High Energy Beam THz Backward Wave Oscillator based on Double Corrugated Waveguide

Jun Zhang ¹
Claudio Paoloni
Rosa Letizia
Lancaster University
Lancaster United Kingdom
LA1 4YR
¹National University of Defense Technology
Changsha China

Neville C. Luhmann Jr
Branko Popovic
Logan Himes
Robert Barchfeld
Diana Gamzina
University of California Davis
Davis USA

Jinjun Feng
Li Li
Pan Pan
Ye Tang
Fuhzi Zhang
Beijing Vacuum Electronics Research Institute and Vacuum Electronics National Lab, China

Abstract: A new approach to realize THz BWOs relaxing the assembly challenge is presented. An international consortium including UC Davis, Beijing Vacuum Electronics Research Institute (BVERI), and Lancaster University is involved in the design and fabrication of 0.346 THz BWOs to replace the bulky FIR laser at the plasma diagnostic at the NSTX-U fusion device. The use of a highly energetic beam permit and a wide channel, double corrugated waveguide permit to achieve about 4 W of output power at 0.346 THz.

Keywords: backward wave oscillator; double corrugated waveguide; electron beam; terahertz; millimeter waves

Introduction
Backward wave oscillators are an intrinsically low efficiency vacuum electron device [1]. The simple structure makes them among the most promising vacuum electron devices to generate power at THz frequency. The fabrication of BWOs in the THz regime, due to the small dimensions, is highly demanding [2-3]. In particular, the alignment of the beam is very challenging due to the length of the interaction channel. An international consortium comprising UC Davis, Beijing Vacuum Electronics Research Institute (BVERI), and Lancaster University aims to find novel approaches to reduce the fabrication effort and the cost.

Different designs of 0.346 THz BWOs based on the double corrugated waveguide (DCW) [4] were presented to replace the bulky FIR lased at the high-k plasma scattering diagnostic at the NSTX-U fusion device. About 0.5 W output power was achieved with a 13.8 kV beam voltage, 10 mA beam current, and 100 µm beam diameter. The beam tunnel was assumed 120 µm.

The DCW was demonstrated suitable to be fabricated by nano-CNC milling [3]. However, the beam alignment is very challenging, with high risk of low yield and beam interception with the pillars.

A new approach is proposed to relax the alignment difficulties and achieve a significantly higher output power. The use of a wide diameter, high energy beam permits one to decrease the filling factor thereby reducing the alignment effort.

High energy beam BWO design
The BWO in [5] was designed with a beam radius of 50 µm, 13 kV and 10 mA. The very narrow beam makes the alignment very challenging. A new BWO with a beam, with 80 µm radius, 22 kV of beam voltage, and 30 mA was designed while keeping the beam density almost the same (Table 1). The period of the DCW was also increased to match the synchronization between the phase velocity of the wave with the high energy beam. To accommodate the wider beam, the gap between pillars was set to 220 µm, one hundred microns wider than the BWO in [5].

Fig.1 Cross section of beams and DCWs of the BWO [5] (a) and the new BWO (b)

This has allowed one to increase the distance from the edge of the beam to the pillar at 40 µm, in comparison to only 10 µm in [5]. As a result, the beam alignment is expected to be much easier in the new BWO. However, the increased distance from the pillar wall makes the space charge field of the beam higher, so a higher guiding
magnetic field is needed to prevent the diocotron instability of the cylindrical beam propagating through the rectangular waveguide.

**Table 1. Dimensions of the BWOs**

<table>
<thead>
<tr>
<th></th>
<th>BWO [5]</th>
<th>New BWO</th>
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<tbody>
<tr>
<td>Beam voltage (keV)</td>
<td>12.8</td>
<td>22</td>
</tr>
<tr>
<td>Beam current (mA)</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Magnetic field (T)</td>
<td>0.25</td>
<td>0.7</td>
</tr>
<tr>
<td>Beam radius (µm)</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>Pillar section (µm)</td>
<td>60*60</td>
<td>70*70</td>
</tr>
<tr>
<td>Beam channel (µm)</td>
<td>120</td>
<td>220</td>
</tr>
<tr>
<td>Pillar height (µm)</td>
<td>155</td>
<td>150</td>
</tr>
<tr>
<td>Period (µm)</td>
<td>140</td>
<td>170</td>
</tr>
<tr>
<td>Period number</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>Waveguide cross section (µm)</td>
<td>1500*235</td>
<td>1500*270</td>
</tr>
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The new high energy beam THz BWO based on the DCW has been investigated by PIC simulations. Figure 3 presents the modulation and bunching of the beam. The optimized output power shown in Fig.4 is about 4.2 W, with an efficiency of 0.64%.

**Fig.4 Output power**

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**References**