Photonic Band Gap Corrugated Slow Wave Structure for THz Sheet-Beam Vacuum Electron Devices

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Abstract: *The use of photonic band gap (PBG) technology is investigated to alleviate some of the typical issues of vacuum electron devices at terahertz and is shown as particularly suitable for the use of large sheet beams. A full interaction structure including the slow wave structure and the coupler based on a tapered PBG corrugated waveguide is proposed for sheet beam backward wave oscillators (BWO). The case of a 346 GHz BWO is considered.*

Keywords: Photonic band gap; backward wave oscillator; Terahertz; sheet beam.

Introduction

Backward wave oscillators (BWOs) are considered among the most promising device to provide power in the THz region (100-1000 GHz), [1]. At this frequency range, photonic band gap (PBG) technology has been recently proposed to alleviate some of the challenges deriving from the use of metallic periodic waveguides with the dimensions in the sub-millimeter range, [2-4]. In particular, the use of PBG structures allows to use a rectangular beam tunnel for very wide sheet electron beams which does not require the implementation of impedance mismatching circuits. In addition, compared to conventional interaction structures used in vacuum electron devices (VEDs), the benefits include the openness of the waveguide to ease the vacuum pumping, easy assembly, flexibility and scalability of the design. In particular an air gap between the PBG and the top lid would simplify the fabrication.

Slow wave structures (SWS) based on a corrugated waveguide can interact effectively with wide sheet electron beams (cross sectional ratio greater than 5:1) which can support high level of current for a given cathode loading and have recently emerged as a promising solution for relatively high output power VEDs in the THz frequency range. In our recent work, we have demonstrated that the metal walls of a conventional corrugated waveguide can be effectively replaced by opportunely designed PBG structures, [2]. In addition, tapered photonic band gap (TPBG) structures still offer an effective confinement of the useful RF signal while maximizing the empty region around the central corrugations. In this paper, the TPBG corrugated waveguide is designed for a BWO at 346 GHz. The 346 GHz is a relevant frequency in plasma diagnostics for nuclear fusion. A suitable and robust coupler is also designed to be embedded in the same TPBG structure.

Tapered PBG Corrugated Waveguide

A metallic PBG waveguide is designed to operate around 346 GHz with width of the central channel $w = 0.71$ mm, and height $b = 0.36$ mm. The 2D periodic structure is based on a square lattice of copper pillars of period $a_p=0.3$ mm and radius $r_p = 0.06$ mm. The band diagram for the PBG structure closed between two metal plates at the distance of 0.36 mm is shown in Figure 1. From this Figure it can be seen that a complete band gap exists at operation. It has been previously shown that a number of four pillars on each side of the central corrugation is sufficient to provide confinement of the signal within the PBG waveguide. Starting from this PBG structure, a modified design is proposed where the radius of the pillars is increased along the transverse direction towards the edges of the SWS. A schematic of the proposed TPBG corrugated waveguide designed at 346 GHz is shown in Table I. The central corrugation has period of 0.1 mm and length of 50 μm. Assuming a beam thickness of about 20 μm, these specifications are suitable for sheet beam ratios up to 15:1.

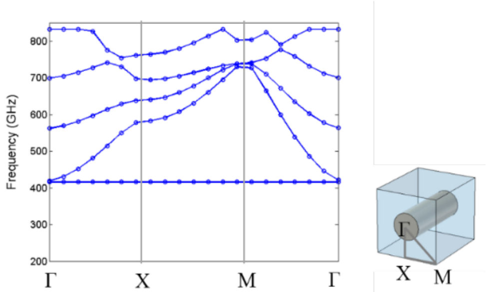


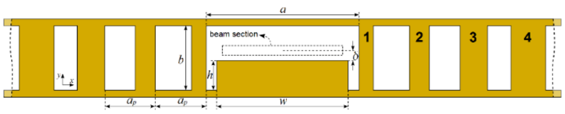
Figure 1. Band diagram for the PBG structure with height of 0.36 mm sandwiched between metal plates. The unit cell is shown in the inset.

Figure 2 shows the comparison between the dispersion diagram obtained for the TPBG corrugated waveguide, the uniform PBG corrugated waveguide with dimensions as described in Figure 1 and the conventional corrugated waveguide which shows similar behavior.

Tapered PBG coupler

A suitable coupler is designed as a 90 degree PBG-bend embedded in the same tapered PBG structure as shown in Figure 3. The performance of the coupler is optimized by tailoring a number of defects (P_1-P_2-P_3 in Figure 3) to optimize the signal coupling into the output port and obtain a very effective design for the beam tunnel. The detailed geometry of the TPBG coupler for 346 GHz can be found in [3].

Table 1. TPBG corrugated waveguide geometry



Pillar	1	2	3	4
r_p (mm)	0.04	0.05	0.07	0.08
r_p/a_p	0.13	0.17	0.23	0.27
a (mm)	0.71			
b (mm)	0.36			
a_p (mm)	0.30			
h (mm)	0.16			
w (mm)	0.54			

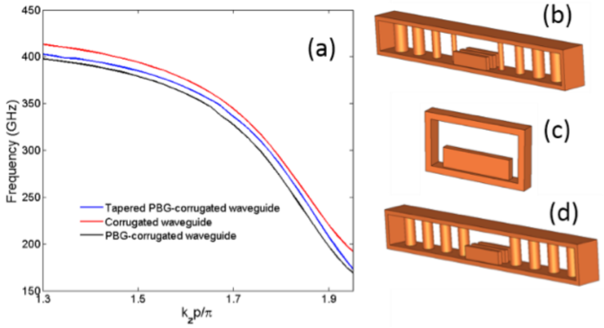


Figure 2. Dispersion curve comparison (a) for the TPBG corrugated waveguide, shown in (b), the conventional corrugated waveguide (c), and the PBG corrugated waveguide (d).

Here, simulation results show that the behavior of the coupler is maintained even in the presence of air gap between the pillars and the top lid. The S-parameters results are shown in Figure 4, where return loss is less than -30dBs and transmission into the beam tunnel is lower than -45dBs around operation.

Conclusions

The design for a BWO at 346 GHz based on a tapered PBG structure has been proposed. With respect to conventional corrugated waveguides for sheet electron beams interaction at the THz range, tapered PBG corrugated waveguides offer the advantages of being a flexible, and effective way to alleviate typical problems of THz tubes such as the low cutoff for sheet beam tunnel and time consuming vacuum pumping of closed structures. The coupler is robust and maintains its performance when an air gap up to 37 µm exists between the pillars and the top lid.

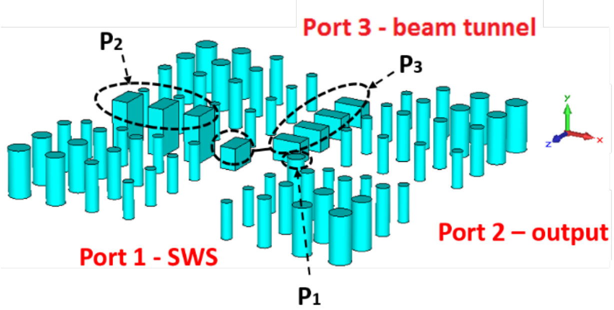


Figure 3. TPBG-coupler schematic. The defects P_1, P_2, P_3 are strategically placed to maximize the transmission in Port 1. The height of pillars P_3 is reduced to 0.16 mm to allow for the beam to be injected.

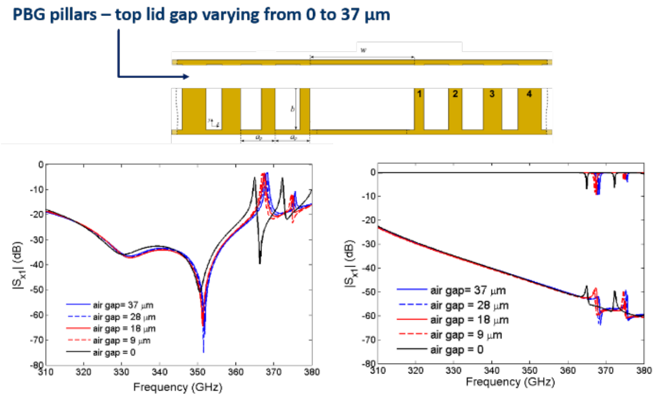


Figure 4. S-parameters for the TPBG-coupler with top lid air gap varying from 0 to 37 µm

References

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