DESIGN AND TESTING OF ADVANCED PHOTONIC BAND-GAP (PBG) ACCELERATOR STRUCTURES

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Abstract

Photonic Band-gap (PBG) structures continue to be an area of promising research for high gradient accelerators with wakefield suppression. Experimental results on an 11.4 GHz PBG structure tested at high power and high repetition rate at SLAC have shown that high gradients can be achieved in these structures. For PBG structures with thin rods, however, pulsed heating of the inner row of rods is a problem. Following these preliminary results, two new PBG structures have been designed. One structure, designated 1C-SW-A5.65-T4.6-Cu-PBG2-SLAC1, utilizes elliptical inner rods to reduce pulsed heating to an acceptable level; it will be tested at SLAC. A second PBG structure with round rods will be tested at 17.1 GHz at MIT. The MIT research will use the improved diagnostic access of the PBG structure to obtain a better understanding of the breakdown process. We will present preliminary results for the design and testing of these PBG structures.

INTRODUCTION

Photonic band-gap (PBG) accelerator structures continue to be a topic of experimental and theoretical interest [1, 2, 3, 4]. Previous experimental work has demonstrated acceleration [1] and measurement of wakefield suppression [4, 5]. More recently an experimental program has been undertaken by MIT and SLAC National Accelerator Lab to investigate the breakdown properties of PBG structures. The first PBG structure tested for breakdown performance showed significant pulsed heating damage to the inner rods and no visible damage elsewhere in the structure, indicating that nearly all the breakdown events occurred on the rods [3]. This led to a revised PBG design using elliptical rods to reduce the pulsed heating; this design has been fabricated and is currently under test. The breakdown properties of PBG structures will also be studied at 17 GHz at MIT using a new test stand which will be suitable for testing standing wave structures and will be operational by summer 2011.

TESTING AT 11 GHz

Photonic band-gap structures have been tested at SLAC as part of an ongoing program at SLAC to test the breakdown performance of different accelerator structures [6, 7]. The structures for breakdown testing are standing wave structures with a single high power test cell and coupling cells on either side of the test cell. The structures are powered axially via a reusable $TM_{0,1}$ mode launcher [8]. Both PBG structures tested at SLAC were tested on klystron test stand #4; the configuration of the test stand will be described in the following subsection.

The first structure tested at SLAC was a round-rod PBG structure designed and tested by Marsh as reported in [3]. After testing on this structure was complete, SEM images of the high-field surfaces were obtained and showed significant pulsed heating damage to the rods in the structure. As a result of this damage a new structure was designed, this time using an elliptical profile to the inner row of rods in order to reduce the pulsed heating [9]. This elliptical-rod PBG structure is now under test at SLAC.

Elliptical Rod Design

Based on the evidence of pulsed heating damage seen in the autopsy of the initial PBG structure tested at SLAC, a new structure was designed to reduce the pulsed heating while maintaining high-order mode (HOM) damping. This was achieved by giving the inner rods an elliptical profile, as seen in Figure 1. Table 1 compares the expected performance of the elliptical-rod structure with the original round-rod structure. The details of the design can be found in [9].

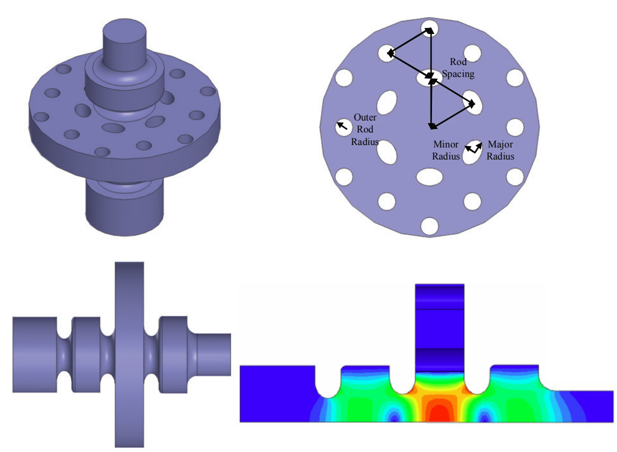

Figure 1: Elliptical-rod PBG structure under test at SLAC

Experimental Setup

Klystron test stand #4 is described in more detail in [3]; a representational schematic of the test stand waveguide and

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Table 1: Comparison of Round- and Elliptical-rod PBG Structures at 100 MV/m

Quantity	Round	Elliptical
Power	5.9 MW	4.4 MW
Peak Surface Electric Field	208 MV/m	207 MV/m
Peak Surface Magnetic Field	890 kA/m	713 kA/m
Pulsed Heating for 150 ns flat pulse	131 K	84 K

diagnostics is shown in Figure 2. The test stand uses a Tektronix AFG3102 Arbitrary Waveform Generator and Hittite HMC-T2100 to generate a stepped rf pulse which fills the structure in 180ns at approximately twice the nominal power, as seen in Figure 3.

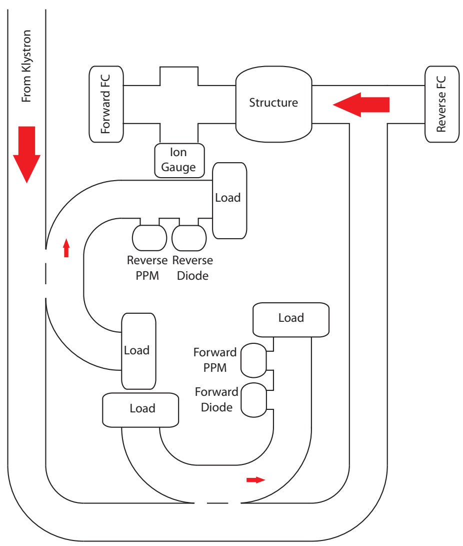

Figure 2: This figure shows a rough schematic of the waveguide configuration at klystron test stand #4. The power incident on the structure is measured by the forward peak power meter (PPM), while the power reflected from the structure is measured by the reverse PPM. The dark current and any breakdown currents are measured by the forward and reverse Faraday cups, and the pressure in the structure is measured using the ion gauge.

Preliminary Results

The initial testing of the elliptical-rod PBG was conducted with strict limits on the pulsed heating that was tolerable, with the intention of collecting breakdown rate data at a safe pulsed heating level. During this phase of the testing the gradient was limited to below 100 MW/m, and very few breakdowns were observed. After some initial processing at a variety of power levels and pulse lengths, shown in Figure 4, 12 hours of data was taken at a power level of 1.9 MW and a pulse length of 200 ns (again, referring to the

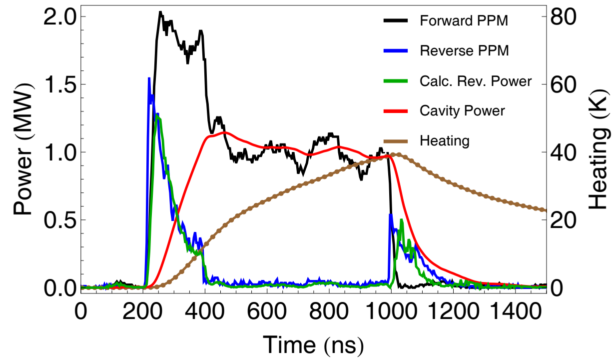

Figure 3: An example of the measured and calculated traces for the elliptical-rod PBG. The forward PPM is black, the measured reverse PPM is blue, the calculated reverse power is green, the calculated power dissipated in the structure is red, and the heating is black with dots. The trace shown here is nominally 600 ns and 1 MW.

nominal power and pulse length, not the total). It is important to note that at this time the structure was, and remains, not fully processed, meaning that the breakdown probabilities reported here are subject to change as the structure is processed more. During the 12 hour period of constant power operation there was one unique breakdown event, followed by 14 consecutive breakdown shots. This gives a very preliminary estimated breakdown probability of approximately $3 \cdot 10^{-5}$ /pulse/m at 69 MV/m gradient.

The testing will continue with a relaxed pulsed heating constraint and the structure will be tested to a breakdown probability of approximately $3.5 \cdot 10^{-3}$ /pulse/m; the expected gradient at this breakdown probability is expected to exceed 100 MV/m.

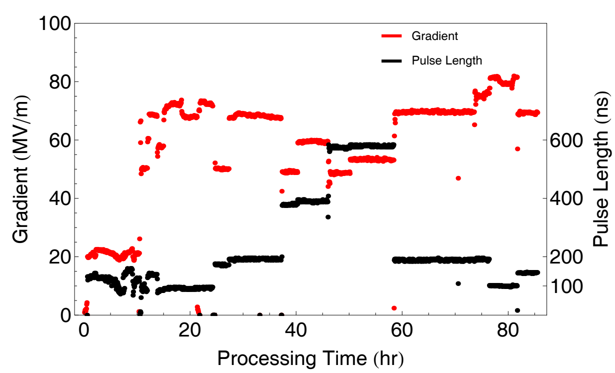

Figure 4: This figure summarizes the initial testing of the elliptical-rod PBG structure at SLAC. The gradient is shown in red (left) and the pulse length is shown in black (right). During this testing the power was limited for each pulse length such that the pulsed heating was limited to below 50 K temperature rise; these power limits resulted very few breakdowns were seen.

TESTING AT 17 GHz

In addition to the testing at 11 GHz at SLAC, PBG testing is also planned for MIT. The structure to be tested is a standing wave structure with one test cell and two coupling cells and is based on the SLAC designs. The MIT test structure will also be axially powered via $TM_{0,1}$ mode launchers built by SLAC [8]. The structure will be installed at a new standing wave test stand, described below. Because the MIT structure is based on the versatile design used at SLAC, a variety of structures can be tested at MIT using essentially the same experimental setup; see e.g. [10].

MIT Test Stand

The standing wave test stand at MIT will be powered by the MIT/Haimson Research Corporation (HRC) relativistic beam klystron operating at 17.1 GHz. The klystron output that can be coupled to the test stand is limited to 12 MW. When coupled through a 4.2 dB hybrid the power available at the test stand is limited to 4 MW. Because the power density increases with frequency, this amount of available power is more than sufficient to conduct breakdown experiments similar to those at SLAC, as seen in Table 2.

The MIT standing wave test stand will also utilize diagnostics not readily available in testing at SLAC in addition to diagnostics similar to those in use in the SLAC testing. This is made possible through the use of an external vacuum chamber used to contain the device under test. This allows line of sight diagnostic access to the high-field regions of the PBG structure through viewports in the vacuum chamber. A fast camera will be used to observe and locate breakdown events, and a spectrometer will be used to identify breakdown materials.

The test stand and its associated diagnostics are expected to go online in summer 2011.

17 GHz Structure

The standing wave test structure under construction for testing at MIT is based on the round-rod PBG structure tested by Marsh at SLAC [3]. The 17 GHz structure uses the same iris geometry and lattice parameters with the dimensions scaled to the new frequency. The only major difference between the two structures will be the lack of an outer wall on the PBG test cell in the 17 GHz design which was required for vacuum confinement in the 11 GHz structure. The operating performance of the 17 GHz structure is shown in Table 2.

Table 2: Performance of 17 GHz Round-rod PBG Structure at 100 MV/m

Power	2.4 MW
Peak Surface Electric Field	200 MV/m
Peak Surface Magnetic Field	900 kA/m
Pulsed Heating for 150 ns flat pulse	163 K

CONCLUSION

Ongoing experiments using photonic band-gap accelerator structures have shown that high gradients can be achieved in these structures but pulsed heating must be taken into consideration in the design. A new elliptical-rod PBG design is under test at SLAC which has significantly reduced pulsed heating relative to the round-rod PBG structure. This new structure has performed well thus far, with very few breakdown events seen up to 70 MV/m gradient. Testing on this structure will continue up to a higher breakdown rate and the structure should reach greater than 100 MV/m gradient. A round-rod PBG structure has also been designed for testing at MIT using a new versatile standing wave test stand powered by the MIT/HRC 17 GHz klystron. Testing on this structure should begin in summer 2011.

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