HIGH-GRADIENT PHOTONIC BAND-GAP (PBG) STRUCTURE BREAKDOWN TESTING AT Ku-BAND*

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Abstract

Photonic Band-gap (PBG) structures continue to be a promising area of research into 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. Two single-cell standing-wave structures have been constructed at MIT to investigate breakdown performance of PBG structures. A metallic structure with small round rods will be used to intentionally test performance with very high surface temperature rise, while an over-moded structure with dielectric rods will investigate alternative solutions to the issue of surface temperature rise. Both structures are expected to reach gradients of at least 100 MV/m and will 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].

In addition to this X-band breakdown testing, two standing-wave PBG structures have been designed for high-gradient breakdown testing at Ku-band at MIT. One structure is a fundamental-mode metallic PBG structure which will investigate the effects of pulsed heating on breakdown probability. The second structure is a dielectric-rod PBG structure where the lowest frequency mode is a $TM_{0,2}$-like mode, which is designed to avoid pulsed heating affects by using an over-moded design. Both structures are designed on the SLAC standing wave breakdown structure model [7, 8, 9] with two coupling cells on either side of a high-field test cell. The structures are axially powered via reusable $TM_{0,1}$ mode launchers fabricated by SLAC and are designed with approximately half the field amplitude in the coupling cells relative to the central test cell.

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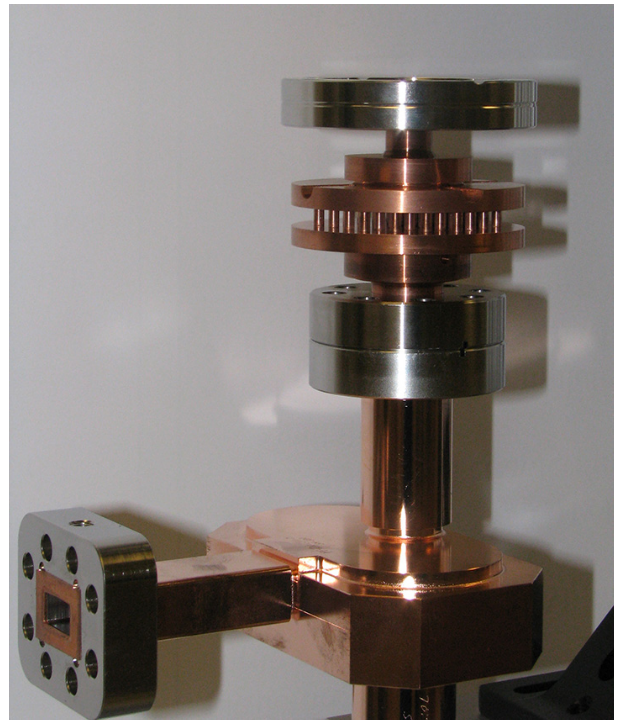

Figure 1: Metallic PBG structure and $TM_{0,1}$ mode launcher at MIT prior to structure brazing. Note the open outer wall of the PBG cell.

METALLIC STRUCTURE

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 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 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 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 affect 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.

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. These cups will be brazed together in the final step of fabrication. The structure can be tuned after fabrication by perturbing the coupling cells using stainless steel tuning studs.

DIELECTRIC STRUCTURE

Unlike metallic PBG structures, lattices of dielectric rods can be designed such that no $TM_{0,1}$-like mode is confined, and the lowest frequency mode that is confined to the defect region is a $TM_{0,2}$-like mode. This use of an overmoded accelerator structure offers several benefits, including improved azimuthal uniformity of the accelerating mode where it intersects the beam and decreased magnetic fields at the rod surface. To take advantage of these benefits, an overmoded PBG structure using sapphire rods has been designed for breakdown testing at MIT. This structure has $a/b = 0.35$ to ensure that the $TM_{0,2}$-like mode is the lowest frequency cavity mode. A consequence of this larger a/b ratio is that some higher-frequency modes are confined in the defect; this is corrected by the removal of several columns of rods, which decreases the Q of the HOMs while increasing the accelerator mode Q. This damping is shown in Fig. 2.

The major advantage of the overmoded dielectric PBG structure is the decrease in peak surface magnetic field at the rods. High surface magnetic fields have caused significant damage in previous metallic PBG structure testing [3], limiting structure performance. By moving the rods away from the highest-field region of the structure, an overmoded design reduces this surface heating effect, which should improve structure performance. This decrease in peak surface magnetic field is shown in Fig. 3. This structure is also expected to achieve greater than 100 MV/m gradient (Table 2).

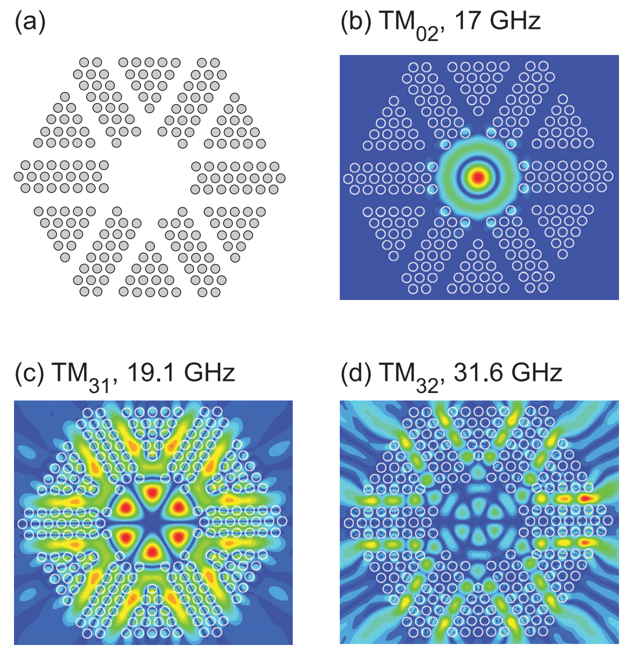

Figure 2: HOM damping. (a) PBG cavity with rows of rods removed radially. (b) TM_{02}-like mode in damped cavity. (c) TM_{31}-like mode damped by radial defects. (d) TM_{32}-like mode damped by radial defects.

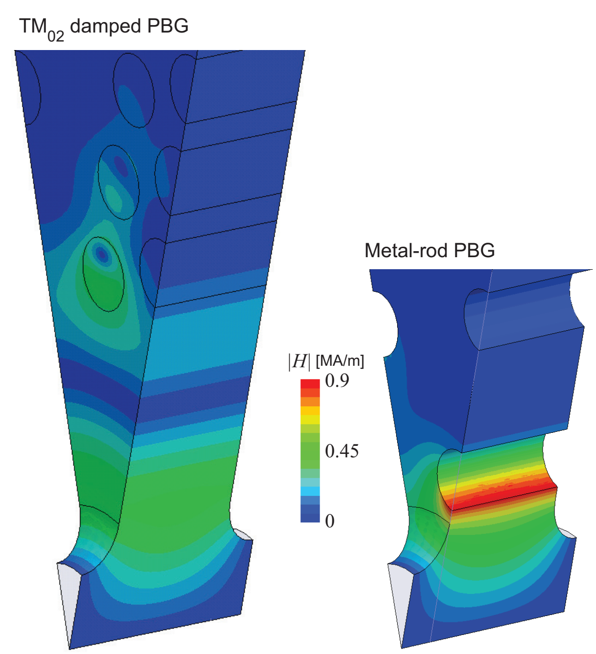

Figure 3: Model of central high-field cell of dielectric PBG structure showing reduction in magnetic field at the rod surface relative to a metallic PBG structure.

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Table 2: Performance of 17 GHz Dielectric PBG Structure at 100 MV/m

Power	2.9 MW
Peak Surface Electric Field	200 MV/m
Peak Surface Magnetic Field	400 kA/m
Pulsed Heating for 150 ns flat pulse	163 K

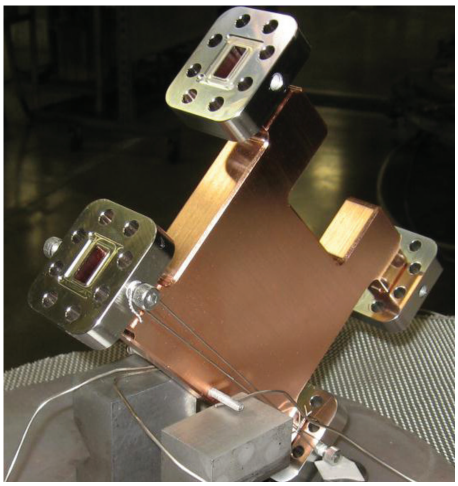

Figure 4: 4.2 dB hybrid from Haimson Research Corporation.

This structure is currently under fabrication. The structure will be clamped together in final assembly to ease the insertion of the sapphire rods into the copper end plates.

MIT 17GHz 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 (Fig. 4) 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 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 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.

CONCLUSION

Metallic and dielectric PBG structures have been designed for breakdown testing at Ku-band at MIT. These structures will take advantage of the novel diagnostic access offered by the PBG lattice to investigate breakdown physics. These experiments should provide insight into pulsed heating damage to metallic surfaces, as well as novel approaches to avoiding this problem by using overmoded structures. Both structures are expected to achieve greater than 100 MV/m gradient, and are currently under fabrication.

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