RF DESIGN AND SIMULATION OF A NON-PERIODIC LATTICE PHOTONIC BANDGAP (PBG) ACCELERATING STRUCTURE

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Abstract

Photonic bandgap (PBG) structures (metallic and or dielectric) have been proposed for accelerators. These structures act like a filter, allowing RF fields at some frequencies to be transmitted through, while rejecting RF fields in some (unwanted) frequency range. Additionally PBG structures are used to support selective field patterns (modes) in a resonator or waveguide. In this paper, we will report on the RF design and simulation results of an X-band PBG structure, including lattice optimization, to improve RF performance.

INTRODUCTION

Photonic bandgap (PBG) structures for particle acceleration have the capability of single-mode confinement while damping unwanted higher order modes (HOMs). A PBG accelerating cavity employs a PBG structure in the form of a metallic or dielectric lattice with a single rod removed from the center. This periodic lattice prevents propagation of electromagnetic waves at certain frequencies through the lattice. A rejection band is created which serves to confine and localize the desired mode around the defect. The spacing of the array and the diameters of rods are adjusted so that the frequencies of unwanted higher-modes fall outside of the rejection band. In this manner, the wakefields are not confined at the center and may be extracted from the structure.

PBG RESONATOR

In any accelerating cavity, such as a pillbox cavity, there exists many HOMs, which can be excited by a beam passing through the cavity. The excited modes, and wakefields, induce unwanted transverse motion or energy spread in the beam and could produce beam emittance growth. The advantage of a PBG accelerating resonator is in the efficient and economical suppression of higher order modes wakefields [1]. This structure has a rejection band which confines and localizes the accelerating mode around the missing rod (defect) in a PBG resonator. Other frequencies will leak out to varying degrees through the PBG wall.

A simple PBG resonator schematic is shown in figure 1. It uses a two-dimensional triangular lattice where a single rod is withdrawn from the center of the lattice. A mode outside the rejection band is confined around the defect by internal reflection from the PBG lattice. The electric field of the monopole mode for the PBG cavity is shown in figure 2.

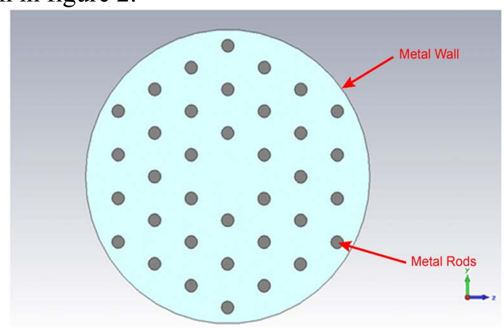

Figure 1: Strict two-dimensional triangular lattice in PBG resonator.

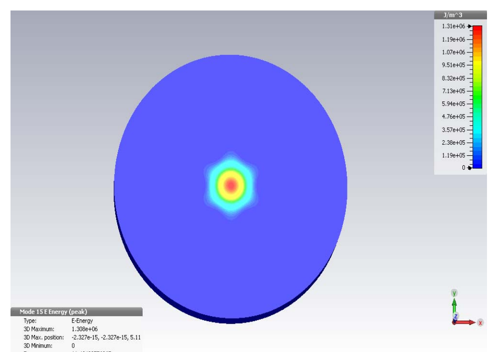

Figure 2: Electric field of the monopole mode in PBG resonator.

OPTIMIZED PBG RESONATOR

In a recent investigation [2] it was demonstrated that the possible advantages of arranging rods in according to various non-periodic geometries [3] in PBG resonators. It was shown that some rod arrangements which lacked lattice symmetry (but retained some rotational symmetry) dramatically reduced the radiative losses of the accelerating mode as compared to lattice arrangements of equal rod count [4]. In addition, simulation results indicated lower wakefields in these optimized structures [5].

The non-periodic lattice shown in figure 3 consists of three layers. On the first layer, all six metal rods are retained. For subsequent layers, radial lines are drawn from the origin through each of the rods, retained rods which are along those lines, removed the rest rods in lattice. In this case, the number of metal rods was reduced

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from 36 to 18. The electric field of its monopole mode is shown in figure 4 for the non-periodic lattice. Note that the field confinement is nearly identical to that in figure 2.

Adjustment of the rotation angle of the second and third-layer of rods, or the radial distance of two adjacent layers, affected the RF performance of the resonator. It was noted that changes in the radial distance predominantly shifted the frequency of the resonator while any changes in the rotation angle affected peak surface magnetic field of the fundamental mode.

The non-periodic lattice design provides further degrees of freedom to enhance mode confinement. It also facilitates the optimization of coupling strategies for extracting detrimental wakefields.

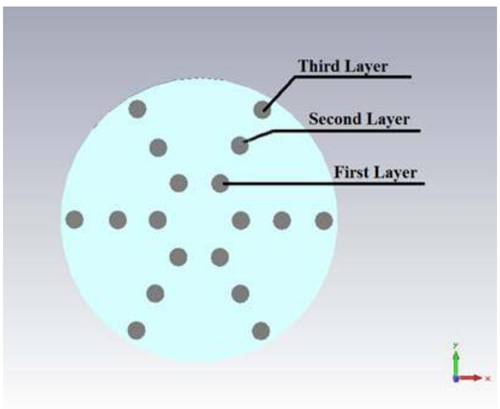


Figure 3: Non-periodic PBG lattice design.

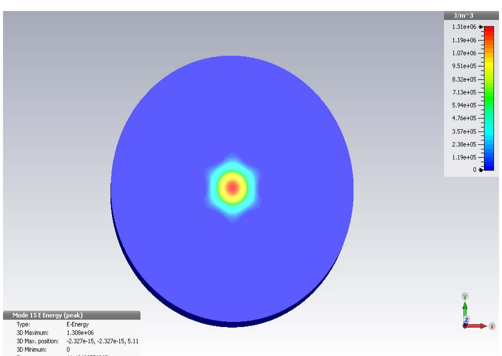
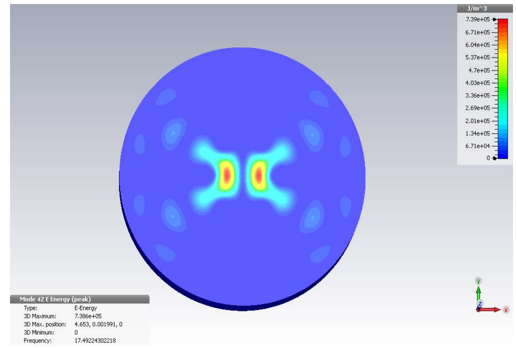
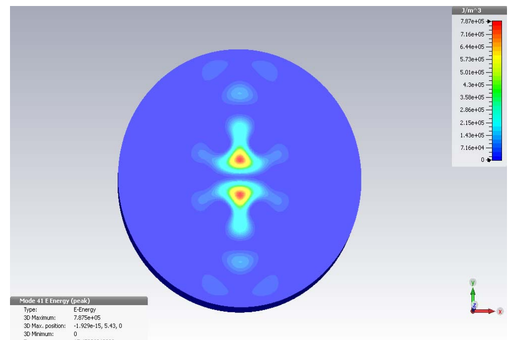


Figure 4: Electric field of monopole mode in non-periodic PBG lattice.

It was further investigated for the damping of higher-order dipole modes. The vertical and horizontal dipole modes shown in figure 5 are not entirely degenerate due to the asymmetry of the lattice. However, it is clear from the field plots that both modes are predominantly confined to the center of the cavity and are only transmitted through the PBG with limited effectiveness. The non-periodic lattice provides the flexibility to adjust the lattice and improve the coupling, distribution, and damping of HOMs.



(a)



(b)

Figure 5: Dipole modes in non-periodic PBG lattice: (a) horizontal- dipole mode and (b) vertical-dipole mode.

MODEL OF PBG ACCELERATOR STRUCTURE

A complete X-band PBG traveling wave accelerator structure was designed with two mode launchers and two coupling cells is shown in figure 6.

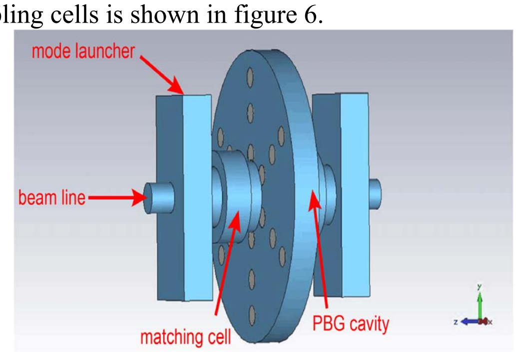


Figure 6: A model of an X-band PBG structure with non-periodic lattice, coupling cells, and mode launchers.

The PBG cell is designed for X-band operation at 11.424 GHz, and must be within 100 MHz of the RF power source frequency. Coupling into the entire structure is accomplished via a mode launcher from a WR-90 rectangular waveguide. Slight over-coupling was designed for the power coupler to accommodate beam loading. Dimensions of the structure are summarized in Table 1.

Table 1: Dimensions of the PBG Accelerator Structure

Parameters	Value
Spacing between the rods of first layer	10.4 mm
Matching cell radius	11.43 mm
Matching cell length	8.3737 mm
Length of the PBG cavity	13.1213 mm
Radius of the PBG cavity	38 mm
Iris length of the PBG cavity	4.6 mm
Iris radius of the PBG cavity	4.6 mm
Diameter of metal rods	4 mm
Distance between first and second layer	10.4 mm
Distance between first and second layer	11.5 mm
Iris length of the matching cell	4.1225 mm
Iris radius of the matching cell	5.6492 mm

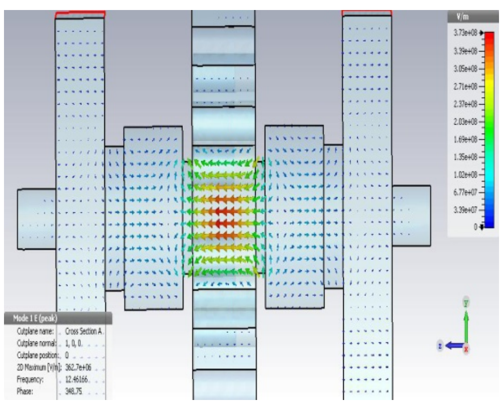


Figure 7: The accelerating mode of PBG structure.

The distribution of the electric field for the accelerating mode is shown in figure 7. From the field plot, it can be seen that the PBG cavity confine the desired accelerating mode. The lattice is being optimized to transmit the dominant HOM frequency ranges for damping. It can be seen from the plot that the field in the matching cell is weak compared with the field in the PBG cell. Future work includes the optimization of the coupling efficiency of the matching cells, as well as an exploration of the most effective PBG lattice for damping. During the refinement of the simulation, the rotation angles of the second and third layer have some affect on the dipole mode which will be investigated.

CONCLUSION

The PBG structure with periodic and non-periodic lattices is presented. Major advantages of the PBG structure are the confinement selective modes as well as the suppression of HOMs. Simulation results indicate that the non-periodic lattice has flexibility on frequency selection and reduction of field intensity of metal surfaces as well as on overall lattice design and performance parameters. Optimization to improve structure's RF performance and reduction of wakefield excitations are in progress.

ACKNOWLEDGMENT

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