DEVELOPMENT OF COPPER COATED CHAMBER FOR THIRD GENERATION LIGHT SOURCES

Hiroshi Sakai, Isao Ito, Hirofumi Kudo, Norio Nakamura, Takashi Shibuya,
Kenji Shinoe, Hiroyuki Takaki, Masanori Kobayashi*
Institute for Solid State Physics, the University of Tokyo, Chiba 277-8581, Japan
*Photon Factory, KEK, Ibaraki 305-0801, Japan

Abstract

We describe the development of the copper coated chamber, which is suitable for the 3rd generation light sources. This chamber aims to reduce the resistive-wall impedance [1]. However, this coating might affect the ultra-high vacuum condition worse. In order to check the validity of this chamber for the ultra-high vacuum condition, we have produced the copper coated chamber and built the test bench. The measured outgassing from the inner surface of the newly developed copper coated chamber is sufficiently small to utilize in ultra-high vacuum condition.

INTRODUCTION

For 3rd generation light sources such as the Super-SOR ring, which is planed by the University of Tokyo and aims to produce the highly brilliant light in the vuv-sx regime [2], a lot of insertion devices (ID's) are set in the straight sections. In the ID sections the vertical apertures of the vacuum chambers are much smaller than that of the other section because the narrow ID gaps are required. In order to obtain the high mechanical strength comparing with thin thickness of ID duct, the ID duct is usually made of stainless steel. As a result, the resistive-wall impedance will much increase and cause the coupled-bunch instability because of the comparatively low conductivity of stainless steel as well as narrow vertical apertures. Although this instability can be suppressed by applying the bunch-by-bunch feedback technique, the large impedance will make the load of the feedback very large. Therefore, the reduction of the resistive-wall impedance itself is essential. In order to reduce the resistive-wall impedance, we already proposed that the inner surfaces of the SS ID vacuum ducts should be coated with a highly conductive metal such as copper or silver [1]. Fig.1 shows the calculated transverse impedances of the SS ID ducts without and with copper coatings of 50, 100, 150 and 200 μm in thickness and the copper ID duct. The impedance calculation shows that the copper coating with thickness of 150 to 200 μm can reduce the resistive wall impedance down to that of the copper duct in the frequency range of 107 – 960 kHz corresponding to the betatron tune fraction of 0.1 – 0.9 in the Super-SOR ring, where the resistive-wall impedance is very high and hence the growth rate can be large. This results in the suppression of the transverse instability. In addition the eddy currents in the copper coating due to the change of the magnetic gap or phase of the insertion device are sufficiently small to have little effect on the beam.

We have many advantages when we apply the copper coated chamber to ID chamber with narrow aperture. However, the effect of copper coating on the ultra-high vacuum condition has not investigated. This situation leads us to produce the copper coated chamber and measure the outgassing from this chamber. In this paper, we present the measurement of the outgassing from the newly developed copper coated chamber.
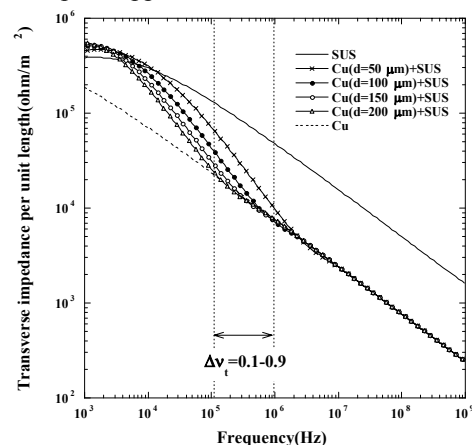

Figure 1: Calculated transverse impedances (the real parts) per unit length of the ID ducts as a function of frequency. The frequency range between the dotted lines corresponds to the betatron-tune fraction of 0.1 – 0.9.

COPPER COATED CHAMBER

The copper coated chamber was produced by plating the copper on the fabricated inner surface of the stainless-steel (SUS316L) chamber. To plate the copper, the SS chamber put into the copper sulfate solution at the room temperature. After 3 hours dipping, the copper was coated inside the SS chamber. Fig.2 shows the photograph of the test ID chamber. The ID chamber was only plated between –25 and 25 mm from the center of the inner surface. Any crack and flaw was not found on the copper coating. And the copper was plated successfully from 110 to 140 μm thicknesses, which was measured with a microscope by using the test piece for copper plating on the same plating condition. After succeeding this test piece for copper coating, we also produced another test copper coated chamber (called as "Cu coated chamber" from here) to measure the outgassing from the copper coating under plating in the same procedure. Fig.3 shows the photograph of the Cu coated chamber. This chamber has 1.4m lengths and diameter is 152mm lengths. The copper was coated all over the inner surface of the SS(SUS316L) chamber with

copper coating of 150±50 μm thickness. Any crack and flaw was not found on the copper coating either.
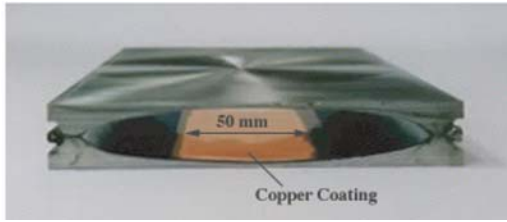

Figure 2: A test stainless-steel chamber coated with copper for ID section.

Figure 3: A test stainless-steel chamber coated with copper ("Cu coated chamber").
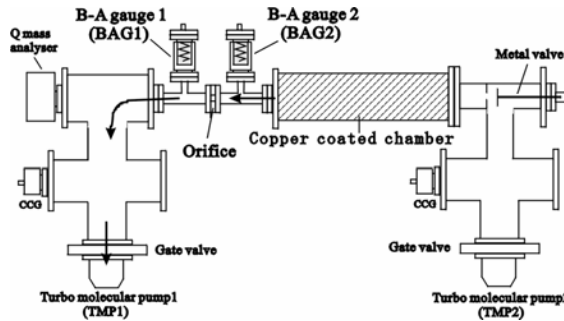
EXPERIMENTS

Setup

Figure 4: A set-up of test bench for the measurement of the outgassing from the copper coated chamber. The shadow area shows the main Cu coated chamber.

We apply the orifice method to measure the outgassing from the Cu coated chamber. Fig.4 shows the set-up for the measurement. This system consists of the main Cu test chamber, two B-A gauges (BAG), the orifice between them, the Q-mass analyser, the metal valve, two molecular pumps (TMP), two gate valves in the upstream of the TMPs and two cold cathode gauges (CCG). The pumping speed of TMP is 300l/s, which is large enough to achieve the ultra-high vacuum condition. All of the chambers except for the orifice were made by SS. The orifice was made by copper to reduce the outgassing from the orifice itself. First we opened the metal valve and pumped the entire chamber during baking out. The CCGs were mainly used for measuring the vacuum pressures in baking. After baking out, the metal valve was closed. The gas from the inner surface of the chamber passes through

the orifice and pumps out by the TMP1 as shown in the arrows of Fig.4. The outgassing rate per unit area "q" from the chamber with the equilibrium condition is described by

$$q = C(P_2 - P_1)/A, \qquad (1)$$

where P_1 and P_2 are the measured pressures by BAG1 and BAG2, C is the conductance of orifice and A is the area of the inner surface of the chamber. To consider the pumping speed of the B-A gauge itself and the achievable time to the equilibrium condition, we determined the diameter of orifice was 5mm. The Q-mass analyser was also utilized to measure the residual gas components.

The B-A gauges (BAG1 and BAG2) were calibrated by using the well-calibrated extractor gauge (EXT) [3]. Fig.5 shows the results of the calibration. The calibration was done by inserting the nitrogen gas into the calibration chamber. As shown in Fig.5, the measured pressures of B-A gauges are almost proportional to the values of extractor gauge. This calibration was only carried out above $5×10^{-8}$ Pa because of the poor pumping speed for the hydrogen gas. However, we have obtained the calibration factor between the pressures of each B-A gauge (P_{BAG}) and extractor gauge (P_{EXT}) by applying the linear fitting with offset in Fig5. This applied linear fitting forms as

$$P_{BAG} = α×P_{EXT} + β, \qquad (2)$$

where α is the coefficient and β is the offset. Table 1 shows the summary of fitting with Eq. (2) of each BAG with reduced chi-squares. No difference was seen with each B-A gauge. We note that this linear fitting in Eq. (2) is much better than the linear fitting without offset by comparing with $χ^2/ν$. (The $χ^2/ν$ on the latter case is more than 10.)
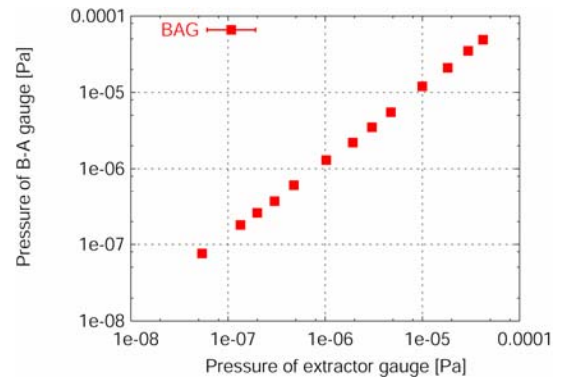

Figure 5: The typical result of the calibration of B-A gauge. Horizontal (vertical) axis shows the pressure measured by extractor gauge (B-A gauge).

Table 1: The calibration factor between the each B-A gauge and the extractor gauge

	BAG1	BAG2
α	1.19±0.01	1.19±0.02
β [Pa]	$(1.23±0.17)×10^{-8}$	$(1.23±0.17)×10^{-8}$
$χ^2/ν$	1.65	2.06

Performance of Outgas Measurement System

First, we measured the outgassing from the chamber made of usually used stainless steel (SUS304) with the same size as the Cu coated chamber (called as "SS chamber" from here) in order to check the performance of this outgas measurement system ("Case 1"). The #400 buffing grinding was applied to the inner surface of this SS chamber and the electro polishing (EP) was also applied to realize the ultra-high vacuum condition. Before and after the EP, the pure water rinsing was applied twice. The measurement system was baked out during 100 hours at 300℃, prior to the measurement of the outgas from the SS chamber. After cooling down the SS chamber at 24℃ for 48 hours and settling down it to the equilibrium condition, we measured both pressures of the BAGs. The measured P_1 was $(2.32\pm0.15)\times10^{-8}$ Pa and P_2 was $(1.91\pm0.02)\times10^{-7}$ Pa. These data have already calibrated by using Eq. (2). (Hereafter, we denote that the measured pressure P_1 and P_2 are calibrated.) These measured pressures were based on the nitrogen gas. The area of the inner surface of the test chamber A was 0.763 m^2 and The conductance of orifice C was 2.28×10^{-3} m^3/s (N$_2$, 24℃). From Eq. (1), we concluded that the outgassing rate per unit area q from the SS chamber was $(5.02\pm0.08)\times10^{-10}$ [Pa m^3 s^{-1} m^{-2}] (N$_2$, 24℃). This value was almost consistent with the other experimental data [4]. From this, we found that this system worked well to measure the outgassing in ultra-high vacuum condition.

Measurements of the Outgassing Rate

We measured the outgassing from the Cu coating chamber ("Case 2"). After installing the Cu coating chamber, the measurement system was also baked out during 200 hours at 300℃ and cooled down for 48 hours at 24℃. After that, we measured the pressures of B-A gauges. P_1 was $(1.24\pm0.14)\times10^{-8}$ Pa and P_2 was $(4.26\pm0.15)\times10^{-8}$ Pa. By using the same area of the inner surface and the same conductance of orifice, we concluded that the outgassing rate per unit area q from copper coating chamber was $(0.90\pm0.06)\times10^{-10}$ [Pa m^3 s^{-1} m^{-2}] (N$_2$, 24℃). This value was smaller than the value of the SS chamber. We should not compare these results because of the different baking time. To evaluate the validity of this measured outgas data from copper coated chamber, we measured the outgassing from the SS chamber again on the same baking time condition ("Case 3"). After replacing the SS chamber, we baked out this system during more 100 hour at 300℃. After cooling down the SS chamber at 24℃ for 48 hours and settling down to the equilibrium condition, we measured the both pressures of the BAGs. P_1 was $(0.65\pm0.14)\times10^{-8}$ Pa and P_2 was $(5.18\pm0.15)\times10^{-8}$ Pa. From this, we obtained the outgassing rate per unit area q of $(1.36\pm0.06)\times10^{-10}$ [Pa m^3 s^{-1} m^{-2}] (N$_2$, 24℃).

Results and Discussions

Table 2: The summary of the measured outgassing rate on three times. The outgassing is based on N$_2$ at 24℃.

Measurement cases	The outgassing rate [Pa m^3 s^{-1} m^{-2}] (N$_2$, 24℃)	Baking time [hour]
Case 1 (SS)	$(5.02\pm0.08)\times10^{-10}$	100
Case 2 (Cu)	$(0.90\pm0.06)\times10^{-10}$	200
Case 3 (SS)	$(1.36\pm0.06)\times10^{-10}$	200

We summarize this measured outgassing rate in Table 2. These results show that the outgassing from the SS chamber is reduced by adding the baking time. But the outgas from the Cu test chamber is smaller than that of the SS chamber on the same baking conditions. We also took the mass spectrum of the Cu coated chamber ("Case 2") and the SS chamber ("Case 3"). Fig.6 shows the measured mass spectrum. The hydrogen gas is dominant on both cases. Both spectrums are almost the same except for the mass numbers of 25,26 and 27. We add that no signal was observed above mass number of 50.
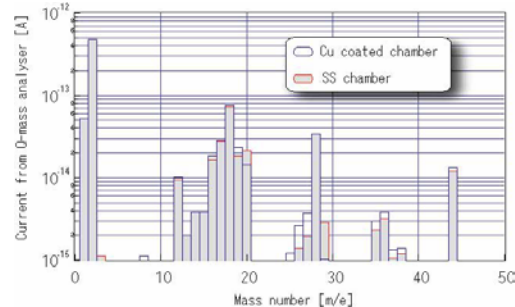

Figure 6: Measured mass spectrum.

CONCLUSION

In conclusion, we measure the outgassing from the copper coated chamber. The measured outgassing rate per area of inner surface q is $(0.90\pm0.06)\times10^{-10}$ [Pa m^3 s^{-1} m^{-2}] (N$_2$, 24℃). Comparing with the measured outgassing from the usually used SS chamber, no clear difference was observed after the same baking condition at 300℃. These results denote that the outgassing from this copper coated chamber is sufficiently small. This copper coated chamber can be used under the ultra-high vacuum conditions of 3rd generation light sources.

REFERENCES

[1] N.Nakamura et.al., Proc. of the 6th European Particle Accelerator Conference, Stockholm, 1998, p984.
[2] N.Nakamura, Proc. of the 9th European Particle Accelerator Conference, Lucerne, 2004, p2350
[3] LEYBOLD VAKUUM GmbH, IE514.
[4] J.R.Young, J. Vac. Sci. Technol. 6, 398 (1969).