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EXPERIMENTAL STUDY OF WAKEFIELDS IN AN X-BAND PHOTONIC BAND GAP ACCELERATING STRUCTURE*

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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. Here we describe fabrication and tuning of PBG cells, the final cold-test of the traveling-wave accelerating structure, and the results of the beam testing at AWA.

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 filter out 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.

Two attempts to experimentally study wakefields in PBG accelerators were conducted to date, but were incomplete [3,4]. At this point, the full experimental characterization of the wakefield spectrum in a traveling-wave PBG accelerator is overdue.

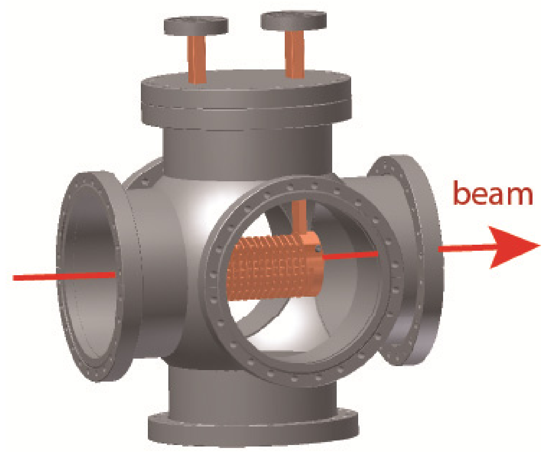

Figure 1: A 16-cell traveling-wave PBG accelerator structure with two waveguide couplers installed in a vacuum chamber for the wakefield tests.

DOE HEP funded a project at Los Alamos National Laboratory (LANL) to conduct the experimental characterization of the wakefield spectrum of a traveling-wave PBG accelerator structure. We put together an 11.7 GHz $2\pi/3$-mode accelerating structure of 16 PBG cells, installed it at the Argonne Wakefield Accelerator (AWA), passed an electron beam through the structure (as shown in Figure 1) and recorded the full traveling-wave (TW) wakefield spectrum.

DESIGN OF 11.7 GHz TW PBG ACCELERATOR

We designed a 16-cell traveling-wave $2\pi/3$-mode PBG accelerator structure with characteristics similar to the 6-cell MIT PBG structure [2]. 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 exact dimensions and the accelerator characteristics of the structure are summarized in Table 1.

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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

FABRICATION AND COLD TESTS OF THE 16-CELL STRUCTURE

PBG cells were fabricated by electroforming. The total number of cells was 29, which included 25 TW cells and 4 coupling cells. The cells were tuned according to procedure described in [5]. The structure was assembled of 2 coupler cells and 14 traveling-wave cells. The structure was cold-tested, and the final cold test results are described in [5]. Since the electroformed PBG cells could not be brazed due to internal stresses, the tuned structure underwent bonding with a vacuum-compatible non-conductive Hyson EA9394 epoxy. The electrical contact between the cells was ensured by having elevated rings around the beam holes polished to the mirror finish which were not covered by the epoxy and touched the neighboring cells. The bonded structure was cold-tested again and the results were nearly identical to those for the clamped structure.

WAKEFIELD TESTS AT ARGONNE WAKEFIELD ACCELERATOR

Next, the structure was bolted onto a 10-inch stainless steel flange and installed inside a vacuum chamber at the end of the beamline at AWA (Figure 2). An electron beam with the energy of approximately 65 MeV was passed through the structure, and the transmitted charge varied between 0.25 nC and 7 nC. The spectrum of the excited wakefields was recorded with different probes. Two probes were installed on directional couplers at the input and output waveguides. Also four loop antennas were installed on the periphery of the structure in four different cells to couple to the magnetic field of the HOM modes.

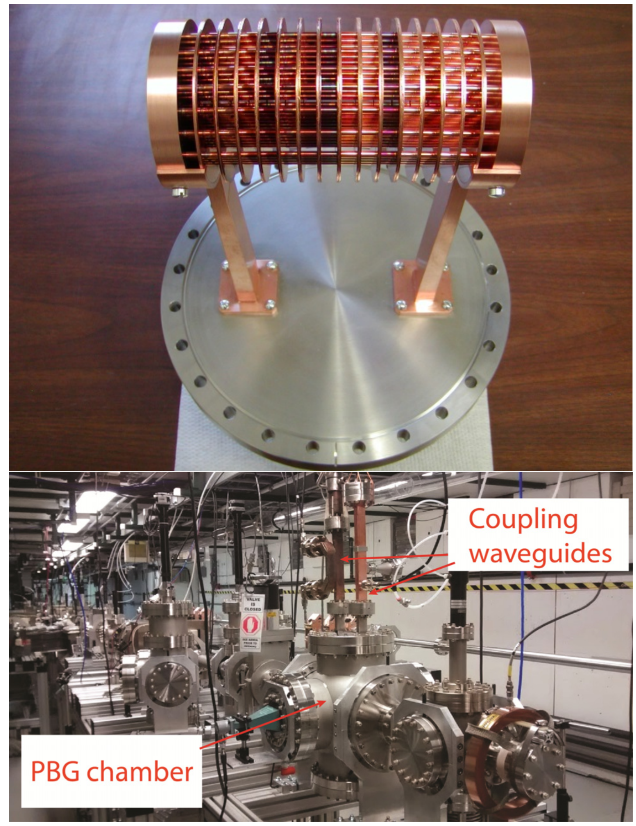

Figure 2: Photographs of the electroformed 11.7 GHz PBG cells installed on the 10 inch flange of a SS chamber and the beamline at Argonne Wakefield Accelerator with the PBG experimental chamber.

The rf signal in the downstream coupling waveguide was studied first. The length of the measured rf pulse was approximately 30 ns, in a very good agreement with simulations (Figure 3(a)). The Fourier spectrum of the forward signal was dominated by the fundamental mode at 11.700 GHz with no power transmitted at any other frequencies (Figure 3(b)). The power coupling into the 11.700 GHz mode scaled quadratically with the transmitted charge as predicted (Figure 4).

The rf signal picked up by the loop antennas was analysed next. The most downsteam antenna picked up the clearest signal and the least noise. The Fourier spectrum of the antenna signal revealed the presence of the fundamental mode (leaking at a low level through the PBG structure) and a number of low-Q HOMs at the frequencies in between 15 GHz and 18 GHz (Figure 5). The HOM spectrum was recorded in different configurations: in a PBG structure wrapped in foil and in an open PBG structure, with 6 SiC absorbers attached to the sides of the structure. The level of HOMs varied depending on the boundary conditions as expected. The structure with SiC absorbers had the most attenuated higher order modes which were only slightly visible above the noise level (Figure 5(b)); in the structure wrapped in foil, the level of HOMs was much higher

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since HOMs were not being filtered out of the structure (Figure 5(a)). The measurements clearly confirmed the effectiveness of the PBG structure for suppression of HOMs.

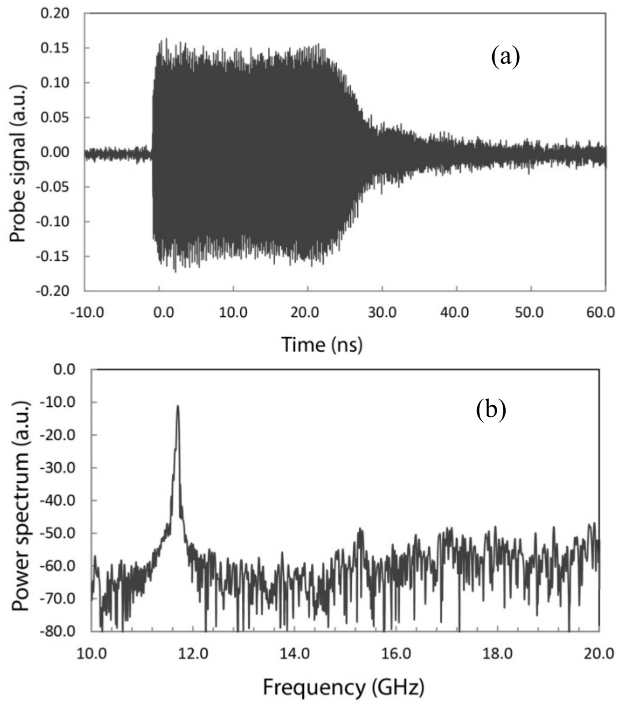

Figure 3: The rf signal in the downstream coupling waveguide of the PBG structure: (a) time-domain; (b) Fourier transform.

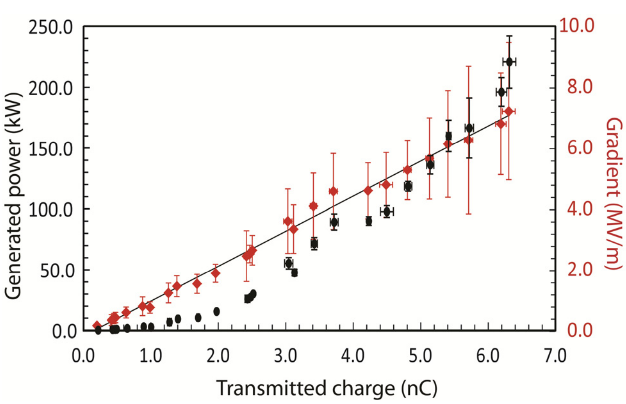

Figure 4: Power in the downstream coupling waveguide of the PBG structure as a function of the transmitted charge. The gradient in the structure computed from the measured power is also shown.

CONCLUSION

We have experimentally demonstrated suppression of the higher order mode wakefields in a room-temperature traveling-wave open photonic band gap accelerating structure at the frequency of 11.7 GHz. A 16-cell TW PBG accelerator structure was fabricated, tuned and tested at the Argonne Wakefield Accelerator. The spectrum of wakefields was recorded in the forward waveguide and with the loop probes installed at the periphery of the structure. The wakefields were measured for different configurations: for the PBG structure wrapped in foil and for the open PBG structure with 6 SiC slabs installed at the periphery. It was clearly demonstrated that the level of higer-order-mode wakefields was much lower for the open structure. This clearly confirms that the PBG structure filters out and suppresses the higher order modes.

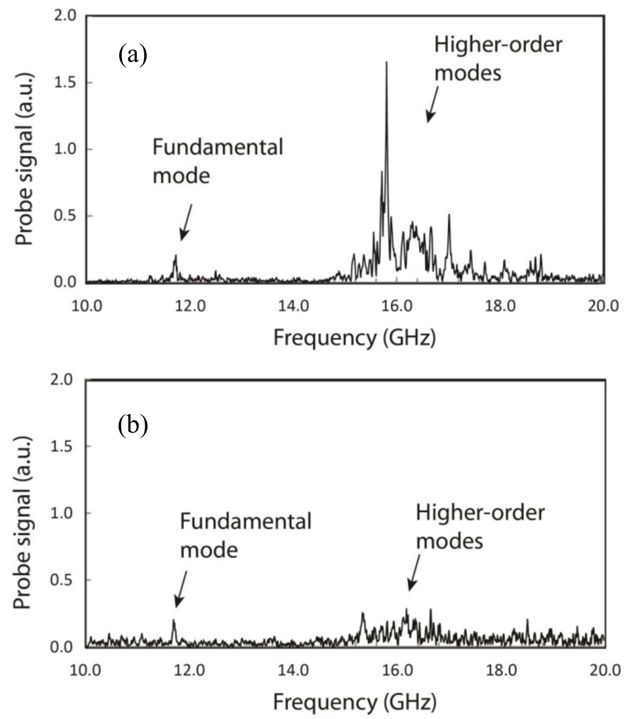

Figure 5: The rf spectrum of the signal picked up by a loop antenna at the periphery of the PBG structure: (a) the structure wrapped in foil; (b) the structure with 6 SiC absorbers.

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