# Single-Mode Cavity with HOMs Absorber

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## Abstract

We present a new 500 MHz cavity which has a simple damped structure for the 1.5 GeV high-brilliant VUV ring. The feature of the cavity design is that higher-order modes(HOMs) propagate out from the cavity through the beam duct with a large diameter and are absorbed in resistive parts in the duct. A low power measurement on a prototype model of the cavity was carried out and the Q-values of HOMs were confirmed to strongly reduce. Thus the coupled-bunch instabilities due to HOMs are expected to be sufficiently suppressed.

## Introduction

A 1.5 GeV electron storage ring for high-brilliant synchrotron radiation in the wavelength region of soft x-ray and vacuum ultraviolet is being designed at ISSP of the University of Tokyo in collaboration with the Photon Factory at KEK. The storage ring is aimed at obtaining a low emittance of several nm·rad and a maximum beam current of 400 mA. The detailed description of the storage ring is given in ref. [1].

Because of its relatively low beam energy and proposed high beam current, very low impedances of higher-order modes are required for the accelerating cavity to suppress the coupled-bunch instabilities. Furthermore, a simple cavity structure is preferable for reliable operation. We have designed an RF cavity and carried out its low-power test with the prototype model. The specific features of the present cavity are that a beam duct with large diameter is attached to the cavity and that a part of the beam duct is made of the resistive material. Since the frequency of accelerating mode is sufficiently below the cutoff frequency of the beam duct, the accelerating field is fully trapped in the cavity. On the other hand, the HOMs, which can propagate out of the cavity through the beam duct, are damped by the resistive part.

## Design considerations

Four cavities made of copper will be installed in a long straight section of the VUV ring and required to generate a total RF voltage of 1.4 MV. To maintain the dissipation power for each cavity below 40kW, it is desirable that the cavity should have the shunt impedance of more than 6 MΩ. The cavity shape was optimized using the computer codes of SUPERFISH and URMEL. In this calculation, the power loss of HOMs on the wall was estimated by taking into account the conductivity of resistive material.

The schematic of a quadrant of the designed cavity is shown in Fig.1. The conductivity of the resistive material was assumed to be 100 $(\Omega m)^{-1}$ in this design. Small nose cones are attached to the cavity not only to increase shunt impedance of accelerating mode but also to prevent the accelerating power from being absorbed in the region of resistive material. For this design, we obtained the shunt impedance $R_s$ of 7.75 MΩ and Q-value of 44000 for the accelerating mode.

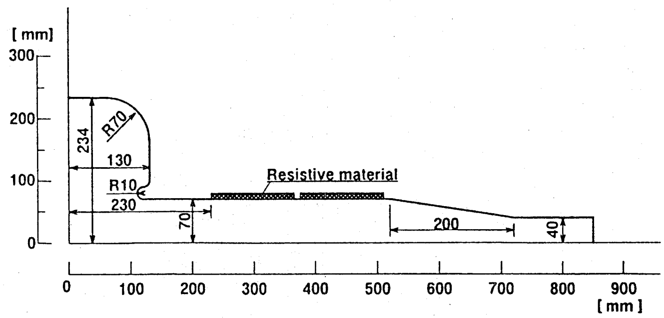


Figure 1: Schematic view of the cavity.

Figures 2 and 3 show the calculated longitudinal and transverse coupling impedances of the HOMs in this cavity. In these figures, (a) is the case without resistive material on beam duct and (b) is the case with resistive material on beam duct. The critical impedances in these figures denote the impedances, above which a coupled-bunch instability may occur at the beam current of 400 mA in the VUV ring[1].

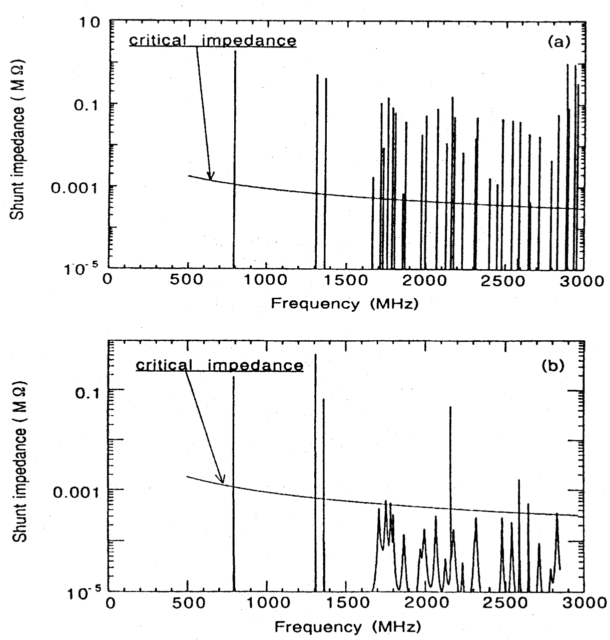


Figure 2: Longitudinal HOMs in the cavity : (a) without resistive beam duct, (b) with resistive beam duct.

By using the resistive material on beam duct, most of HOMs whose frequencies are higher than the cutoff frequency of the

[1] The ring parameters, which were used in the calculation of the critical impedances, are appeared in ref. [1].

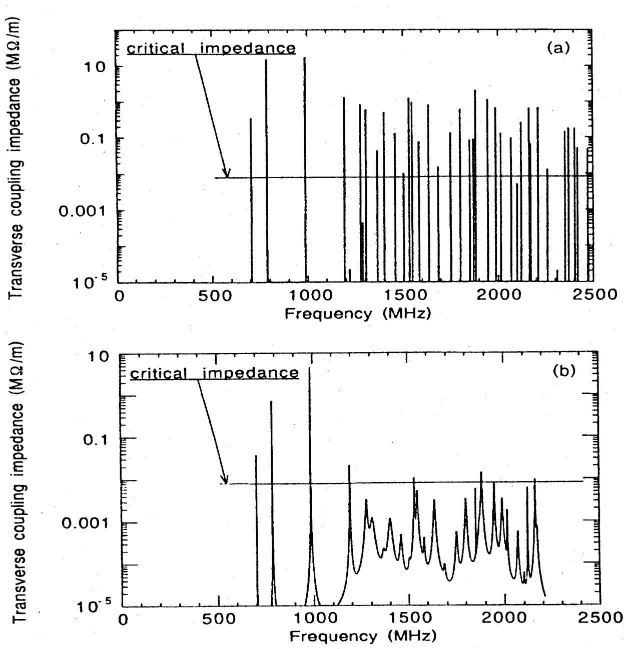


Figure 3: Transverse HOMs in the cavity : (a) without resistive beam duct, (b) with resistive beam duct.

beam duct are absorbed, so that their impedances become smaller than the critical impedance. Only for a few unabsorbed HOMs, their resonant frequencies will be detuned not to induce the coupled-bunch instability[2].

## Low power measurements on the prototype cavity

A prototype cavity of the same shape as in Fig. 1 was made and its low power test was carried out. The prototype was made of aluminum and three types of beam duct were prepared for the test. One duct was made of aluminum and the other two ducts were of sintered SiCs. A type of SiCs is named TPSS ( TOSHIBA CERAMICS ) and the conductivity is 250~500 $(\Omega m)^{-1}$ in the frequency region of 1.5 GHz to 4.5 GHz. The other type of SiCs is more resistive and is named CERASIC-B ( also TOSHIBA CERAMICS ). Its conductivity is 5 $(\Omega m)^{-1}$ in the same frequency region.

The TPSS duct is 135 mm long and two TPSS ducts were installed each side of cavity as shown in Fig. 1. Then the resistive part was positioned at 230 mm away from the cavity center. On the other hand, the CERASIC-B duct is 98 mm long and since its conductivity is smaller than TPSS, only one CERASIC-B duct was installed each side of cavity in the position 300 mm away from the cavity center [2].

The RF characteristics, i.e. resonant frequency, Q-value, field distribution etc., of both fundamental and HOMs were measured using a network analyzer ( HP8510C )[3]. The resonant frequencies and Q-values are summarized in Table 1, and Table 2. The measured and calculated Q-values are denoted as $Q_m$ and $Q_c$, respectively. Assuming the conductivity of Al alloy as $2.0\times10^7$ $(\Omega m)^{-1}$ and that of TPSS as 333 $(\Omega m)^{-1}$ and CERASIC-B as 5 $(\Omega m)^{-1}$, most of measured Q-values are consistent with calculated ones. As seen in these tables, strong reduction of Q-values were observed for the SiC ducts. Since the conductivity of the TPSS is slightly larger than the design value in the previous section, some of the HOMs are not damped sufficiently in the case of TPSS. So, in this connection, CERASIC-B is more suitable for our purpose than TPSS.

[2] So that in the case of CERASIC-B, the total length of the beam duct became shorter than Fig. 1

## Loss parameter measurements of the SiC ducts

The wall heating due to ohmic loss in the SiC duct is one of the important problems in our designed cavity. We measured the loss parameters of the SiC ducts by using the network analyzer in a similar method described in ref. [4]. The results are shown in Fig. 4. The solid curves are the loss parameters $k_r$ calculated by[5] ;

$$k_r(\sigma_b) = \frac{1}{\pi}\int_0^\infty Re\{Z(\omega)\}e^{-\omega^2\sigma_b^2}d\omega, \qquad (1)$$

where $\sigma_b$ is the bunch length and $Z(w)$ is the impedance of the duct[6] ;

$$Z(\omega) = (1+i)\frac{L}{2\pi b\delta\sigma}. \qquad (2)$$

Here $\delta$ is the skin depth, $\sigma$ the conductivity of the duct. $b$ and $L$ are radius of the duct and its length. The measured loss parameters can be well reproduced by this simple formula.

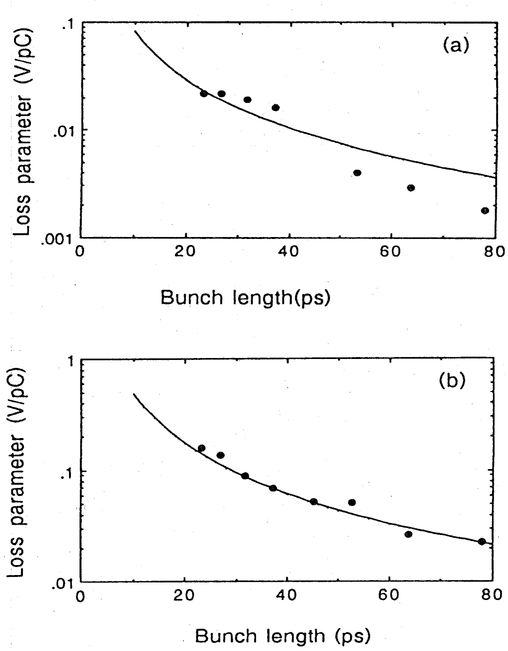


Figure 4: Loss parameter of the SiC-duct : (a) TPSS, (b) CERASIC-B

At the bunch length of 11.7 ps ( 3.5 mm ), which is the design value of the VUV ring, the loss parameter of the CERASIC-B duct is calculated to be 0.39 V/pC. In addition to the ohmic loss, there is wall heating caused by HOM losses due to cavity shape. According to our rough estimation of the HOM losses, SiC duct should be water cooled in single-bunch operation of the VUV ring.

## Near-future plan

The shape of the beam duct, especially the position and length of the SiC section will be optimized using the results of the present study. We also intend to investigate the effects of tuner and coupler on the RF characteristics for the prototype cavity.

We carried out some vacuum tests of the sintered SiCs used in this prototype cavity. The small samples of TPSS and CERASIC-B were put in a vacuum chamber and the amount of out-gas from them were measured under the vacuum pressure of $8\times10^{-8}$ Torr. In these tests, serious out-gases from these samples were not observed. As the next step, ultra-high vacuum sealing by the SiC duct will be tested in near future.

Table 1: Summary of Q-values for Al and TPSS ducts.

**Longitudinal mode**

| | Al duct | | TPSS duct | |
|---|---|---|---|---|
| Freq.(MHz) | $Q_m$ | $Q_c$ | $Q_m$ | $Q_c$ |
| 496.47 | 24000 | 25000 | 24000 | 25000 |
| 790.91 | 22000 | 22000 | 21000 | 22000 |
| 1153.1 | 32000 | 35000 | 31000 | 34000 |
| 1308.6 | 32000 | 33000 | 33000 | 33000 |
| 1362.3 | 24000 | 27000 | 23000 | 25000 |
| 1660.2 | 17000 | 24000 | 100 | 110 |
| 1662.7 | 18000 | 23000 | - | 120 |
| 1710.6 | 24000 | 27000 | 290 | 300 |
| 1729.5 | 22000 | 24000 | 200 | 200 |
| 1754.7 | 23000 | 25000 | 350 | 310 |
| 1786.3 | 29000 | 31000 | 690 | 570 |
| 1801.8 | 40000 | 42000 | 690 | 590 |
| 1852.6 | 24000 | 27000 | 290 | 270 |
| 1869.7 | 24000 | 28000 | 320 | 280 |
| 1968.7 | 25000 | 30000 | 320 | 270 |
| 1995.7 | 24000 | 26000 | 300 | 240 |
| 2067.3 | 33000 | 33000 | 350 | 390 |
| 2127.4 | 28000 | 28000 | 320 | 290 |
| 2160.1 | 23000 | 28000 | 350 | 360 |
| 2177.4 | 22000 | 26000 | - | 1100 |
| 2232.6 | 29000 | 29000 | 510 | 450 |
| 2292.6 | 25000 | 27000 | 340 | 310 |
| 2320.4 | 26000 | 29000 | 510 | 460 |
| 2402.4 | 29000 | 33000 | 460 | 540 |
| 2449.1 | 27000 | 28000 | 420 | 340 |
| 2479.0 | 38000 | 43000 | 630 | 710 |
| 2541.4 | 28000 | 34000 | 770 | 370 |
| 2581.9 | 27000 | 30000 | 450 | 400 |
| 2590.4 | 35000 | 35000 | 4500 | 3900 |

**Transverse mode**

| | Al duct | | TPSS duct | |
|---|---|---|---|---|
| Freq.(MHz) | $Q_m$ | $Q_c$ | $Q_m$ | $Q_c$ |
| 702.93 | 24000 | 30000 | 22000 | 27000 |
| 786.05 | 26000 | 33000 | 24000 | 28000 |
| 985.81 | 18000 | 25000 | 12000 | 14000 |
| 1189.5 | 24000 | 31000 | - | 1500 |
| 1216.2 | 39000 | 49000 | - | 2900 |
| 1276.8 | 19000 | 21000 | 200 | 210 |
| 1287.3 | 15000 | 18000 | - | 90 |
| 1305.9 | 16000 | 20000 | 130 | 120 |
| 1363.7 | 18000 | 20000 | 210 | 170 |
| 1399.5 | 17000 | 21000 | 180 | 150 |
| 1456.5 | 17000 | 23000 | 270 | 220 |
| 1502.1 | 30000 | 38000 | 510 | 490 |
| 1529.6 | 30000 | 33000 | 1300 | 690 |
| 1547.9 | 19000 | 24000 | 480 | 370 |
| 1581.1 | 31000 | 35000 | 640 | 470 |
| 1635.9 | 20000 | 28000 | 410 | 340 |
| 1685.3 | 23000 | 27000 | 290 | 320 |
| 1749.8 | 21000 | 29000 | 390 | 340 |
| 1798.9 | 22000 | 27000 | 540 | 410 |
| 1850.1 | - | 75000 | 33000 | 25000 |
| 1869.3 | 27000 | 33000 | 550 | 450 |
| 1881.0 | 21000 | 27000 | 560 | 580 |
| 1945.9 | - | 35000 | 960 | 760 |
| 1986.9 | 24000 | 30000 | 600 | 470 |

Table 2: Summary of Q-values for CERASIC-B duct.

**Longitudinal mode**

| Freq.(MHz) | $Q_m$ | $Q_c$ |
|---|---|---|
| 496.41 | 25000 | 24000 |
| 785.99 | 23280 | 22000 |
| 1153.0 | 30000 | 34000 |
| 1308.5 | 33000 | 33000 |
| 1362.2 | 23000 | 25000 |
| 1663.9 | - | 40 |
| 1669.4 | 40 | 30 |
| 1720.5 | 120 | 60 |
| 1756.5 | 90 | 70 |
| 1777.5 | 160 | 130 |
| 1806.5 | 200 | 120 |
| 1827.0 | 200 | 160 |
| 1931.5 | 120 | 100 |
| 1955.0 | 100 | 70 |
| 2044.0 | 160 | 100 |
| 2126.0 | 130 | 80 |
| 2155.0 | - | 2500 |
| 2186.5 | 90 | 130 |
| 2246.5 | 170 | 140 |
| 2307.3 | - | 140 |
| 2310.5 | - | 80 |
| 2402.3 | - | 170 |
| 2471.9 | 120 | 110 |
| 2553.8 | 180 | 130 |
| 2590.0 | 800 | 700 |
| 2612.0 | 150 | 150 |
| 2645.7 | - | 200 |
| 2695.9 | 170 | 120 |
| 2761.0 | 180 | 160 |

**Transverse mode**

| Freq.(MHz) | $Q_m$ | $Q_c$ |
|---|---|---|
| 702.87 | 22000 | 28000 |
| 785.99 | 23000 | 30000 |
| 985.72 | 12000 | 14000 |
| 1189.0 | 500 | 800 |
| 1215.8 | - | 1420 |
| 1279.7 | - | 130 |
| 1302.8 | - | 30 |
| 1393.3 | 70 | 40 |
| 1447.8 | 110 | 60 |
| 1509.4 | 190 | 130 |
| 1520.0 | 790 | 840 |
| 1558.8 | 370 | 250 |
| 1602.5 | 170 | 130 |
| 1648.5 | 100 | 90 |
| 1726.9 | 160 | 100 |
| 1779.9 | 160 | 120 |
| 1845.2 | - | 3300 |
| 1855.9 | 200 | 150 |
| 1872.0 | 240 | 180 |
| 1945.0 | 210 | 230 |
| 1989.0 | 150 | 140 |
| 2014.0 | 620 | 470 |
| 2076.0 | 190 | 170 |


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[6] For example, see F.Sacherer, *"Transverse instabilities of relativistic particle beams in accelerators and storage ring, Part II- Bunched beams"*, CERN 77-13, pp. 198-218, 1977.