Research of Copper Thermal Spray Coating for Mitigating Electron Cloud

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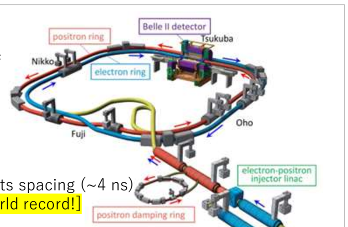
Introduction

SuperKEKB

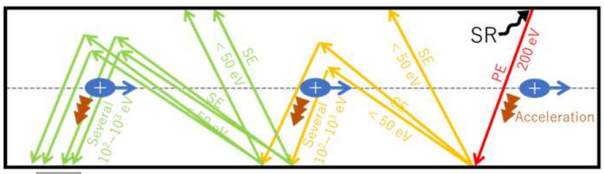
SuperKEKB e⁻ - e⁺ two-ring collider consisting of

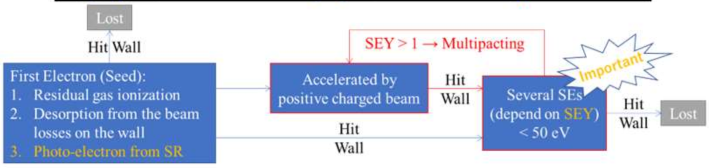
- BELLE-II detector
- Injector (Linac): L ~600 m
- Damping ring (e+): C ~135 m
- Main ring (MR): C ~ 3016 m
  - HER: 7 GeV e⁻, Max. current 1.14 A
  - LER: 4 GeV e+, Max. current 1.46 A
- Max. number of bunches = 2346 with ~2 RF-buckets spacing (~4 ns)
- Achieved peak luminosity: 4.65 × 10^{34} $cm^{-2}s^{-1}$ [World record!] (HER 1.10 A/LER 1.32 A/ 2249 bunches)
- The ECE will become a potential problem in SuperKEKB positron ring when we strive for a higher luminosity by increasing beam current in the future.



Electron Cloud Effect (ECE)

- For the beam with positive charge (proton and positron), the high-density electrons around the beam, also called as "electron cloud (EC)", cause the beam instability.
- Electron Cloud Formation:



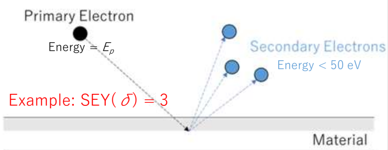


- Beam size starts to increase at a threshold bunch current, resulting in the reduction of the luminosity.
- This is known as the electron cloud effect (ECE).
- Threshold electron density in SuperKEKB LER: 3 × 10^{-11} /m³

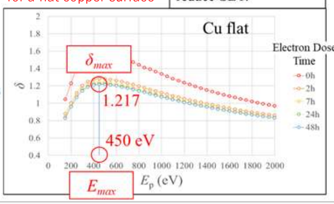
Conditioning: Electron bombardment of the inner surface of the beam pipes can reduce SEY.

SEY

- The Secondary Electron Yield (SEY or δ) is a primary parameter for controlling the ECE.

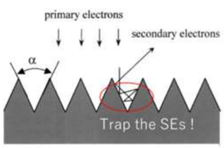


Example: Measured SEY for a flat copper surface



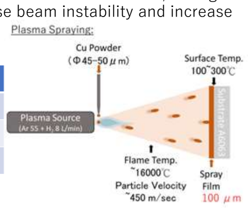
Thermal Spray

- Materials with Low SEY can be used to reduce ECE. TiN, for example, has been used in 90% of the SuperKEKB LER.
- In addition, rough surface generally has a lower SEY than smooth surface. However, a rough surface will increase the surface impedance, which may cause beam instability and increase heat load.



After conditioning ≈ 1 × 10^{-1} C/mm²

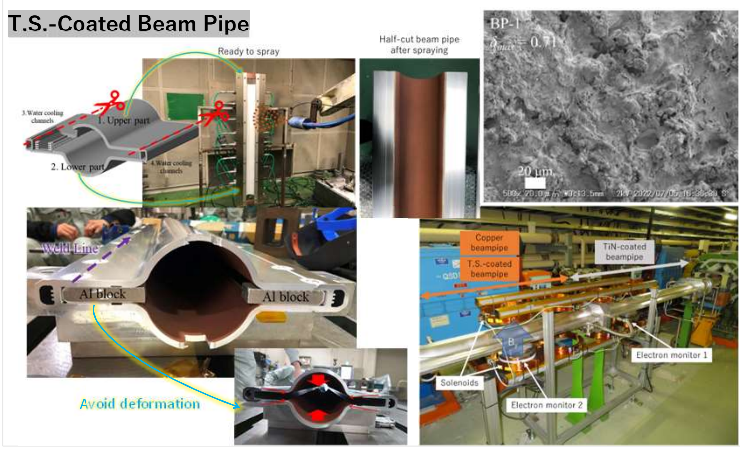
Surface	δ_{max}	E_{max} [eV]
Flat Cu	1.2	450
TiN	0.9	400
T.S. coating	0.7~0.8	700~2000



Thermal Spray Coating (T.S. Coating)

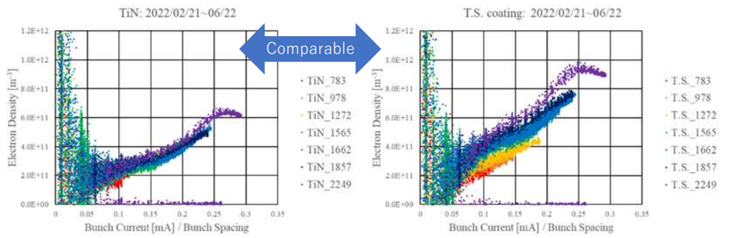
- Coating process: Melted or heated powdered materials are sprayed onto a surface.
- Original function: Protective layer, such as crankshaft reconditioning, corrosion protection, etc.
- Here we use this technology to increase roughness and, as a result, to reduce SEY.

T.S.-Coated Beam Pipe



Results

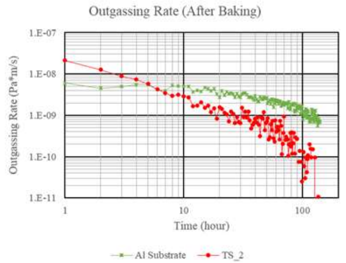
Electron Density around the Beam



- These figures show the electron density around the beam against the current linear density (i.e., bunch current/ RF bucket spacing) in the TiN-coated and T.S.-coated beam pipes of SuperKEKB.
- The numbers on the right represent the bunch number.
- The electron density in the T.S.-coated beam pipe was in the same order as that of TiN-coated beam pipe.
- Another phenomenon to be aware of was that the electron density in the T.S.-coated beam pipe increased with the bunch number.
- It may be caused by the differences in the characteristics or locations between monitors (to be checked).

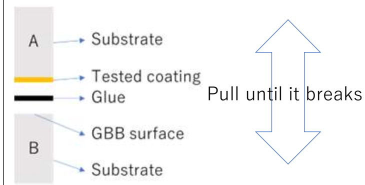
Feasibility in Accelerators

Outgassing Rate Measurement



- Method: CM method
- Outgassing rates: T.S. coating ≈ Flat Al surface (< 1 × 10^{-9} Pa·m/s after 100 h)
- Static desorption rate requirement of SuperKEKB: < 10^{-8} Pa·m/s

Adhesive Strength



- Method: JIS H 8402
- T = P/A
  T [N/mm²]: Tensile adhesive strength
  P [N]: Tensile breaking load
  A [mm²]: : Coating area
- T values [MPa]:
  -T.S. coating on Al: 29.17
  -Electroplating Cu on SS: 27.17

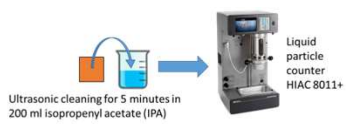
Surface Resistance

Sample	σ @5.044GHz [S/m]	$R_s = \sqrt{\frac{\pi\mu_0 f}{\sigma}}$ [Ω]
Polished Cu	5.9E+7	1.8E-2
Machined Al	3.3E+7	2.5E-2
GBB Al	6.8E+6	5.4E-2
T.S. coating	1.9E+6	1.0E-1
Ti	2.4E+6	9.2E-2
SUS304	1.5E+6	1.2E-1

- Method: Cavity-resonator method
- Surface Resistance: T.S. coating ≈ Ti and SUS304

Dust

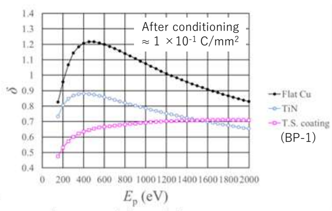
- Method:



- Number of particles/coating area: T.S. coating ≈ NEG strip 707

Conclusion

- The T.S. coating had a lower δ_{max} = 0.7~0.8 at higher E_{max} than that of flat Cu and TiN.



- The outgassing rate and adhesive strength of T.S. coating were adaptable.
- The amount of dust and impedance were not inconsiderable.
- The electron density in the T.S.-coated beam pipe installed in SuperKEKB LER was comparable to that of the TiN-coated beam pipes.
- In conclusion, according to the comprehensive evaluation, the T.S. coating can be considered as a candidate technology for reducing ECE, while there are still room for improvement.
- This study can provide a new and useful information for researchers in this field in developing a low-SEY coating on beam pipes.