DESIGN OF A WAKEFIELD EXPERIMENT IN A TRAVELING-WAVE PHOTONIC BAND GAP ACCELERATING STRUCTURE*

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Abstract

We present the design of an experiment to conduct a thorough investigation of the higher order mode spectrum in a room-temperature traveling-wave photonic band gap (PBG) accelerating structure at 11.7 GHz. It has been long recognized that PBG structures have great potential to reduce long-range wakefields in accelerators. The first ever demonstration of acceleration in room-temperature PBG structures was conducted at MIT in 2005. However, the full experimental characterization of the wakefield spectrum in a beam test has not been performed to date. The Argonne Wakefield Accelerator (AWA) test facility at the Argonne National Laboratory represents a perfect site where this evaluation could be conducted with a single high charge electron bunch and with a train of bunches. We present the design of the accelerating structure that will be tested at AWA in the near future. The structure will consist of sixteen $2\pi/3$ PBG cells, including two coupler cells. We will also present the results of the initial cold-testing of the few sample cells and a plan for the beam test.

INTRODUCTION

The next generation of linear colliders with multi-hundred GeV to TeV beam energies pushes the frontiers of the current beam physics and technology with the goal of obtaining high luminosity of the beam and avoiding bunch to bunch beam breakup. Thus, the accelerating cavities for the future linear colliders must be selective with respect to the operating mode, and higher order mode (HOM) wakefields that affect the quality of the beam must be suppressed. Photonic Band Gap [1] (PBG) cavities have the unique potential to absorb all HOM power and greatly reduce the wakefields. A PBG structure or simply, photonic crystal, represents a periodic lattice of macroscopic components (e.g., rods), metallic, dielectric or both. For accelerator applications, two-dimensional PBG resonators based on arrays of metal rods are commonly employed. The first ever demonstration of acceleration in a PBG resonator was conducted at Massachusetts Institute of Technology (MIT) in 2005 (the 17 GHz MIT PBG accelerator is shown in Figure 1) [2]. Since then, the importance of PBG structures for accelerators has been recognized by many research institutions worldwide.

Two attempts to experimentally study wakefields in PBG accelerators were conducted to date, but were incomplete [3,4]. The MIT team [3] cold-tested the 6-cell PBG accelerator structure of [2] in a wide frequency range and recorded the wakefield spectrum. They also ran a beam test with a train of 200 picosecond electron bunches with the charge of 1-18 pC per bunch. Radiation was observed at the output port of the PBG structure and had a quadratic scaling with current at 17 GHz and at 34 GHz. However, with the MIT setup, observation of significant wakefield radiation into other important HOMs, such as a dipole mode was impossible. A more advanced test was conducted by a team at Argonne National Laboratory (ANL) [4]. They observed wakefields in a three-cell X-band standing wave PBG structure when driven by a single electron bunch with a charge up to 80 nC. Major monopole and dipole modes were identified in the collected signal. A variable delay low charge witness bunch following a high charge drive bunch was used to calibrate the gradient. However, this test was not the test of the actual traveling-wave PBG accelerator. At this point, the full experimental characterization of the wakefield spectrum in a traveling-wave PBG accelerator is overdue.

An experimental evaluation of wakefield suppression in room-temperature PBG accelerators will potentially benefit and jumpstart the research on wakefield suppression in superconducting rf (SRF) PBG higher order mode couplers, which are of interest not only to the future linear colliders, but also for the drive linacs for the free-electron lasers (FELs) [5,6].

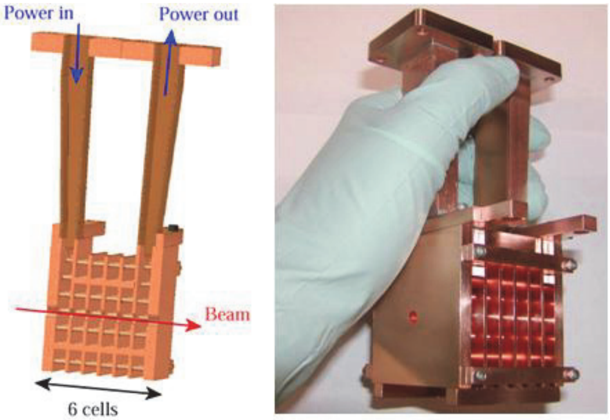

Figure 1: The 17 GHz MIT PBG accelerator structure [2,3].

DESIGN OF 11.7 GHz TW PBG ACCELERATOR

We have initiated a project at Los Alamos National Laboratory (LANL) to conduct the full experimental characterization of the wakefield spectrum of a traveling-wave PBG accelerator structure. We designed and started

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to fabricate a 16-cell traveling-wave (TW) $2\pi/3$-mode PBG accelerator structure with characteristics similar to the 6-cell MIT PBG structure. The structure will be tested at the Argonne Wakefield Accelerator (AWA) user facility. Therefore, the PBG accelerator was designed at the frequency of 11.7 GHz, which is 9 times the frequency of the AWA (1.3 GHz). The design of the traveling-wave cells was conducted with the CST Microwave Studio [7] and benchmarked with the HFSS [8]. The exact dimensions and the accelerator characteristics of the structure are summarized in Table 1. The structure has a slightly bigger beam opening and slightly larger group velocity than the MIT structure to be more appropriate and attractive for higher current operations. We plan to have 14 traveling-wave and 2 coupler cells in the structure, 16 cells total.

Table 1: Dimensions and Accelerator Characteristics of the 11.7 GHz Traveling-wave PBG Accelerator

Frequency	11.700 GHz
Phase shift per cell	$2\pi/3$
Q_w	5000
r_s	72.5 MΩ /m
$[r_s/Q]$	14.5 kΩ /m
Group velocity	0.015c
Gradient	$15.4\sqrt{P[\mathrm{MW}]}$ MV/m
Rod radius, *a* (TW cell/coupler cell)	1.55 mm/1.54 mm
Lattice vector, *b* (TW cell/coupler cell)	10.33 mm/10.30 mm
a/b	0.150
Length of the cell	8.53 mm
Diameter of the iris	6.31 mm = 0.250 in
Thickness of the iris	1.90 mm = 0.075 in
OD of the cavity	76 mm = 3 in

The coupler cells were designed with the HFSS using periodic voltage standing-wave ratio method. There rods were removed from the PBG structure to form the opening as shown in Figure 2. The dimensions of the coupler cell differ slightly from the dimensions of the TW cell (Table 1).

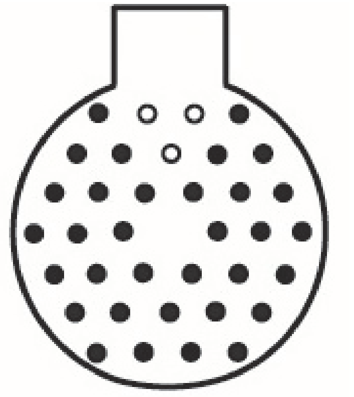

Figure 2: The schematic of the arrangement of the rods in the coupler cells. White circles correspond to the removed rods.

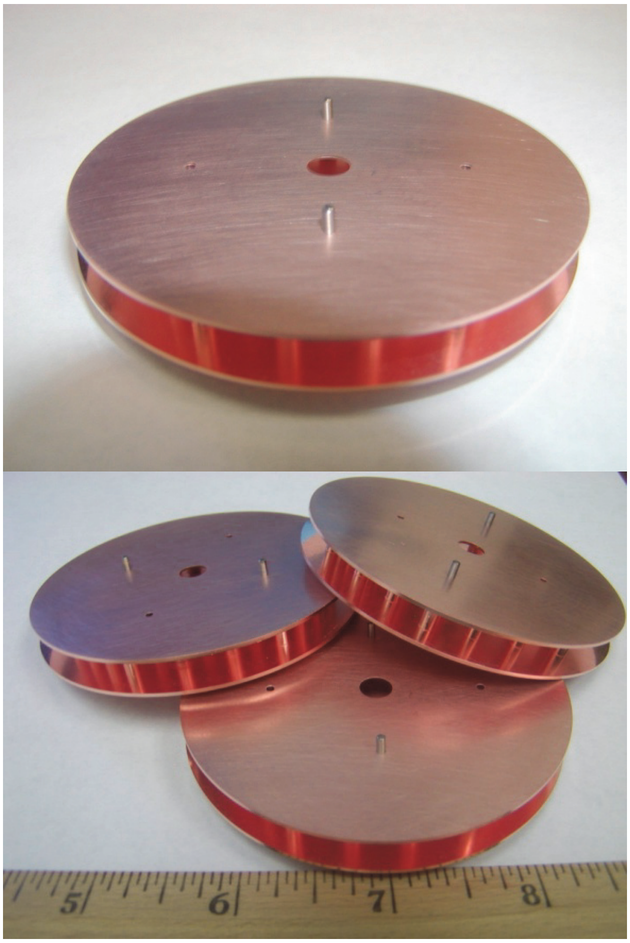

Figure 3: Photographs of the electroformed 11.7 GHz PBG cells.

FABRICATION AND COLD TESTS OF THE PROTOTYPE PBG CELLS

Three TW test cells were fabricated in order to benchmark the tuning and brazing processes before fabricating and assembling the 16 cell structure. The cells were electroformed by Custom Microwave, Inc. The photographs of the electroformed cells are in Figure 3.

The fabrication tolerances were defined so that the electroformed cells would have higher frequencies than the target design frequency.

The frequency of the cells was tested with the two E-field antennas on axis. The 11.700 GHz 2π/3-mode TW cell should have the frequency of 11.659 GHz when tested with the two antenna method. The initial frequencies of the cells are summarized in Table 2 and were higher than the target frequency, in agreement with the design and the 0.001 inch standard tolerance of fabrication. Etching was then performed to tune the frequency of the cells to the target frequency of 11.659 GHz. The etching was performed by the Metallurgy Group of the Material Science and Technology division at LANL. Etching was done as following. The acid solution consisted of 100 ml nitric acid, 275 ml phosphoric acid, 125 ml acetic acid. The two plates of each cell were masked with the jack-o-lantern candle wax to preserve the thickness. Etching temperature was 45 C. The etching was performed for 1 or 2 minutes and the etching rate was slower during the 2 minute etch. At this point we have completed two etching cycles and the results are summarized in Table 2. Each cell was initially etched for 1 minute to establish the etch rate. The frequency of the cells was lowered by 6-7 MHz corresponding to removing approximately 0.0002 inches off the diameter of the rod per minute. This was in perfect agreement with the etching rate that was observed during the tuning of the 6-cell MIT PBG accelerator [9]. The second etching was performed for 1 minute for the first two cells and for 2 minutes for the third cell that was the highest in frequency. The second etching confirmed the etch rate and also demonstrated that the rate slows down significantly if the cell remains in the acid for longer than 1 minute. The frequencies of the first two cells were lowered by 6 MHz, but the frequency of the third cell went down by only 9 MHz. During the third etching the cell #2 will be etched for 1 minute and the cell #3 will be etched twice for 1 minute each time and the acid solution will be prepared from scratch for each etching. The cells will be brazed together once the etching is complete to benchmark the brazing process. Stainless steel pins on the end plates of the cells will provide alignment of the cells during the brazing stage.

Table 2: Frequencies of the Three Test Traveling-wave PBG Cells Right After Electroforming and Following the Two Etching Cycles

	Cell #1	Cell #2	Cell #3
Frequency as fabricated	11.672 GHz	11.677 GHz	11.689 GHz
Frequency after the first etch (1 minute each cell)	11.665 GHz	11.671 GHz	11.682 GHz
Frequency after the second etch (1 minute cells #1 and #2, 2 minutes cell #3)	11.659 GHz	11.665 GHz	11.673 GHz

CONCLUSION AND PLANS

We have planned an experiment to conduct a complete evaluation of the higher order mode wakefields in a room-temperature traveling-wave open photonic band gap accelerator structure at the frequency of 11.7 GHz. A 16-cell TW PBG accelerator structure (Figure 4) will be fabricated, tuned and brazed in FY13. The structure will go onto the Argonne Wakefield Accelerator beamline in early FY14. We plan to drive the structure with a single 100 nC electron bunch first and look at the spectrum of the wakefields at the waveguide outputs and with antennas on the side of the structure. We might be able to conduct some experiments with a train of bunches and with a low charge witness bunch.

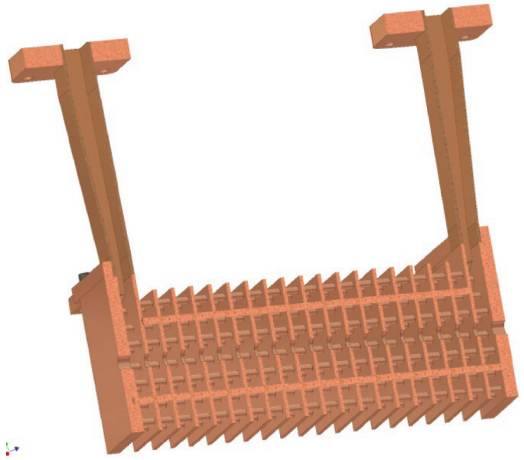

Figure 4: A 16-cell traveling-wave PBG accelerator structure with two waveguide couplers.

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