UPDATE ON FABRICATION AND TUNING OF THE PHOTONIC BAND GAP ACCELERATING STRUCTURE FOR THE WAKEFIELD EXPERIMENT*

Evgenya I. Simakov#, Sergey Arsenyev, Randall L. Edwards, Samuel Elson, Cynthia Heath, David Lizon, and William Romero, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.

Abstract

We designed an experiment to conduct a detailed investigation of 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 in reducing long-range wakefields in accelerators. The first ever demonstration of acceleration in room-temperature PBG structures was conducted at MIT in 2005. Since then, the importance of that device has been recognized by many research institutions. 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 describe the design of the accelerating structure that will be tested at AWA in the near future. We also report the results of fabrication and tuning of PBG cells and the initial cold-testing of the traveling-wave accelerating structure. We discuss the plan for the wakefield experiment.

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 aaccelerating 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 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 [2]. Since then, the importance of PBG structures for accelerators has been recognized by many research institutions worldwide.

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#smirnova@lanl.gov

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.

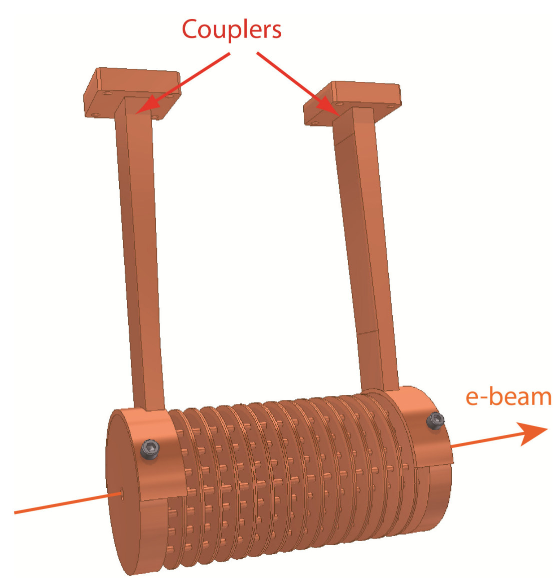

Figure 1: A 16-cell traveling-wave PBG accelerator structure with two waveguide couplers.

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 plan to put together an 11.7 GHz 2π/3-mode accelerating structure of 16 PBG cells, install it at the Argonne Wakefield Accelerator (AWA) facility and test it with a high charge (up to 100 nC) electron bunch (as shown in Figure 1) to record the full traveling-wave (TW) wakefield spectrum.

DESIGN OF 11.7 GHZ TW PBG ACCELERATOR

We designed a 16-cell traveling-wave 2π/3-mode PBG accelerator structure with characteristics similar to the 6-cell MIT PBG structure. 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 [5] and benchmarked with the HFSS [6]. 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 scaled 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	2π/3
Q_w	5000
r_s	72.5 MΩ /m
$[r_s/Q]$	14.5 kΩ /m
Group velocity	0.015c
Gradient	15.4 √P[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 a periodic voltage standing-wave ratio method. WR-90 waveguides were attached to the coupler cells, and three rods next to the waveguides were removed from the PBG structure to achieve critical coupling for the fundamental mode. The period and the diameters of the rods in the coupler cell differed slightly from the dimensions of the TW cell (Table 1) [7].

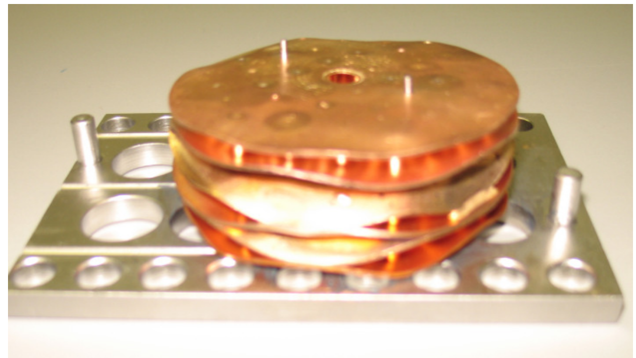

Figure 2: Photograph of the electroformed cells destroyed by brazing.

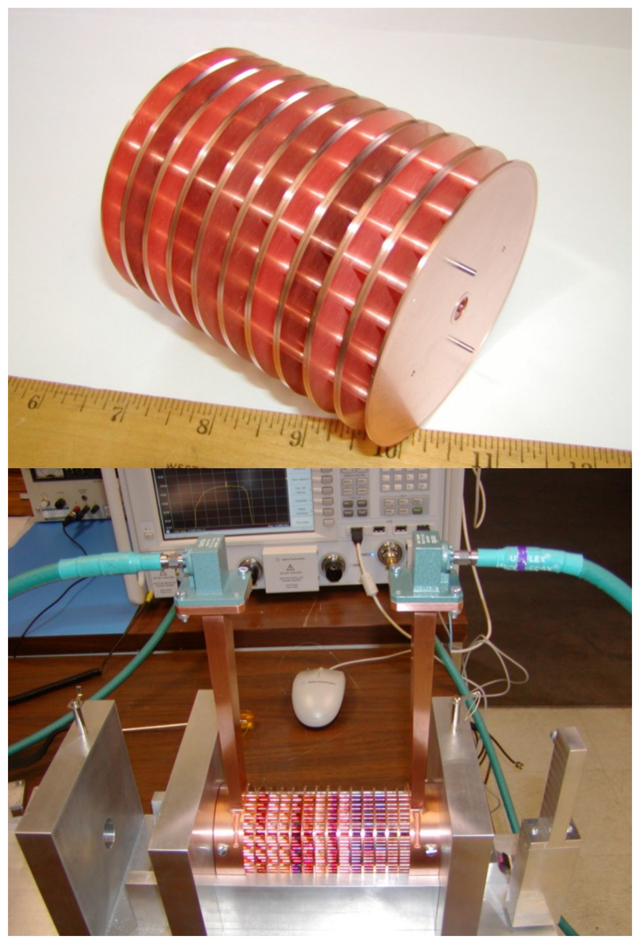

Figure 3: Photographs of the electroformed 11.7 GHz PBG cells and the assembled 16 cell PBG structure on a cold test bench.

FABRICATION AND COLD TESTS OF THE 16-CELL STRUCTURE

Three TW test cells were fabricated first in order to benchmark the tuning and brazing processes before

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fabricating and assembling the 16 cell structure [7]. The cells were electroformed by Custom Microwave, Inc. and then tuned at LANL with the same etching procedure as described in [7,8]. The cells were then brazed in a hydrogen furnace and this step was totally unsuccessful. The internal stresses in electroformed cells caused deformations in the structure and the cells were destroyed (Figure 2). The lesson learned was that the electroformed structures cannot be brazed and the future 16-cell structure will have to be bonded instead of brazed.

Next we fabricated PBG cells for the 16-cell structure. The total number of fabricated cells was 29, which included 25 TW cells and 4 coupling cells. The photographs of the several TW cells joined together and the assembled 16-cell PBG structure with waveguides are shown in Figure 3. The PBG cells were fabricated with small rings surrounding the beam holes which were elevated above the end surface and polished to mirror finish (Figure 3). This would ensure good electrical contact between the cells after bonding with non-conductive vacuum-compatible epoxy.

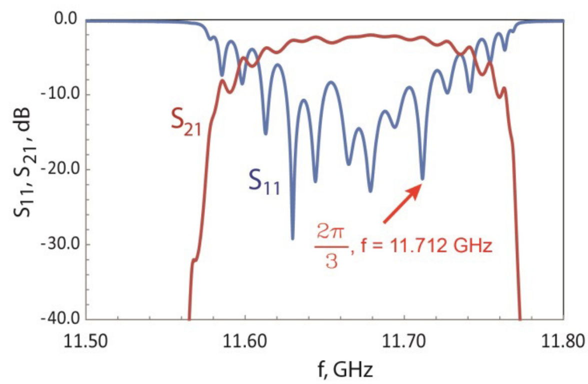

Figure 4: Transmission and reflection through the assembled 16 cell PBG structure.

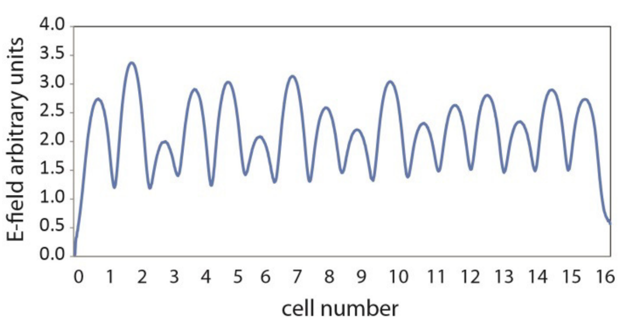

Figure 5: Bead pull field profile measurement in the 16 cell PBG structure.

The cells were tested with a network analyser and it was concluded that the frequencies of the end cells were close to the design value and the frequencies of TW cells were high. The frequencies of individual cells differed between each other all within 10 MHz frequency interval. This corresponded to approximately 0.1 thousand of an inch difference in the actual dimensions of cells. The two etching cycles were conducted to lower the frequencies of the TW cells following the procedures described in [7,8]. Each cycle removed 0.1 thousand of an inch or less off the diameter of each PBG rod. The frequencies of all PBG cells were equalized and lowered.

The transmission and reflection from the assembled PBG structure after the two etch cycles is shown in Figure 4. The 2π/3-mode is the 6^{th} dip from the right on the reflection curve, at the frequency of 11.712 GHz. The reflection curve shows that the frequencies of TW cells were still higher than the target frequency and more etching cycles are needed.

The same conclusion can be made from the field profile measured with a bead pull method (Figure 5). The electric field in different cells of the structure differs slightly. The measurement of the phase shift between the cells confirms that the frequencies of the TW cells still need to be tuned down.

Another etching cycle is currently underway. Once the etching is complete, it will be followed by bonding.

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 was fabricated and is currently undergoing tuning. Once tuned, the cells will be bonded together. The structure will go on the Argonne Wakefield Accelerator beamline in 2014. 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 at 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.

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