HIGH-POWER WAVEGUIDE DAMPERS FOR THE SHORT-PULSE X-RAY PROJECT AT THE ADVANCED PHOTON SOURCE*

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Abstract

High-power waveguide dampers have been designed and are being prototyped for the Short-Pulse X-ray (SPX) cavities at the Advanced Photon Source (APS). The cavities will operate at 2.815 GHz and utilize the TM_{110} dipole mode to deflect the electron beam. Higher-order mode (HOM) and lower-order mode (LOM) dampers have been designed to satisfy the demanding broadband damping requirements in the APS storage ring. The SPX single-cell cavity consists of two waveguides for damping the HOMs, a waveguide input coupler that serves a dual purpose for HOM damping, and a waveguide for primarily damping the LOM where, collectively, approximately 2.3 kW is dissipated in the damping material. The damper designs and the extent of high-power experimental results will be discussed in this paper.

INTRODUCTION

The superconducting cavities for the SPX project [1] require high damping levels in order to maintain beam stability in the APS ring. As a result, a single-cell cavity using multiple waveguide dampers with strong parasitic mode coupling has been designed [2].

LOM damping is required for the SPX cavities since the lowest-order fundamental monopole mode is not the operating mode of the deflecting cavity. The LOM contributes considerably to the damper loading where the cumulative load in all the damper elements is estimated to be 2.3 kW for a 200-mA beam current with a 33-ps beam sigma. More than 65% of that power, or approximately 1.5 kW, is transmitted to the LOM dampers, primarily at the monopole mode frequency of 2.3 GHz, as shown in Fig. 1(a).

The HOM dampers are broadband in order to handle the HOM power across the frequency spectrum produced by the APS beam. They have been designed to absorb power just above the operating frequency to 8 GHz where the power density spectrum in the HOM dampers is shown in Fig. 1(b). In order to maintain its broadband performance, the dampers share the same vacuum environment with the SPX cavity. The HOM damper waveguide and lossy material are located entirely within the cryomodule at 300 K where they will be water-cooled with a power loading of approximately 300 W per damper.

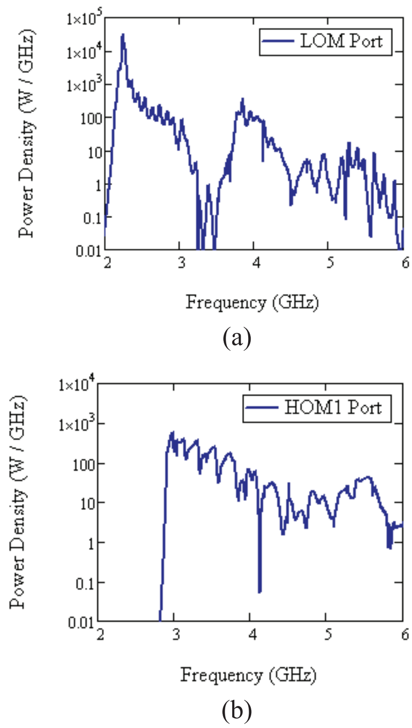

Figure 1: Power densities vs. frequency in (a) LOM port and (b) HOM port of the SPX cavity with 200-mA beam current.

The LOM damper described in this paper resides entirely within the cavity vacuum, similar to the HOM loads discussed previously. However, due to the near mono-chromaticity of the LOM damper, an external, out-of-vacuum damper utilizing an rf window is in development which simplifies packaging issues and mitigates risk associated with the high-power, narrowband loading from the SPX cavity. The effects of the rf window are carefully being considered due to additional, harmful resonances that interact with the cavity if the window bandwidth is not sufficient.

DAMPER DESIGN

The SPX cavities utilize waveguide dampers based on their relative simplicity and their proven performance at PEP-II and KEK [3, 4]. At PEP-II, a two-wedge waveguide damper was used for power levels up to 10 kW at a frequency range between 700 – 2500 MHz. The power loading was distributed across the material volume

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in order to reduce local material stresses. Due to the reduced size of the SPX dampers, the high-frequency operation, and the near mono-chromaticity of the LOM damping, the local power density is higher for a similar geometry. As a result, a four-wedge design was adopted for the LOM dampers and was standardized for use with the HOM dampers, with two wedges on each of the upper and lower broadwalls. Additionally, the LOM damper utilized a taper of the Silicon Carbide (SiC) tiles in two planes, as compared with a single taper plane for the HOM damper, to reduce the peak volumetric power loading and minimize the temperature gradient.

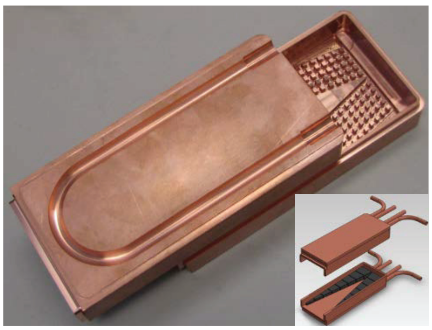
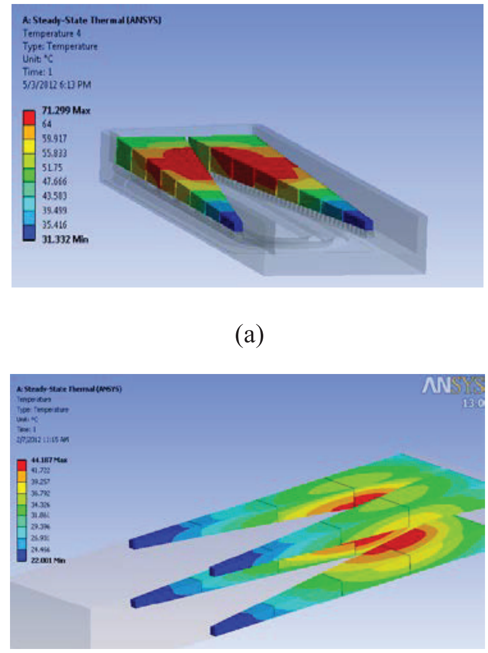


Figure 2: Prototype HOM damper with copper pinbed substrate. Inset shows LOM damper with SiC tiles.

Hot isotropically pressed SiC ceramic from Saint Gobain was selected as the lossy rf material for the SPX due to its availability, success as an rf damping material, high density, material property repeatability, and good thermal conductivity. The high density of SiC was important for limiting the particulate shedding of the material near the vacuum environment of the superconducting cavity. However, the difference in the coefficient of thermal expansion (CTE) between SiC and its copper substrate is substantial and would result in excessive cracking and failure of the ceramic during high-temperature brazing. Therefore, the SiC material was cut into tiles prior to fabrication in order to reduce the cumulative effects during heating due to the difference in the material CTE. Additionally, a pinbed structure, as shown in Fig. 2, was manufactured into the copper substrate to allow for plastic deformation of the pins to reduce the stresses in the ceramic.

An analysis was undertaken to determine a reliable method for bonding the SiC and to explore its dependence on surface preparation, brazing/soldering alloys, intermediate buffer layers, and copper substrate geometry. Surface preparation techniques were developed; these consist of grinding the surface of the as-received SiC to remove the relatively loose ‘soot-layer’ produced during manufacture of the SiC material, in addition to applying an acetone ultrasonic bath to remove any organic contaminants. The edges of the SiC tiles were chamfered to eliminate high-stress regions associated with edges and corners in order to prevent cracking and chipping of the SiC. This helped to minimize failure points as well as sources of particulate generation.



(a)

(b)

Figure 3: Temperature profile from Ansys in LOM damper for (a) brazed damper geometry with pinbed substrate and (b) soldered damper geometry with flatbed substrate.

Soldering consists of the metallization of the SiC surface followed by a high-temperature, proprietary Sbond solder [5]. The solder has an approximate melting temperature of 220°C and was tested and approved for ultra-high vacuum compatibility with the APS ring. Brazing occurs at approximately 800°C with either Cusil ABA or Incusil ABA where titanium was used to diffuse into the SiC to create a durable bonding. A layer of molybdenum was also evaluated during brazing as an intermediate buffer layer to bridge the CTEs of both copper and SiC. Its intent was to reduce the failure rate of the brazing and limit material damage. Interestingly, all of the tested samples with molybdenum failed during the brazing operation, which may be explained if the molybdenum acted as an inhibitor to the diffusion of the titanium.

For the brazing and soldering operations, the 200-mm-long LOM and the 150-mm-long HOM were divided into 25-mm- and 50-mm-long tiles, respectively. Figure 3 shows the thermal distribution, due to rf loading from the beam, of the WR284 LOM damper assembly for the brazed and soldered geometries. As shown, the peak temperature for the brazed geometry is significantly larger than the soldered geometry due to the larger thermal impedance between the SiC and the copper as a consequence of the pinbed substrate.

Brazing and soldering were compared to determine the preferred choice for the SPX damper assemblies. Experimental criteria included the soldering/brazing failure rate, total bonded area, and strength-of-bond pull

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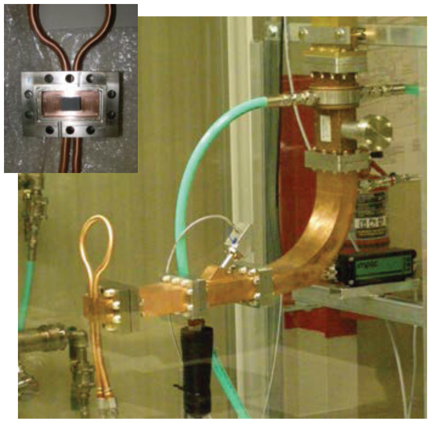

Figure 4: Test setup for evaluating particulate generation of SiC brazed / soldered to a water-cooled copper flange. The inset shows the inside surface of the flange with a SiC tile.

tests. Based on these tests, as well as the approved vacuum compatibility of the solder, the minimized peak temperature of the four-wedge damper design, and the anticipated tolerance to shock, the Sbond solder was chosen for the prototype assemblies.

QUALIFICATION TESTING AND INTEGRATION

The damper material, together with brazing / soldering alloys, have undergone preliminary qualification testing at the APS to determine their suitability as reliable and cleanable high-power components near the SPX superconducting environment. Testing included vacuum-compatibility, high-power conditioning, particulate generation, and lifetime tests in order to pre-evaluate the damper materials prior to manufacturing of the prototypes.

Figure 4 shows the test setup for analyzing the temperature dependence of the particulate generation of a bonded SiC tile. During the particulate tests, the SiC was heated from rf losses, and any particulates were forced into a particulate counter using positive N_2 pressure in the waveguide. Additionally, lifetime qualification tests were performed, with approximately 15 k cycles, using pulsed rf to produce a thermal gradient across the SiC sample comparable to that expected during normal beam operations in the APS ring. The tests were successfully completed on single SiC tiles, as shown in the inset in Fig. 4, which were either soldered to a flatbed substrate or brazed to a pinbed. No significant differences among the various test samples were observed. However, these tests will be repeated for the actual high-power damper prototypes to give a more definitive analysis of the reliability, particulate generation, and structural integrity of the damper design.

Figure 5 shows the layout of a single SPX cavity in the cryomodule with the damping waveguide. The design of the LOM damper in the figure utilizes an rf window and assumes an external damper load. The HOM dampers, on the other hand, are located on the outer periphery of the cryomodule at 300K where they will be water cooled.

CONCLUSION

Monochromatic LOM dampers and broadband HOM dampers have been designed for high-power application for the SPX project. High-temperature, Sbond soldering and brazing trial runs with Cusil ABA and Incusil ABA were evaluated. Soldering was chosen for the bonding of the SiC to the copper substrate due to its superior strength, thermal properties, and manufacturability. High-power testing of the SiC material and soldering/brazing alloys was performed to qualify the material for use in the APS storage ring.

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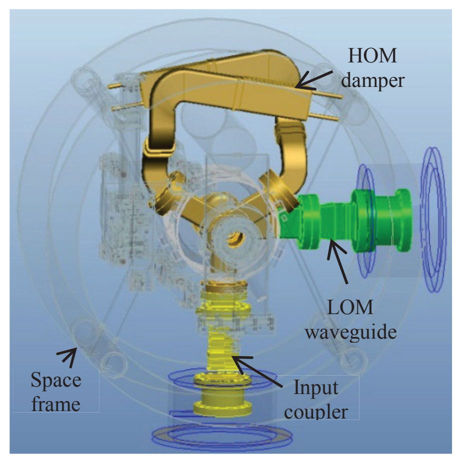

Figure 5: Layout of the SPX cavity and waveguides in the cryomodule.

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