ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPML053

AVAILABILITY OF THE TiN COATING-FREE CERAMIC IN THE STF-TYPE POWER COUPLER FOR ILC

Y. Yamamoto†, E. Kako, T. Matsumoto, S. Michizono, A. Yamamoto, KEK, Tsukuba, Japan
M. Irikura, M. Ishibashi, H. Yasutake, TETD, Otawara, Japan
E. Montesinos, C. Julie, CERN, Geneva, Switzerland

Abstract

In the Superconducting RF Test Facility (STF) in KEK, the research and development for the power coupler with the Titanium-Nitride (TiN) coating-free ceramic has been done from 2014. In 2016, the high power test at the test bench was stopped due to the worse vacuum level by the unusual heating around the RF window with the TiN coating-free ceramic and the coaxial tapered section, which was caused by the enormous emission of the secondary electrons from the ceramic. And, the situation was never also changed by the ultrapure water rinsing for the power couplers several times. However, in 2017, the ultrasonic rinsing was done for the power couplers for the first time by the collaboration between KEK and TETD. After that, the situation was drastically improved, and the secondary electron emission almost disappeared even in the higher RF duty. This shows that the TiN coating-free ceramic is the prospective item for the cost reduction in International Linear Collider (ILC). In this report, the recent result for the power coupler with the TiN coating-free ceramic will be presented in detailed.

INTRODUCTION

From 2017, cost reduction R&D for ILC started between Japan and U.S. The main tasks are shown in Table 1.

Table 1: Four Main Tasks for Cost Reduction R&D in ILC as Collaborative Work Between Japan and U.S.

Program	Item
A-1	Lower RRR Nb material
A-2	N_2 infusion technique
A-3	Power coupler
A-4	Vertical electro-polishing

As cost reduction for power coupler (A-3), studies for copper plating, ceramic material and TiN coating are under progress in KEK. Generally, TiN coating is essential for reduction of secondary electron emission coefficient (δ_{SEE}) on ceramic surface. However, it was revealed that the cost of TiN coating was never cheap in the trial calculation done by a Japanese company. Therefore, KEK, CERN and TETD developed power coupler with a TiN coating-free ceramic using a new material together with KYOCERA. All production processes including brazing except for TiN coating were the same as those of the STF-type power coupler [1] that has been operated in the STF-2 cryomodule [2] so far. After the fabrication of power couplers, they are usually rinsed by ultrapure water without ultrasonic in Class 1000 area, assembled for test bench in Class 10 area, and tested by high RF power from 5 MW klystron in STF.

† yasuchika.yamamoto@kek.jp

RESULT OF HIGH POWER TEST

The high power test for these power couplers with TiN coating-free ceramic has been carried out four times in total as shown in Table 2. As already mentioned in the reference [3, 4], in 2016, the performance for these power couplers with TiN coating-free ceramic were limited due to unusual heating around the RF windows and the tapered section connected to the waveguide system. It was concluded that this unusual exothermic behavior must have been caused by secondary electron emission from the TiN coating-free ceramic, as it changed by putting some small magnets closer to the heating location.

Table 2: History of High Power Test/Ultrasonic Rinsing for Power Coupler with TiN Coating-Free Ceramic (the Conditions of Ultrasonic Rinsing Are for the Cold Part)

Test #	Experiment Period	Result
1	May/2016~Jun/2016	Not keeping at 266 kW (1.5 msec)
	Ultrasonic rinsing: 120 W (0.26 W/ℓ)	
2	Jun/2017~Jul/2017	Not keeping at 510 kW (1.65 msec)
	Ultrasonic rinsing: 600 W (1.28 W/ℓ)	
3	Sep/2017~Oct/2017	Not keeping at 800 kW (1.65 msec)
	Ultrasonic rinsing: 1200 W (2.56 W/ℓ) + WRS	
4	Feb/2018~Mar/2018	3 hours keep at 800 kW (1.65 msec)

Ultrasonic Rinsing for Power Couplers

In order to suppress secondary electron emission from TiN coating-free ceramic, ultrasonic rinsing was performed on the power couplers for the first time by collaborative work of KEK and TETD. Figure 1 shows the status during the ultrasonic rinsing, and the waterproof parts. The specification for the ultrasonic rinsing bath is shown in ref [5]. The assembly work after the ultrasonic rinsing is the same as that of STF-type power coupler. The power of the ultrasonic rinsing gradually increased while checking the suppression of secondary electron emission in the high power test. Table 2 shows the specification of ultrasonic rinsing for each stage. WRS in Table 2 means "Water Resonant System", which has the effect of removing air bubbles in the ultrapure water, therefore, the power of ultrasonic rinsing increases by about 1.5 times higher.

9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPML053

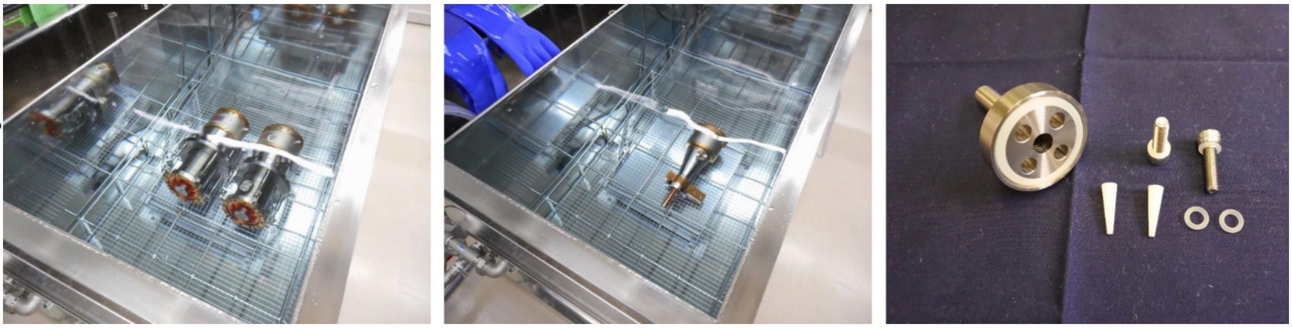

Figure 1: Power couplers in the ultrasonic rinsing bath at TETD (Left: Warm parts, Center: Cold part, Right: Waterproof parts). The maximum power of ultrasonic rinsing for warm parts was 360 W to avoid the removal of TiN coating from TiN coated ceramics used for warm windows.

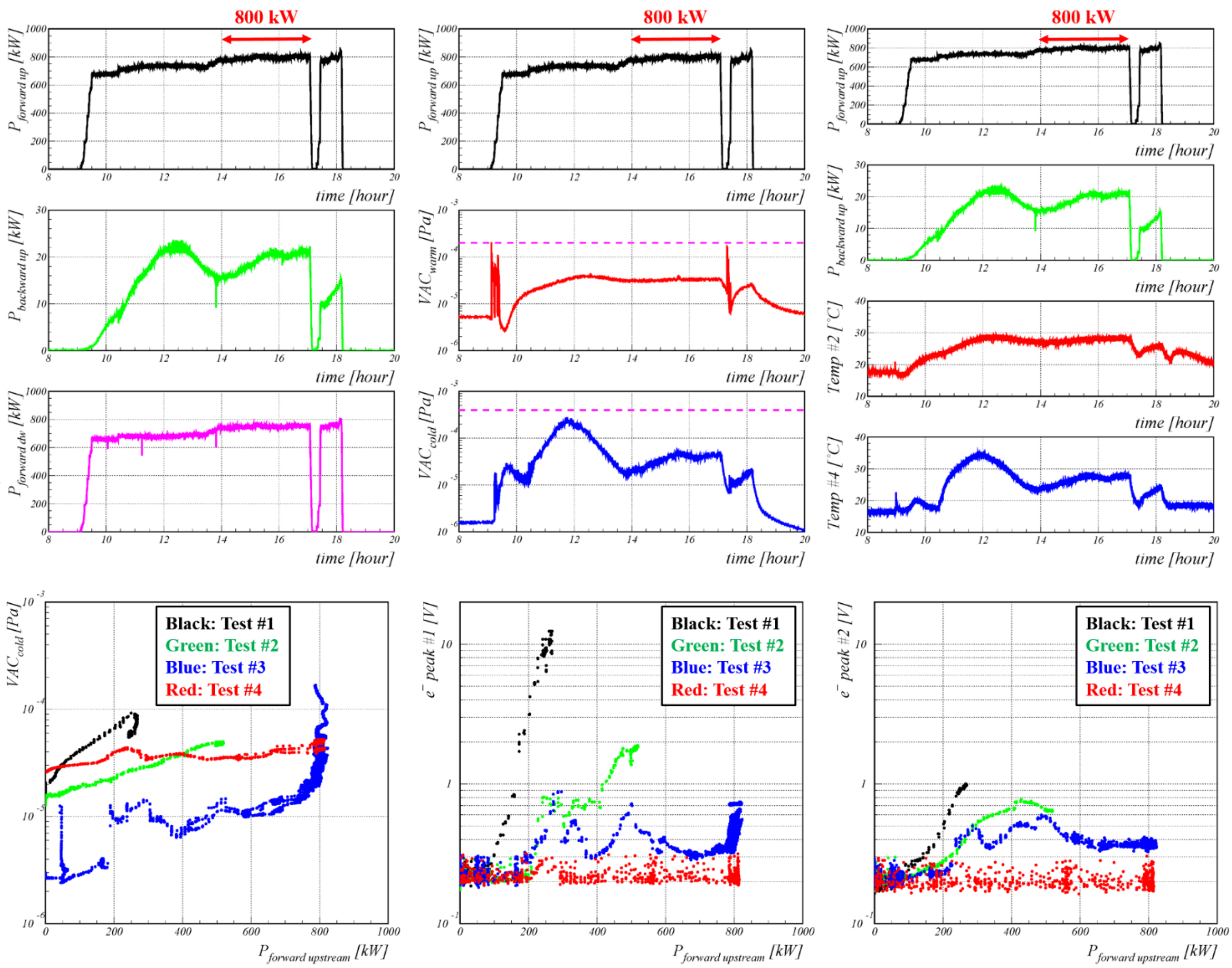

Figure 2: Upper three figures show the trend graphs for forward/backward power monitored at upstream and downstream of test bench (left), warm/cold vacuum level (center), temperature at cold window (Temp #2), and temperature at flange (Temp #4) jointed between cold part and waveguide system (right) in Test #4 under the RF conditions of 1.65 msec/5 Hz. Lower three figures show the correlation plots between cold vacuum level (left), electron emission at upstream (center) / downstream (right) coupler and forward power. In lower three figures, four different colours mean as follows; black: Test #1, green: Test #2, blue: Test #3, red: Test #4 as shown in Table 2. Only Test #1 was done for 1.5 msec/5 Hz. The technical interlock level is 4 x 10^{-4} Pa for cold vacuum, and 2 x 10^{-4} Pa for warm vacuum shown as purple dotted line in the upper center figure.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPML053

High Power Test

The goal of the high power test for the STF power coupler is to be able to keep for over 1 hour at 800 kW under RF conditions of 1.65 msec (pulse width) / 5 Hz (repetition rate). As a usual method, RF conditioning starts from the pulse width of 20 µsec, gradually increases it, and finishes 1.65 msec. The specification power is 1.2 MW (<500 µsec) and 800 kW (≥500 µsec).

The upper figures in Figure 2 show the trend graphs during the high power test (Test #4) in the pulse width of 1.65 msec/5 Hz. The lower figures show the correlation plots between the cold vacuum level (left), electron emissions at upstream coupler (center), and downstream coupler (right). It is clear that these power couplers with TiN coating-free ceramic passed the goal, and simultaneously, the suppression of secondary electron emission by ultrasonic rinsing was observed, and no signals from electron probes in Test #4.

Heating Phenomena

During the high power test, strange heating phenomena was observed at the both cold flanges connected between power couplers and waveguide system as shown in the upper right figure in Figure 2. Temp #2 (temperature at cold window) shows the saturation in temperature rise during keeping 800 kW; on the other hand, Temp #4 (temperature at flange) shows a tendency to rise up once, however then to fall down. And more strangely, the reflected power (green line) shows a similar trend. This phenomena was repeatedly observed in the past high power tests.

MEASUREMENT OF CERAMIC PROPERTIES

The following four parameters are important for evaluating the properties of ceramics:

- Surface/volume resistance (ρ)
- Relative permittivity (ε)
- Dielectric loss tangent (tanδ)
- Secondary electron emission coefficient (δ_{SEE})

For this TiN coating-free ceramic, the relative permittivity and the dielectric loss tangent were measured as shown in Figure 3. As a result, it was revealed that the dielectric loss tangent at 1 GHz and 2 GHz were around 10^{-3} as shown in Figure 4. This higher dielectric loss tangent possibly generated the strange heating phenomena, however, it is not clear yet. In near future, the secondary electron emission coefficient for this ceramic will be measured by scanning electron microscope (SEM) with beam blanking system. The result may bring new insight.

CONCLUSION

In the cost reduction R&D for power coupler, TiN coating-free ceramic was developed by KYOCERA, and the power couplers were developed, fabricated, and tested by KEK, CERN and TETD. Although they satisfied the specifications of the bench test (keeping 800 kW for over 1 hour under the RF conditions of 1.65 msec/5 Hz), the dielectric loss tangent was high and a strange heating phenomenon was also observed. From now on, it is necessary to promote research on the ceramic.

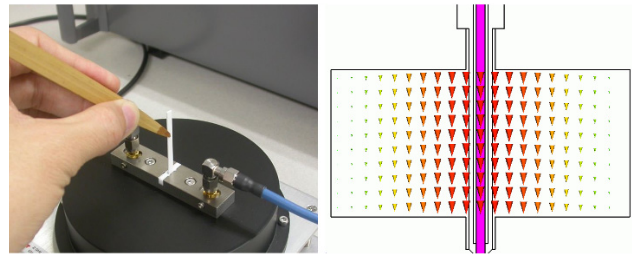

Figure 3: Measurement of relative permittivity and dielectric loss tangent for TiN coating-free ceramic (left: setup, right: schematic view).

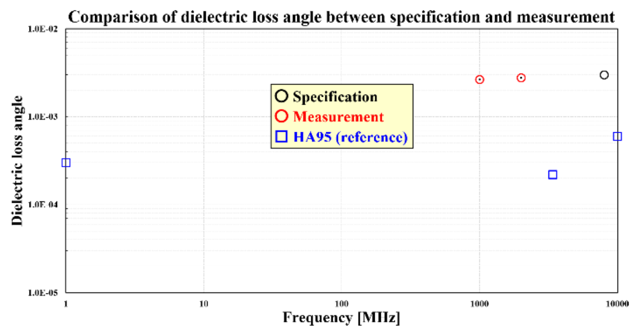

Figure 4: Result of dielectric loss tangent for TiN coating-free ceramic. The specification of HA95 is shown in ref [6].

ACKNOWLEDGEMENT

The authors would like to thank KYOCERA for the development of this new ceramic. Special thanks are given to these companies; NAT, K-VAC, and KIS.

REFERENCES

[1] E. Kako *et al.*, "Advances and Performance of Input Couplers at KEK", *in Proceedings of SRF2009*, Berlin, Germany, pp. 485-490.

[2] Y. Yamamoto *et al.*, "Achievement of Stable Pulsed Operation at 36 MV/m in STF-2 Cryomodule at KEK", *in Proc. of SRF2017*, Lanzhou, China, Jul. 2017, pp. 722-728, doi:10.18429/JACoW-SRF2017-THYA02

[3] Y. Yamamoto *et al.*, "STF-2 Cryomodule Performance and New Input Coupler R&D for ILC", PoS(ICHEP2016)066, ICHEP2016, Chicago, U.S.

[4] Y. Yamamoto *et al.*, "High Power Test for Plug-compatible STF-type Power Coupler for ILC", *in Proc. of SRF2017*, Lanzhou, China, Jul. 2017, pp. 199-204, doi:10.18429/JACoW-SRF2017-MOPB064

[5] Y. Yamamoto *et al.*, "Fundamental Studies for the STF-type Power Coupler for ILC", *in Proc. of SRF2017*, Lanzhou, China, Jul. 2017, pp. 194-198, doi:10.18429/JACoW-SRF2017-MOPB063

[6] https://www.ngkntk.co.jp/english/product/list/property.html