

第15回日本加速器学会年会

Recent results on power coupler R&D for future accelerators

Yasuchika Yamamoto (KEK)

Member list

Y. Yamamoto, E. Kako, T. Matsumoto, S. Michizono, A. Yamamoto (KEK)

M. Irikura, M. Ishibashi, K. Tetsuka, H. Yasutake (TETD)

Y. Okii (Nomura plating Co., Ltd.)

C. Rin, H. Funo (TIGOLD Corporation; attributed to ULVAC)

E. Montesinos, C. Julie (CERN)

W. Kaabi, H. Guler (LAL/IN2P3)

C. Arcambal, E. Cenni, F. Aurelien (IRFU/CEA)



**TOSHIBA ELECTRON
TUBES & DEVICES**

NOMURA PLATING
株式会社野村鍍金



LAL
LABORATOIRE
DE L'ACCÉLÉRATEUR
LINÉAIRE



ULVAC タイゴールド株式会社 Tigold Corporation

Outline

- ◆ Cost reduction in power coupler
- ◆ R&D Items
 - ◆ TiN coating-free ceramic
 - ◆ Ceramic property
 - ◆ Copper plating
 - ◆ TiN coating
- ◆ Summary

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US-JAPAN cost reduction R&D

昨年度から日米の間でSRFのcost reductionのためのR&Dが始まっている

Presented by S. Michizono

Short-term R&D (2–3 years)

A-1. Niobium material preparation

- with new processing for sheeting and piping

A-2. SRF cavity fabrication for high gradient and high Q

- with a new surface process recipe provided by Fermilab

A-3. Power input coupler fabrication

- with new-ceramic window (w/o additional coating)

A-4. Cavity chemical treatment


- with vertical configuration and new chemical

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TiN coating-free ceramic as new material

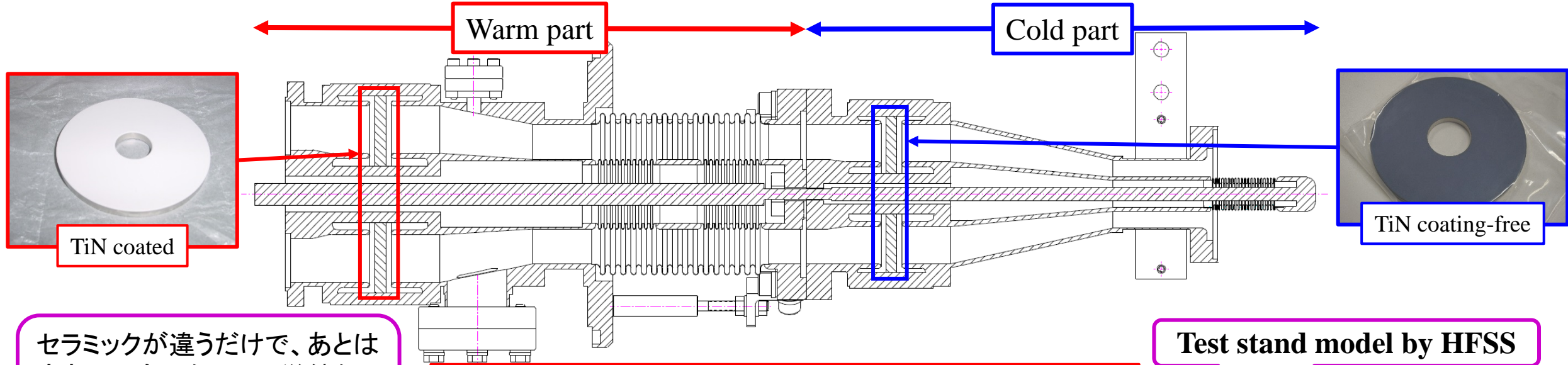


			99.8% Alumina for RF Application (A479B)	AH100A	LSEEC	
Electrical Property	Volume Resistivity	ohm·cm	min. 1 X 10 ¹⁴	min. 1 X 10 ¹⁴	-	
	Surface Resistivity	ohm/□	8.9 X 10 ¹⁴	7.4 X 10 ¹⁵	1.2 X 10 ¹⁴	
	SEE Coefficient	-	11.4	4.6	3.2	
	Dielectric Constant	1MHz	-	9.9	10.2	-
		8GHz	-	9.9	10.0	10.0
	Dielectric Loss Angle	1MHz	-	1 X 10 ⁻⁴ *1	1 X 10 ⁻⁴ *1	-
8GHz		-	4 X 10 ⁻⁵	1 X 10 ⁻⁴	3 X 10 ⁻³	
Mechanical Property	Ave. Flexural Strength(RT) ASTM D2442 TYPE3	MPa	300	330		
	Young's Modulus	GPa	370	380		
	Poisson Ratio	-	0.23	0.25		
Thermal Property	Thermal Conductivity (RT)	W/mK	29	24	-	
	Coeff. Thermal Expansion	RT-400deg.C	ppm/K	7.0	7.4	-

元々、二次電子放出係数が低く、窒化チタンコーティングの不要なセラミックが京セラ社により開発された。ただし、誘電損失が高く、ハイパワー投入時の発熱が気になるところである。

K. Iwamoto, et al., in TTC meeting 2014

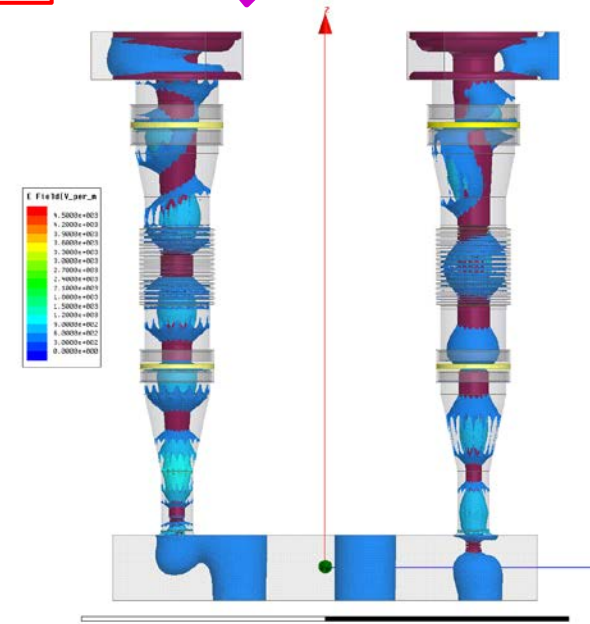
STF-type power coupler with TiN coating-free ceramic



セラミックが違うだけで、あとは全部同じものなので、単純な性能比較には丁度良い。

2014年度にCold側4本、Warm側2本を製造した。

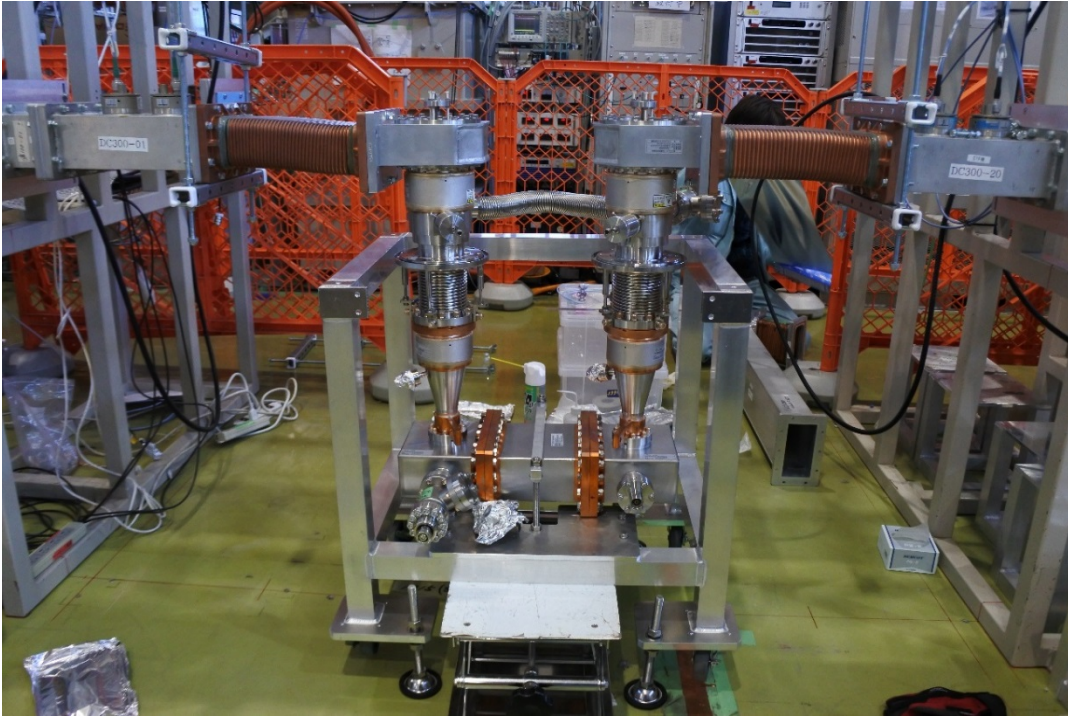
Test stand model by HFSS



Warm側は共通

Ceramic	TiN coating
Cold window (KYOCERA, LSEEC)	free
Cold window (NTG/NTK, HA95)	10 nm (両面)
Warm window (NTG/NTK, HA95)	10 nm (片面)

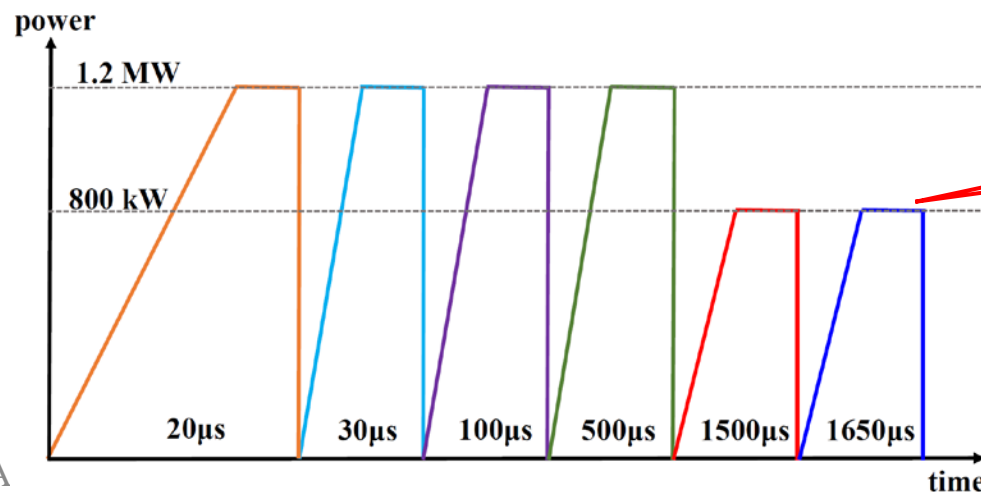
High power test at test bench in STF



Technical interlock system

- ◆ Warm/Cold vacuum level (2×10^{-4} Pa)
- ◆ Arc sensor @ Warm window/waveguide system
- ◆ Forward/backward power limit

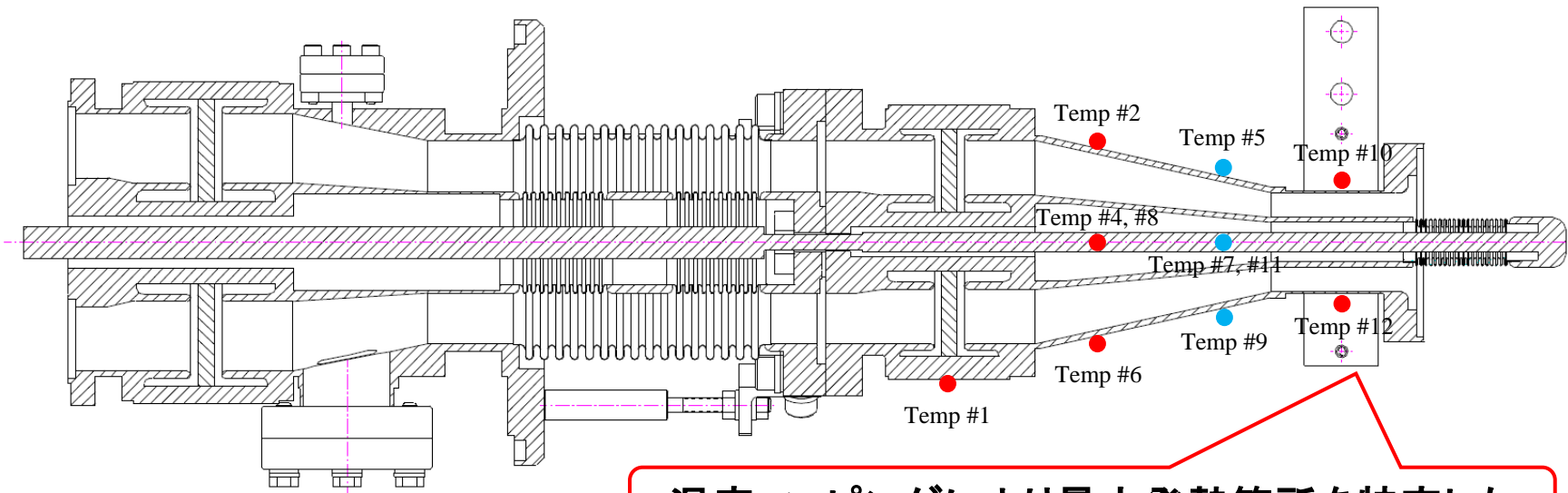
※ No TIL for electron emission @ Cold window



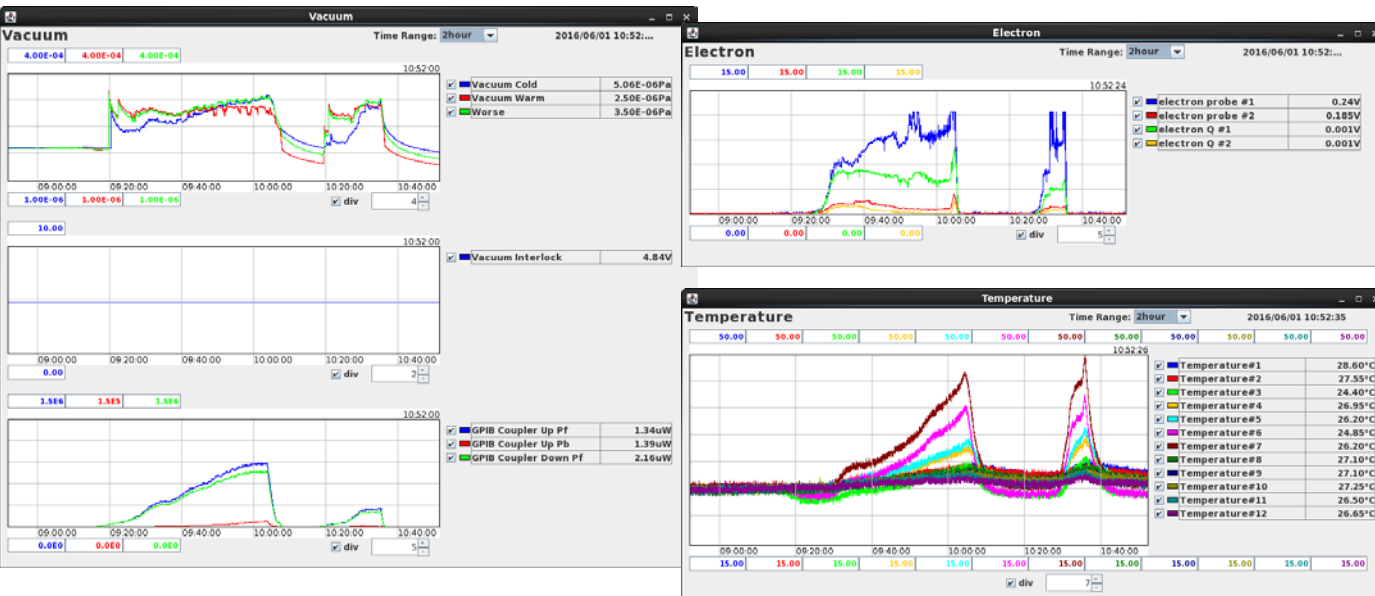
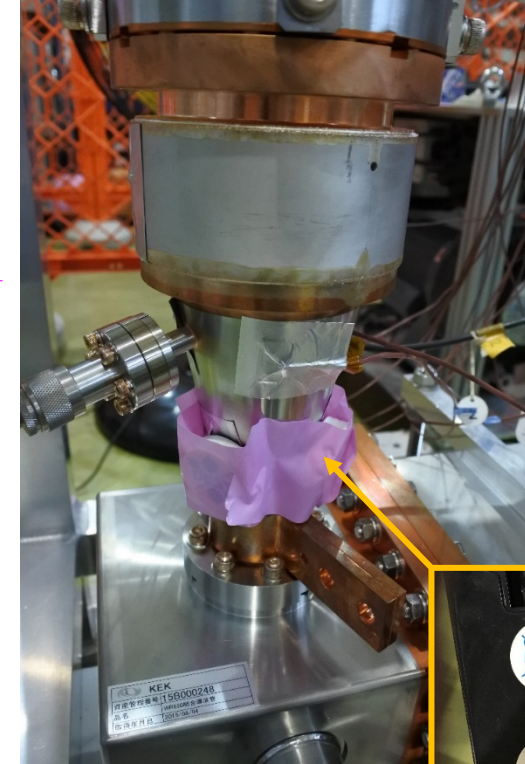
目標は、最大RF dutyのところまで800kWで1時間以上キープ出来るかどうか

RFの繰り返しは5 Hz

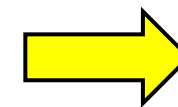
High power test stopped by unusual heating in 2016



温度マッピングにより最大発熱箇所を特定した



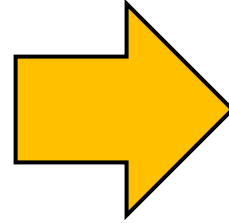
- ✓ 異常発熱による真空圧力の悪化
- ✓ 窓だけでなく(通常は発熱しない)テーパ部が発熱している
- ✓ 磁石を近づけたところ電子出力と温度の振る舞いが変わった
- ✓ セラミックからの電子放出が原因と結論
- ✓ エージングを長時間行なったり、超純水洗浄を再実施しても変化無し



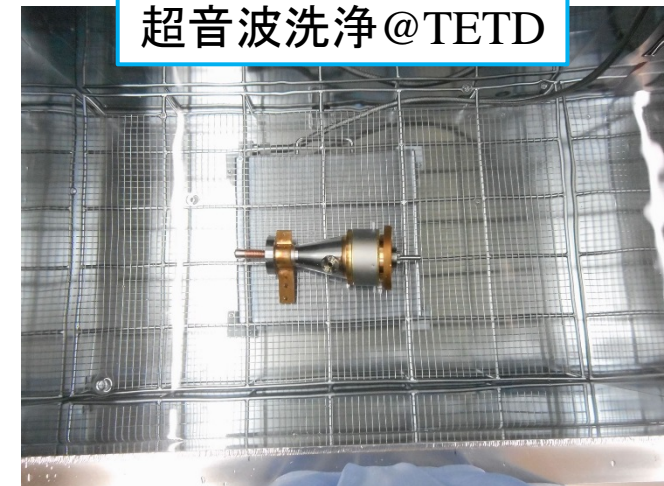
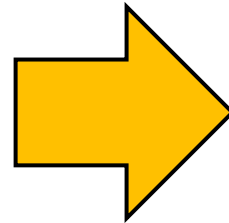
諦めかけていたが...

カップラーの超音波洗浄の実施

- ◆ Ultrapure water rinsing
- ◆ Enormous electron emission
- ◆ Unusual heating



- ◆ **Ultrasonic rinsing**
- ◆ No electron emission
- ◆ Little heating



Comparison of Ultrasonic Rinsing Methods

Company/Institute	TETD (M. Ishibashi)	LAL/IN2P3 (W. Kaabi)	IRFU/CEA (C. Arcambal)	
Project	STF	E-XFEL	ESS	
Vendor	KAIJO	BANDELIN SONOREX TECHNIK RM 180 UH	VWR (USC2600TH)	Branson Ultrason (B 8525-36)
Power [W]	120 ~ 1200 (600)	2000	300	3000
Power per liter [W/ℓ]	0.26 ~ 2.56 (w/ WRS)	10 (at max.)	12	8.6
Frequency [kHz]	38	40	45	25
Water temperature [°C]	~25	50	50 ~ 60	
Detergent		Tickopur R33 (2.5 %)	Tickopur R33 (5%)	Tickopur R33 (2.75%)
Time duration [min]	30	15	10	
Bath size [ℓ]	468	200	25	350



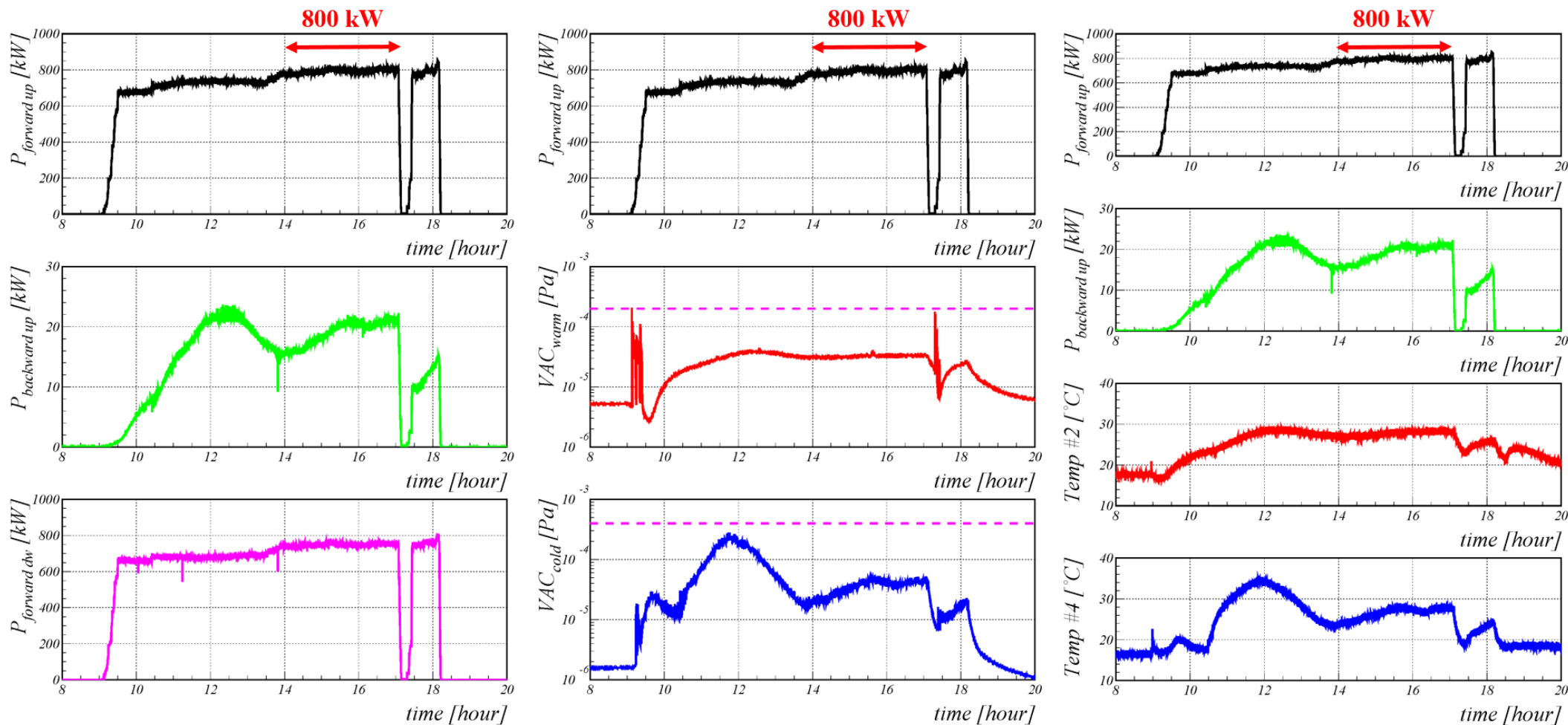
- 海外との相違点
- 超音波のパワー
 - 中性洗剤の使用
 - 水温



超音波洗浄後のハイパワーテストの結果

Trend graph at 1.65 msec/5 Hz

最大RF dutyのところでも800kWを3時間以上キープできた!!



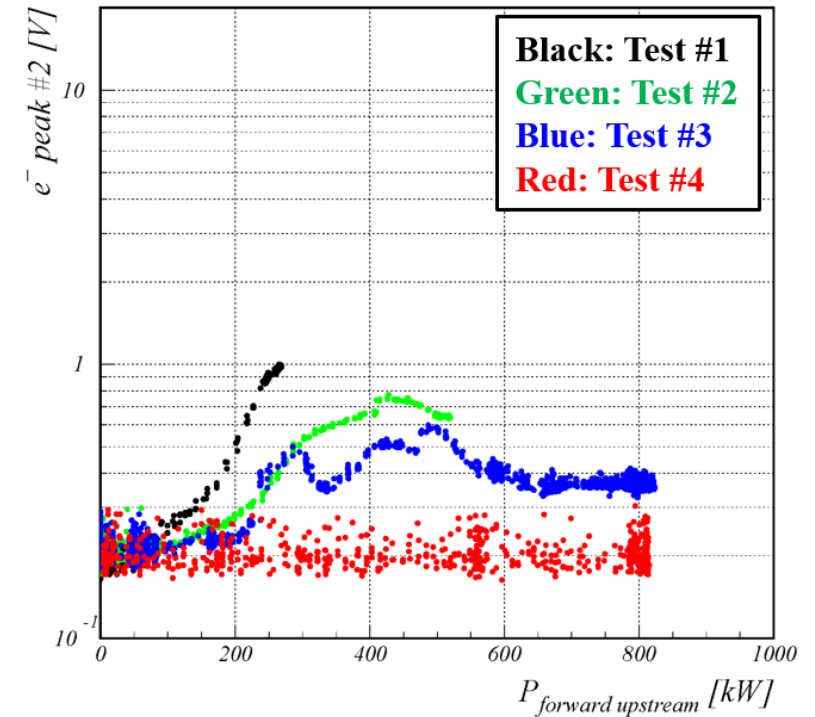
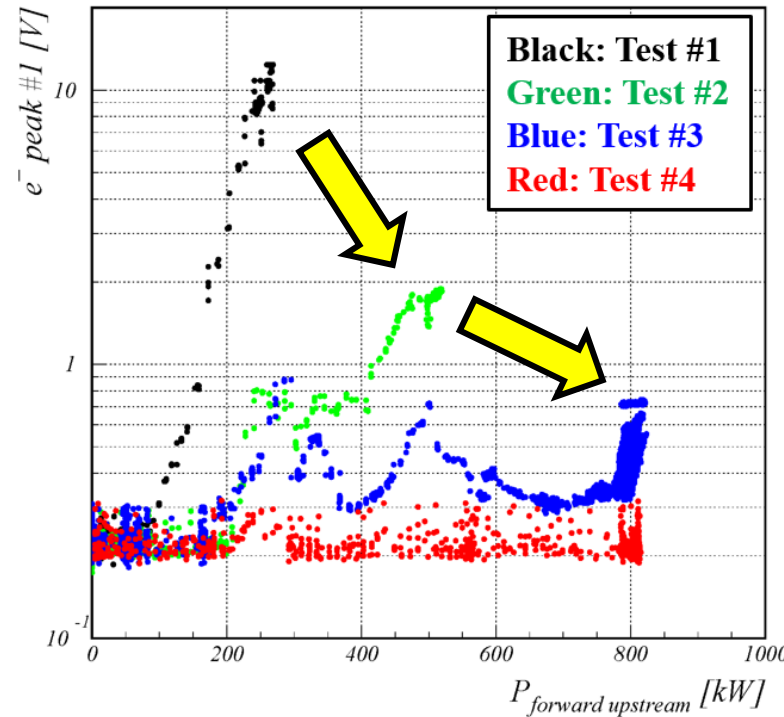
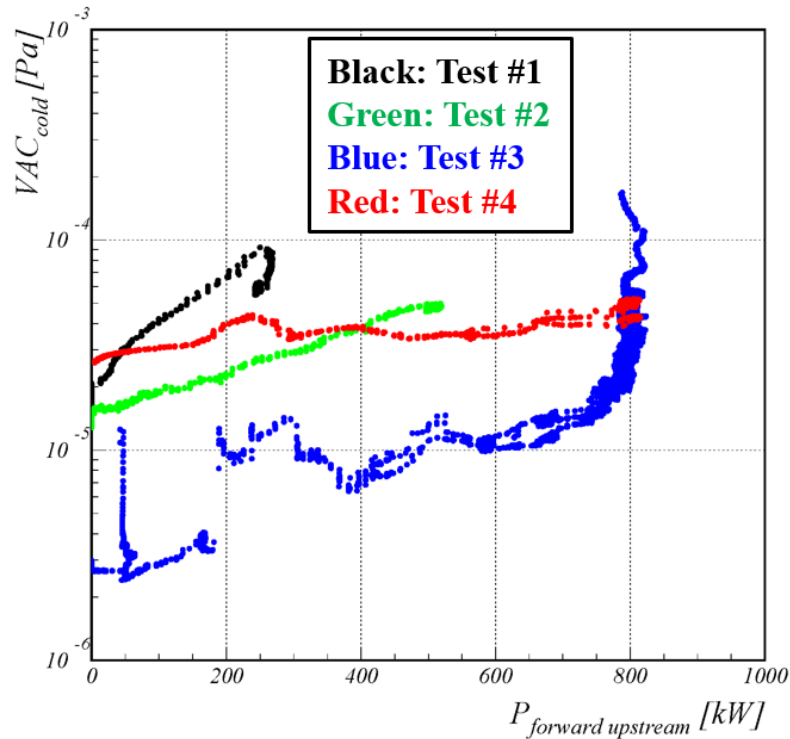
超音波洗浄後は電子出力もアーク出力も全く観測されなかった。

最大RF dutyにおける諸々の相関図の変遷

Ultrasonic rinsing had drastic effect for reduction of electron emission!

Test #1: Black (w/o USR)
Test #2: Green (0.3 W/ℓ)
Test #3: Purple (1.3 W/ℓ)
Test #4: Red (3.8 W/ℓ)

Scattered plot at 1.65 msec/5 Hz



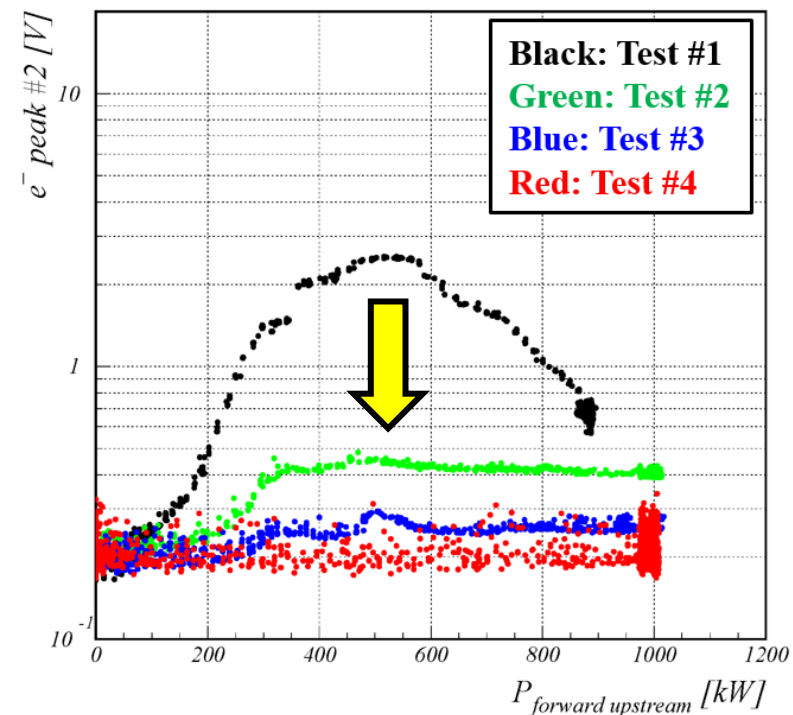
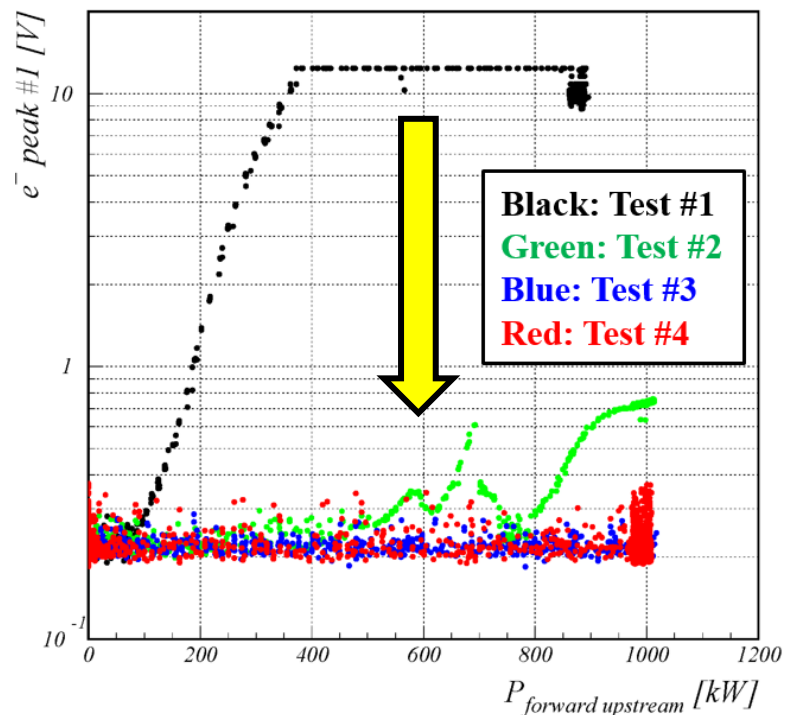
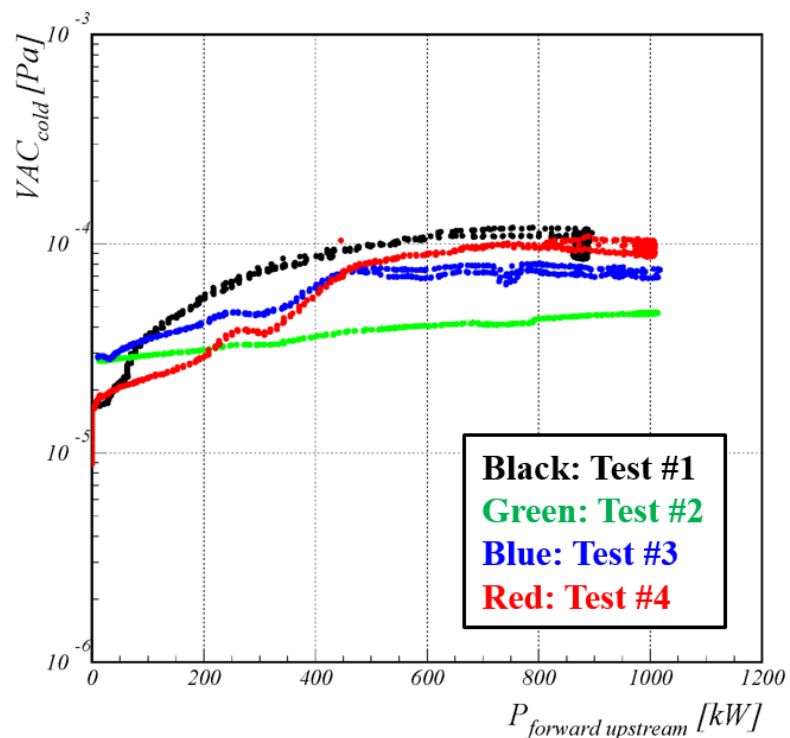
最終的に電子プローブからは何の信号も出てこなくなった

500 μ sec/5Hzの時の相関図の変遷

Ultrasonic rinsing had drastic effect for reduction of electron emission!

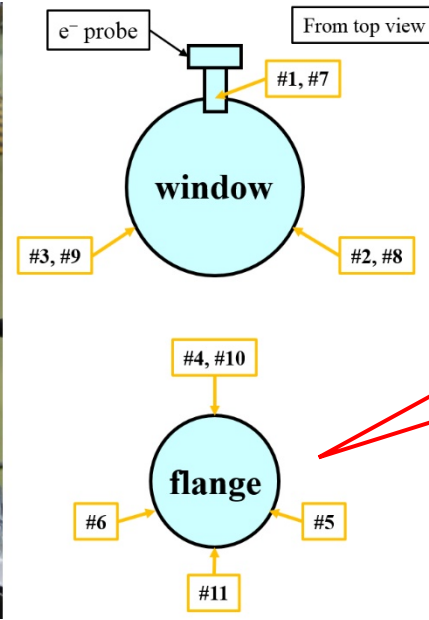
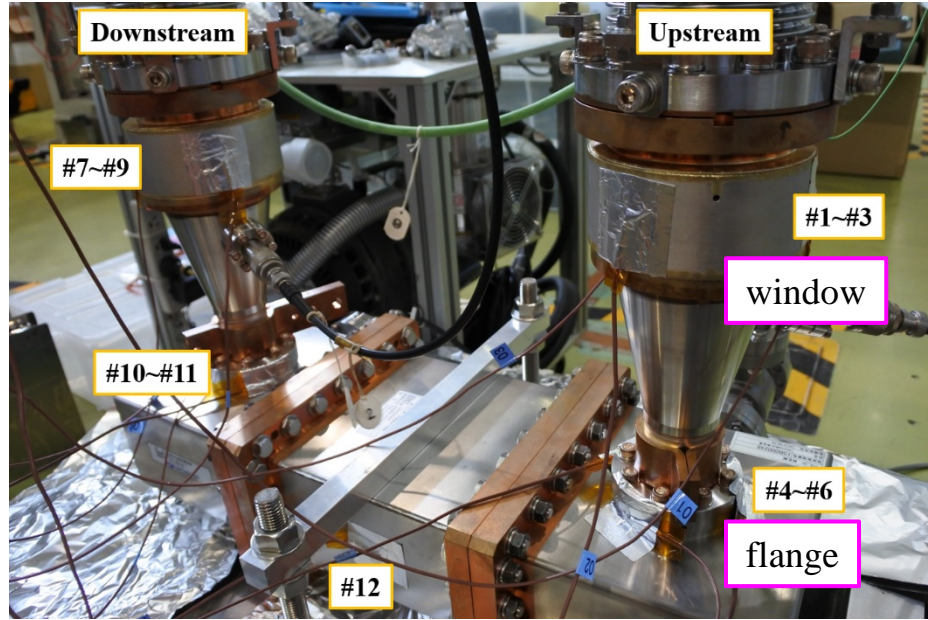
Test #1: Black (w/o USR)
Test #2: Green (0.3 W/l)
Test #3: Purple (1.3 W/l)
Test #4: Red (3.8 W/l)

Scattered plot at 500 μ sec/5 Hz



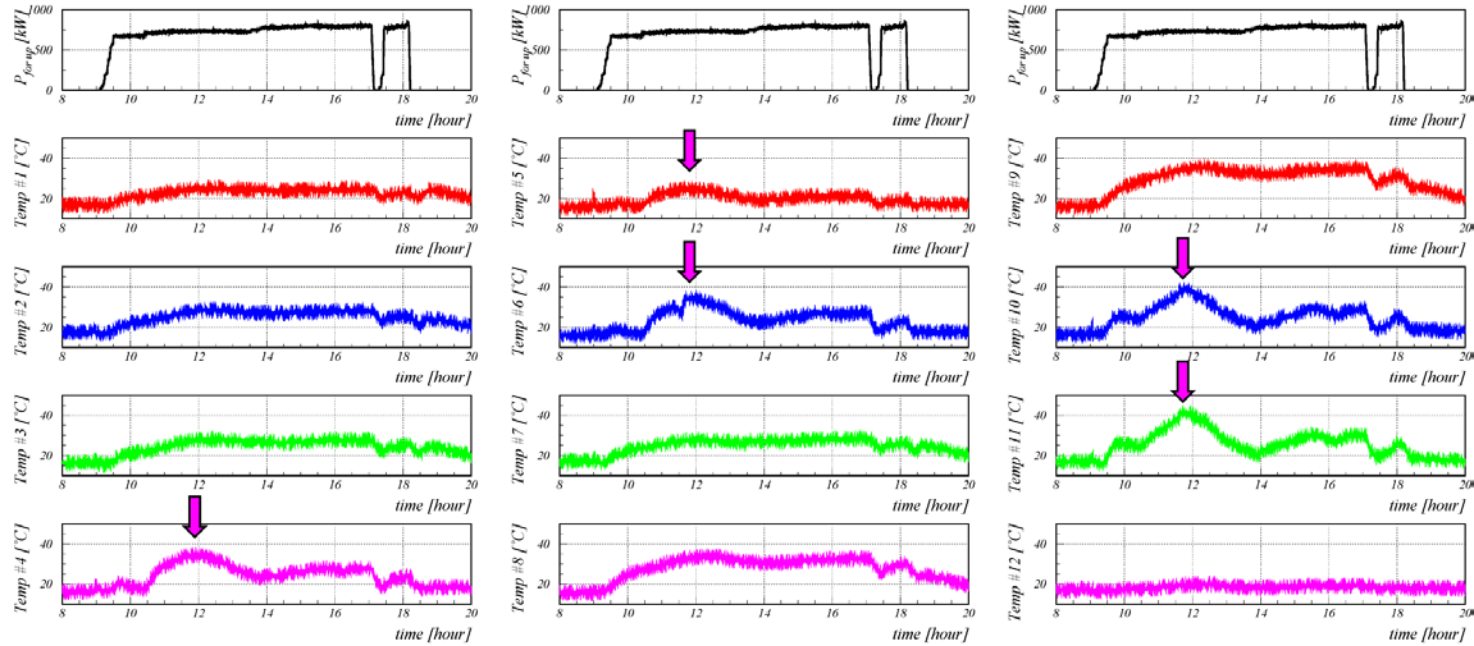
最終的に電子プローブからは何の信号も出てこなくなった

異常な発熱現象はまだ観測されている



Temperature trend at 1650 $\mu\text{sec}/5\text{ Hz}$

今回も温度マッピングを行なった結果、フランジ部に発熱が観測された

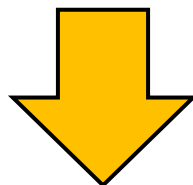


最大RF dutyで750kWキープ時にフランジ部に発熱現象が見られた。これは徐々に無くなっていったが、窓以外の部分が発熱するという意味ではなお問題があるものと考えられる。

“Updated understanding” for TiN coating-free ceramic

Available for normal conducting accelerator, waveguide, klystron

Not available for superconducting cavity due to heating phenomena



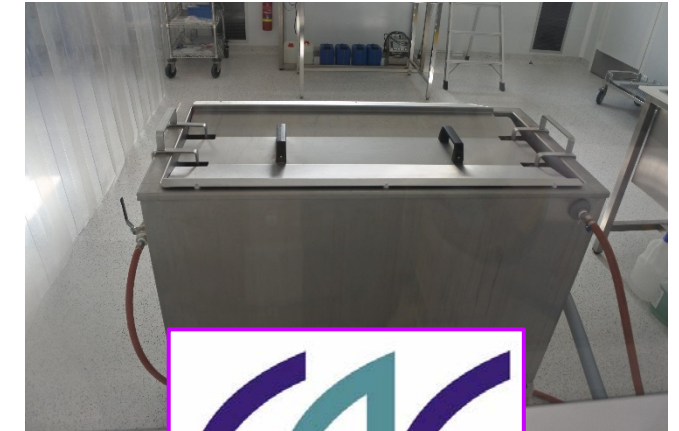
We can try more powerful ultrasonic rinsing!
Heating phenomena may disappear completely.

LALの超音波洗浄装置を使わせてもらう

- ✓ Ultrasonic rinsing → more powerful machine
- ✓ Baking → 150°C or higher
- ✓ High power test → higher power level, cross check for measurement system



KEK sends power couplers to LAL



Ultrasonic rinsing machine
Baking furnace
High power test stand
are still available at LAL

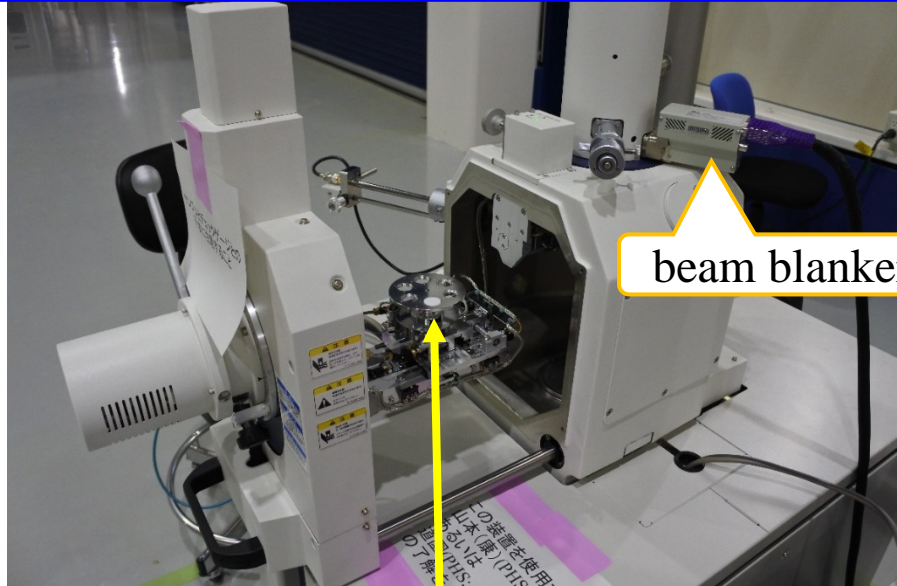
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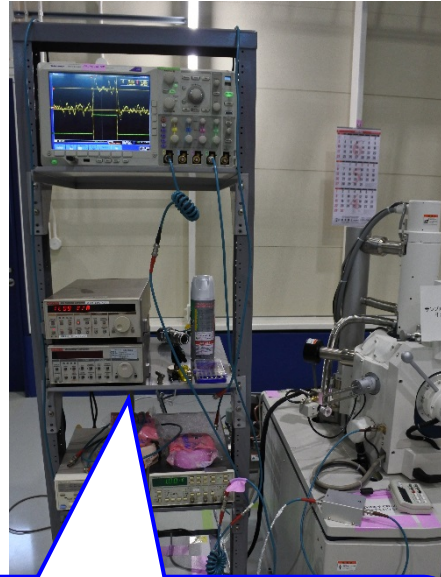
セラミックの二次電子放出係数を測定する

THP053で発表

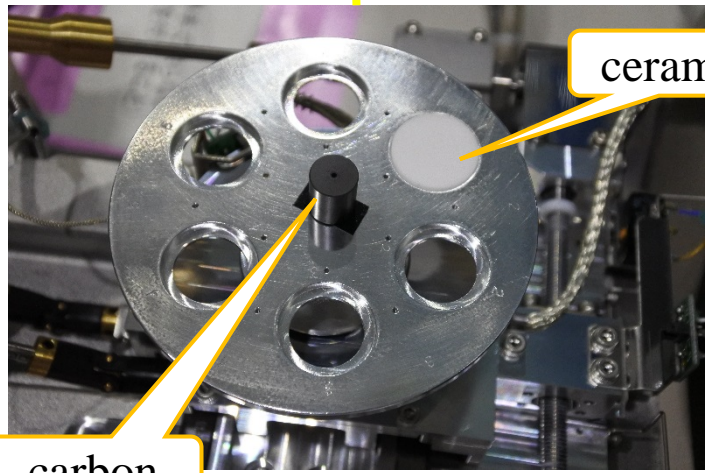
Scanning electron microscope with beam blanker



Measurement device

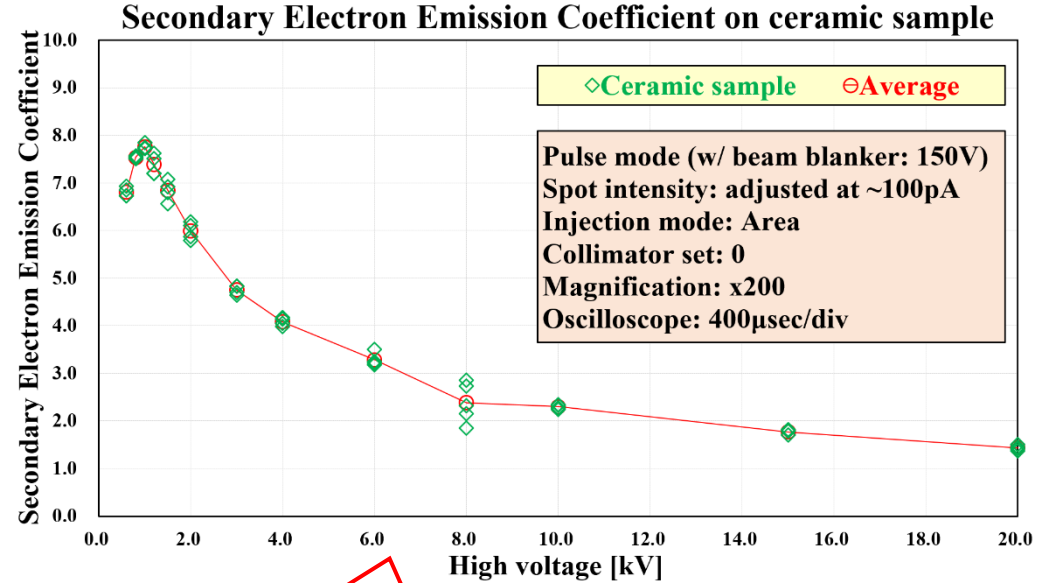
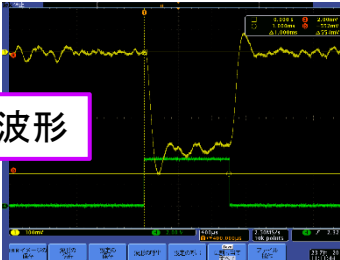


発熱原因や超音波洗浄の効果調べるためセラミックの二次電子放出係数の測定を始めた。4社から6種類のサンプルを集め、これから順次測定していく予定。来年の国際会議にて発表予定。



- ◆ 電流電圧変換器
- ◆ パルスジェネレータ
- ◆ オシロスコープ
- ◆ バイアス電圧モジュール

観測される波形



最近ようやく二次電子の測定に成功した

Research on ceramic properties

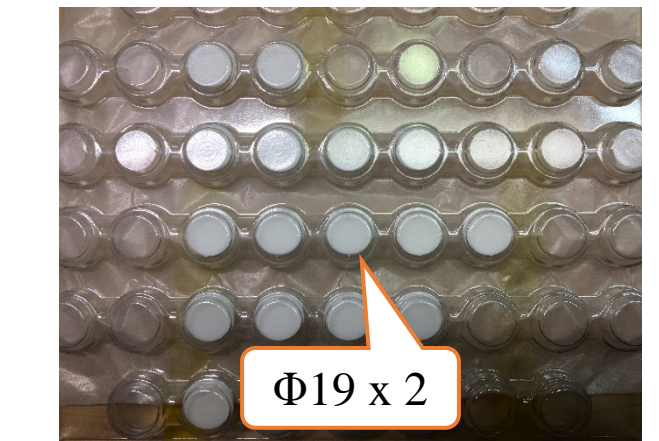
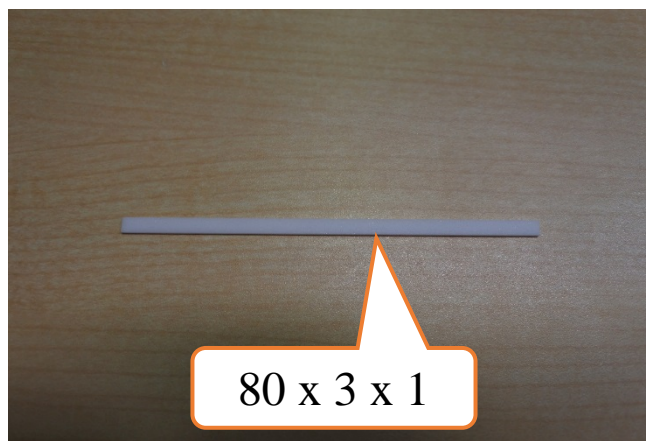
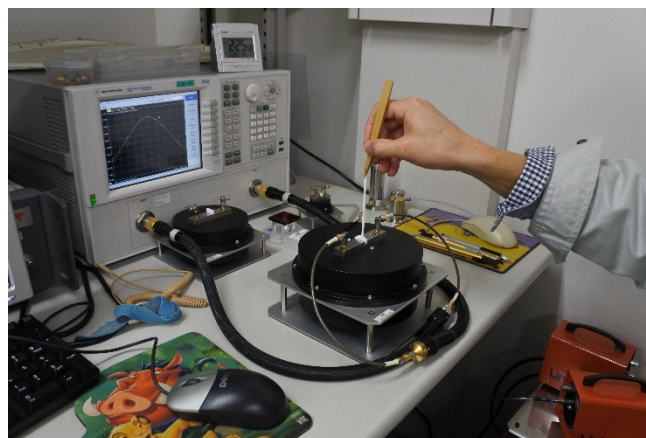
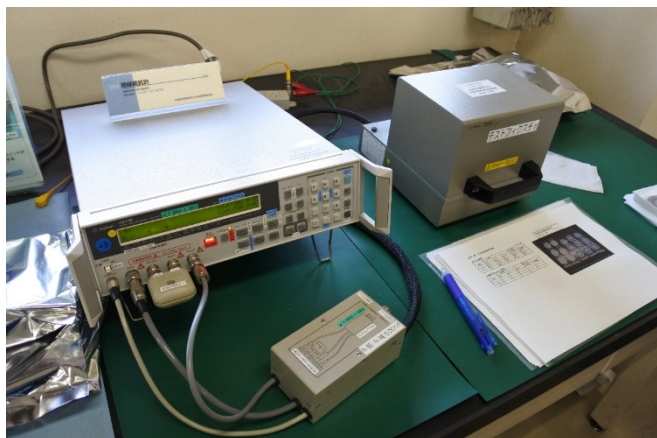
THP053で発表

KEK is researching properties for six kinds of ceramics fabricated by four companies

✓ Surface/Volume resistance

✓ Relative permittivity
Dielectric loss angle

Secondary electron emission



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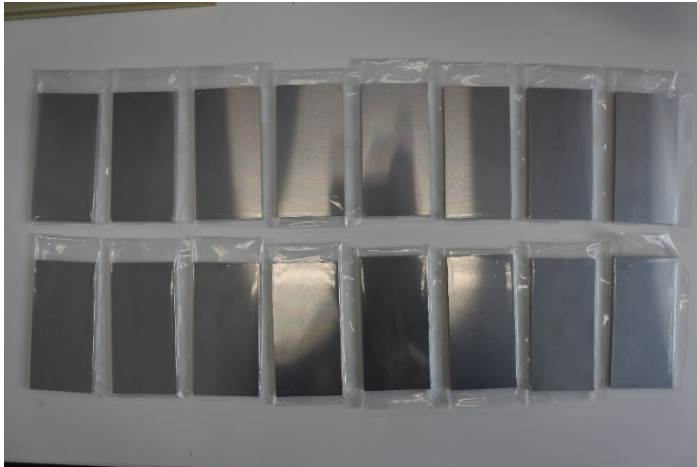
Research on copper plating

THP053で発表

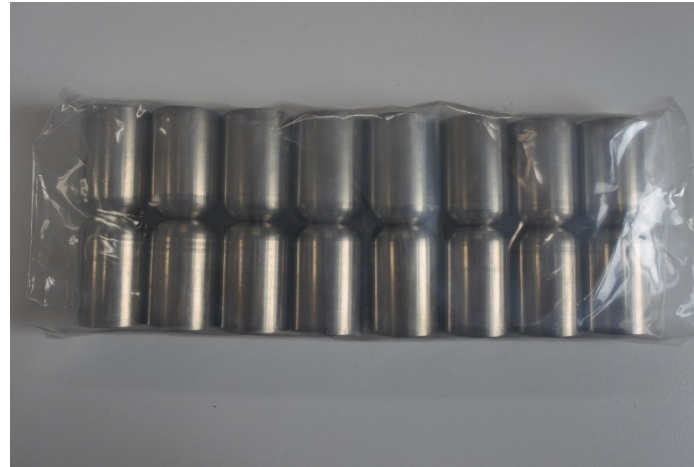
- Research on change after brazing process (heat treatment)
 - RRR measurement in KEK/CEA
 - Analysis of Cu-Ni inter-diffusion by SIMS in LAL
 - Research on plating thickness by KEK/LAL
- Research on adhesion strength
 - Peeling test done by KEK
 - Ultrasonic rinsing test by CEA and LAL
- Cross check for RRR measurement system between KEK and CEA
 - Target RRR: 20 ~ 40 (for ESS)
 - RRR measurement done using same sample by KEK and CEA
- Research on acid temperature dependence (for more effective process)
 - Possible cost reduction (suggested from a vendor)

Three SUS316L samples for copper plating study

Plate shape



Like head of inner conductor



Bar shape



THP053で発表

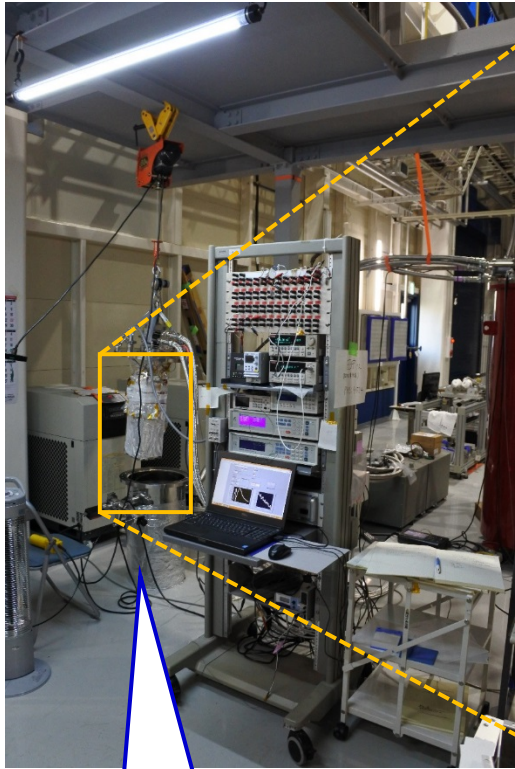
For adhesion test



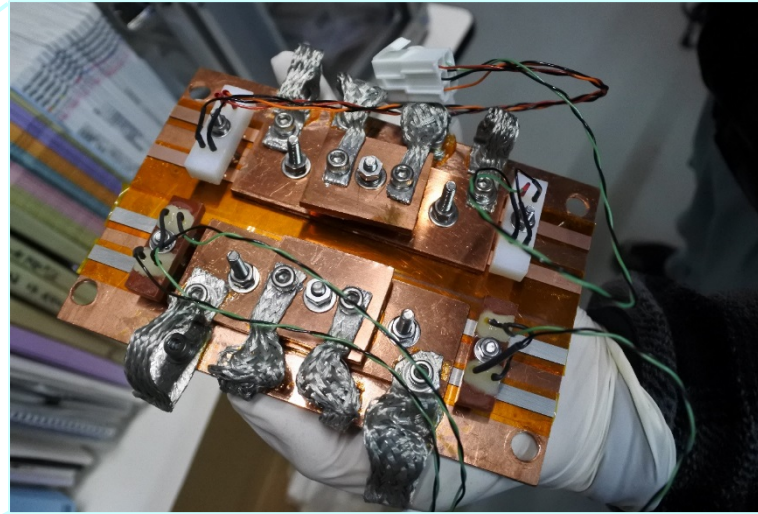
For RRR measurement

← In F.Y. 2017, adhesion test was done by KEK-CEA collaboration. The results were presented in LCWS2017 at Strasbourg.

Commissioning test for RRR measurement in KEK



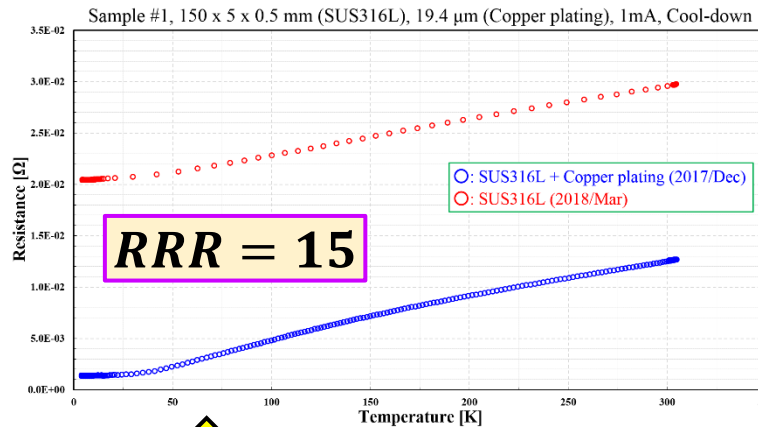
Small cryostat



SUS316L



Copper plating on SUS316L



Commissioning test

$$RRR = \frac{\rho_{300K}}{\rho_{4K}} = 30 \sim 50 \text{ (target)}$$

Too low! Investigation in progress

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Study for TiN coating with TIGOLD Corporation

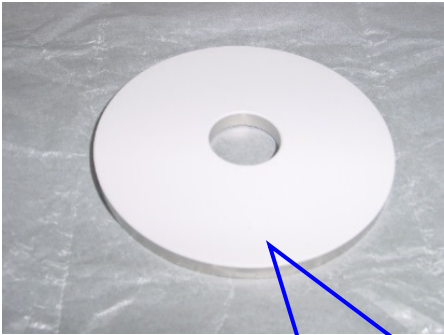
THP053で発表

Recently, KEK started the study on TiN coating with TIGOLD corporation.

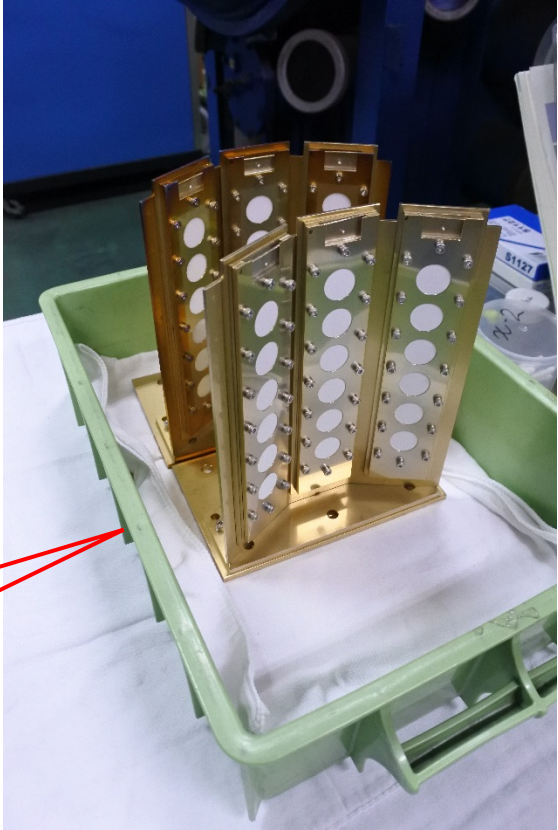
The main purpose:

- More effective & Larger quantity
- Cost reduction

Vacuum furnace for TiN coating @TIGOLD



Ceramic for STF power coupler



TiN coating for ceramic samples
Target thickness: 10 ± 2 nm

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Summary

- ◆ TiN coating-free ceramic passed the power specification at test bench
- ◆ Ultrasonic rinsing for power couplers brought drastic reduction of emitted electrons
- ◆ SEE measurement for ceramic samples are successfully done
- ◆ Commissioning test for RRR measurement of copper plating is finished
- ◆ Study for TiN coating just started

Thank you very much

続きはTHP053で報告します