Environment exposure tests of Electron Emitting Film for Spacecraft Charging Mitigation (ELF's CHARM)

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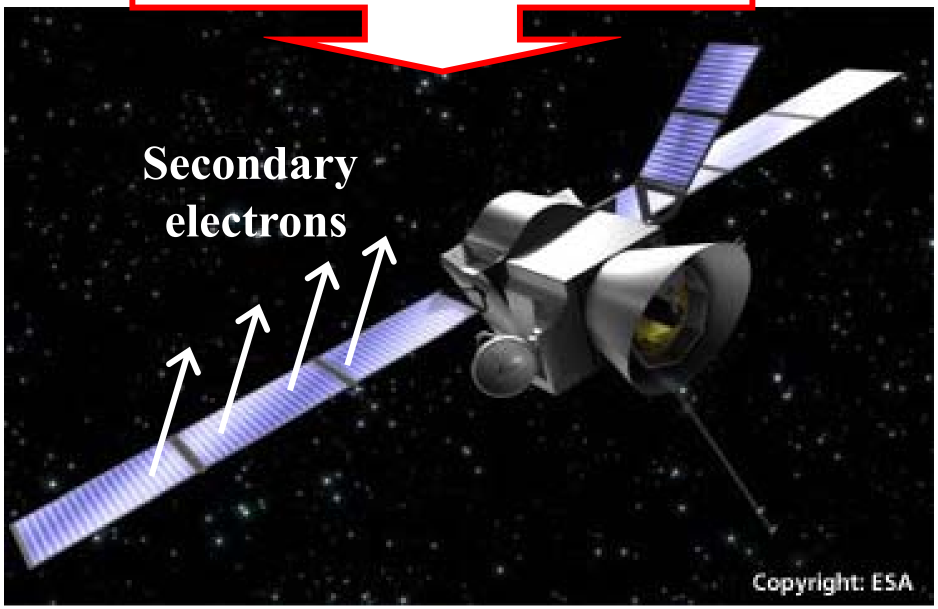
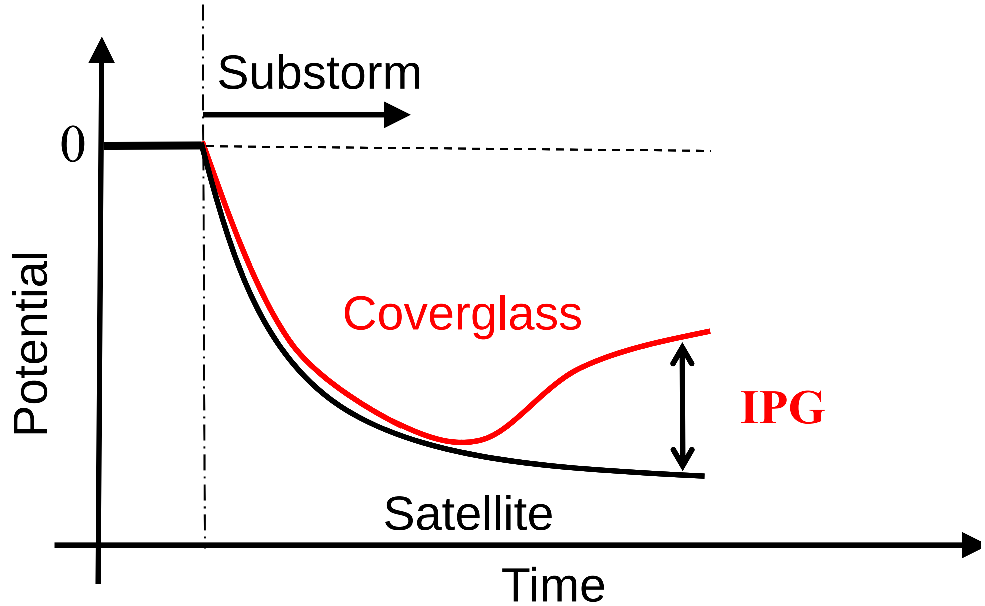
Outline

- Background of emitter
  - Basic idea
  - Theory
  - Practical situation
- Electron emission activity
- Environmental durability
- Conclusion
- Future tasks

Background: Basic idea

High energy electrons (due to substrom)





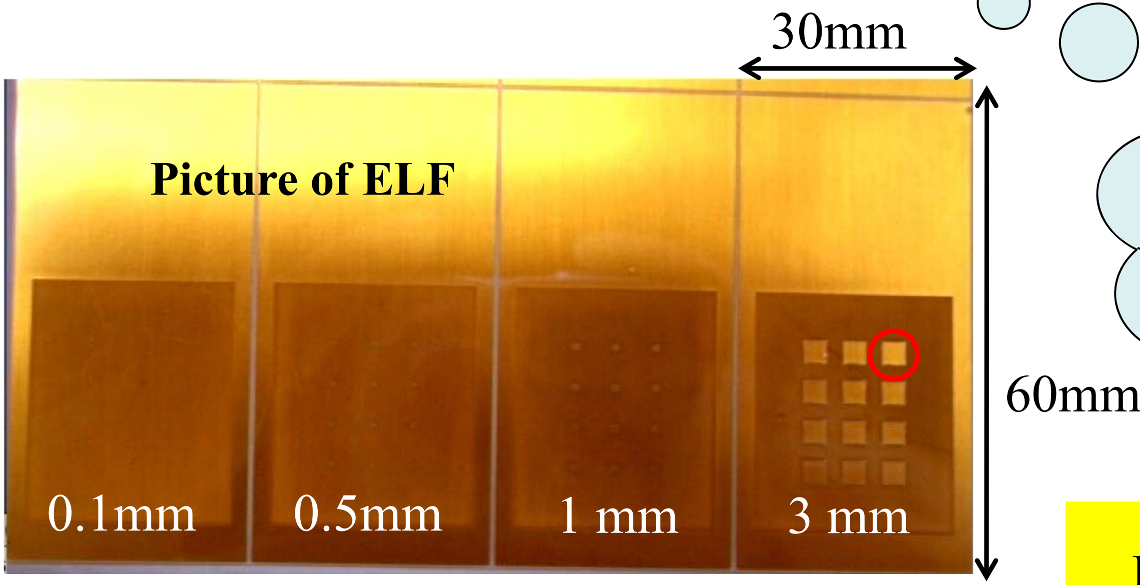
Arc threshold: 400V

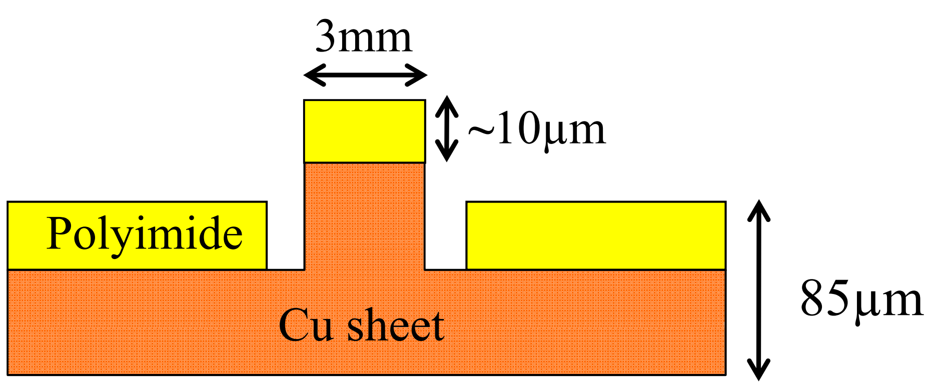
- **Satellite turns to negative potential (shown by black line)**
- **Coverglass turns to less negative potential (shown by red line)**

→ **Inverted Potential Gradient (IPG)** → **Responsible for ESD followed by on-orbit anomalies.**

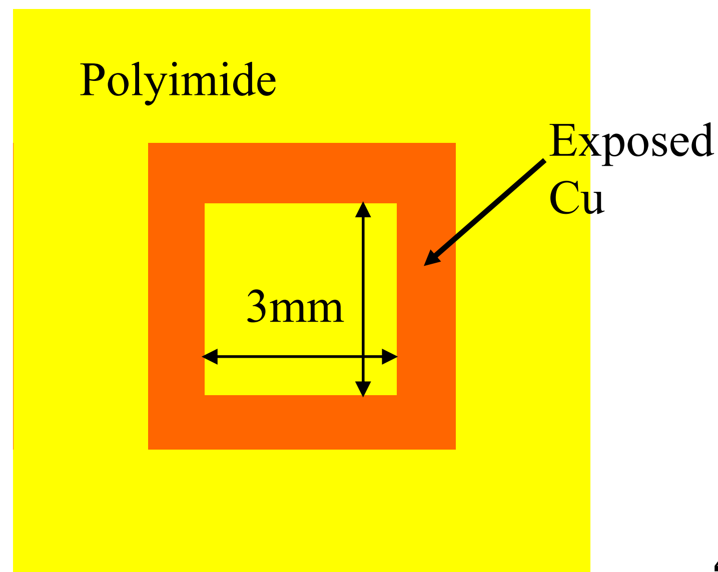
How to mitigate the ESD ?

Electron Emitting Film (ELF)





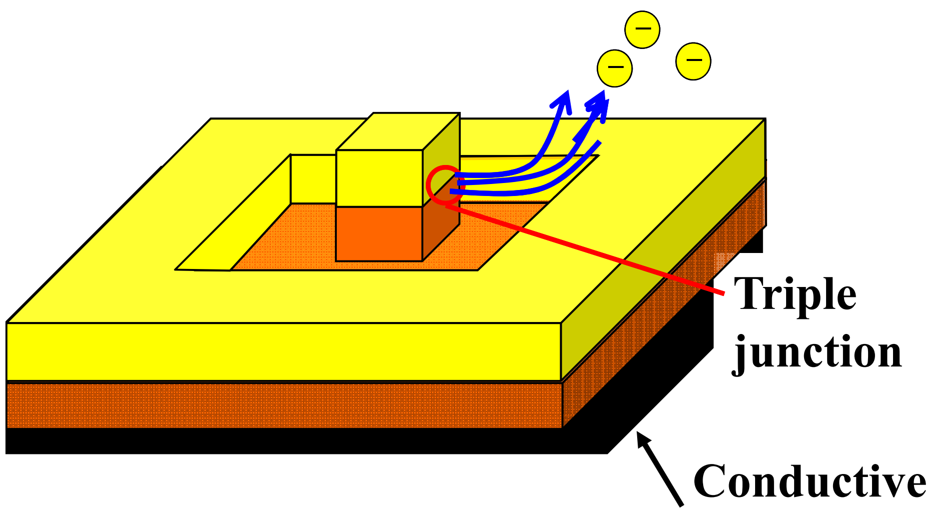
Cross sectional view



Top view

Electron emitting Film (ELF)

Pre-condition for operation
- Inverted Potential Gradient (IPG)
- Existence of Triple Junction (TJ)



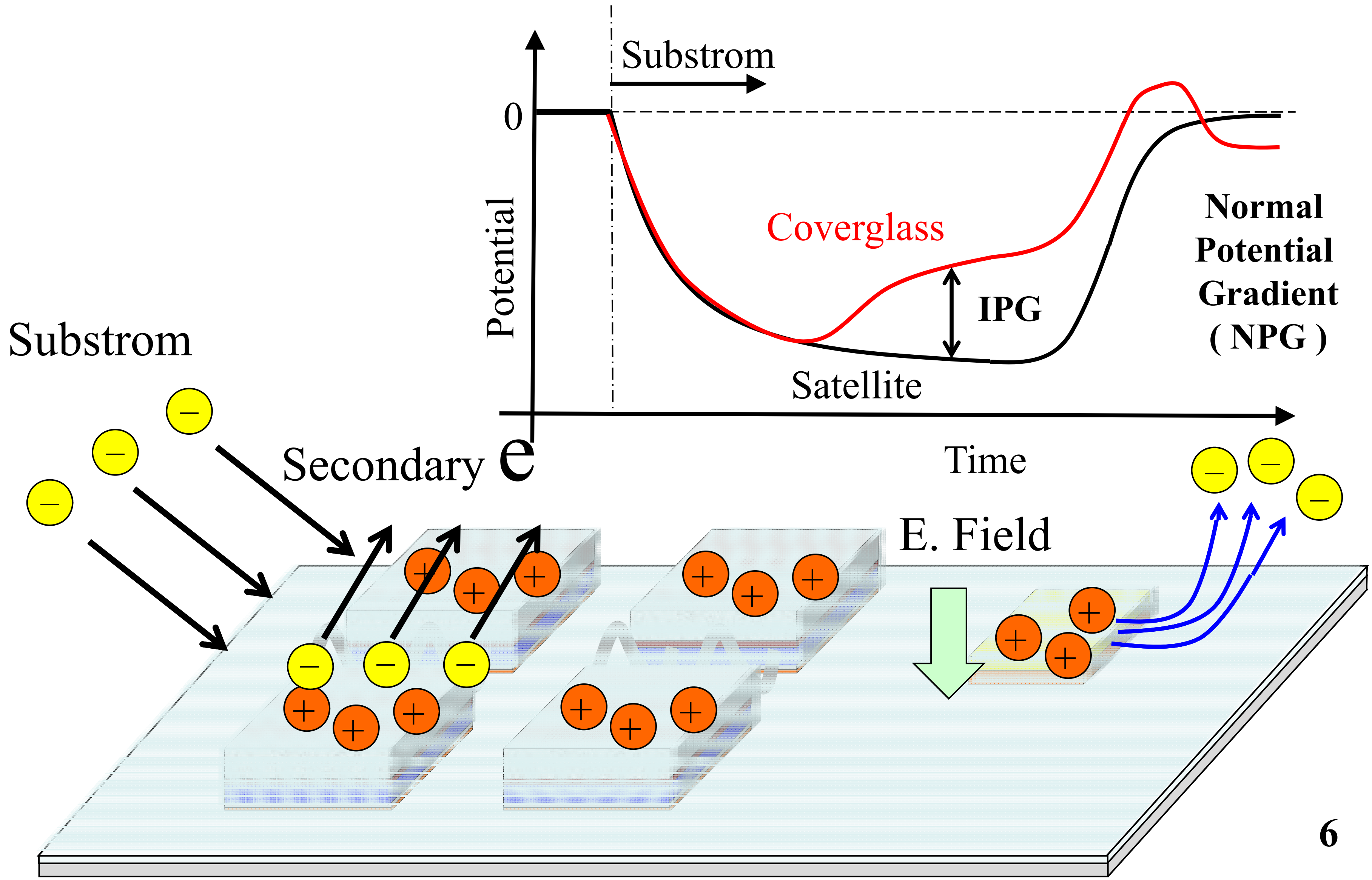
Schematic 3D view of ELF

IPG → **Electric field** → **Field Emission**

Advantages

- Passive in operation
- No sensor needed
- No wire harness
- Lightweight (~1.4g)
- Acts as surface charging monitor (SCM)

Operational mechanism of ELF



Background: Theory

Fowler-Nordheim (F-N) field emission current

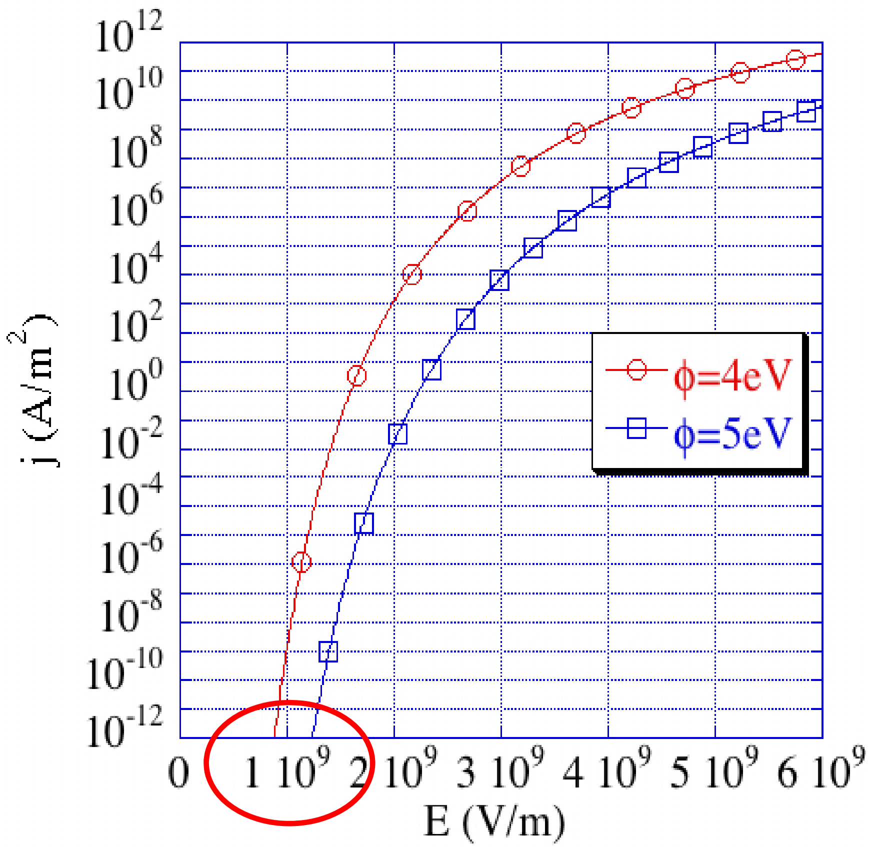
$$j = A(E)^2 \exp\left(-\frac{B}{E}\right)$$

$$A = \frac{1.54\times10^{-6}10^{4.52/\sqrt{\phi}}}{\phi}$$

$$B = 6.53\times10^{9}\phi^{1.5}$$

E: Field strength on surface (V/m)

ϕ: Work function (eV)



To have appreciable current, we need an electric field in the order of 10^9 V/m

How do we get high E. field ?

- By charging the insulator by ambient charged particle (e.g. electron)

$$E_{\circ} = \frac{\Delta V}{d} = \frac{1000}{25\times 10^{6}} = \underline{4\times 10^{7}}\, V/m$$

ΔV = voltage across the insulator
d = thickness of insulator

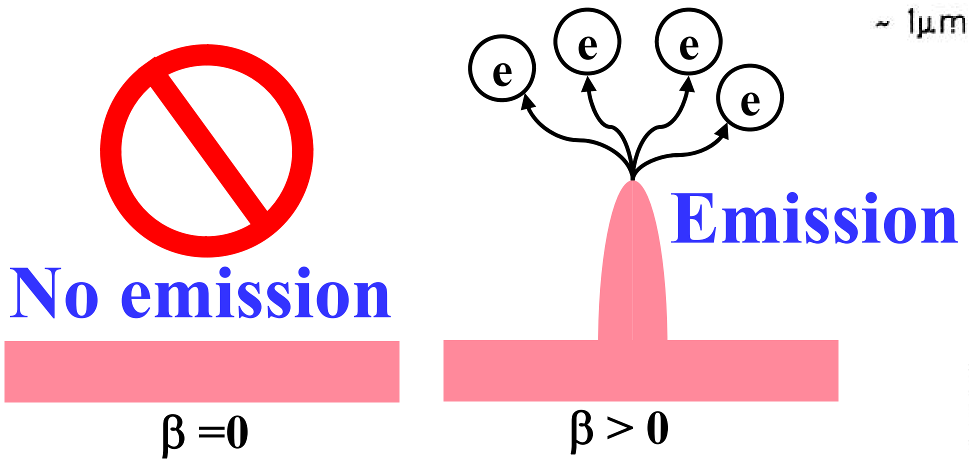
100x

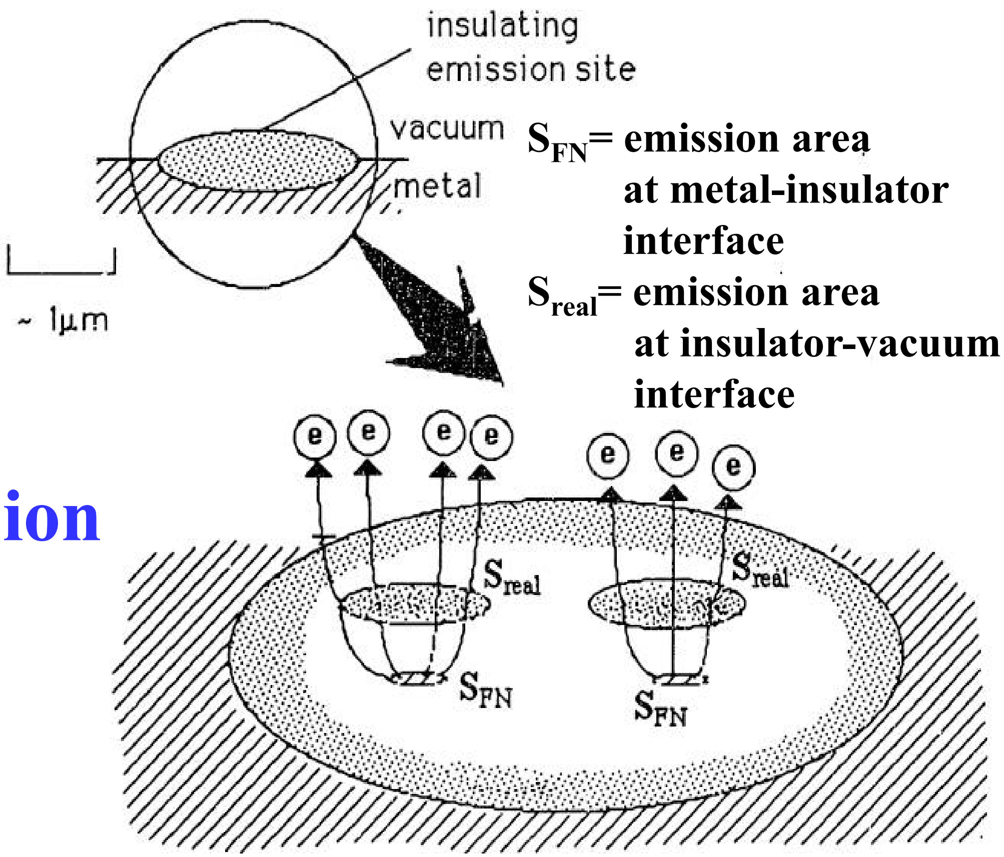
- By dielectric impurity (e.g. local ionization and diffusion) or by micro-protrusion, local enhancement of electric field ($E=\beta E_0$) is possible. Therefore, macroscopic field can be enhanced microscopically by a factor of β that must be more than 100 to get the field emission.

Field enhancement factor, β

–If β =0, ideal flat surface

–If β > 0, surface will be rough with many sharp emission sites.



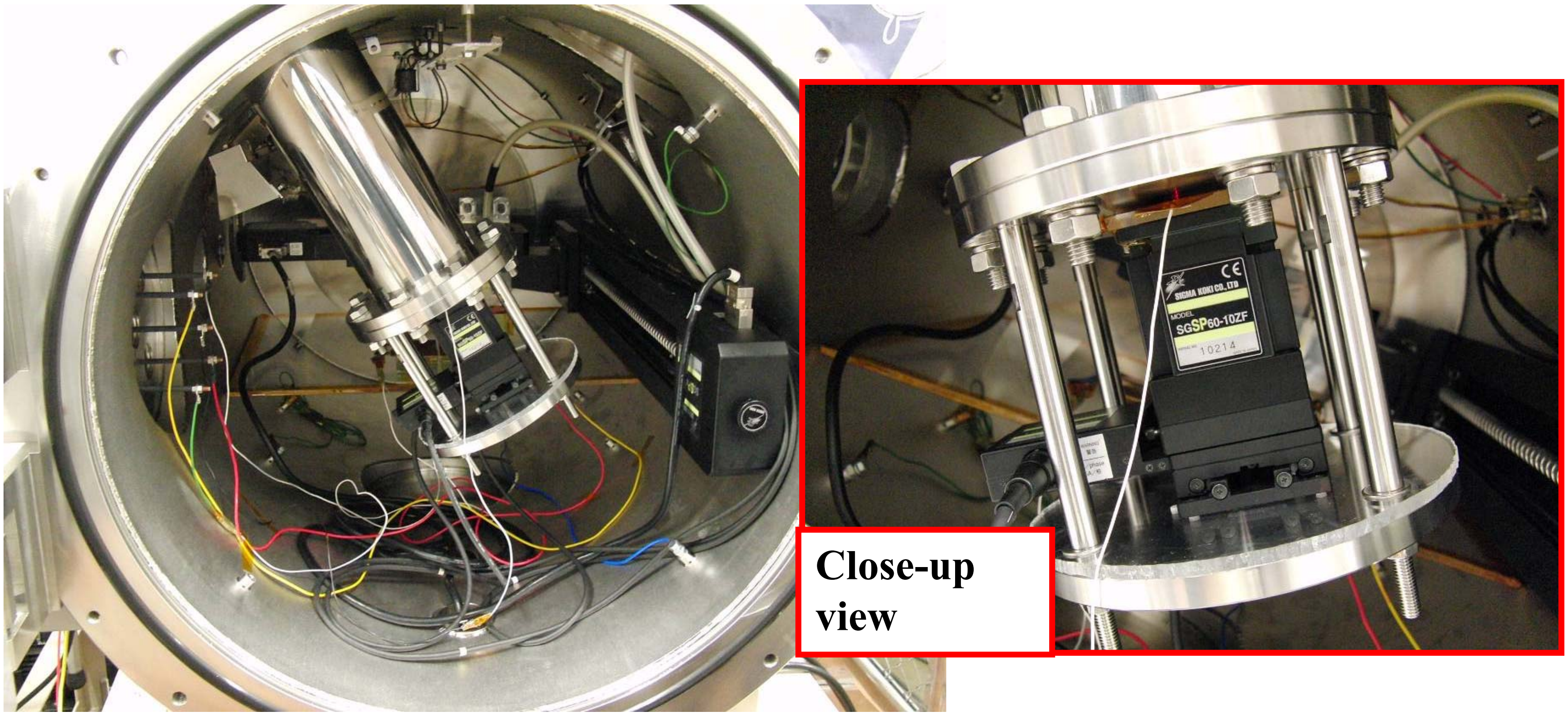


Ph.D. thesis, Mengu Cho, MIT, 1992

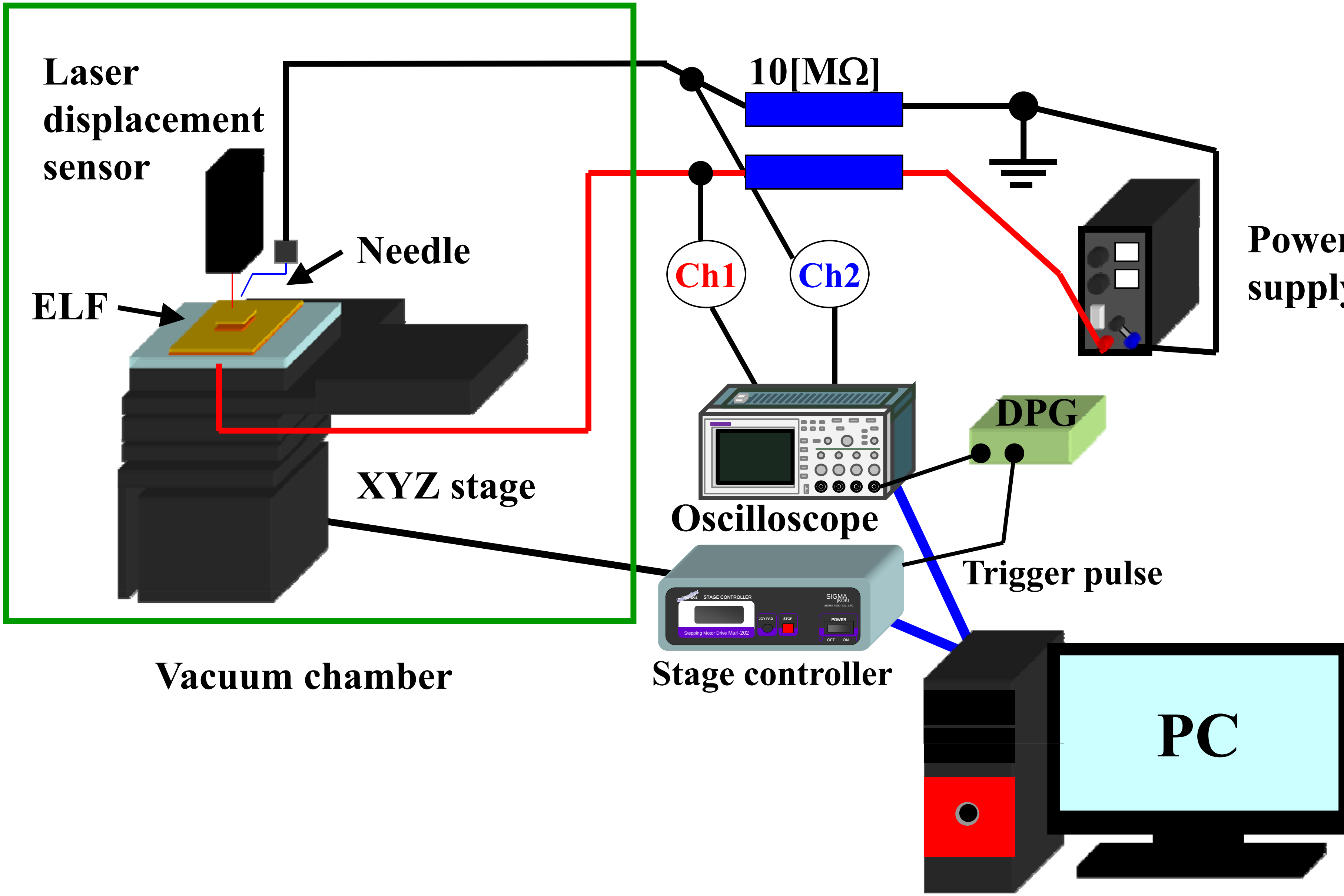
Local ionization and diffusion effects the inside dielectric impurity and increase the emission area (S_{real}). Thus β > 1000 is possible.

Background: Practical situation

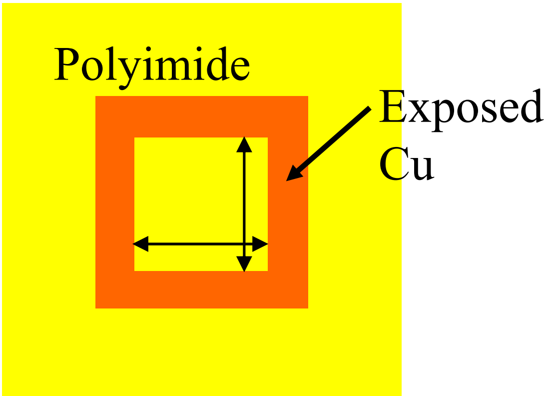
β measurement via field emission microscope (FEM)

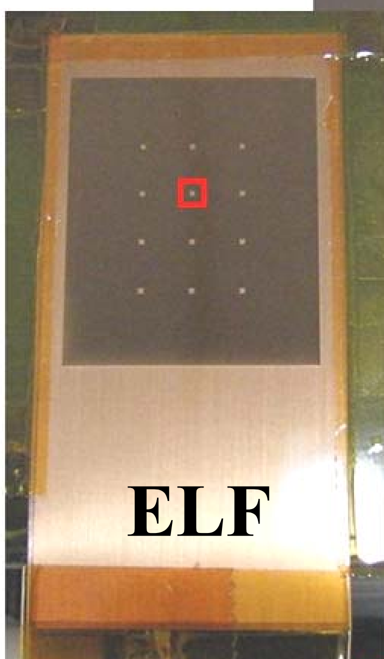


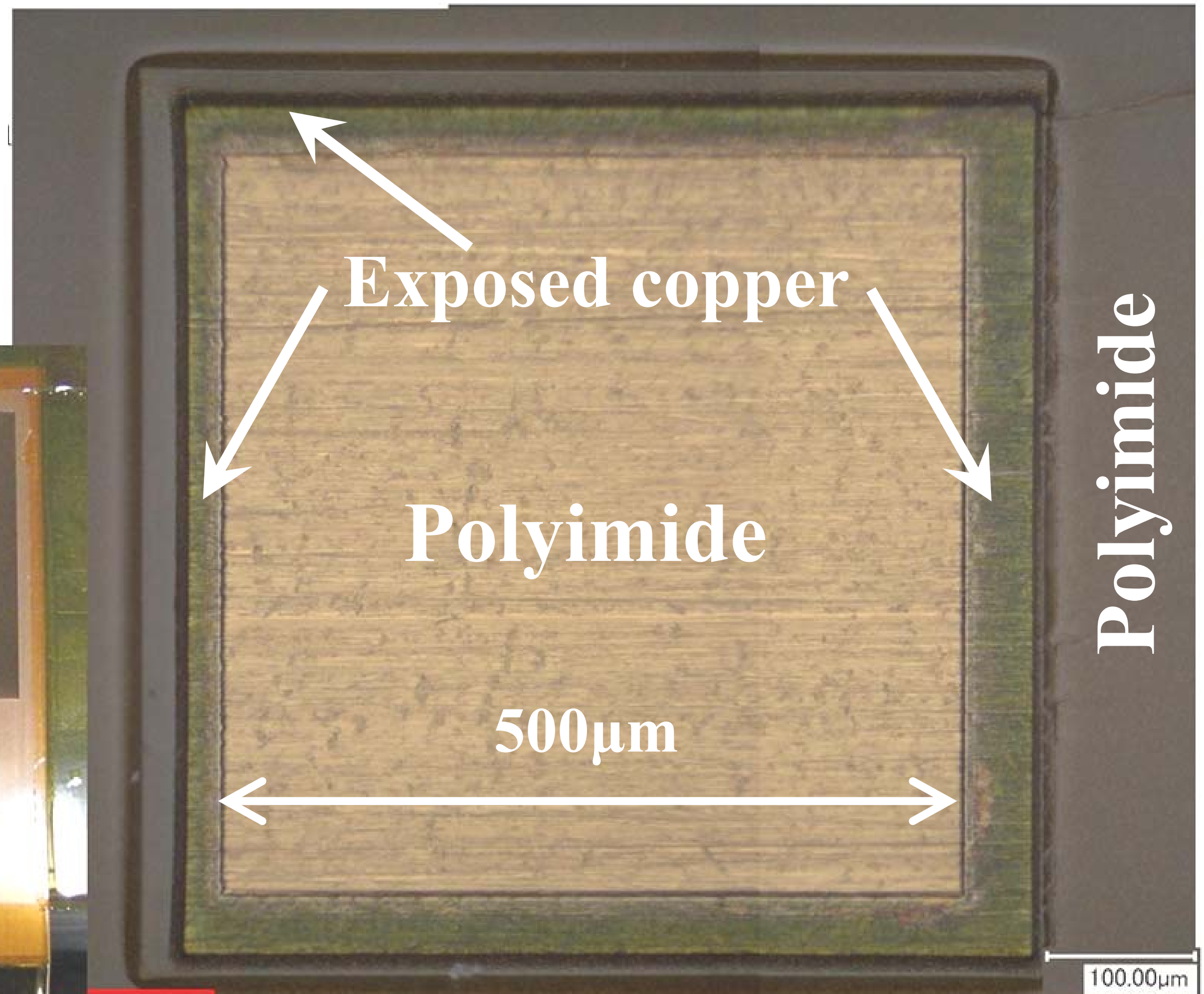
Measurement schematic (FEM)



ELF before measurement

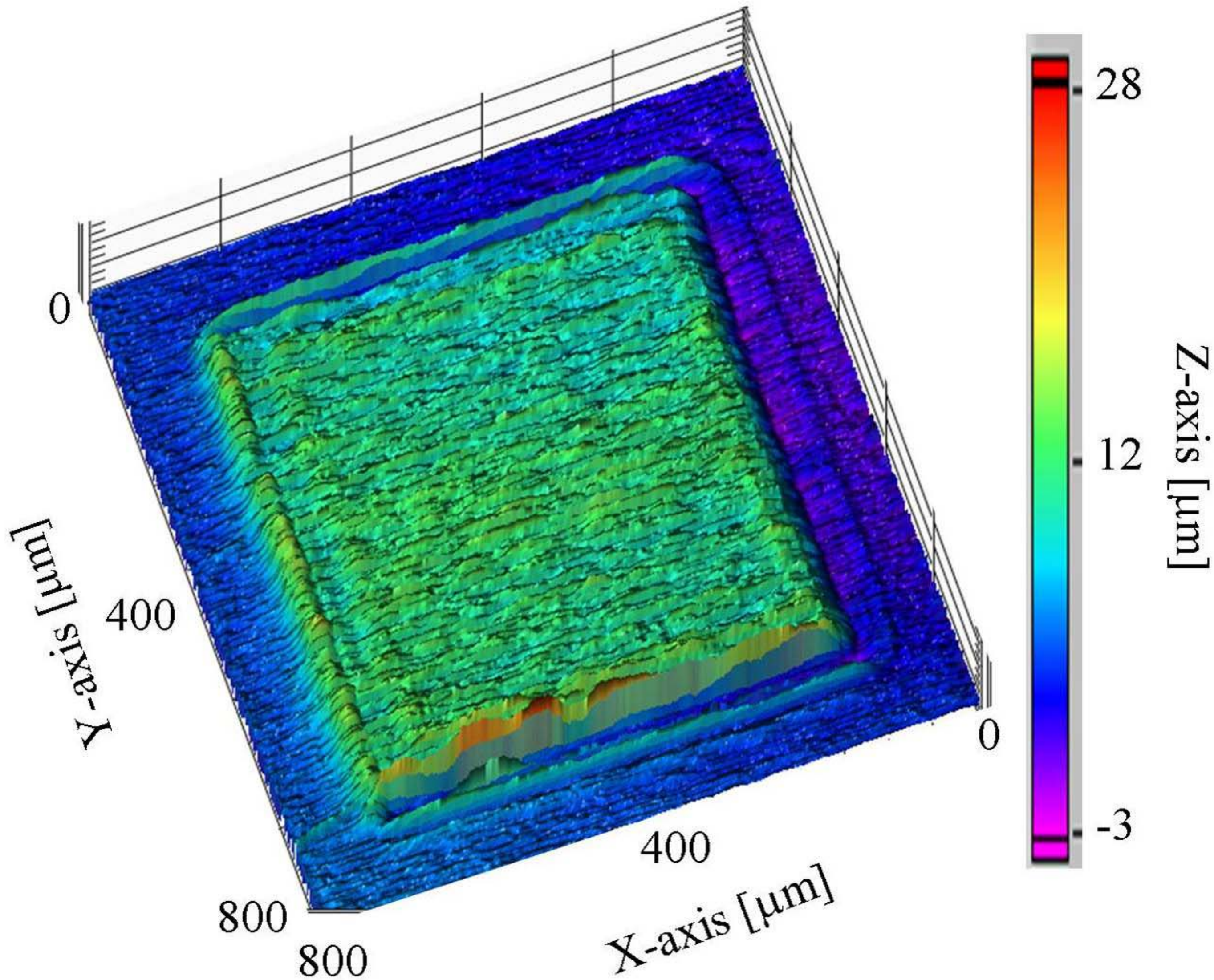






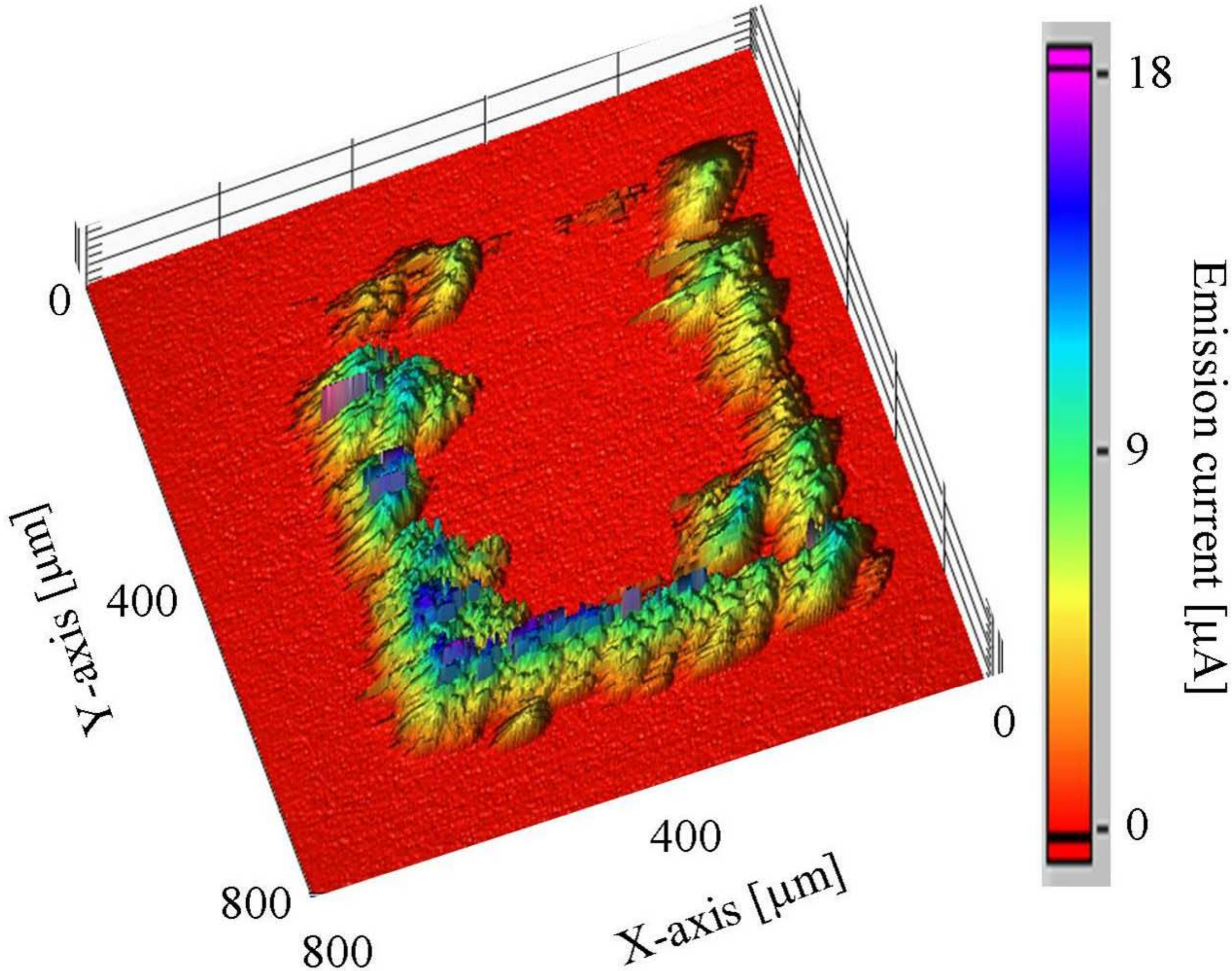
x500

After surface mapping



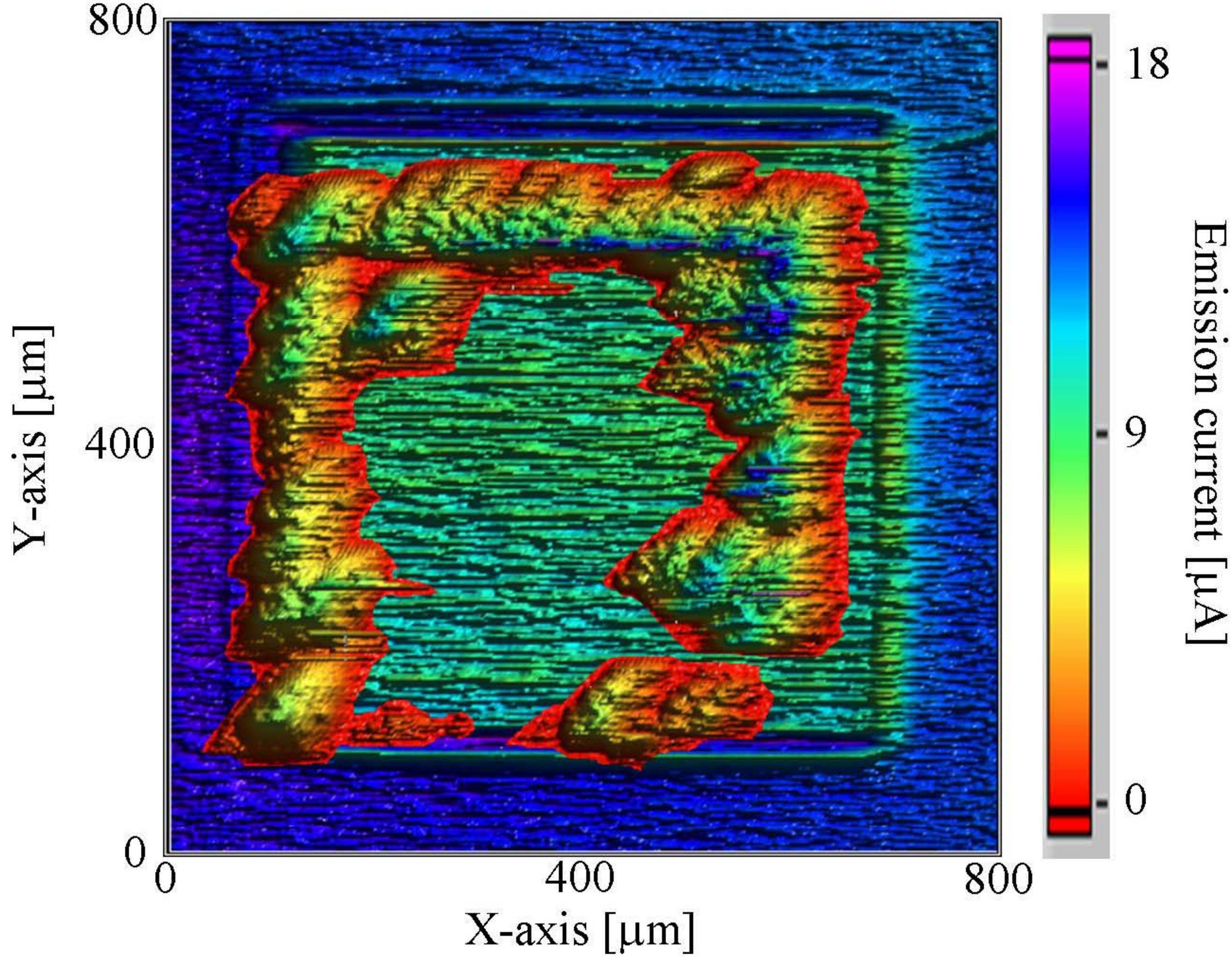
Scanning resolution: dx = dy = 2µm

Emission current distribution

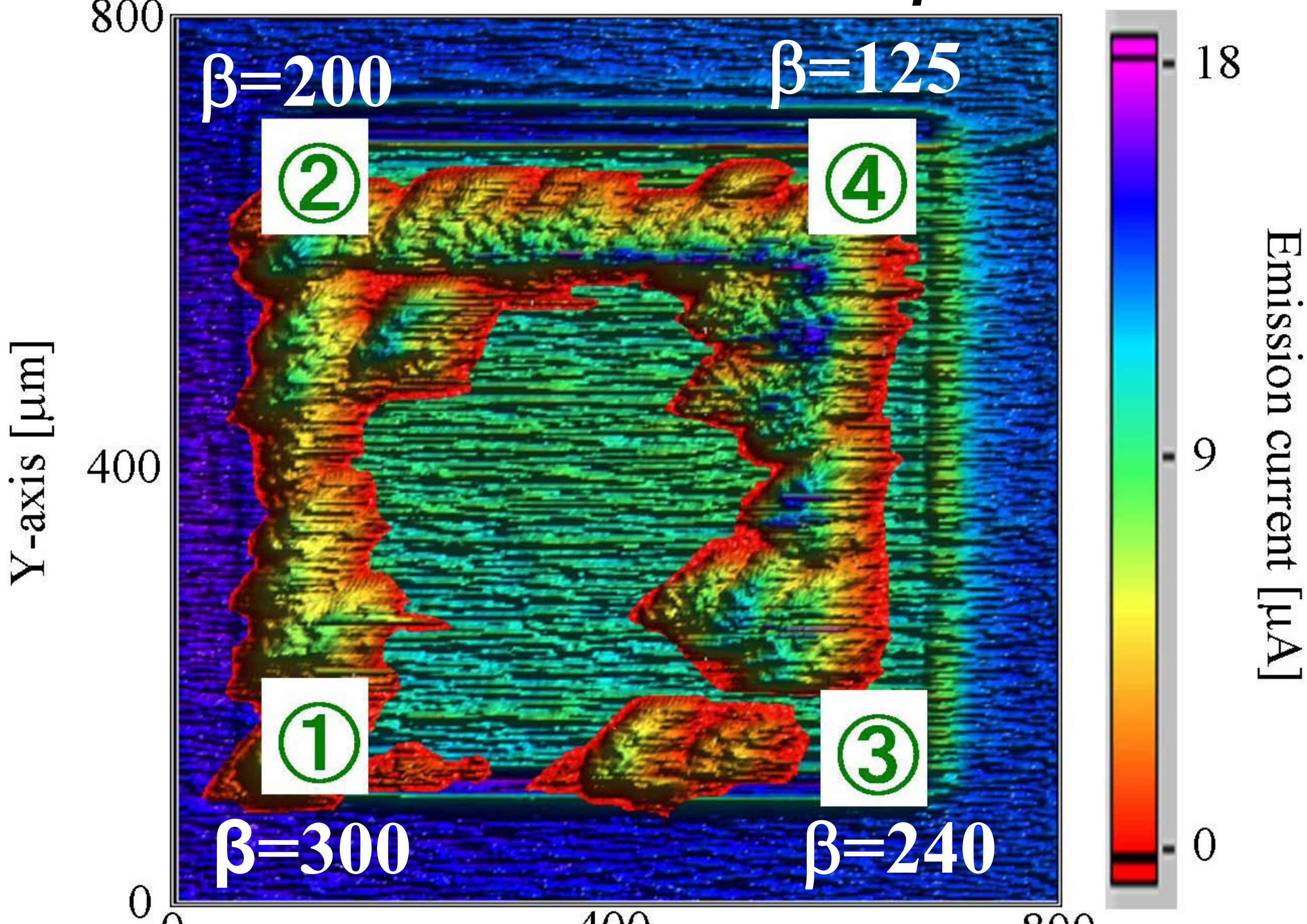


Scanning resolution: dx = dy = 2μm

Superposition of two pictures



Distribution of β

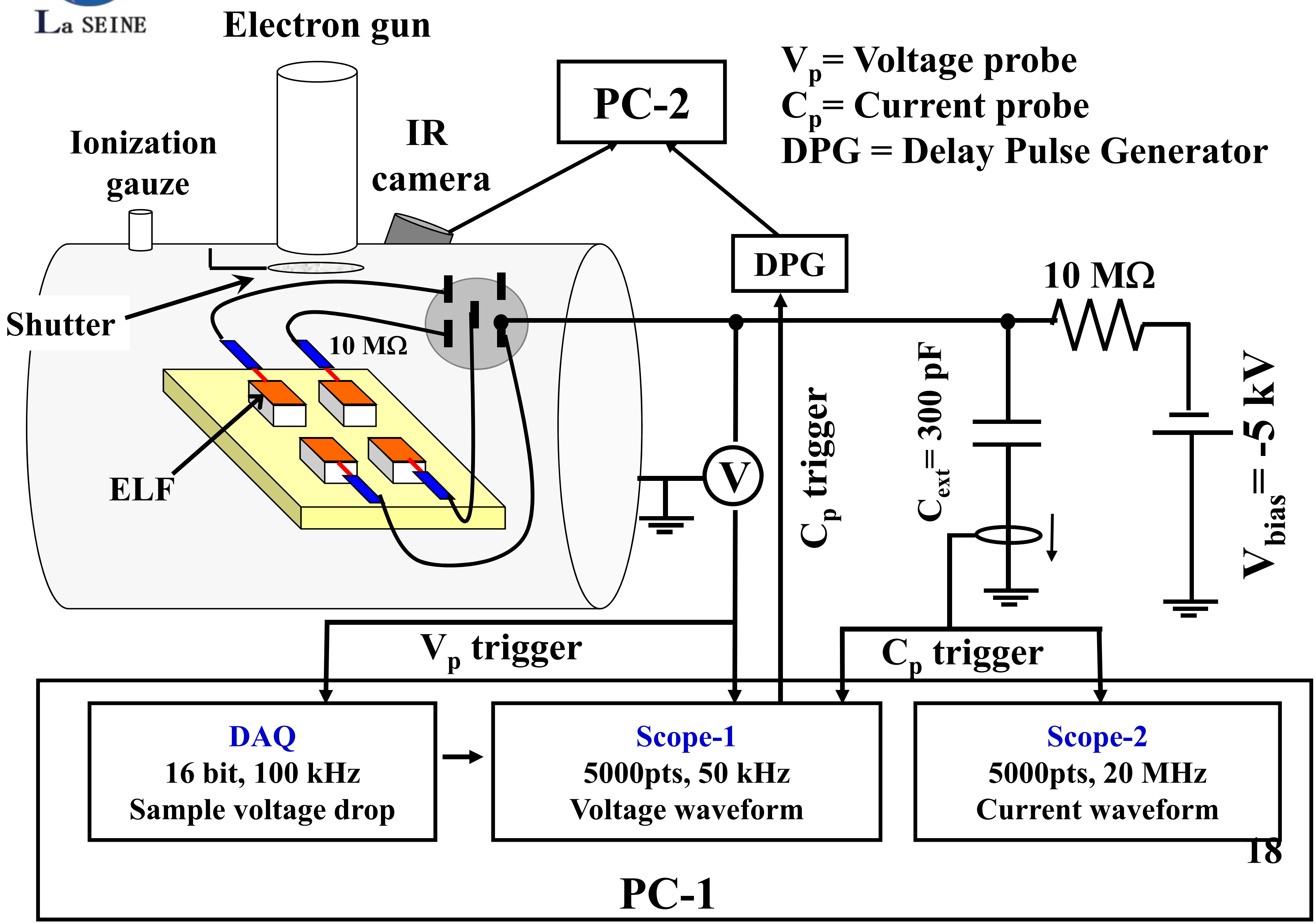


There are many active sites on this emitter surface that should emit electrons

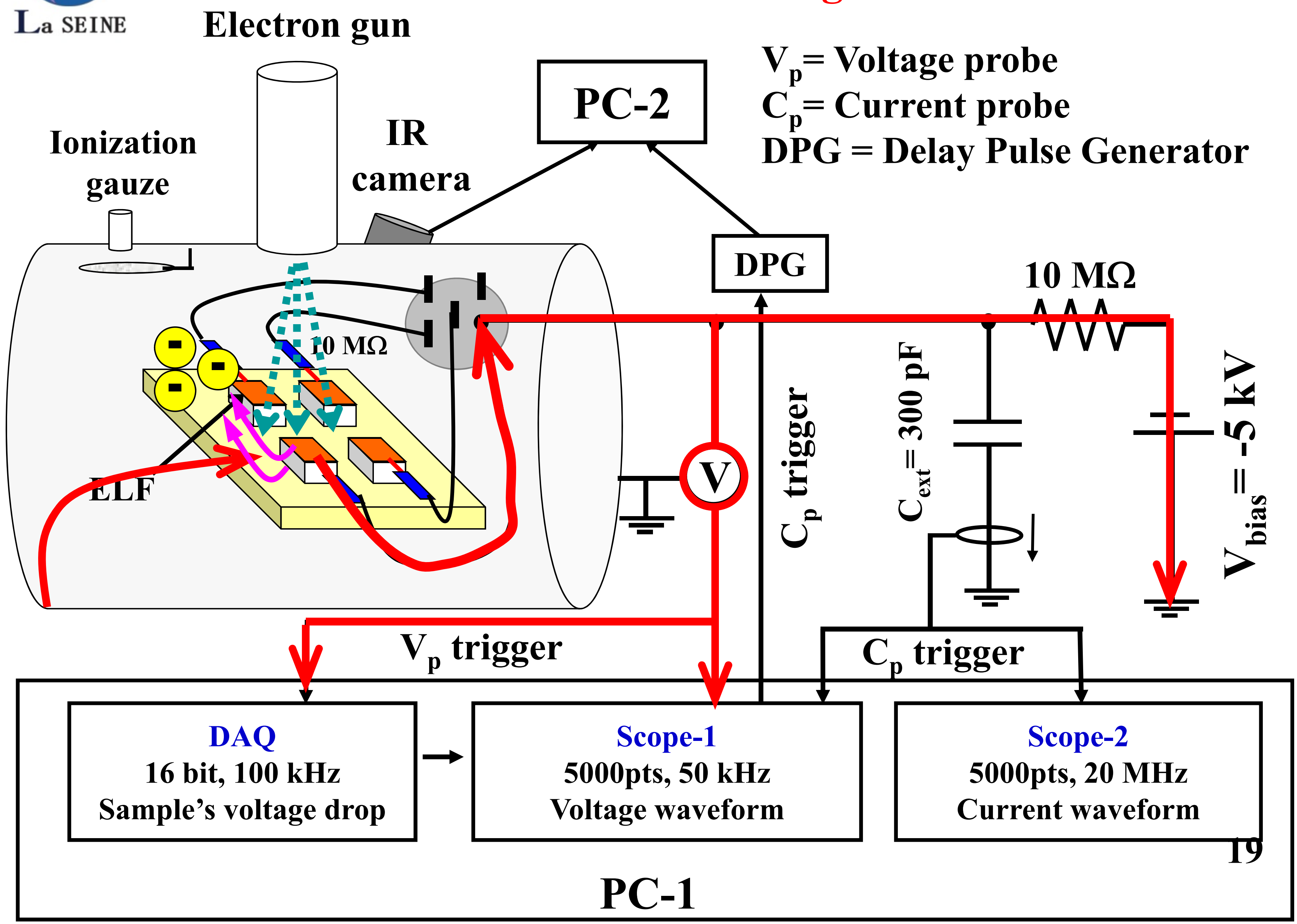
La SEINE

Electron emission from emitter (ELF)

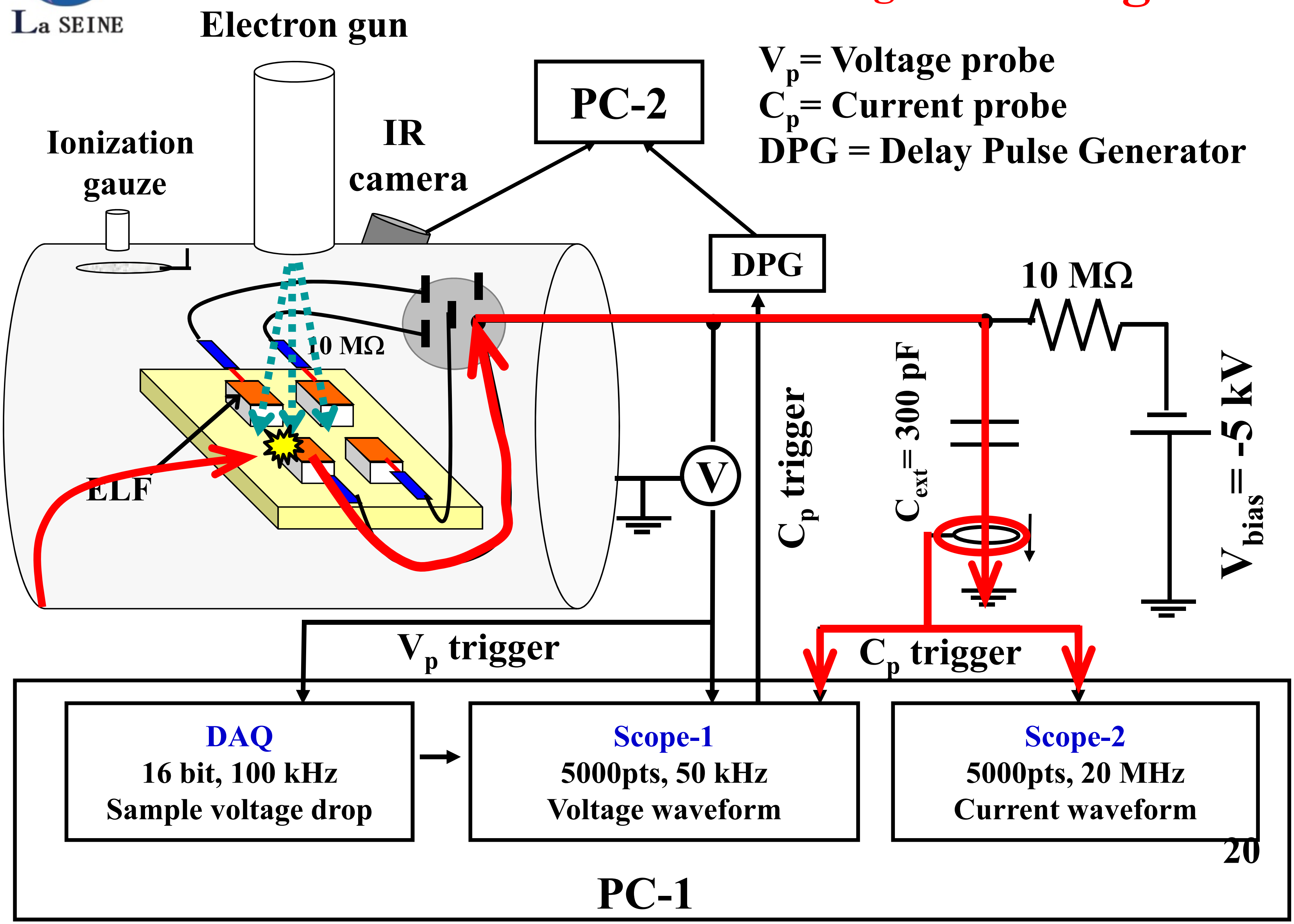
Experimental setup and electrical circuitry



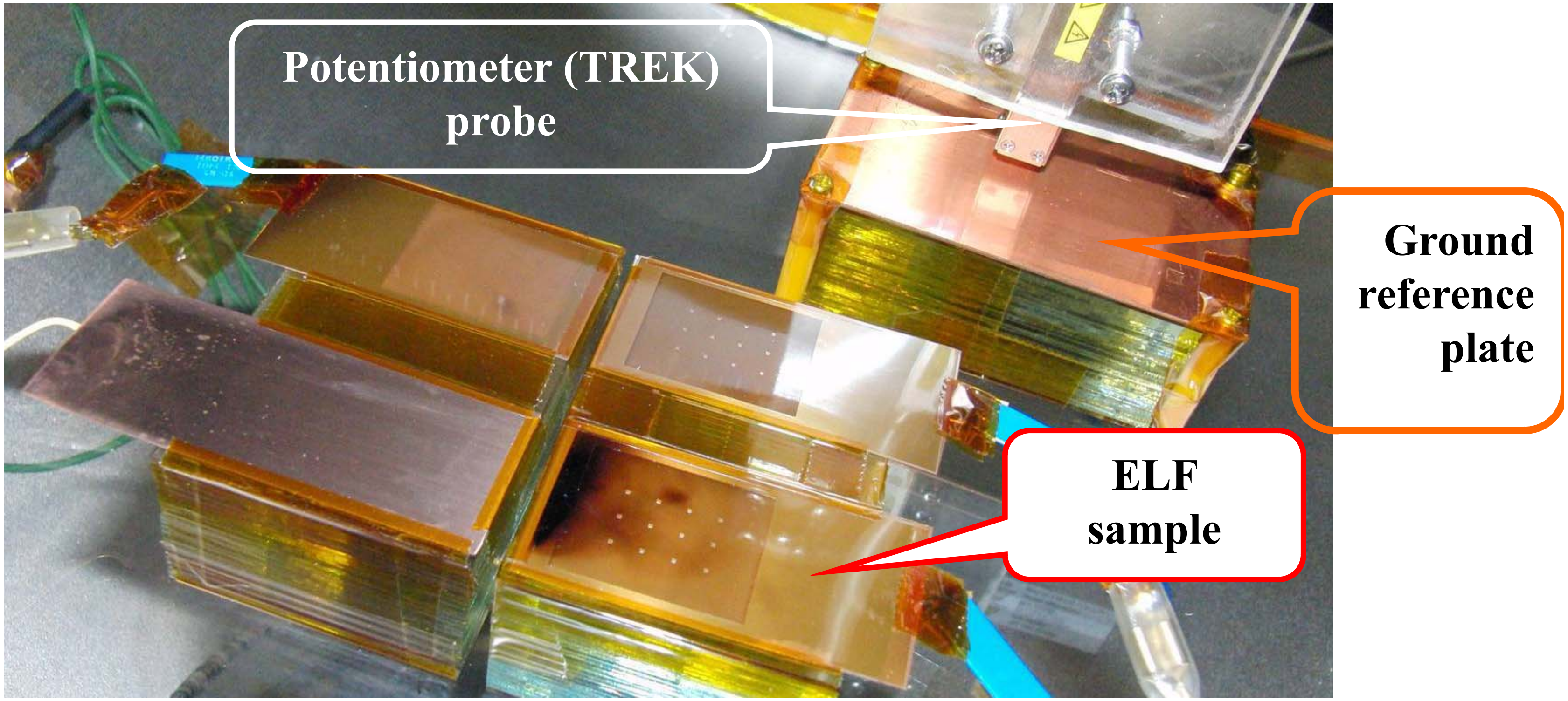
Current flow during Field emission



Current flow during Discharge



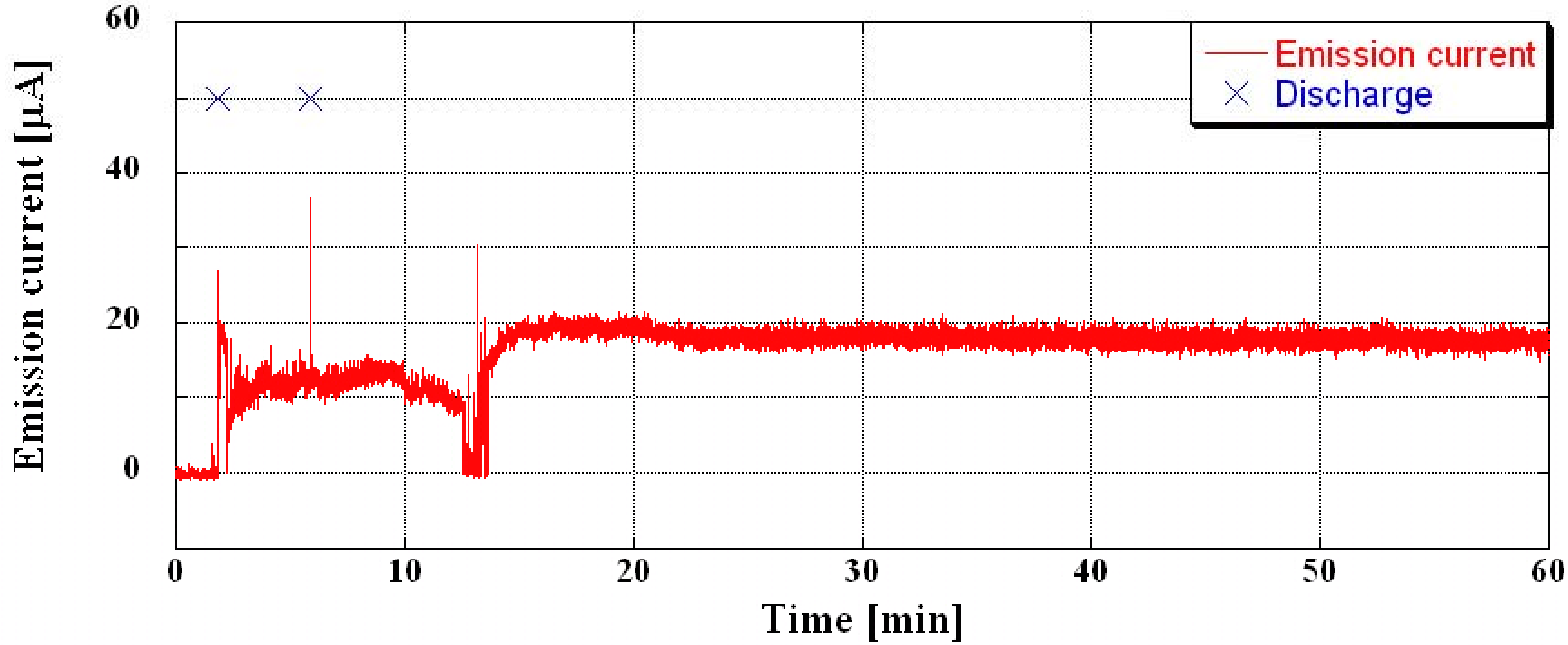
ELF in vacuum chamber



Experimental condition

Pressure : 4~6 x 10^{-4} Pa
Sample Bias = - 5.0 kV
Beam Energy = 5.5 keV
Beam current = 50 μA

Continuous Emission from ELF

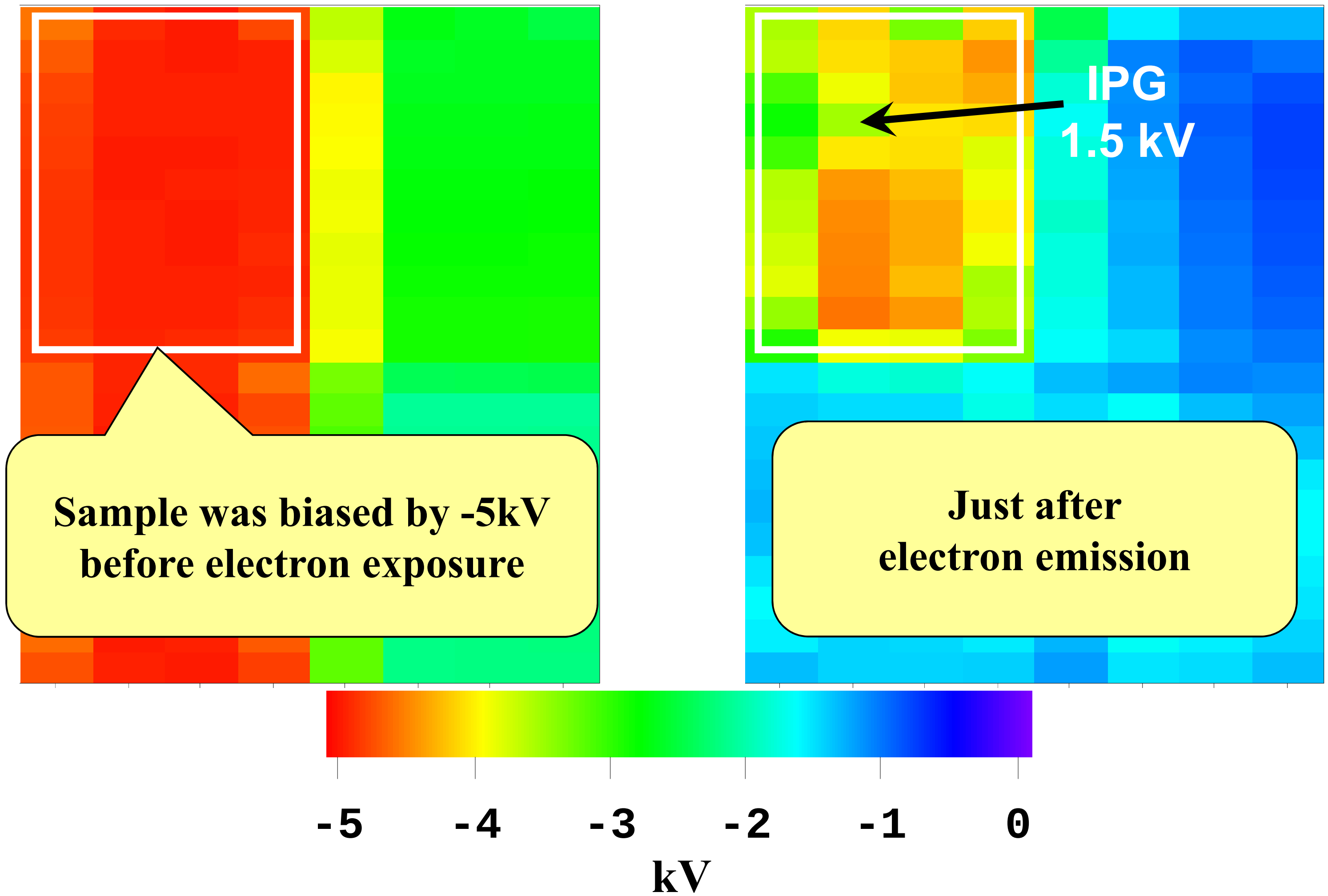


Continuous 9 hours emission is also confirmed

To check the emission longevity (Endurance), recently accumulated 100 hours emission is completed and result is submitted for publication to *Journal of Spacecraft and Rocket*

Surface potential distribution

(before and after emission)



During emission, IPG is confirmed as well

Vital parameters
(must be examined)

- Contamination effect
- Emission longevity (100 hours)

Checked and passed

- Environmental durability
  1. High energy Proton and Electron effect (10 solar years equivalent)
  2. Effect of Thermal cycling (10 solar years equivalent)
  3. Effect of VUV irradiation (10 solar years equivalent)

Environmental durability

Effect of high energy
Proton and Electron irradiation
(10 solar years equivalent)

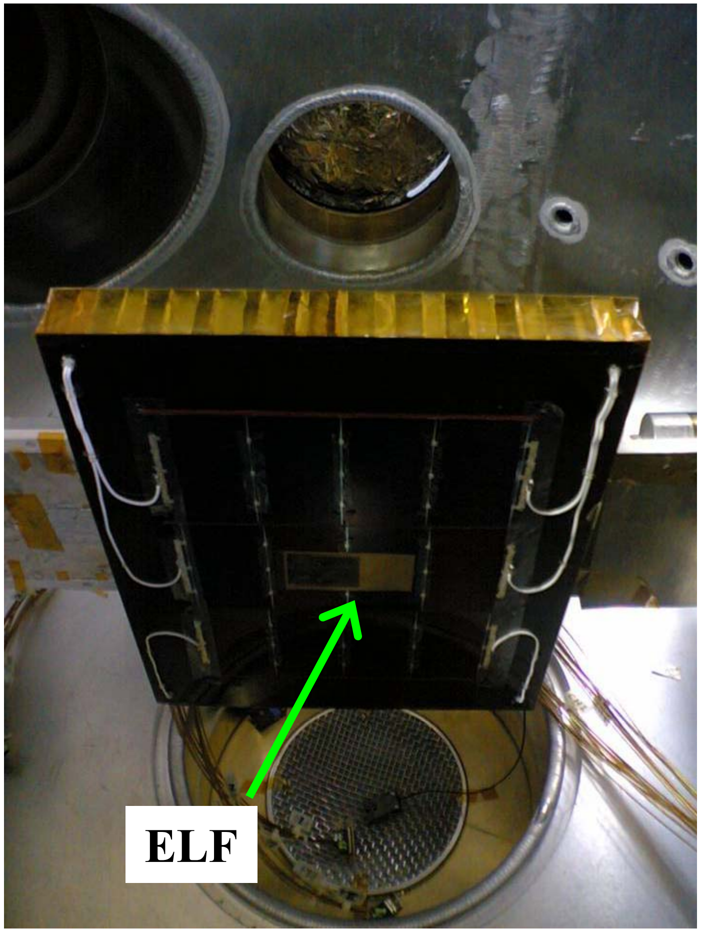
Proton and Electron irradiation

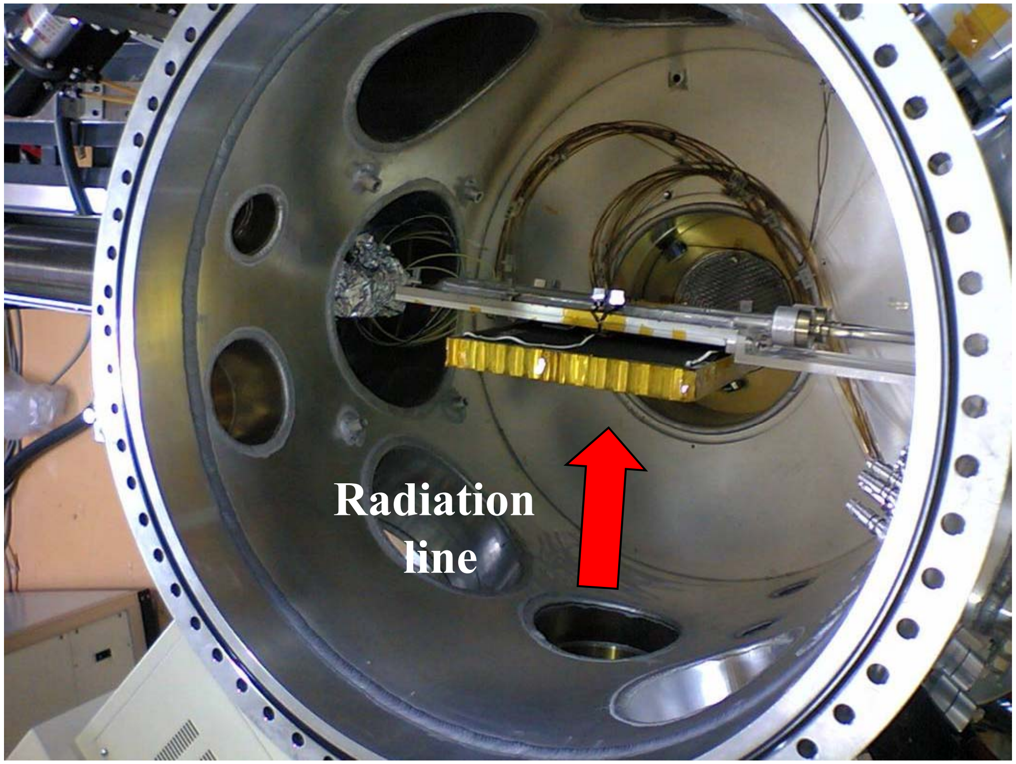
Experimental condition (equivalent to 10 years)

- Dosing time : 800s
- Proton fluence: $1x\ 10^{12}\ cm^{-2}$
- Proton energy : 10 MeV
- Electron fluence: $1x10^{16}\ cm^{-2}$
- Electron energy : 1 MeV
- Scan area : $10x10\ cm^2$
- Pressure : $\sim 10^{-4}$ Pa

Performed in Japan Atomic Energy Agency (JAEA)

ELF in the irradiation chamber

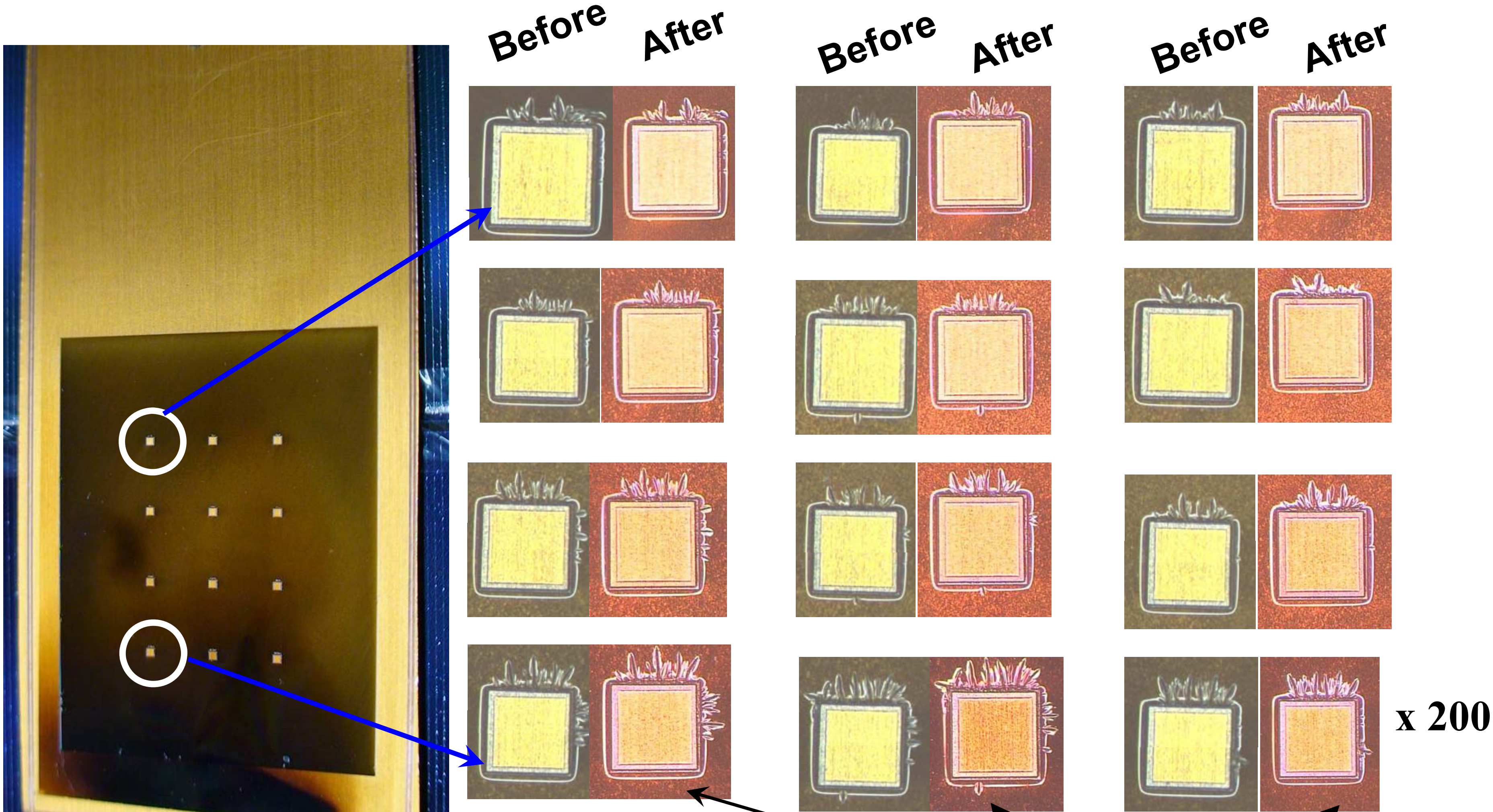




Performed in Japan Atomic Energy Agency (JAEA)

Microscopic pictures

(after 100 hrs Endurance and Proton irradiation test)

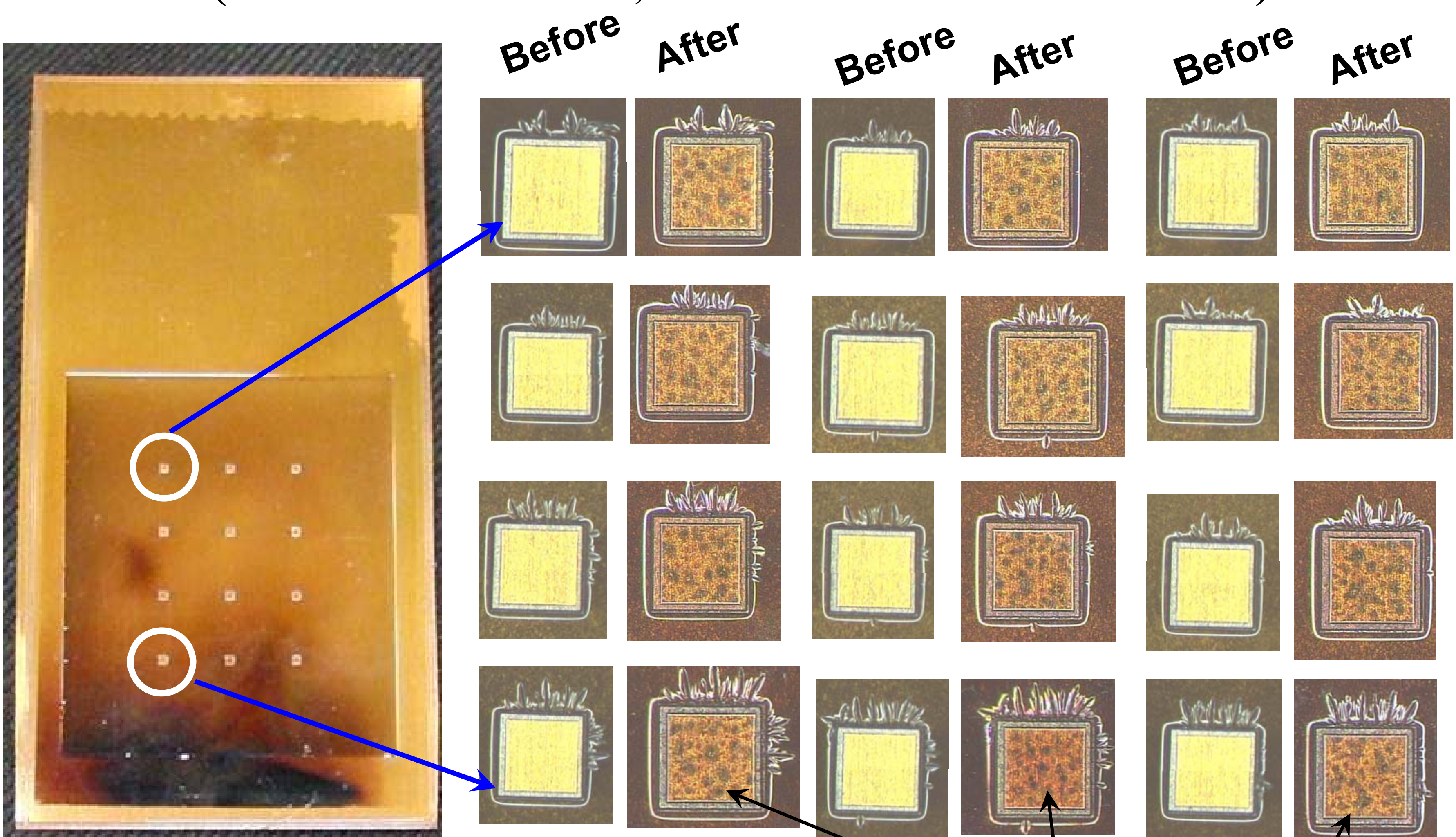


Area around Triple Junctions (TJ) found unaffected

Reddish due to outside light effect

Microscopic pictures

(after 100 hrs Endurance, Proton and Electron irradiation test)



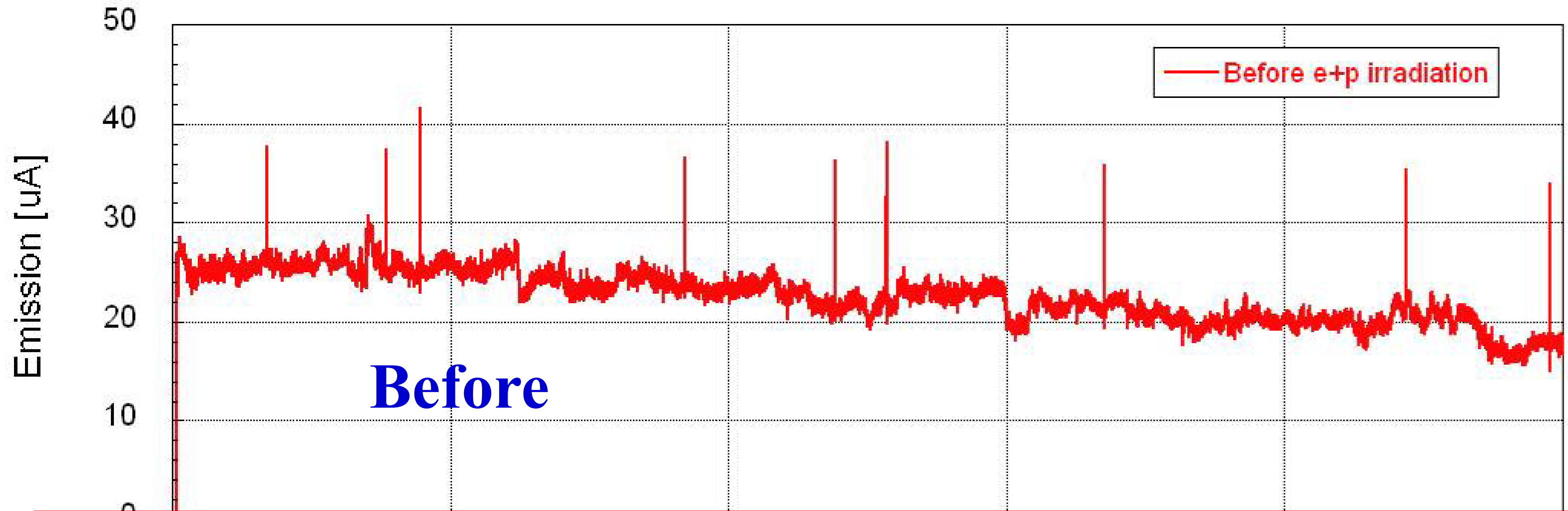
Area around Triple Junctions (TJ) found unaffected

Black spots are due to electron

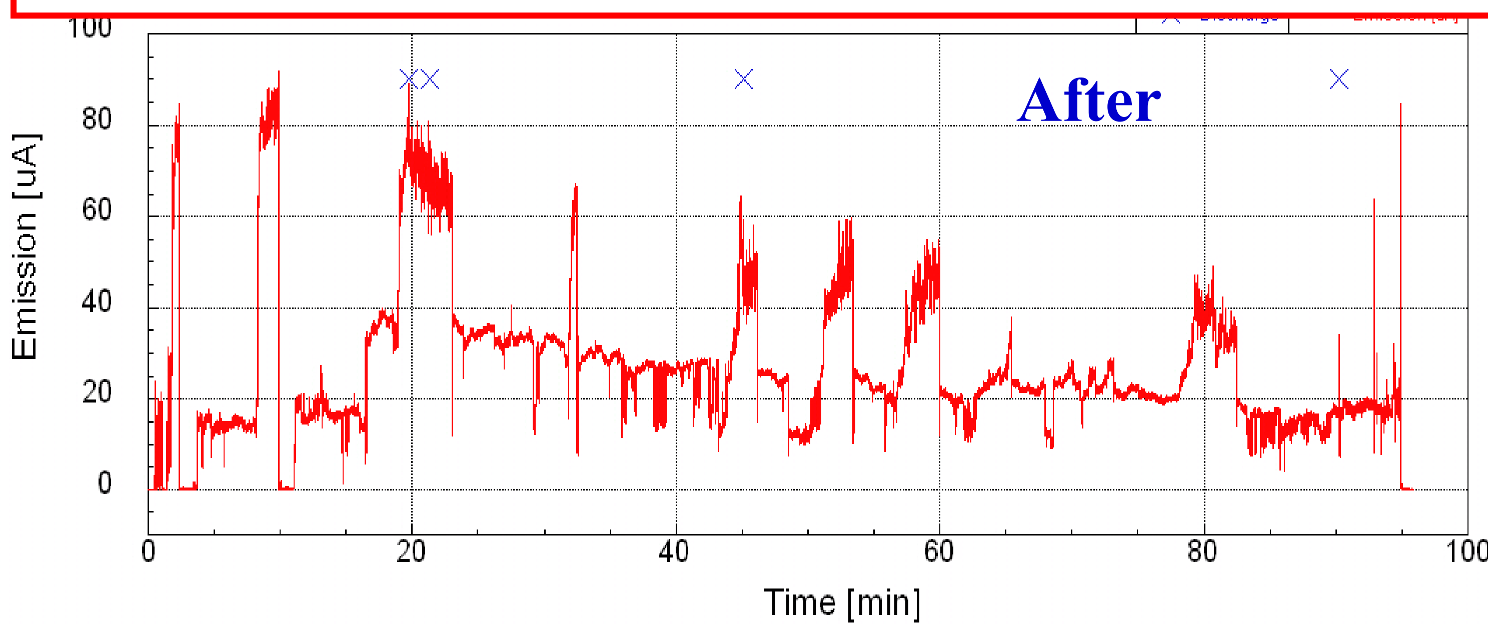
x 200

Emission comparison

(before and after Electron, Proton irradiation)



There is no effect of high energy particles on this emitter



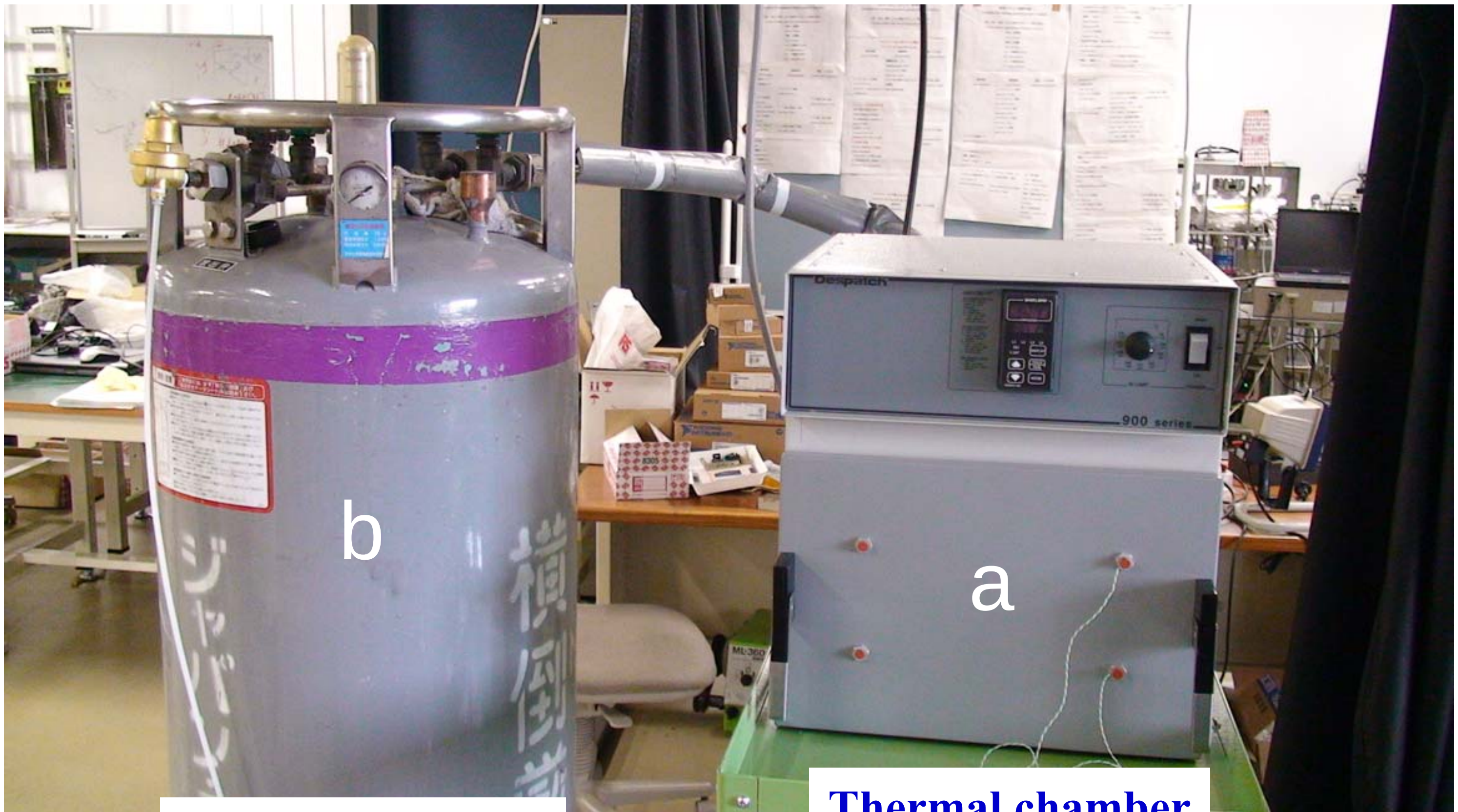
Environmental durability

Effect of

Thermal cycling

(10 solar years equivalent)

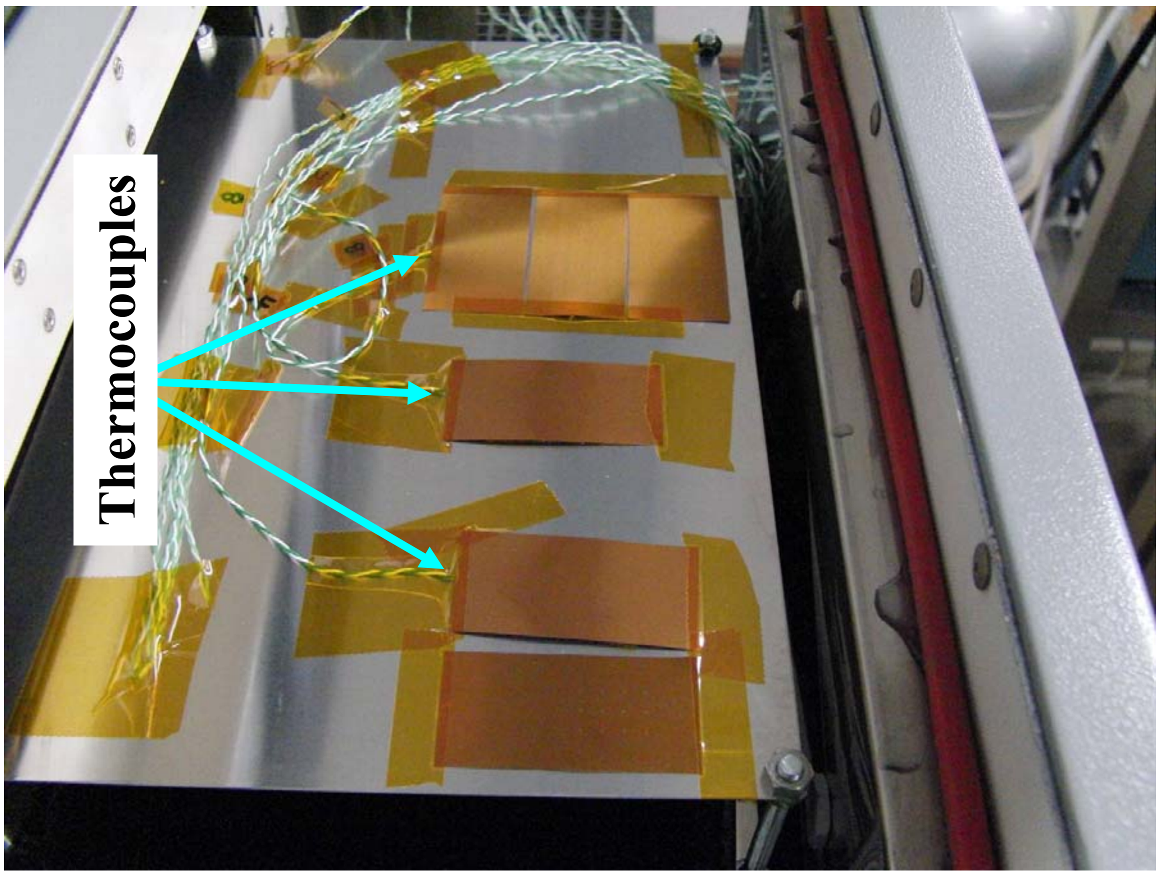
Thermal Cycling experiment



Liquid N_2 cylinder

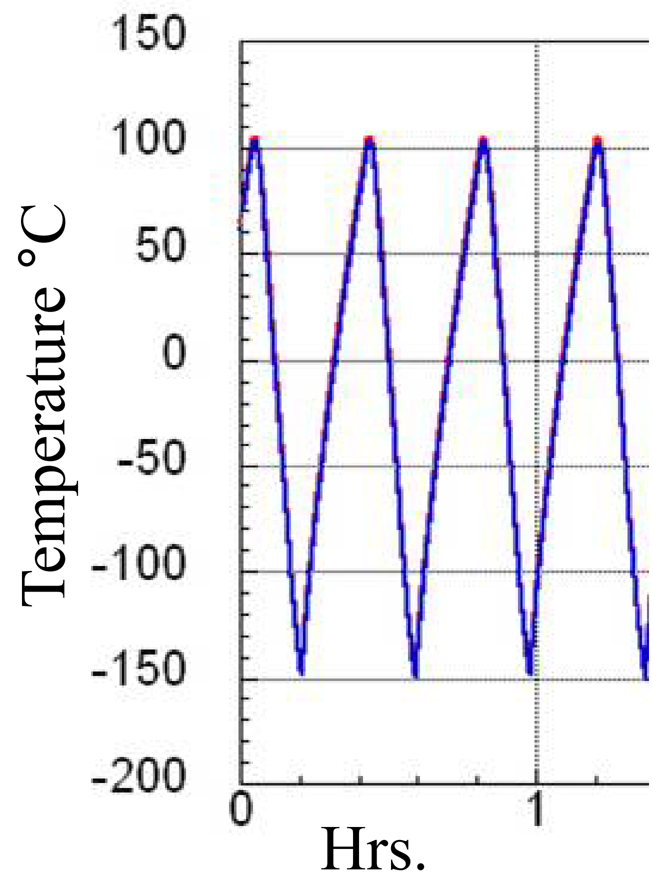
Thermal chamber

Experimental condition

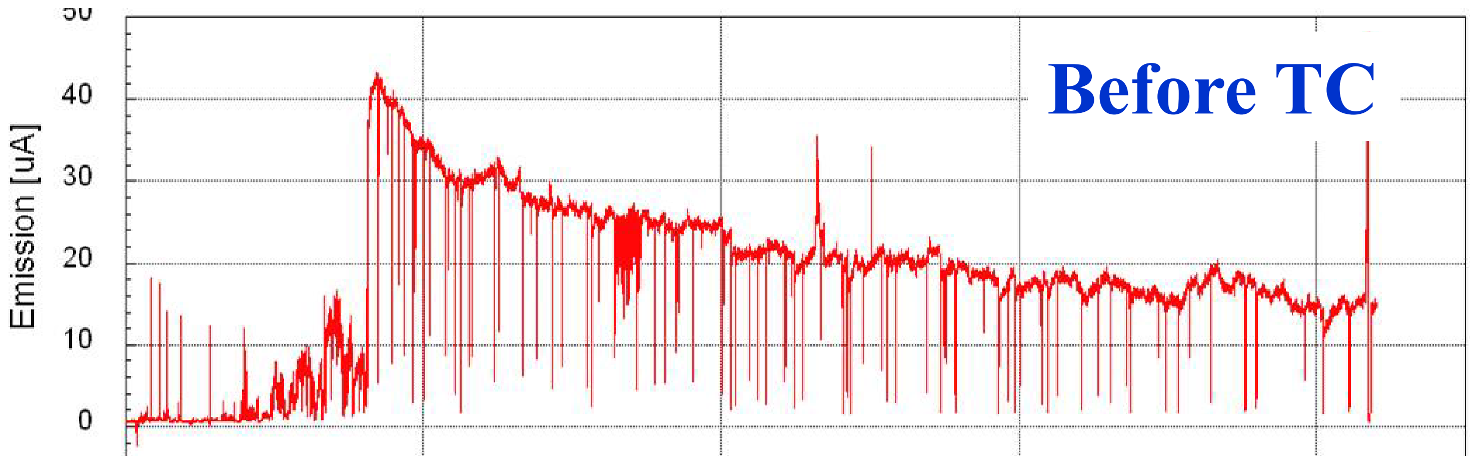


ELF arrangement inside TC chamber

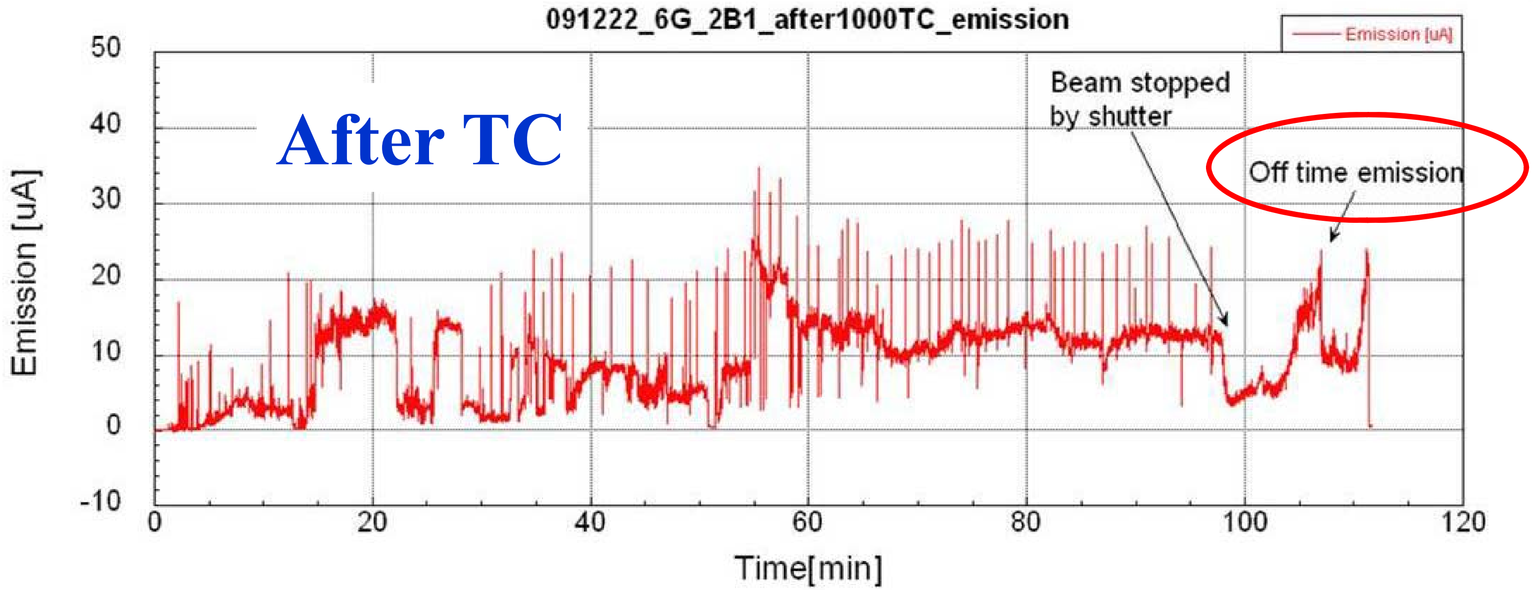
Max. temp: 100°C
Min. temp: -150°C
Rate: 20°C/min
Total cycles done: 1018



Emission comparison
(before and after TC)



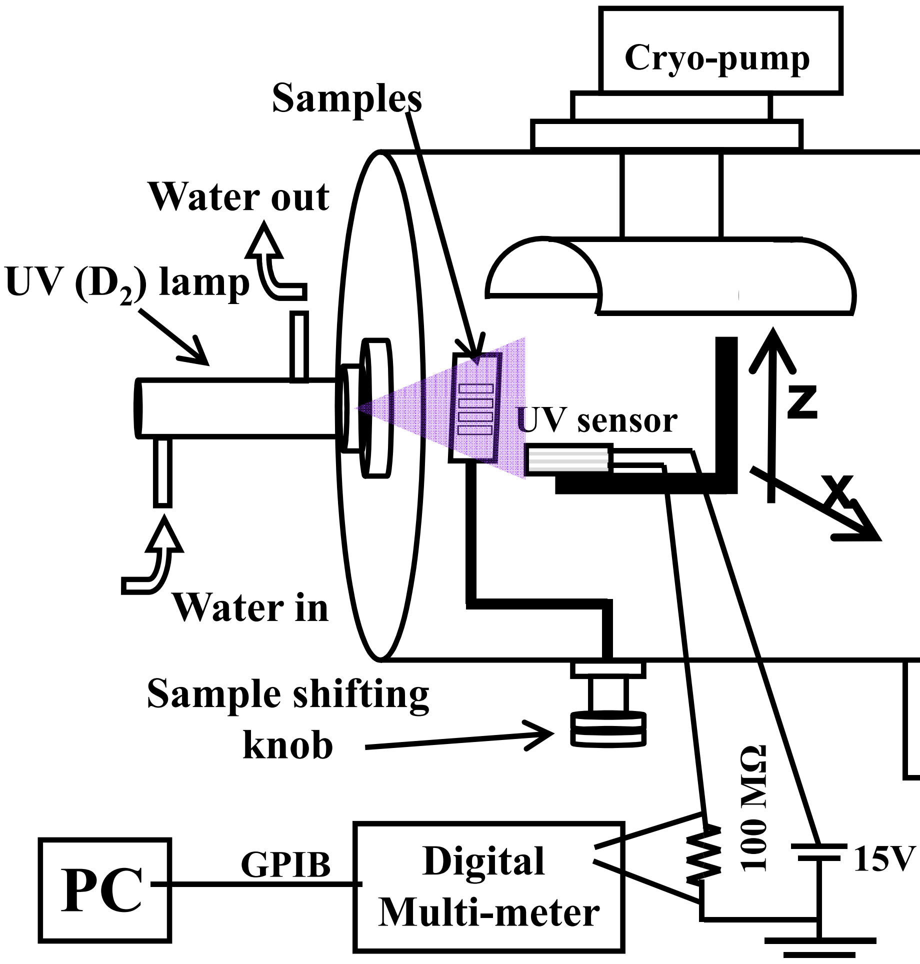
There is no effect of thermal cycling on this emitter

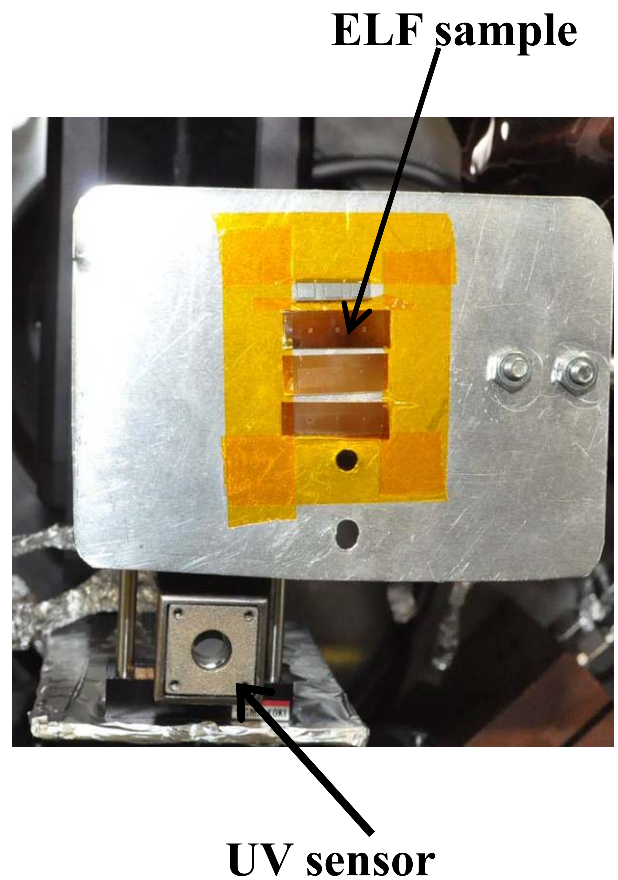


Environmental durability

Effect of
VUV irradiation
(10 solar years equivalent)

VUV irradiation





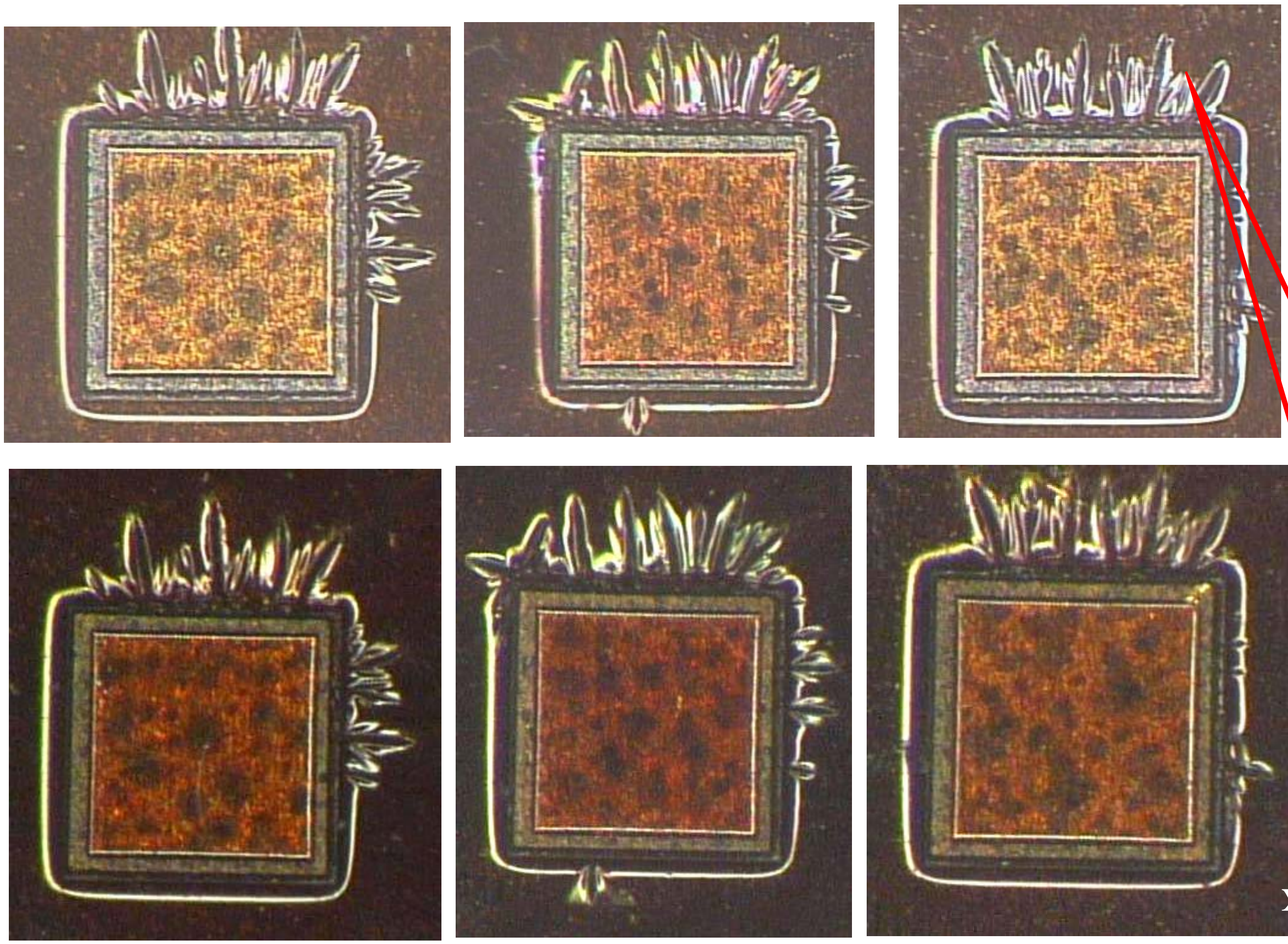
$$\text{Equivalent Solar Hour} = \int_0^{2480.8} Sc(t)dt = 88014.87\ hrs$$

= 10.04 yrs

Effect of VUV irradiation
(around triple junctions)

Before

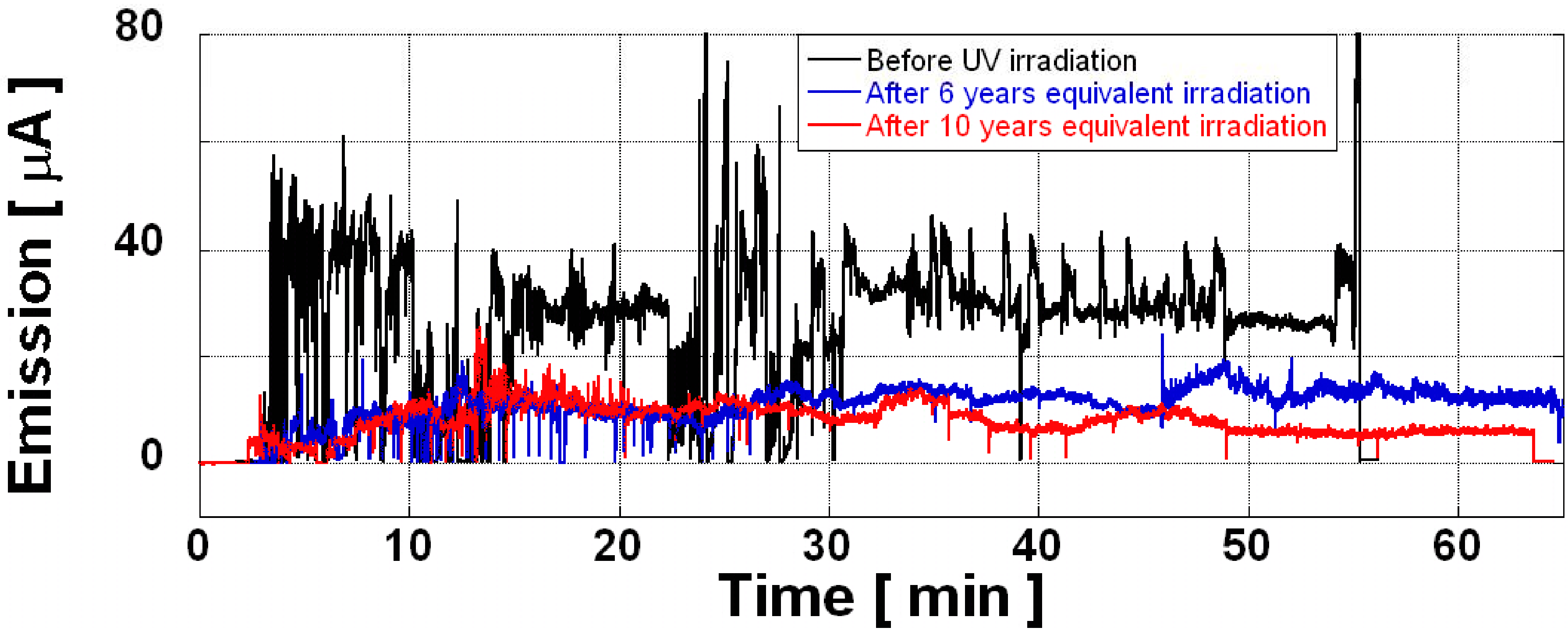
After



Formed during patterning not due to other effect while doing experiment

No visual damage seen

Effect of VUV on emission



Although the emission level reduced with time, after 10 years equivalent solar exposure, this emitter is still active.

Conclusion

After high energy Proton and Electron irradiation, thermal cycling and VUV irradiation experiments equivalent to 10 solar years,

- No physical damage is found
- Little emission level deterioration is observed
- Emitter is still active.

Therefore, this electron emitting film is durable and resistance to those harsh space environments.

Future tasks

- Checking the emission longevity for longer period around 600 hours.
- Checking the effectiveness of ELF after setting on solar panel and measuring the discharge on it whether ELF help reduce discharge or not.
- Improving emission level (e.g.by changing the film materials, etching pattern, thickness, roughness, etc.)
- Finding the mechanism, cause of off-time emission, role of other parameters (e.g.UV, beam current density, surface roughness, etc.) on emission of this emitter.
- Flight demonstration: HORYU-2 (KIT student satellite)

Thank you