DUCT-SHAPED SIC DUMMY LOAD OF LBAND POWER DISTRIBUTION SYSTEM FOR XFEL/SPRING-8*

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Abstract

TOSHIBA is manufacturing the L-band acceleration system for the SPring-8 Joint Project for XFEL. We have developed a new type duct-shaped SiC dummy load for its power distribution system. The load terminates a WR650 waveguide and can absorb the maximum mean power of 10kW. In order to reduce VSWR less than 1.1 in the frequency range of 1.428GHz, we shaped the SiC absorber into a 35cm long tapered cylinder and mounted matching stubs in the waveguide near the inlet of the load. The SiC absorber was fit into a cylindrical copper with efficient water-cooling channels. The design and manufacture and the low-power tests of our original dummy load are described in this paper.

INTRODUCTION

We have designed and manufactured the 1428MHz dummy load of L-band acceleration system for the SPring-8 Joint Project for XFEL(X-ray Free Electron Laser), which is under construction in Hyogo prefecture [1]. Because its power distribution system is designed to work under vacuum condition, it is essential that the cooling channel of the dummy load is out of vacuum boundary. SiC ceramic is selected as an absorber of microwave for its high loss-tangent, high thermal conductivity and low out gassing rate.

The SiC duct was used as absorber of higher-order-mode (HOM) escaped from an rf cavity by Dr. M.Izawa in KEK/PF [2]. Beam tests of the SiC duct demonstrated that the dissipated power in the SiC was measured 220 W and an operating vacuum pressure was less than 2 x 10^{-10} Torr. Based on this performance, we developed rod-shaped HOM damper and radiation mask with SiC duct [3],[4]. The thermal test of the HOM damper shows that the heat load of this SiC absorber up to 2 kW is confirmed.

We applied the duct-shaped SiC to a basic design of the L-band dummy load because of these satisfactory results.

DESIGN OF THE DUMMY LOAD

Design Concept and Specifications

Figure 1 shows a cross sectional view of SiC dummy load. A rectangular waveguide transmits TE10 wave of 1428MHz to the cylindrical shaped dummy load. TE10 mode is transformed into TE11 mode and dissipated in the SiC absorber.

The waveguide is WR650 which has an inner height of 82.55 mm and an inner width of 165.1 mm and made of 10mm thick OFHC copper. It has two stubs on the E-plane in order to match WR650 waveguide with cylindrical dummy load.

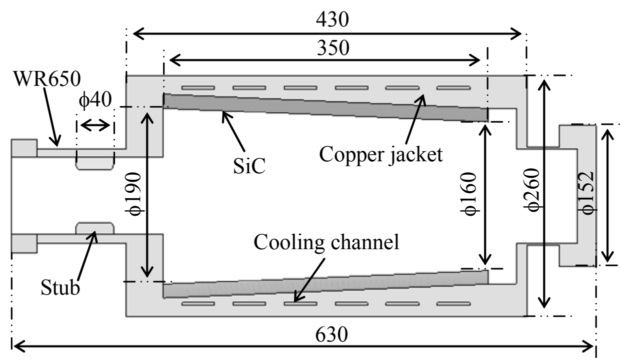

Figure 1: Cross sectional view of the dummy load.

The SiC absorber is a tapered cylindrical shape whose inner diameter is 190 mm at the beginning and 160 mm at the end of the dummy load. The length of SiC duct is designed as 350 mm which is 1.25 times longer than a wave-propagation wavelength of 272 mm. The SiC absorber is fit into a cylindrical OFHC copper jacket which has the cooling channel inside. Since the contact area between the SiC and the copper jacket is large, good heat-transfer efficiency is obtained.

The specification of the SiC dummy load is summarized in Table 1. In order to satisfy input VSWR less than 1.1, we optimized SiC shape and matching stubs.

Table 1: Specifications of the SiC dummy load

Working frequency	1428 MHz
Input VSWR	< 1.1
Averaged input power	4.2 kW (~10 kW maximum target)
Bandwidth	60 MHz (designed) 6 MHz (measured)
Length of load	430 mm (630 mm including ports)
Cooling water temperature	28 °C
Cooling water flow	20 L/min
Vacuum pressure	≤ 10^{-6} Pa

SiC Ceramic Characteristics

When SiC is used as a microwave absorber, it is important to figure out the dielectric constant of the SiC before designing SiC dummy load.

In collaboration with KEK, we measured a complex dielectric constant of SiC samples for the dummy load using the dielectric probe kit (HP85070B) and a network analyzer. We used an SiC product named CERASIC from Covalent Materials Corporation. The SiC samples used for dielectric measurement have a diameter of 30 mm and

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a height of 20 mm. The material lot number of the samples is the same as that of SiC duct used for the dummy load.

Figure 2 shows the measured dielectric constant of the SiC samples. Three samples have almost the same characteristics and their averaged value is plotted. The real part (εr': solid line) and imaginary part (εr": dotted line) of dielectric constant are shown for various temperatures from about 30 ^{o}C to 80 ^{o}C. At the frequency of 1428 MHz, εr' is about 14 and εr" is about 7 when its temperature is 30 ^{o}C.

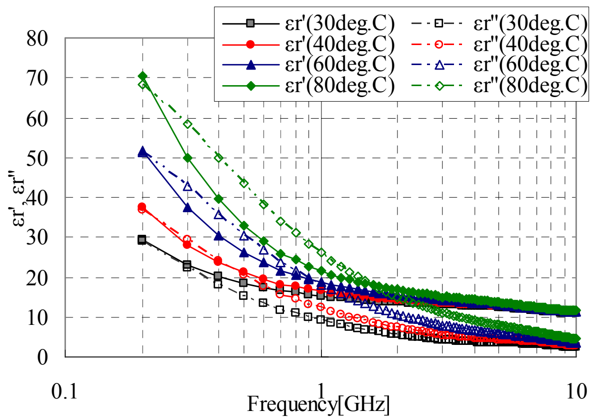

Figure 2: Measured dielectric constant of SiC sample.

Optimization by Simulation

The basic design and optimization was made using simulation codes HFSS and ePhysics[5].

In order to study the SiC thickness dependency of VSWR, we calculated VSWR for thicknesses from 12 mm to 17 mm using the property of SiC measured above. As shown in Figure 2, the dielectric constant of SiC varies gradually according to its temperature. Supposed that the temperature of SiC will be changed by the input power, temperature dependency is also calculated.

Figure 3 shows the calculated VSWR for the SiC duct at the frequency of 1428 MHz. As described hereinafter, the temperature of SiC absorber is calculated to be 40 ~ 50 ^{o}C by thermal analysis. When the SiC temperature is 40 ^{o}C, VSWR of 16 mm thickness has the minimum value. On the other hand, when the SiC temperature is 50 ^{o}C or more, VSWR of 15 mm thickness has the minimum value or less than that of 16 mm. At this stage, we selected 15 mm as the SiC thickness.

Secondary, we performed VSWR calculation to optimize the matching stubs. A height from the waveguide surface and a position from the SiC's edge of the stabs were the parameters. The diameter of stubs is 40 mm.

Figure 4 shows VSWR calculations when the SiC temperature is 40 ^{o}C and the height of the stubs is 14.5 mm. The closed squares show the optimum position of the stubs at the frequency of 1428 MHz and the bandwidth which satisfies VSWR less than 1.1 is about 60 MHz. The closed circles and triangles show the calculated VSWR in positions of -1 mm and +1 mm from the optimum position, respectively. In this way, the best position and the height of the matching stubs were estimated.

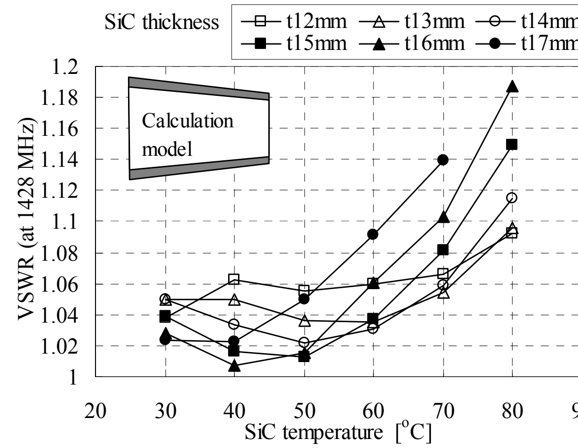

Figure 3: VSWR calculation for optimizing SiC thickness.

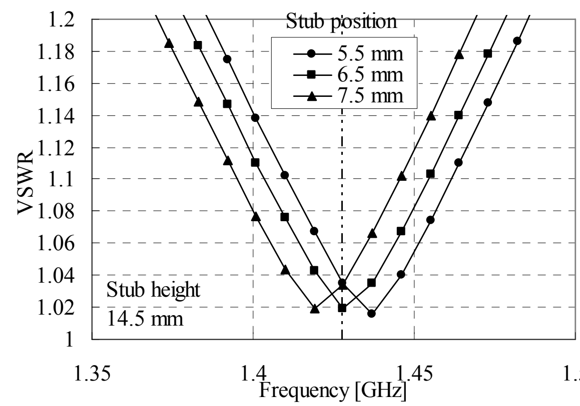

Figure 4: VSWR calculation for optimizing matching stubs.

Thermal Analysis

The power loss in the SiC and the surface loss on the waveguide obtained by HFSS code are available to ePhysics, thermal stress analysis code. The temperature rise caused by the input wave of 1428 MHz with a power of 4.2 kW was calculated using this ePhysics code.

Figure 5 shows the results of thermal analysis. In Figure 5, the temperature distribution of the SiC absorber is shown. The maximum and average temperature were about 45 ^{o}C and 35 ^{o}C, respectively. Since the temperature rise is proportional to the heat loss in the SiC, the maximum temperature of the SiC is estimated to be about 60 ^{o}C with a power of 10 kW. In Figure 3, the VSWR difference between 40 ^{o}C and 60 ^{o}C of 15 mm-thick SiC is about 0.02, we expect that it possibly works with 10 kW heat load.

Furthermore, the stress analysis shows the maximum von mises stress is less than 70 MPa which is less than the averaged tensile strength of SiC .

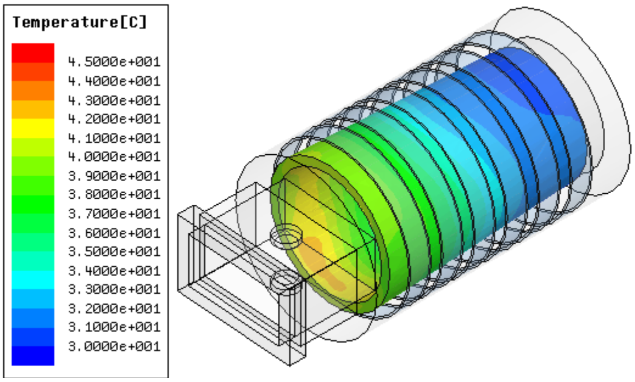

Figure 5: Temperature distribution of SiC by static thermal calculation (4.2 kW).

LOW POWER TEST FOR THE SIC DUMMY LOAD

Based on the study above, we manufactured an SiC dummy load. Before assembling, we performed a low power test for the matching stubs using a network analyzer. In order to simulate the temperature rise by the power loss in the SiC, the cooling water temperature was changed. The temperature of the SiC and the copper jacket were almost the same as the cooling water temperature.

Figure 6 shows the results of the parameter test. The temperature which has the minimum VSWR slightly differs according to the stub height. The stub height of 25.18 mm, which has the minimum VSWR near the operating temperature, was selected for the dummy load.

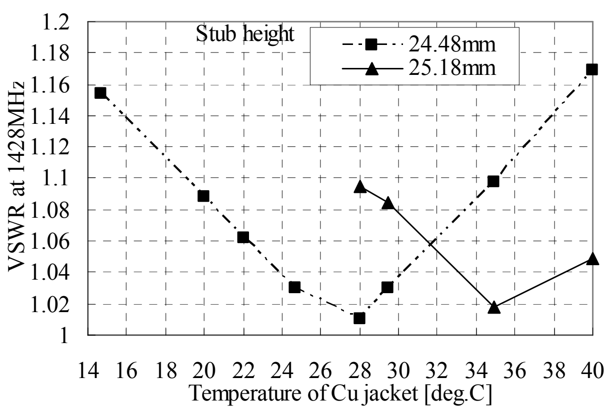

Figure 6: Measured VSWR vs. temperature at 1428MHz

Although we could obtain the VSWR specifications by matching the stubs, the optimum conditions of the stubs were different from the calculation results. And the bandwidth was 6 MHz which was one tenth of the designed value. One of the reasons is the dielectric constant of the SiC [6]. If the dielectric constant of the dummy load would be different from the SiC samples, the microwave absorbing performance could be decreased, because the shape of SiC was optimized using the dielectric constant of the samples. The dielectric constant of cylindrical SiC used for this dummy load will be estimated by calculation, however, the reproducibility of the SiC has to be investigated for the next SiC dummy load. [7]

Figure 7 shows the duct-shaped SiC L-band dummy load we manufactured. It has the vacuum port to achieve high vacuum pressure at operation. The vacuum test result shows the vacuum pressure is less than 10^{-6} Pa.

Figure 7: Duct-shaped SiC dummy load

CONCLUSIONS

In conclusion, we have designed and manufactured the duct-shaped SiC L-band dummy load for XFEL/SPRING-8 project. The calculations and the low power tests indicate that its VSWR at a frequency of 1428 MHz is less than 1.1 under a heat load in the SiC absorber of 4.2kW. A high power test of the SiC dummy load will be performed to confirm its high power performance.

ACKNOWLEDGMENTS

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