AN UPDATE ON A SUPERCONDUCTING PHOTONIC BAND GAP STRUCTURE RESONATOR EXPERIMENT*

Evgenya I. Simakov#, W. Brian Haynes, Michael A. Madrid, Frank P. Romero, Tsuyoshi Tajima, and Walter M. Tuzel, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.
Chase H. Boulware, Terry L. Grimm, Niowave, Inc., Lansing, MI, 48906, U.S.A.

Abstract

We report the results of high gradient testing of two superconducting RF photonic band gap (SRF PBG) accelerator cells which were recently completed at LANL. Two cavities were tested at both 4K and 2K and performed quite well, demonstrating accelerating gradients as high as 15 MV/m and high unloaded Qs close to theoretical predictions. The tests were conducted in the framework of the DOE Early Career project on PBG resonators for accelerator applications. It has been realized long ago that photonic band gap (PBG) structures have great potential in reducing long-range wakefields in accelerators. Using PBG structures in superconducting particle accelerators may allow operation at higher frequencies and significantly higher beam luminosities thus leading towards a completely new generation of colliders for high energy physics.

INTRODUCTION

Superconducting radio frequency (SRF) cavities are the natural choice for the future generation of high energy linacs, especially for high-duty-factor machines where the heat produced in the accelerating structure cannot be effectively extracted. Going to higher frequencies in SRF accelerators will save on RF power as well as provide a more compact and lower cost accelerating structure. In addition, operating at high frequency and low bunch charge reduces the risks of brightness degradation in electron beam transport. However, with the current technology, higher order mode (HOM) wakefields in the main linac scale as frequency cubed and can greatly reduce luminosity and strongly affect interaction of the beams at the collision point [1]. Photonic Band Gap [2] (PBG) cavities have the unique potential to absorb all HOM power and greatly reduce the wakefields. A PBG structure or simply, photonic crystal, represents a periodic lattice of macroscopic components (e.g., rods), metallic, dielectric or both. For accelerator applications, it is relatively easy to employ two-dimensional PBG resonators based on arrays of metal rods.

The first ever demonstration of acceleration in a PBG resonator was conducted at Massachusetts Institute of Technology (MIT) in 2005 [3]. Since then, the importance of PBG structures for accelerators has been recognized by many research institutions worldwide. In the experiment reported in [3], the 6-cell open PBG structure was employed to construct a travelling-wave 2pi/3-mode accelerator with inherit ability to filter out wakefields. However, for the SRF accelerators, the SRF PBG resonators rather serve as a novel, elegant, and very effective way to incorporate HOM couplers, and also, the fundamental mode coupler as a part of the accelerating structure [4] (Figure 1). Since substantial accelerating gradients could be maintained inside of a PBG resonator incorporating HOM waveguides, placing those in the PBG structure instead of the beam pipes may greatly increase the overall real estate gradient.

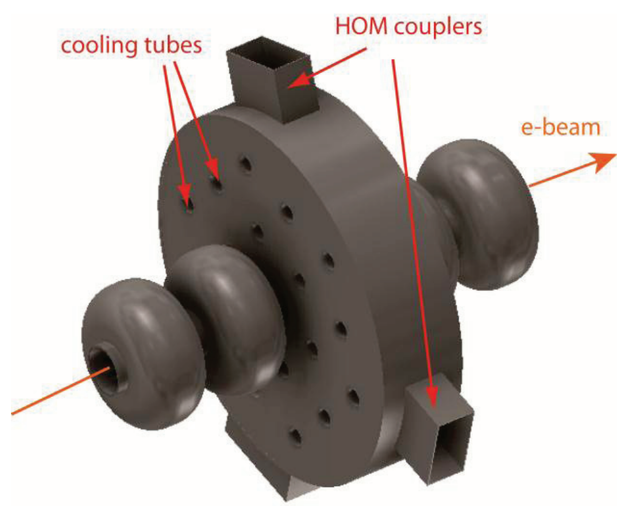

Figure 1: Conceptual drawing of an SRF accelerator section incorporating a PBG cell with HOM couplers.

The idea that PBG cells will greatly benefit higher-frequency superconducting electron accelerators by greatly reducing the wakefields was first expressed by the authors of [5], who fabricated and cold-tested the first ever superconducting PBG cell at 11 GHz. We are also aware of another successful attempt to fabricate a superconducting PBG cell at 16 GHz [5]. However, the authors of [5,6] have only completed the low power tests, and therefore never proved that their designs and fabrication procedures are able to withstand high power.
We have initiated a project at Los Alamos National Laboratory (LANL) to evaluate the high gradient performance of the SRF PBG resonators and demonstrate the applicability of the PBG resonator technology to SRF accelerators.

2.1 GHZ SRF PBG RESONATOR

Two 2.1 GHz SRF PBG resonators were recently designed at LANL and fabricated at Niowave, Inc. The design was performed with the CST Microwave Studio [7] and later verified with the HFSS [8,9]. The structure

* Work is supported by the U.S. Department of Energy (DOE) Office of Science Early Career Research Program.
# smirnova@lanl.gov

was designed with the 18 straight niobium rods sandwiched in between two niobium plates and enclosed by a niobium outside wall. The beam pipe had the inner diameter of 1.25 inches and blended edges. The dimensions of the cell are listed in Table 1. The table also lists the other characteristics of the designed cell. It can be seen from the table that the breakdown due to high maximum magnetic fields is going to be the most critical limit to the high gradient performance of the designed cell. The maximum surface electric field in the PBG cell is reached on the blended edge of the beam pipe, as expected. However, the maximum surface magnetic field does not occur on the side wall of the cavity as in the case of a simple elliptical cavity. Instead, the maximum is reached on the rods of the PBG structure [4].

Table 1: Dimensions and Accelerator Characteristics of the 2.1 GHz SRF PBG Accelerator Cell

Spacing between the rods, p	56.56 mm
OD of the rods, d	17.04 mm = 0.3*p
ID of the equator, D0	300 mm
Length of the cell, L	60.73 mm (λ/2)
Beam pipe ID, Rb	1.25 inches = 31.75 mm
Radius of the beam pipe blend, rb	1 inch = 25.4 mm
Q_0 (4K)	$1.5*10^8$
Q_0 (2K)	$5.8*10^9$
R/Q	145.77 Ohm
E_{peak}/E_{acc}	2.22
B_{peak}/E_{acc}	8.55 mT/(MV/m)

Figure 2: Photograph of the 2.1 GHz PBG cell during manufacturing stage.

The resonators were fabricated by Niowave, Inc from a combination of stamped sheet metal niobium with the residual resistance ratio RRR>250 and machined ingot niobium components with RRR>220. After the electron beam welding, a buffered chemical polish etch was performed to prepare the RF surface for testing. The temperature of the acid is carefully monitored during the etching. A photograph of one resonator during the fabrication stage is shown in Figure 2. The co-axial couplers were designed to be placed in the beam pipe for high gradient tests.

HIGH GRADIENT TESTING OF THE 2.1 GHZ SRF PBG RESONATORS

The resonators underwent high gradient testing at LANL at the beginning of 2012. Each cavity delivered from Niowave was opened in a class 100 clean room and a pickup coupler flange and a flange with a matched moveable power coupler were attached at the ends of the beam pipes. The cavity was then sealed and taken out of the clean room, set on the vertical cryostat insert, pumped down and leak checked (Figure 3).

The cavity was then moved into a vertical cryostat of 965 mm in diameter and 3048 mm in depth. The cavity was actively pumped down all the time with a 30 L/s ion pump attached on the cryostat lid. The atmospheric pressure at Los Alamos is about 600 Torr which corresponds to ~4 K as LHe boiling temperature. A 4 K measurement was carried out on the first day. On the second day more liquid helium was added and the cryostat was pumped down for a 2 K measurement.

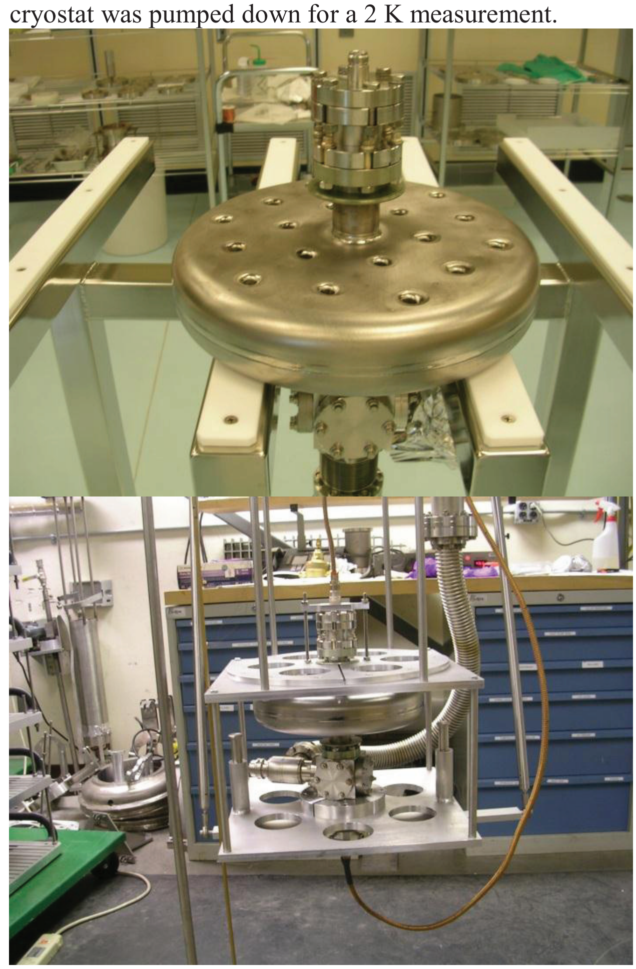

Figure 3: The 2.1 GHz PBG cell assembled with the couplers in the clean room and installed on the vertical test stand before lowering into the cryostat.

At the start of each test we adjusted the moveable coupler to a slightly over-coupled position, the decay time of the reflected power was measured in a pulsed mode at a low field. The unloaded Q (Q_0) and coupling Q's of input and pickup couplers were calculated from this pulsed-mode measurements. Next, the Q_0 – E_{acc} sweep data was obtained in a CW regime for different drive powers and the gradient and the external Q-factors were computed from measured drive, reflected and transmitted powers.

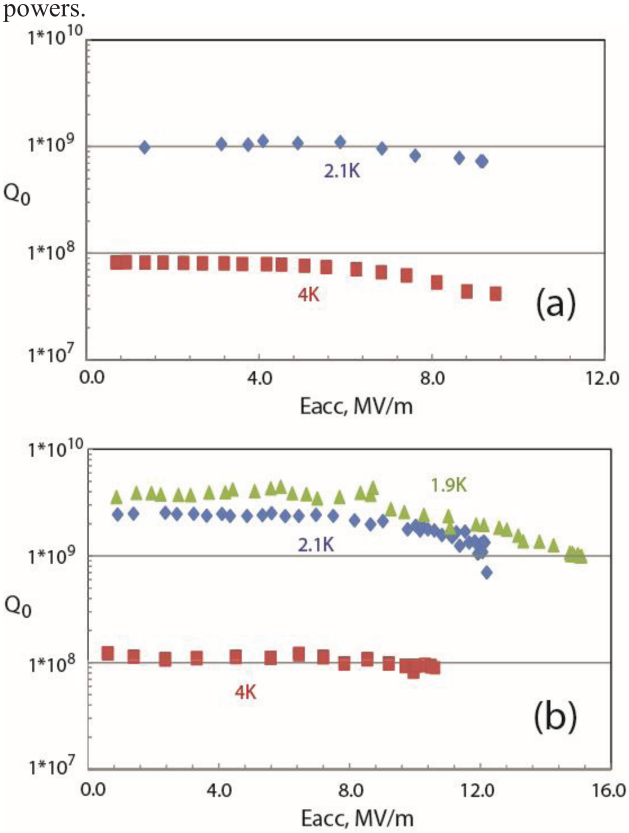

Figure 4: Unloaded Q (Q_0) as a function of accelerating gradient (E_{acc}) off the 2.1 GHz SRF PBG cavities: (a) cavity #1 tested on 3/30/12, and (b) cavity #2 tested on 4/27/12.

Table 2: Measured Performance of two 2.1 GHz SRF PBG Resonators and Comparison to Theory

	Theory	Cavity #1	Cavity #2
Frequency	2.100 GHz	2.10669 GHz	2.09984 GHz
Q_0 (4K)	$1.5*10^8$	$8.2*10^7$	$1.2*10^8$
Q_0 (2K)	$5.8*10^9$	$1.1*10^9$	$3.9*10^9$
Maximum E_{acc} (4K)		9.5 MV/m	10.6 MV/m
Maximum E_{acc} (2K)		9.1 MV/m	15.0 MV/m
B_{peak} (4K)		81 mT	91 mT
B_{peak} (2K)		78 mT	129 mT

Figure 4 shows the Q_0 – E_{acc} curves at 4 K and 2 K for the two cavities. Table 2 summarizes the test results including frequencies, Q-factors, and maximum achieved gradients. Cavity #1 was the first one to be tested and was opened up in the clean room a few times during the preparation stages. It may explain its slightly worse performance at 4K. Also, during the 2K testing, cavity #1 developed a super-leak, which resulted in a quite poor performance. Measured characteristics of the Cavity #2 were very close to theoretical predictions. The achieved accelerating gradients were as high as 15 MV/m, limited by the magnetic quench.

CONCLUSION AND FUTURE PLANS

We have demonstrated the proof-of-principle fabrication and high gradient operation of superconducting photonic band gap cavities at 2.1 GHz. Two cavities were tested at both 4K and 2K and performed quite well, demonstrating accelerating gradients as high as 15 MV/m which corresponds to the peak surface magnetic fields of approximately 130 mT. The PBG technology may significantly reduce the size of SRF accelerators and allow increasing the brightness of the electron beam transport.

The next step of the DOE Early Career project would be the design and testing of a 2.1 GHz SRF accelerator section which includes a PBG cell serving as a fundamental and a high order mode coupler. A spin-off project funded by the Office of Naval Research through the DOD Joint Technology Office was also initiated recently with the goal of modifying the shape of the PBG resonator in order to push the gradient limitations of the PBG technology [9].

REFERENCES

[1] D. Schulte, Proceedings of the 2003 Particle Accelerator Conference, p. 2727 (2003).

[2] E. Yablonovitch. Phys. Rev. Lett., 258, p.2059, (1987).

[3] E.I. Smirnova, A.S. Kesar, I. Mastovsky, M.A. Shapiro, and R.J. Temkin, Phys. Rev. Lett. 95(7), p. 074801 (2005).

[4] Evgenya I. Simakov, Chase H. Boulware, Terry L. Grimm, Proceedings of the PAC 2011, p. MOP042, (2011).

[5] D.R. Smith, D. Li, D.C. Vier, N. Kroll, and S. Schultz. AIP Conference Proceedings, 398, p. 518, (1997).

[6] M. R. Masullo, M. Panniello, V. G. Vaccaro, A. Andreone, E. Di Gennaro, F. Francomacaro, G. Lamura,V. Palmieri, D. Tonini, Proceedings of EPAC 2006, p. MOPCH167, (2006).

[7] CST Microwave Studio, Computer Simulation Technology, www.cst.com.

[8] Ansys HFSS, Ansys Inc., www.ansys.com.

[9] Evgenya I. Simakov, W. Brian Haynes, Sergey S. Kurennoy, James F. O'Hara, Eric F. Olivas, Dmitry Yu. Shchegolkov, p. WEPPP035, these proceedings.