EXPERIENCE ON THE HIGH-POWER SiC MICROWAVE DUMMY-LOAD USING SiC ABSORBER

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Abstract

A new type microwave dummy-load using Silicon Carbide (SiC) ceramic, which has an indirect water cooling structure, was successfully operated with up to 50-MW of rf power at a 1-µs pulse width and 50-pps repetition rate in the S-band frequency. The input VSWR obtained was less than 1:1.1 at the maximum rf power. The vacuum pressure in the rf-load raised from the base pressure of 1 x 10^-6 Pa with no rf power to 2 x 10^-6 Pa at the maximum rf-power; and there was found to be no special out gassing from the SiC-ceramics.

1 INTRODUCTION

Our first microwave dummy-load using SiC-ceramic was originally developed for an S-band 2.5-GeV electron linac at KEK in 1980, and has been used for 17 years without trouble. The old model SiC-dummy-load used a direct water cooling method, because there was no brazing method available due to the big difference in thermal expansion coefficients of SiC and Oxygen-Free-Copper.

The upgraded version of the S-band dummy-load using brazed rod-shaped SiC pieces for the high peak power microwave absorber was developed in 1993 during the course of R&D for the e⁺e⁻ Japan Linear Collider (JLC). It will be used for the more than 10,000 dummy-loads in the rf system for 500 GeV C.M. version accelerator [1]. Because of the large numbers, increased reliability and cost reduction become very important design considerations. Therefore, I decided to use an indirect water cooling method instead of the previous direct cooling. In 1995 at KEK, the resulting design was tested up to a maximum input rf power of 50 MW, 1 µsec pulse width and 50 pps repetition rate.

The new type SiC-dummy-loads have already been in use on the KEKB 8 GeV electron linac (250 pieces) since 1998 [2, 3]; a photograph is shown in Figure 1.

2 BASIC CHARACTERISTICS OF THE SiC CERAMIC

SiC powders can crystallize into either α- or β-forms. I choose the β-crystallization SiC powder to reduce the variation in microwave loss-tangent after the sintering process. The β-crystallized SiC, which has a good uniformity of powder size is produced by a chemical reaction between silicon-dioxide (SiO₂) and carbon-black (3C) powder at a temperature range of 1500 to 1800 °C in an inert gas atmosphere. The reaction can be expressed as

\[ \text{SiO}_2 + 3\text{C} = \text{SiC} + 2\text{CO}. \]

SiC-ceramic is then made from the SiC powder by sintered in a vacuum furnace at a 2100 °C temperature [4]. The basic characteristics of the SiC-ceramic are listed in table 2.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>3.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (Knoop, kgf/mm²)</td>
<td>2900 at RT⁴</td>
</tr>
<tr>
<td>Thermal conductivity (cal/cm·sec·°C)</td>
<td>0.19 at RT⁴ to 0.14 at 600 °C</td>
</tr>
<tr>
<td>Thermal expansion coefficient (°C⁻¹)</td>
<td>4.6 x 10⁻⁶ RT⁻¹ to 1200 °C</td>
</tr>
<tr>
<td>Oxidation weight gain (mg/cm²)</td>
<td>0.015 at 1200 °C for 24 hours</td>
</tr>
<tr>
<td>DC Resistivity (Ω·cm)</td>
<td>5 x 10⁸ at RT⁴ to 7 x 10⁻¹ at 800 °C</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>30–35 at 0.5 to 20 GHz⁶</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>0.3–0.5 at 0.5 to 20 GHz⁶</td>
</tr>
</tbody>
</table>

Note: 1) RT: Room Temperature, 2) The measured frequency range is limited by the network analyzer.
Figures 2 and 3 show the variations in dielectric constant and loss tangent of some SiC-ceramic samples, for the KEKB dummy-load. This result shows that the variation of both parameters (dielectric constant and loss) are dependent on amount of sintering binders, since the binder is evaporated from the SiC-ceramic during the second sintering process.

The design arrives at a compromise to obtain an input VSWR of less than 1:1.1 while keeping the temperature rise at the top of each SiC-ceramic rod below 30 °C; both at the maximum operation condition (2.5-kW average power). The input VSWR was minimized by adjusting the spacing between the SiC-ceramic rods using a simple quarter-wave impedance matching method as shown in Figure 5. It was still necessary to experimentally tune the SiC positions to minimize the input VSWR of below 1:1.1. Figure 6 shows typical characteristics of the reflection coefficient (S11) as a function of the distance between SiC-ceramic rods.

An important design consideration is that the structure be as simple as possible; this includes the shape of SiC-ceramic absorber, housing and cooling structures. I decided to use a conventional S-band rectangular waveguide for the housing, with a 7.21-cm x 3.4-cm cross section and a 5-mm wall thickness. Simple rod shaped SiC-ceramics each 2-cm in diameter were chosen for the microwave absorbers; they are brazed to the inner wall on the narrow side of the wave-guide as shown in Figure 4 [5].

We calculated the temperature rise between bottom and top of the SiC-ceramic absorbers using steady state thermal conducting theory based on an attenuation curve along the axis of the dummy-load and the measured rf power loss per cubic centimeter of ceramic absorber.

Figure 7 shows the first high-power model S-band dummy-load. A total of 28 SiC-ceramic rods are brazed to the narrow walls of the rectangular wave-guide housing. Two water channels attach to both narrow walls and the typical flow rate for the cooling water is 20 liters per minute. In this case, the maximum temperature raise at each top of the SiC-ceramic rod is below 30 °C at 2.5-kW average rf power. In actual operation, the inlet water temperature is around 30 °C, so that the absorber rod temperature will be increased to close to 60 °C. Good frequency response was obtained in low power measurements as shown in Figure 8.
Further there was no breakdown signal from the scintillator. At this time, the vacuum pressure of 2 x 10^6 Pa was achieved during rf power turn on.

The temperature sensitivity of the SiC-ceramic absorber was studied by measuring the input VSWR as a function of cooling water flow rate as shown in Figure 11. It is clear that the SiC-ceramic absorber is not sensitive to its temperature of operation.

5 CONCLUSIONS

We have confirmed the design and operation of a new type high power dummy-load using SiC-ceramic absorber. The load is improved in using an indirect cooling method to increase reliability. The first model was successfully operated at 50-MW of rf power (1-µsec and 50-pps for a 25-kW average power). Thus, we may conclude that this SiC-ceramic dummy-load can provide the same reliability as the conventional metal type load.

6 REFERENCE