

ARES S-cav is made of Iron with copper electroplating.

✍ S-cav in KEKB --- electroplating in a pyrophosphate bath

- With brightener → few defects in the surface
- The facility has been retired.

✍ S-cav for SuperKEKB --- new electroplating in an acid sulfate bath performed in the periodic reverse (PR) process

(H. Ino, et. al, "Advanced copper lining for accelerator components",
Proc. of LAC2000, Monterey, CALIFORNIA, 1015 (2000))

- w/o brightener → high purity, high electric conductivity (102%IACS),
but possible defects in the surface
- Using the facility being used for J-Parc

E.g. DTL tank



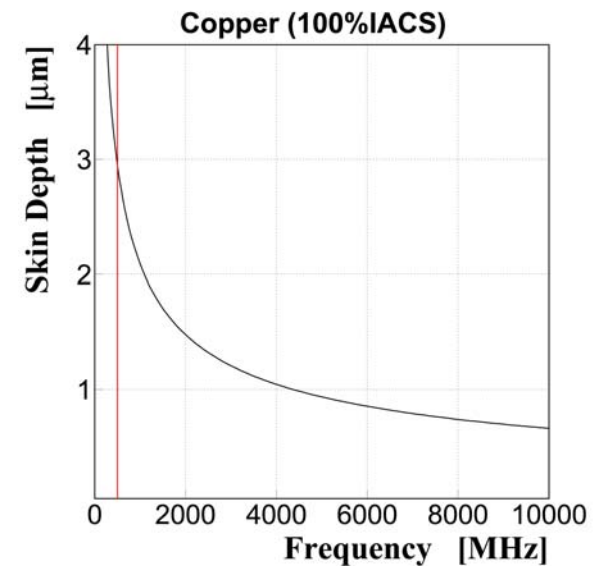
Differences between J-Parc and SuperKEKB

- J-Parc case
 - Thickness:~1mm → Mechanical polishing(-0.5mm) → Electropolishing (EP)
- SuperKEKB case
 - Thickness:~0.2mm → Electropolishing (EP)



Studies on

- **Thickness** (targets for the center of the barrel)
 - Ground(alkalinity): ~50μm
 - Main(acidity): ~150μm
 - EP: about -40μm
- **Fewer defects**
- **Electric performance**
 - Check Q_0 (Unloaded quality factor)



Pillbox Test Cavity

Diameter: 451.2mm
Height: 260.0mm

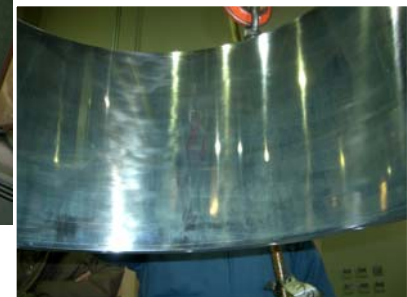


(After copper electroplating)

Made from steel (SS400)



(Before copper electroplating)



Theoretical Calculation of Q₀ (Q₀(cal))

✎ Analytical solution of the electromagnetic field in the pillbox cavity

$$\begin{array}{l}
 \text{TE}_{mnp} \text{ mode} \left\{ \begin{array}{l}
 E_r = A \frac{j\omega\mu_0}{k^2} \frac{m}{r} J_m \left(\frac{j'_{mn}}{b} r \right) \sin m\theta \sin \frac{p\pi z}{d} \\
 E_\theta = A \frac{j\omega\mu_0}{k^2} \frac{j'_{mn}}{b} J'_m \left(\frac{j'_{mn}}{b} r \right) \cos m\theta \sin \frac{p\pi z}{d} \\
 E_z = 0 \\
 H_r = A \frac{1}{k^2} \frac{p\pi}{d} \frac{j'_{mn}}{b} J'_m \left(\frac{j'_{mn}}{b} r \right) \cos m\theta \cos \frac{p\pi z}{d} \\
 H_\theta = -A \frac{1}{k^2} \frac{p\pi}{d} \frac{m}{r} J_m \left(\frac{j'_{mn}}{b} r \right) \sin m\theta \cos \frac{p\pi z}{d} \\
 H_z = A J_m \left(\frac{j'_{mn}}{b} r \right) \cos m\theta \sin \frac{p\pi z}{d}
 \end{array} \right.
 \end{array}
 \qquad
 \begin{array}{l}
 \text{TM}_{mnp} \text{ mode} \left\{ \begin{array}{l}
 E_r = -A \frac{1}{k^2} \frac{p\pi}{d} \frac{j_{mn}}{b} J'_m \left(\frac{j_{mn}}{b} r \right) \cos m\theta \sin \frac{p\pi z}{d} \\
 E_\theta = A \frac{1}{k^2} \frac{p\pi}{d} \frac{m}{r} J_m \left(\frac{j_{mn}}{b} r \right) \sin m\theta \sin \frac{p\pi z}{d} \\
 E_z = A J_m \left(\frac{j_{mn}}{b} r \right) \cos m\theta \cos \frac{p\pi z}{d} \\
 H_r = -A \frac{j\omega\varepsilon_0}{k^2} \frac{m}{r} J_m \left(\frac{j_{mn}}{b} r \right) \sin m\theta \cos \frac{p\pi z}{d} \\
 H_\theta = -A \frac{j\omega\varepsilon_0}{k^2} \frac{j_{mn}}{b} J'_m \left(\frac{j_{mn}}{b} r \right) \cos m\theta \cos \frac{p\pi z}{d} \\
 H_z = 0
 \end{array} \right.
 \end{array}$$

$$\begin{array}{l}
 \text{✎ } Q_0(\mathbf{m}, \mathbf{n}, \mathbf{p}) = \omega_{mnp} \frac{U}{P_{\text{wall}}} \\
 \left\{ \begin{array}{l}
 U = \frac{\varepsilon_0}{2} \int_{\text{cavity}} dV |\vec{E}|^2 = \frac{\mu_0}{2} \int_{\text{cavity}} dV |\vec{H}|^2 \\
 P_{\text{wall}} = \frac{1}{2} \sqrt{\frac{\omega\mu}{2\sigma}} \int_{\text{cavity}} dS |\vec{H}|^2
 \end{array} \right.
 \end{array}$$

✎ Assuming

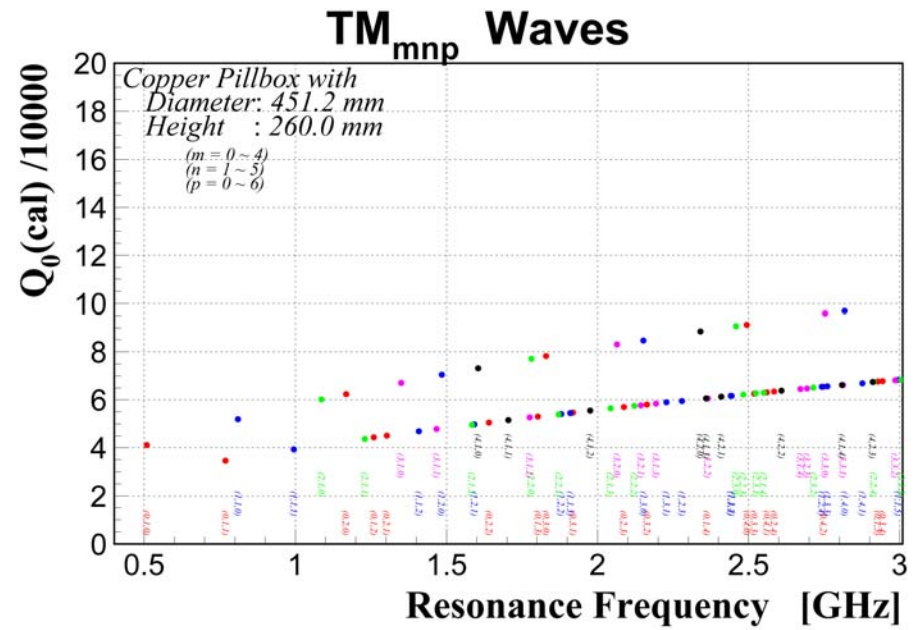
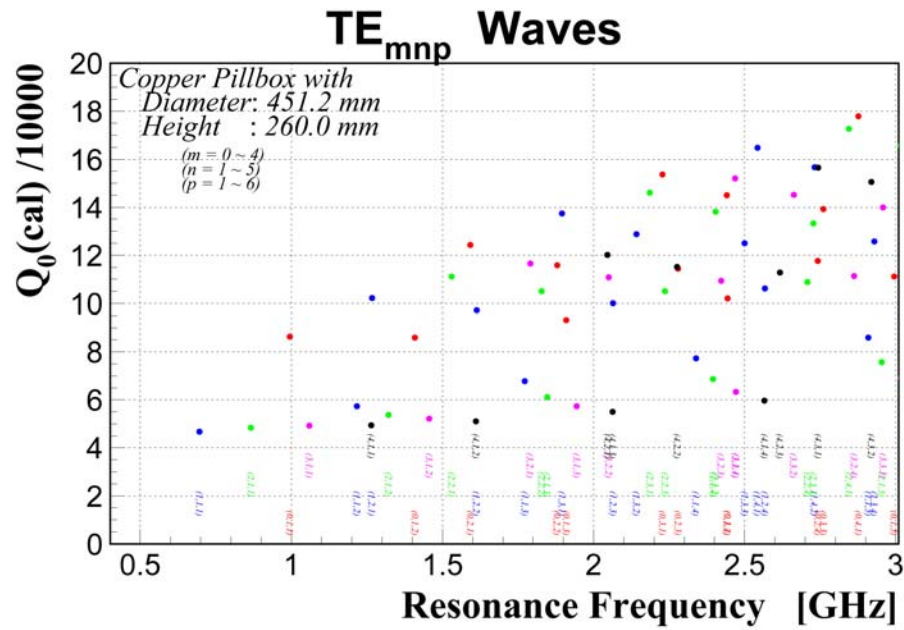
- **100% IACS** electric conductivity (=1/1.72E-8Ωm)
- **Completely-flat surface with no defect**

IACS

- International Annealed Copper Standard
- 100%IACS electric conductivity: $1/1.72E-8\Omega m$
- The electric conductivity of the highest-class oxygen-free copper: 102%IACS

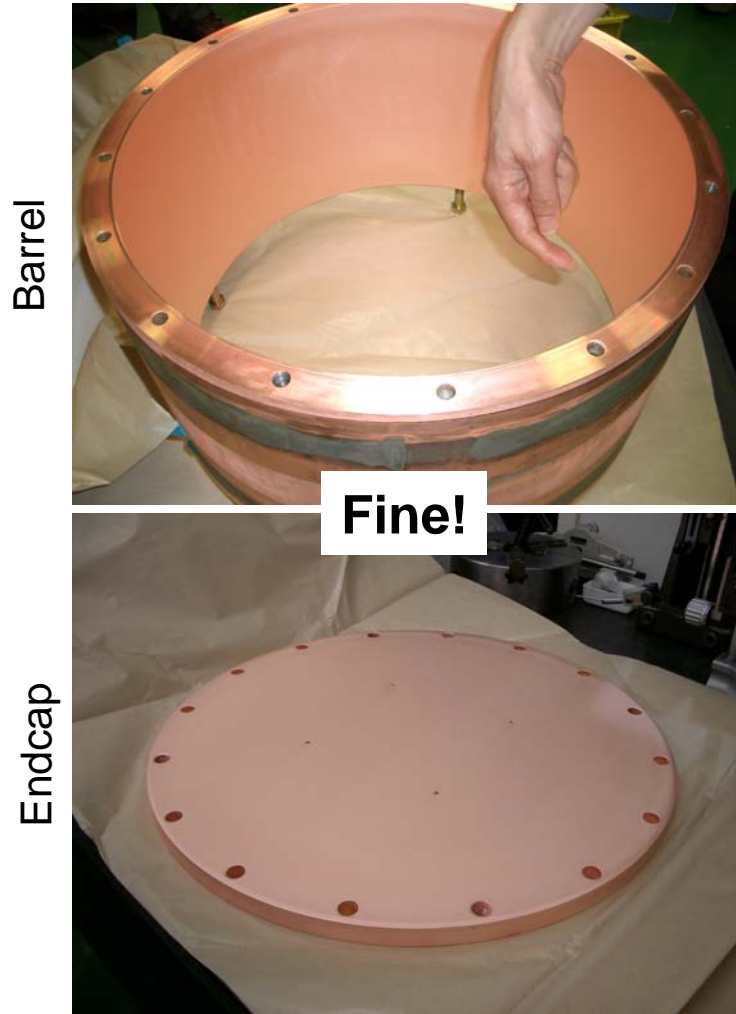
Cf. Electroplating in an acid sulfate bath w/o brightener: 102%IACS

Q₀(cal) for the test cavity

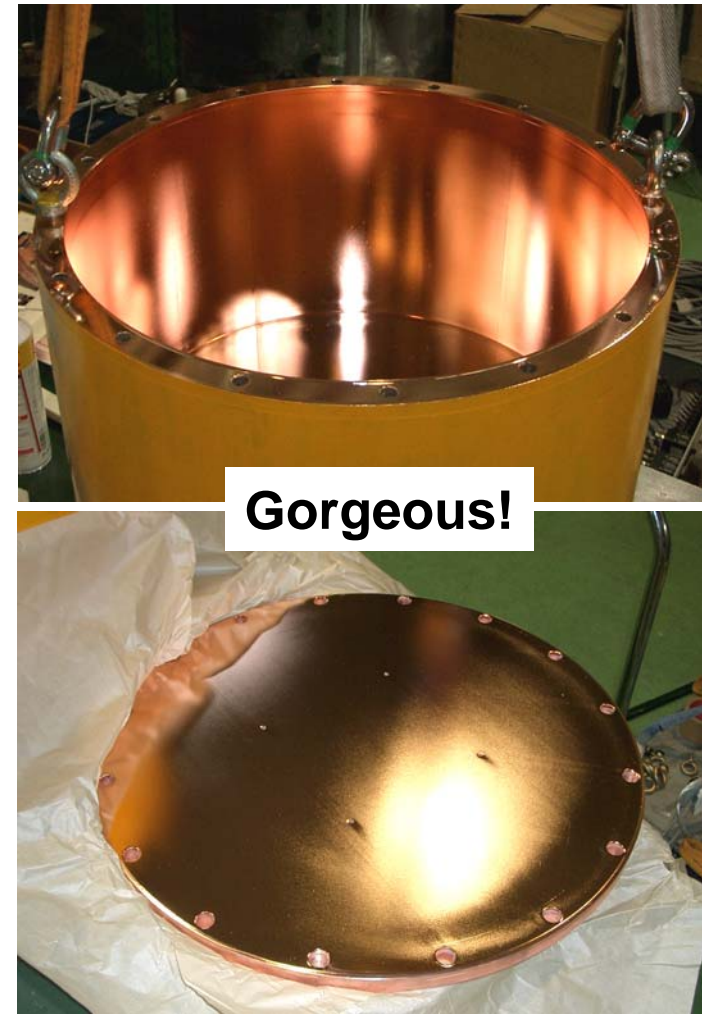


After Trial and Error...

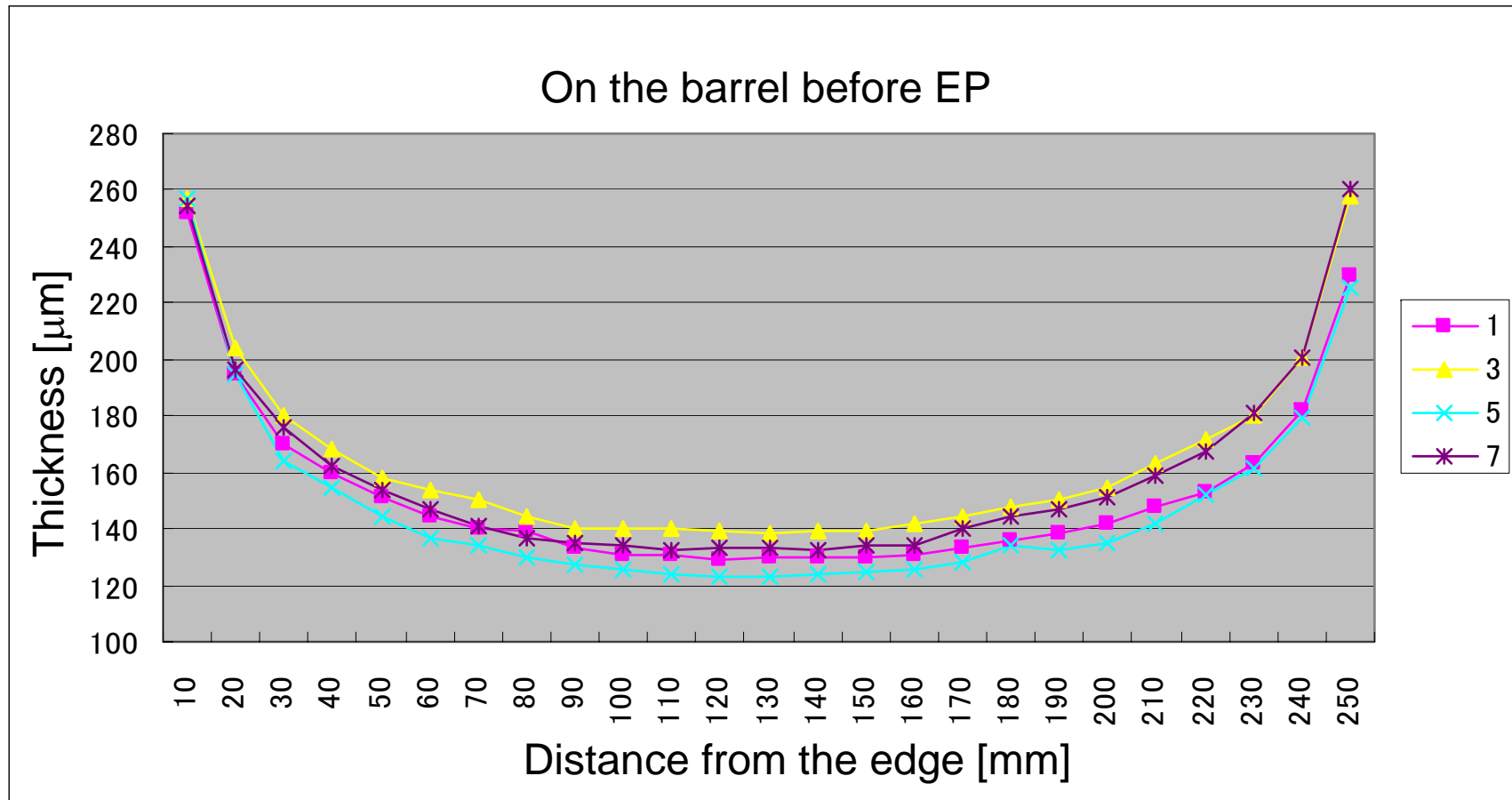
Copper Electroplating in an acid sulfate bath w/o brightener (PR process)



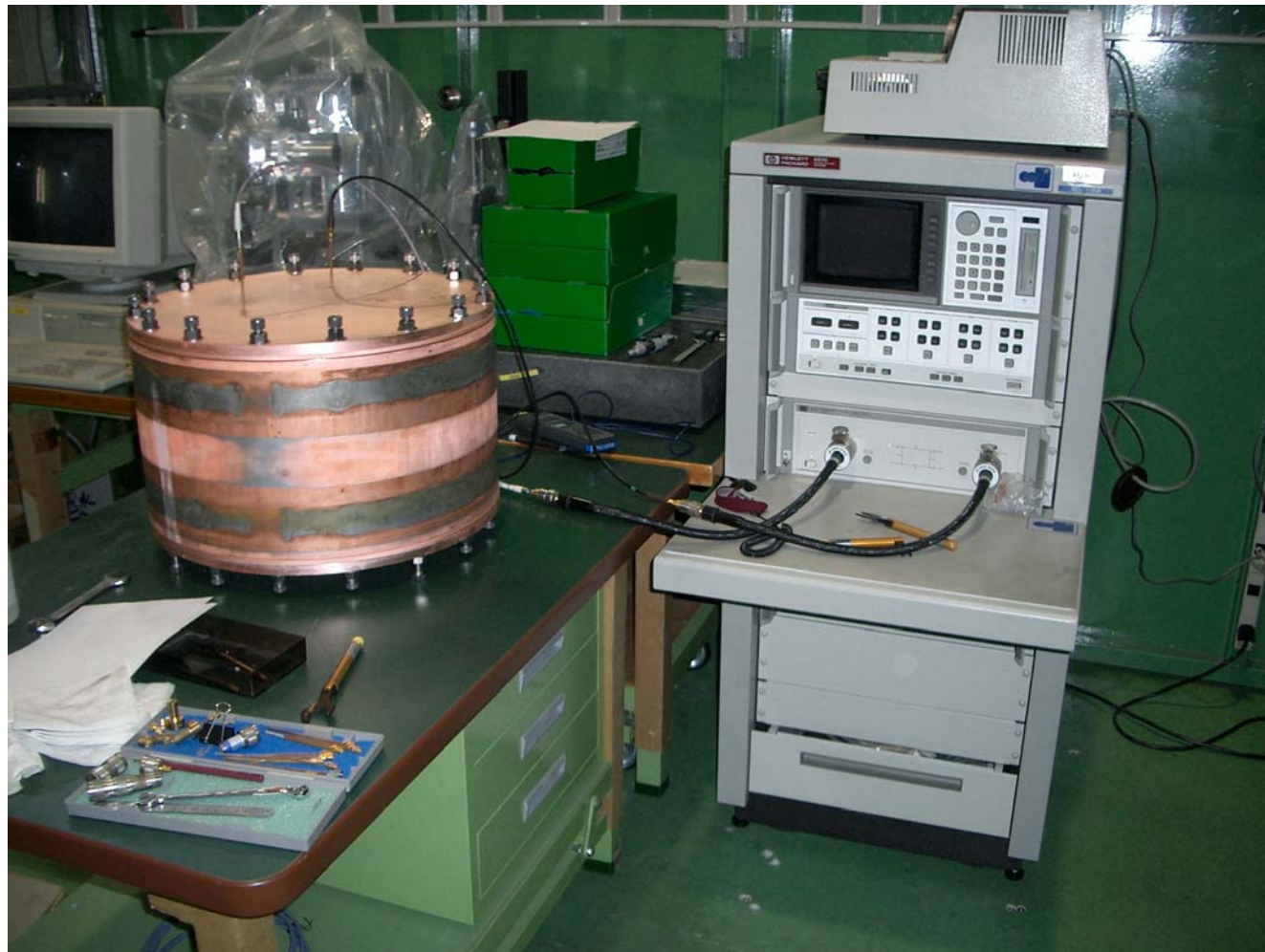
EP →



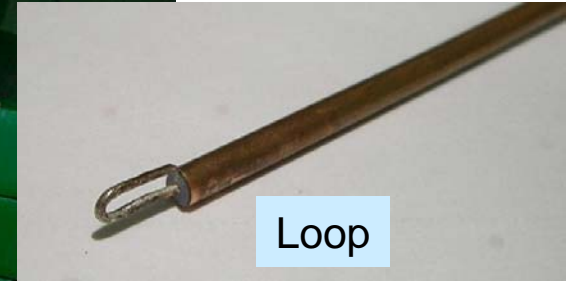
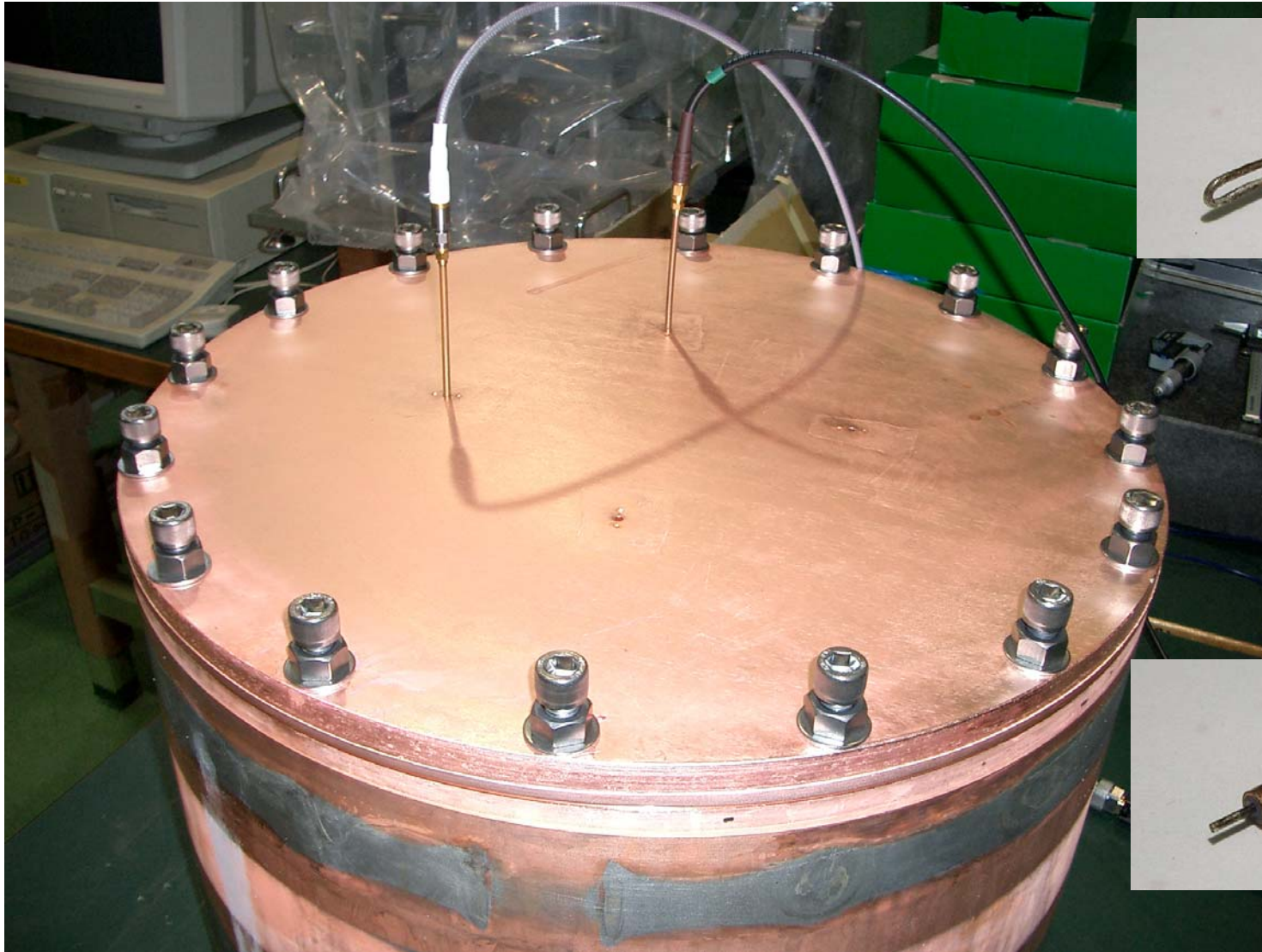
Thickness Measurements



Setup of the Q_0 Measurement

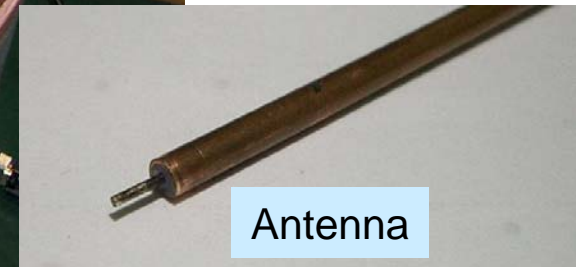


Setup (close view)



Loop

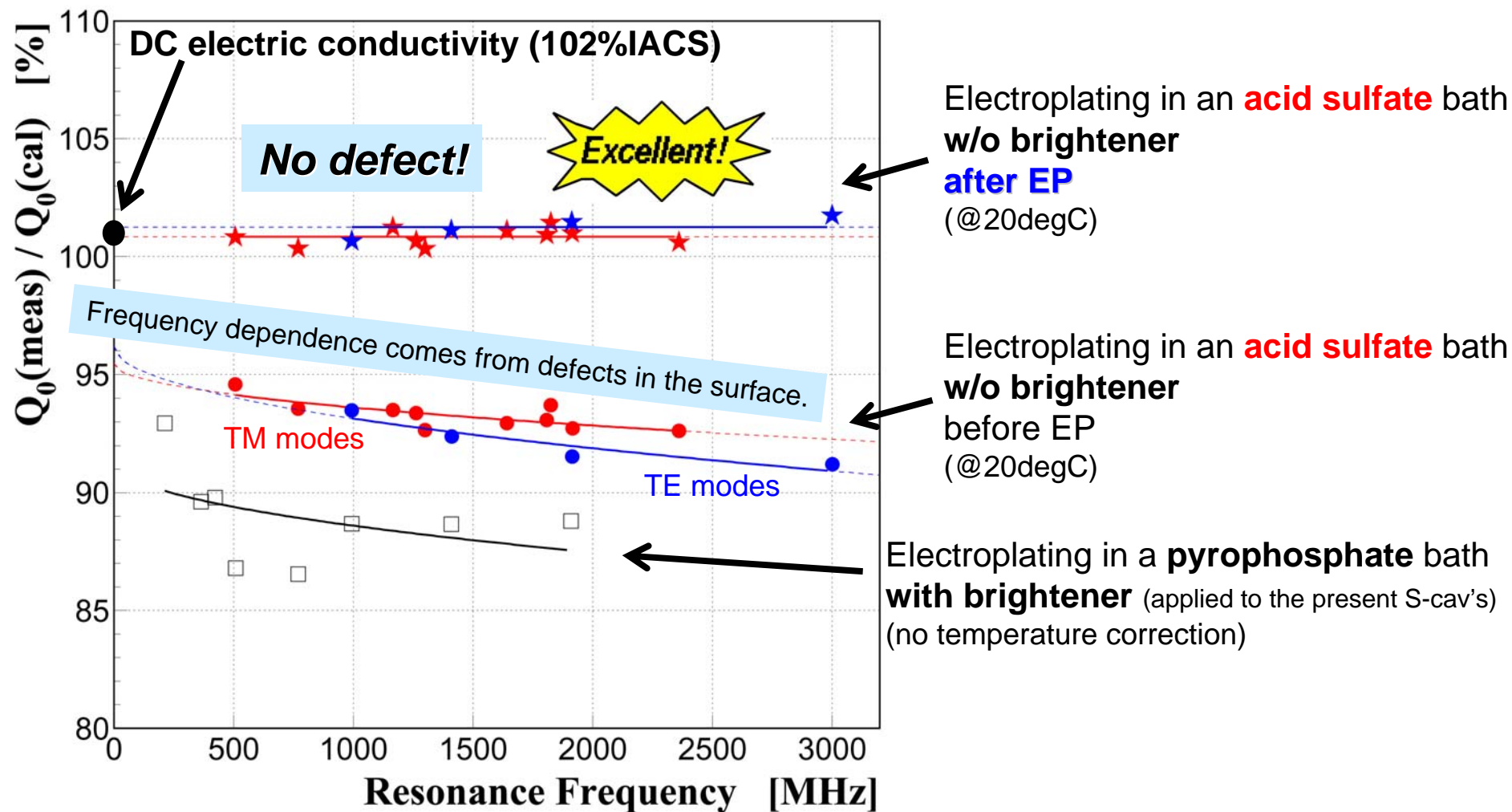
couples with magnetic field.



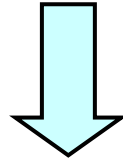
Antenna

couples with electric field.

Results of the Q_0 Measurements

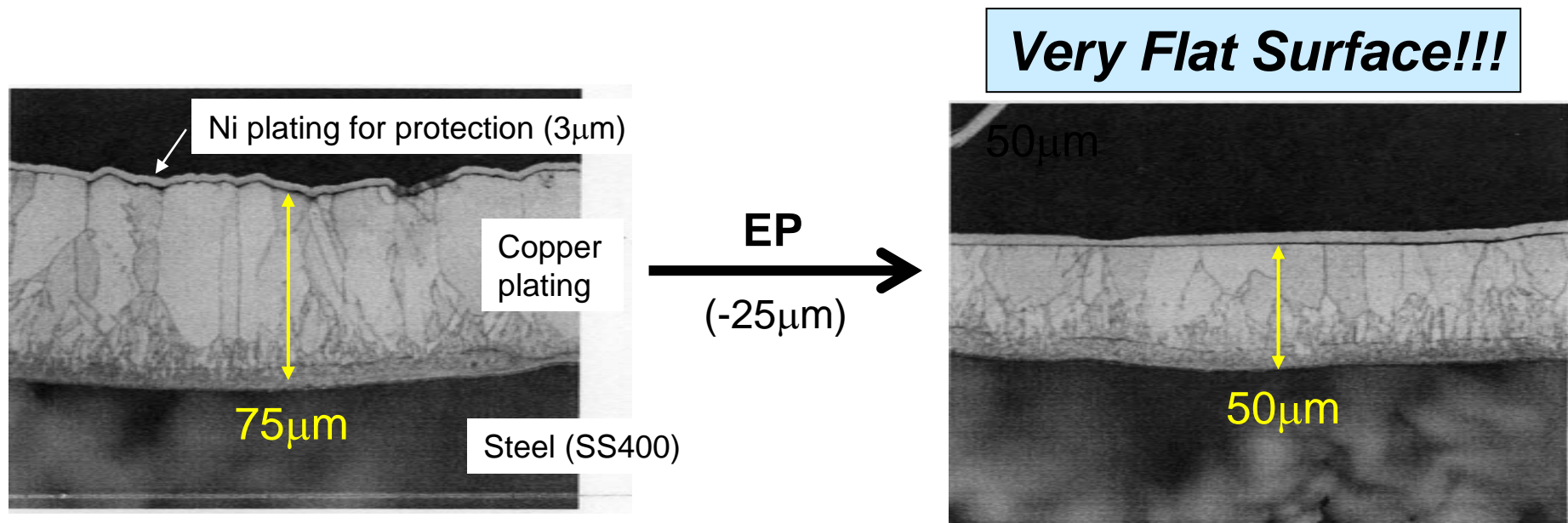


Why So High-Q?



Cross-section Images by SEM

for Copper Electroplating in an acid sulfate bath w/o brightener (PR process)

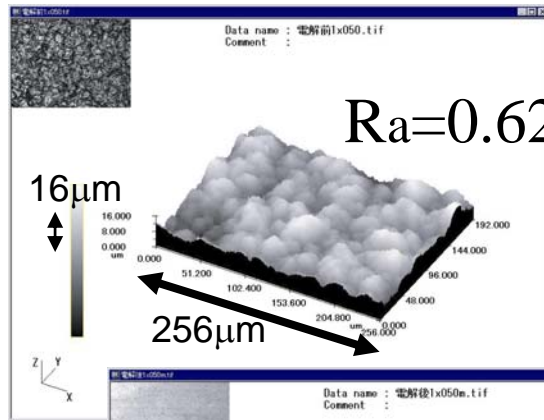


Surface Microscopies

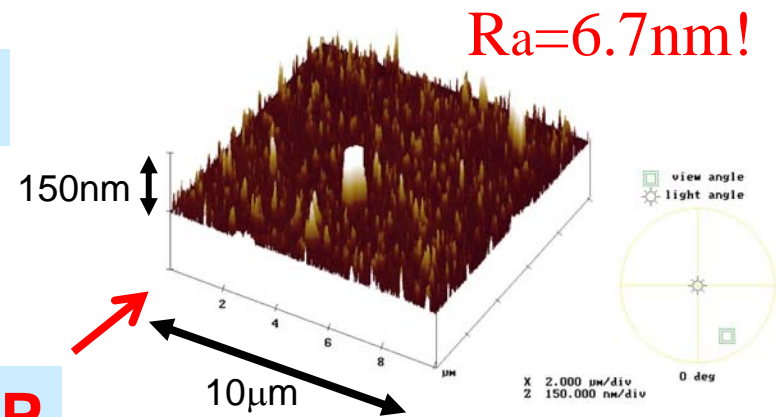
for Copper Electroplating in an acid sulfate bath w/o brightener (PR process)

By Laser Scanning Microscope

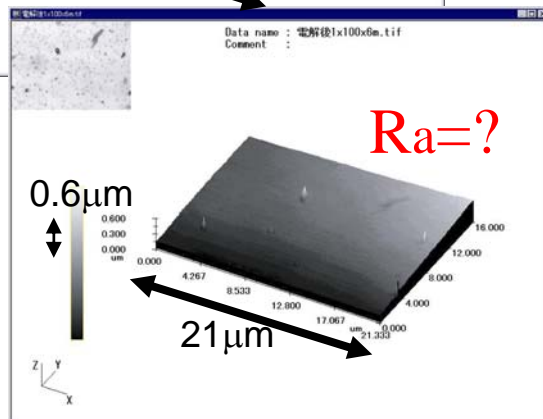
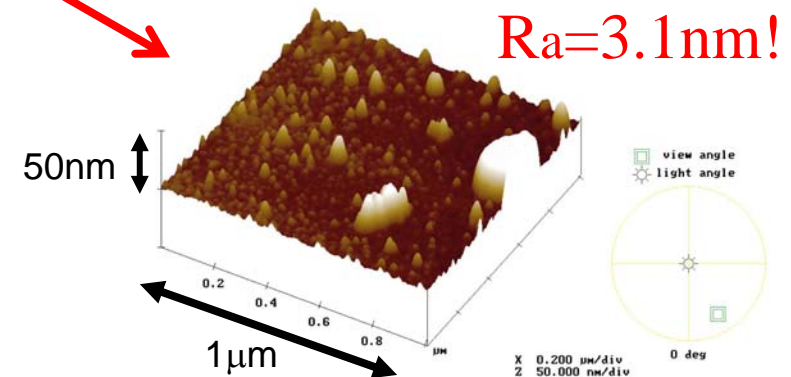
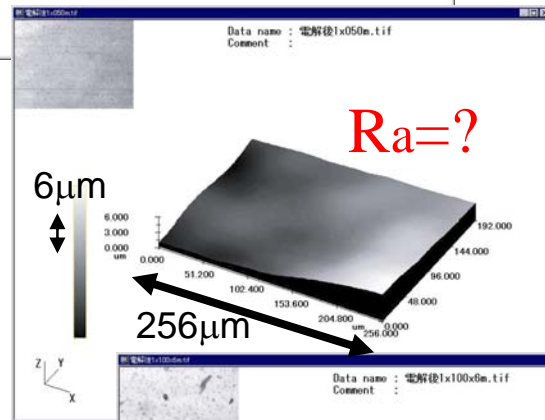
By Atomic Force Microscope



Before EP



After EP



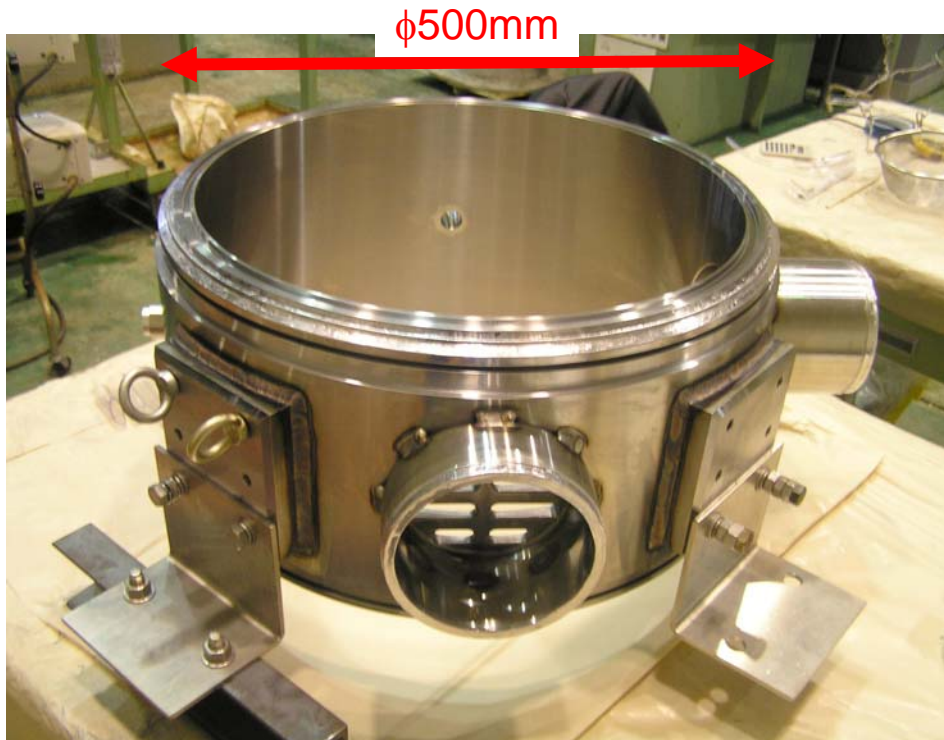
NANO-scale!!!

Conclusions

- **We apply a new highly-pure copper lining by**
 - Electroplating in an acid copper sulfate bath w/o brightener (PR process) and
 - Electropolishing (EP)to ARES S-cav for SuperKEKB.
- **Q₀ measurements** using a pillbox test cavity
 - Excellent and maximum Q₀ (after EP)
 - No frequency dependence (→ no defect in the surface)
- **Microscale investigations** of the copper surfaces
 - The roughness after EP is in NANO-scale.

Next Step: Vacuum Tests

- *The test cavity has been fabricated.*
- *The electroplating is ongoing.*
- *Vacuum tests will be done in near future.*



Barrel



Endcap