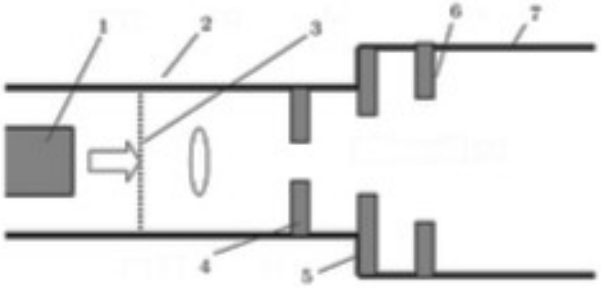


Fig. 1. Schematic structure of the novel vircator: (1) cathode, (2) waveguide, (3) anode mesh, (4) the first annulus, (5) the second annulus, (6) the third annulus, (7) output waveguide.

Figure 1 shows the novel configuration. In this structure, the first cavity, formed by the first annulus and the foil, can effectively enhance the beam-microwave power conversion efficiency. The second cavity, consisting of the first annulus and the second annulus, can obviously improve the extraction efficiency of microwave power. The third cavity composed of the second annulus and the third annulus can effectively reduce the reflection of the microwave from the output waveguide port. It should be noticed that there is a non-continuous region, namely, the waveguide diameter at the upstream of the second annulus is smaller than that at its downstream. In addition, the annulus inner diameters are tapered along the microwave propagation direction, which is beneficial to the power extraction along the axial direction.

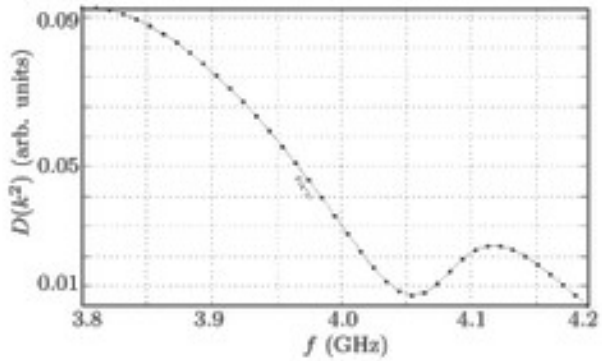


Fig. 2. Resonance points.

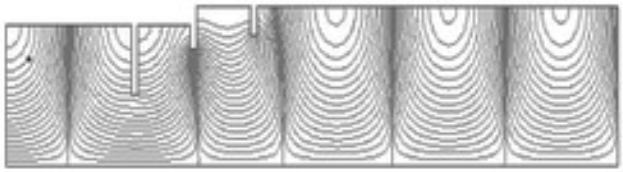


Fig. 3. Electric field distribution at frequency 4.04 GHz.

The width of the first cavity between the mesh and the first annulus is $3\lambda_g/4$(λ_g is the wavelength of the waveguide), the second is $\lambda_g/4$, and the last is also about $\lambda_g/4$. Using the electromagnetic computing program, we can obtain the three cavities resonant frequencies where $d(k^2) = 0$ and $d(k^2)/df = -1$.[8]

From Fig. 2, we know that the resonant frequencies are 4.04 GHz and 4.16 GHz. The field distribution of 4.04 GHz (Fig. 3) shows that the microwave mode is TM_{01}, which is beneficial to the beam-microwave energy change.

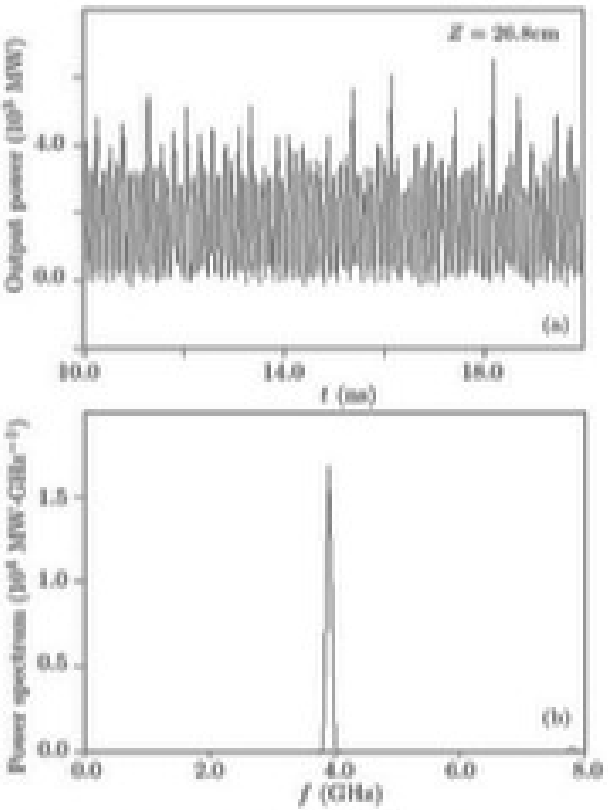


Fig. 4. Typical simulation results of the novel vircator: (a) output power versus time, (b) frequency spectrum.

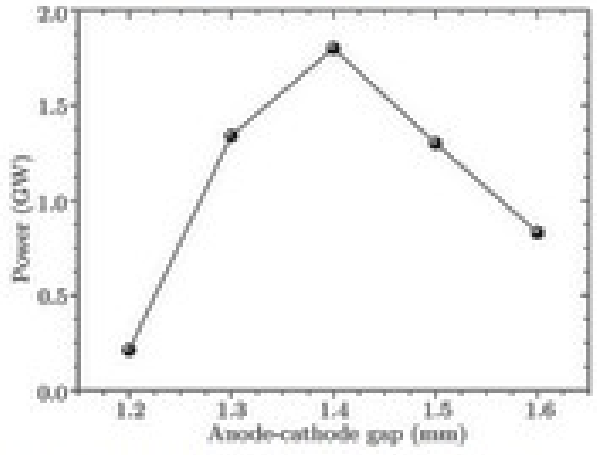


Fig. 5. Microwave power versus anode–cathode gap.

Through PIC code KARAT, the novel configuration vircator is designed and optimized. The diode diameter is 80 mm, and the cathode diameter is 64 mm. The anode-cathode gap is about 15 mm. The op-

4 shows the simulation results of the novel axially-extracted vircator with three resonant cavities under the diode voltage of 700 kV. This new configuration can effectively improve the performance of the vircator and generated microwave power more than 1.80 GW at 3.98 GHz. The maximum power efficiency is 10%. Otherwise, under the same diode conditions, the vircator with one feedback annulus[4] can only generate the power of 795 MW, and the maximum power efficiency is only 4.7%.

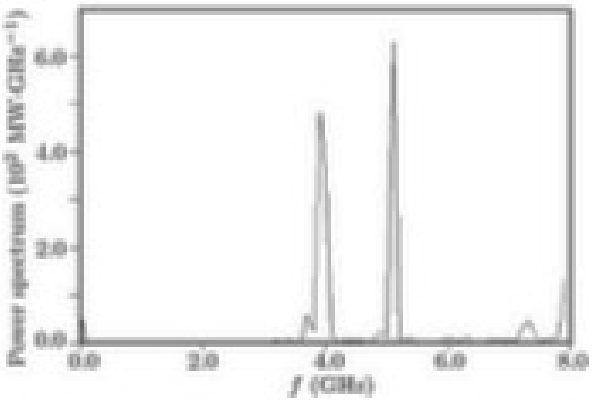


Fig. 6. Frequency spectrum with the diode gap of 12 mm.

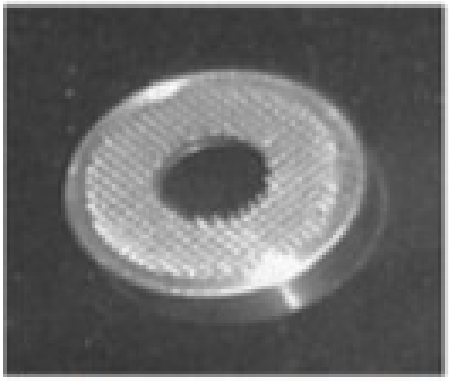
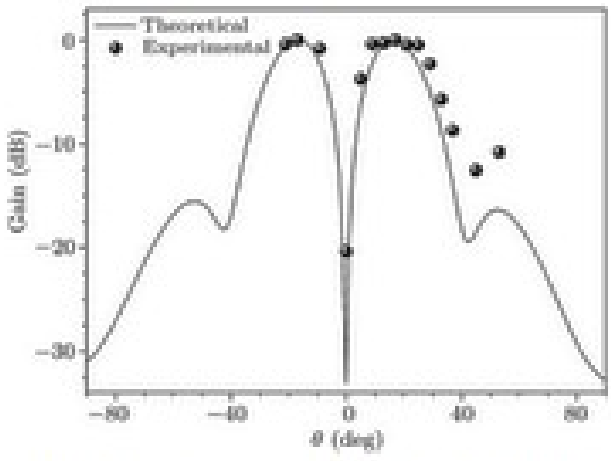


Fig. 7. Stainless steel pin cathode.



By changing the anode–cathode gap from 16 mm to 13 mm, the microwave power is also changed (Fig. 5), while the frequency is stabilized by the three resonant cavities. When the gap is less than 13 mm, other frequencies appear and the power decreases quickly (Fig. 6). The virtual cathode loses resonance with the cavity.

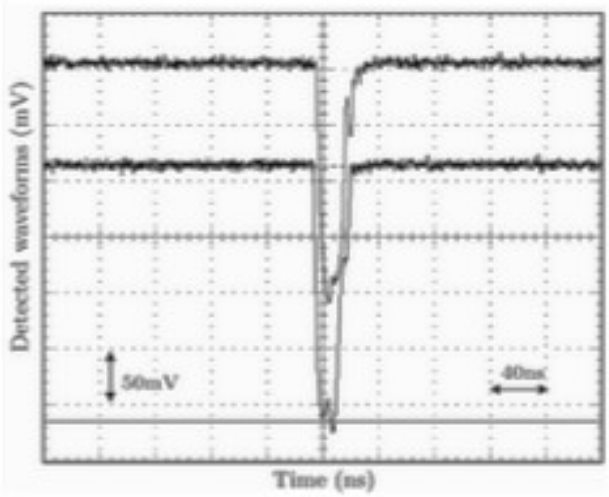


Fig. 9. Typical experimental microwave waveforms.

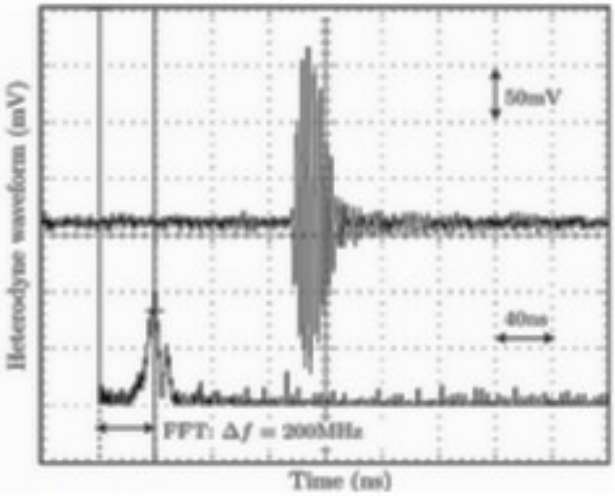


Fig. 10. Heterodyne waveform with the reference frequency 4.3 GHz.

Using the optimized structure parameters obtained from simulations, we constructed the novel vircator and carried out the experiment. The device was driven by a compact electron beam accelerator-Spark04 based on a Blumlein pulse forming line and a high pulse voltage transformer. The stainless steel pin cathode was used in the experiment (Fig. 7). The output microwave power was received using a calibrated waveguide-coax convertor BJ-48 by means of integration over the radiation pattern.[9] Figure 8 shows the comparison between the experimental and theoretical radiation patterns. Obviously, the experimental radiation pattern is in agreement with the theoretical radiation pattern, which indicates that the dominant microwave is of the TM_{01} mode. Figure 9 shows the typical experimental microwave waveforms. Figure 10 shows the heterodyne frequency waveform with the upper reference frequency of 4.3 GHz and its spectrum by the FFT transformation. Under the diode voltage of 630 kV and the diode current of 24 kA, the peak microwave output of over 1 GW is obtained at around 4.1 GHz, which is in agreement with the simulation results well. The peak power efficiency is about 6.6%.

In conclusion, we have proposed a new configuration of an axially-extracted vircator with three resonant cavities and it is optimized by PIC simulation. Particle simulation shows that the novel structure can achieve much better performance. The peak microwave power of over 1 GW is obtained at around 4.1 GHz with the dominant mode TM_{01} in experiments, which corresponds to the peak power efficiency of about 6.6%. The simulation results are demonstrated by experiments.

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