Fundamental studies for power coupler in KEK

TTC meeting 2020 @CERN

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Kirk

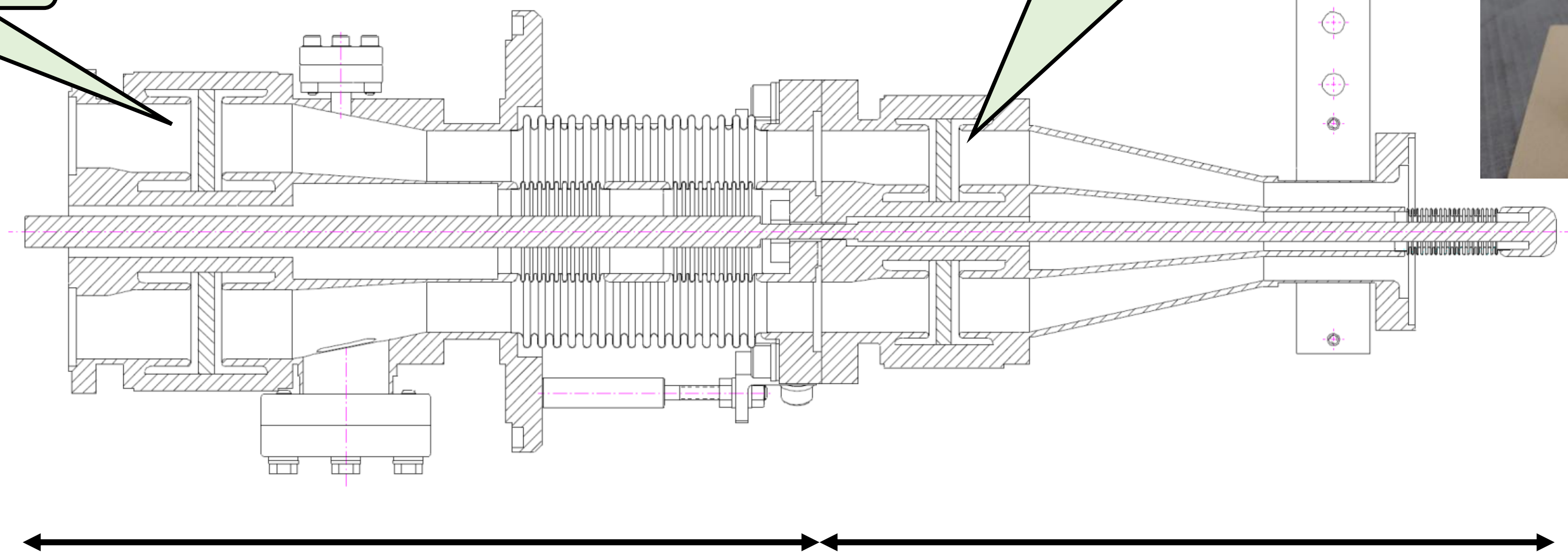
Outline

- Motivation
- Research on ceramic
- Research on copper plating
- Summary & Future prospect

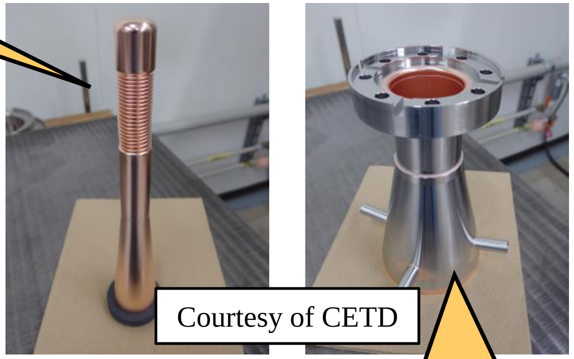
Motivation

KEK has investigated ceramics including coating and copper plating used for STF power coupler since 2016.
The goal is to search **"optimum choice (including cost)"** in them.

- Ceramics
- Coating
- Copper plating



Inner/outer part of cold coupler



Research on ceramics

In this talk, I'd like to concentrate on δ_{SEE}!

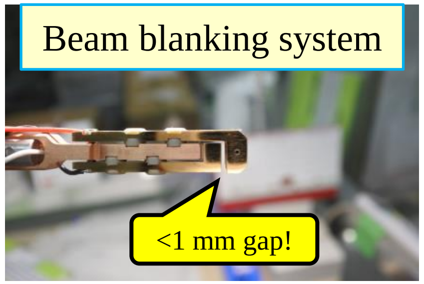
- ◆ **Secondary electron emission (δ_{SEE})**
- ◆ **Loss tangent, Relative permittivity ($\tan\delta$, ε)**
- ◆ **Surface resistivity, Volume resistivity (ρ_S, ρ_V)**

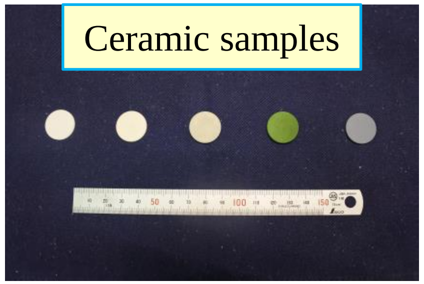
KEK has investigated these parameters for various ceramics, and the result was summarized in the following paper.

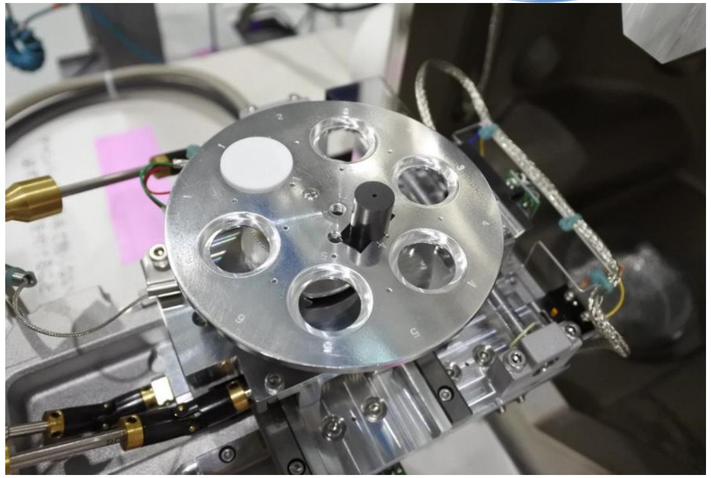
Please check "MOP077" in SRF2019

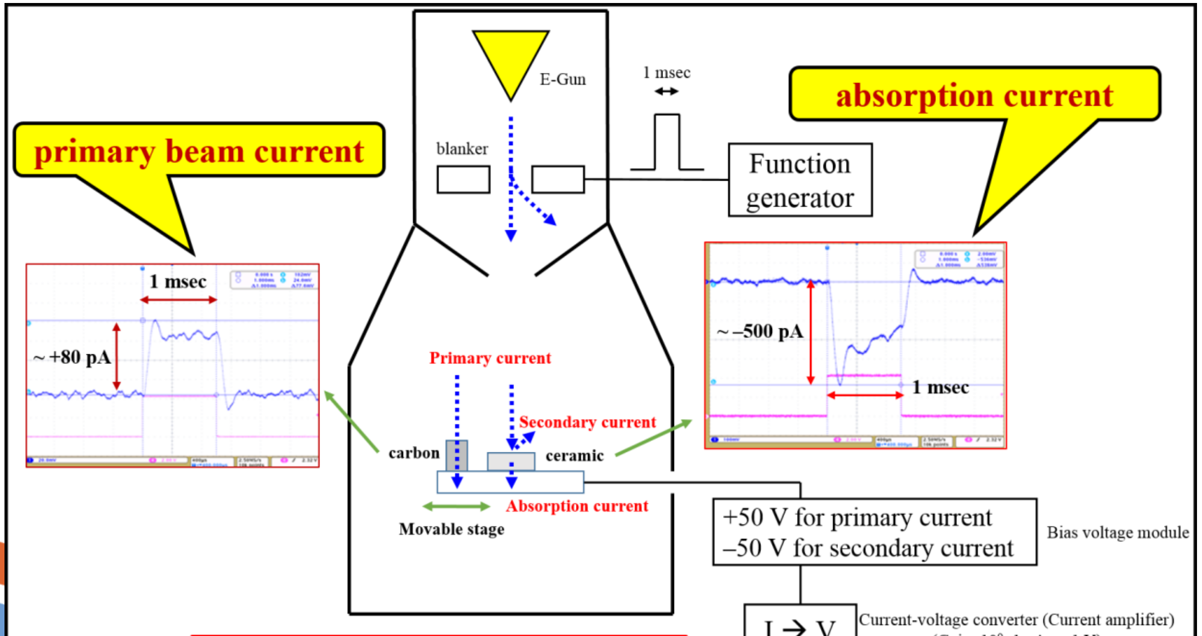
Measurement of secondary electron emission

- ✓ SEM with beam blanking system
- ✓ Pulsed beam (width of 1 msec)
- ✓ Sample shape: 19 (dia.) x 1~3 (thick.) [mm]
- ✓ Target: carbon (primary beam current)
  ceramics (absorption current)









$$I_{primary} = I_{absorption} + I_{secondary}$$
$$\delta_{SEE} = I_{secondary} / I_{primary}$$

Vendor	Ceramic name	Coating	# of sample
NGK/NTK	HA95	TiN / Free	20 (=18 + 2)
KYOCERA	LSEEC	Free	10 (= 3 x 3 + 1)
	A479B	TiN / Free	6 (= 3 + 3)
	AO473A	Free	2
Company A	Sample A	TiN / Free / Cr_2O_3	45 (=18 + 7 + 20)
	Sample B	TiN / Free / Cr_2O_3	45 (=18 + 7 + 20)
COORSTEK	AD-995-LT	TiN / Free	20 (=18 + 2)
		TiN (by different cond.)	4
FERRO TEC	AM997Q	Free	12
	AM997	Free	12

※HA95 was standard ceramic in KEK (production discontinued in 2016)
※Sample B has higher purity than Sample A

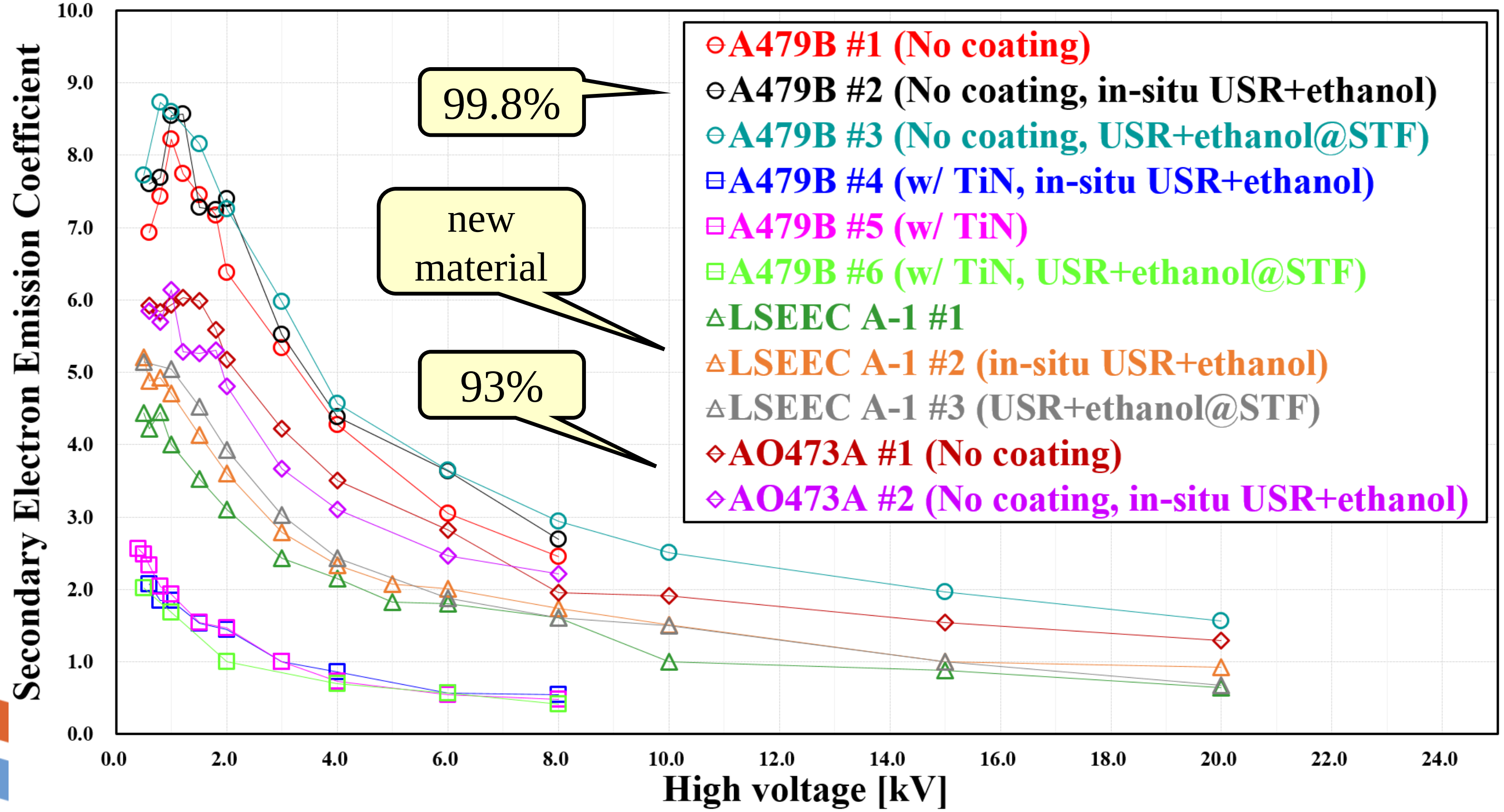
Comparison of different ceramics (typical result)

KYOCERA provided A479B incl. TiN coating, AO473A, and LSEEC.

- δ_{SEE} depends on purity of ceramics
- TiN coating reduces δ_{SEE} drastically

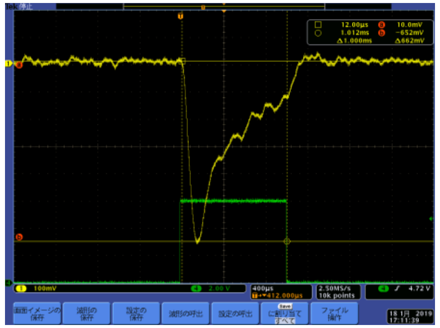
new material based on AH100A

Comparison of Secondary Electron Emission Coefficient on KYOCERA ceramic

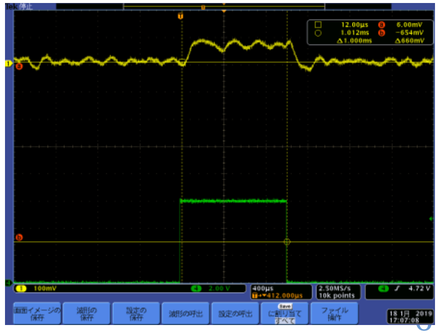


In-situ USR with ethanol

Normal signal

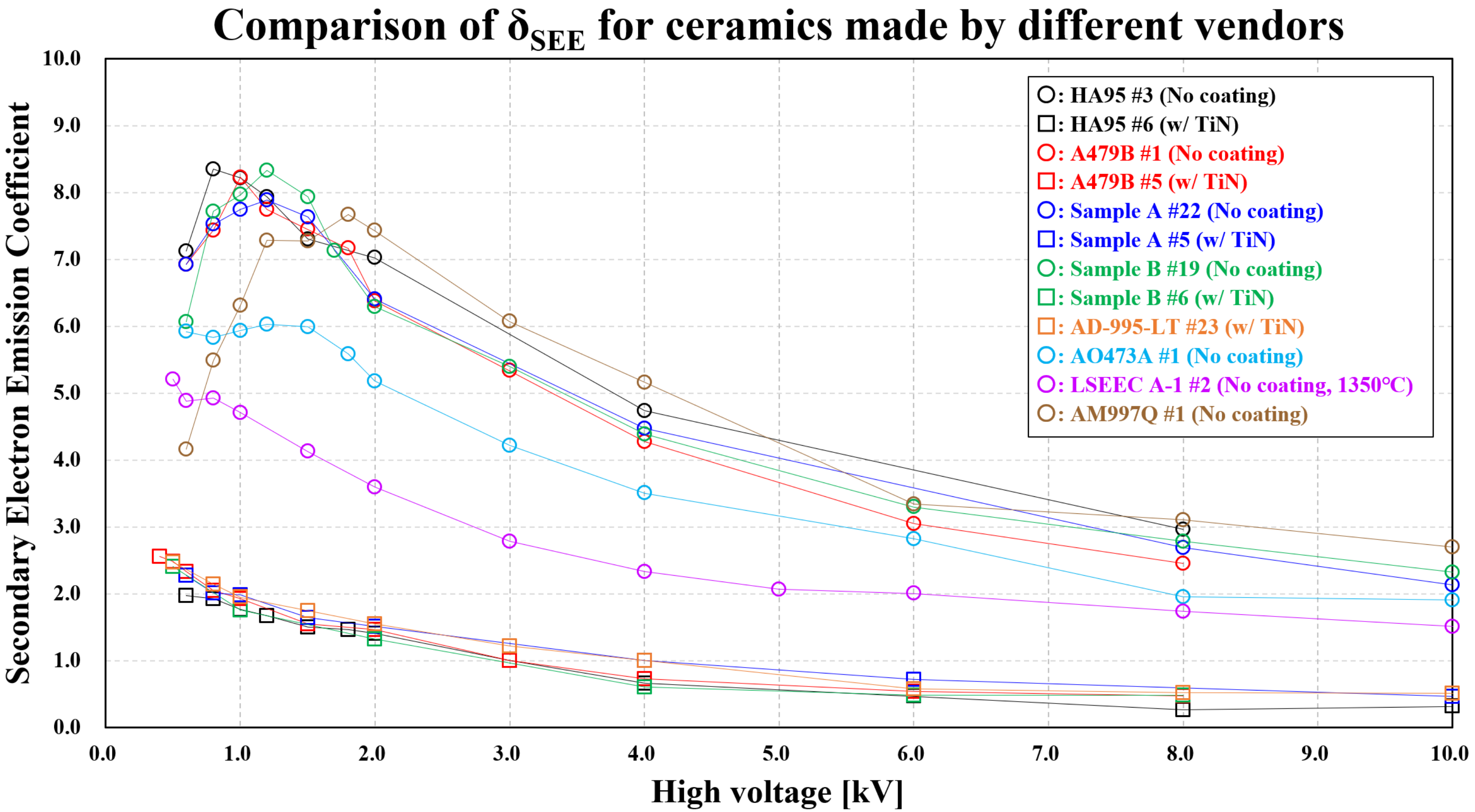


Junk (due to static electricity)



Comparison of different vendors

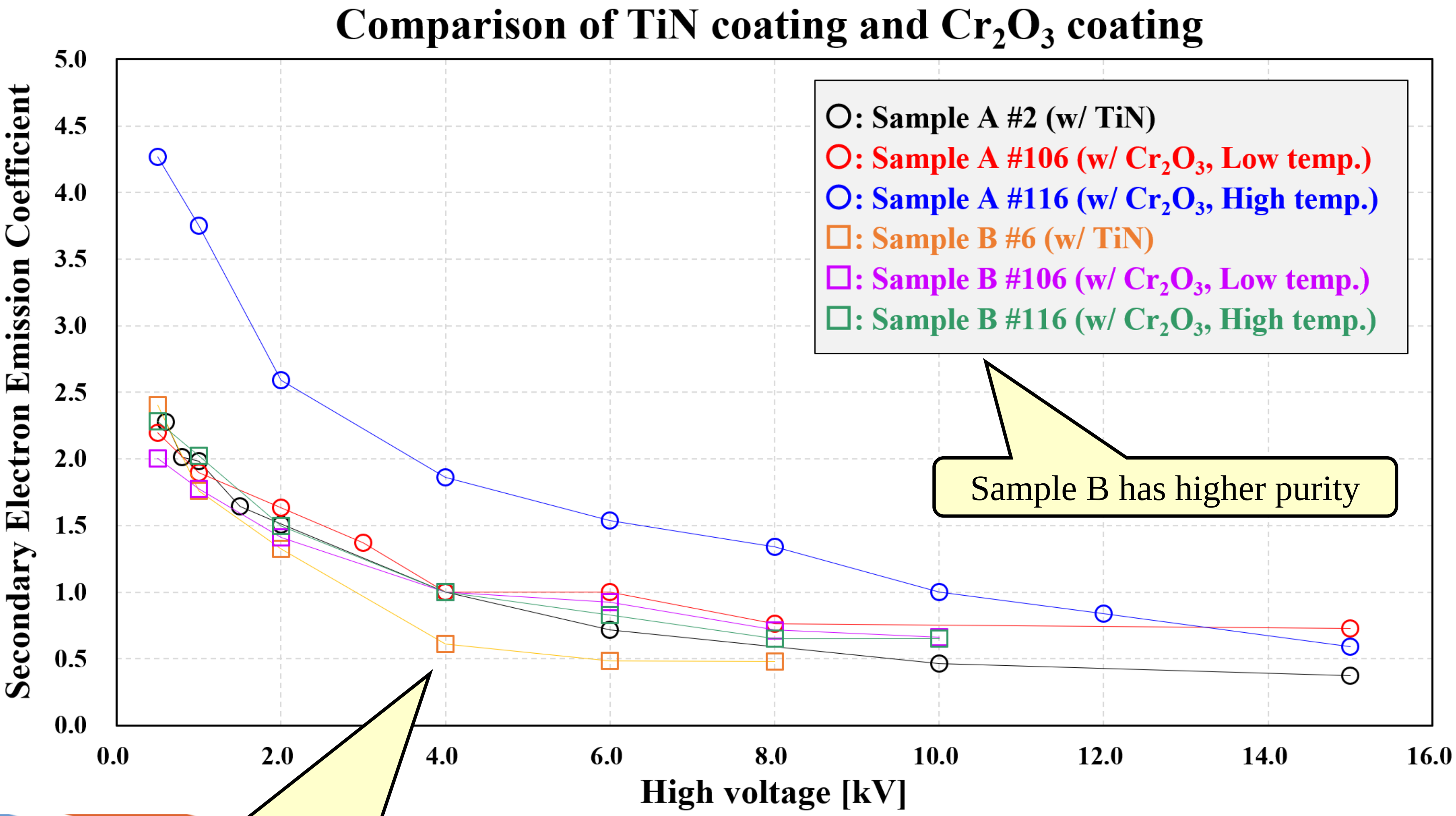
- No coating samples: Good consistency for HA95, A479B, Sample A and Sample B
- TiN coating samples: Good consistency for every sample



Systematic error is under investigation, roughly 10% at each point.

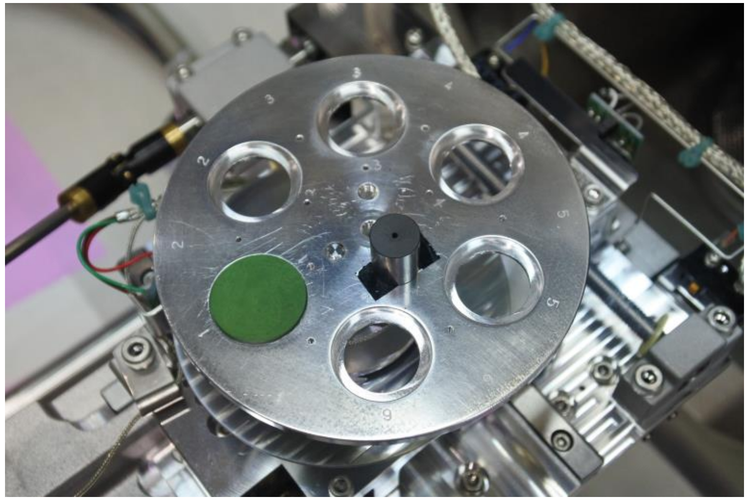
Cr_2O_3 (chrome-oxide) coating

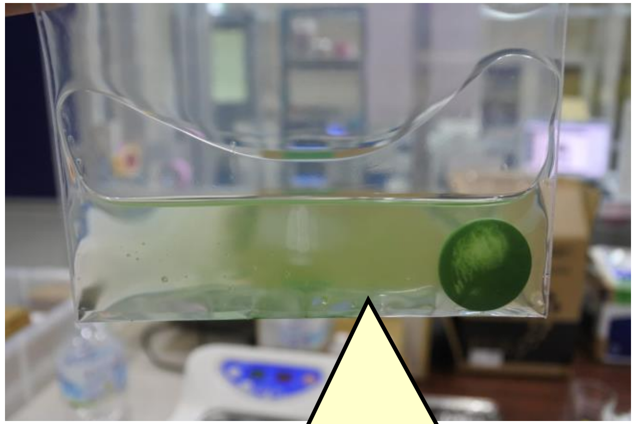
Company A provided two samples (Sample A and B) with Cr_2O_3 coating done by four conditions.
(Four conditions: High/Low temperature, Thick/Thin coating)



Sample B has higher purity

In some conditions, Cr_2O_3 coating has same δ_{SEE} as TiN coating



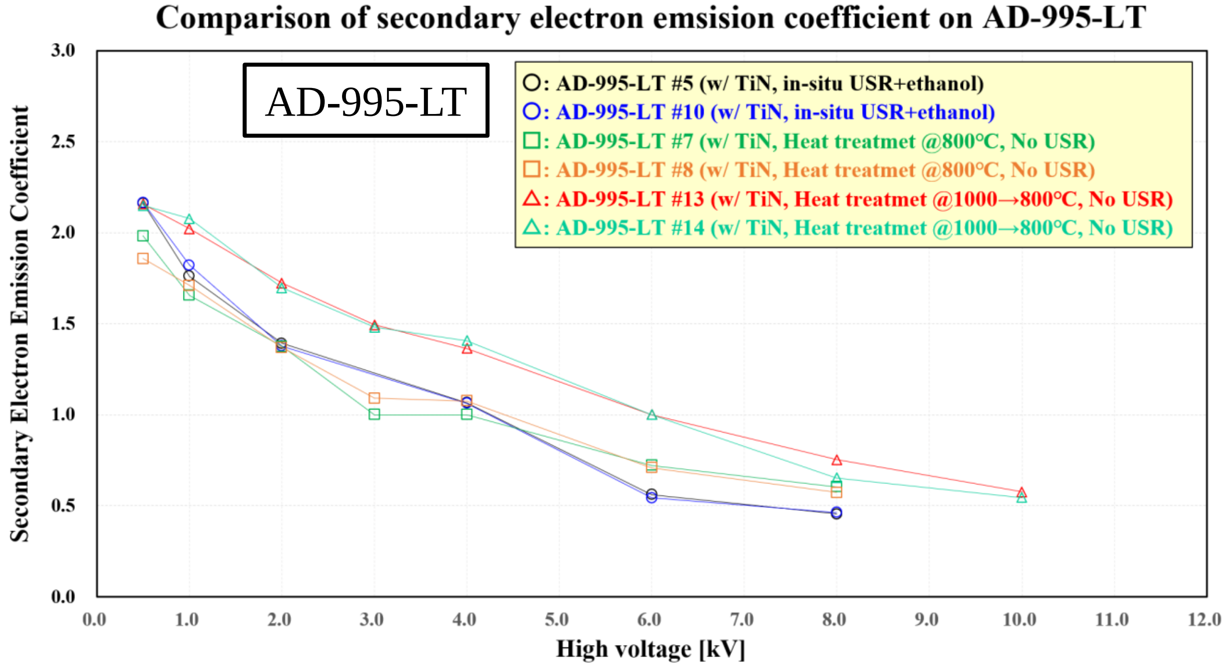


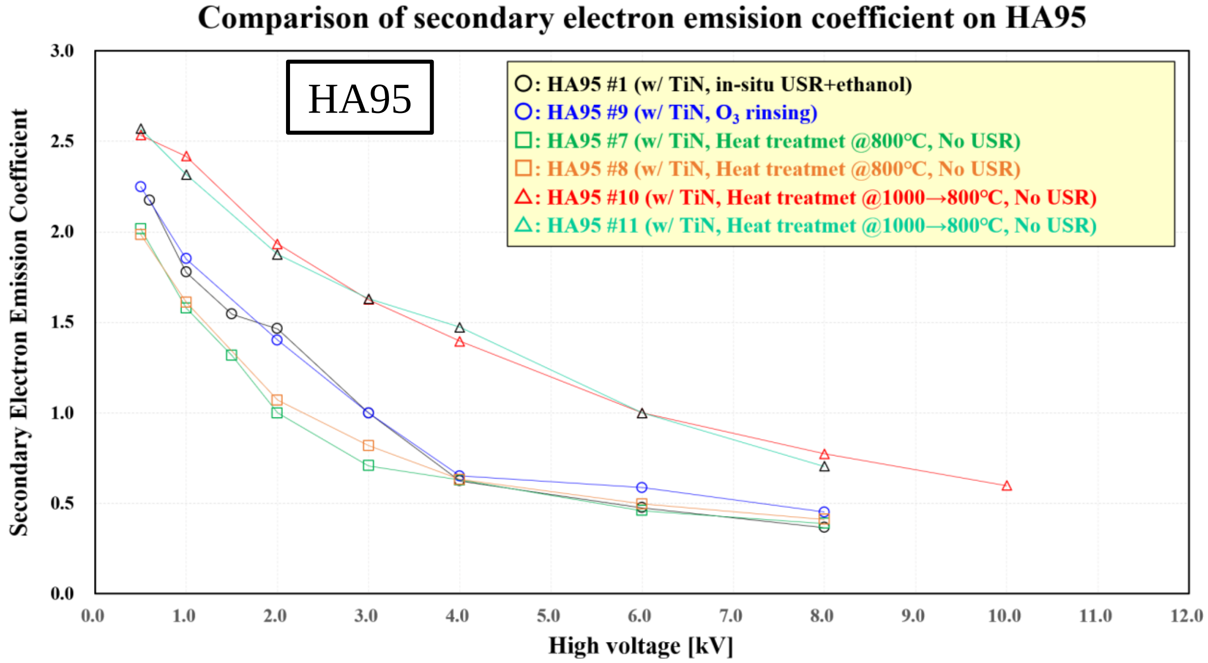
Insufficient adhesion at low temp.
(after in-situ USR)

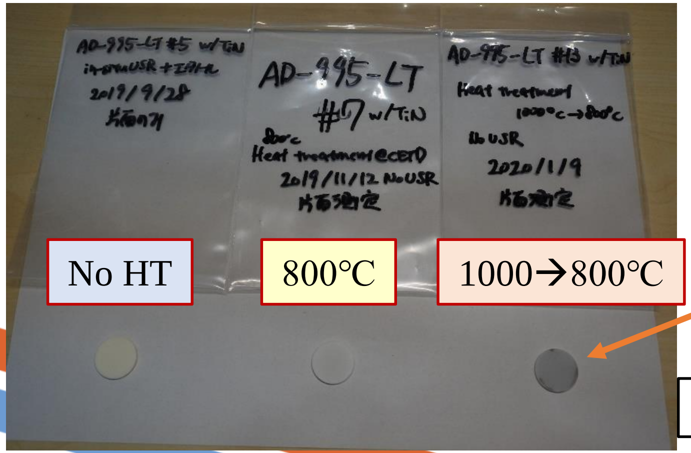
Effect of heat treatment (brazing process)

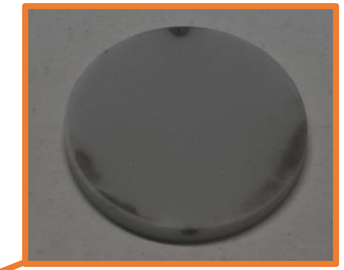
Ceramic experiences gold/silver brazing processes at 1000°C /800°C.
After HT, ceramic occasionally has higher secondary electron emission.
And also, the color changes to gray and dark.

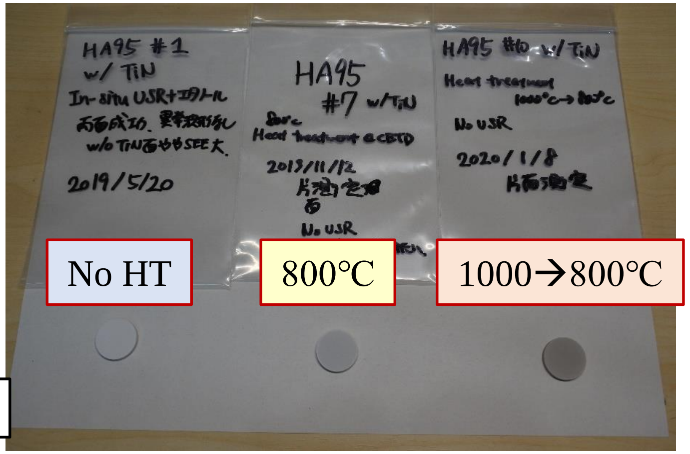
Reduction action by hydrogen?











※Collaboration between CETD and KEK.

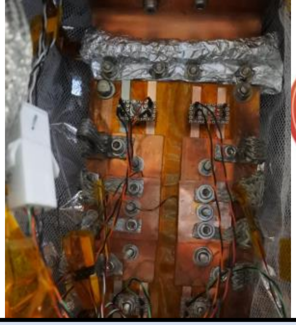
Research on copper plating

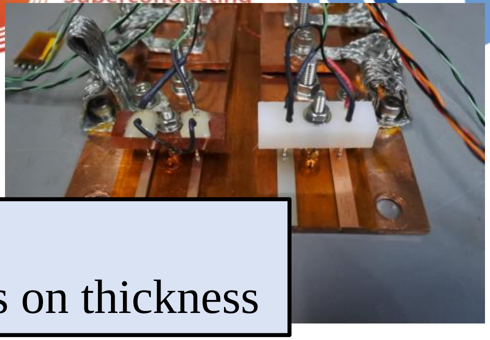
- ◆RRR measurement
- ◆Microstructure observation
- ◆Effect of heat treatment (brazing process)

Please check “MOP083” in SRF2019

RRR measurement

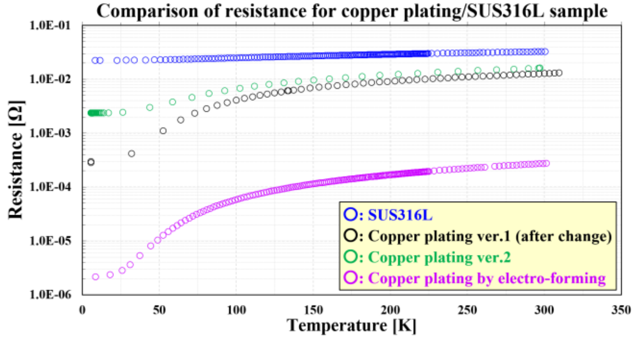
Sample size: 150 x 5 x 0.5 mm

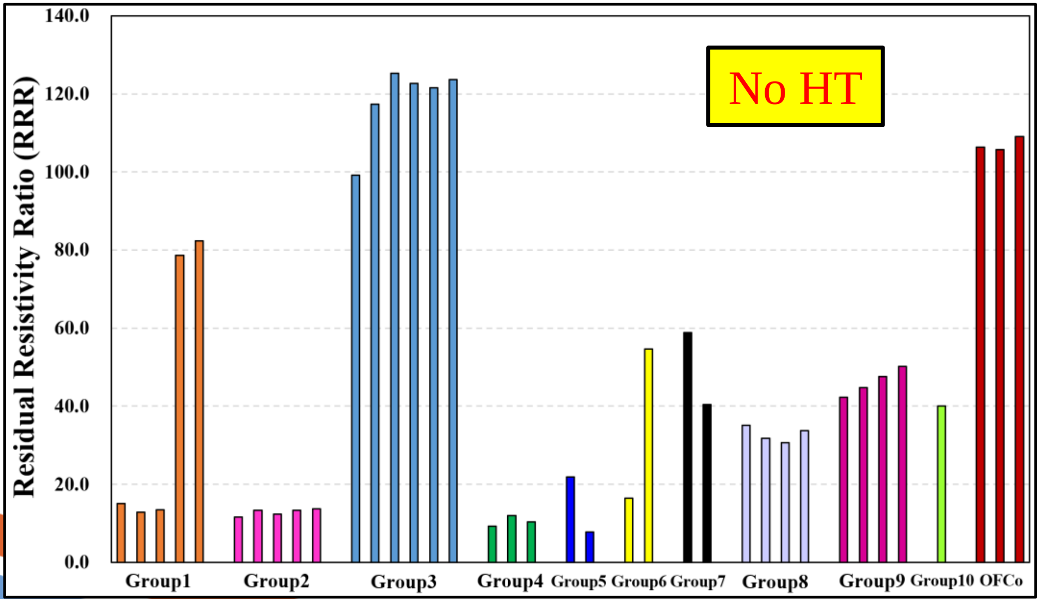


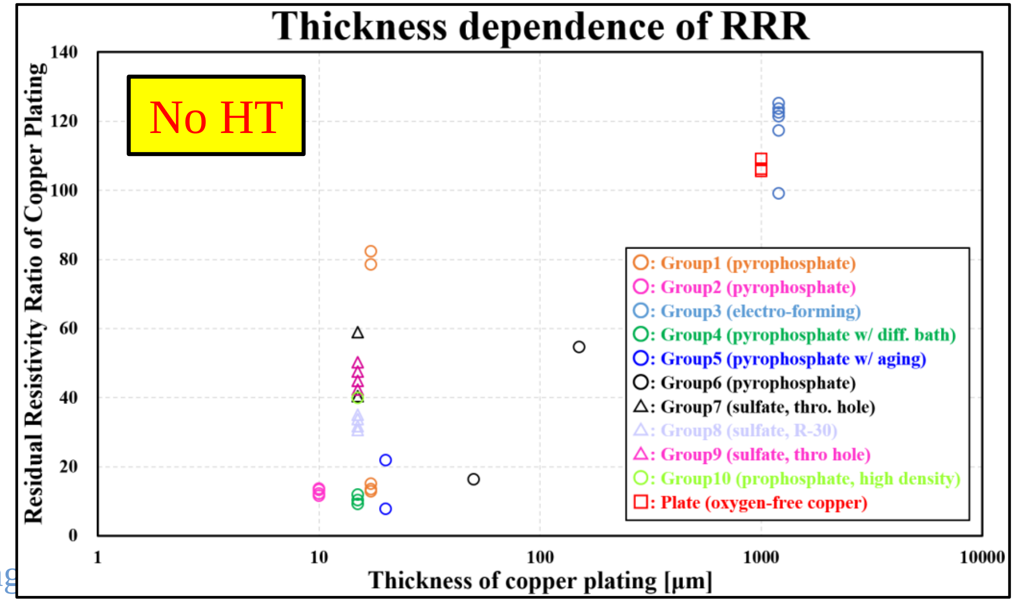


Group 1	pyrophosphate	17.2 μm
Group 2	pyrophosphate	10 μm
Group 3	pyrophosphate (electro-forming)	1200 μm
Group 4	pyrophosphate (w/ different bath)	15 μm
Group 5	pyrophosphate (w/ aging process)	20 μm
Group 6	pyrophosphate	50, 200 μm
Group 7	sulfate (through hole w/ brighter)	17 μm
Group 8	sulfate (R-30)	15 μm
Group 9	sulfate (through hole)	15 μm
Group 10	pyrophosphate (high elec. density)	15 μm
OFCo	Oxygen-free copper	1000 μm

- ➢ Copper-sulfate has higher RRR
- ➢ RRR of copper-pyrophosphate depends on thickness







※Collaboration between Nomura and KEK.

Microstructure observation on grain boundary

Three samples were investigated by laser microscope and EBSD.

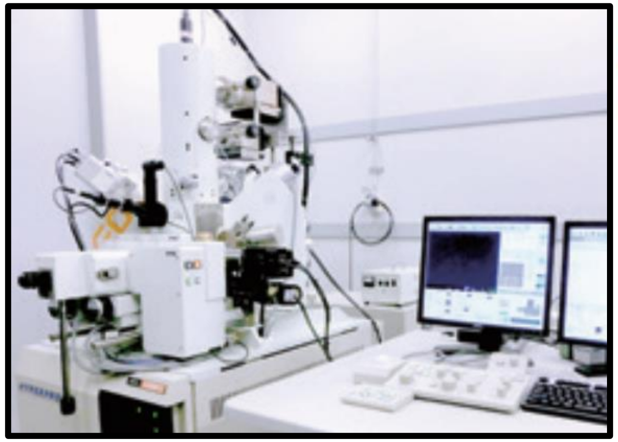
Copper-Sulfate has larger grain!

- Copper-sulfate has larger grain size
- Grain size of copper-pyrophosphate depends on thickness

Choice of copper-sulfate in fabrication of power coupler

Laser microscope

EBSD



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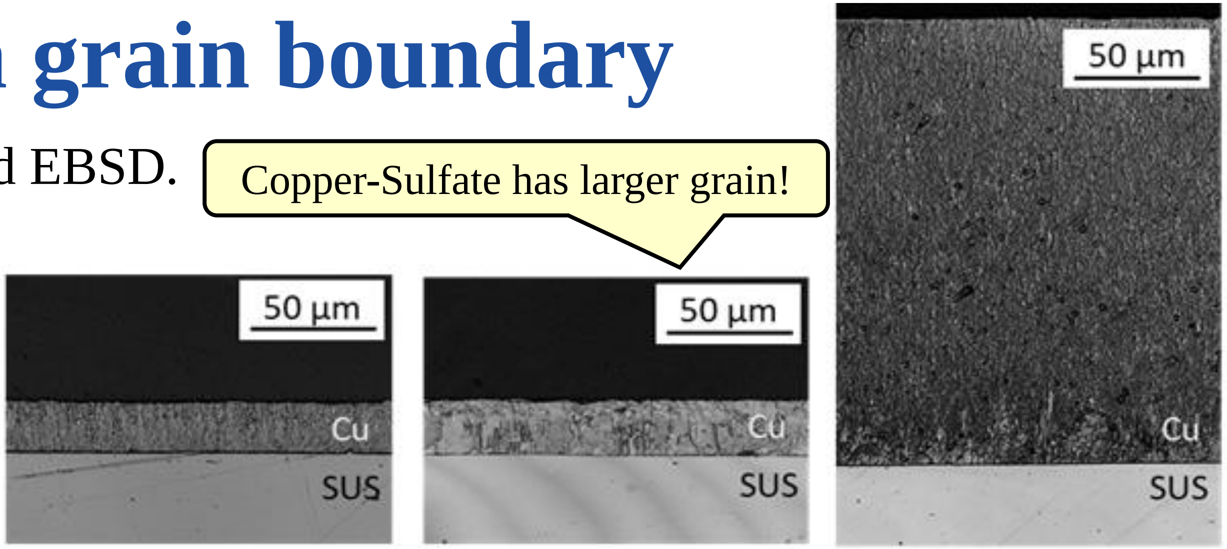
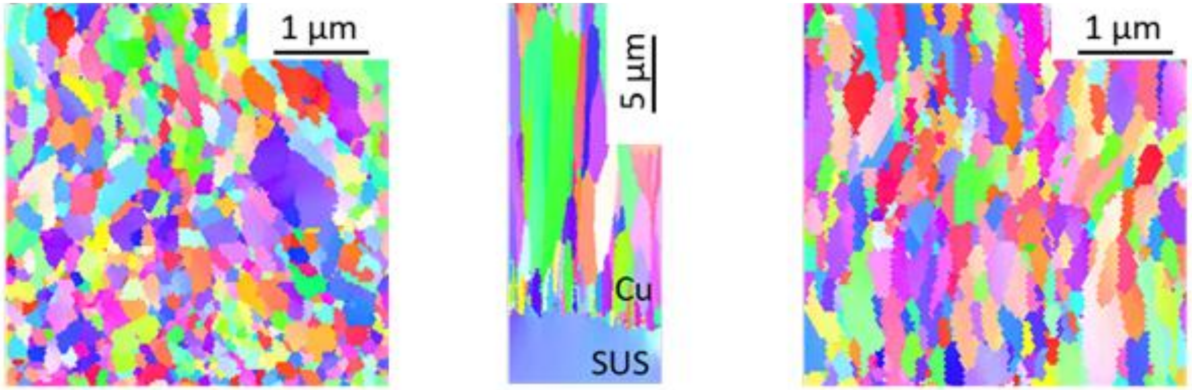
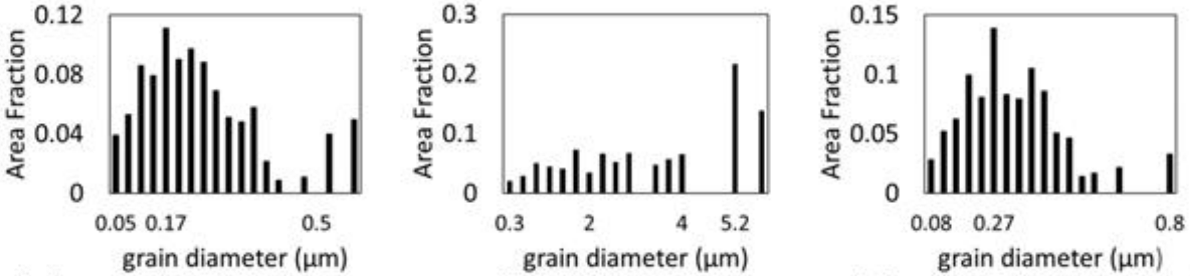


(a) Pyrophosphate, 20μm (b) Sulfate, 20μm (c) Pyrophosphate, 150μm



(a) Pyrophosphate, 20μm (b) Sulfate, 20μm (c) Pyrophosphate, 150μm



(a) Pyrophosphate, 20μm (b) Sulfate, 20μm (c) Pyrophosphate, 150μm

Effect of heat treatment (brazing process)

Copper plating experiences silver brazing process at 800℃.

Group	Sample	Bath	additives	Thickness	before HT	after HT
Group 5	#1	pyrophosphate	Silicon oil @200℃	20 μm	21.9	12.8
	#2		Silicon oil @100℃	20 μm	7.8	16.8
Group 6	#1	pyrophosphate		50 μm	16.4	256
	#2			100 μm	54.7	480
Group 7	#1	sulfate	w/ brighter	17 μm	58.9	111
	#2			17 μm	40.4	1.9
Group 8	#1	sulfate (R-30)		15 μm	35.1	5.6
	#2			15 μm	31.8	4.5
Group 9	#1	sulfate		15 μm	42.3	4.2
	#2			15 μm	44.8	4.3
Group 10	#1	pyrophosphate (higher electric current density)		15 μm	40.0	159.5

Heat treatment generates lower RRR in some cases, but higher RRR in the other cases!
(W. Singer already pointed out this effect in SRF1995)
We are investigating thickness dependence in copper-sulfate samples.

※Collaboration between CETD, Nomura and KEK.

Summary & Future prospect

- Good consistency in δ_{SEE} of no-coating/TiN-coated ceramics
- Good consistency in δ_{SEE} between TiN-coating and Cr_2O_3-coating
- Copper-sulfate has larger grain size than copper-pyrophosphate
- Copper-sulfate has higher RRR than copper-pyrophosphate at same thickness
- Heat treatment generates lower/higher RRR of copper plating

- ☐ Cr_2O_3-coating will be more investigated by new collaborative research
- ☐ The thickness dependence of copper-sulfate will be investigated
- ☐ STF power coupler (only cold part) will be high-power-tested
  - ☐ Some new attempts in the fabrication process were tested

Courtesy of CETD

Delivery on January!

THANK YOU VERY MUCH FOR YOUR ATTENTION

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