X-BAND PHOTONIC BAND GAP ACCELERATING STRUCTURES WITH IMPROVED WAKEFIELD SUPPRESSION*

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Abstract

We designed a new photonic band gap (PBG) accelerating structure with elliptical rods and improved wakefields suppression. The experimental characterization of the wakefield spectrum in a PBG accelerator with an electron beam was recently performed at Argonne Wakefield Accelerator facility, and the superior wakefield suppression properties of the PBG structure were demonstrated. In 2013 the team from MIT and SLAC demonstrated that the X-band PBG structures with elliptical rods have reduced breakdown rate compared to PBG structures with round rods, presumably due to the reduced surface magnetic fields. However, the structure with elliptical rods designed by MIT confined the dipole higher order mode in addition to the accelerating mode and thus did not have superior wakefield suppression properties. We demonstrate that PBG resonators can be designed with 40% smaller peak surface magnetic fields while preserving and even improving their wakefield suppression properties as compared to the structure with round rods. The structure will be fabricated, tuned, and tested for high gradients and for wakefield suppression.

INTRODUCTION

The next generation of linear accelerators has to address the unprecedented requirements on electron beam's quality, acceleration gradients, and peak currents. The accelerating cavities for the future machines must be able to provide acceleration for the high currents while at the same time preserving the tightly focused low emittance beam. The higher order mode (HOM) wakefields that get excited more easily by the high current electron bunches can affect the quality of the beam and must be suppressed. Photonic Band Gap [1] (PBG) cavities have the unique potential to filter out HOM power and greatly reduce wakefields. The first ever demonstration of acceleration in a PBG resonator was conducted at Massachusetts Institute of Technology (MIT) in 2005 [2]. Since then, a number of important PBG accelerator experiments have been conducted which improved our understanding of the PBG accelerators, their limitations, and ability to suppress wakefields.

The first experimental observation of excitation and suppression of wakefields in a PBG accelerator structure was recently conducted at the Argonne Wakefield Accelerator [3]. It was demonstrated that the Q-factors of most major HOMs could be reduced to about 100 in the structure consisting of 16 PBG resonators with the accelerating frequency of 11.700 GHz. However, previous experiments by the team from MIT and SLAC [4] demonstrated that because of the relatively high peak surface magnetic fields on the rods of the PBG structure, the performance of the PBG accelerator may not be optimal at high gradients. The MIT team suggested that if the shape of the six innermost rods of the PBG structure was changed from round to elliptical, then the peak surface magnetic fields would be reduced and the high gradient performance of the PBG resonator would improve [5].

MIT came up with the new design for the PBG resonator with six elliptical rods and tested it at high gradients demonstrating better performance as compared to the resonators with round rods [5]. However, the question remained if the new MIT resonator would be as effective with regards to the HOM suppression as the original PBG resonator with round rods.

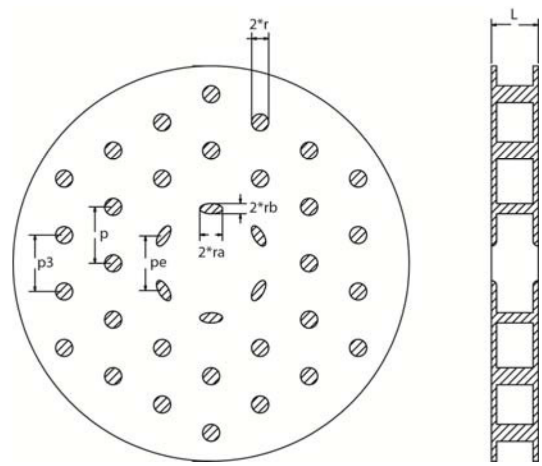

Figure 1: A schematic of the PBG resonator with six elliptical rods.

DOE HEP funded a project at Los Alamos National Laboratory (LANL) to conduct the thorough investigation of the X-band PBG resonators with elliptical rods and design and test a resonator with elliptical rods, reduced peak surface magnetic fields, and improved suppression of wakefields.

DESIGN OF 11.7 GHZ TW PBG RESONATOR WITH ELLIPTICAL RODS

We started the design of the new PBG resonator with the optimization of the shape of the elliptical rod for the minimal magnetic field. Similar optimization was already conducted by our team for the case of the

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superconducting radio-frequency (SRF) PBG resonator at the frequency of 2.1 GHz [6]. The schematic of the 11.7 GHz PBG resonator with six elliptical rods is shown in Figure 1. Similar to the SRF case, we discovered that the biggest surface magnetic fields occur on the inner surfaces of the six elliptical rods, and for the given major radius of the elliptical rod, the magnetic field is minimized if the minor radius $rb = 0.09*p$, where p is the period of the PBG structure. The magnitude of the electric field in the resonator with elliptical rods is shown in Figure 2 and looks very similar to the magnitude of the electric field in a resonator with round rods.

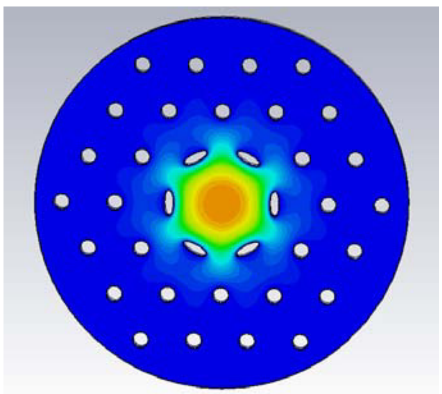

Figure 2: Magnitude of the electric field in a resonator with six elliptical rods.

The dependence of the peak surface magnetic field on the major radius of the elliptical rod is shown in Figure 3. It can be seen from the graph, that even if the major radius of the elliptical rod is made equal to the radius of the round rods in the previous versions of the PBG resonator ($r=0.15*p$), the peak surface magnetic fields are significantly reduced if the minor radius of the rod is made equal to $0.09*p$. The value of the peak surface magnetic field on the rods of the MIT's design from [5] is also shown in Figure 3, and it can be seen that the value is greater than that for the new optimized design.

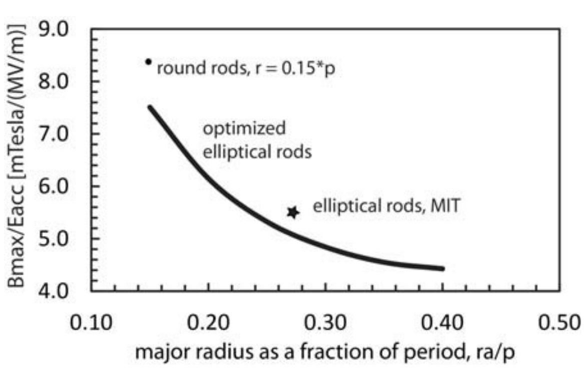

Figure 3: Peak surface magnetic fields in the PBG resonator with elliptical rods as a function of the major radius of the elliptical rods.

The excitation and decay of the HOMs in the resonator with elliptical rods was studied next. The resonator was modelled with a transient solver of the CST Microwave Studio. The resonator was excited with a current pulse placed slightly off-axis with the frequency content of 12-20 GHz (this frequency range encompasses all major dangerous HOM wakefields including the dipole and the quadrupole modes). Open boundary conditions were defined at the periphery of the resonator, and the decay of the excited mode spectrum was studied.

Table 1: Dimensions and Accelerator Characteristics of the ew 11.7 GHz Traveling-wave PBG Accelerator with Elliptical Rods

Frequency	11.700 GHz
Phase shift per cell	$2\pi/3$
Period of round rods, p	10.33 mm
Radius of round rods, r	1.55 mm = $0.15*p$
Period of e-rods, pe	10.22 mm = $0.99*p$
Period of the 3rd row of rods, $p3$	10.85 mm = $1.05*p$
Major radius of e-rods, ra	2.58 mm = $0.25*p$
Minor radius of e-rods, rb	0.93 mm = $0.09*p$
OD of the cell	76 mm = 3 in
Length of the cell, L	8.54 mm
Diameter of the iris	6.31 mm = 0.250 in
Thickness of the iris	1.90 mm = 0.075 in
Q_w	5600
r_s	83.7 MΩ /m
$[r_s/Q]$	14.94 kΩ /m
Group velocity	0.015*c
Q_{diff}(HOMs)	130

We discovered that the structure's periodicity needs to be altered in order to improve the suppression of HOMs. For the major radius of the elliptical rod $ra=0.25*p$ we numerically optimized the configuration of the PBG rods so that the diffraction Q of the fundamental mode in the structure was no lower than the diffraction Q of the fundamental mode in the structure with round rods (of the order of 10^5). At the same time, the diffraction Q for the slowest decaying HOM in the frequency range of 12-20 GHz (which in fact was the dipole mode at the frequency of around 17 GHz) was nearly two times lower than the diffraction Q of the dipole mode in the structure with all round rods. In this new design the spacing between the elliptical rods had to be made smaller than the spacing between the round rods in the second ring of the PBG structure (*pe=0.99*p*), and the spacing between the round rods of the third ring of the PBG structure was made larger than the spacing between the round rods in the second ring (*p3=1.05*p*). The final dimensions and the accelerator characteristics of the new resonator's design are listed in Table 1.

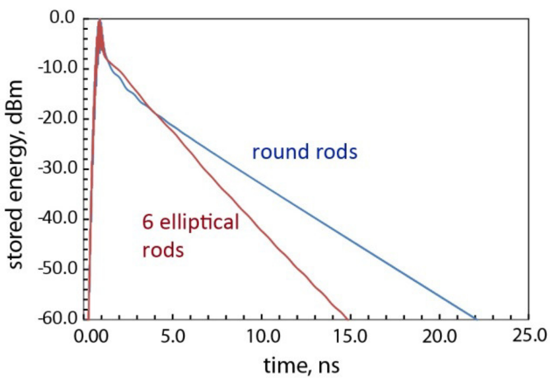

Figure 4: Decay of the energy stored in HOMs in the frequency range of 14-18 GHz in PBG resonator with six optimized elliptical rods versus PBG resonator with only round rods.

Figures 4 and 5 illustrate the decay of the HOMs excited in the PBG resonator as simulated with CST Microwave Studio. Figure 4 shows the decay of the energy stored in all HOMs in the frequency range of 12-20 GHz versus time. Figure 5 is the spectrogram that illustrates what frequencies get excited and how fast separate frequencies decay. The geometries with optimized elliptical rods, all round rods, and the old MIT design with elliptical rods scaled to the frequency of 11.700 GHz were simulated and compared. It can be seen from Figures 4 and 5 that the dipole mode is excited with larger amplitude in the newly designed PBG resonator with elliptical rods than the dipole mode in the resonator with round rods, however it decays much faster. In the old MIT design the dipole mode is excited with big amplitude and decays slowly. Therefore, the old MIT design of the PBG resonator with elliptical rods provides worse suppression of wakefields than the resonator with round rods.

CONCLUSION

We have designed a new traveling-wave photonic band gap resonator with elliptical rods operating at the frequency of 11.700 GHz. This new design has smaller peak surface magnetic fields than previously designed PBG resonators with either round or elliptical rods. At the same time the new resonator has better wakefield suppression properties than the previously tested resonator with round rods and much better wakefield suppression. The new resonator will be constructed and tested for high gradient performance at the test stand at SLAC National Accelerator Laboratory in the near future. Also, the new PBG accelerating structure will be put together with the PBG resonators with optimized elliptical rods. The structure will be tuned and tested for wakefields at Argonne Wakefield Accelerator.

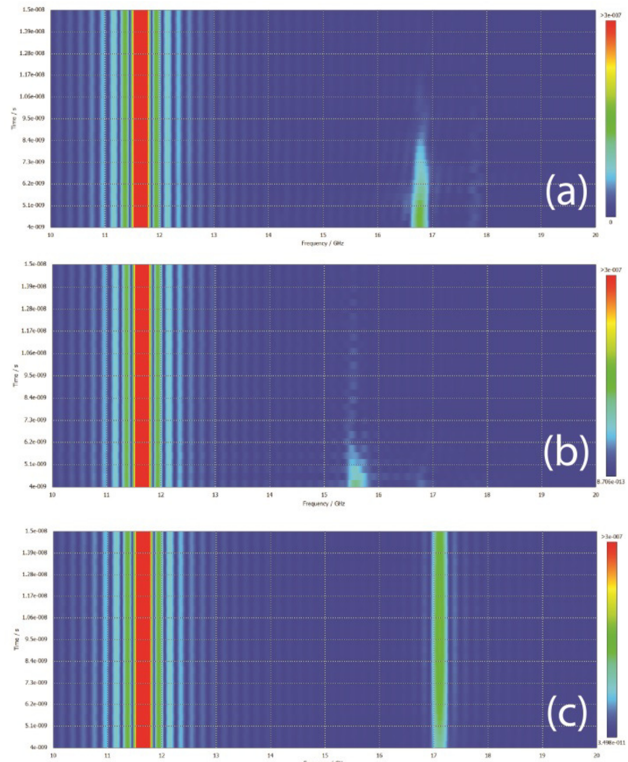

Figure 5: The Fourier spectrum of the decay of the stored HOMs power in PBG resonators: new design with optimized elliptical rods (a); round rods (b); old MIT design with elliptical rods (c).

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