DEVELOPMENT OF HOM ABSORBER FOR SuperKEKB

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Abstract

Higher-order modes (HOM) absorber is an indispensable components for recent high-power accelerators in order to prevent beam instabilities (e.g. HOM- Beam Break Up instabilities) or the overheating of vacuum components. Several kinds of absorber materials, such as SiC, ferrite and Kanthal, have been investigated and applied in accelerators [1-3]. Among these materials, ferrite has been found to be superior to others because of its higher HOM absorbing efficiency. However, because of its low tensile strength and small thermal expansion rate, it is difficult to bond to other metals, which has been limiting the application of ferrite to a reliable HOM absorber for high intensity accelerators. We proposed a fabrication method of ferrite-copper blocks using the spark plasma sintering (SPS) technique last year. The productivity has been improved by optimizing and re-examining the SPS process since then. We also report some key properties of the ferrite block, such as the RF absorbing property measured using a high-power RF source, and the gas desorption rate from the ferrite.

INTRODUCTION

Ferrite is a well-known material for effectively absorbing electromagnetic waves, and has been sometimes used in accelerators as higher-order modes (HOM) absorber in vacuum beam pipes. However, one of difficulties in using ferrite for high-intensity accelerator is the weak adhesion to metals due to its low thermal expansion rate and small tensile strength. The cracking and the detaching of bonding plane, for example, were frequently observed during the blazing heat cycle. HIP (Hot Isostatic Pressing) method was available only for a small ferrite-metal block or for a special structure. High thermal strength and good heat transfer at the ferrite-metal bonding are required for the wide applications as HOM absorbers.

We reported the fabrication of ferrite-copper blocks using the spark plasma sintering (SPS) technique, in which the ferrite powder is directly sintered on the copper block, last year [4]. A cylindrical ferrite-copper block up to a diameter of 40 mm was successfully produced. The RF properties were measured using a low-power microwave source and the results were just as expected.

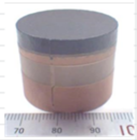
Following the R&D last year, we improved the production technique to increase the productivity. We optimized and re-examined the SPS process. Furthermore, the RF properties of the ferrite-copper block were investigated using a high-power RF source. Some important parameters from the view point of ultra-high vacuum were also measured, such as the gas desorption rate from the ferrite-copper block, the gas desorption by

Table 1: History of Achievement in Fabricating Ferrite-copper Blocks by SPS Method

No.	1	2	3	4	5	6	7	8	9	10
Date	2014/7/16	2015/9/28	2015/9/28	2015/10/15	2015/10/26	2016/2/18	2016/11/7	2016/12/19	2016/12/21	2017/2/14
Bake powder of ferrite	○	?				○				
storage period since bake powder of ferrite	17 months	?				2 weeks	2 weeks	2 months	2 months	1 weeks
Temperature conditions during SPS	900℃-10min		870℃-2min							870℃-10min
Retention conditions of low temperature during SPS	No		300℃-5min	400℃-2min				300℃-5min		400℃-4min
Pressurization conditions	10MPa		Initial pressurization: 5MPa Over 500° : 10MPa	10MPa				Initial pressurization: 5MPa Over 500° : 10MPa	10MPa	10MPa
Cooling spped (remove from furnace after SPS)	30min			17min				30min		2h
Yeild	1/1	0/1	1/1	1/1	7/20	10/10	5/20	0/5	0/5	20/20
Results	◎	×	◎	◎	△	◎	△	×	×	◎

Photo

No.1



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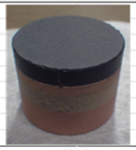

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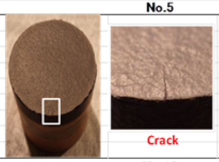

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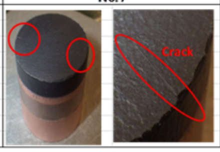

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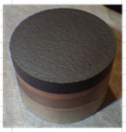

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electron bombardment, and the secondary electron yield from the ferrite surface.

IMPROVEMENT OF FABRICATION METHOD USING SPS

The history of achievement in fabricating ferrite-copper blocks by SPS method is shown in Table1. The ferrite-copper blocks fabricated in the series of No. 6 were all successful, but the production yields in the series of No.7, 8, and 9 were decreased in spite of almost the same condition. We carried out following two workarounds: First, to slower the raising and decreasing rates in temperature during SPS. Second, to replace the die and punch of the jig in SPS with new ones. As a result, the production yield in the series of No.10 recovered. One reason of the low production yield in the series of No. 7-9 was that the die and punch were worn away by rubbing and electrical discharges. A photograph of the used die is presented in Fig. 1 (a). The color change due to the discharging was observed on the inner surface of the center hole.

In order to investigate the extent of the wear, the surface of the used die was investigated using a coordinate measuring machine (CMM), and compared to the new one. The setup of the measurement is shown in Fig.1 (b). The flatness of the used die had not changed. However, the circularity of the used die had deteriorated. The measured circularities are summarized in Table 2. It was indicated that the production yield in the series of No. 7-9 was decreased because the samples were pressed with uneven stress by the depleted die.

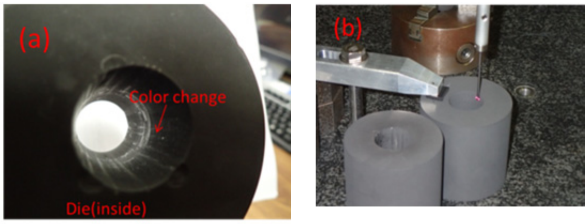

Figure 1: (a) A photograph of the used die, and (b) setup of measuring the flatness and the circularity of the dies.

Table 2: Measured Circularities of the Dies

The distance from the surface	2mm (NEW) 4mm (USED)	40mm(center)
The circularity of the die inside (NEW)	0.007mm	0.0063mm
The circularity of the die inside (USED)	0.028mm	0.096mm

PROPERTIES OF FERRITE-COPPER BLOCK FABRICATED BY SPS

Gas Desorption Rate after Baking

We reported that the gas desorption rate of a ferrite block without baking was approximately 1×10^{-7} Pa m^3 s^{-1} m^{-2} last year [4]. The gas desorption rate after a baking at 200 °C for 24 h was measured this year. The two ferrite-copper blocks with a diameter of 40 mm and a ferrite thickness of 5 mm were used in the measurement. The measured gas desorption rate was 1×10^{-8} Pa m^3 s^{-1} m^{-2} at room temperature. The gas desorption rate decreased by one order after the baking. No damage was found at the bonding of the block to the copper plate. A baking process is indispensable for the ultra-high vacuum application.

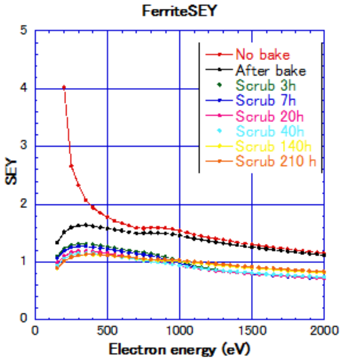

Figure 2: Dependence of SEY from the ferrite surface on the primary electron energy.

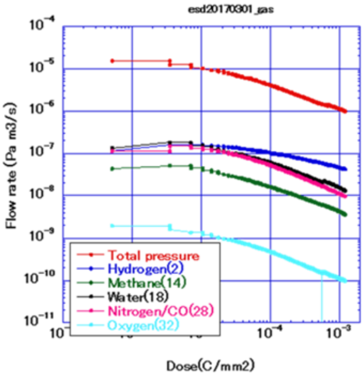

Figure 3: Pressure during the electron bombardment as a function of electron dose (integrated charge density).

Secondary Electron Yield (SEY)

In relation to the electron cloud instability in positron or proton rings, the SEY from the ferrite surface was measured considering the case that the ferrite blocks were faced to the beam. Figure 2 shows the SEY as a function of the primary electron energy for several conditions. Here the legend “Scrub” means the time of electron bombardment. The primary electrons hit normally to the surface. The beam current and beam energy during the scrubbing are about 10 µA and 250 eV, respectively. The SEY of the ferrite is approximately 1.5 times higher than that of TiN film coated on aluminum-alloy substrate, which is used for most of beam pipes in the SuperKEKB.

Electron Stimulated Desorption (ESD)

Considering the application of the ferrite blocks for ultra-high vacuum system of storage rings, it is required to decrease not only the thermal desorption rate but also the photon stimulated desorption (PSD), because the HOM absorbers are likely to be irradiated by the synchrotron radiation or the scattered photons. As a test,

ISBN 978-3-95450-182-3

the electron stimulated desorption (ESD) rate was measured. Note that the main PSD process is said to be actually ESD on the surface. The measured gas desorption rate during the electron bombardment are presented in Fig. 3 as a function of the incident electron dose (integrated charge density). Here we assumed a pumping speed of 0.2 $m^3\ s^{-1}$ for all gas species. The beam current and beam energy during the ESD measured are about 100 µA and 1000 eV. The main gas is H_2, H_2O and CO (N_2), as in the case of typical ESD. The ESD rate decreases monotonically as the increase in the electron dose, although the decrease rate is slow for H_2. Further detailed investigation is ongoing.

HIGH-POWER RF TEST

Setup

To estimate the power handling capability of the ferrite block fabricated by the SPS, a high-power test using 1.25 GHz 2~3 kW power source was performed in air. The schematic diagram and the photograph of the test stand are shown in Fig. 4 and 5, respectively. Six ferrite blocks with each has a surface of 18 mm × 18 mm was assembled to one unit (we call it a ferrite unit here). The ferrite unit was attached to the top side of the wave guide (E-plane). The absorbed power to the ferrite unit was measured from the difference between the input power and the absorbed power in the dummy load at the end of the microwave circuit. A ferrite unit was cooled by water from the back side. The difference in temperatures of cooling water at the inlet and the outlet pipes were also measured. The cooling water was flowing with a rate of 3 L min^{-1}. The top surface of the ferrite protruded 1 mm from the inner surface of the waveguide. The temperature of the ferrite surface was measured using a radiation thermometer through a pin hole at a side of the waveguide. To detect the moment of cracking of the ferrite in case, an acoustic emission sensor (AE sensor) was also attached to the waveguide.

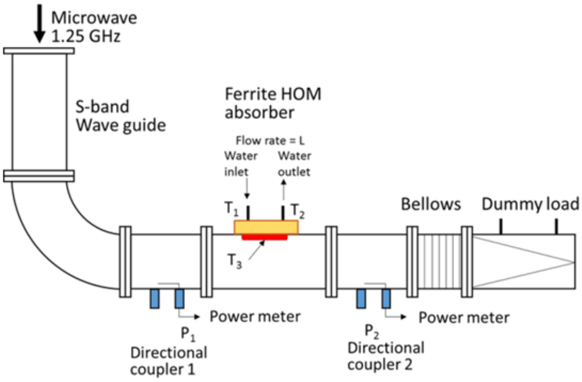

Figure 4: Schematic diagram of the setup for high-power RF test.

Results

The absorbed power and the temperature of the ferrite surface, and the temperatures of the inlet and outlet cooling water pipes are presented in Fig.6 (a) and (b), respectively. The ferrite unit absorbed a power up to approximately 250 W, which means that a ferrite block absorbed a power of approximately 20 W. From the test using a high-power RF source, it was found that the ferrite-copper blocks fabricated by the SPS method is applicative for a HOM absorber. On the other hand, the temperature of the surface is approximately 110°C at that absorbed power. It is indicated that more effective cooling structure would be required for stable operation, because lowering the maximum temperature of the ferrite should decrease a possibility of fatigue fracture.

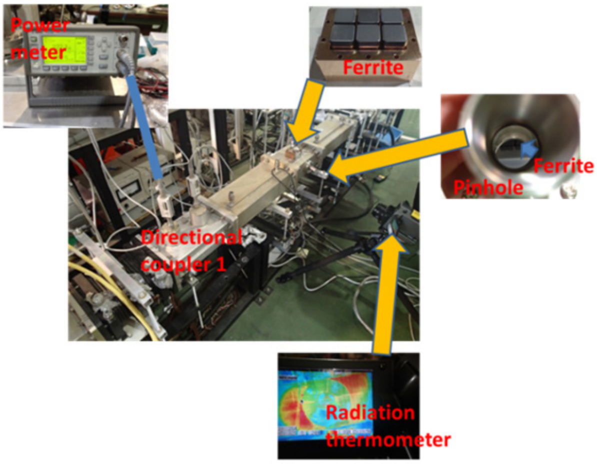

Figure 5: Photograph of the setup and some key components.

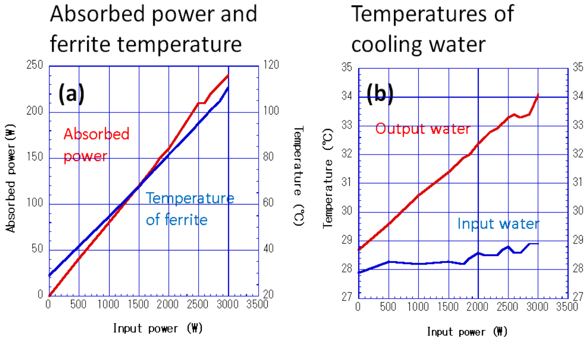

Figure 6: (a) The absorbed power and the temperature of the ferrite surface, and (b) the temperatures at the inlet and outlet cooling water pipes as a function of the input RF power.

CONCLUSION

The production yield of the ferrite-copper blocks was improved by re-examination of the SPS process. The thermal gas desorption rates after a baking and the gas desorption by electron bombardment were estimated. The absorbing power was evaluated by a high-power RF test. Although further detailed investigation is required, promising results were obtained for the application of the ferrite blocks as HOM absorbers. We have a plan to manufacture a prototype of the beam pipe with the ferrite-copper block, which will be installed in SuperKEKB as a HOM absorber for beam collimators.

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