AN 11 GHZ PHOTONIC BAND GAP ACCELERATOR STRUCTURE WITH WAKEFIELD SUPPRESSION

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Abstract

We report the design and cold test results for an 11 GHz photonic band gap (PBG) cell, which can be utilized as an accelerator cavity with reduced long-range wakefields. The eigenmodes of the two-dimensional (2D) PBG cavities formed by the defect in a triangular array of metal rods were studied numerically. A 2D PBG cavity with reduced HOM content was designed and built. Cold test results proved the suppression of the higher order modes (HOM) in the PBG cavity. A 6-cell 17.137 GHz PBG accelerator structure is proposed and designed.

1 INTRODUCTION

Metallic photonic band gap (PBG) structures have received considerable attention recently, because of their possible applications in rf accelerators and high-power microwave electronics [1-3]. A remarkable property of the PBG structure is its ability to reflect waves in certain ranges of frequencies (called *global band gaps*) while allowing other frequencies to pass through. A defect in periodic structure forms "PBG cavity" in which a mode with the frequency inside the global band gap can be confined under certain conditions. The PBG cavity is advantageous over the conventional pillbox cavity because of its high mode selectivity: only the modes with frequencies within the band gap can be confined.

We investigate the PBG structures based on triangular lattice of metal rods. A cavity is formed with a missing rod and can confine eigenmodes (see Fig. 1). Two important aspects need to be studied in order to facilitate the design of PBG-based cavities. One involves the global band gaps calculation, and the other concerns mode confinement in PBG cavity. Global band gaps for two-dimensional (2D) triangular lattice of metal rods have been recently calculated by these authors and reported in [3]. For analysis of PBG resonators, we apply the HFSS code [4].

Fig. 1: A PBG resonator built for the cold test. The cavity is formed by a missing rod in a triangular array of copper rods with *a/b = 0.15*.

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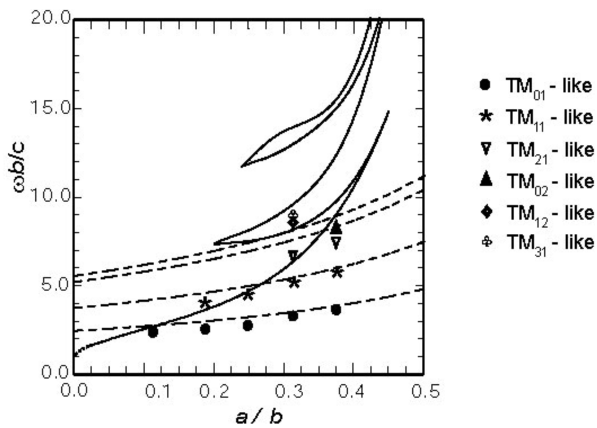

Fig. 2: TM eigenfrequencies of a PBG cavity formed by single rod missing in triangular array of metal rods (solid lines show the boundaries of global band gaps).

The PBG cavity supporting a single TM_{01}-like mode is a good candidate for an accelerator cell. A disk-loaded $2\pi/3$ accelerator structure can be built with a stack of PBG cavities set between the disks with the beam holes inserted on axis. A complete design of a 6-cell PBG accelerator structure was performed using the HFSS code [4]. We plan to construct and test a 6-cell PBG accelerator structure.

2 MODES OF A PBG RESONATOR

We studied a 2D PBG resonator formed by a single rod missing in a triangular lattice of metal rods. We kept only three rows of rods and surrounded them by a metal wall. The results of our HFSS computation for the frequencies of eigenmodes are presented in Fig. 2. In Fig. 2 the global band gap boundaries derived in [3] are plotted with solid lines as functions of the ratio of rods radii (*a*) to the rods spacing (*b*). The region of frequencies to the right of solid curve corresponds to the global band gap, whereas the frequencies to the left of the curve lie in the pass band. The frequencies of the defect modes are plotted over the band gap picture with dots. Dashed lines in Fig. 2 show the eigenfrequencies of the pillbox cavity with the radius *R=b-a*, which is about the effective radius of the PBG cavity.

It can be seen from Fig. 2 that for *a/b = 0.15* only a single TM_{01} mode is confined below the cutoff. The field patterns of two lowest modes in a PBG resonator with *a/b = 0.15* are shown in Fig. 3. The TM_{11} mode is confined by the metal wall placed at the periphery of the PBG structure and can be suppressed if we eliminate the wall or put an absorber at the periphery. Thus we can construct a resonator with reduced HOM content on the basis of a PBG structure.

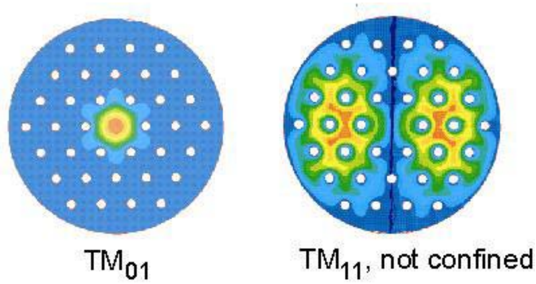

Fig. 3: Modes of a PBG resonator with *a/b=0.15.* TM_{01} mode is confined, TM_{11} mode is not confined.

Table 1. Dimensions of the PBG resonator for cold test.

Rod radius *a*	0.16 cm
Lattice spacing *b*	1.06 cm
a/b	0.15
Freq. (TM_{01})	11.00 GHz

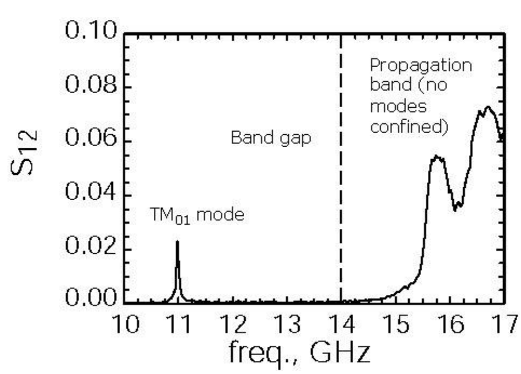

Fig. 4: The transmission curve for a PBG resonator.

3 COLD TEST OF PBG RESONATORS

In order to verify experimentally the suppression of higher order modes in PBG resonators, we constructed a resonator for cold testing. The resonator was made out of brass (see Fig. 1). The dimensions of the resonator are shown in Table 1.

A WR62 waveguide was employed to feed the rf power to the resonator. We measured the S_{12} element of the scattering matrix using the HP8510 vector network analyzer (Fig. 4). We placed the eccosorb at the periphery of the cavity, so that the Q-factors of the modes not confined by the PBG structure were reduced by the factor of 10. The Q-factor of the TM_{01} mode at 11 GHz was not reduced. These results agree with the design. We also measured the S_{11} elements of the scattering matrices and derived from those that the ohmic Q-factor for the TM_{01} mode was about 2000. This was much lower than a

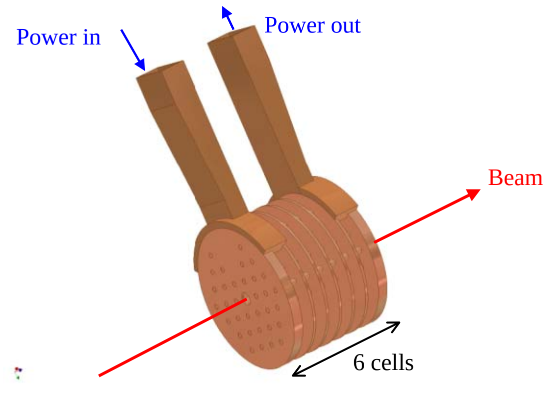

Fig. 5: A 6-cell $2\pi/3$ PBG accelerator structure

theoretically predicted Q of 5300. To resolve this problem we manufactured a second PBG resonator with the same dimensions out of the OFHC copper. Then we brazed the rods into the end plates. This increased the Q-factor up to 4000, which is much closer to the theoretically predicted Q.

4 A 6-CELL PBG ACCELERATOR DESIGN

We have designed and are now building a disk-loaded $2\pi/3$ accelerator structure at 17.137 GHz with a stack of PBG cavities set between the disks with the beam holes inserted on axis (see Fig. 5). A complete design of a 6-cell PBG accelerator structure was performed using the HFSS [4].

Table 2. Dimensions of the $2\pi/3$ PBG accelerator structure.

Rod radius (structure cell) *a*	1.04 mm
Rod radius (coupler cell) a_1	1.05 mm
Lattice spacing *b*	6.97 mm
a/b	0.155
Cavity radius	24.38 mm
Cavity length	5.83 mm
Iris radius	1.94 mm
Iris thickness	0.96 mm
Freq. (TM_{01})	17.137 GHz

First, the PBG cell dimensions were calculated and the cells were tuned to 17.137 GHz. Second, the coupler cell was tuned following [5,6]. The dimensions of the structure are listed in Table 2. The coupler cell will have three rods withdrawn and the rods in the coupler cell are 0.01 mm thinner than in traveling wave cells. The dependence of the reflection from the PBG coupler on the coupler's dimensions is shown in Fig. 6. It can be seen from the picture that the reflection is as big as 0.6 to 0.8 if either a rod radius or distance between the rods differs by 0.025 mm from those given in Table 2. This means, that tuning will be needed in order to achieve small reflection from the coupler. Two methods of tuning are considered: putting clips on the rods of the second row and bending the rods.

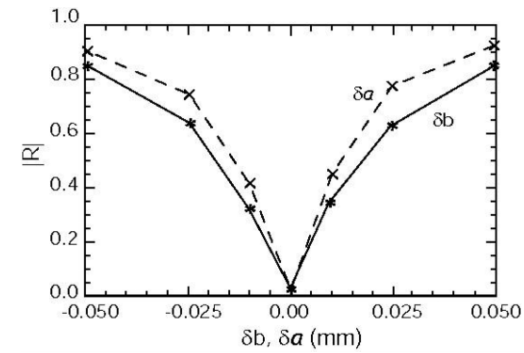

Fig. 6: The reflection from the PBG coupler as a function of deviation of the rods radii (*a*) and spacing (*b*) from those given in Table 2.

The accelerator characteristics of the PBG structure were calculated and compared to those of a pillbox structure (see Table 3.). It was discovered that the shunt impedance for a PBG cell is lower than for a pillbox cell. However, the group velocity for a PBG structure is 10% lower than the group velocity for a pillbox structure with the same irises (see Fig. 7). Thus the PBG structure has an average gradient close to that of a pillbox structure.

Table 3. Comparison of acceleration parameters of 2π/3 PBG and pillbox structures.

	Pillbox	PBG
Frequency	17.137 GHz	
Q_W	4188	5618
r_S	0.46 MΩ/cm	0.71 MΩ/cm
$[r_S/Q]$	0.11 kΩ/cm	0.126 kΩ/cm
Group velocity	0.011c	0.012c
Gradient	18.9√P[MW] MV/m	19.4√P[MW] MV/m

5 THE PLAN OF PBG ACCELERATOR TEST

An experiment to test the PBG accelerator is planned at Massachusetts Institute of Technology (MIT). The MIT Plasma Science and Fusion Center currently has a 17.137 GHz accelerator, which was built by the Haimson Research Corporation (HRC). We plan to fabricate a 6-cell PBG accelerator section to accelerate a 7 MeV accelerator beam to 8 MeV. The PBG accelerator will be powered with 3 MW coming from the HRC klystron [7]. This will allow us to achieve the acceleration gradient of 32 MV/m.

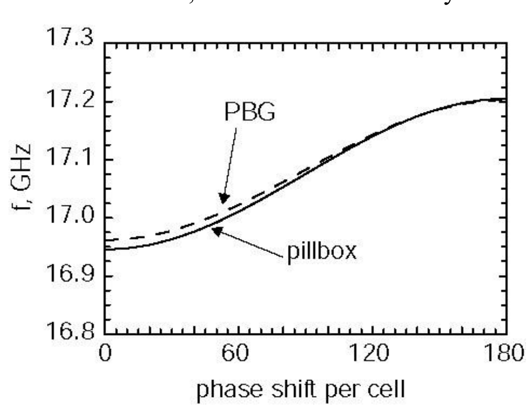

Fig. 7: A comparison of dispersion characteristics for PBG and pillbox accelerator cells with similar irises.

Finally, the wakefields in PBG structure will be measured in cold-test.

6 CONCLUSION

An extensive research on PBG structures for accelerator applications is underway at MIT. The main advantage of PBG cavities over the conventional pillbox cavities lies in their high mode selectivity. Thus, if applied to the linear accelerators the PBG cavities will sufficiently reduce the long-range wakefields.

We have already studied the bulk properties of the PBG structures [3] and investigated the properties of PBG resonators. We will continue our research towards the constructing and testing a 6-cell 2π/3 PBG accelerating structure.

Additionally, we conduct the investigation of dielectric PBG structures [8]. Use of dielectric PBG structures may allow construction of a PBG resonator, which selectively confines the TM_{02}-like mode. This may allow extension of accelerator operation to higher frequencies using HOM without facing the problem of lower order wakefields.

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