THE SECONDARY ELECTRON YIELD OF THE MATERIAL FOR THE KEKB SUPERCONDUCTING CAVITY INPUT COUPLER

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Abstract

The secondary electron yields for copper, copper-plated stainless steel, and ceramic windows, materials used in the couplers for KEKB superconducting cavities, have been measured. We show that electron bombardment is effective in decreasing the secondary electron yield (SEY) of the metal surfaces, and the TiN coating and window fabrication processes influence the SEY of the ceramic window.

1 INTRODUCTION

The input couplers for the KEKB superconducting cavities have been used to feed a power exceeding 300 kW stably with high current [1,2]. The successful use of these couplers depends sensitively on the condition and preparation of their surfaces. In this paper we report measurements of the SEY of alumina and metal surfaces treated by the processes used in standard KEKB coupler production.

The as-received couplers need processing for 6 to 8 hours to reach a power of 300kW. In processing, we initially observe electron current, pressure increases, and arcing. After enough processing-induced multipacting, these phenomena are no longer observed. The surface condition is evidently changed by the processing.

Near the ceramic window, discharges and multipacting are observed during the initial processing for travelling wave power below 150kW [4]. We use ozonized water rinsing to remove contamination from the coupler surface. This is effective in decreasing the discharge at low power levels. Part of the measurements we present here (section 4) show in detail how the various procedures of window fabrication affect the surface SEY of the window surface.

On the metal surface of the coupler coaxial line, electron current is observed first, followed by an increase in pressure after a time delay of more than 100ms. This means that electron bombardment is effective in cleaning the metal surface [3]. Another part of the measurements we present here (section 5) show the detailed effects of electron bombardment on SEY as a function of the metal surface condition.

2 MEASUREMENT TECHNIQUES

Our measurements were carried out with a modified scanning electron microscope (SEM), shown in Fig. 1 [5,6]. It consists of an electron gun, two Faraday cups (FC), a sample holder and a vacuum system. Primary electrons are injected by the electron gun with energies between 0.6keV and 30keV. The lower limit of the energy is extended down to 0.35kV by applying a bias voltage of –0.25kV to the sample holder.

The primary current I_p and secondary current I_s are measured with a FC interposed between electron gun and sample. In the measurement of primary current the primary FC is set facing the electron gun. In the measurement of secondary current the hole of the secondary FC is moved to allow the primary electron beam to pass, and the electrons emitted from the sample are collected. The secondary electron yield δ is calculated from $\delta = I_s/I_p$.

The primary current is normally set to pulsed beam, 200pA peak, 30Hz and 2msec duty. With the low duty cycle and low bombardment current, charging of insulating sample surfaces is negligible.

The vacuum system is fitted with oil-free pumps. The vacuum during measurement is 2×10^{-4}Pa.

The parameters of the equipment are shown in Table 1.

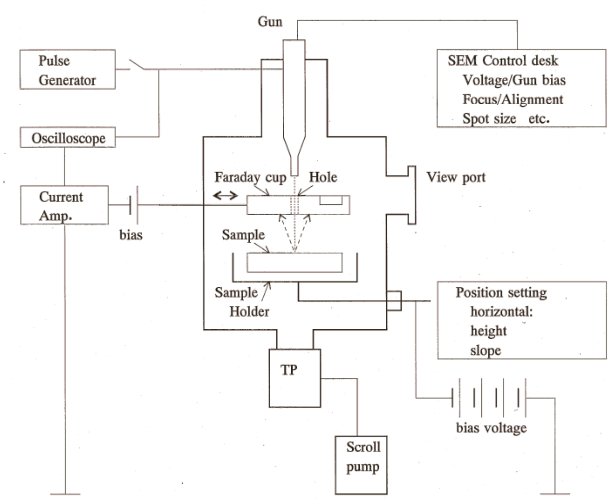

Fig.1 SEY measurement apparatus

Table 1 Parameters of SEY measurement apparatus

Primary electron energy	0.6keV-30keV
Vacuum pressure	2×10^{-4} Pa
Magnification	30 - 200000
Sample holder diameter	100mm
Sample stage motion	x: 0-32mm y: 0-50mm

3 MATERIALS FOR KEKB COUPLER

The KEKB coupler has a 50Ω coaxial structure, composed of an antenna type inner conductor, an outer conductor and a ceramic disk window in order to isolate the vacuum from the atmosphere and to pass RF power. Fig. 2 shows its structure. Table 2 summarises the structure and treatment of the coupler.

The ceramic window is made from 95% pure alumina coated with a 100Å thick TiN_xO_{1-x} film on the vacuum side[7]. The coating film is formed from TiN deposited by DC sputtering, and is oxidized to TiN_xO_{1-x} by the vessel's residual gas (pressure ~10^{-4}Pa). The ceramic window is subsequently brazed in a hydrogen gas vessel at 1000˚C and 800˚C, which presumably alters the coating film. The window fabrication procedure is shown in Table 3.

The inner conductor is manufactured to connect the window structure and antenna of electropolished copper by electron beam welding. The outer conductor is made of stainless steel plated with copper using pyrophosphoric acid.

After fabrication we rinsed the inner conductor with window and outer conductor with ozonized (3 ppm) ultra-pure water for 3 min. After rinsing the coupler is baked at 100˚C for 1 day, and the processing is started.

During processing of the couplers, their metal surfaces are subjected to multipacting in the presence of bias voltages ±2000V and power up to 300kW. Under these conditions, electron bombardment energies are estimated to be between 100eV and 2000eV, and it is this bombardment that is presumably responsible for the improved coupler performance after processing.

Table 2 Input coupler structure and treatment

Coupler	
Loaded Q	7×10^4
Impedance	50 Ω
Window	
Structure	choke: gap 3 or 4 mm
Size	ceramic: ϕ170-ϕ42 × 10mm^3
Material	95% purity alumina
Coating	TiN_xO_y 100Å
Inner conductor	
Structure	antenna ϕ 53mm
Material	copper (OFHC)
Surface treatment	electropolishing
Outer conductor	
Structure	inner diameter ϕ120mm
Material	30µm Cu-plated stainless steel
Surface treatment	plated, pyro-phosphoric acid
Outer conductor connected to the Nb cavity	
Structure	inner diameter ϕ120mm,100mm
Material	Nb
Surface treatment	electropolishing

Table 3 Window fabrication procedure

New ceramic
Metalize window surface
Anneal at 800˚C for inspection
Coat TiN_xO_{1-x} by DC sputtering
Au braze at 1000˚C
Ag braze at 800˚C

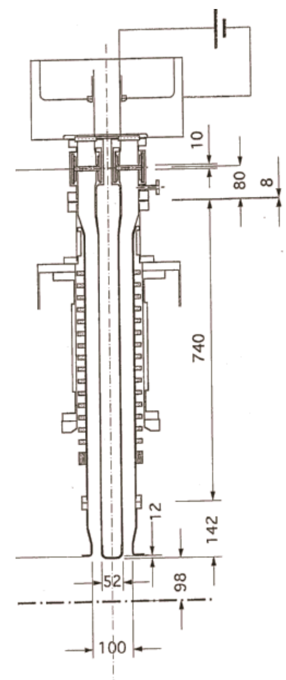

Fig.2 Structure of the KEKB coupler

4 THE CERAMIC WINDOW

4.1 Materials and sample preparations

Samples were prepared from 95% pure (HA95) and 99.7% pure (HA997) alumina, as used for pulsed X-band klystrons [8]. The samples were coated with TiN_xO_{1-x} films of thickness 50Å, 100Å, and 200Å, and brazed at 1000˚C and 800˚C in a hydrogen gas vessel, just as in the window fabrication process. Before measurement all samples were rinsed with ultrapure water to reduce static electricity charging. The properties of the samples are shown in Table 4.

We used these samples to study the effects of material purity and the adjustment of the TiN coating (e.g. thickness and the manufacturing process) on the SEY.

Table 4 Sample preparation and properties of alumina

Properties of alumina used for samples		
Material	HA95	HA997
Alumina content [%]	95	99.7
Specific gravity	3.65	3.95
Flexual strength [GPa]	350	300
Dielectric constant (3.5GHz)	9.1	9.95
Dielectric loss tangent (3.5GHz)	2.2×10^{-4}	4.2×10^{-4}
Samples		
Ceramic size	Thickness of TiN coating film	
HA95 ϕ92×t3.5mm	no coating/50 Å/100 Å/200 Å	
HA997ϕ53×t2.5mm	no coating/100 Å	

4.2 Results

The SEY of these samples was measured at several points of the fabrication process: before the TiN coating, after the TiN coating, and after brazing in hydrogen gas. The 100Å TiN coated HA95 sample was measured after ozonized water rinsing.

Figures 3 and 4 show the results of SEY measurements for 100Å TiN coated HA95 and HA997 samples. Fig. 5 shows the SEY for HA95 with TiN coating thicknesses of 50Å, 100Å, and 200Å. The measurement of the sample before coating was made on a different uncoated sample, because charging due to electron emission during the measurement may later disturb the coating process. The SEY measurements after TiN coating and after brazing were made on the same sample. The charging was reduced by the brazing at 1000˚C. The SEY of the bare alumina surface had a high maximum value of 4-6, but after the TiN coating the SEY decreased. After the brazing, the SEY was increased and the charging by electron emission was negligible.

The results are summarized in the following and in Table 5.

- High purity uncoated alumina ceramic has a high SEY.
- The TiN coating is effective in reducing the SEY. The characteristics of the coating are dominant for the SEY.
- After the brazing, the characteristics of the coating film are changed. The surface conductivity changed to conductive from resistive, and the SEY was increased. After ozonized rinsing the SEY decreased to the same value as the TiN coated surface. Ozonized water rinsing is effective in removing contamination on the ceramic surface after brazing.
- The SEY is nearly the same for thicknesses of TiN coating of 50Å, 100Å, or 200Å.

Fig. 6 shows a photograph of alumina surfaces after TiN coating and brazing at 1000˚C and 800˚C, in the case of coating thickness of 50Å, 100Å, and 200Å. Fig. 7 shows an SEM photograph of an HA95 surface with 100Å TiN coating (after brazing at 1000˚C and 800˚C).

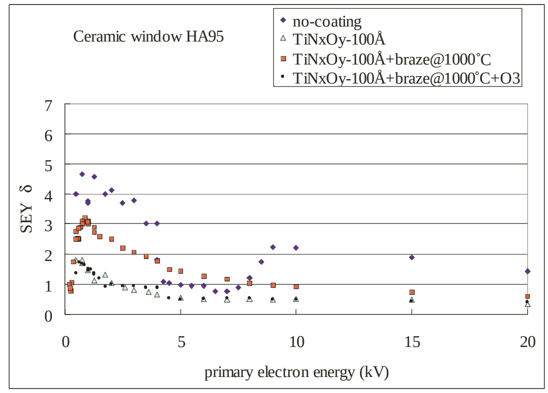

Fig. 3 SEY of HA95 with 100Å TiN coating

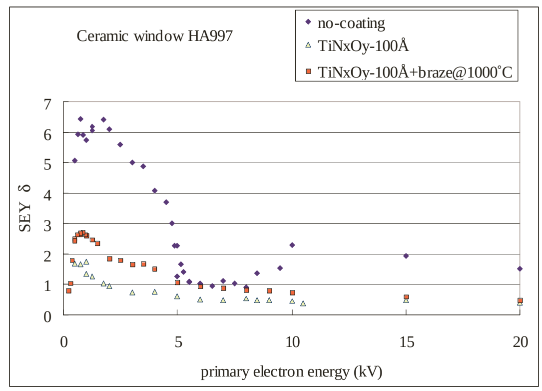

Fig. 4 SEY of HA997 with 100Å TiN coating

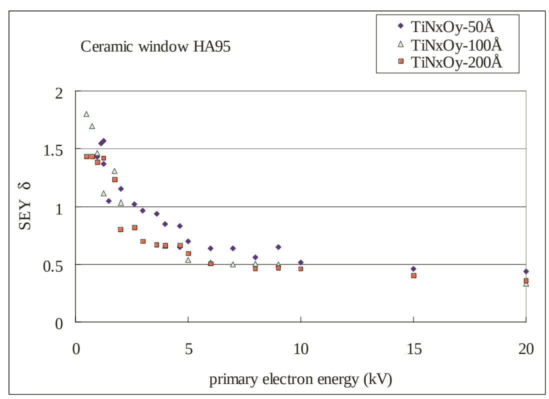

Fig. 5 SEY of HA95 with 50Å, 100Å, and 200Å TiN coating

Table 5 Alumina SEY (maximum value) vs treatment

Treatment	Al_2O_3	TiN coating	braze 1000˚C	O_3 rinse
HA-95 50Å		1.9	3.3	
HA-95 100Å	4.8	1.8	3.3	1.8
HA-95 200Å		1.5	2.4	
HA-997 100Å	6.5	1.8	2.7	
Conductivity	Resistive (charging)	-	Conductive	-

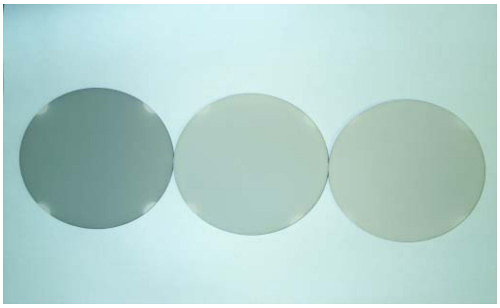

Fig.6 Alumina samples with TiN coating (left: 200Å, center: 100Å, right: 50 Å) after brazing

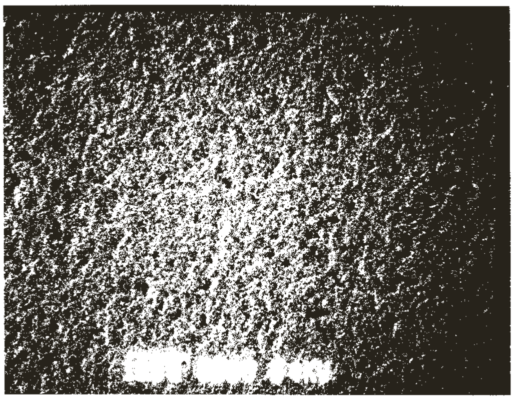

Fig.7 SEM photo of HA95 surface with 100Å TiN coating after brazing

5 THE METAL SURFACE OF THE COAXIAL LINE

5.1 Sample preparation

Three kinds of metals—oxygen free copper (OFHC), stainless steel (SS) plated with copper, and niobium—were given the same preparation as the surface of the coupler coaxial line.

The OFHC grade 1 is cut to size (20mm×10mm×2mm) and treated by electropolishing (EP). The plated SS is prepared from 100mm×10mm SS sheet and plated 30µm thick with copper using pyro-phosphoric acid. The solution of pyro-phosphoric acid contains mainly pyro-phosphoric copper ($Cu_3P_2O_3$-$3H_2O$) and pyro-phosphoric potassium ($K_4P_2O_7$-$3H_2O$). The niobium sample was treated with the same process as the cavities, i.e. EP 100µm, 700˚C anneal for 2hr, EP 15µm, pure water rinsing and 150˚C bake for 24hr.

5.2 Results

To check the influence of rinsing on the SEY, the OFHC and Cu-plated SS samples were measured ‘as received’, after pure water flow rinsing for 3min, and after ozonized water flow rinsing for 3min. As shown in Figs. 8 and 9, no clear difference due to rinsing can be seen in the SEY.

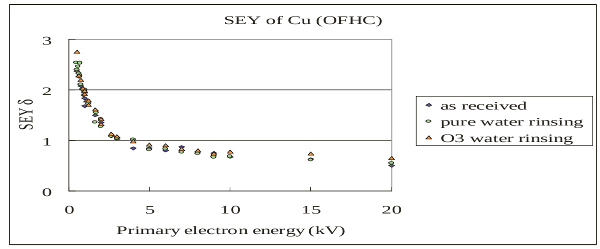

Fig. 8 The SEY of OFHC: as received, after pure water rinsing, and after ozonized water rinsing

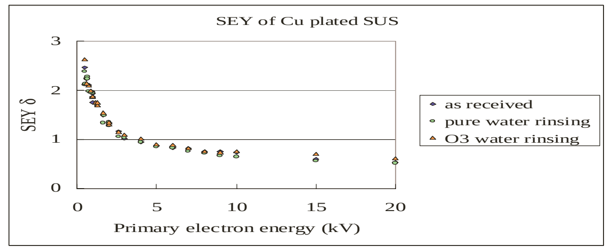

Fig. 9 The SEY of Cu plated SS: as received, after pure water rinsing, and after ozonized water rinsing

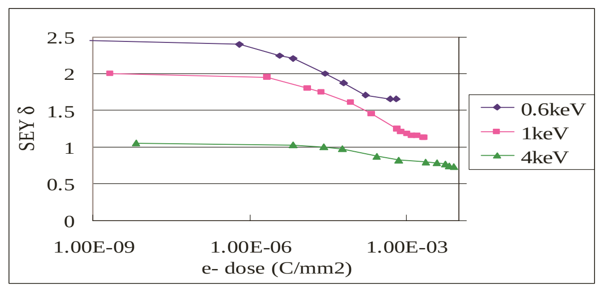

Fig.10 The SEY decrease after electron bombardment (OFHC sample)

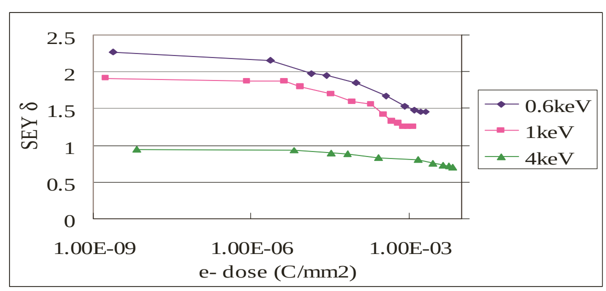

Fig.11 The SEY decrease after electron bombardment (Cu-plated SS sample)

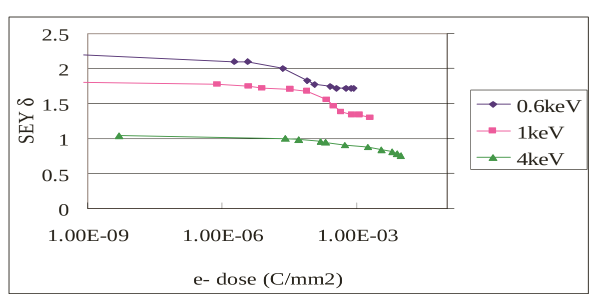

Fig. 12 The SEY decrease after electron bombardment (Nb sample)

Next we investigated the effects of electron bombardment, simulating conditions under multipacting by setting primary electron energies to 0.6keV, 1keV and 4keV. The primary electrons irradiated a surface area of 0.02-0.07mm^2 with a constant beam current of 1nA and energy 0.6, 1.0, or 4.0keV. The SEM vacuum during the electron bombardment was 2x10^{-4} Pa. The relation between the electron dose and the SEY is shown in Figs. 10-12. It is clear that the SEY decreases with increasing electron dose, reaching a limiting decrease of 30-40% with doses of 10^{-3} C/mm^2.

Fig. 13 shows an SEM photograph after electron bombardment. The bombardment area was estimated from this picture.

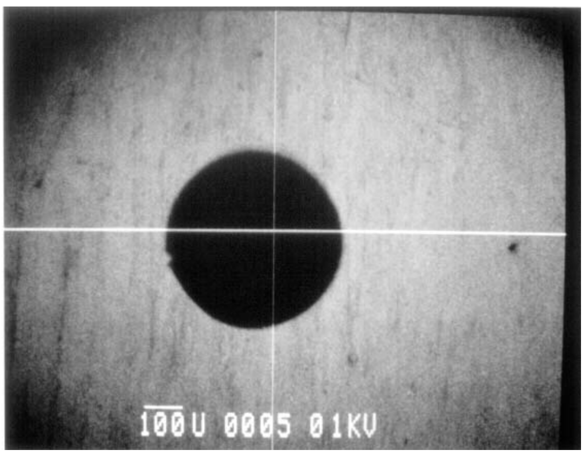

Fig. 13 SEM photograph after electron bombardment at 1keV on Cu-plated SS.

6 SUMMARY

We have studied the electron emission properties of the materials used in the KEKB coupler.

In the ceramic window, though the high purity alumina has a high SEY, the SEY was decreased by the TiN coating. After brazing, the SEY was increased and the characteristics of the coating film were changed. After ozonized rinsing the SEY decreased to the same value as the TiN coating. The ozonized rinsing appears effective in removing contamination produced in the brazing process.

On the metal surface of the coaxial line, the SEY was decreased by the electron dose, reaching a level of 70% after bombardment with doses of 10^{-3} C/mm^2. This indicates that the RF conditioning using electron bombardment is effective.

We will study the effects of baking and gas exposure.

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