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# Development of Field Emission Scanner Combined with SEM-EDX

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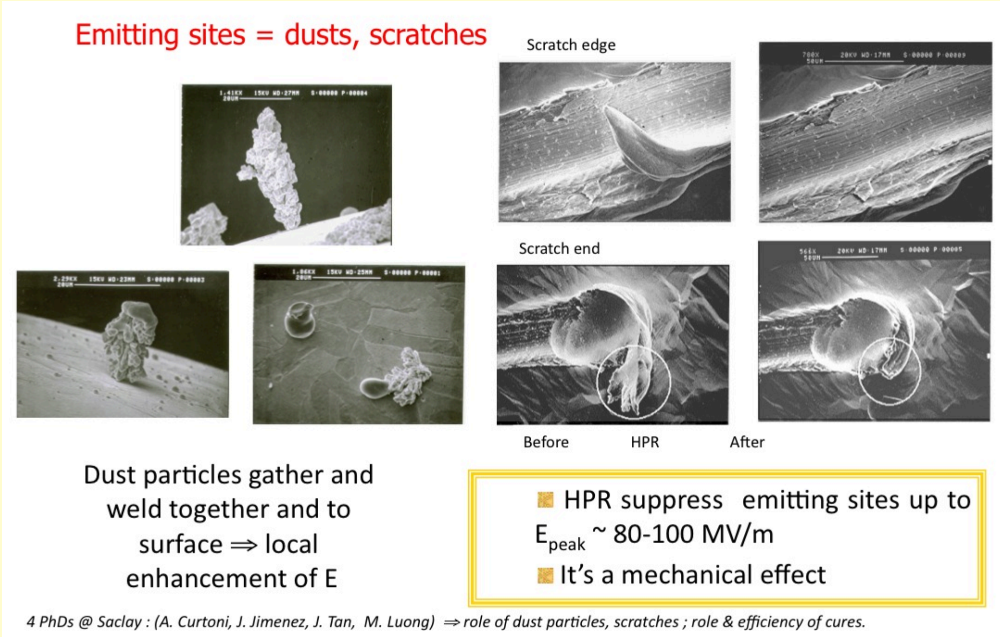
# Outline

- Aim of Study
- Design Principles of Field Emission Scanner @ KEK
- How to Map Field Emitters on Surface?
- Details of KEK Field Emission Scanner
- First Application of FES to OFHC Copper Surface
- Summary

# Field Emission Limits Acceler. Cavity Performance




- Scratches
- Pits and Bumps
- Dust Particles
- Residues

◆ This issue has been much improved by careful handling in the material preparation, machining, welding, polishing and so on.

◆ However, FE is still a big concern, specially in mass production process.

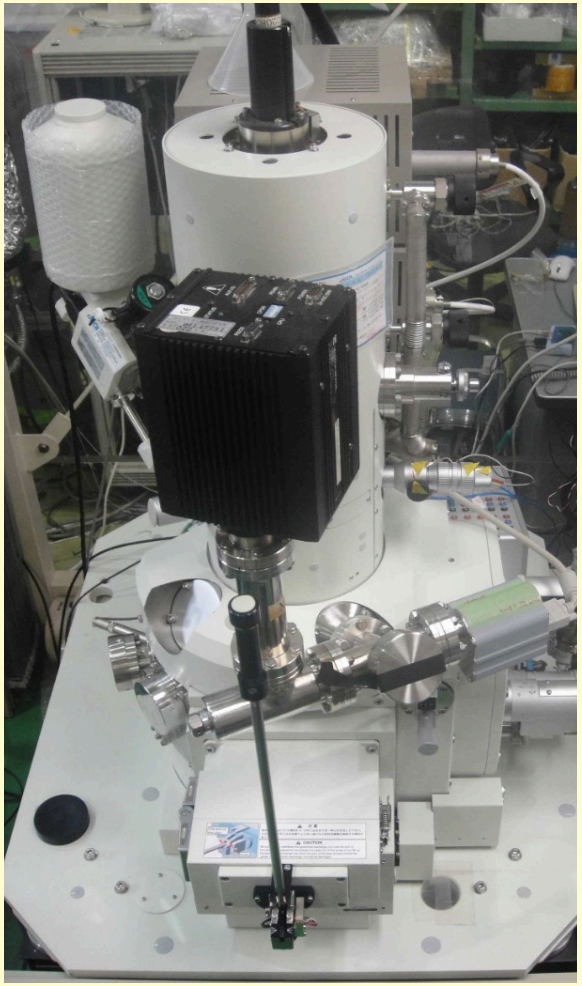
◆ There was no good tool to find and quantify the field emitters, strongly depending on both their surface topography and surface atomic composition.

◆ We need capabilities to carry out in-situ mapping of the emitters, the topography and the atomic composition at the same position.

# Design Principles of Field Emission Scanner @ KEK

**FE-SEM + EDX**

**Imaging Resolution :1.5nm**



- **Designed FES in order to enable :**
  1/ In-situ FES mapping and SEM + EDX observation.

  2/ Vibration-free scanning

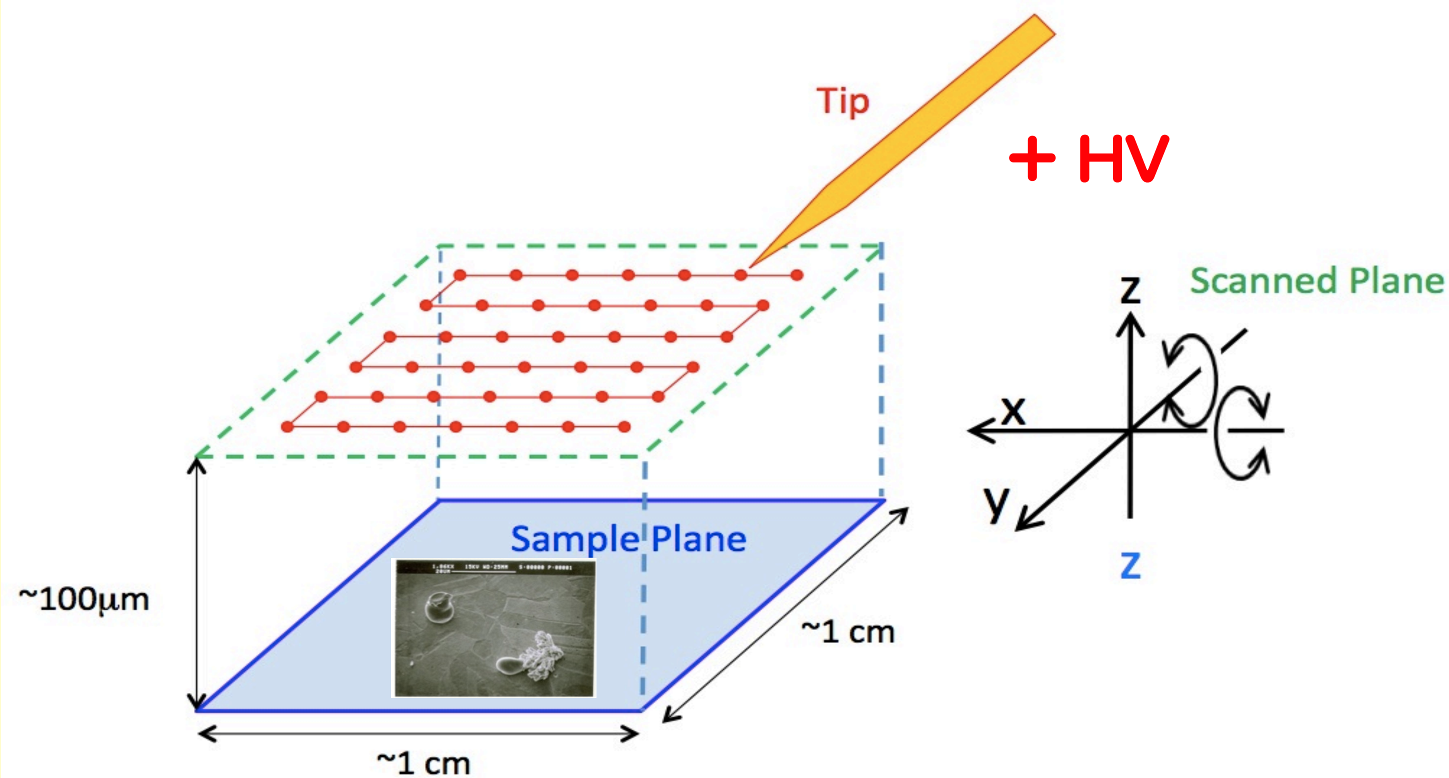
  3/ Sample loading via UHV suitcase + loadlock from surface treatment facility or XPS equipment, to keep a sample coupon dust particle free and in UHV

  4/ No sample transfer between FES mapping and SEM-EDX observation

  5/ Easy operation switching between FES and SEM-EDX modes, keeping the same SEM working distance
- **Our FES was built not only in the SEM chamber but also on its sample stage.**

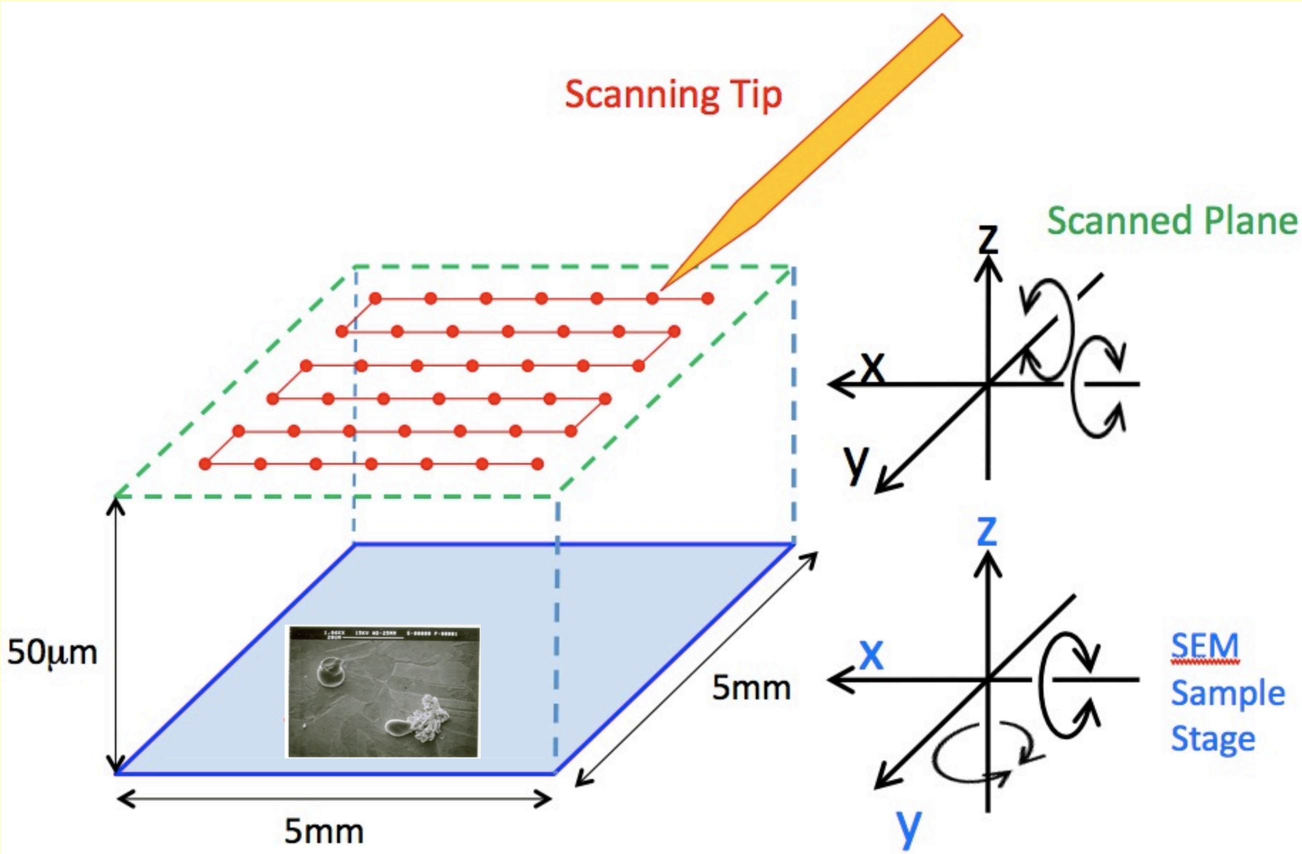
# How is FES mapping done?

- A positively biased tip is scanned over sample surface.
- If the tip is above some projection or irregular atomic composition, an emission current from the sample will increase at that location.
- In order to carry out this scanning, what is important is to keep both the sample plane and the scanned plane parallel even the sample is tilted in any direction with some mechanism.

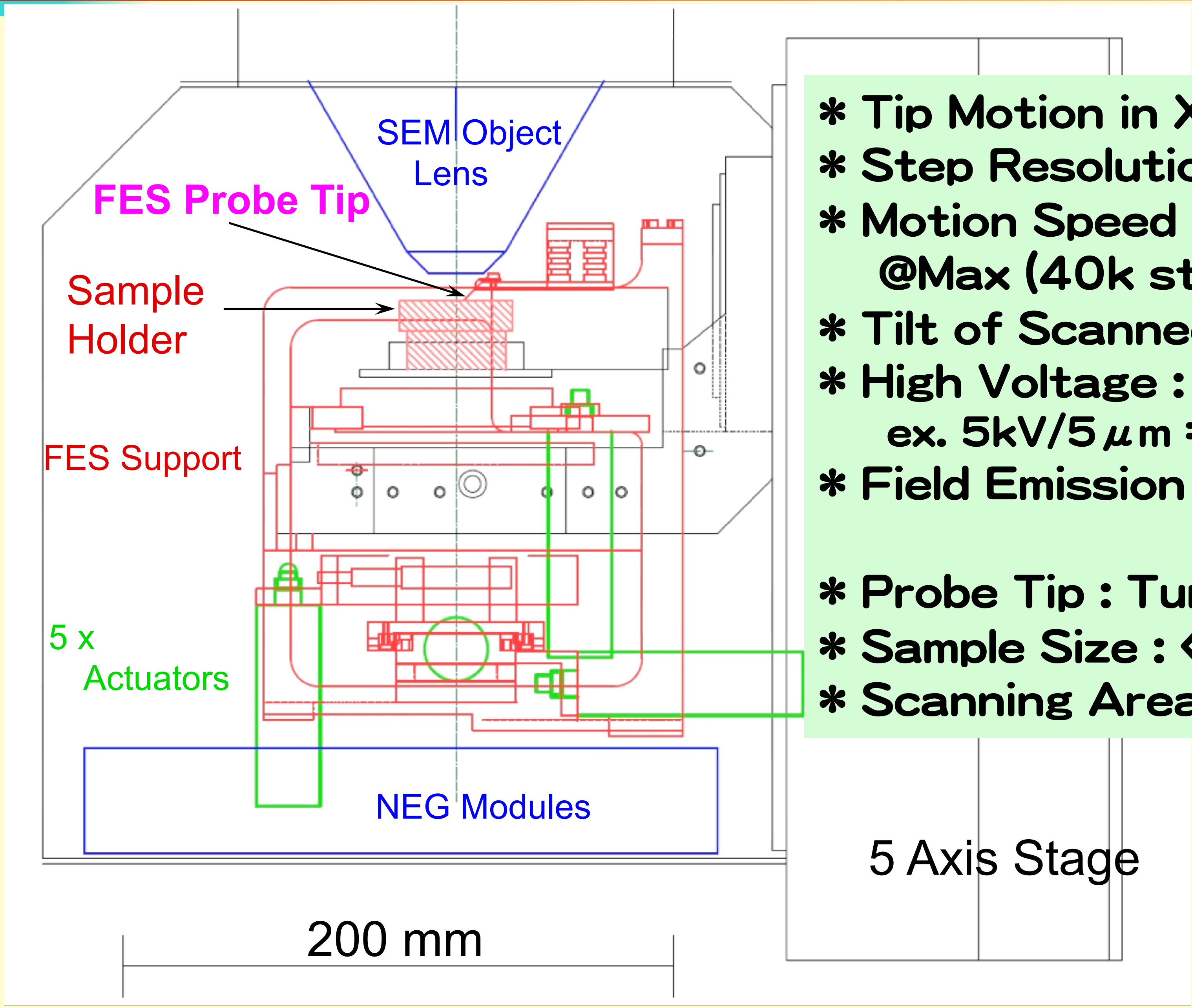


# How is FES mapping done? (contn'd)

**Three steppers for linear motion (x, y and z) of the tip and two steppers for tilt motion (around x and y) of the scanned plane were installed on SEM sample stage.**

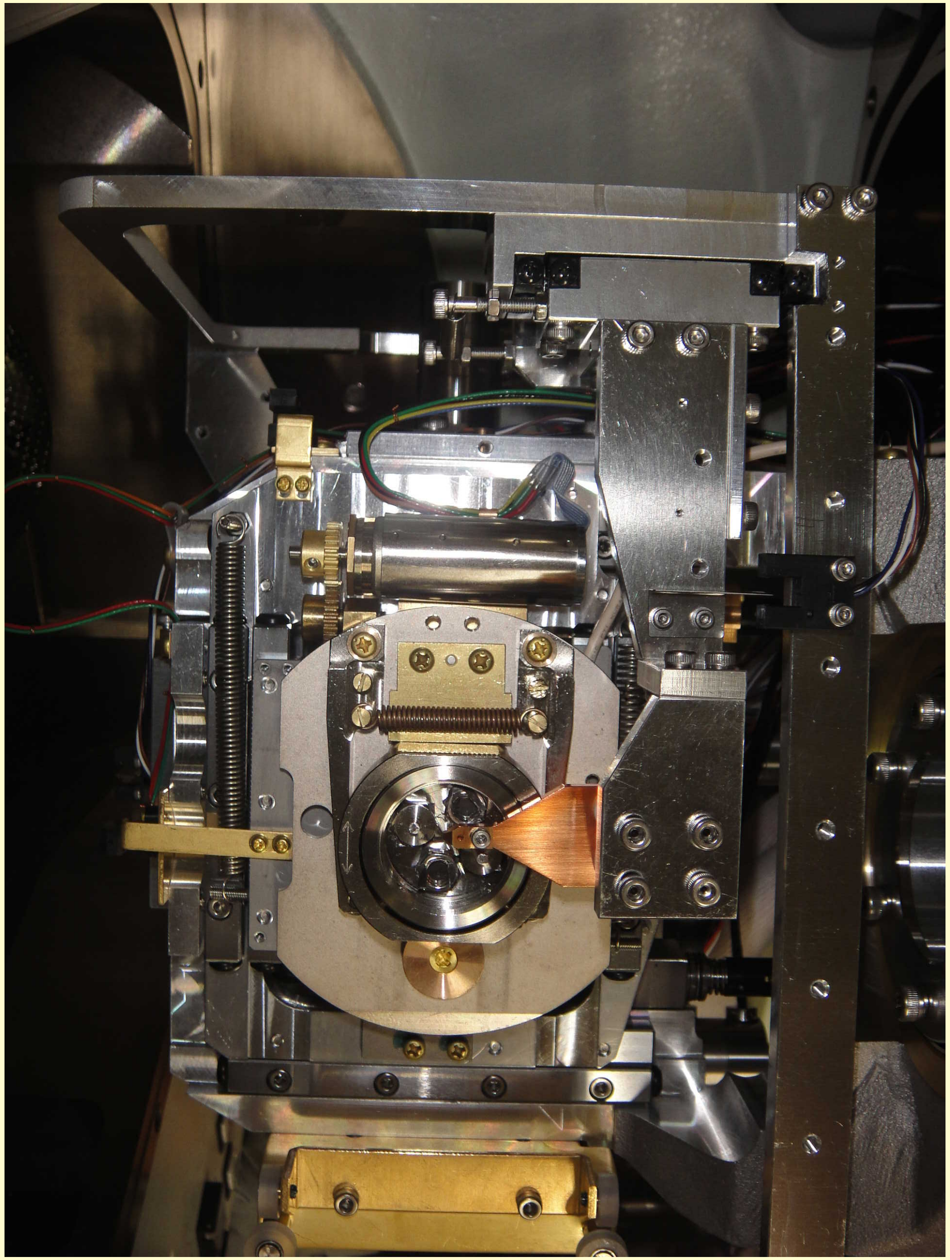


# Schematic View and Instrumental Parameters

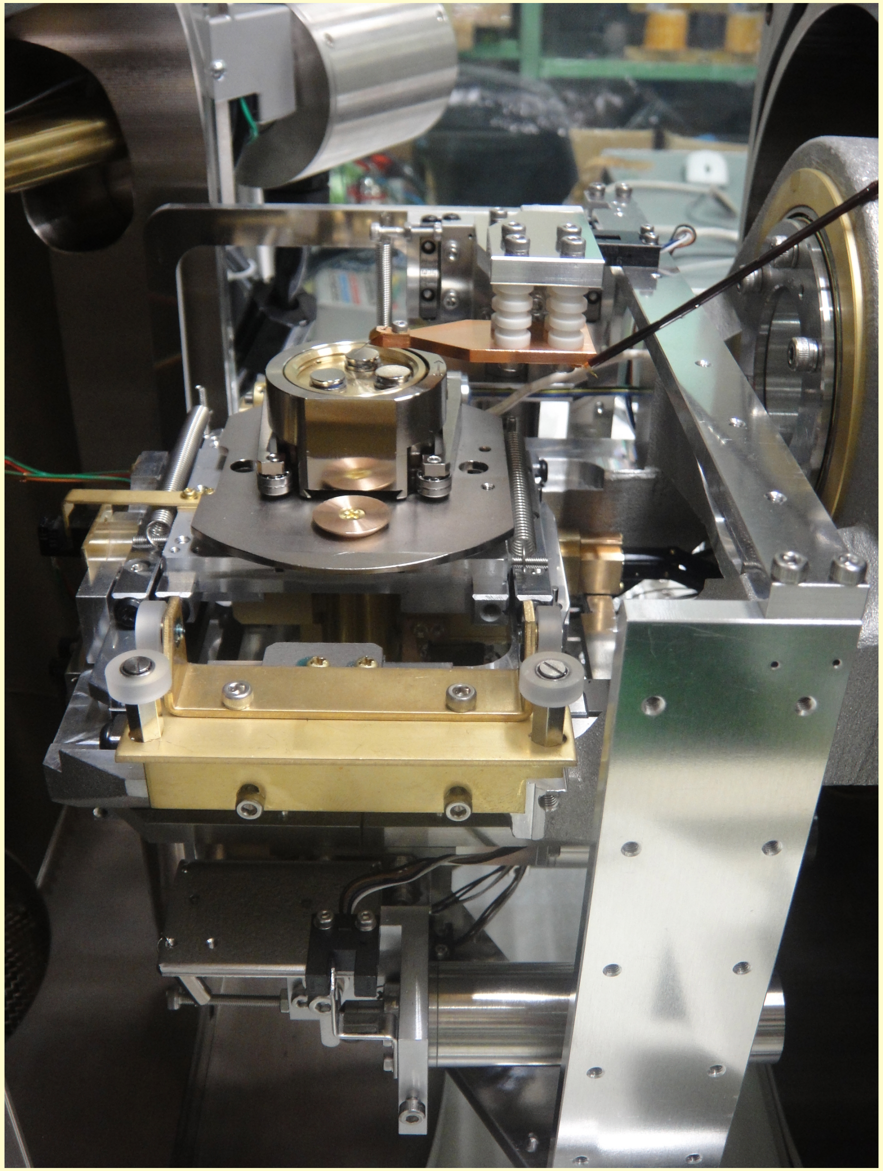



* Tip Motion in X, Y, Z: ±10mm
* Step Resolution : 250nm
* Motion Speed : 20mm/36s @Max (40k steps)
* Tilt of Scanned Plane : ±3°
* High Voltage : <15kV ex. 5kV/5μm = 1000MV/m
* Field Emission Current : > 0.1pA
* Probe Tip : Tungsten
* Sample Size : < φ8
* Scanning Area : 5mm x 5mm

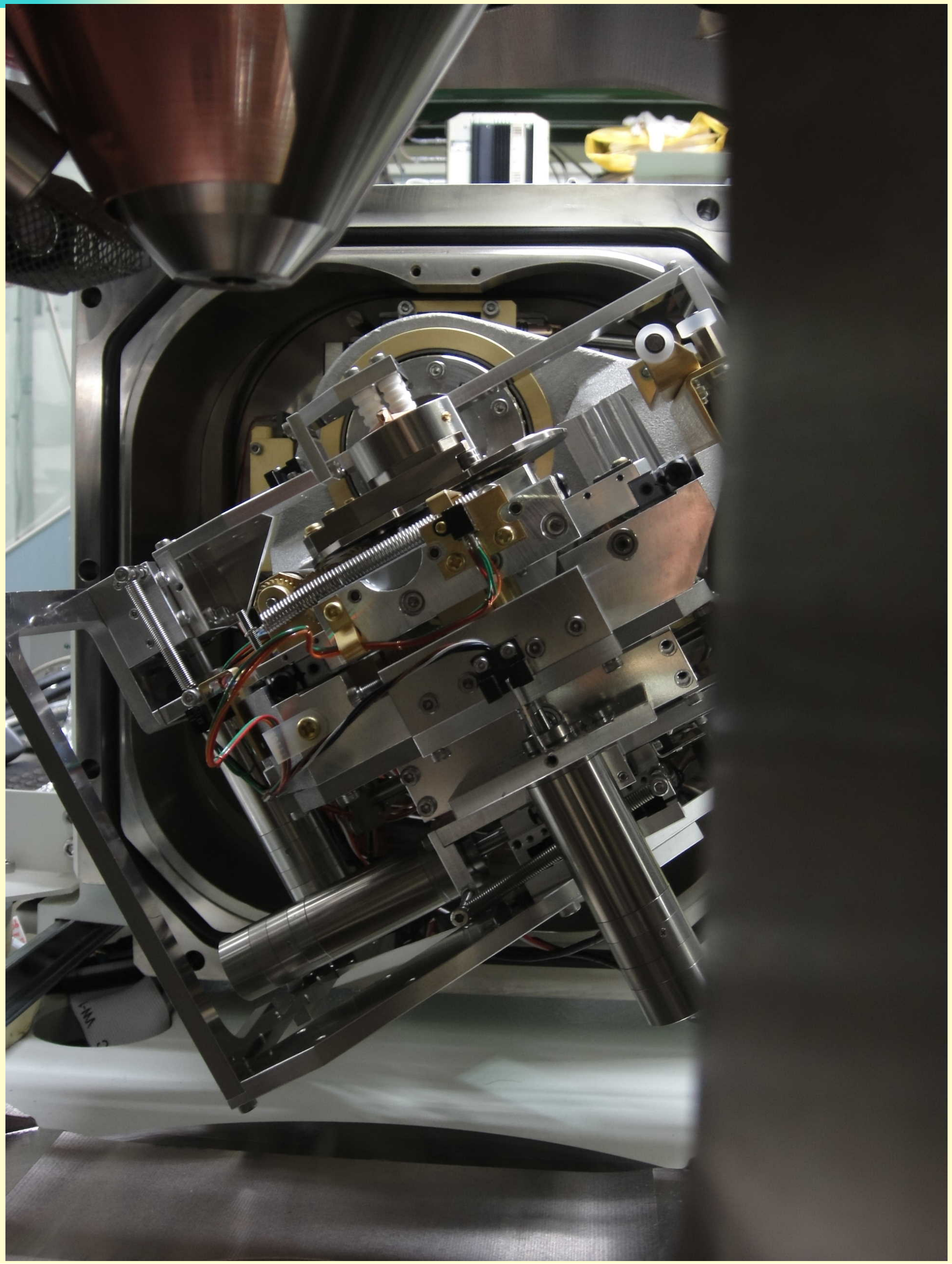
# Top View of FES on SEM Stage



# Side View of FES on SEM Stage

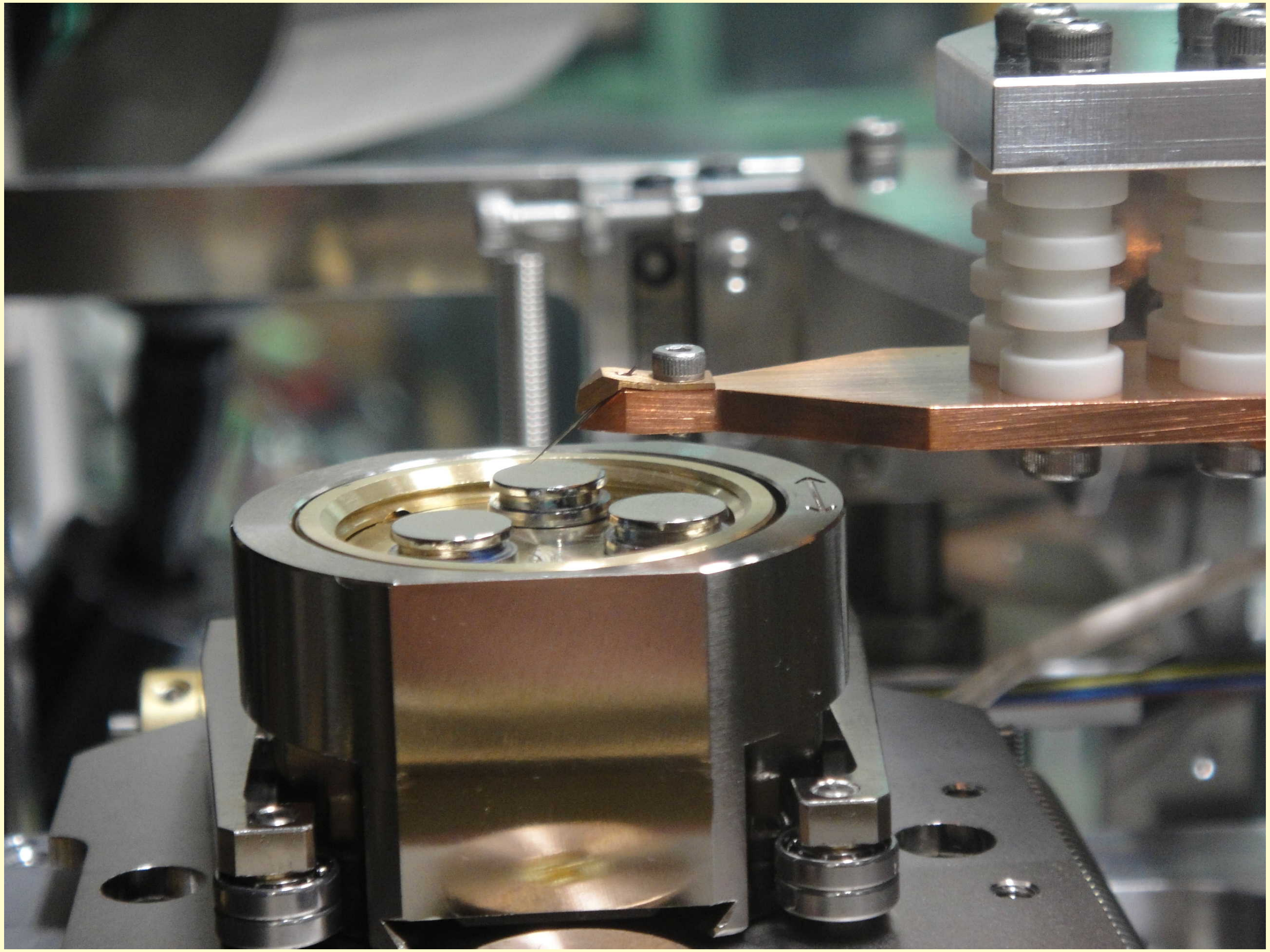


# Another Side View of FES on SEM Stage



- The whole FES was built on the SEM stage.
- Retraction of the scanner head is not needed for SEM-EDX observation.
- Operation switching between FES and SEM-EDX can be done in seconds, keeping a SEM working distance.

# Close-up of Tip and Sample Holder



- Tip raster scan over a size of 5mm x 5mm with help of SEM observation

# Combined System of SEM+EDX+FES Equipped with UHV Suitcase + Loadlock

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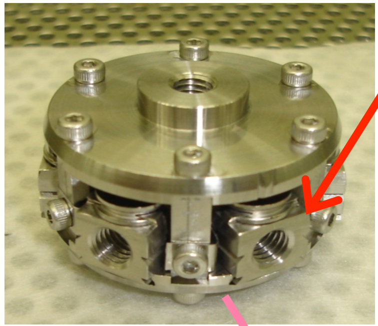
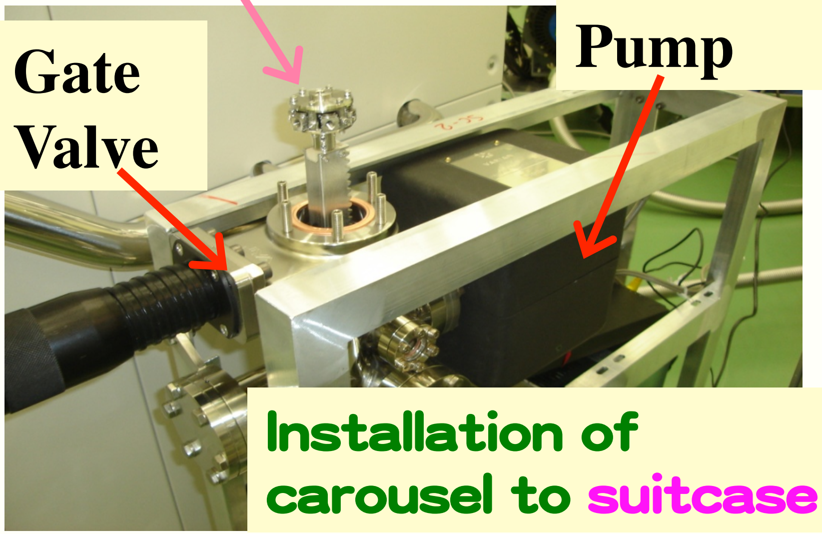
# UHV Suitcase

## Clean Room

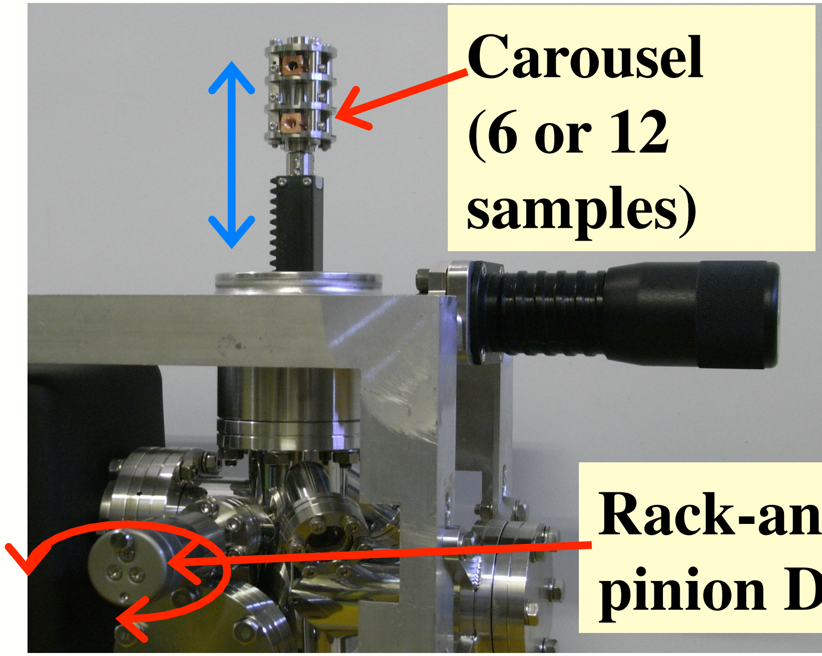


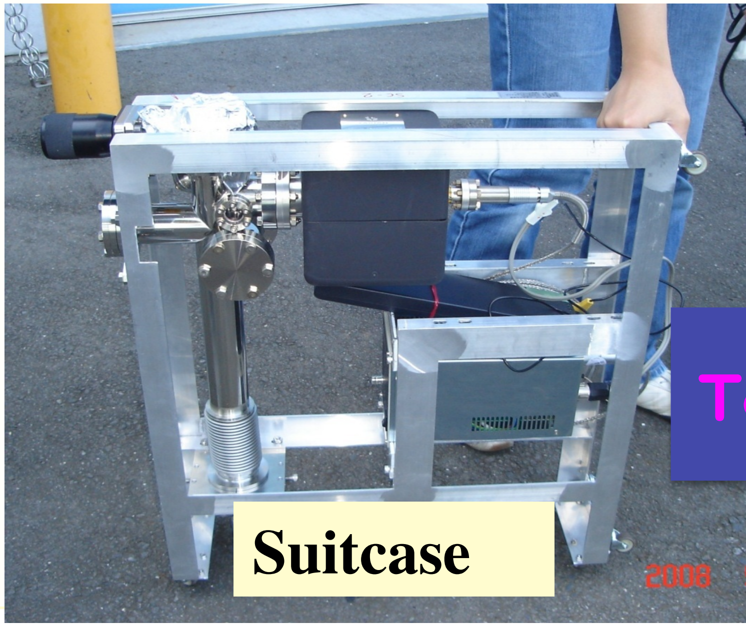
Coupons are set to a carousel in a clean room.




Installation of carousel to suitcase

- Base pressure : $10^{-6}$~$10^{-7}$ Pa
- Rack-and-pinion system
- Gate valve
- Ion pump
- Battery driven IP Controller
- Weight : 16kg



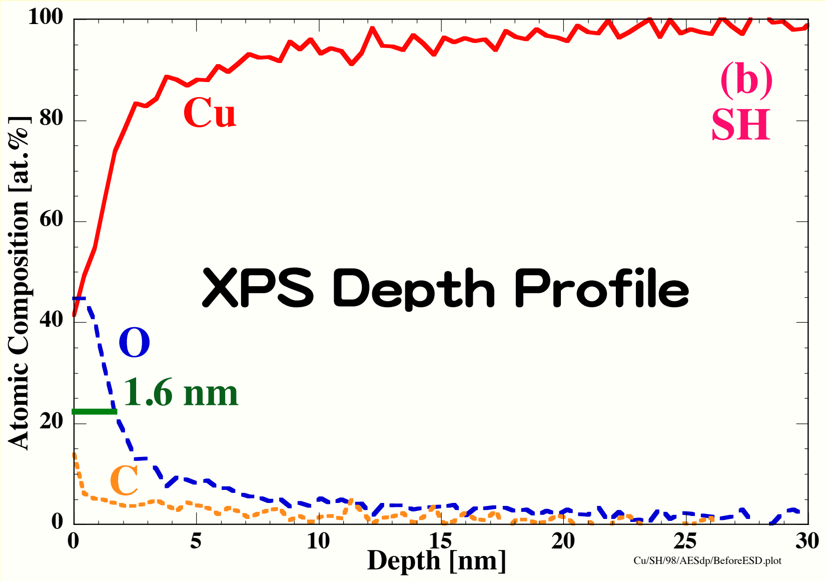

To SEM

# First Application of FES to Copper Surface

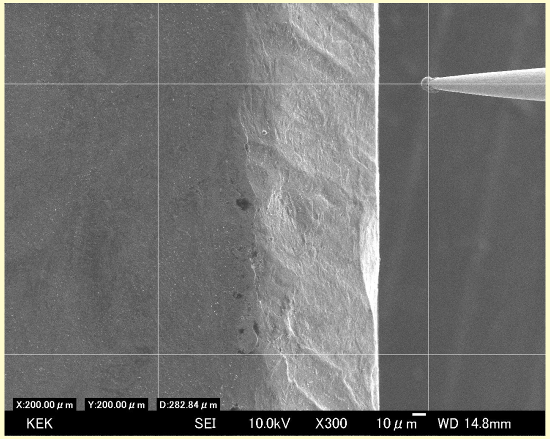
OFHC copper samples were machined and chemical-polished.

| Degreasing | Alkaline Degreaser |
|---|---|
| Solution (vol.%) | $H_2SO_4+H_2O_2$ |
| Concentration (vol.%) | 1.8 + 1.0 |
| Temperature (°C) | 25 |
| Etching Time (min.) | 10 |
| Removal Thickness (nm) | 1100 |
| Roughness $R_z$, $R_a$ (μm) | 0.9, 0.1 |

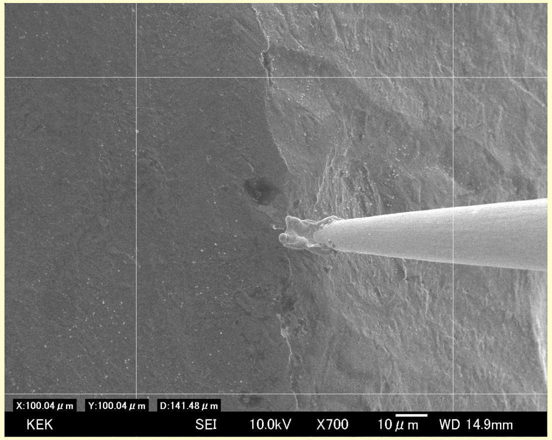
←→ 10 μm



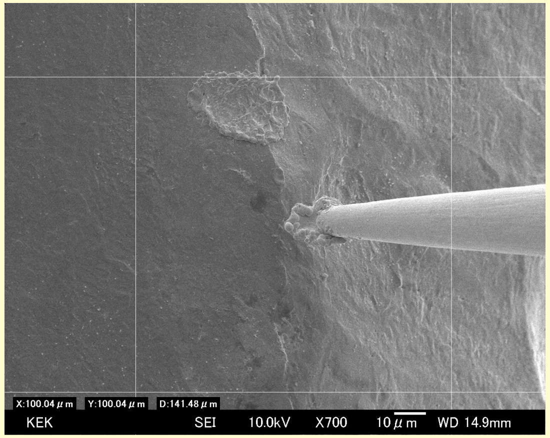
# Emission Mapping at chamfer of OFHC Copper Sample with 340MV/m



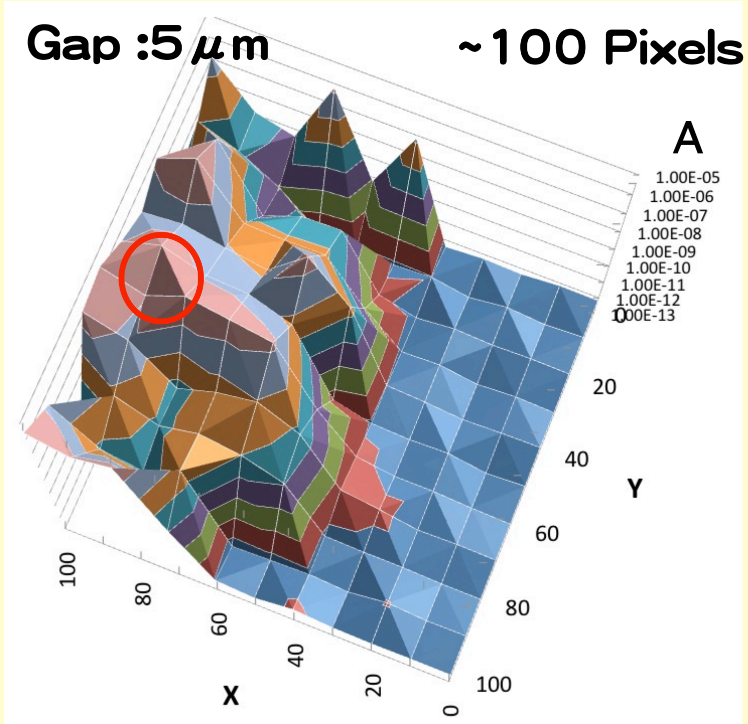

200 μm




100 μm



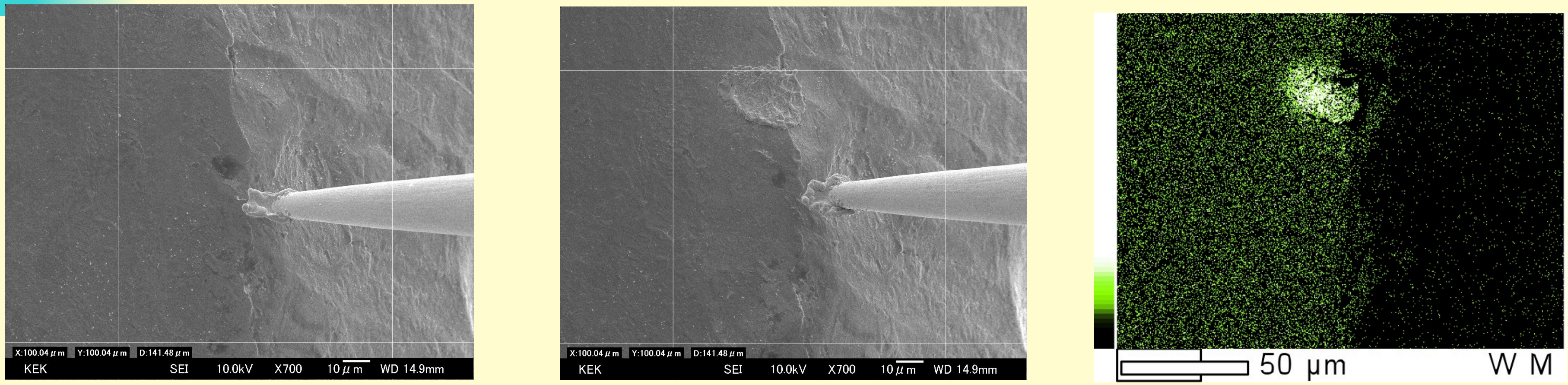

Surface Roughness at :
Rz = 0.90 μm
Ra = 0.10 μm




100×100 $\mu m^2$

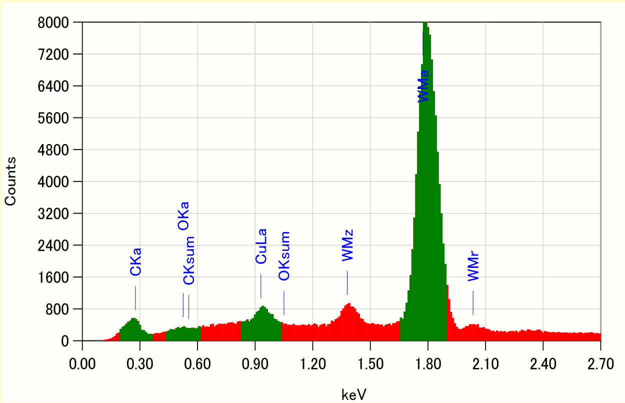
- The emission mapping is almost in good agreement with the SEM images.
- The peak current was 5 μA.
- A destructive discharge occurred during the measurement due to the too high gradient.

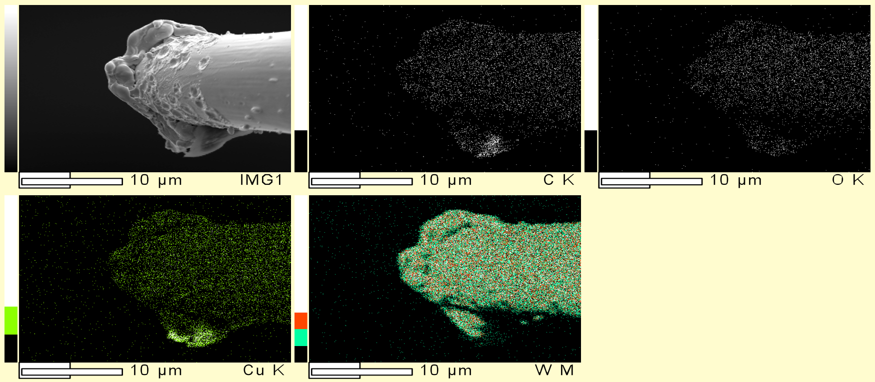
# EDX Map after FES Scanning




100μm

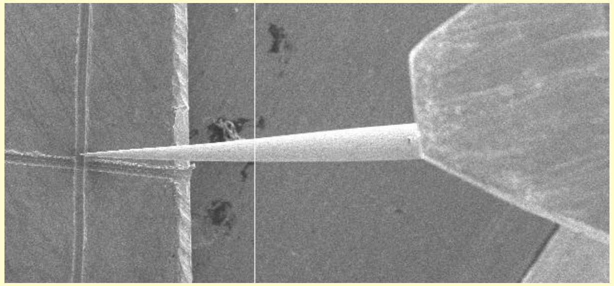
- **EDX result implies that the destructive discharge would cause electron beam induced "spattering" of the tungsten tip and subsequent tungsten droplet deposition on the copper surface.**

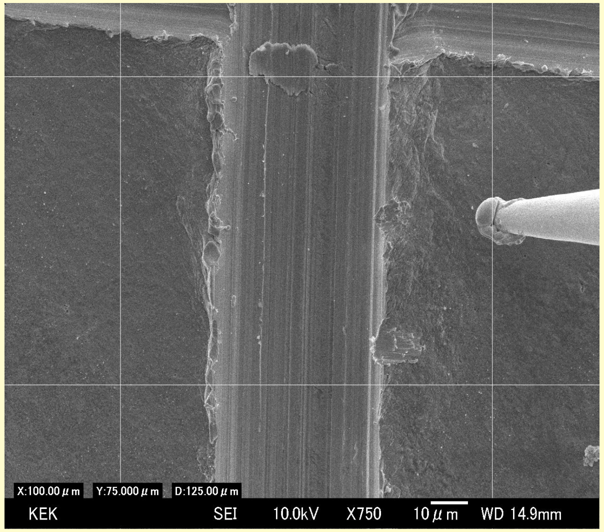



- **EDX result implies that some portion of melted copper due to probable electromigration would splash on the tungsten tip and/or sputtered copper due to self-sputtering would deposite on it.**

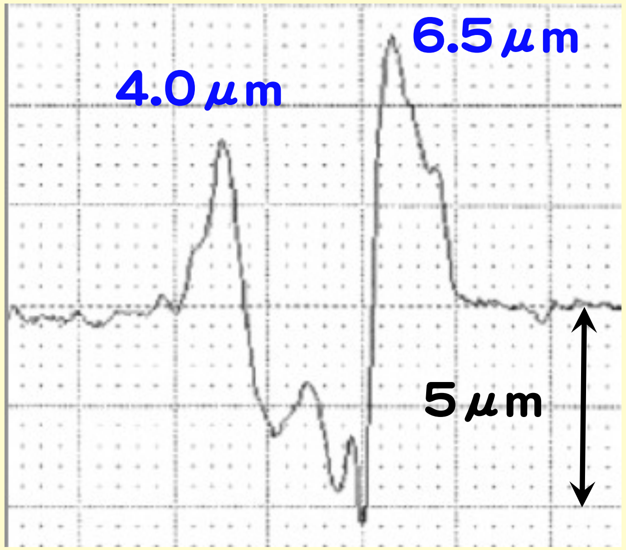
# Emission Mapping at Scratched OFHC Copper Surface with 120MV/m






$100 \times 75\,\mu m^2$

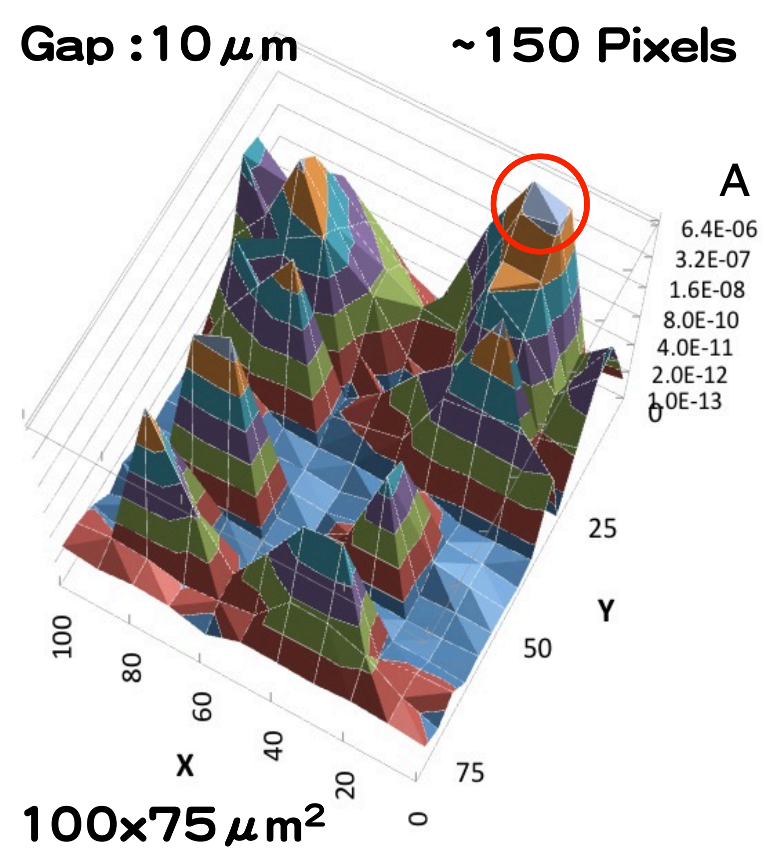
100 μm

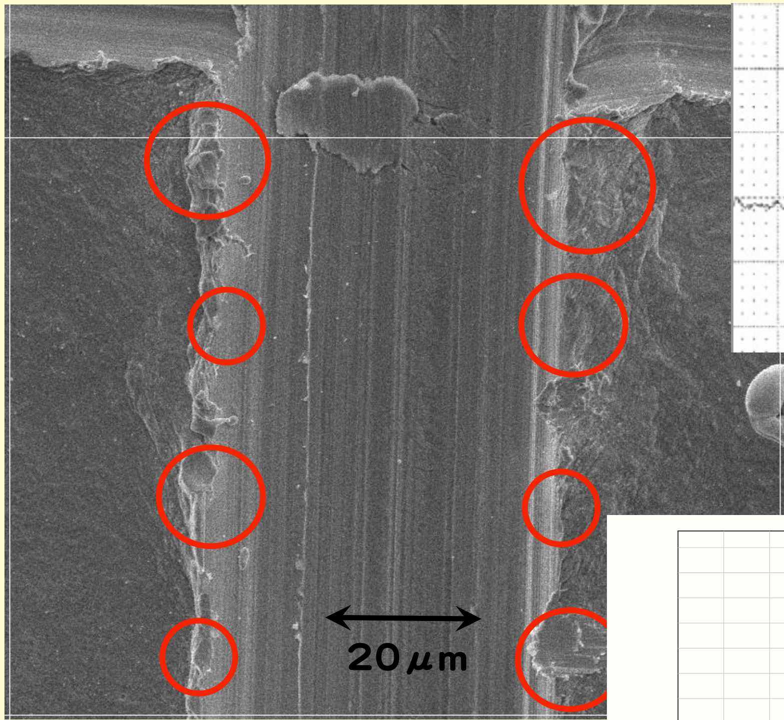


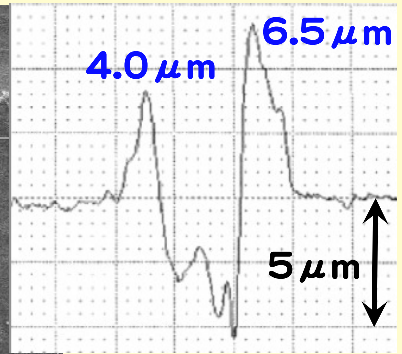

- Surface Roughness at :
  - Rz = 0.90μm
  - Ra = 0.10μm

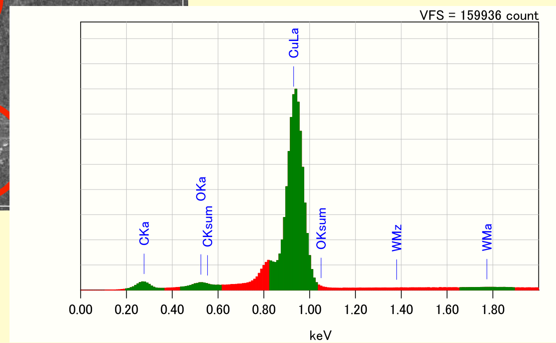
- Groove Depth = 3~5μm
- Side rise = 4~7μm

# Emission Mapping at Scratched OFHC Copper Surface with 120MV/m (cont'd)




- The FES mapping at the artificial damage corresponds to SEM images.
- The peak emission current was measured to be ~10μA, that would trigger BD.
- In general, one should consider surface composition of the emitter as well as its topography.
- EDX showed there was no special elements which would cause the field emission at this position.

# Summary

- Field emission is one of critical issues to achieve higher performance of accelerating cavities.
- Designing of FES was done in order to enable in-situ scanning and SEM + EDX observation, vibration-free scanning, quick mode change and sample loading through UHV suitcase + loadlock for keeping dust particle free and UHV.
- Three steppers for linear motion and two steppers for tilt motion were installed on the SEM sample stage to keep the tip-surface distance constant over the scanned surface.
- FES has a potential to map field emitters with a lateral resolution down to 250nm over a surface of 5mm x 5mm.
- First application study of FES to OFHC copper coupons was done.
- The emission mapping is almost in good agreement with the SEM image.
- One should consider surface composition of the emitter as well as its topography.

# Fin


**Thank you for attention!**