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FUNDAMENTAL STUDIES FOR THE STF-TYPE POWER COUPLER FOR ILC

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Abstract

From the view point of mass-production for the power coupler in ILC (International Linear Collider), the fundamental studies for the STF-type power coupler are under progress by the collaboration between KEK and TETD. At present, there are various rinsing procedures for power coupler in the world-wide laboratories. In this R&D, the main topic is to investigate the various rinsing effects in the copper plating and the ceramic through the high power test. In this paper, the first results will be presented.

INTRODUCTION

In recent years, the SRF accelerator with several hundreds of superconducting cavities becomes standard in the real world. For example, ~800 cavities are used for European X-ray Free Electron Laser (E-XFEL) [1], ~300 cavities for Linac Coherent Light Source II (LCLS-II) [2], and ~100 for European Spallation Source (ESS) [3]. Naturally, the number of cavity is same as that of power coupler. The quality control in the mass-production of the power coupler is significantly important, similar to the cavity. Actually, the quality control of the power coupler was significant in E-XFEL [4]. The points in the quality control are the copper plating, the ceramic quality, the Titanium-Nitride (TiN) coating procedure, the rinsing procedure, and so on. As the first milestone, this R&D started from the quality check of the copper plating, and the rinsing effect by the different method in the power coupler.

FABRICATION OF TEST PIECES

At first, the 20 test pieces were fabricated for the copper plating, and the ceramic as shown in Figure 1. Each specification is described in the following:

Copper Plating Sample

The specification of the copper plating is as follows:

- Substrate: SUS316L
- Size: 50 mm x 100 mm x 5 mm
- Thickness of copper plating: 25 µm
- Base plating: Gold strike
- Copper plating: Pyrophosphate

During the process of copper plating from test piece #7 to #9, the quality was suddenly changed due to the malfunctioning in the pre-cleaning process, and then another process line was used after grinding the "No good" copper plating, and consequently, it was successfully done from test piece #7.

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Ceramic Sample

The specification of the ceramic sample is as follows:

- Purity: 95%
- Size: 19 mm (diameter) x 3mm (thickness)
- Relative permittivity: 8.8 @10GHz
- Dielectric loss tangent: 6 x 10^{-4} @10GHz
- Resistivity: >10^{12} Ω·m

This type of ceramic has been used for the STF-2 power couplers installed into the S1-Global, the capture, and the STF-2 cryomodules [5].

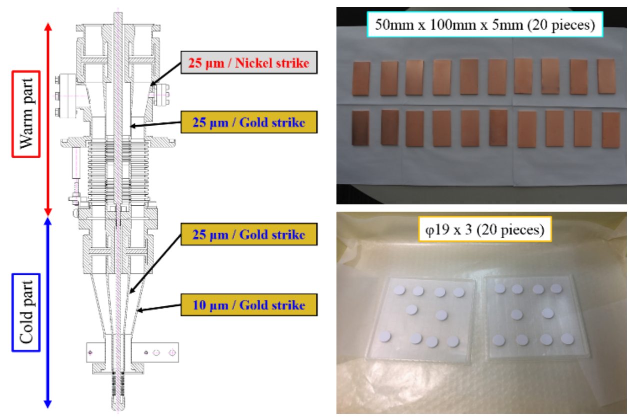

Figure 1: Plug-compatible STF-type power coupler (left), and the test pieces for the copper plating and the ceramic (right).

STUDY FOR COPPER PLATING

The first goal is the investigation for the various rinsing procedures carried out in the various laboratories in the world. Specifically, the rinsing effect was investigated by the following three methods:

- Ultrapure water rinsing; used in STF
- Ultrasonic rinsing; used in E-XFEL, ESS
- Ozonized water rinsing; used in Super-KEKB

Heat Treatment

After the copper plating process, the test pieces were heat-treated for about 30mins at 800℃, and after that, two pieces had many blisters on the edge region as shown in Figure 2. These blisters are quite similar to that observed at the cold part #1 for the plug-compatible STF-type power coupler [6]. Presumably, the hydrogen gas remained inside the copper plating layer after the copper plating process, then, it swelled during the heat treatment, and the copper plating also had many blisters. However, it is difficult to spot the quality of copper plating as "No good" at the incoming inspection after the copper plating process. In the mass-production, it is crucial to keep checking the quality

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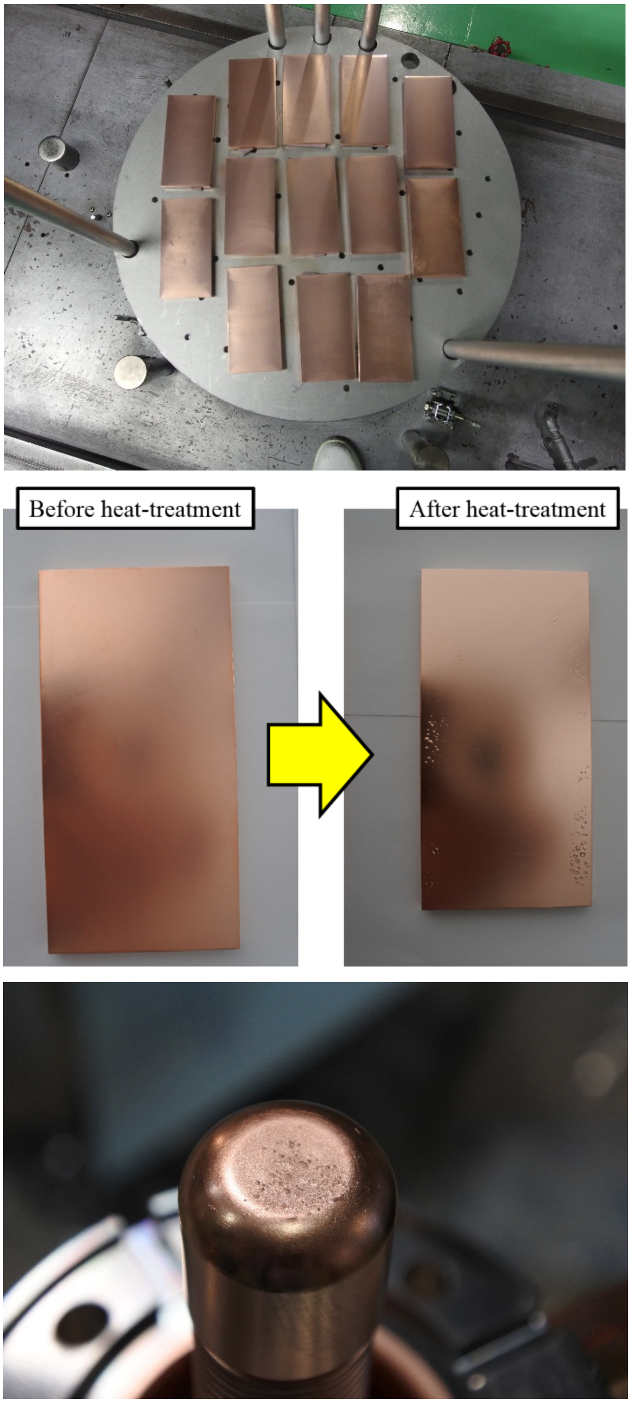

Figure 2: Installation of the copper plating samples into the heating furnace (top), comparison of test piece #2 before and after the heat treatment (middle), and many blisters observed on the inner conductor head of the cold part #1 for the plug-compatible STF-type power coupler (bottom).

of copper plating using the test pieces with the fabrication of power couplers.

Study for Ultrasonic Rinsing

The study of the ultrasonic rinsing (USR) for the copper plating samples was done at the four steps from 120 W to 1200 W for the power of the ultrasonic as shown in Table 1. The surface of copper plating was inspected by the digital microscope (MIYOSHI UK-03). In the last rinsing, the water resonant system (WRS) was used to decrease the number of bubble, and increase the power of the ultrasonic up to the 1.5 times higher level. There was no change before the last rinsing. However, after the last rinsing, the copper plating was partly peeled off as shown in Figure 3. This means the "No good" copper plating could be damaged by the ultrasonic rinsing, especially in the higher power level. Similarly, if the ultrasonic rinsing with higher power level was done for the cold part #1, the copper plating at the head might be peeled off.

Table 1: Condition of The Study for USR

# of USR	Power level	Rinsing time	WRS
1st rinsing	120 W	30 min.	w/o
2nd rinsing	360 W	30 min.	w/o
3rd rinsing	1200 W	30 min.	w/o
4th rinsing	1200 W	30 min.	w/

Peeling Test for Test Piece #2

During the study for the ultrasonic rinsing between 1st and 3rd rinsing, the peeling test by some tapes, which specification is listed in Table 2, was done to investigate the adhesion of copper plating with blisters for the only test piece #2 as shown in Figure 4. In Japan, the peeling test is standardized by Japanese Industrial Standards (JIS H 8504:1999). "CELLOTAPE No.405" has the same adhesion strength as JIS. The process is as follows:

- Attaching each tape on the coated surface with many blisters
- Waiting for 10 sec
- Pulling up perpendicular to the coated surface

The peeling test was done in order of the increasing adhesion strength. After the last test, there was no change for many blisters, and it was clear that they have hard structure beyond expectation.

Table 2: Specifications for JIS and Each Tape

Content	Tape width	Adhesion strength
JIS		8 N / 25 mm
3M #244	18 mm	2.7 N / 25 mm
CELLOTAPE No. 405	15 mm	9.8 N / 25 mm
3M #2525	18 mm	18.8 N / 25 mm

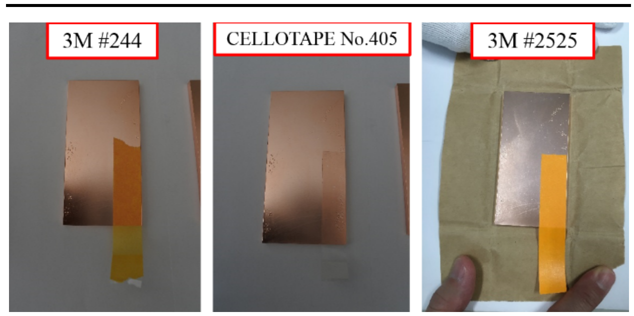

Figure 4: Three kinds of tape used for the peeling test.

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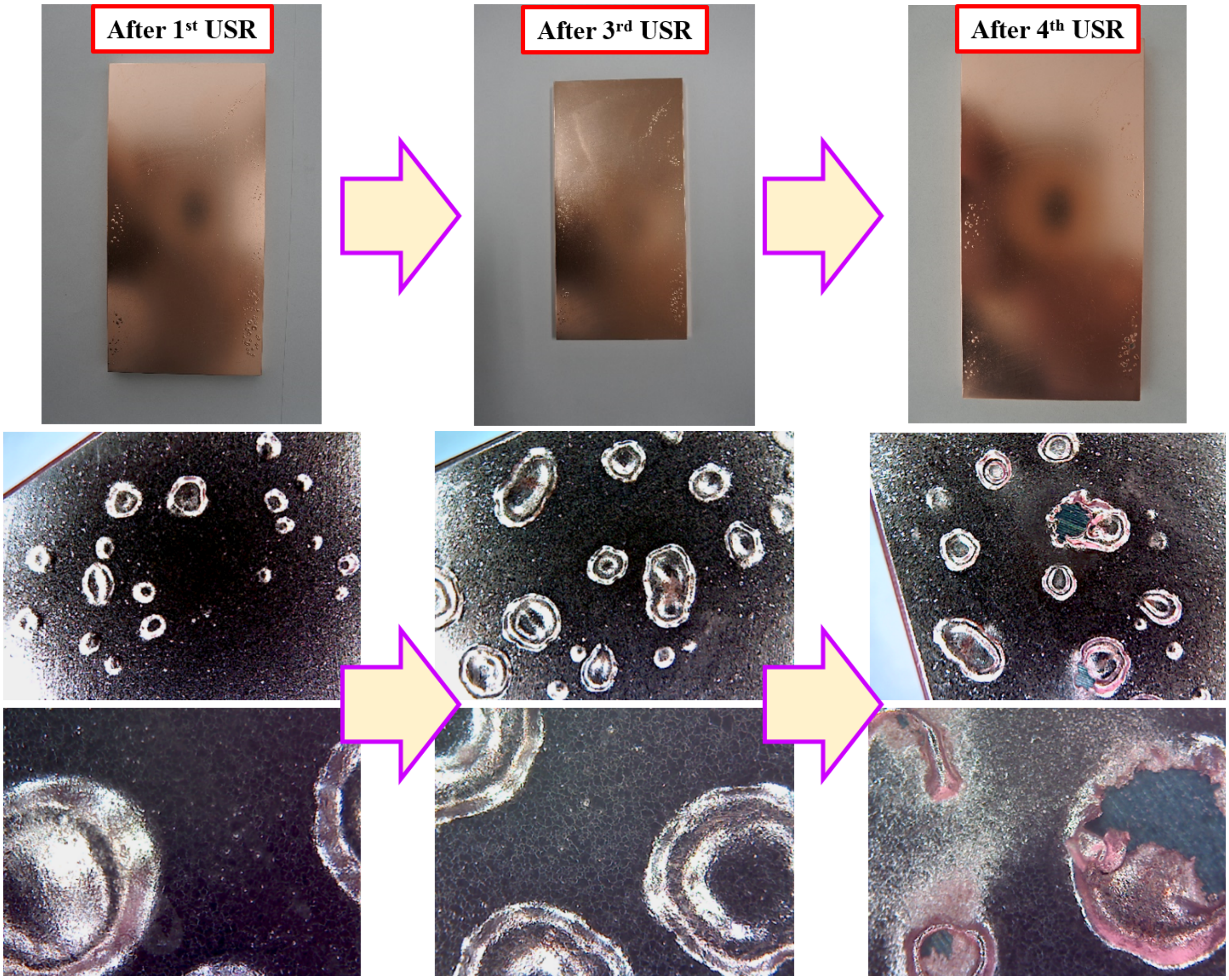

Figure 3: Change of the surface for test piece #2 in the study of the ultrasonic rinsing. After the heat treatment, many blisters appeared, not changed after the 3rd ultrasonic rinsing (left and center), however, in the last rinsing, blisters were partly peeled off (right).

Study for Ozonized Water Rinsing

The ozonized water rinsing has been used for the power coupler in KEKB [7]. In this R&D, test piece #10, #11, and #12 were tested to investigate the effect of the ozonized water rinsing. The condition is as follows:

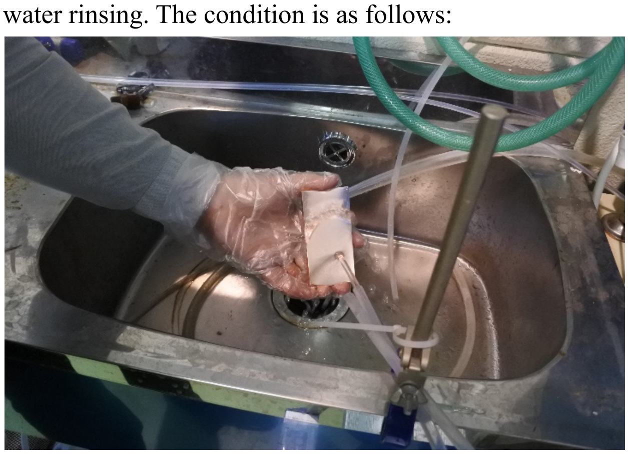

Figure 5: Ozonized water rinsing for the test piece of the copper plating.

- Concentration: 7~8 ppm
- Rinsing time: 20~30 sec
- Flow rate: 2 ℓ/min

After the ozonized water rinsing as shown in Figure 5, the copper plating was not peeled off, and not the colour also changed. As a result, that did not damage for the copper plating.

Figure 6 shows the summary of the above results using the copper plating samples. The important thing is that the malfunctioning in the pre-cleaning process during the copper plating can affect the post processes.

ULTRASONIC RINSING AND HIGH POWER TEST FOR POWER COUPLER

After the study for the test pieces, the ultrasonic rinsing was successfully done for the plug-compatible STF-type power coupler with the same condition as the first rinsing, as shown in Figure 7. Before and after the ultrasonic rinsing, the copper plating with many blisters at the head of the cold part #1 was not changed. The condition of the ultrasonic rinsing in each project is summarized in Table 3.

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Test piece #	As delivered	After 800℃ heat-treatment	After 1st USR (120W, 30min, w/o WRS)	After 2nd USR (360W, 30min, w/o WRS)	After 3rd USR (1.2kW, 30min, w/o WRS)	After 4th USR (1.2kW, 30min, w/ WRS)
1	Storage					
2		Blister	No change	No change	No change	Partly peeled, white-colored
3			No change	No change	No change	No change
4		Blister	No change	No change	No change	Partly white-colored
5	Storage					
6			No change			
7	Good gloss	No change	No change			
8	Good gloss	No change	No change			
9	Good gloss	No change	No change	No change	No change	No change
Test piece #	As delivered	After 800℃ heat-treatment	After O_3 rinsing (30sec)			
10		No change	No change			
11		No change	No change			
12		No change	No change			

Figure 6: Summary of study for copper plating samples. Test pieces #1 ~ #6 (Yellow) experienced the malfunctioning in the pre-cleaning process. Test pieces #7 ~ #9 (Light blue) experienced grinding the "No good" copper plating surface, and was processed by another line. Test pieces #10 ~ #12 (Purple) was processed by another line.

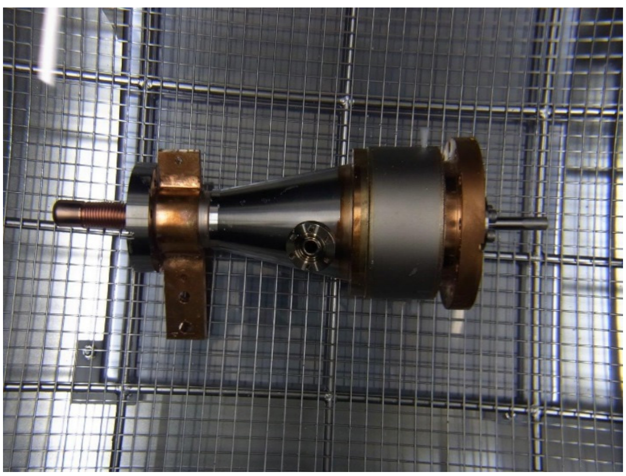

Figure 7: Ultrasonic rinsing for the plug-compatible STF-type power coupler by the same condition as the first rinsing for the copper plating samples.

Table 3: Comparison of Ultrasonic rinsing Procedures in Various SRF Projects [8, 9]

Content	STF	E-XFEL	ESS
Power [W]	120	2000	3000
Power per liter [W/ℓ]	2.6	10	8
Frequency [kHz]	38	35	25
Water temperature [℃]	~25	50	50
Detergent	none	Tickopur R33 (2.5%)	Tickopur R33 (2.75%)
Time duration [min]	30	15	10
Bath size [ℓ]	468		375

After the ultrasonic rinsing, the assembly work for the high power test bench was done by the same procedure as 2016 [6]. The processes of the low/high power tests were also almost same, and the condition of the pulse width partly changed. Figure 8 shows the comparison of the RF conditioning time between the ultrapure water rinsing in 2016 and the ultrasonic rinsing in 2017. In the pulse width of 500µsec in 2017, although the vacuum level became temporarily worse, the RF conditioning was well-done in the end. That is the reason for the longer conditioning time than 2016.

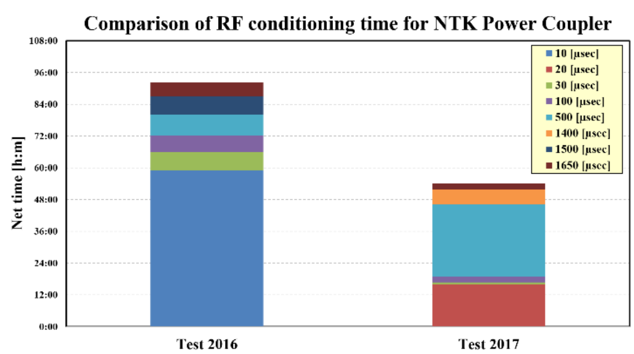

Figure 8: Comparison of the RF conditioning time between the ultrapure water rinsing in 2016 and the ultrasonic rinsing in 2017 for the plug-compatible STF-type power coupler.

Figure 9 shows the correlation plot between the forward power and the cold vacuum level for the short (left) and long (right) pulse width. As the overall trend, the vacuum level in 2017, tested after the ultrasonic rinsing, was lower than 2016, tested after the ultrapure water rinsing. On the other hand, the warm vacuum level was almost same as 2016. This means that the lower vacuum level for the only cold part might be brought by the ultrasonic rinsing. As the next step, the high power test is still under progress for the plug-compatible STF-type power coupler with TiN coating-free ceramic. The result will be presented in near future.

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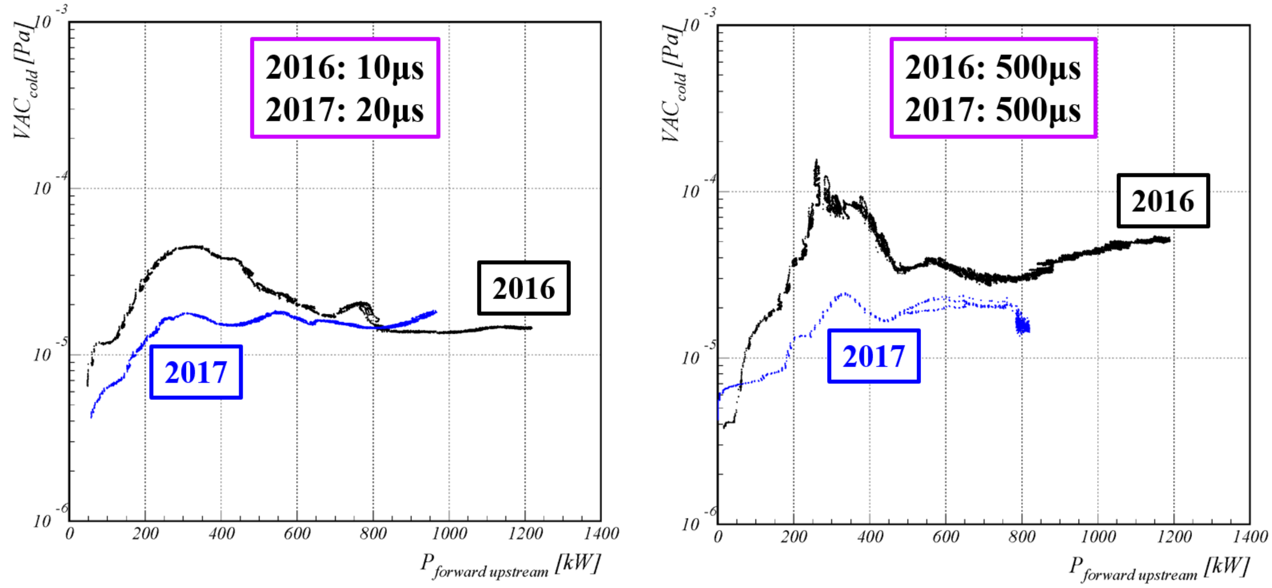

Figure 9: Comparison of the vacuum level in the cold part during the high power test between 2016 and 2017. Left; Result of the short pulse width (10μsec in 2016, and 20μsec in 2017). Right; Result of the long pulse width (500μsec in 2016 and 2017).

CONCLUSION

The ultrasonic rinsing did not damage for the copper plating samples, however, if the quality of the copper plating is "No good", peeling the copper plating off might occur in the higher power level. Consequently, the "No good" copper plating can affect the post processes, that is, the heat treatment, the ultrasonic rinsing, and so on. As for the ultrasonic rinsing for the power coupler, there might be the trend that the vacuum level becomes lower.

FUTURE PLAN

As the next step, the secondary electron emission coefficient in the ceramic samples will be measured for the various rinsing procedures, that is, the ultrapure water rinsing, the ultrasonic rinsing, and the ozonized water rinsing. And, the same process will be also done for the coating-free ceramic samples.

As for the R&D using the power couplers, the ultrasonic rinsing for the warm part will be done up to the same level as E-XFEL, and after that, the ozonized water rinsing will be similarly tested.

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REFERENCES

[1] E-XFEL, http://www.xfel.eu/

[2] LCLS-II, https://portal.slac.stanford.edu/sites/lcls_public/lcls_ii/Pages/default.aspx

[3] ESS, https://europeanspallationsource.se/

[4] D. Kostin and W. Kaabi, World Wide Fundamental Power Coupler meeting #3, https://indico.cern.ch/event/642503/

[5] Y. Yamamoto *et al.*, "Achievement of Stable Pulsed Operation at 36 MV/m in STF-2 Cryomodule at KEK", presented at SRF2017, Lanzhou, China, paper THYA02, this conference.

[6] Y. Yamamoto *et al.*, "High Power Test for Plug-compatible STF-type Power Coupler for ILC", presented at SRF2017, Lanzhou, China, paper MOPB064, SRF2017, this conference.

[7] Y. Kijima *et al.*, "Input Coupler of Superconducting Cavity for KEKB", in Proc. EPAC2000, Vienna, Austria, June. 2000, paper THP1A11, pp. 2040-2042.

[8] D. Kostin, private communication, Jul. 2017.

[9] C. Arcambal *et al.*, "Conditioning of the Power Couplers for the ESS Elliptical Cavity Prototypes", in *Proc.IPA2017*, Copenhagen, Denmark, paper MOPVA044, pp. 957-959.