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RF CHARACTERISTICS OF THE BULLET-SHAPE SiC ABSORBER FOR KEKB

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Abstract

Sixteen bullet-shape sintered SiC (silicon carbide) ceramics were used as the HOM absorbers for a prototype of KEK B-factory (KEKB) normal conducting cavity[1]. RF simulations show that the reflection rate from the SiC absorber increases abruptly when the frequency decreases under 1GHz. This behavior can be explained as the attenuation property of a cylindrical dielectric waveguide. The RF characteristics of the SiC absorber are discussed by analyzing properties of the cylindrical dielectric waveguide.

1. Introduction

A prototype of normal conducting cavity for KEKB was designed and built [2]. This prototype cavity is loaded with a coaxial waveguide for damping higher order modes (HOM's). The waveguide is equipped with a notch filter. Figure 1 shows a schematic drawing of this cavity with the SiC absorber. For HOM absorption, sixteen bullet-shape sintered SiC ceramics are inserted from the end of the coaxial waveguide. The absorber dimensions are 40 mm in diameter, and 400 mm in total effective length including a 100-mm nosecone section. Each SiC absorber has a cooling water channel bored inside and is directly cooled. The HOM power (at frequencies above 0.7 GHz) to be handled will be on the order of ~10 kW per cavity, corresponding to ~1 kW per absorber. The permittivity of the SiC material is 22.2-6.10j at 0.75GHz and 20.7-4.58j at 1.5GHz. The design of the SiC absorber is based on the S-band waveguide load for the 2.5-GeV electron linac in KEK[3].

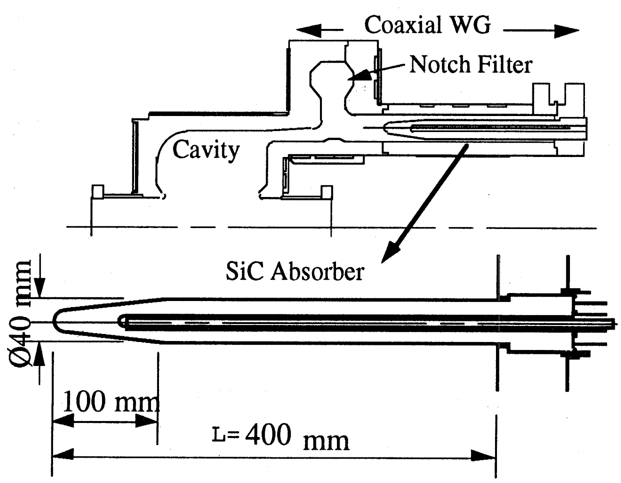


Figure 1: A schematic drawing of the test cavity with the SiC absorber.

Closed circles (a=20mm) in figure 2 show the frequency response of the reflection (S_{11}) from the HOM absorbers in the test cavity, which is simulated with hfss[4]. The TEM mode in the coaxial waveguide is assumed in this simulation. When the frequency decreases under 1GHz, the reflection increases rapidly. This poor absorption properties under 1GHz should be improved because some HOM's exist at 0.7~0.8GHz.

2. Frequency response of the HOM absorber

Several solutions, which improve the frequency response at 0.7~1.0GHz, were obtained through numerical simulations with hfss. It was found that effective parameters are the radius of the absorber (=a) and the real part of the permittivity (=ε'). Figures 2 and 3 show the effects of these parameters. Larger values of a and ε' improve the absorption at lower frequencies. But the length of the absorber is not so effective as a and ε'. Figure 4 shows the effect of the nosecone section at the tip of SiC. A SiC absorber without the nosecone section has a similar frequency response at 0.7~1.0GHz. The taper improves the absorbing properties above 1GHz.

The frequency responses shown Figures 2 and 3 resemble the cutoff response of a metal waveguide filled with a dielectric material. This suggests that the RF propagation properties in the SiC absorber, which is considered a kind of waveguide, are essential in its

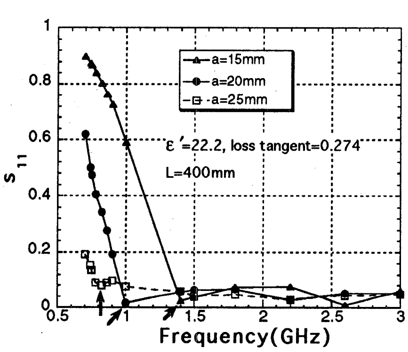


Figure 2: S_{11} frequency response curves for the HOM absorbers with a=15, 20, and 25 mm. Closed circle for the SiC absorber (a=20) employed in the test cavity.

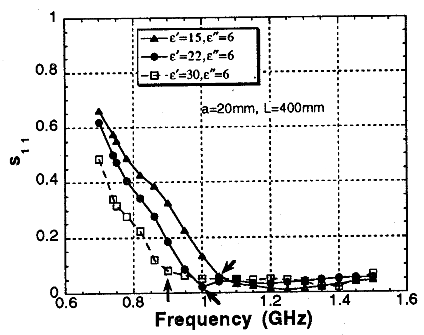


Figure 3: S_{11} frequency response of the SiC absorbers with different permittivities.

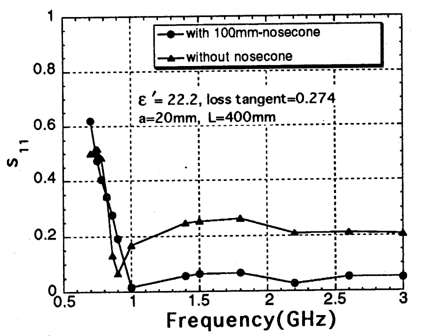
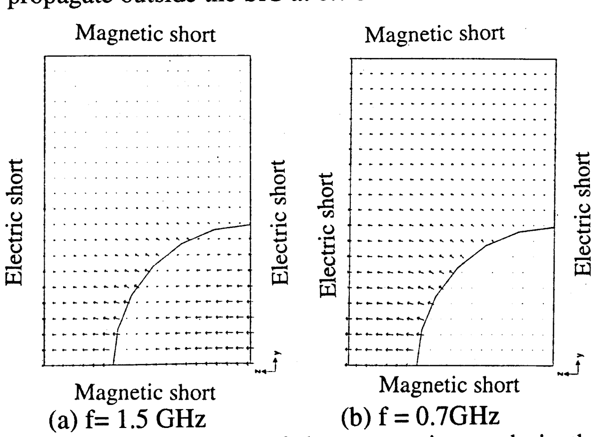


Figure 4: The effect of the nosecone on the S_{11} frequency response.

frequency response.

3. Propagating mode in the SiC absorber

In order to identify the propagating mode clearly, a simplified 2-dimensional lossless model without a cooling water channel was simulated in a parallel plate transmission line. Figures 5-(a) and 5-(b) show the electric field of the propagating mode obtained by the hfss simulation. The electromagnetic wave (HE_{11}-like mode) is mainly propagating inside the SiC at 1.5GHz. On the other hand, the electromagnetic wave tends to propagate outside the SiC at 0.7GHz.



(a) f= 1.5 GHz (b) f = 0.7GHz

Figure 5: Electric field of the propagating mode in the 2-dimensional lossless model. (a=20mm, ε'=22)

4. Analysis using waveguide theory

Here we will analyze the attenuation properties of the cylindrical dielectric waveguide which is regarded as a simplified model of the bullet-shape SiC absorber. Attenuation in a dielectric circular rod was studied by Elsasser and Chandler in detail[5][6]. The analytical solutions of the propagating modes are described in many textbooks. We shall follow the notation in the textbook by Kawakami [7]. We will choose a cylindrical coordinate system r, θ, z with the z axis lying along the guide axis. The radius of the rod will be a; dielectric constants inside and outside the rod will be ε_1 and ε_2 (which are assumed real numbers). The longitudinal components of the field vector are, inside the rod,

$$E_z = A_n J_n(\beta_t r) \cos(n\theta+\delta_n)\, e^{j\omega t}$$
$$Hz = B_n J_n(\beta_t r) \sin(n\theta+\delta_n)\, e^{j\omega t}$$
$$\text{with } \beta_t = (\omega^2 \varepsilon_1 \mu_0 - \beta^2)^{1/2}$$

and outside the rod,

$$E_z = C_n K_n(\alpha_t r) \cos(n\theta+\delta_n)\, e^{j\omega t}$$
$$H_z = D_n K_n(\alpha_t r) \sin(n\theta+\delta_n)\, e^{j\omega t}$$
$$\text{with } \alpha_t = (\beta^2 - \omega^2 \varepsilon_2 \mu_0)^{1/2}$$

where J_n is a Bessel function; K_n is a modified Bessel function. K_n decreases exponentially for large values of r.

The continuity of the tangential components of the field at the boundary $r=a$ gives the following relation.

$$(\eta_1+\eta_2)(\varepsilon_1\eta_1+\varepsilon_2\eta_2)=n^2((1/u^2)+(1/w^2))((\varepsilon_1/u^2)+(\varepsilon_2/w^2)) \qquad (4\text{-}1)$$

with $u = \beta_t a$, $w = \alpha_t a$, $\eta_1 = J_n'(u)/(uJ_n(u))$, $\eta_2 = K_n'(w)/(wK_n(w))$

In addition u and w are related by the equation

$$u^2 + w^2 = \omega^2(\varepsilon_1-\varepsilon_2)\mu_0 a^2 \equiv v^2 \qquad (4\text{-}2)$$

From the equation *(4-1)* the values of u and w of the HE_{11} mode ($n = 1$) are obtained by numerical calculations. These are shown in figure 6. On the other hand, the equation *(4-2)* expresses a circle on the u-w coordinate. The radius of the circle is $\omega a((\varepsilon_1-\varepsilon_2)\mu_0)^{1/2} \equiv v$. Numerical solutions are obtained by the intersections of the circle (expressed by *(4-2)*) with the curves in Fig. 6. No matter how small v becomes, even at $v=0$, there is always an intersection. This means that this mode has no cutoff frequency.

In order to evaluate the field outside the rod, we will pay attention to the value of w $(=\alpha_t a)$. When w is large enough, $K_1(wr/a)$ decreases rapidly as r increases, then the outside field of the propagating mode is confined near the rod surface. Figure 6 shows that w increases abruptly above the some value of u, especially when ε_1 is large. Above this value of u the solution of w becomes large with extreme rapidity with small increase of the

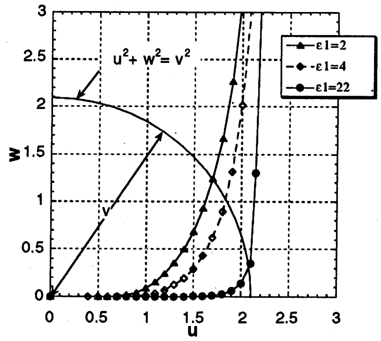


Figure 6: The values of u and w of the HE_{11} mode ($n=1$) are obtained by numerical calculations. A quarter of the circle is given by equation (4-2).

circle radius ($=v$) of *(4-2)*. Let us define this critical value of v as v_t. When v is smaller than v_t the field is spread out and only small amount of the field exists inside the rod. On the other hand, when v is larger than v_t the field concentrates inside the rod and near the rod surface. If the dielectric waveguide is lossy, the attenuation change abruptly at $v=v_t$. Since v is a function of ω, a and ε_1 indicated in *(4-2)*, the attenuation properties strongly depend on these three parameters. It should be noted here again that the absorption properties of the SiC depend on the parameters. Figure 7 shows $w/a(=\alpha_t)$ as a function of frequency for three radii of the rod. The values of $w/a(=\alpha_t)$ are plotted in figure 8 as a function of frequency for three dielectric constants of the rod.

The critical frequencies indicated by arrows in figures 7 and 8, which correspond to v_t, show good agreement with the those of the SiC absorber shown in figures 2 and 3.

5. Conclusion

The frequency response of the bullet-shape SiC absorber can be explained as the attenuation properties of the cylindrical dielectric waveguide in which the HE_{11} mode propagates. The electric field pattern of the

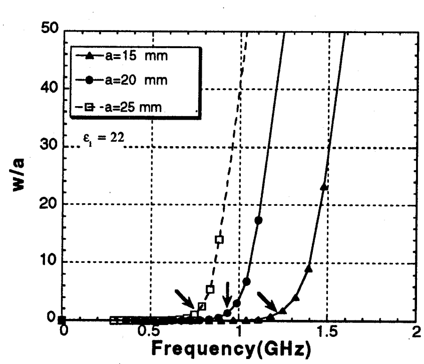


Figure 7: Values of $w/a(=\alpha_t)$ as a function of frequency for three radii.

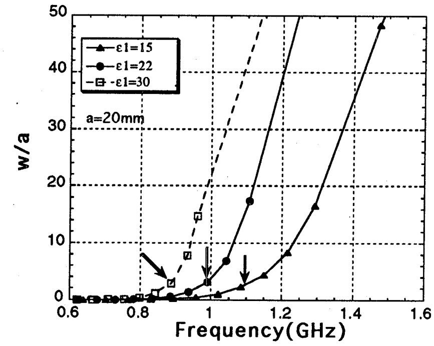


Figure 8: Values of $w/a(=\alpha_t)$ as a function of frequency for three permittivities.

propagating mode dominates the frequency response of the SiC absorber mainly. This dielectric waveguide model gave us much information to design the bullet-shape and similar type absorber. The result of this analysis suggests that a thicker SiC absorber than the present design would be better. Furthermore, a shorter absorber design would be possible because the length of the absorber is not so effective to the frequency response. The design of a new SiC absorber is being under way.

6. Acknowledgment

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7. References

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