HIGH-GRADIENT METALLIC PHOTONIC BAND-GAP (PBG) STRUCTURE BREAKDOWN TESTING AT 17 GHz*

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Abstract

Photonic Band-gap (PBG) structures continue to be a promising area of research for future accelerator structures. Previous experiments at X-Band have demonstrated that PBG structures can operate at high gradient and low breakdown probability, provided that pulsed heating is controlled. A metallic single-cell standing-wave structure has been constructed at MIT to investigate breakdown performance of PBG structures with very high surface temperature rise. The MIT standing-wave structure test stand has an available power of 4 MW for a maximum gradient of 130 MV/m; the actual realized gradient may be lower due to breakdown limitations. The MIT test stand will also utilize novel diagnostics, including fast camera imaging and optical spectroscopy of breakdowns.

INTRODUCTION

Photonic band-gap (PBG) structures, which use a lattice of metallic or dielectric rods to confine an accelerator mode while damping higher-order modes (HOMs), are a topic of ongoing experimental and theoretical work [1, 2, 3, 4]. Previous experimental work has demonstrated successful acceleration using a traveling-wave PBG structure [1] as well as suppression of wakefields [4, 5]. More recent work by MIT and SLAC National Accelerator Lab has shown that metallic PBG structures can operate at high gradient and low breakdown probability, achieving gradients of greater than 100 MV/m with a breakdown probability of less than 10^{-3} per pulse per meter of structure [6]. To expand on this X-band (11.4 GHz) testing a metallic PBG structure has been designed for testing at Ku-band (17.1 GHz). This metallic structure will be used to further investigate the role of pulsed heating on breakdown probability.

STRUCTURE DESIGN

The metallic PBG structure designed for high-gradient testing at MIT is designed as a scaled version of the round-rod PBG structure previously tested at SLAC and reported in [3]. The structure is axially powered via a scaled version of the SLAC $TM_{0,1}$ mode launcher. The PBG lattice has a filling factor, i.e. the ratio between the rod radius to the rod spacing, of $a/b = 0.18$, the same as the X-band structure. The high-field irises on either side of the PBG cell have an aperture of 0.216λ and a thickness of 0.176λ, again in agreement with the X-band structure. The main variation in structure design is that the Ku-band PBG cell has three rows of round rods, as opposed to the X-band structure's two, which is required by the Ku-band structure's open outer wall, as seen in Fig. 1. This open wall allows a direct line of sight to the high-field surface of the inner rods, allowing significantly greater diagnostic access to the structure during testing.

* This work supported by Department of Energy High Energy Physics, Grant No. DE-SC0010075

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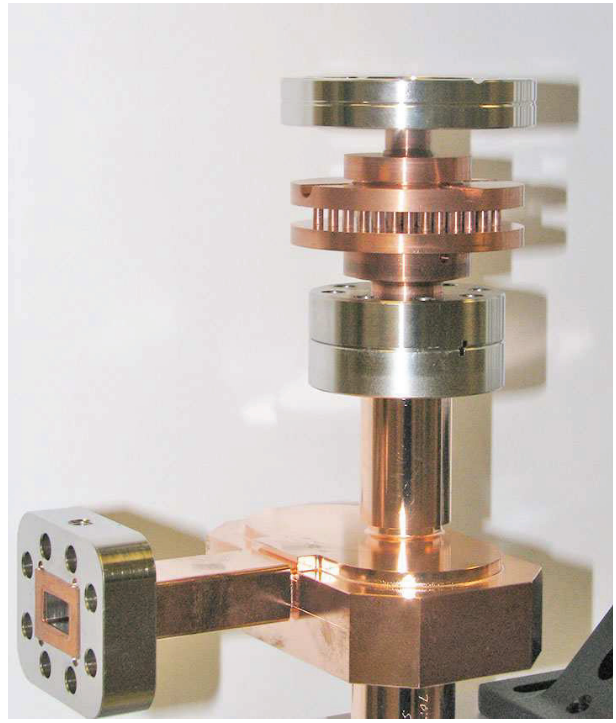

Figure 1: Metallic PBG structure and $TM_{0,1}$ mode launcher at MIT prior to structure brazing. Note the open outer wall of the PBG cell.

This structure will investigate the frequency scaling of breakdown behavior first observed in the testing of the PBG structure at X-band at SLAC, namely the effect of high surface magnetic fields on breakdown probability. To provide an accurate comparison the structure needs to be exposed, as limited by the breakdown probability, to gradients greater than 100 MV/m. The metallic PBG structure is expected to achieve 100 MV/m gradient at 2.4 MW of input rf power, as shown in Table 1. Note that the pulsed heating for this structure is higher than the X-band structure because of the increase in both the surface resistivity of copper and the power density with frequency. This power level is well below the approximately 4 MW of rf power available at the MIT test stand. The advanced optical diagnostics available at MIT combined with testing the structure at very high gradient should provide insight into how the structure fails and criteria for evaluating structure condition during testing.

ISBN 978-3-95450-138-0

Table 1: 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

This structure has been fabricated using direct machining of the structure into cups which are then brazed together. The structure can be tuned after fabrication by perturbing the coupling cells using stainless steel tuning studs.

STRUCTURE COLD TEST

Prior to hot testing the PBG structures are cold tested using a vector network analyzer (VNA) to confirm that the quality factor, frequency, and coupling match the design values, shown in Table 2. This is necessary to ensure proper operation in hot test, and to properly model the fields in the structure, as described in [6]. By coupling through the input port of the mode launcher single port measurements of the coupling and quality factor can be made. Single port measurement of the field profile can also be measured using the dielectric perturbation technique described in [6]. The results of this field profile measurement can be seen in Fig.2. This PBG structure showed an asymmetric field profile, reduced coupling, and reduced quality factor, as seen in the cold test results. This structure was installed in the test stand, but sufficient coupling could not be obtained, so a new structure was fabricated.

Table 2: Design values of 17 GHz Round-rod PBG Structure

Frequency	17.140 GHz
Q factor	5600
S11	−46 dB

This new structure was fabricated in the same fashion as the first structure. Prior to brazing the performance of the structure was characterized using two coaxial probes situated on-axis in the structure. The transmission between these probes allowed a measurement of the quality factor of the modes independent of coupling through the mode launcher, which suffers when the structure is press-fit instead of brazed. The results of this measurement can be seen in Fig. 3. Note that this measurement shows a lower Q and a shift in frequency relative to the design point; both these values are expected to be closer to the design values after brazing. This structure will undergo both single-port and transmission Q measurements, as well as field profile measurements using a dielectric perturbation, after brazing to confirm that Q, frequency, and coupling are all within acceptable limits of the design values.

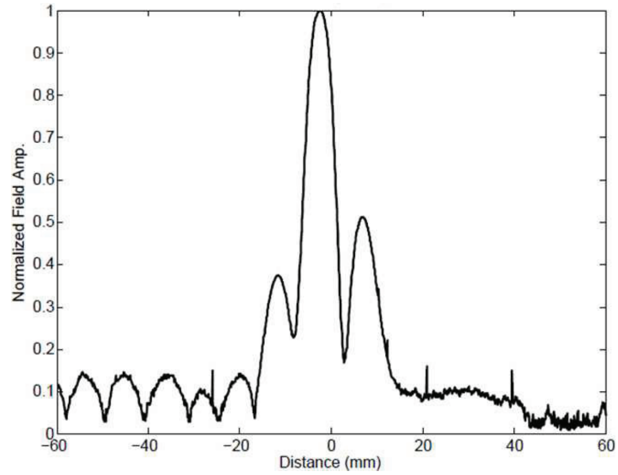

Figure 2: Measured field profile of first 17 GHz metallic PBG structure, obtained via use of a dielectric perturbation technique.

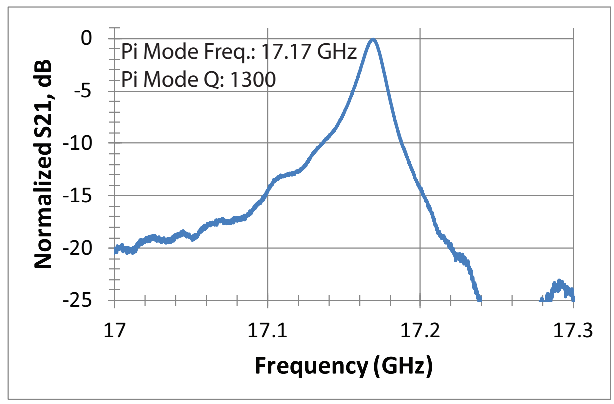

Figure 3: Transmission measurement of the second 17 GHz metallic PBG structure, prior to brazing. The Q of the mode of interest is found to be 1300 at a frequency of 17.169 GHz.

MIT 17 GHz 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 to avoid breakdowns on the microwave window in the transmission line to the test stand. When coupled through a 4.2 dB hybrid (Fig. 4), which is inserted to protect the klystron from reflected power, 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 1.

The MIT standing wave test stand will utilize diagnostics. 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 view ports in the vac-

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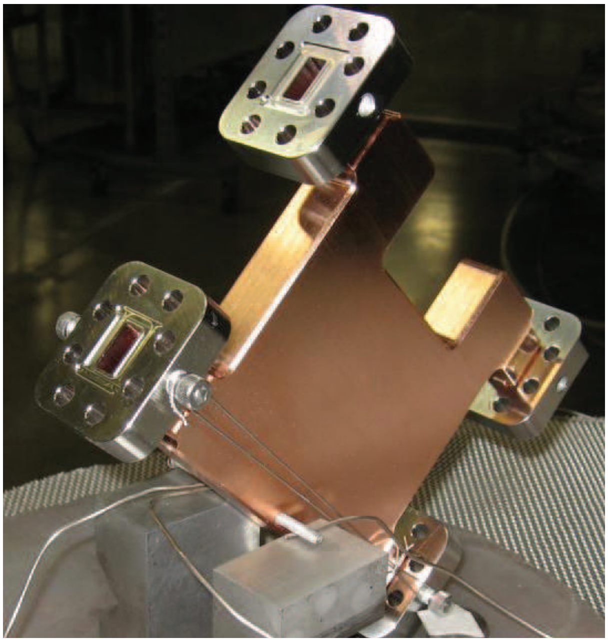

Figure 4: 4.2 dB hybrid from Haimson Research Corporation.

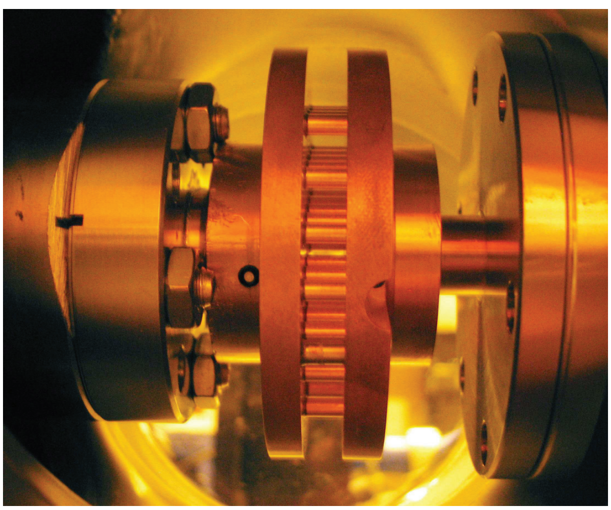

Figure 5: Metallic PBG structure installed in MIT test stand.

uum chamber. A nanosecond-gated ICCD camera will be used to observe and locate breakdown events, and a broadband optical spectrometer will be used to identify breakdown materials. Optical access to the structure can be seen in Fig. 5.

STRUCTURE HOT TEST

The operation of the MIT 17 GHz test stand was validated with the use of the first PBG structure described above. The microwave diagnostics functioned properly, confirming the cold test results that very little power was coupled into the design mode for that structure. Optical diagnostics were not used during this test, but their feasibility was verified as shown in Fig. 5. The second structure should allow proper testing of the high power test stand.

CONCLUSION

A metallic PBG structure has been designed and undergone preliminary tests at MIT. This structure will further investigate the relationship between pulsed heating and breakdown probability in high-gradient accelerator structures. The first iteration of the structure showed reduced coupling and quality factor, likely due to fabrication errors. This structure was used to validate both the cold and hot test procedures at MIT. The Q of the design mode was measured using both single port and transmission techniques, and a dielectric perturbation was used to determine the field profile of the design mode. The structure was briefly placed under hot test. The microwave diagnostics were confirmed to work properly, and optical access to the structure after installation was confirmed. A second iteration of the structure has been constructed and shows improved performance in cold tests of the structure prior to brazing. This structure will undergo further testing after brazing to confirm proper fabrication prior to being installed for hot testing.

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