Search for Location of Enhanced Field Emission

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International Workshop on Vacuum Arcs,

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Outline

- Results of high-power tests of single-cell Standing-Wave structures related to surface processing and copper purity

@Effect of near-perfect surface cleaning on high gradient performance

@ Effect of purity of copper on high gradient performance (4N OFC copper, 6N copper treated with HIP, and 7N large grain copper)

- Development of Scanning Field Emission Microscope (SFEM)
- Search for location of enhanced field emission

@ Grain boundary measurement on the 7N large grain copper

@ Random search for enhanced field emission on the OFHC Class1 copper

- Summary

This work is supported by US – Japan Cooperation Program

High Gradient study

In-Situ Observation

1. Observation of surface deformation due to pulse heating using laser interferometer
2. Pulse heating temperature measurement by IR
3. High resolution microscopy
4. Particles observation using laser scattering

Materials

1. Cu/Mo, Cu/Stainless Steel clad Single Cell SW structure
2. 6N, Mo 4mm choke SW structures
3. Cu/Beryllium alloy

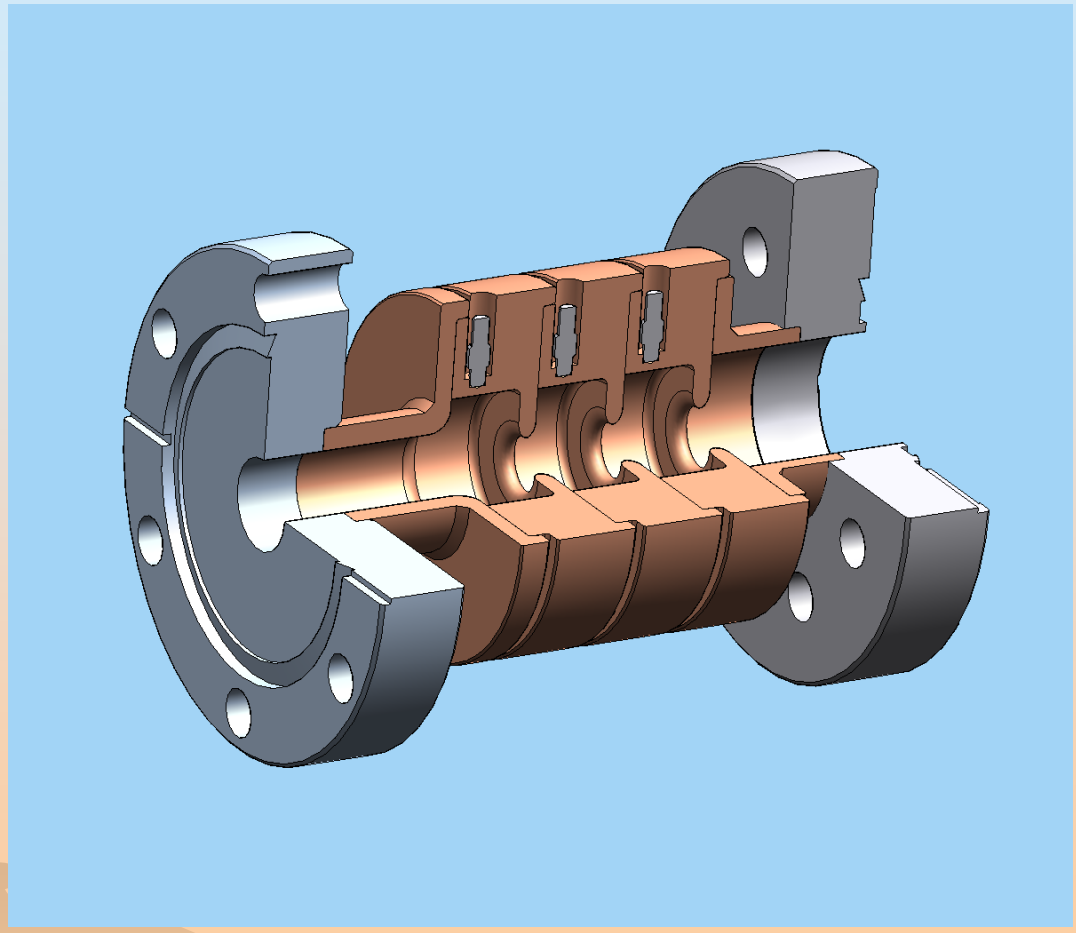
Surface Treatment

1. Chemical Polishing
2. Electro Polishing
3. Dust Free
4. High Temp. Vacuum Baking (controling residual gas content)

Surface Inspection
Scanning Field Emission Microscope

Single-Cell SW Structure for High Gradient Test

High shunt impedance structures, $a/\lambda=0.143$

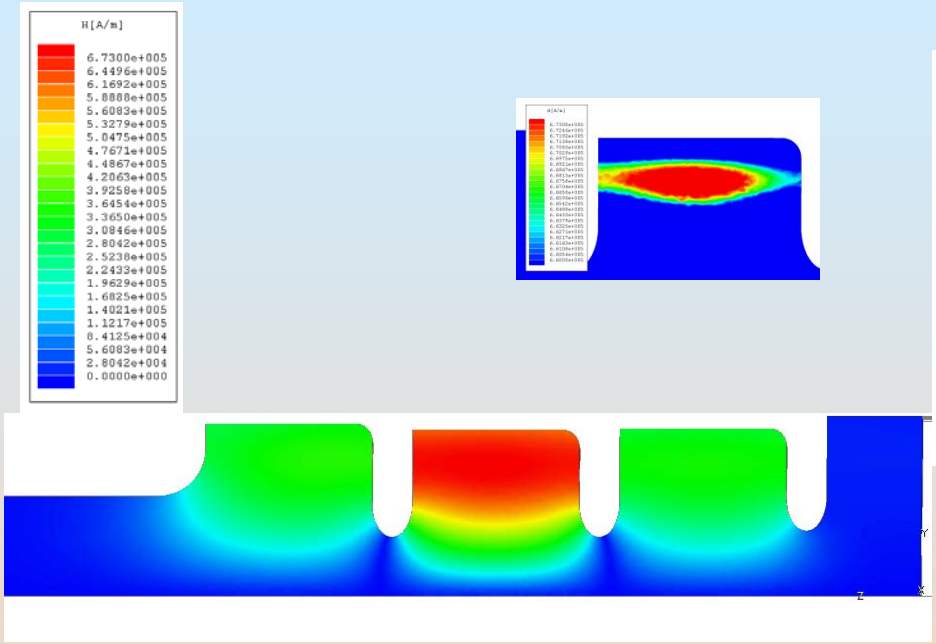


1C-SW-A3.75-T2.6-Cu

Solid Model: David Martin

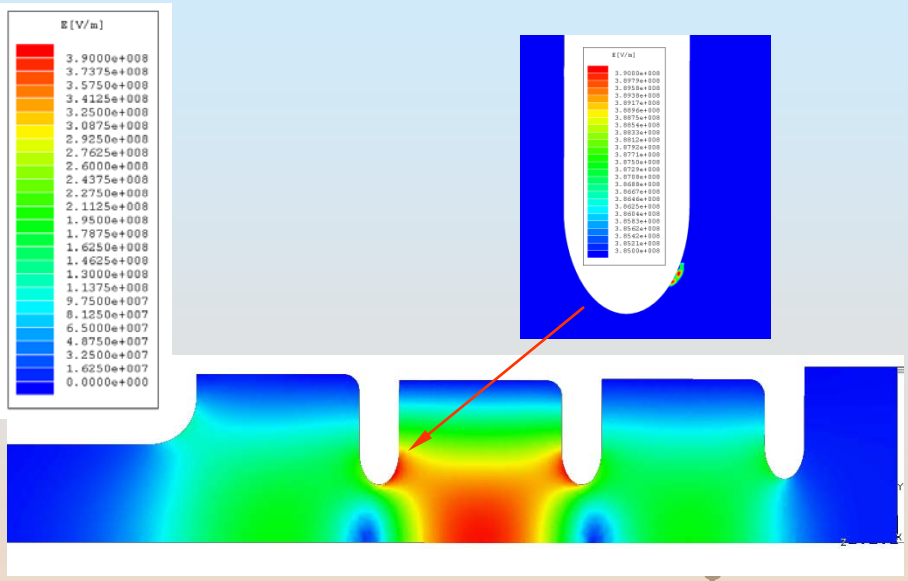
1C-SW-A3.75-T2.6-Cu, a/λ=0.143

10 MW input



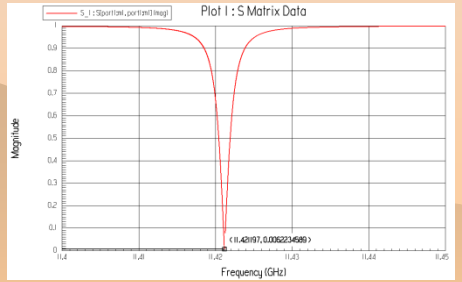
Maximum magnetic field 672 kA/m

(SLANS 668.0 kA/m)



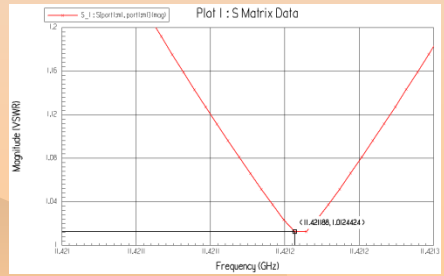
Maximum electric field 390 MV/m

(SLANS 398.9 MV/m)



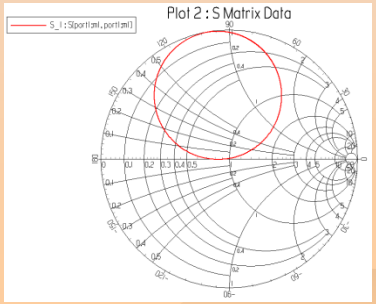
Resonance at 11.4212 GHz

(SLANS 11.4241 GHz)



β = 0.988

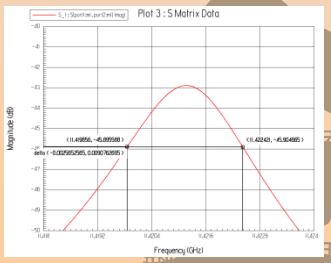
(SLANS 1.032356)



Under-coupled loaded Q

Unloaded Q=8,849.8

(SLANS 8,912.5)



$$\frac{11.4212}{0.00256526} = 4.452 \times 10^3$$

$$\frac{11.4212}{0.00256526} \cdot (1 + 0.987710) = 8.8498 \times 10^3$$

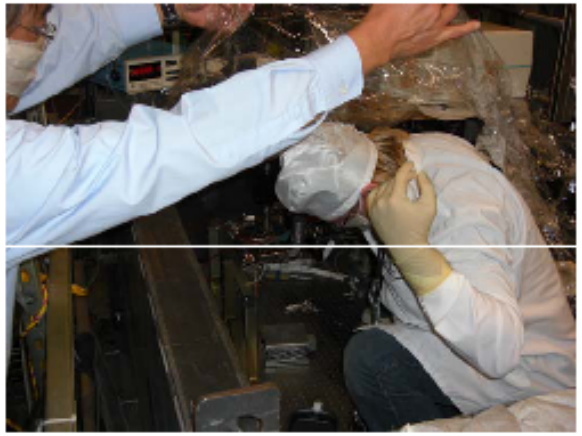
Y.Higashi, Mevarc Workshop, 1-4 October, 2012

V.A. Dolgashev, 25 September 2007

Surface processing

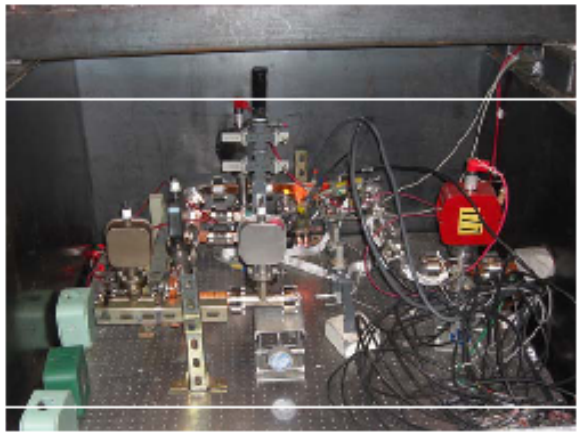
A special structure was built and processed (with best cleaning and surface processing we can master) at KEK and hermetically sealed, then assembled at SLAC at the best possible clean conditions

Dr. Yasuo Higashi and Richard Talley assembling Three-C-SW-A5.65-T4.6-Cu-KEK-#2

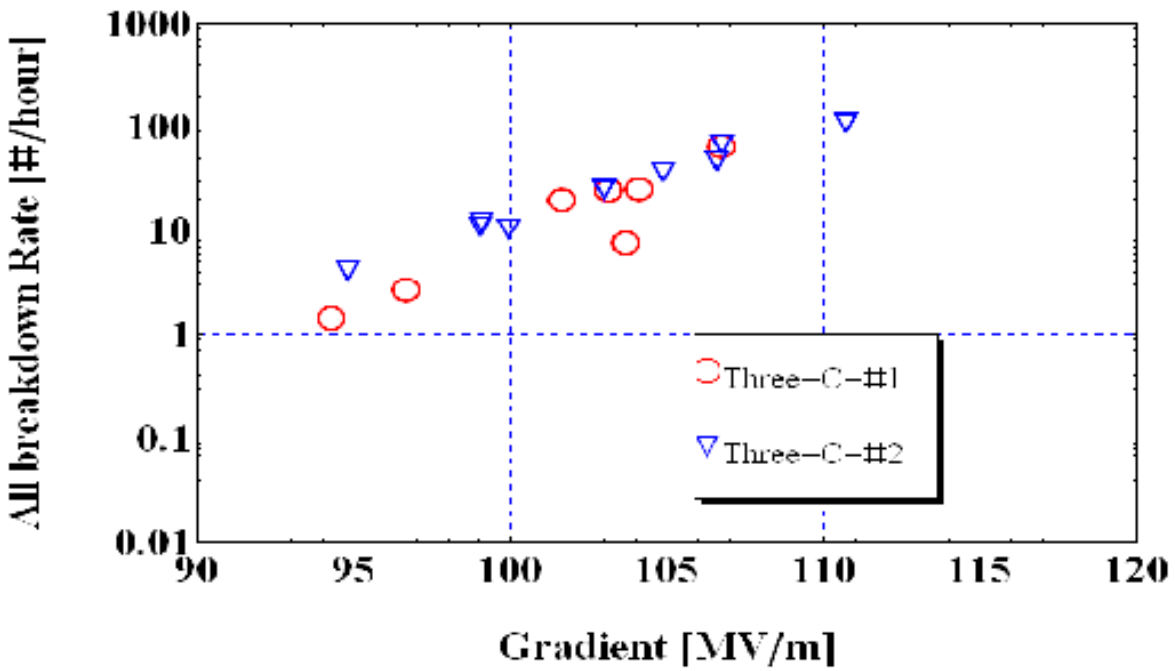


at KEK

1.Bonding
2.Megasonic rinsing with degreaser
3.500degC baking
4.N2 gas purged
5. Goes to SLAC



Two structured #1 processed normally and #2 processed similar to superconducting accelerator structures

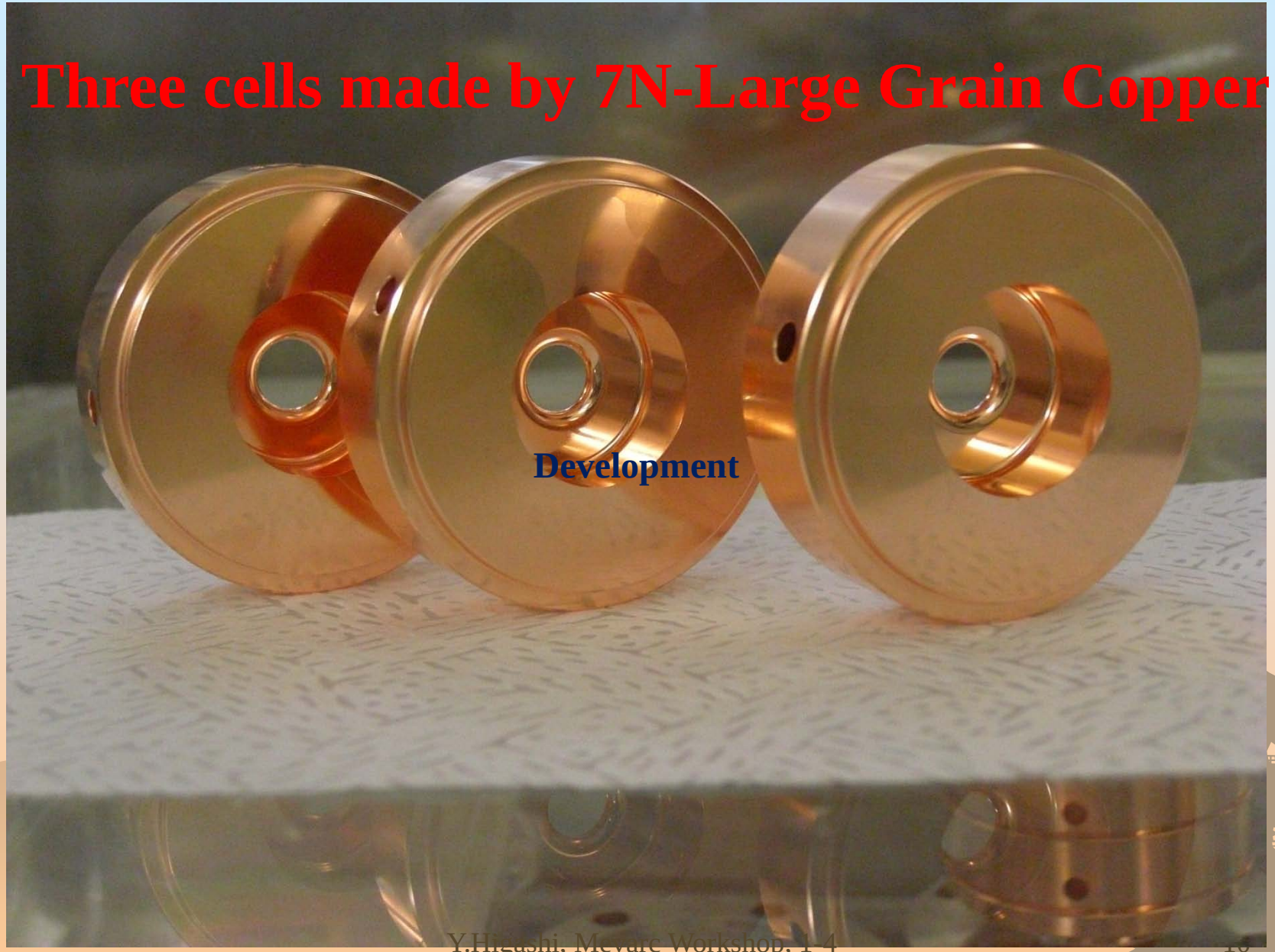


The near perfect surface processing affected only the processing time. The second structure processed to maximum gradient in a few minutes vs few hours for the normally processed structure.

Large Grain 7N copper

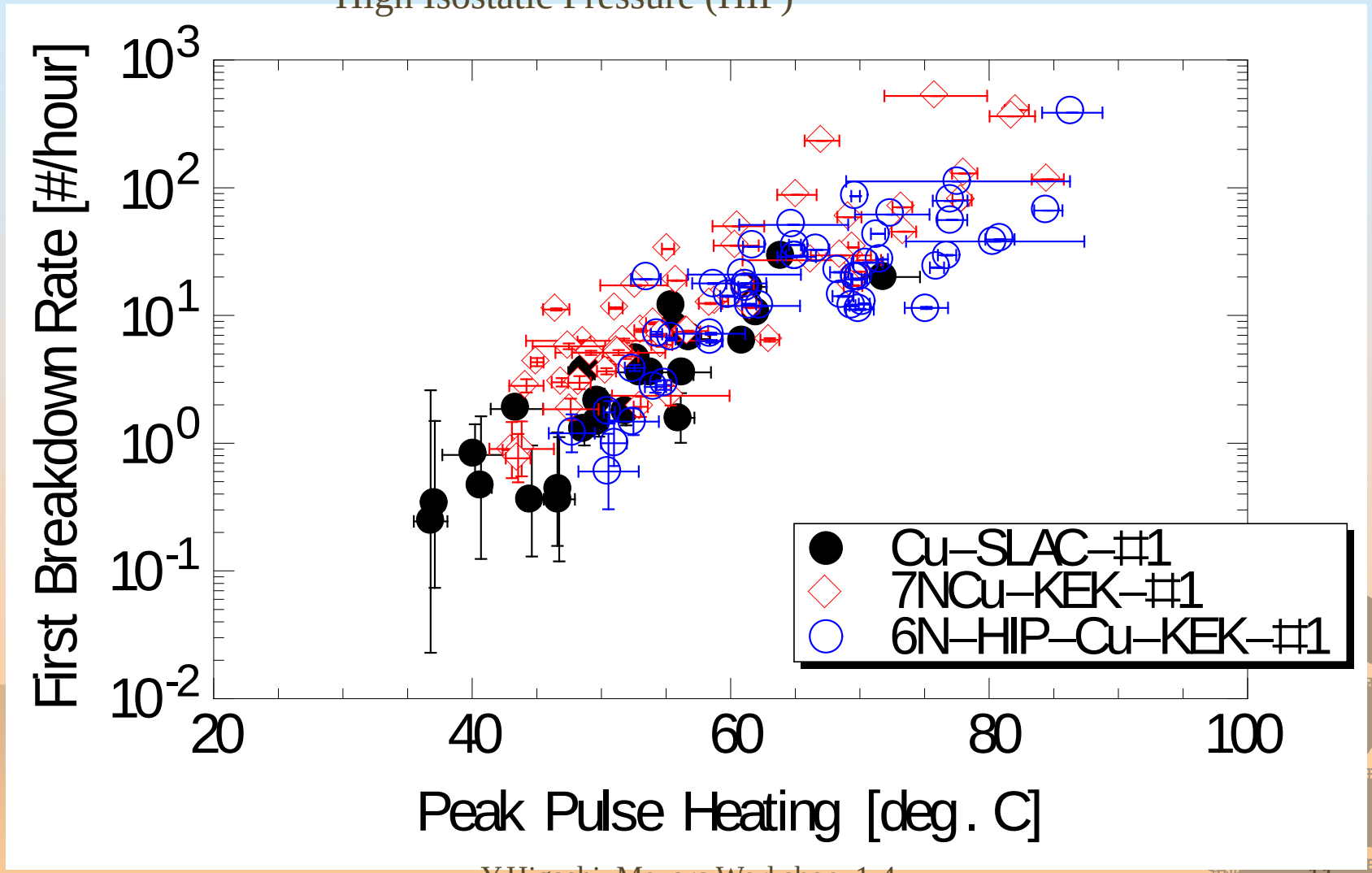
Developed by MITSUBISHI MATERIAL Co.

Three cells made by 7N-Large Grain Copper

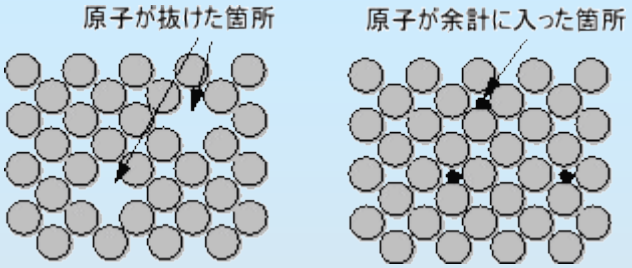


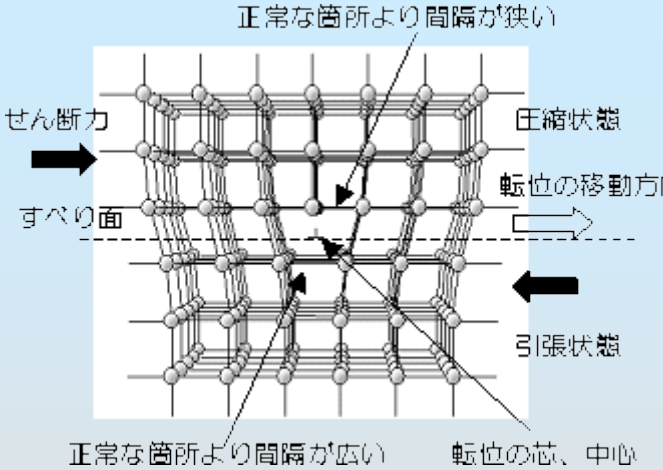
Breakdown rate *vs.* pulse heating for three A3.75-T2.6 copper structures, one OFC copper, 6N copper treated with HIP, and 7N large grain copper

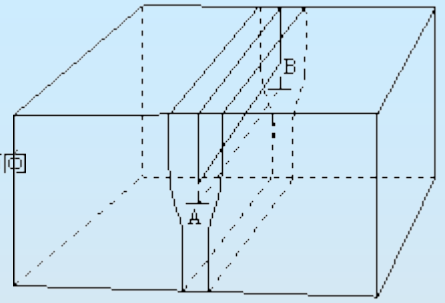
High Isostatic Pressure (HIP)

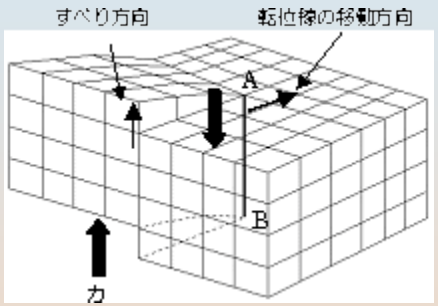


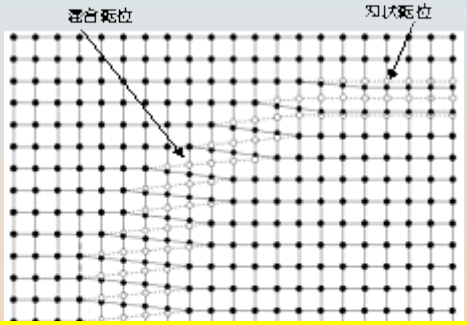
Why we don’t see difference in rf breakdown performance of ultra-pure copper?











Crystal defect density almost the same in 4N, 6N, and 7N copper:

- Dislocation density seems to be 10^6 ~ 10^8 cm/cm^3 even with annealing.

- Distance to dislocation is approximately 1 ~ 10 μm

Results of High Gradient Tests

- Sophisticated fabrication technologies for X-band high gradient accelerating structures successfully developed at KEK with SLAC, INFN and CERN.
- We compared breakdown rate for three A3.75-T2.6 copper structures, one OFC copper, 6N copper treated with HIP, and 7N large grain copper. But rf breakdown performance was almost same.
- The nearly perfect surface processing affected only processing time. Ultra-clean structures conditioned faster then the normally processed structure.

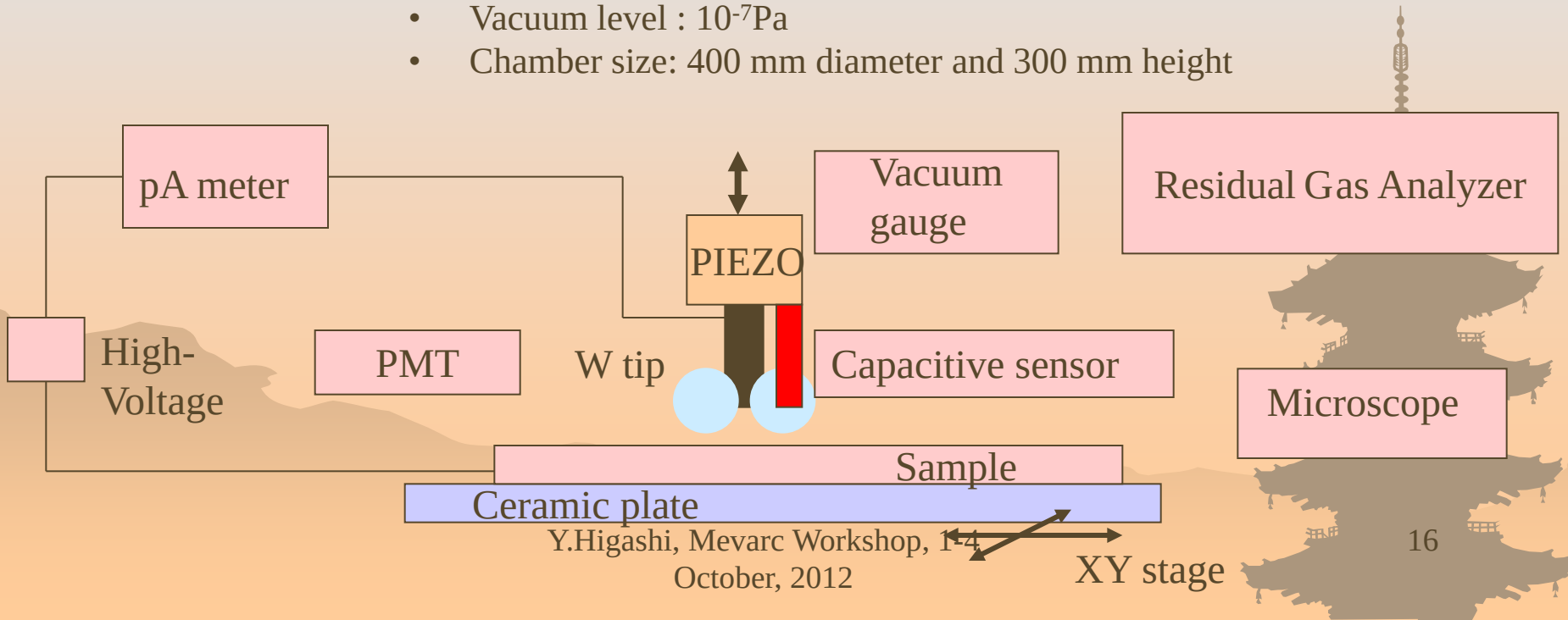
We want to identify crystal defects by looking at regions with enhanced field emission

We developed Scanning Field Emission Microscope

(First Presented Mevarc workshop 2011)

Scanning Field Emission Microscope Configurations

- Tungsten tip: < 1micron radius
- Tip movement: linear stage+PIEZO mover
- Gap: 1 micron
- XY stage stroke +/- 6mm (rough 50mm)
- Bias voltage ~240V
- Pico-ammeter: ~pA resolution
- In-situ gap sensor: 0.01micron resolution
- Microscope
- Residual Gas Analyzer
- Vacuum gauge
- Vacuum level : 10^{-7}Pa
- Chamber size: 400 mm diameter and 300 mm height



Before the measurement of field emission

- Parallelize sample surface and stage movement

  <0.1μm/5mm stroke

- Bake vacuum chamber

  150 deg.C for 10 hours

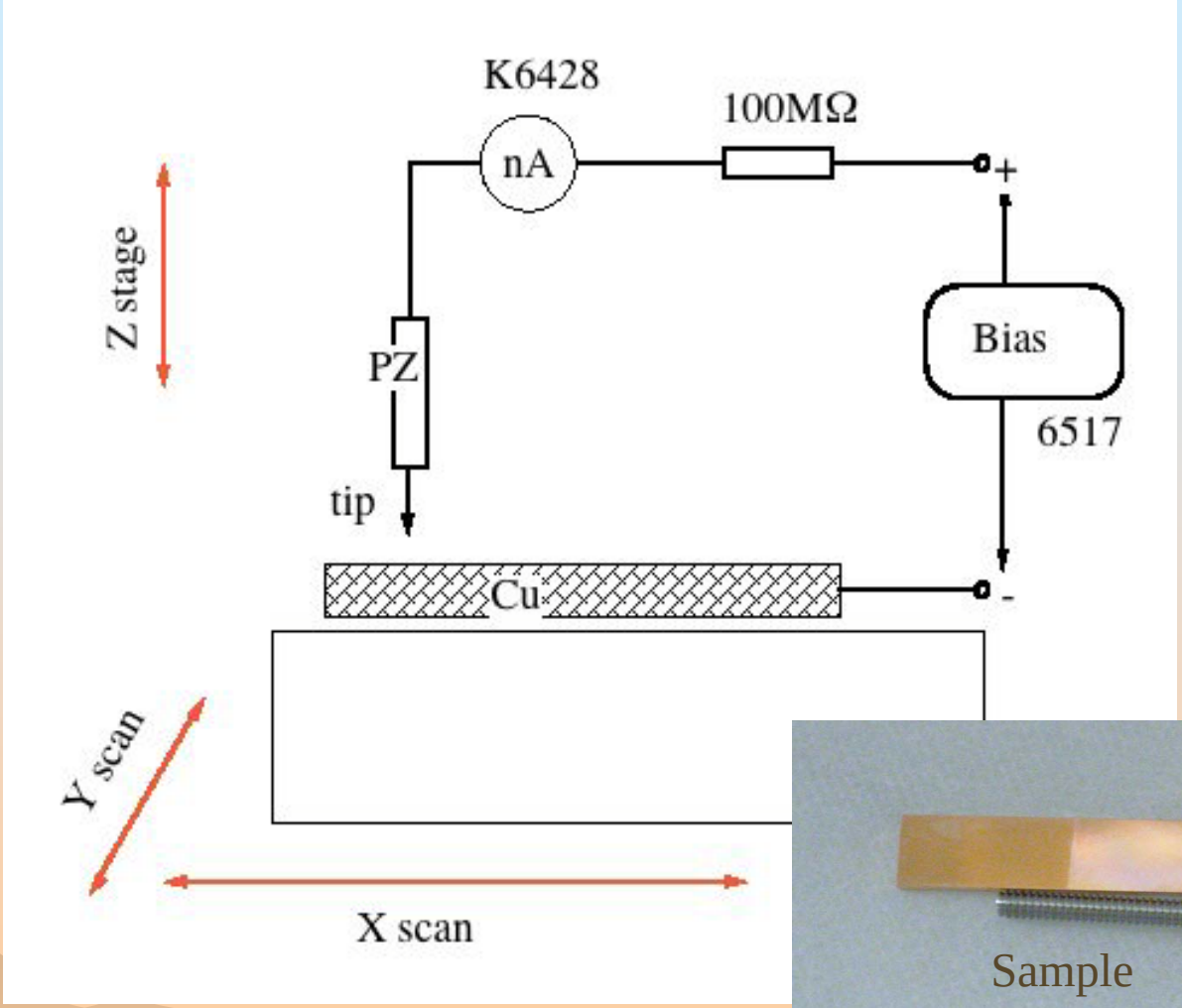
- Clean tungsten tip with high fields

  200V@~1μm gap for 10 min period

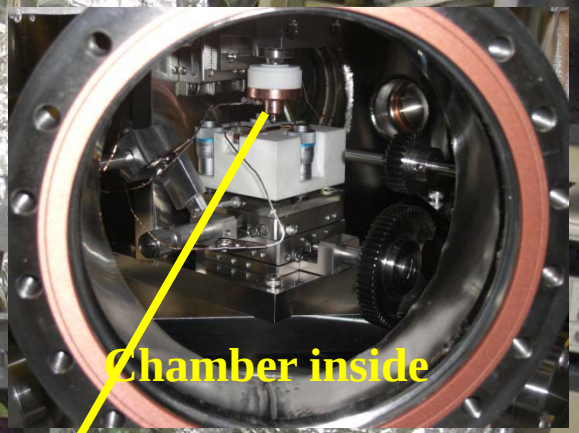
- Measure gap

  Capacitive gauge, PIEZO actuator

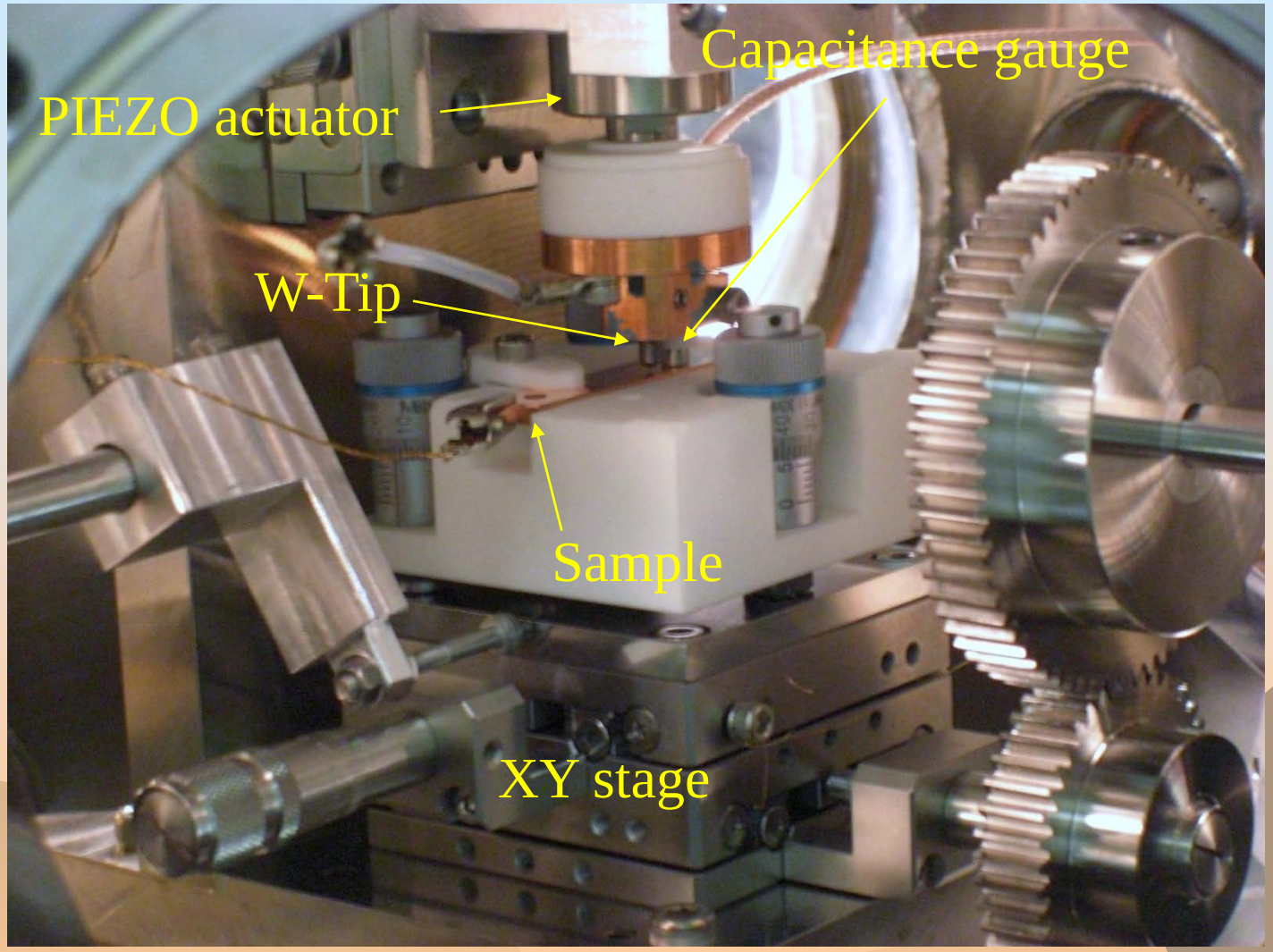
Schematic view of Scanning Field Emission Microscope



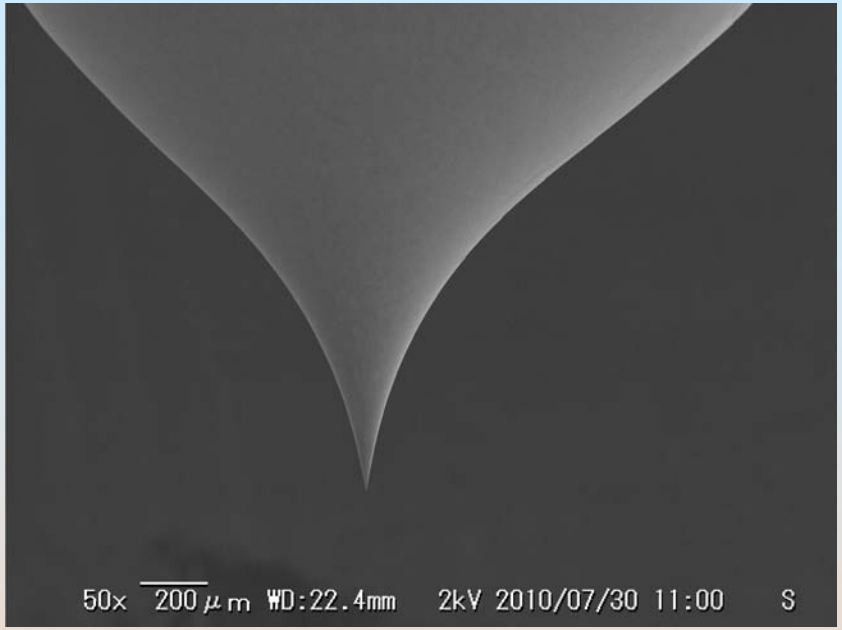
Scanning Field Emission Microscope

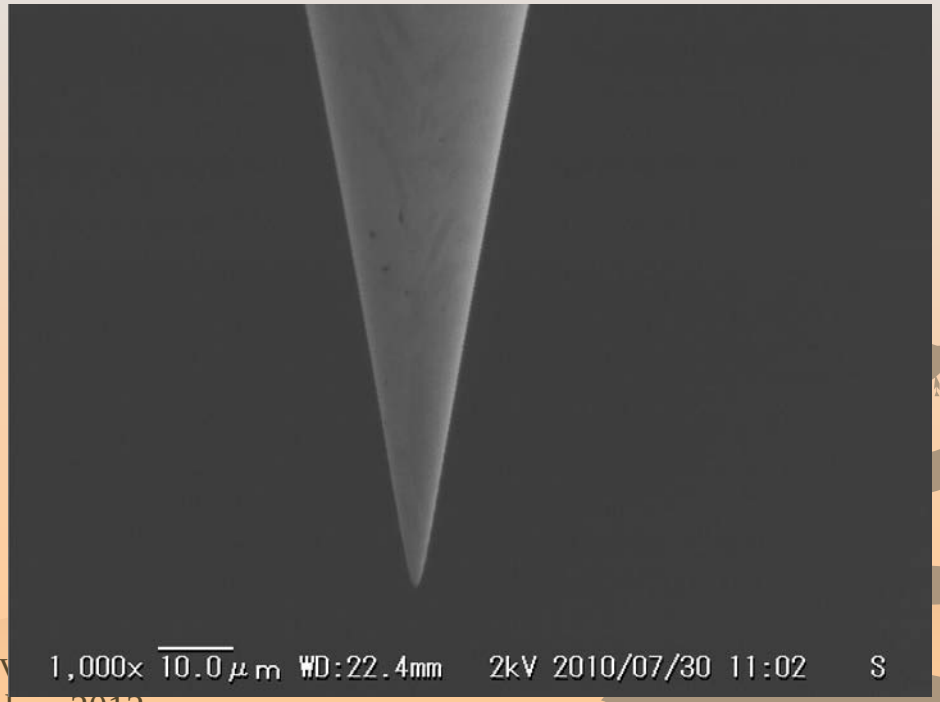


Sample and moving stages



Tungsten Tip made by electro polishing





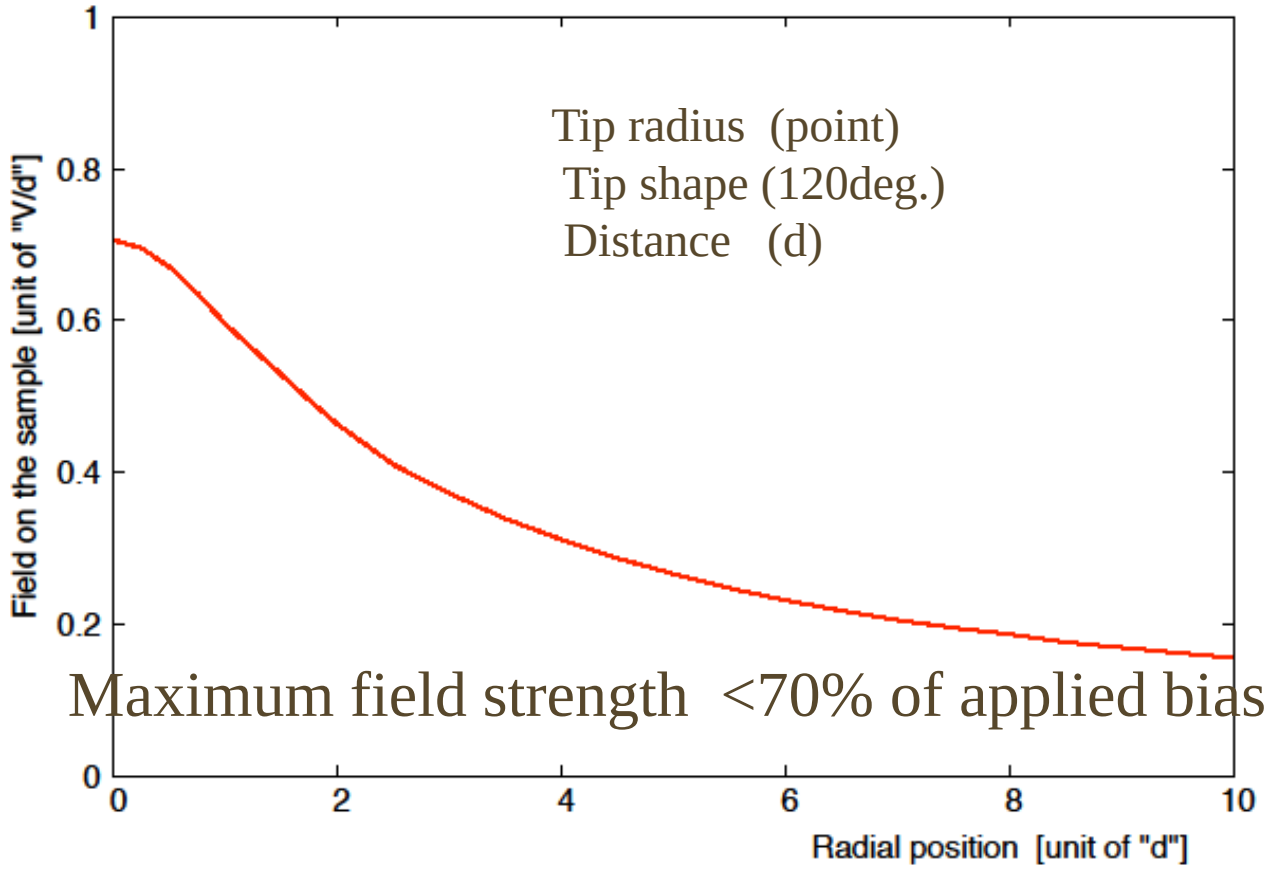
No1

KOH: 1 mol

Voltage: 30 V

Current: 200mA

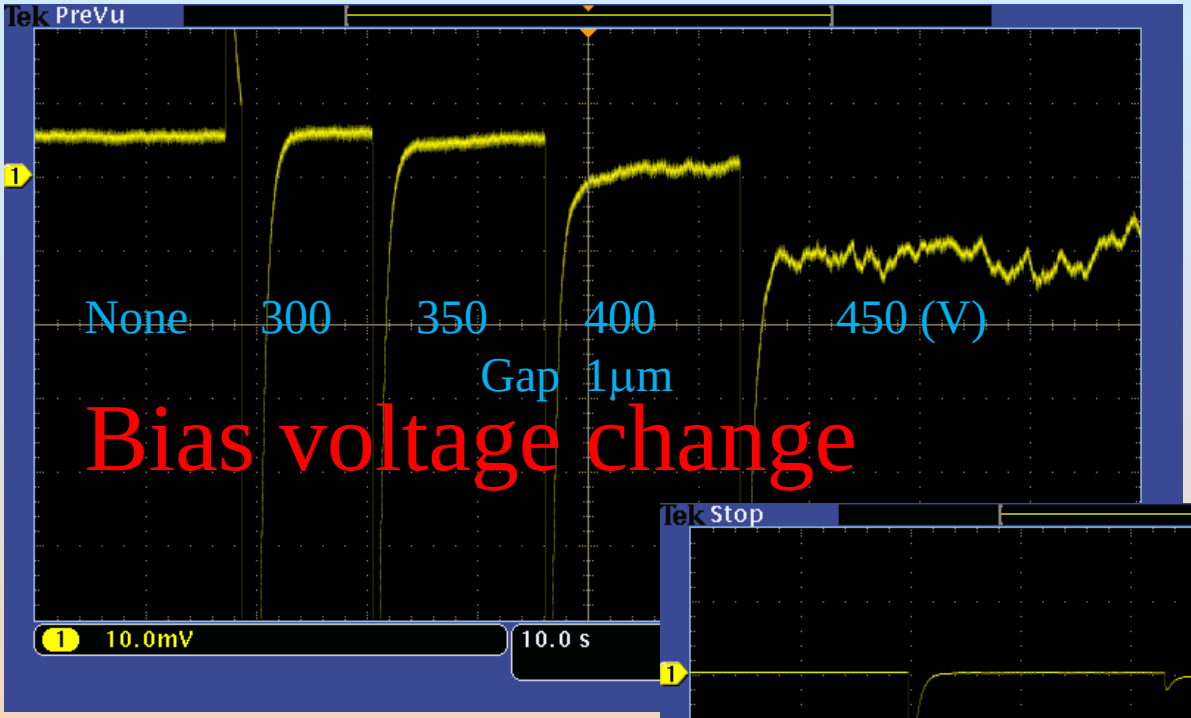
Field pattern under W-tip

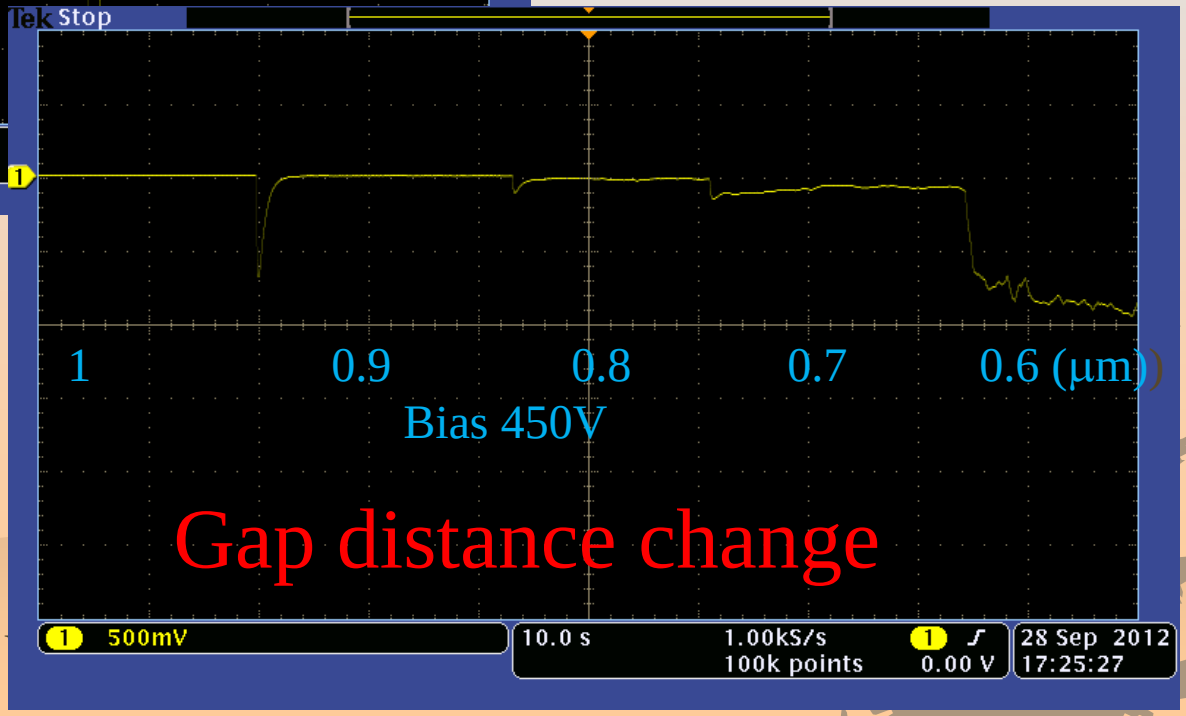


Tip radius (point)
Tip shape (120deg.)
Distance (d)

Maximum field strength <70% of applied bias

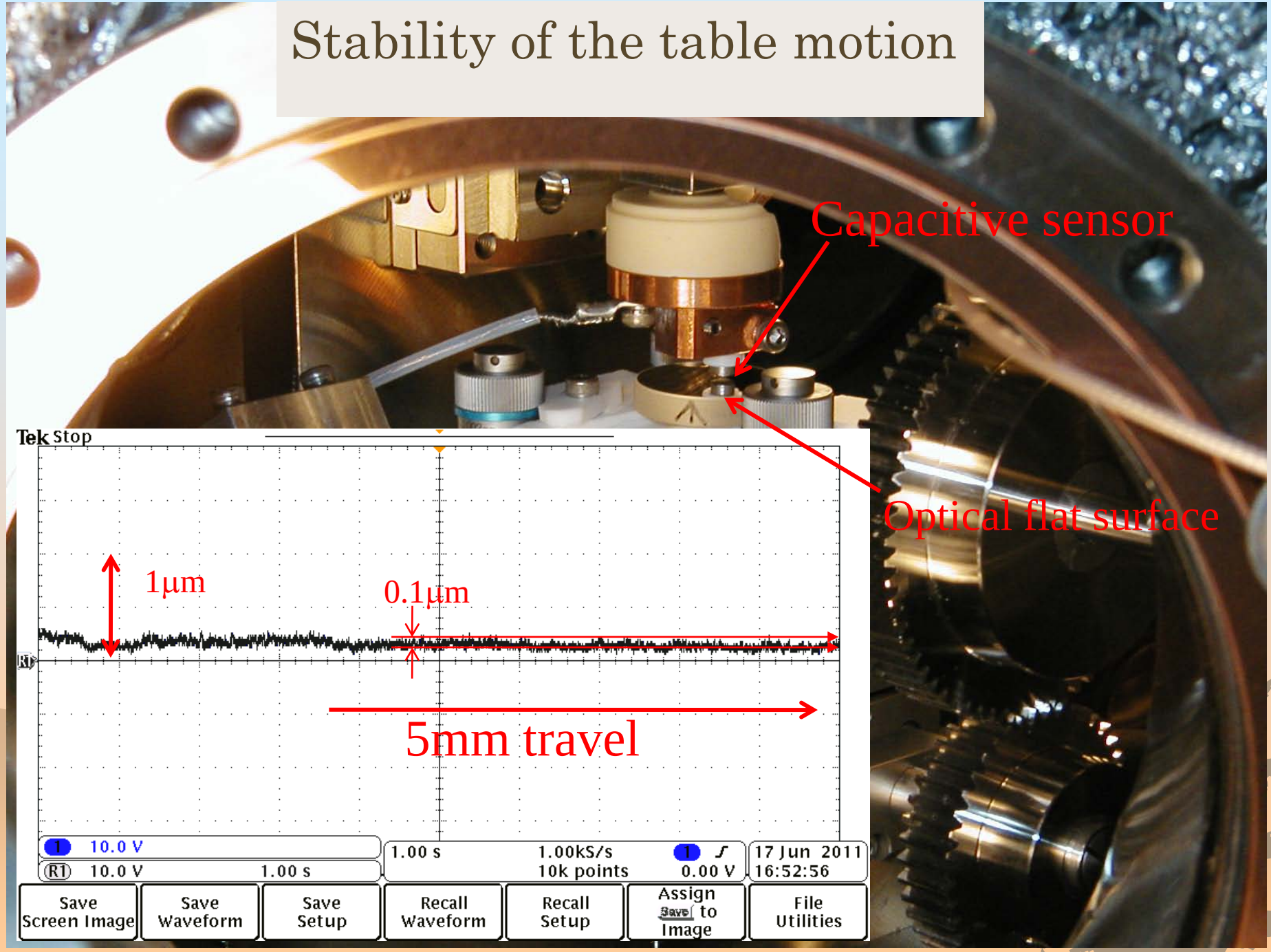
Field Emission Current change due to bias voltage and gap



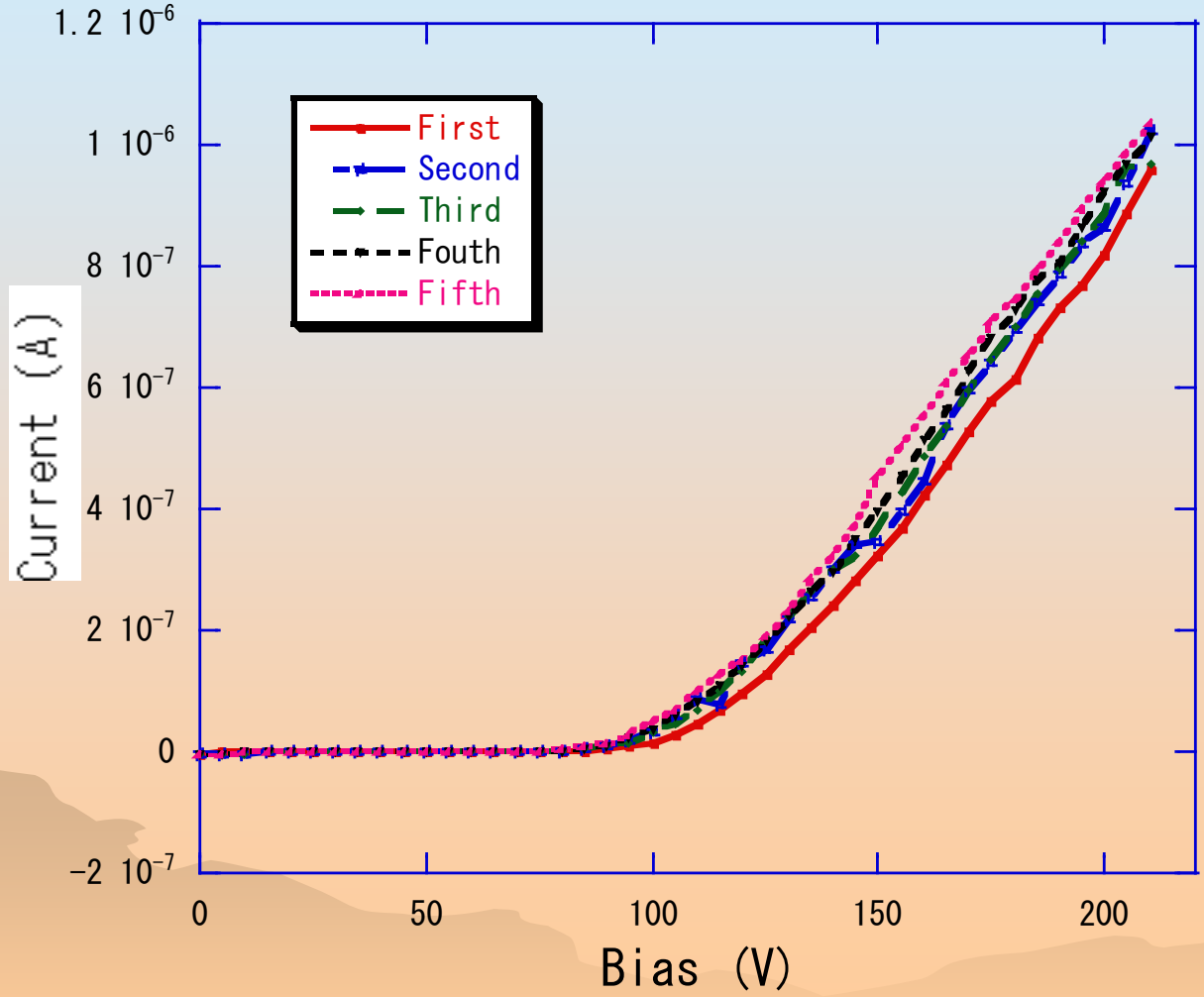


Electrode : OFHC Class1

Stability of the table motion

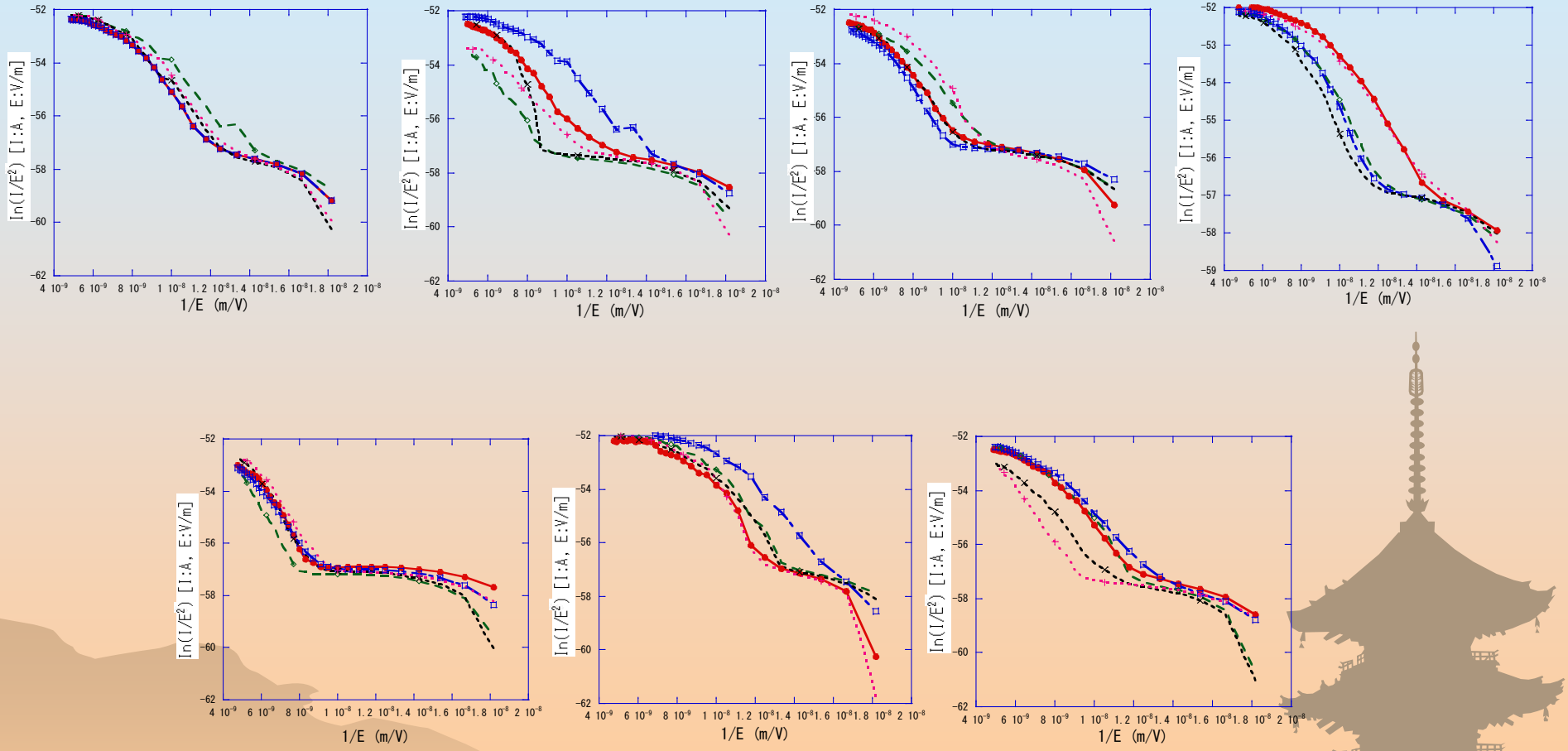


Reproducibility of the measurement of the field emission current vs. bias voltage, tip is not moving

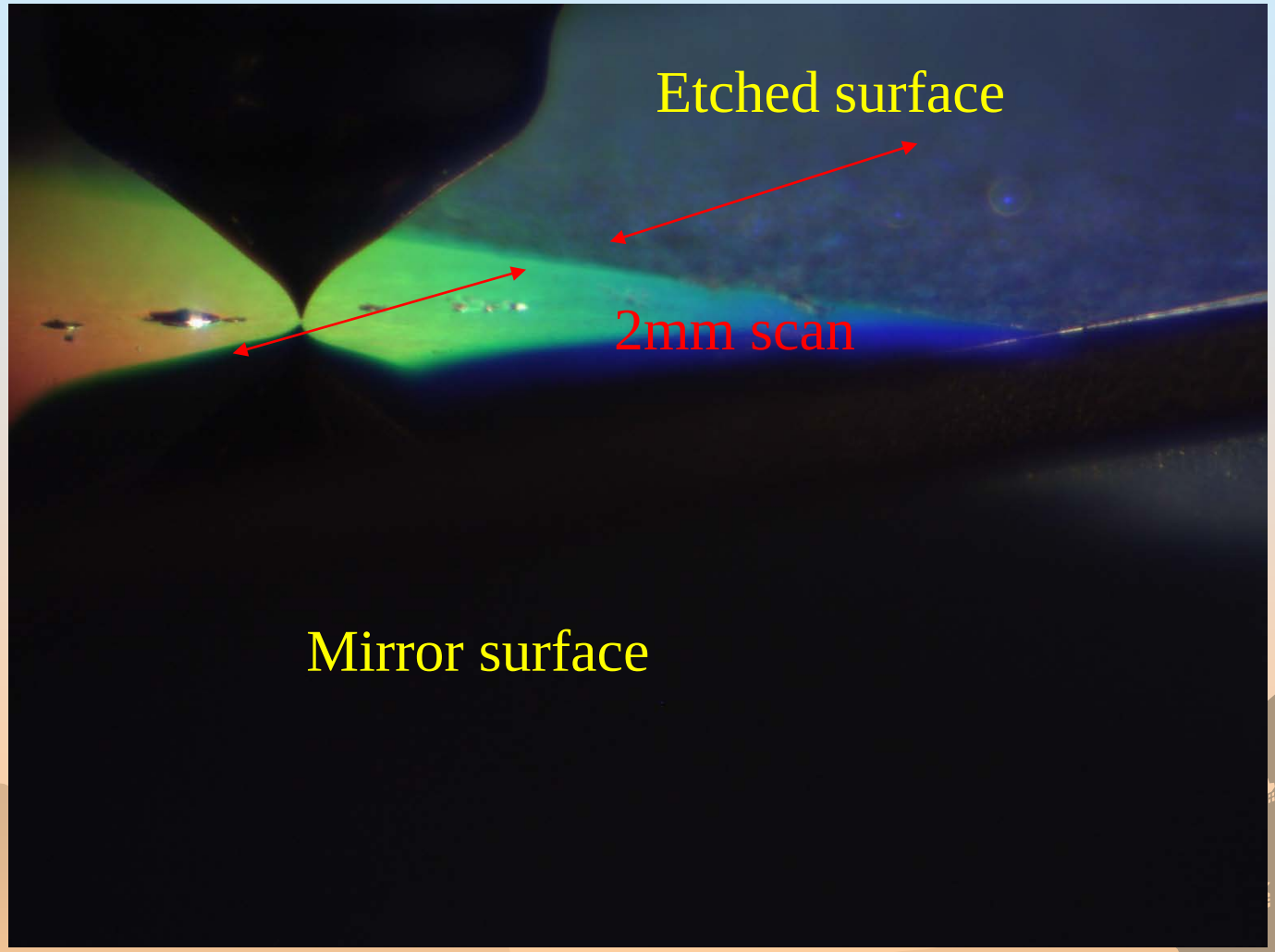


Fowler-Nordheim plots at 35 arbitrary points

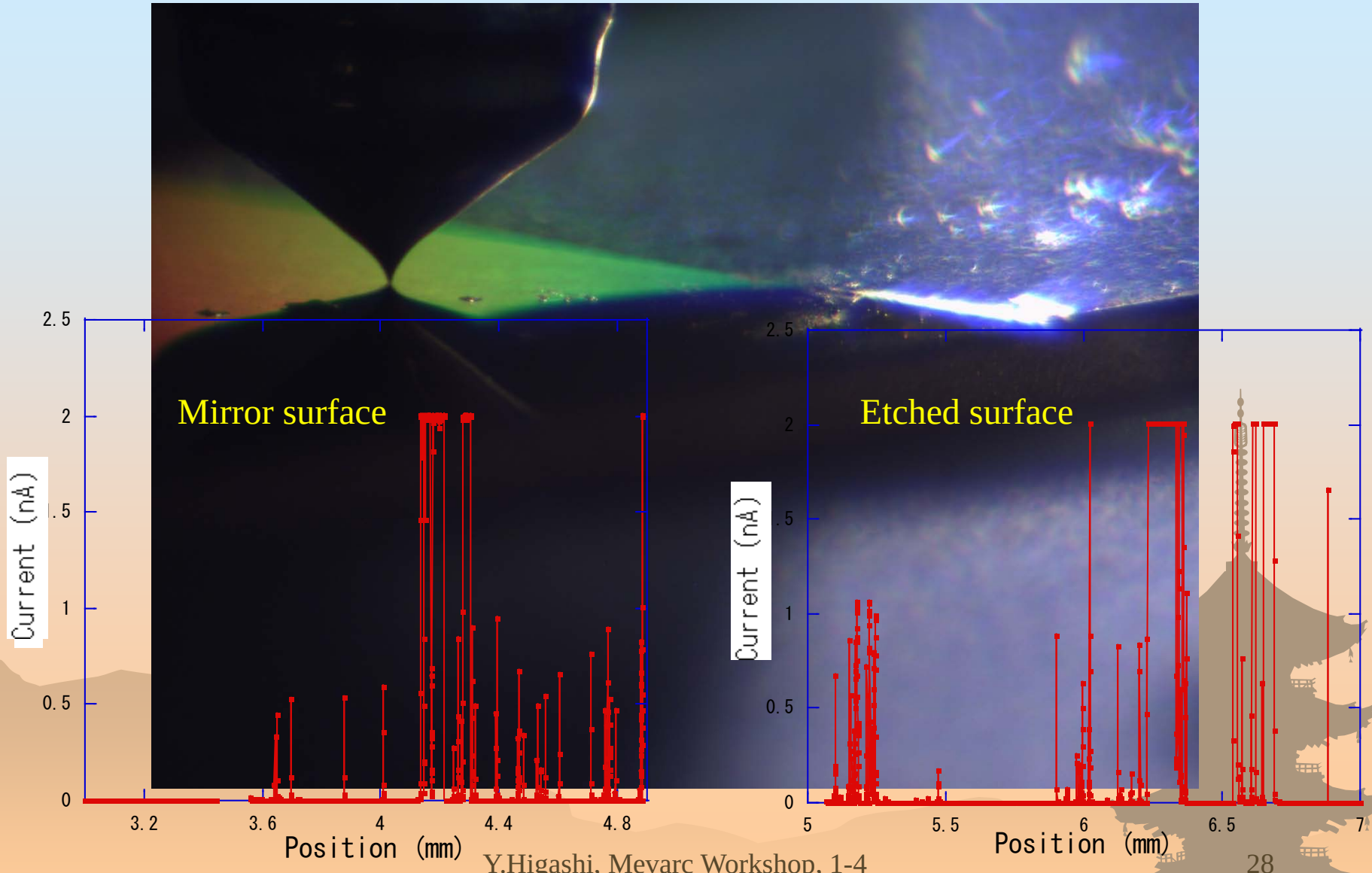
Each of the 7 frame includes data for 5 different locations



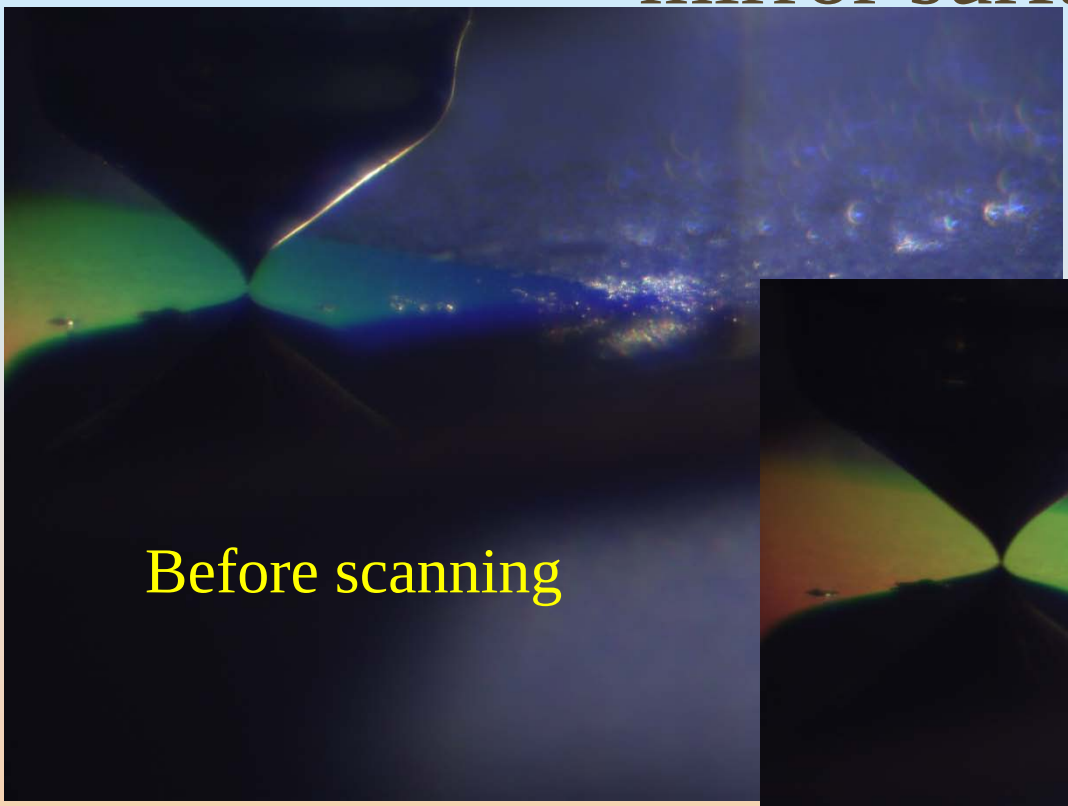
Surface Scan

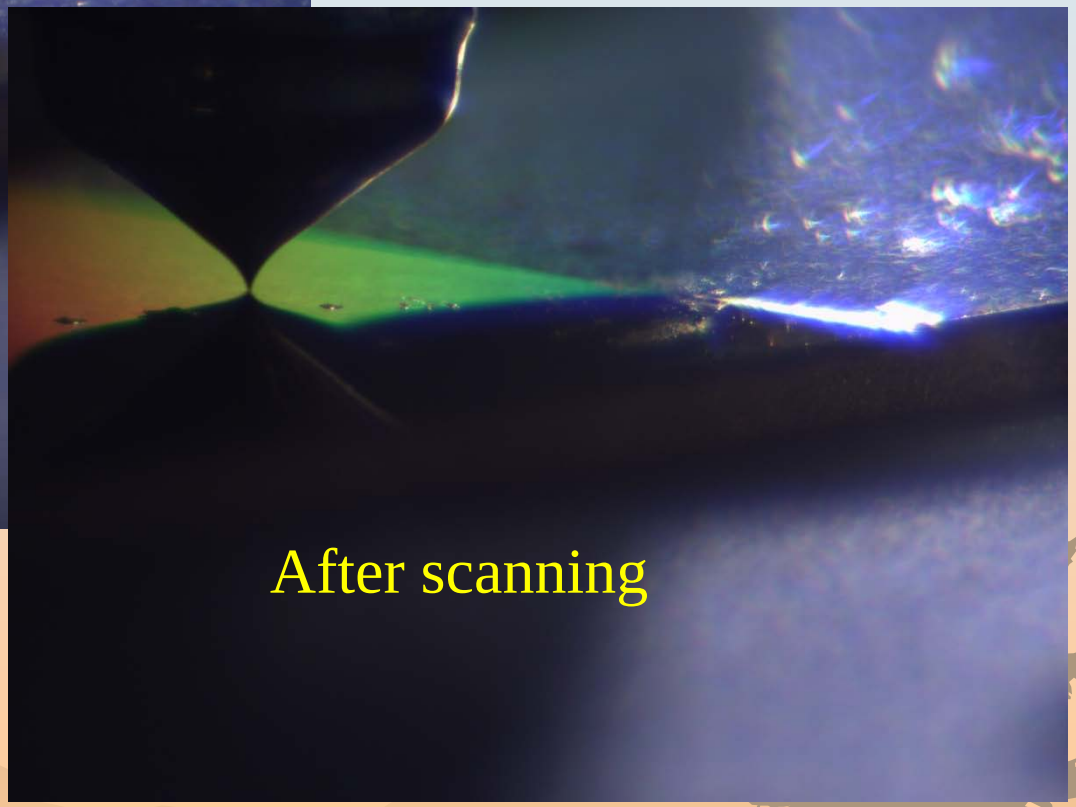


Measured field emission distributions



We found no surface damages after scanning on mirror surface

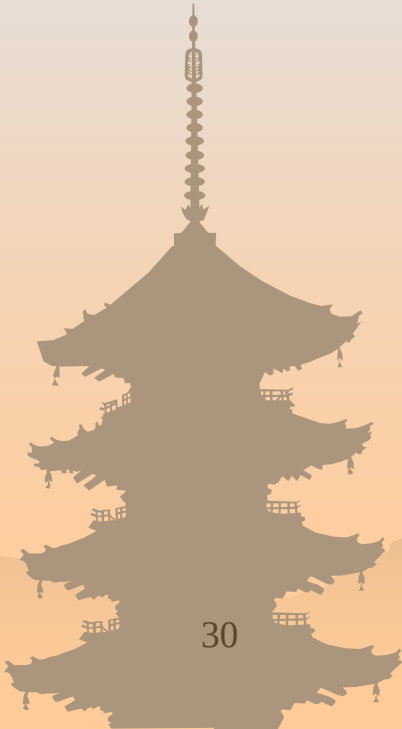




Setup commissioning

- We found out that pulse motor drive generates vibration so impossible to get accurate data

- Now we move sample manually

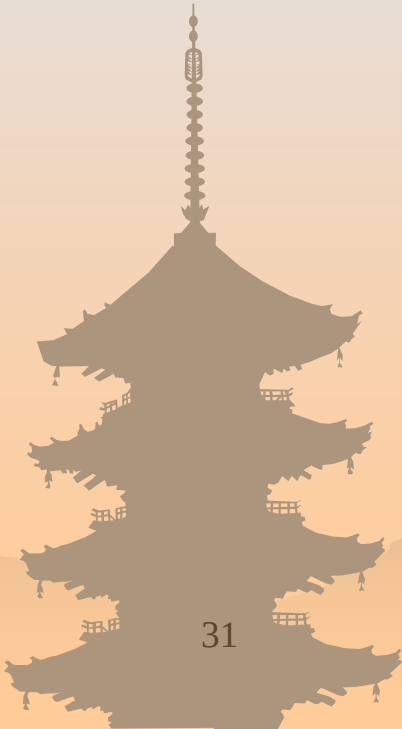


Search for Location of Enhanced Field Emission

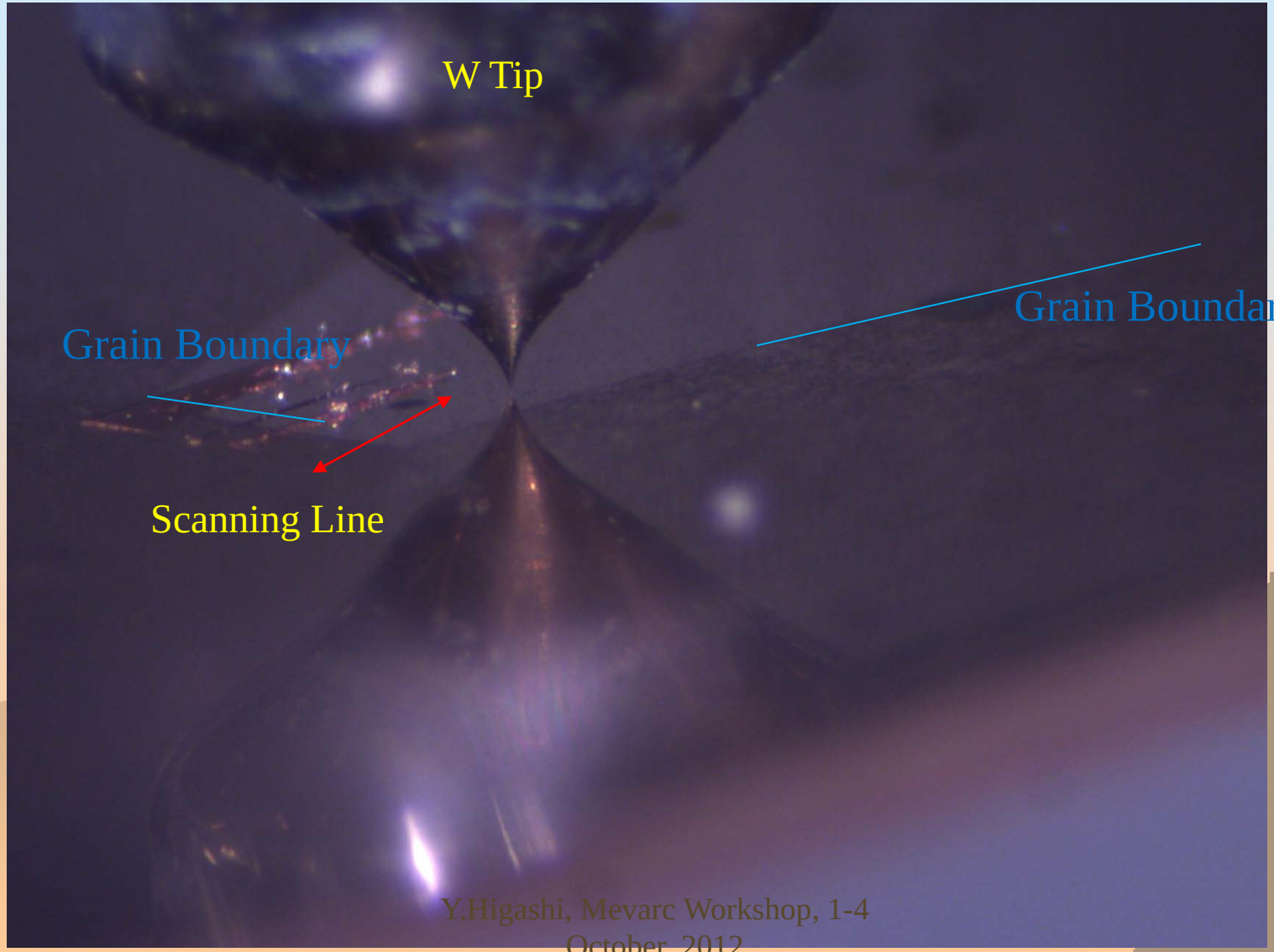
- Scanning grain boundary on the ultra-pure 7N-LG copper
- Random scan on the standard purity, OFHC Class1 copper

Sample Surface Preparation

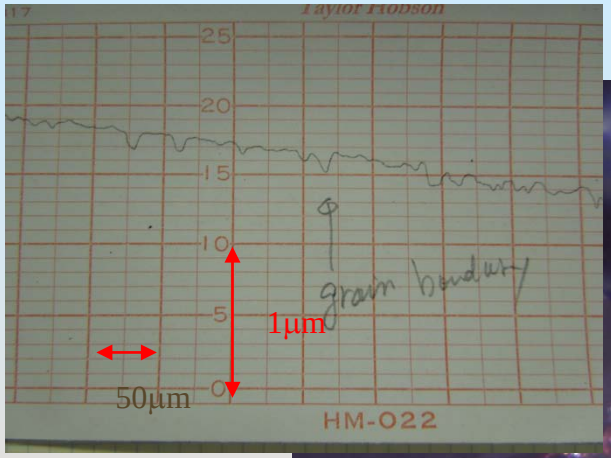
- Diamond Turning (20nm rms)
- 600 deg.C/1 hour heat treatment in vacuum
- 3 μm chemical etching

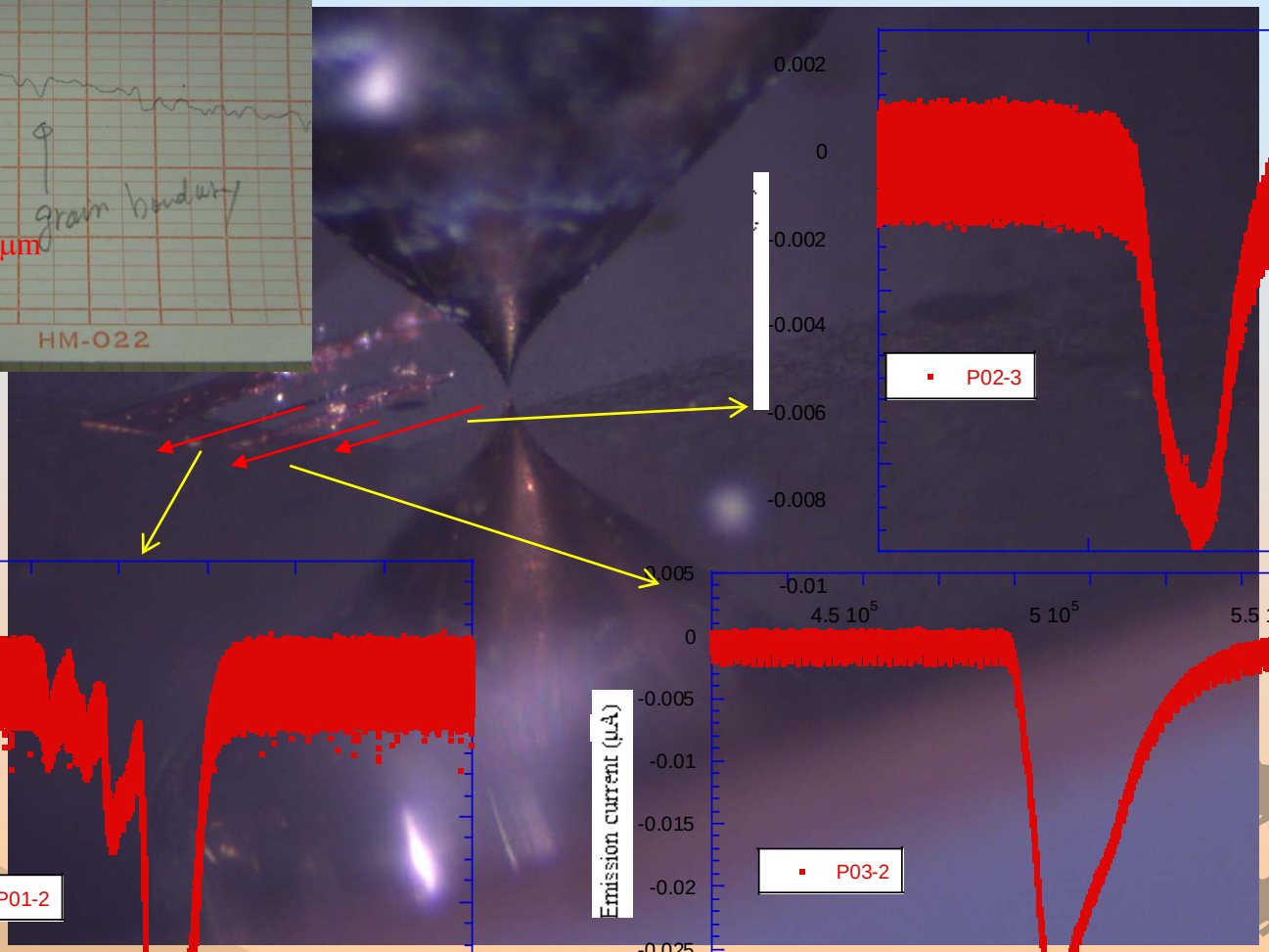


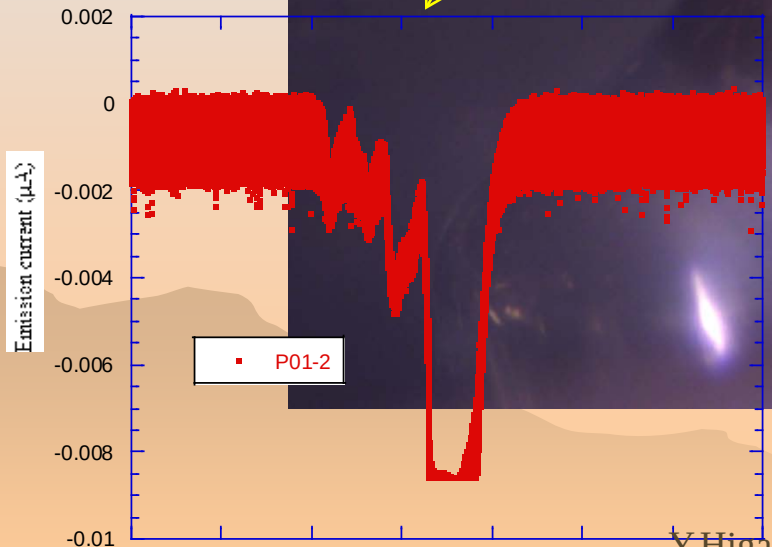
Grain boundary of ultra-pure 7N-LG copper



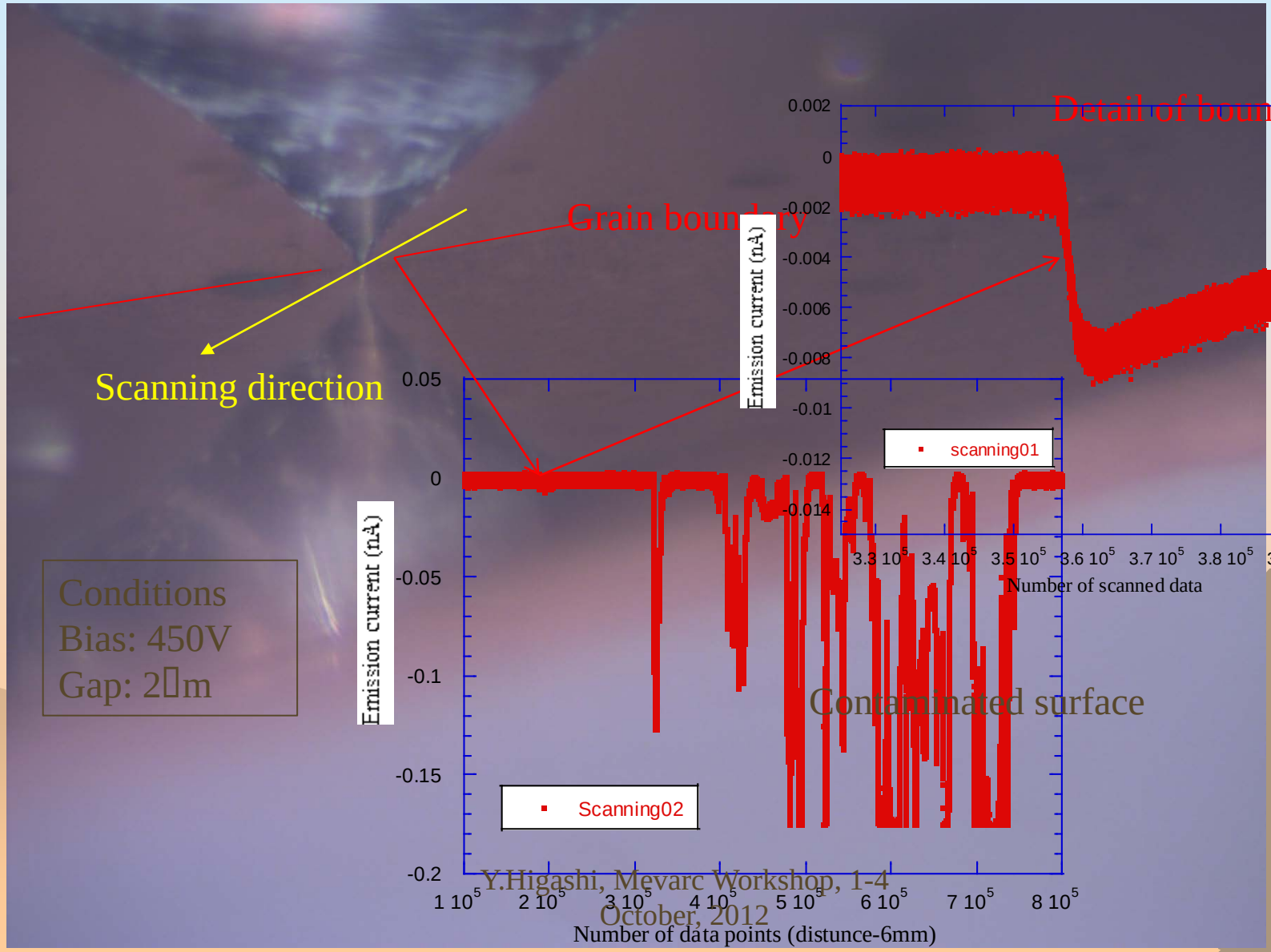
Enhancement of field emission on a grain boundary



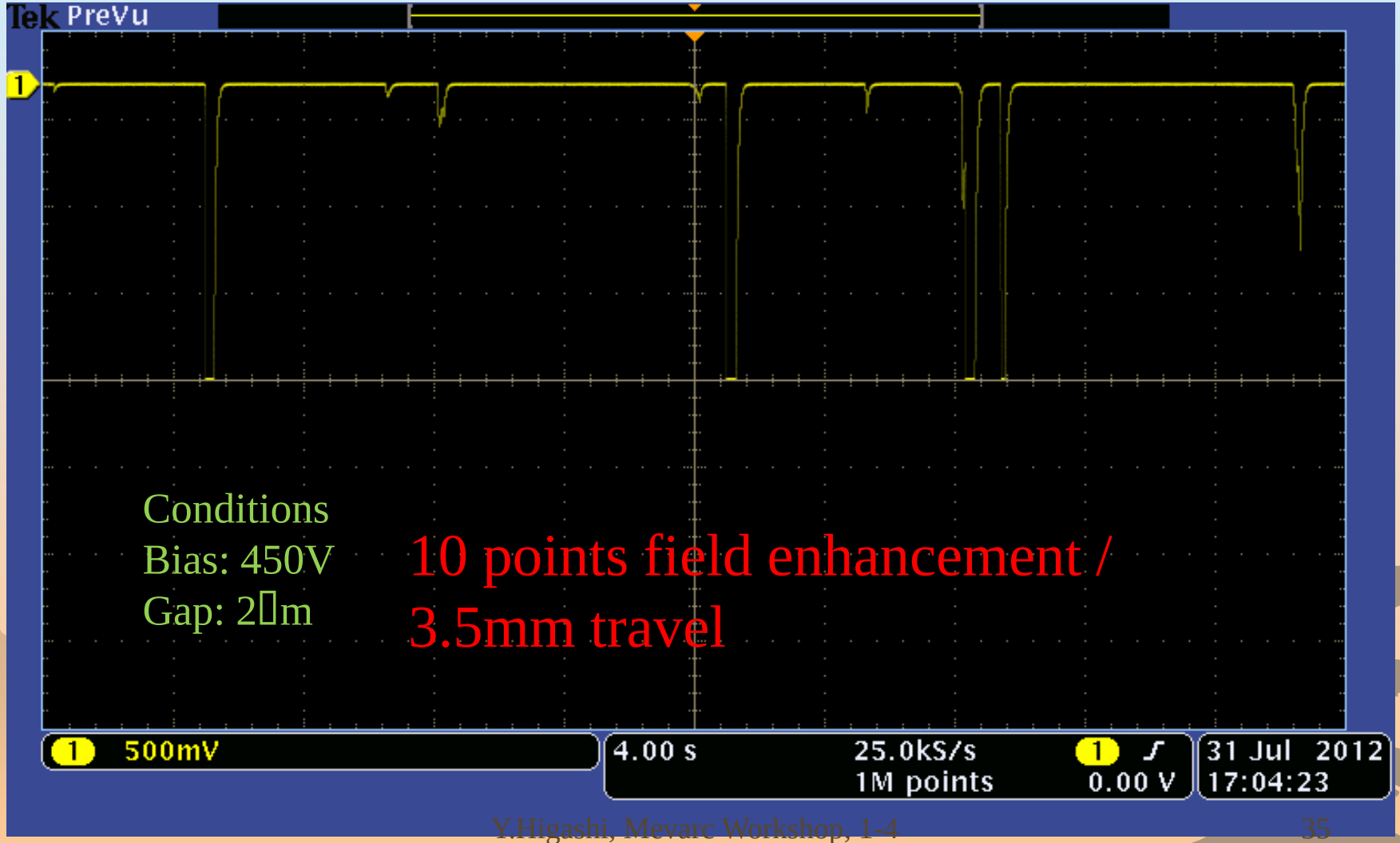




Enhansement of field emission on another grain boundary and on contaminated surface

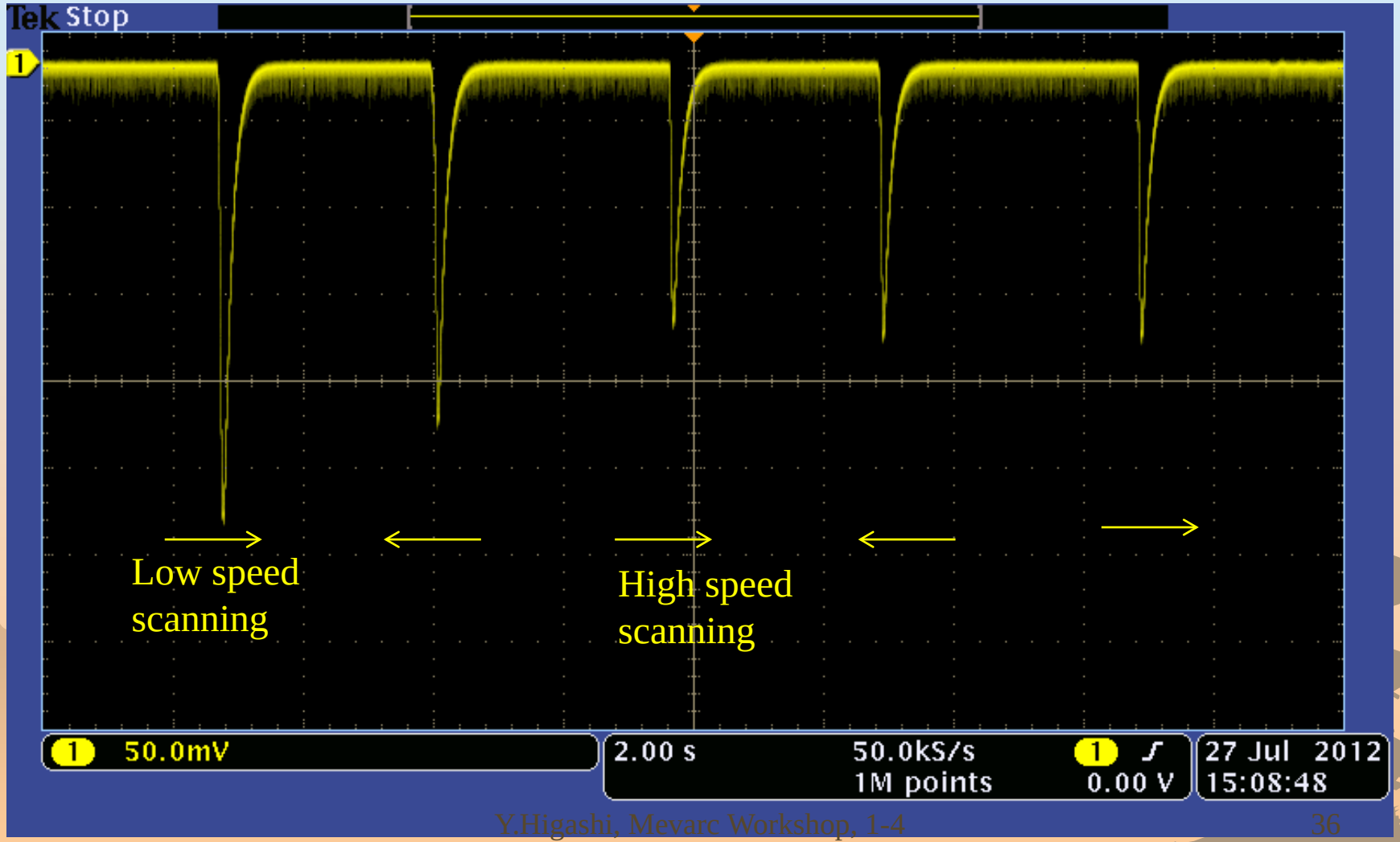


Typical Field Emission distribution on surface of standard, OFHC Class1 copper

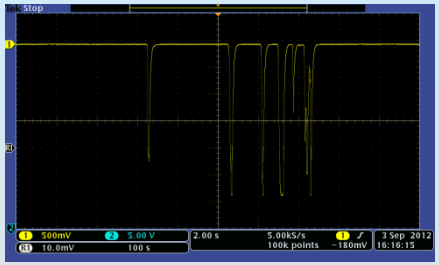
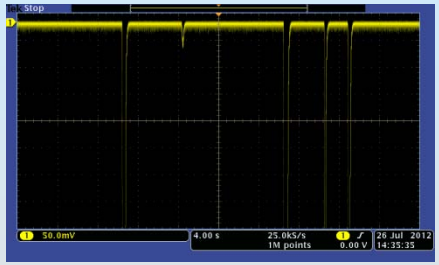
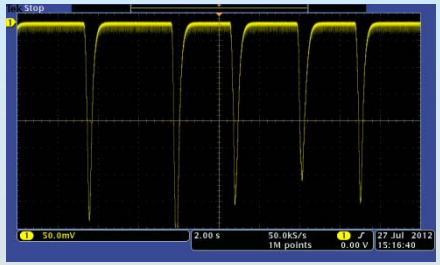
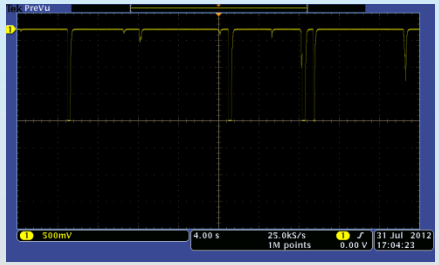
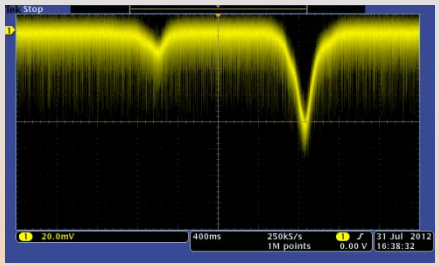
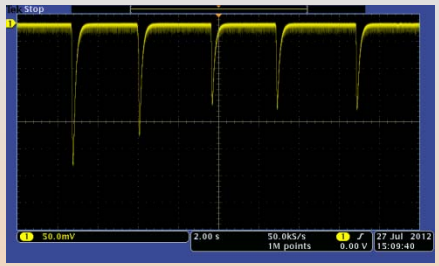
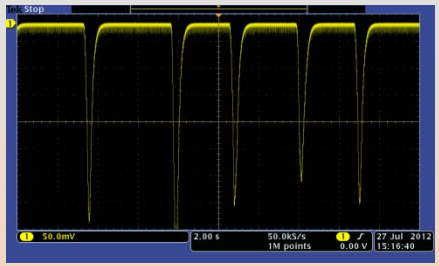
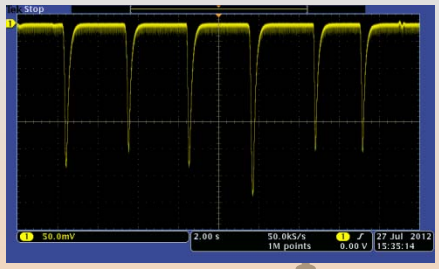
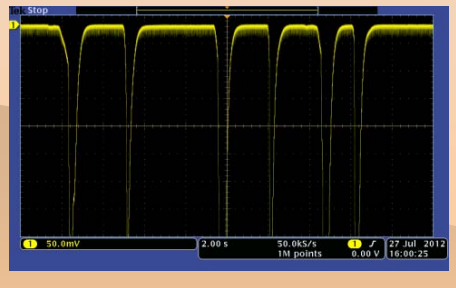
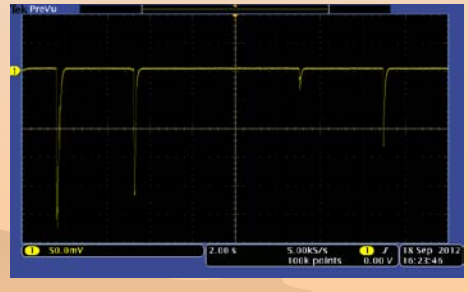
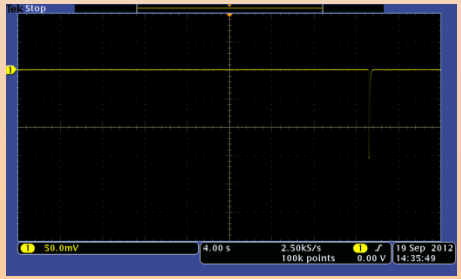


Reproducibility check

Back-and-forth scan of one point of enhanced field emission

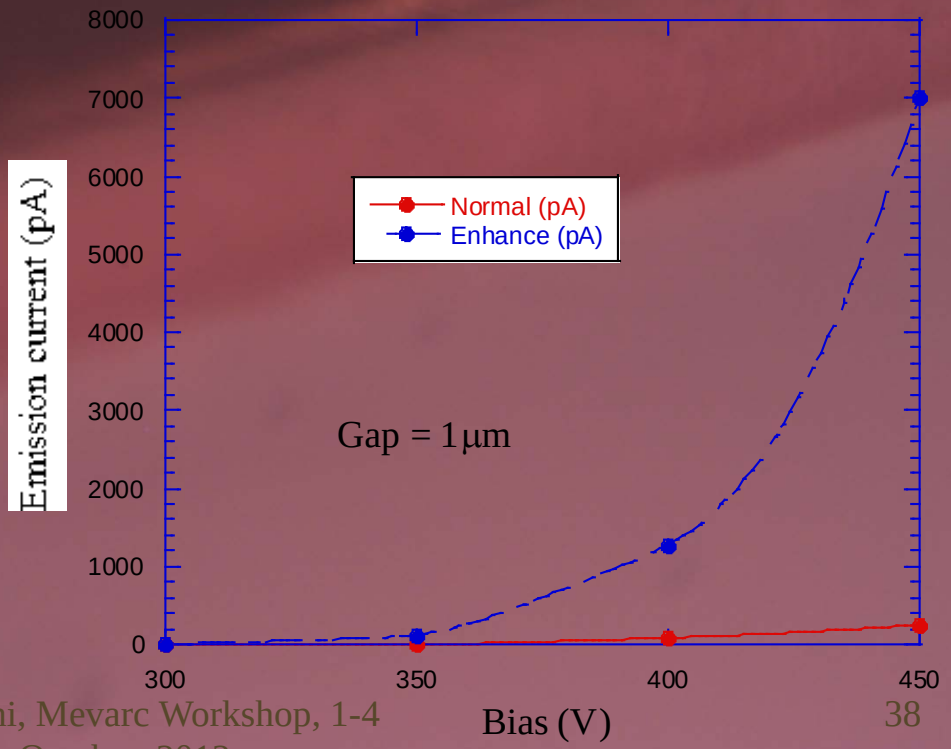


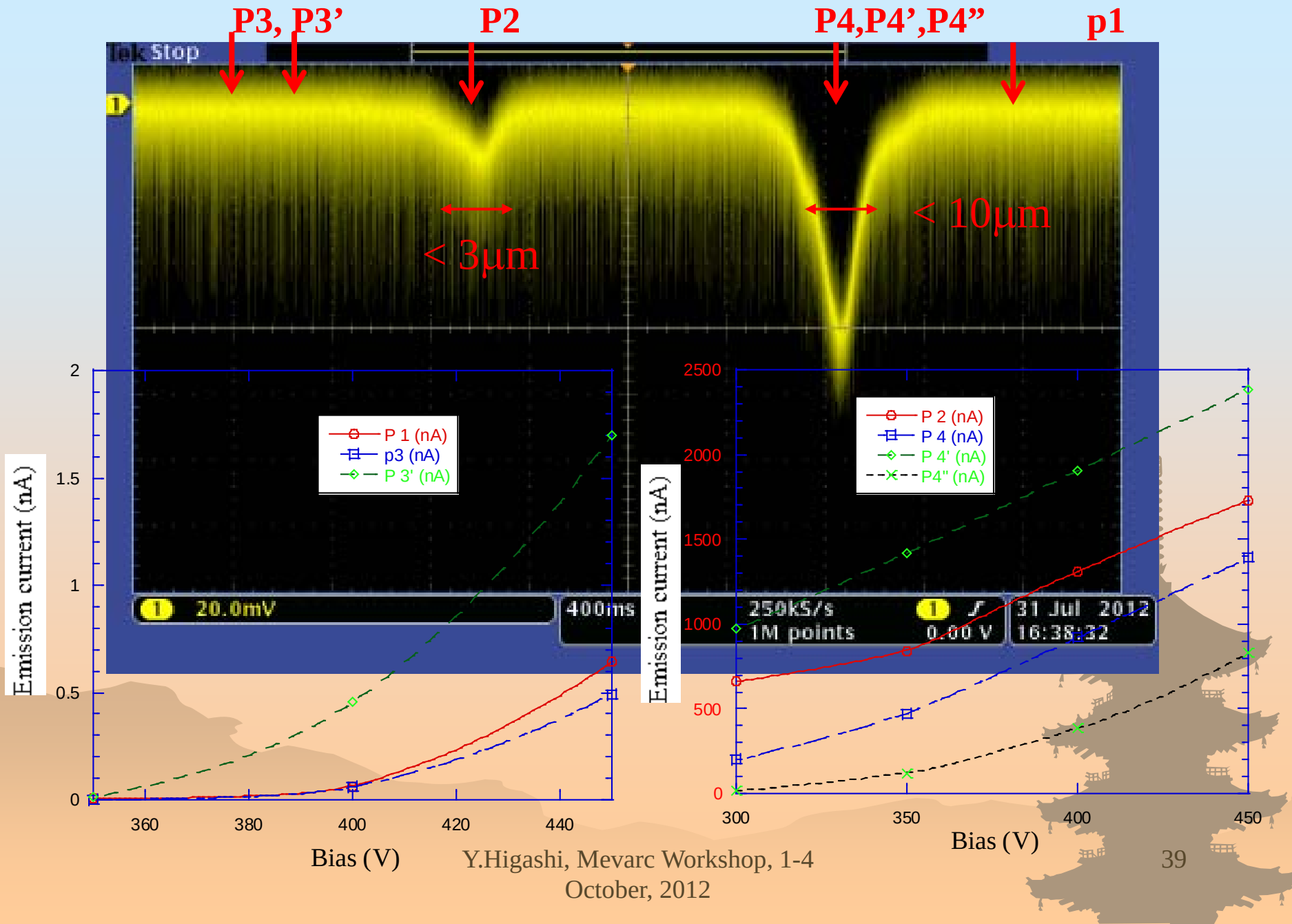
Getting statistics on the field enhancement: 1D scans 12 random locations


Comparison of currents from enhanced and "base" field emission

Location of Enhanced Field Emission

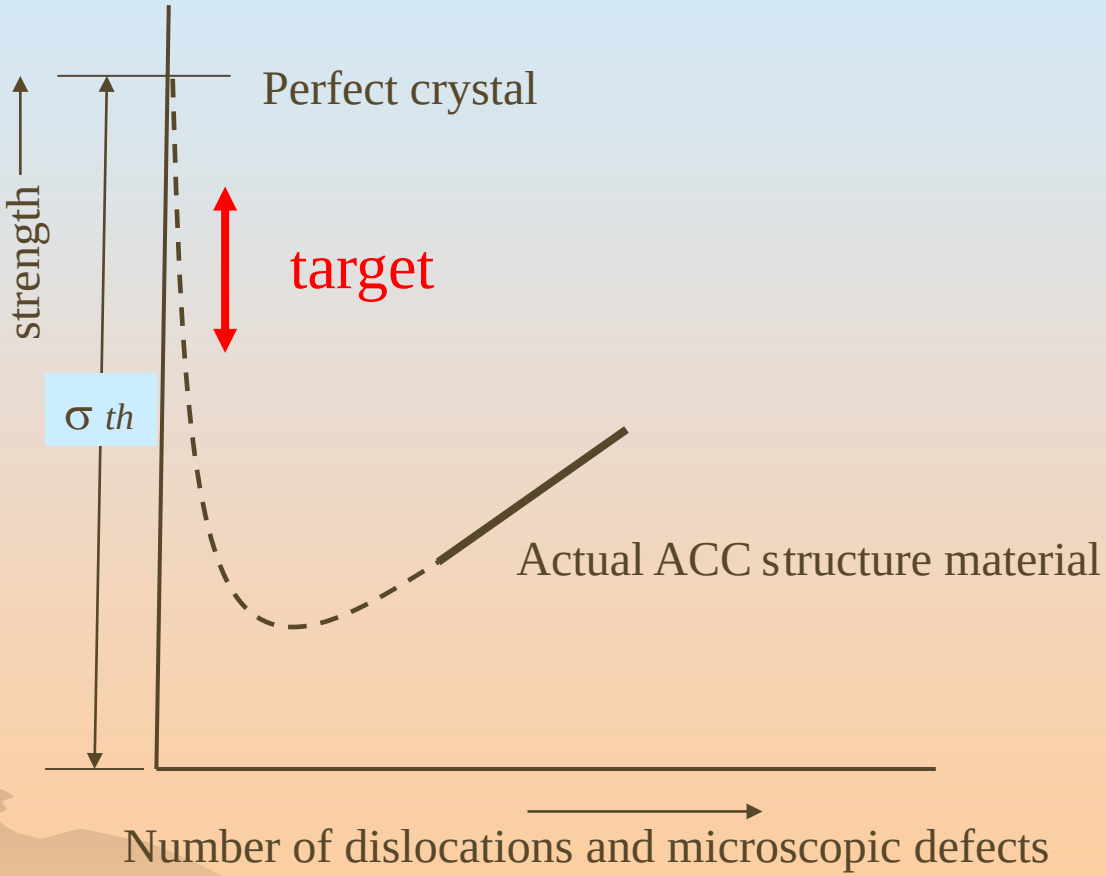



P3, P3'
P2
P4,P4',P4"
p1
Tek Stop
< 3µm
< 10µm
20.0mV
400ms
250kS/s
1M points
31 Jul 2012
16:38:32
P 1 (nA)
p3 (nA)
P 3' (nA)
Emission current (nA)
Bias (V)
P 2 (nA)
P 4 (nA)
P 4' (nA)
P4" (nA)
Emission current (nA)
Bias (V)

Summary

- We observed enhancement of field emission on a grain boundary of the ultra-pure 7N-LG copper
- We were able to reproducibly measure enhancement points on surface of standard copper

Future Work


Perfect crystal
target
strength
σ th
Actual ACC structure material
Number of dislocations and microscopic defects