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CERAMIC STUDY ON RF WINDOWS FOR POWER COUPLER, WAVEGUIDE, AND KLYSTRON IN PARTICLE ACCELERATOR

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Abstract

R&Ds on different types of ceramic used in power coupler, waveguide, and klystron for particle accelerators are under progress in Center of Innovation (COI) at KEK, and at some outside companies. There are five important parameters on the properties of ceramics; that is, relative permittivity, dielectric loss tangent, surface and volume resistivity, and secondary electron emission coefficient. For measurements of these parameters, eight kinds of ceramic samples supplied from five vendors have been measured using three different measurement systems since 2017. In this report, the recent results for these studies will be presented in detail.

INTRODUCTION

Ceramic used for RF window in power coupler, waveguide, and klystron, is an insulating material mainly composed of alumina (Al_2O_3), and has different dielectric loss tangent (tanδ) depending on the purity. tanδ is an important parameter to evaluate heating effect in high power RF operation, especially, superconducting accelerator. On the other hand, secondary electron emission coefficient (δ_{SEE}) on ceramic surface is closely related to multipacting. Usually, for suppression of multipacting, Titanium-Nitride (TiN) coating is applied to enable ceramic to be used in high power RF operation. The TiN coating is done by applying high voltage to titanium electrode in nitrogen gas in vacuum furnace. The TiN coated ceramic surface has lower δ_{SEE} as well as lower surface resistivity (ρ_s). From the above, it is understood that the measurement of δ_{SEE}, tanδ, and ρ_s is important for evaluation of ceramic. In addition to these three parameters, volume resistivity (ρ_v) and relative permittivity (ε) have been measured by KEK since 2017.

RESEARCH ON SECONDARY ELECTRON EMISSION COEFFICIENT

Secondary electron emission coefficient on ceramics is the most important parameter to estimate effect of multipacting in high power RF operation. In COI at KEK, for the measurement of δ_{SEE} in 2018, scanning electron microscope (SEM) with beam blanking system (like a kicker magnet) to generate a pulse beam was installed. For avoidance of charge-up effect on ceramic surface, it is essential to use a pulse beam, because ceramic is an insulator. The specification of this measurement system was described in reference [1]. Table 1 shows eight ceramic samples including different coating processes provided by five companies for δ_{SEE} measurement. TiN coating is a conventional method to reduce δ_{SEE}, and chrome-oxide (Cr_2O_3) coating is a new attempt for cost reduction in coating process. Figure 1 shows the ceramic samples with diameter of 19 mm including coating-free, two different TiN coating, Cr_2O_3 coating, and new material ceramic (LSEEC). LSEEC is a ceramic developed by KYOCERA to save cost by skipping the TiN coating process. The test result in high power operation was summarized in reference [2].

Table 1: Ceramic Sample List for δ_{SEE} Measurement

Company	Sample	Coating	#
NGK/NTK	HA95	TiN/Free	2/18
KYOCERA	A479B	TiN/Free	3/3
	LSEEC	Free	9
	AO473A	Free	2
COORSTEK	AD-995-LT	TiN/Free	2/22
FERRO TEC	AM997Q	Free	2
Company A	Sample A	TiN/Cr_2O_3/Free	18/20/7
	Sample B	TiN/Cr_2O_3/Free	18/20/7

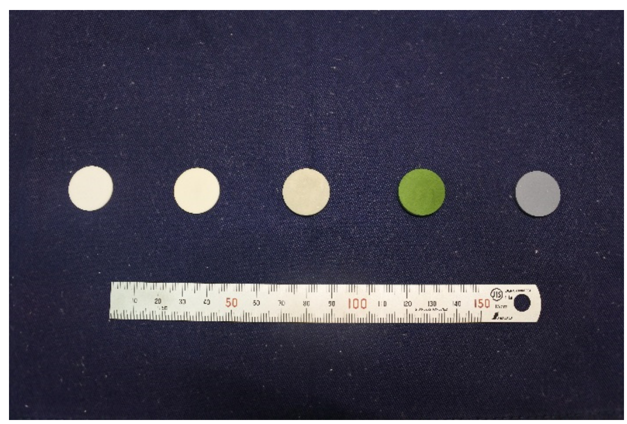

Figure 1: Ceramic samples (coating-free, TiN coating 1, TiN coating 2, Cr_2O_3 coating, and LSEEC from left to right) for secondary electron emission coefficient measurement.

Figure 2 shows SEM with beam blanking system (top-left), sample holder (top-right), schematic view of δ_{SEE} measurement system (middle), and some typical results including waveforms in oscilloscope (down). Carbon target is used to measure primary beam current as shown in top-right figure. The electron beam can pass through the beam blanking system from above cathode voltage of 0.5 kV. The measurable energy range is from 0.5 keV to 30 keV. In down figure, the comparison between coating-free and TiN coating for A479B is shown with some waveforms. The waveform for coating-free ceramic has steep structure (A479B #2 @1 kV and 3 kV), on the other hand, the waveform for TiN coating is similar to that for metal like copper and niobium (A479B #4 @1 kV). At $\delta_{SEE} \sim 1$ around 3 kV, there is no signal (A479B #4 @3 kV), because primary current and secondary current are cancelled each other.

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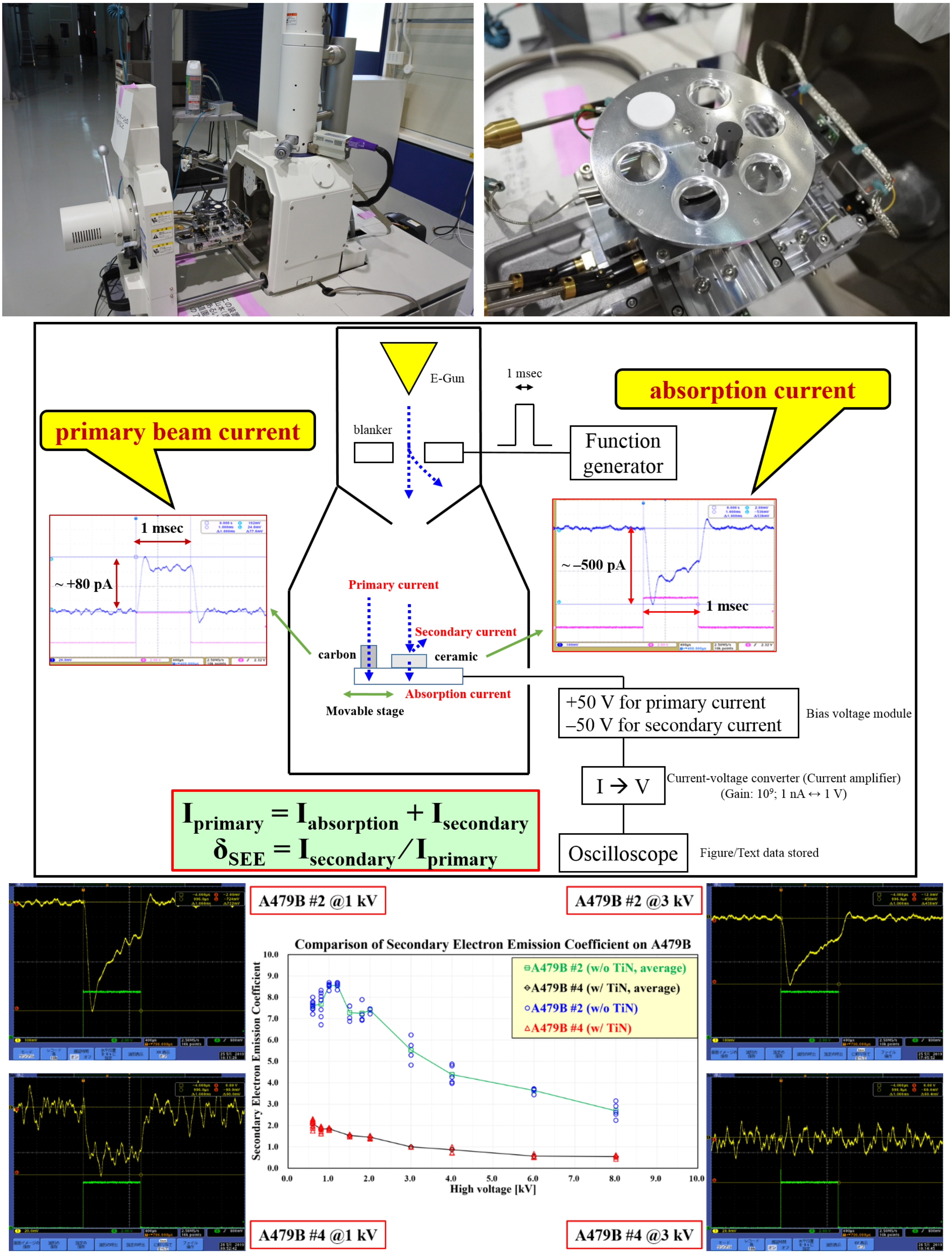

Figure 2: SEM (top-left), sample holder (top-right), schematic view of measurement system (middle), and some typical results including waveforms in oscilloscope (down).

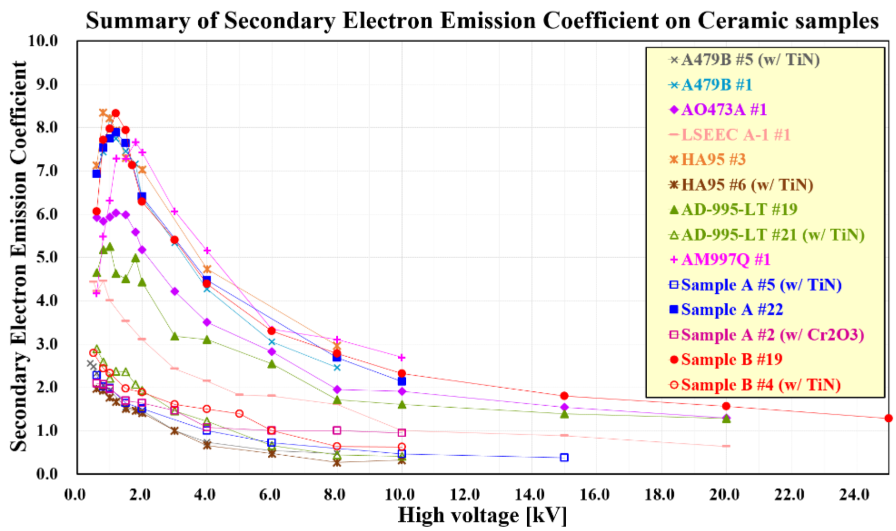

Figure 3: Summary of secondary electron emission coefficient for every ceramic sample including TiN/Cr_2O_3 coatings and LSEEC.

Figure 3 shows recent results of δ_{SEE} measurement. There is a clear difference between TiN coating and coating-free ceramic. AD-995-LT #21 with different TiN coating (TiN coating 2 in Figure 1) is somewhat higher than the other TiN coated samples, and the cause may be difference in coating thickness. There is no difference in TiN coated ceramics with TiN coating 1. Sample A #2 with Cr_2O_3 coating has same δ_{SEE} as TiN coated ceramics. This means Cr_2O_3 coating may be also available for RF window. AO473A #1 and AD-995-LT #19 without coating has lower δ_{SEE} than the other ceramics including HA95, which was the conventional ceramic in KEK. LSEEC also has lower δ_{SEE} within coating-free ceramic samples. However, it is higher than TiN coated ceramics, and also has higher dielectric loss tangent as described in next section.

RESEARCH ON RELATIVE PERMITTIVITY AND DIELECTRIC LOSS TANGENT

Relative permittivity and dielectric loss tangent for five ceramics provided by three companies were measured at AET [3]. The measurement principle is described in reference [4]. The measurement mode is TM_{010}, and the corrections for difference in sample size is included into the calculations. Table 2 shows the ceramic sample list, and Figure 4 shows the five samples with the size of 80 x 3 x 1 mm. The measurements were carried out by averaging three to five measurements per sample at 1 GHz and 2 GHz as shown in Figure 5.

Table 2: Ceramic Sample List for ε and tanδ Measurement

Company	Sample	Coating	#
KYOCERA	A479B	Free	5
	LSEEC	Free	5
COORSTEK	AD-995-LT	Free	5
Company A	Sample A	Free	9
	Sample B	Free	11

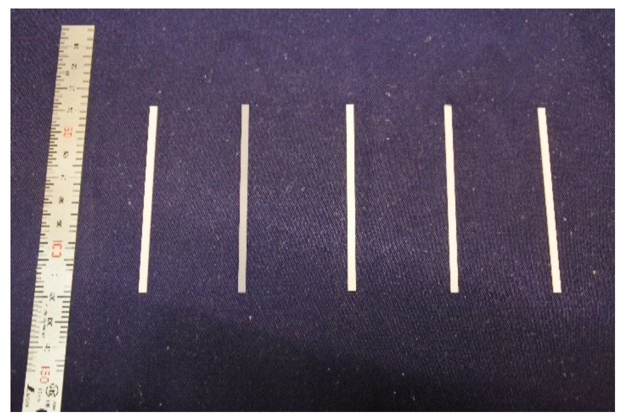

Figure 4: Ceramic samples (A479B, LSEEC, AD-995-LT, Sample A, and Sample B from left to right) for relative permittivity and dielectric loss tangent measurement.

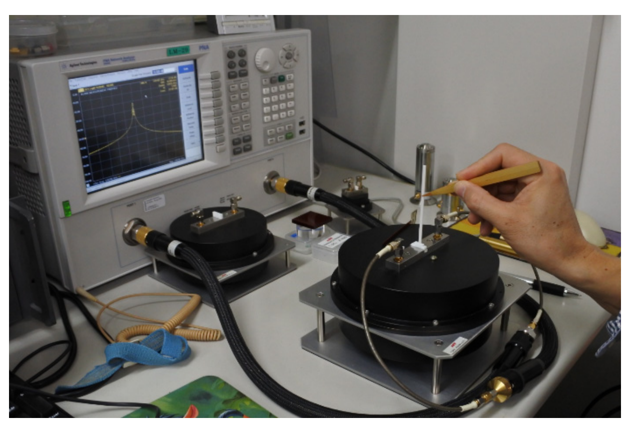

Figure 5: Measurement of relative permittivity and dielectric loss tangent at AET.

Figure 6 shows the results for this measurements including some specific values for each ceramic. The downward

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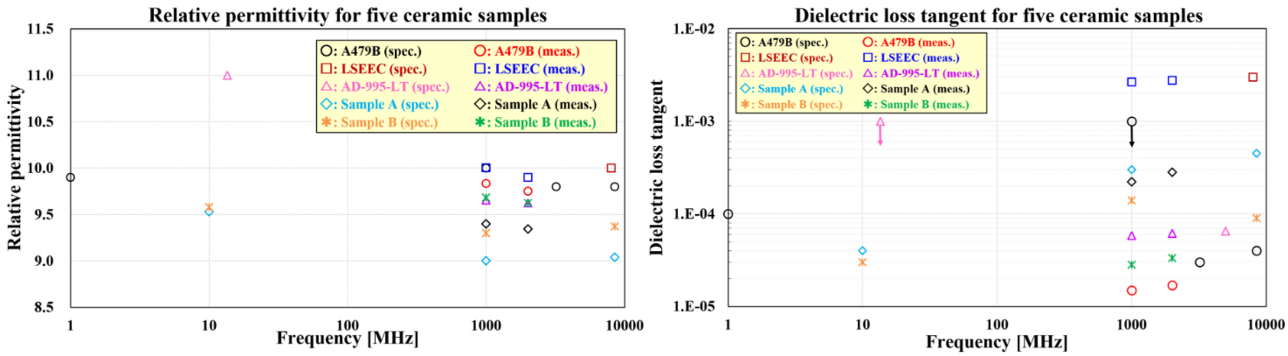

Figure 6: Relative permittivity and dielectric loss tangent for five ceramics including some specific values for each ceramic.

arrows in tanδ represent the upper limit value for that ceramic. All samples satisfy the specification values. The measurement of tanδ revealed a difference depending on a purity of each ceramic. Generally, ceramics with a purity of 99% of alumina have tanδ of 10^{-5}, and 95% of alumina have tanδ of 10^{-4}. LSEEC has much higher tanδ than the other ceramics, and this feature may generate heating phenomena in high power operation [2].

RESEARCH ON SURFACE AND VOLUME RESISTIVITY

Surface and volume resistivity measurement have been done in JFCC [5] using six ceramic samples with diameter of 19 mm as shown in Table 3. At JFCC, all samples experienced electrode burn-in process. Figure 7 shows three samples (coating-free, TiN coating, and Cr_2O_3 coating from left to right) after this process. The measurement principle is shown in Figure 8. The applied voltage is 1 kV, and the applied stress is 10 kgf. The baking process at 120°C/2 hours before and after each measurement process is done. Each measurement time is 1 hour.

Table 3: Ceramic Sample List for ρ_s and ρ_v Measurement

Company	Sample	Coating	#
NGK/NTK	HA95	TiN/Free	1/1
KYOCERA	A479B	Free	1
	LSEEC	Free	1
COORSTEK	AD-995-LT	TiN/Free	2/2
Company A	Sample A	TiN/Cr_2O_3/Free	2/1/2
	Sample B	TiN/Cr_2O_3/Free	3/1/4

Figures 9 shows electric current during the ρ_s and ρ_v measurements. Although it changed rapidly for 10 mins from the start of measurement, it became stable thereafter. The both resistivity was calculated from electric current at last measurement point after one hour. Figure 10 shows the results for ρ_s and ρ_v measurements. The volume resistivity for every ceramic except LSEEC well-agreed within one order. The electrodes were not well formed due to new material in LSEEC. On the other hand, the surface resistivity is distributed from 10^{15} to 10^{18} ohms⁄square. Moreover, there is no clear difference between TiN coating and coating-free ceramics. This means that some improvement is necessary for the measurement of surface resistivity. The flatness and cleanness on ceramic surface may be important.

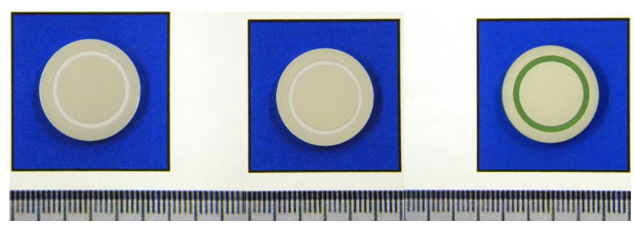

Figure 7: Ceramic samples (coating-free, TiN coating, and Cr_2O_3 coating from left to right) for surface and volume resistivity measurement.

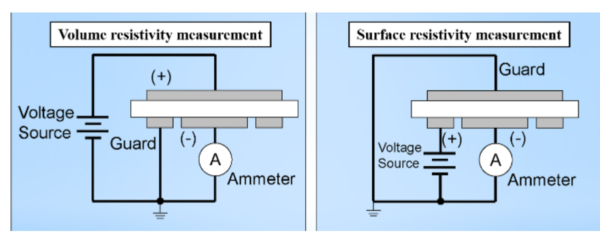

Figure 8: Measurement principle for surface and volume resistivity.

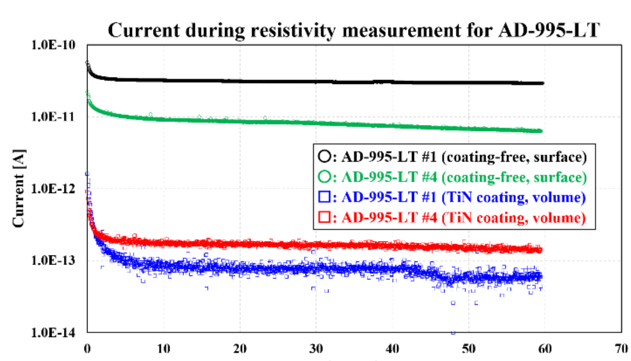

Figure 9: Electric current for surface and volume resistivity measurement.

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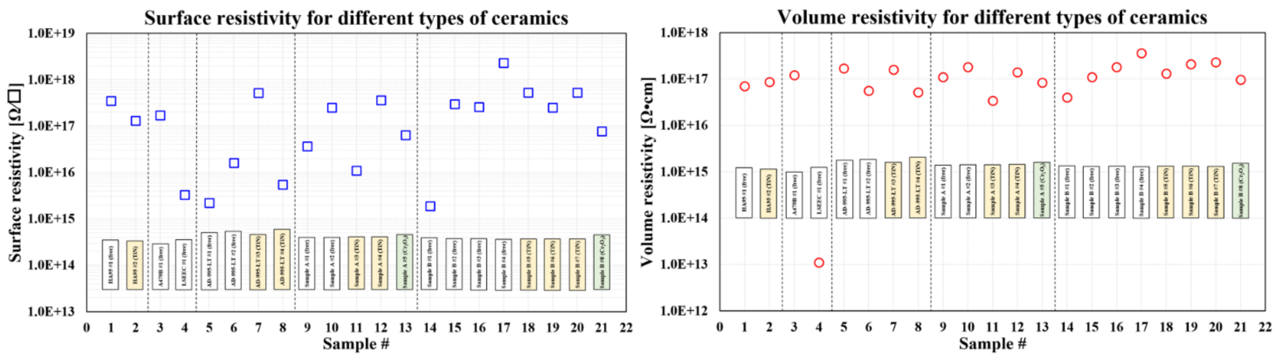

Figure 10: Surface and volume resistivity for five ceramics.

CONCLUSION

Ceramic R&D for RF window in power coupler, waveguide, and klystron has been done in KEK since 2017. The measurement on secondary electron emission coefficient has been successfully done by SEM with beam blanking system. At present, there was no clear difference among TiN coated ceramics, and effect of Cr_2O_3 coating was same as TiN coating. On the other hand, although LSEEC had lower δ_{SEE} than the other coating-free ceramics, it had much higher tanδ than them. Therefore, LSEEC may generate heating phenomena during high power operation. Measurement on relative permittivity and dielectric loss tangent was successfully done, and there was well consistency between measured values and their specifications. Measurement on surface and volume resistivity was also done. Although volume resistivity was almost uniform among six ceramics including TiN/Cr_2O_3 coating, surface resistivity was distributed from 10^{15} to 10^{18} ohms/square, there was no difference between TiN coated and coating-free ceramic. Some improvements for surface resistivity measurement is necessary.

FUTURE PLAN

The measurement on secondary electron emission coefficient will be continued for more detailed inspection. Specifically, rinsing effect including ultrasonic and ozonized (O_3) water is inspected. Thickness effect for TiN coating and different coating method will be also inspected.

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