Dislocation of Lattice Points for Impedance Matching of a Photonic Bandgap Cavity Resonator

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Abstract*---A photonic bandgap (PBG) cavity resonator encompassing a metamaterial with a sparsely populated array of metallic rods has been arrived at for potential application in future generations of particle accelerators. The star-shape array was evolved from a two-dimensional triangle lattice with certain lattice points vacant. Optimized for the TM_{01} – like mode with the electric field concentrated at the center while the higher-order modes (HOMs) are constrained from the center, the cavity is excited by a standard rectangular waveguide. Input matching is accomplished by fine tuning in the positions of selected metal rods in the two outer layers. The cavity-waveguide assembly was fabricated with copper and cold tested for resonance characteristics. A return loss of over 20 dB at the designed resonance frequency of 11.41 GHz was measured. A bead pull experiment was performed to confirm the uniformity of the field along the axis of the cavity resonator.

***Keywords*— Photonic band gap structure, cavity resonator, particle accelerator, impedance matching**

I. INTRODUCTION

Photonic bandgap (PBG) structures consisting of two-dimensional array of metal or dielectric rods received much attention for future accelerator applications, owing to their ability to suppress higher order mode (HOM) wakefields without affecting the operating mode, hence providing better assurance for beam quality. PBG also enables oversized accelerating structures to be employed, which are favorable for implementing accelerators driven by higher frequency microwave sources. The PBG cavity is often formed by removal of a rod at the center while additional rods are withdrawn or removed to achieve optimal input coupling to the RF source [1]-[4]. In this paper, the efforts to test alternative PBG structures and impedance matching approach for accelerators are described. Refinement in the array structure for input coupling optimization is carried out by displacement of certain rods from their nominal lattice points, hence can be viewed as a form of dislocation in the PBG structure. Cold test of the PBG cavity using a network analyzer and measurement results are presented.

II. STAR SHAPE ARRAY

The study described in this paper is motivated by the capability of sparse array in supporting the accelerating mode while maintaining effective restraint on HOMs in the location of the beam pipe [5]. A PBG cavity resonator with a star shape array of metallic rod loading is designed to provide high field intensity in the center beam pipe region while maintaining the target resonance frequency of 11.4 GHz. Non-periodic lattice structures could avoid the inherently poor damping characteristics found in a periodic lattice cavity. A non-periodic lattice PBG can be accomplished by shifting the lattice points of the metal rods at each layer symmetrically, guided by electromagnetic simulation tool CST Microwave Studio to give optimal performance in field confinement. The PBG cavity structure resulting from the optimization routine is shown in Figure 1 (left), in which the metal rods in the second and third layers are dislocated from the original triangular lattice, with the latter shown in dotted circles. A color plot of the simulated electric field intensity of the TM_{01}-like mode is shown in Figure 1 (right). Coupling of microwave power into and out of the cavity is accomplished by joining the side wall to two WR-90 rectangular waveguides with full opening of the waveguide cross section. The metal rods in the cavity are also taking up the action usually provided by the coupling iris in a conventional pillbox cavity. The PBG cavity with the waveguide sections were optimized as a unit for maximum input return loss and high transmission in the final design iteration. A photograph of the cavity-waveguide assembly fabricated with copper is shown in Figure 2.

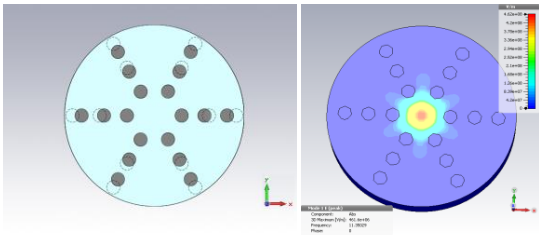

Fig. 1. An optimized PBG cavity with second and third layer rods dislocated from the original triangular lattice. Original locations shown by dotted circles, and simulated electrical field pattern of the TM_{01}mode in the PBG cavity

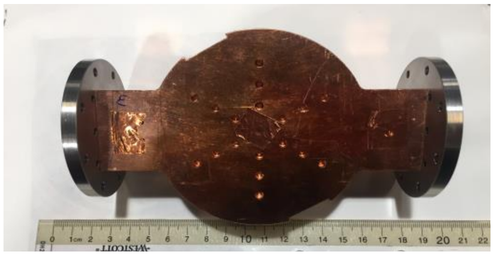

Fig. 2. PBG cavity with coupling waveguide integrated..

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TABLE I. PARAMETERS OF PBG CAVITY WITH STAR SHAPE 2D ARRAY LOADING

Radius of rod, a	2.89 mm
Inner layer rods' spacing, b	11.87 mm
Ratio of a/b	0.243
Spacing between first layer and second layer	10 mm
Spacing between second layer and third layer	7.87 mm
Inner radius of PBG cavity	39 mm
Wall to wall longitudinal length of PBG cavity	12.04 mm
Radius of Beam pipe	1.5 mm
WR90 waveguide inside dimension	22.86 mm × 10.16 mm
Length of coupling WR90 waveguide	11.43 mm

III. MEASUREMENT RESULTS

Reflection and transmission characteristics of the PBG cavity were measured using an Agilent E8362B network analyzer. Due to manufacturing tolerance, the input matching exhibited by the structure had a return loss of 6 dB (S_{11} = - 6 dB). Upon fine tuning with a small parasitic insert near the aperture, a return loss of 24 dB was measured for the TM_{01} -like mode at 11.41 GHz, as shown in Figure 3, with frequency spanning from 8 to 20 GHz. It can be seen that besides the TM_{01}-like mode, several HOMs are excited. The field patterns of these HOMs have been found to have strong field intensity only in the region of the cavity far away from the beam pipe location at the center. Hence the PBG structure is serving its purpose of suppression of HOM effects on the beam.

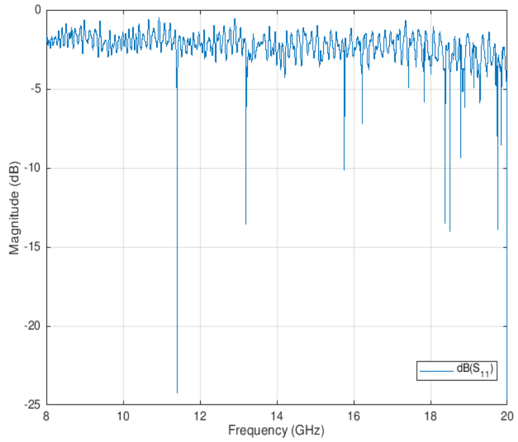

Fig. 3. Frequency sweep of the return loss of the PBG cavity resonator.

The trajectory of S_{11} on a Smith chart over the frequency range of 11.37 to 11.47 GHz in the vicinity of the TM_{01}-like mode resonance is shown in Figure 4. Following the validation of resonant mode and close to critical coupling for the structure, a bead-pull experiment was performed to examine the field intensity variation along the axis of the cavity. Results of the bead-pull measurement revealed very good uniformity in field intensity, indicating that the mode excited is a close approximation to the TM_{010} mode.

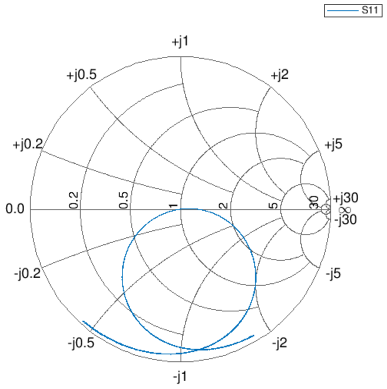

Fig. 4. Smith chart trajectory of S_{11} of the cavity in the vicinity of the TM_{01}–like resonant mode.

IV. SUMMARY

A PBG cavity resonator employing a sparsely populated structure has been designed to be used for particle accelerator application. To accomplish impedance match to a standard X-band waveguide for input power coupling, some members of the metal rods in the metastructure are dislocated from their lattice point in the prototype triangular lattice. Cold test of a cavity fabricated with copper validated the design, showing a measured return loss of over 20 dB for the TM_{01} –like mode at 11.41 GHz. Results of a bead pull experiment performed for the resonant mode showed very good field uniformity along the cavity axis. Performance of the PBG cavity renders it a strong candidate for the construction of a multi-cell resonant structure for the next generation of particle accelerator with advancement in beam quality.

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