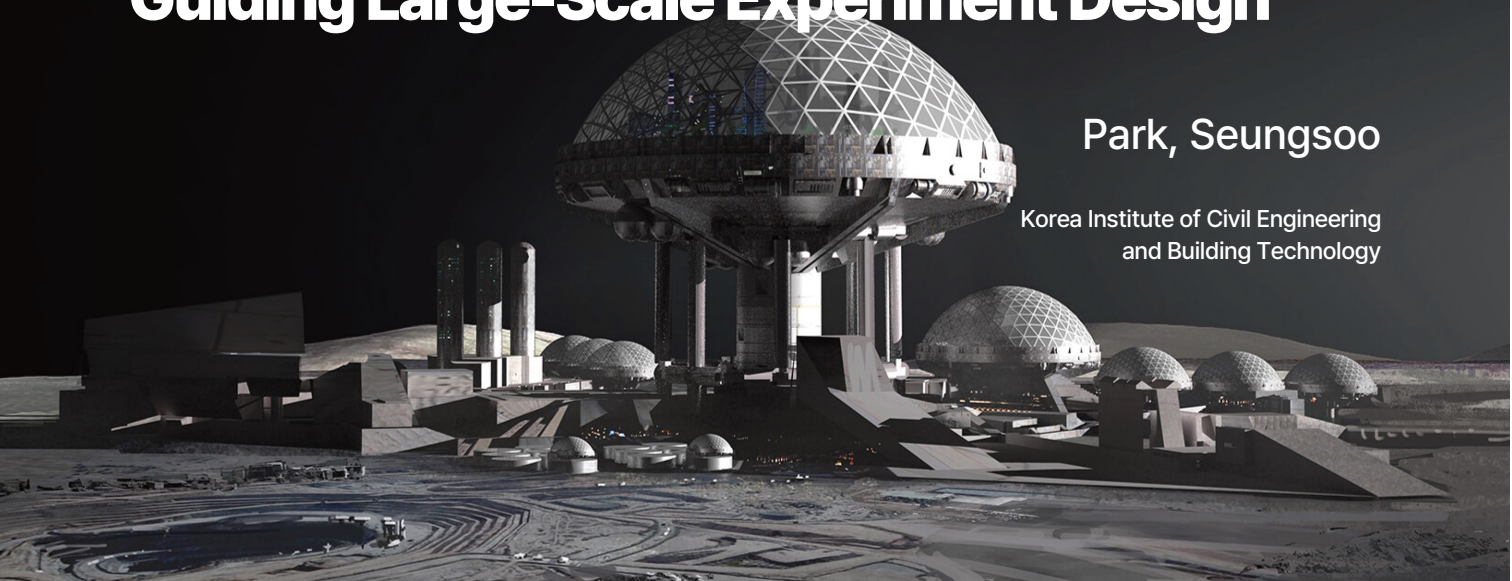
KICT 한국건설기술연구원
KOREA INSTITUTE of CIVIL ENGINEERING and BUILDING TECHNOLOGY

2023-06-07
XXIII Space Resources Roundtable @ Colorado School of Mines

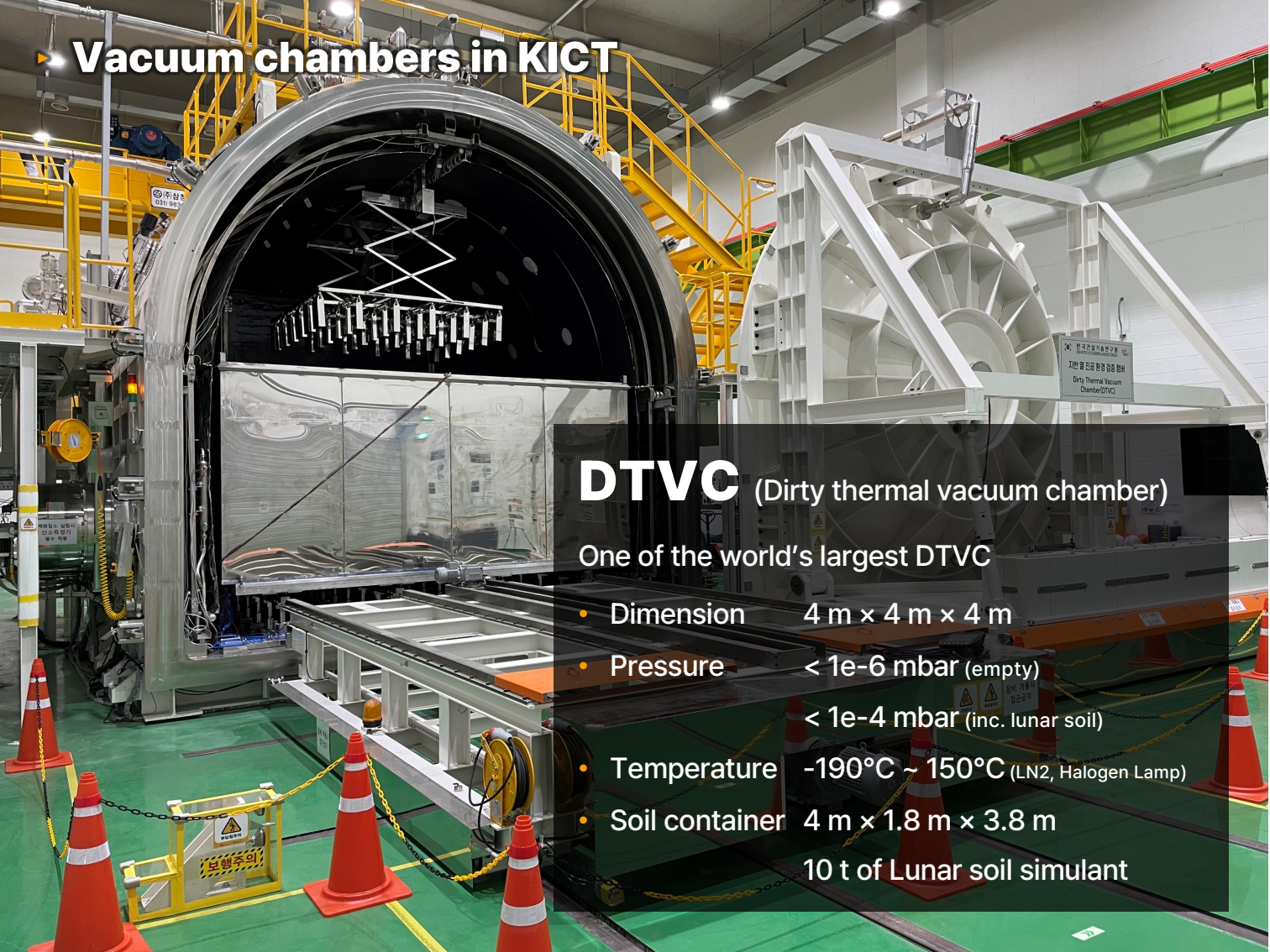
Photoelectric Current Density Measurement for Lunar Daytime Simulation: Guiding Large-Scale Experiment Design



Park, Seungsoo

Korea Institute of Civil Engineering
and Building Technology

Vacuum chambers in KICT

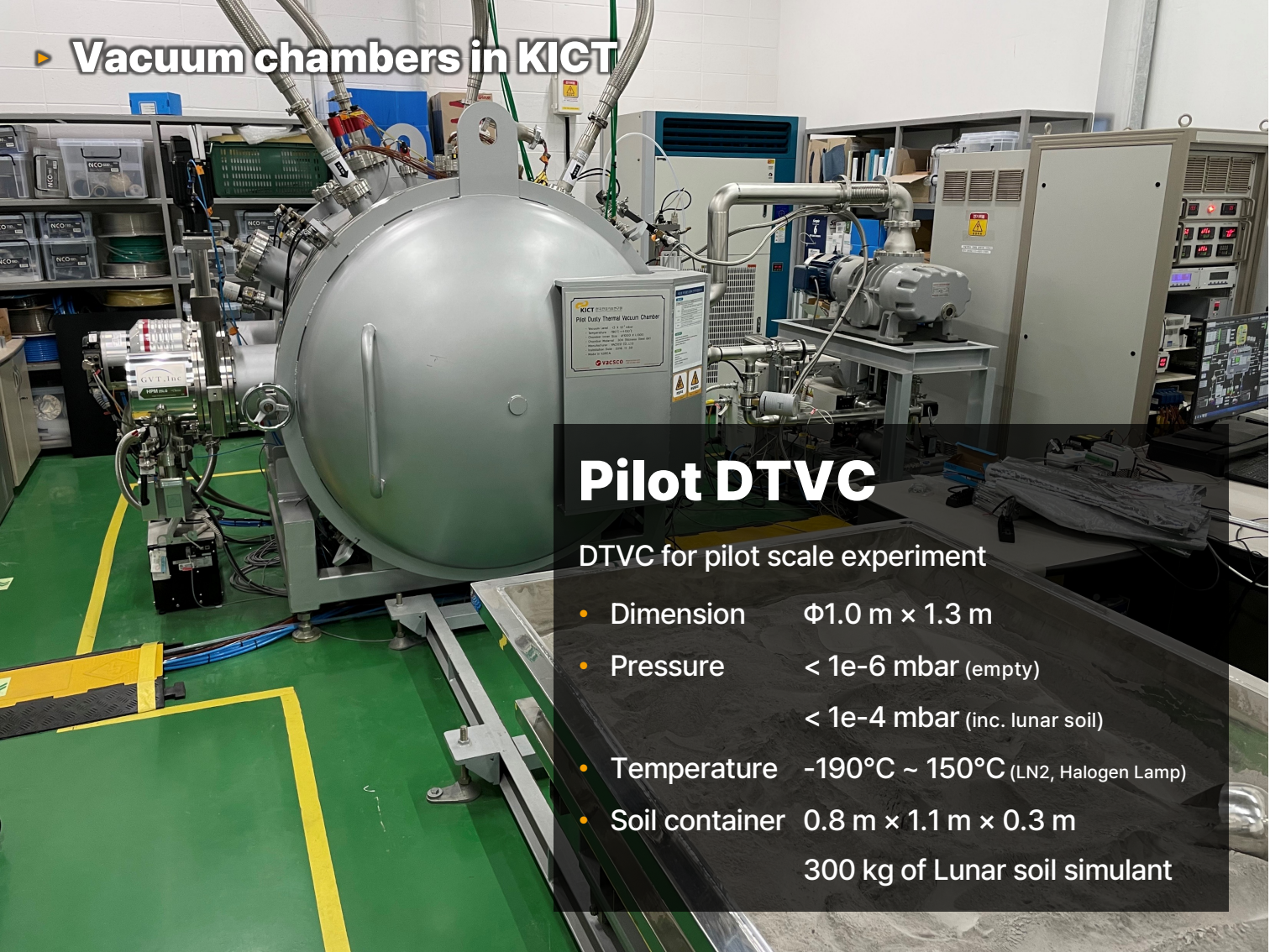


DTVC (Dirty thermal vacuum chamber)

One of the world's largest DTVC

- Dimension 4 m × 4 m × 4 m
- Pressure < 1e-6 mbar (empty)
  < 1e-4 mbar (inc. lunar soil)
- Temperature -190°C ~ 150°C (LN2, Halogen Lamp)
- Soil container 4 m × 1.8 m × 3.8 m
  10 t of Lunar soil simulant

Vacuum chambers in KICT



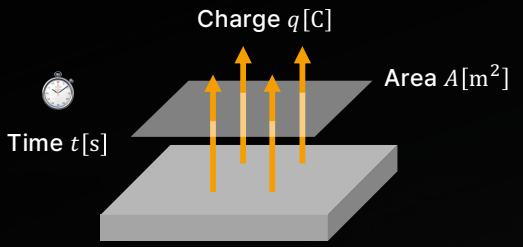
Pilot DTVC

DTVC for pilot scale experiment

- Dimension Φ1.0 m × 1.3 m
- Pressure < 1e-6 mbar (empty)
  < 1e-4 mbar (inc. lunar soil)
- Temperature -190°C ~ 150°C (LN2, Halogen Lamp)
- Soil container 0.8 m × 1.1 m × 0.3 m
  300 kg of Lunar soil simulant

Introduction

- Photoelectron, J_p
  - Photo electrons emitted from the lunar surface due to solar UV
- Electron in solar wind plasma, J_e
  - Electrons supplied from the plasma
- Ion in solar wind plasma, J_i
  - Ions supplied from the plasma
- Secondary electron, J_s
  - Secondary electrons emitted by photoelectrons or plasma electrons



"Charge movement per unit time per unit area"
"Electric current per unit area"

$J = q/(t \cdot A)$ [C/s · m^2] or [A/m^2]

Fig. Conceptual graphic of current density

Fig. The main electric current sources that charge the lunar surface

Introduction

- Purpose of the study
  - Designing photoelectric current measuring unit(PCMU) to quantify the current I_p
  - Acquiring the photoelectric current density J_{pm} from I_p
  - Validating if the measured number is reasonably correct or not.

    (Calculate J_{pc} of given experiment condition, i.e., light source and sample material information)
  - Hopefully, $J_{pm} \approx J_{pc}$.

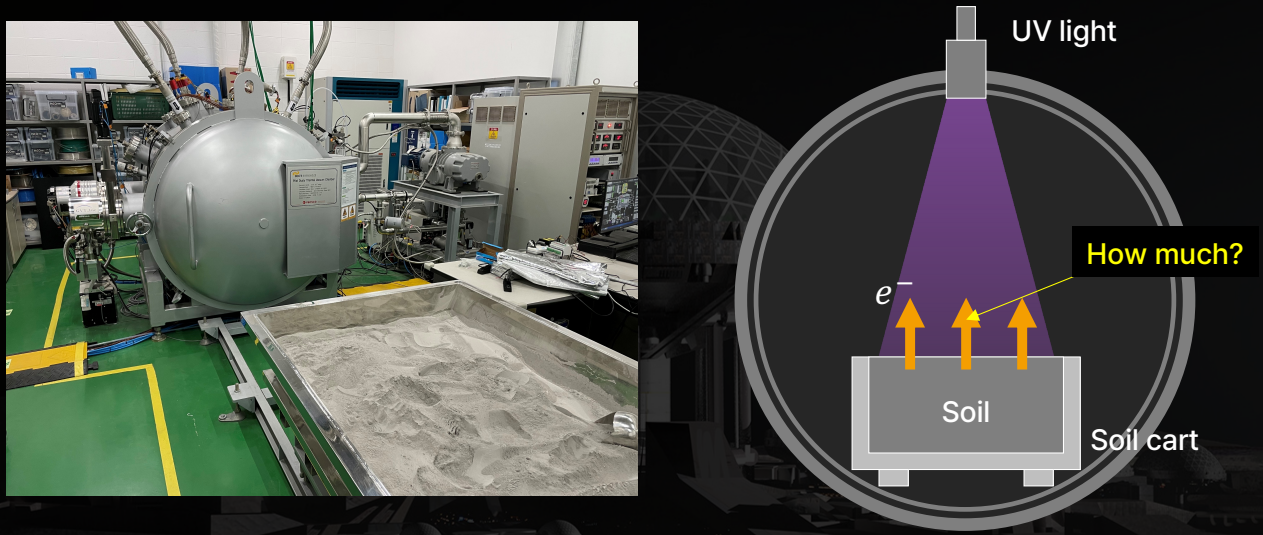
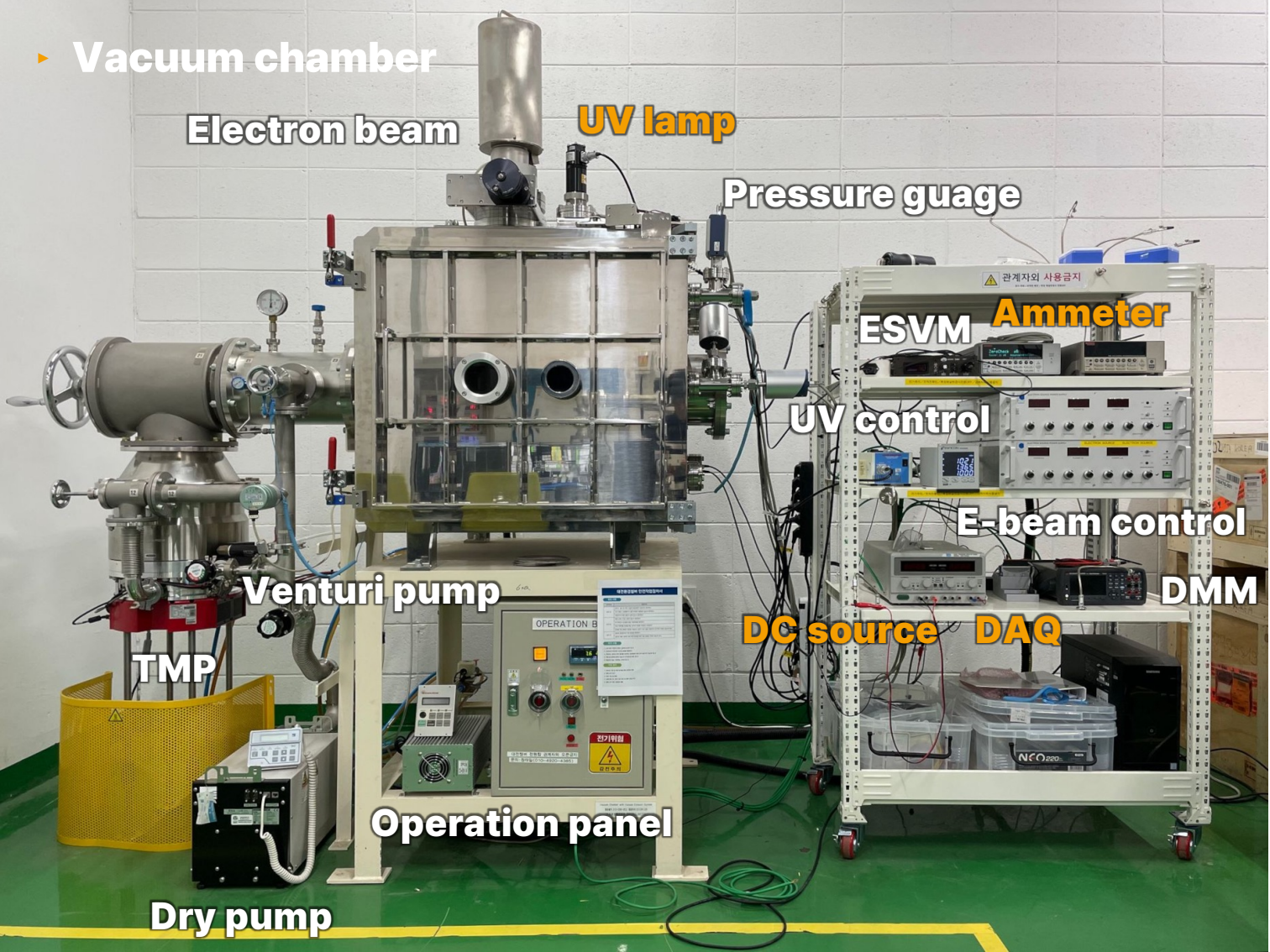


Fig. Photograph of pilot-scale DTVC and a conceptual graphic of the chamber equipped with UV light and soil cart

Vacuum chamber



Vacuum chamber

- Measurement configuration example
  - Simulateneous irradiation with ultraviolet and electron beam
  - Syncronized data acquisition (current, voltage, UV intensity, etc.)

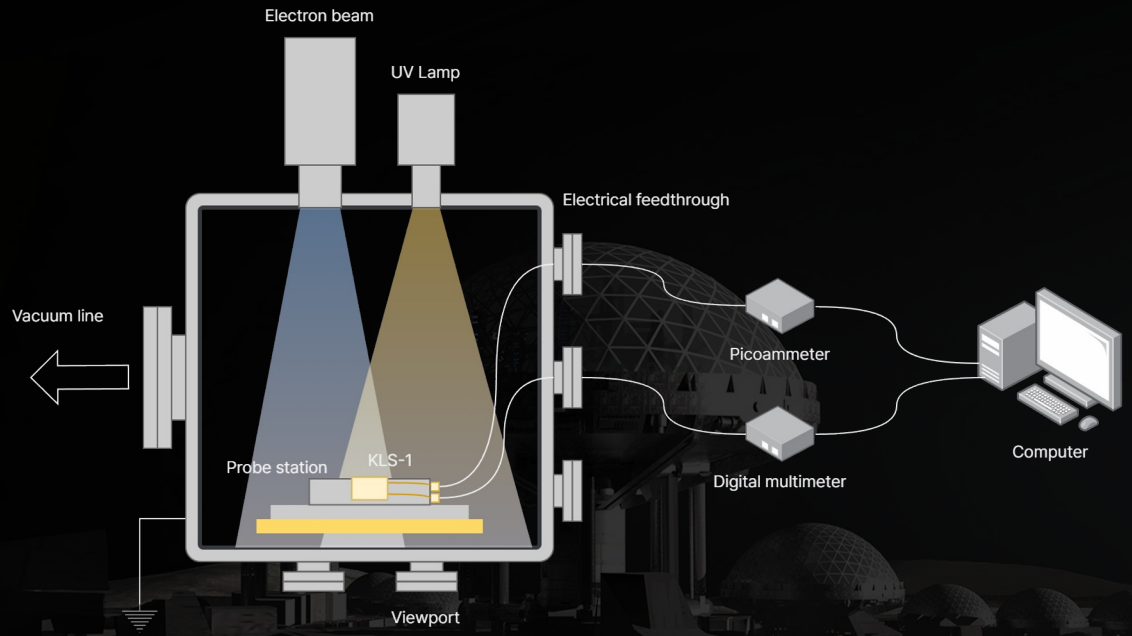


Fig. Configuration for measuring current and voltage from KLS-1 bed while irradiating UV light and electron beam

Light and material characteristics

- VUV source (Hamamatsu D2 lamp)
  - The most dominant wavelength is 160 nm
  - The work function of aluminum is 4.2 eV (295 nm, equivalent)

$$\lambda = \frac{hc}{\phi}$$

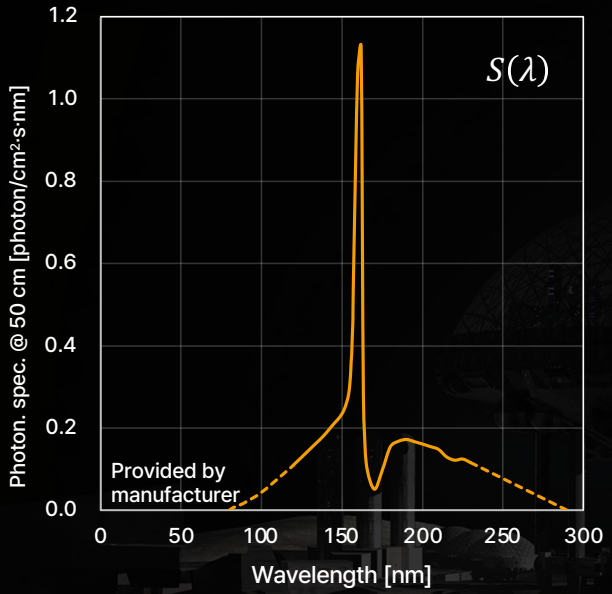


Fig. Photon emission spectrum of UV lamp
(The dashed line indicates the extrapolated values)

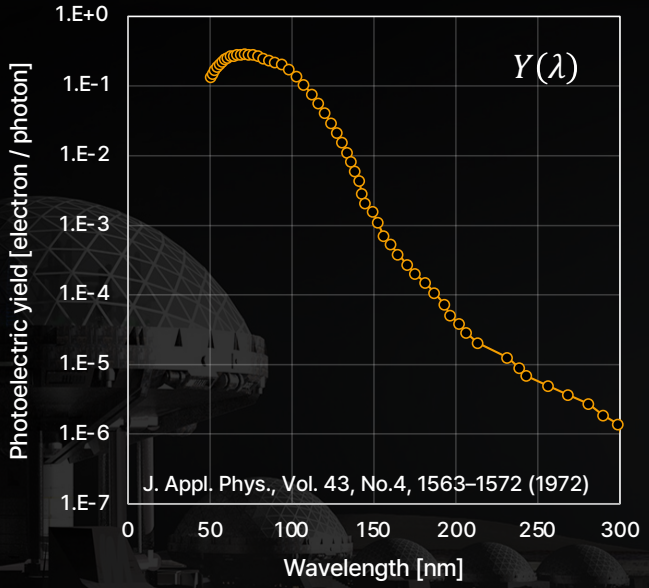
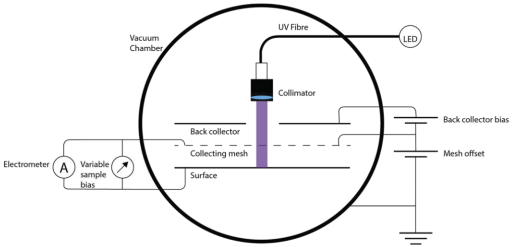


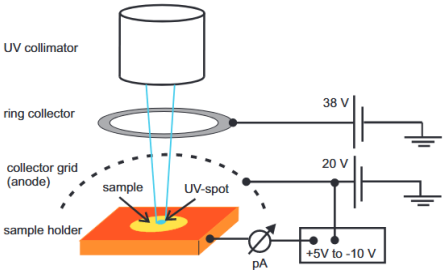
Fig. Photoelectric yield* of aluminum

*The probability of generating photoelectrons per absorbed or incident photon.

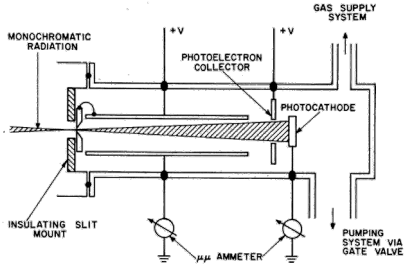
Motivations



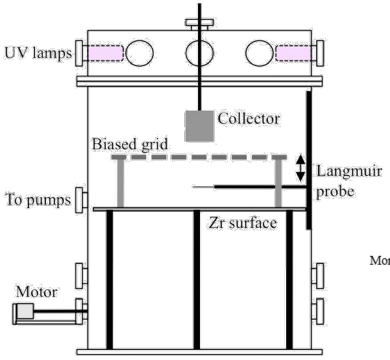
Rev. Sci. Instrum. 90, 064501 (2019)



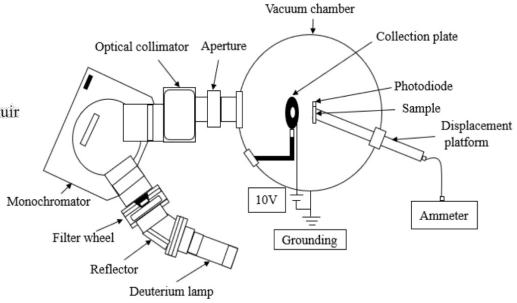
J. Appl. Phys. 111, 124914 (2012)



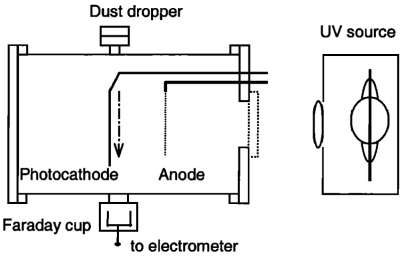
GCA Technical report No. 66-17-N (1966)



Phys. Plasmas 19, 043502 (2012)

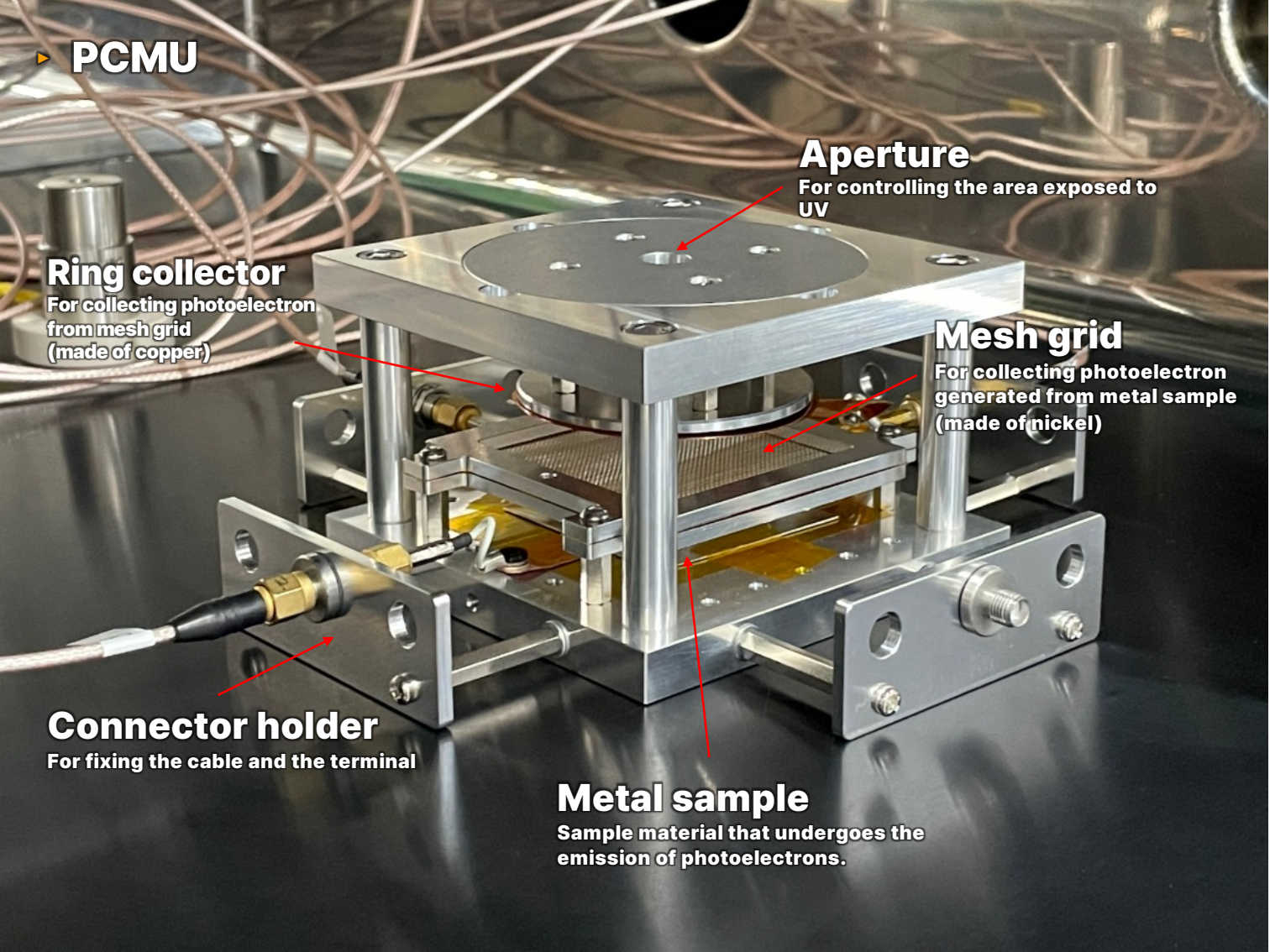


ICSMD, pp. 148-151 (2020)



J. Geophys. Res. 160, 8343-8356 (2001)

PCMU


Aperture
For controlling the area exposed to UV
Ring collector
For collecting photoelectron from mesh grid (made of copper)
Mesh grid
For collecting photoelectron generated from metal sample (made of nickel)
Connector holder
For fixing the cable and the terminal
Metal sample
Sample material that undergoes the emission of photoelectrons.

PCMU

- How it works
  1. UV light irradiates from the top of the chamber
  2. A consistent amount of light is irradiated as it passes through the aperture.
  3. The light irradiates on the metal sample, photoelectrons are emitted from the sample
  4. The generated photoelectrons are attracted to the positively charged mesh grid
  5. Electric current due to photoelectron flow is measured.

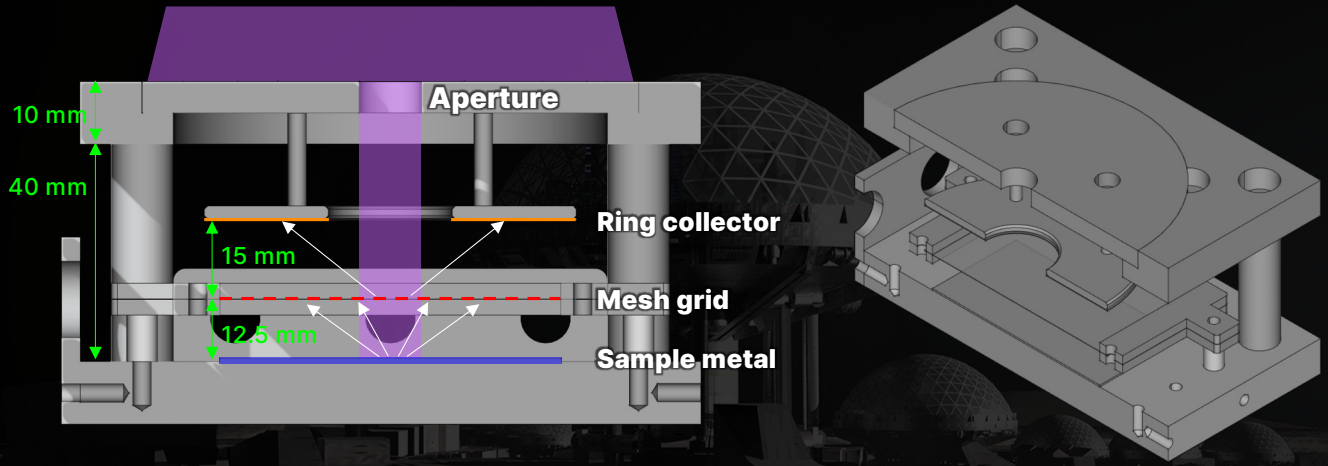


Fig. Cross-sectional view of the measurement unit with detailed parts:
(left) front view, (right) upper-right isometric view

Methods

- Configuration
  1. V_S Potential difference between mesh grid and sample metal $(\phi_m - \phi_s)$ -20 to 50V, ΔV = 1V
  2. V_m Potential difference between mesh grid and earth $(\phi_m - 0 = \phi_m)$ 0 to 30V, ΔV = 10V
  3. V_c Potential difference between ring collector and mesh grid $(\phi_c - \phi_m)$ 0 to 30V, ΔV = 10V
  4. I_p Electric current due to photoelectron moving from sample metal to mesh grid

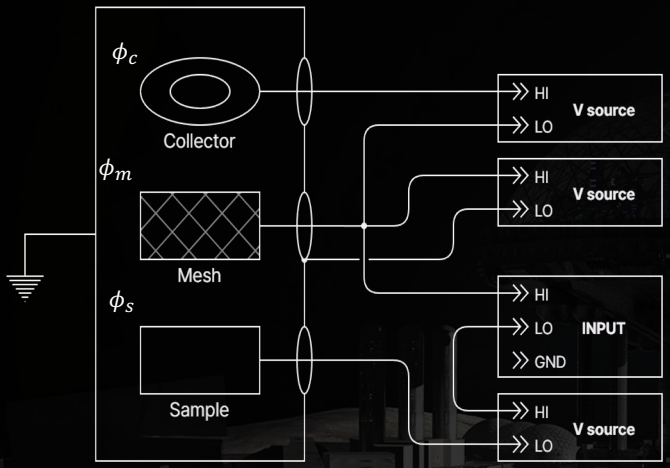


Fig. Wiring diagram

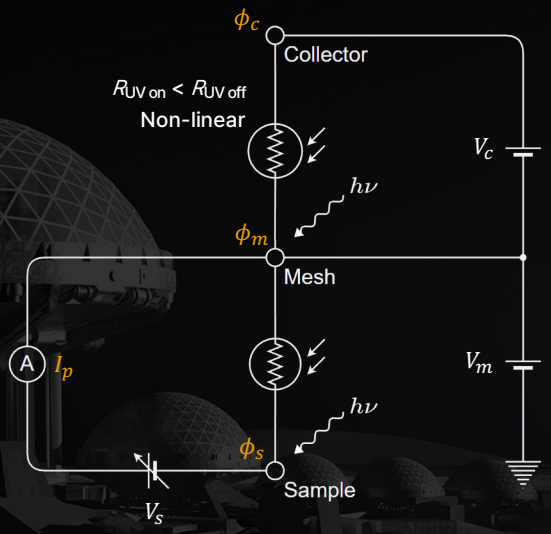


Fig. Equivalent circuit diagram

Methods

Experiment settings

Sample metal	Aluminum (Nilaco Corp., > 99.5% Al, thickness: 0.5t)
Mesh grid	Nickel (opening rate ≈ 70%)
Distance from the UV light source to the sample	800 mm
Area of UV exposure (Aperture size)	78.54e-6 m^2 (diameter = Φ10)
Pressure	< 5e-5 mbar
NPLC (Number of powerline cycle)	10
Number of experiments / each condition	5 (average value was taken)

Instruments

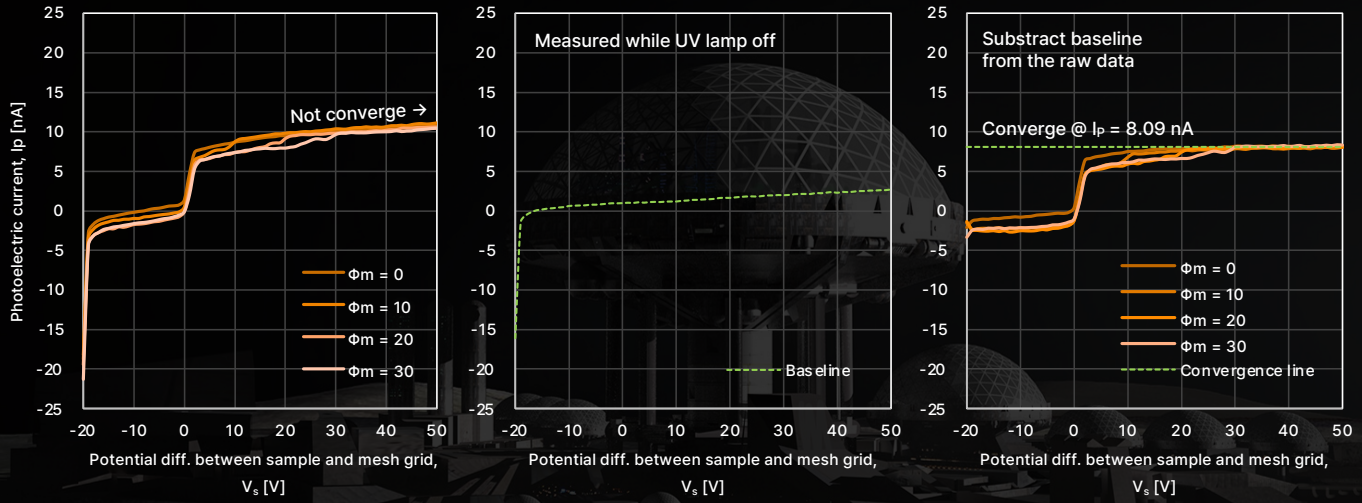
Photoelectric current I_p measurement	Keithley 6517B
Potential difference between sample and mesh V_S control	Keithley 6517B
Mesh grid potential $V_m (= \phi_m)$ control	GPC 6030D
Potential difference between mesh and ring collector V_C control	GPC 6030D
Data acquisition (DAQ)	National instruments NI-9205

Notes

- The sample aluminum was polished with lubricant (Pikal Care) for more than 3 minutes before the experiment.
- The unit was covered with MLI, while exposing the aperture only.

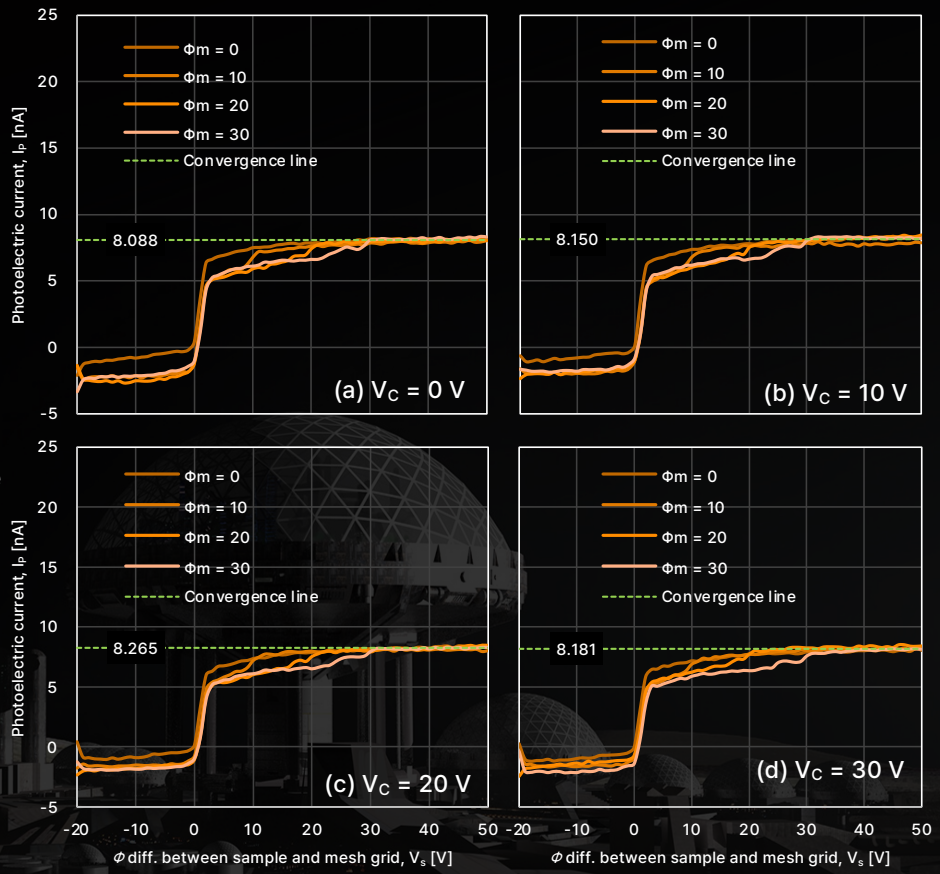
Result

- Photoelectric current measurement procedure
  1. Measured I_P (UV on) while incrementing V_S from -20 to 50 V
  2. Measured I_P (UV off) while incrementing V_S as a baseline data
  3. Substract 2. from 1. for the processed data
  4. Repeat 1 to 3 varying V_m from 0 to 30 V.
  5. Repeat 1 to 4 varying V_C from 0 to 30 V.



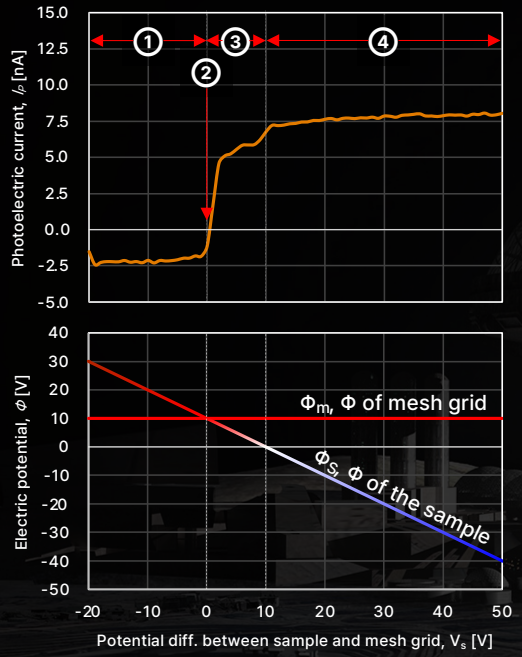
Result

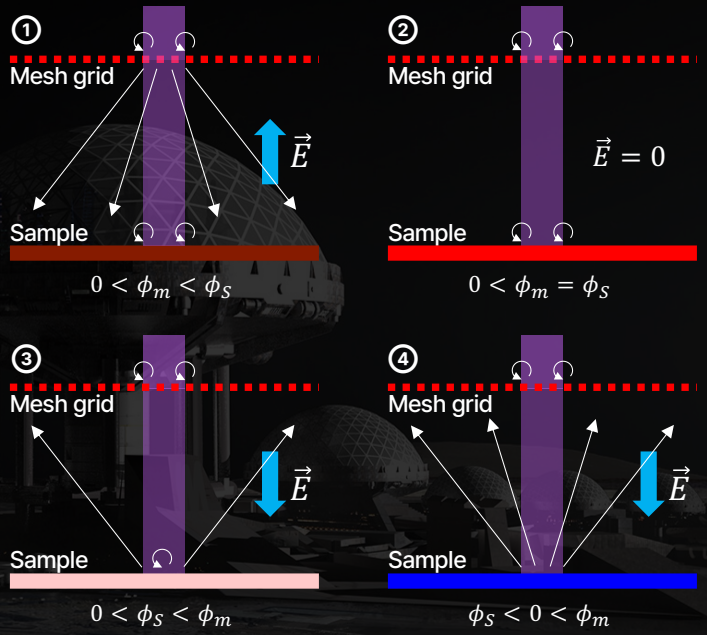
- Effect of V_C
  - Measured I_p (UV on) while incrementing V_C (ϕ difference between mesh grid and ring collector) from 0 to 30 V
  - Variation of V_C does not affect on I_P.
  - The deviation of convergence values of I_P at each condition was within 2% of the mean value ($I_{p,\text{avg.}} = 8.171$ [nA])



Result

- I_p vs. V_s $(\phi_m - \phi_s)$
  1. $0 < \phi_m < \phi_S$ Photoelectrons from mesh grid attracted to metal sample $(\vec{E}_y > 0)$
  2. $0 < \phi_m = \phi_S$ No electric field due to zero potential difference between mesh grid and metal sample $(\vec{E}_y = 0)$
  3. $0 < \phi_S < \phi_m$ The returned photoelectrons from metal sample start to be released $(\vec{E}_y < 0)$
  4. $\phi_S < 0 < \phi_m$ The most photoelectrons from the sample are captured to the mesh grid $(\vec{E}_y < 0)$

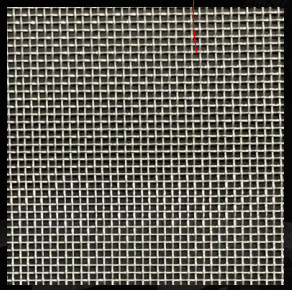




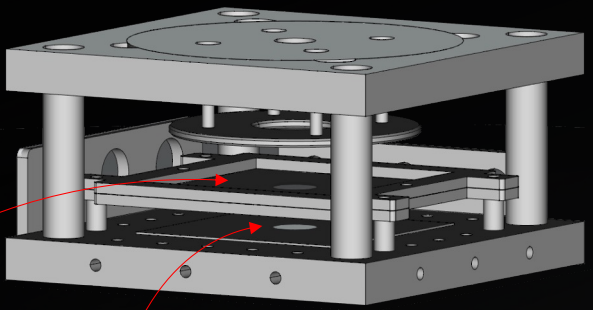
Photoelectric current density J_p

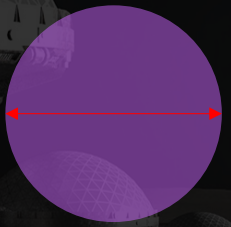
- J_{pm} from experiment result
  - J_{pm} was calculated from I_p by adjusting the values based on the influence of mesh grid opening rate r and UV exposed area A
- Values for calculating J_{pm}
  - Photoelectric current, $I_p = 8.171\times10^{-9}$ [A]
  - Mesh grid opening rate, $r \approx 70$ [%]
  - UV exposed area, $A = 78.54\times10^{-6}$ [m^2]

$$J_{pm} = \frac{I_p}{A \cdot r} = 0.160\times10^{-3}\ [\mathrm{A}\cdot\mathrm{m}^{-2}]$$



$r \approx 0.70$ [−]





UV exposed area dia.
10 mm

$A = \pi(5\times10^{-3})^2 = 78.54\times10^{-6}$ [m^2]

Photoelectric current density J_p

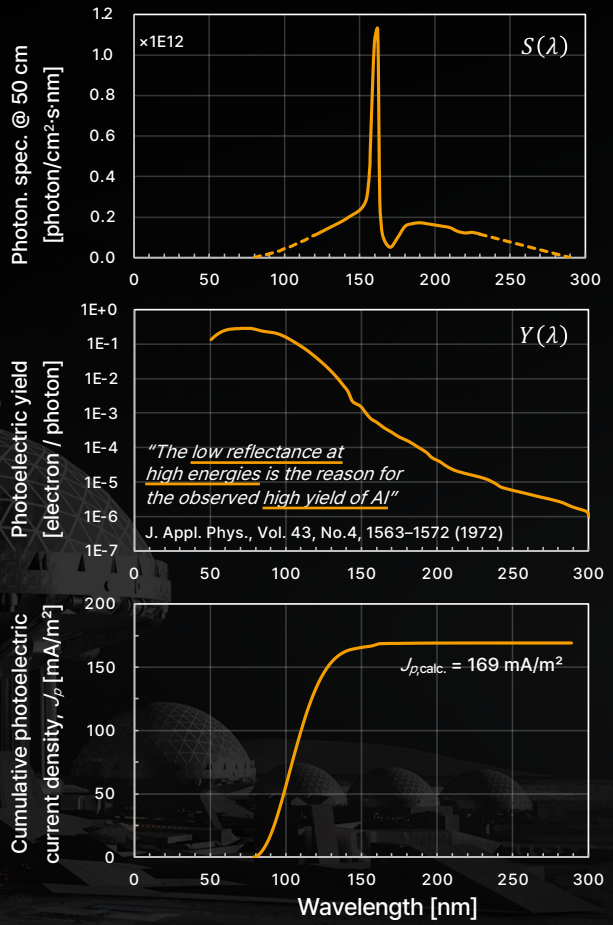
- J_{pc} from light & material information
  - J_{pc} was calculated from the optical informations of UV light source and sample metal.
- Values (functions) for calculating J_{pc}
  - UV light source characteristics
    - Photoemission spectrum, $S(\lambda)$ $[\mathrm{photon \cdot cm^{-2} \cdot s^{-1} \cdot nm^{-1}}]$
      (consider the light intensity attenuation)
      (calculated from irradiance spectrum , $F(\lambda)$ $[\mathrm{W \cdot cm^{-2} \cdot nm^{-1}}]$)

$$E = \frac{hc}{\lambda}$$

  - Sample metal characteristics
    - Photoelectric yield of aluminum, $Y(\lambda)$ $[\mathrm{electron \cdot photon^{-1}}]$
  - Other constant
    - Elementary charge, e $[\mathrm{C \cdot electron^{-1}}]$

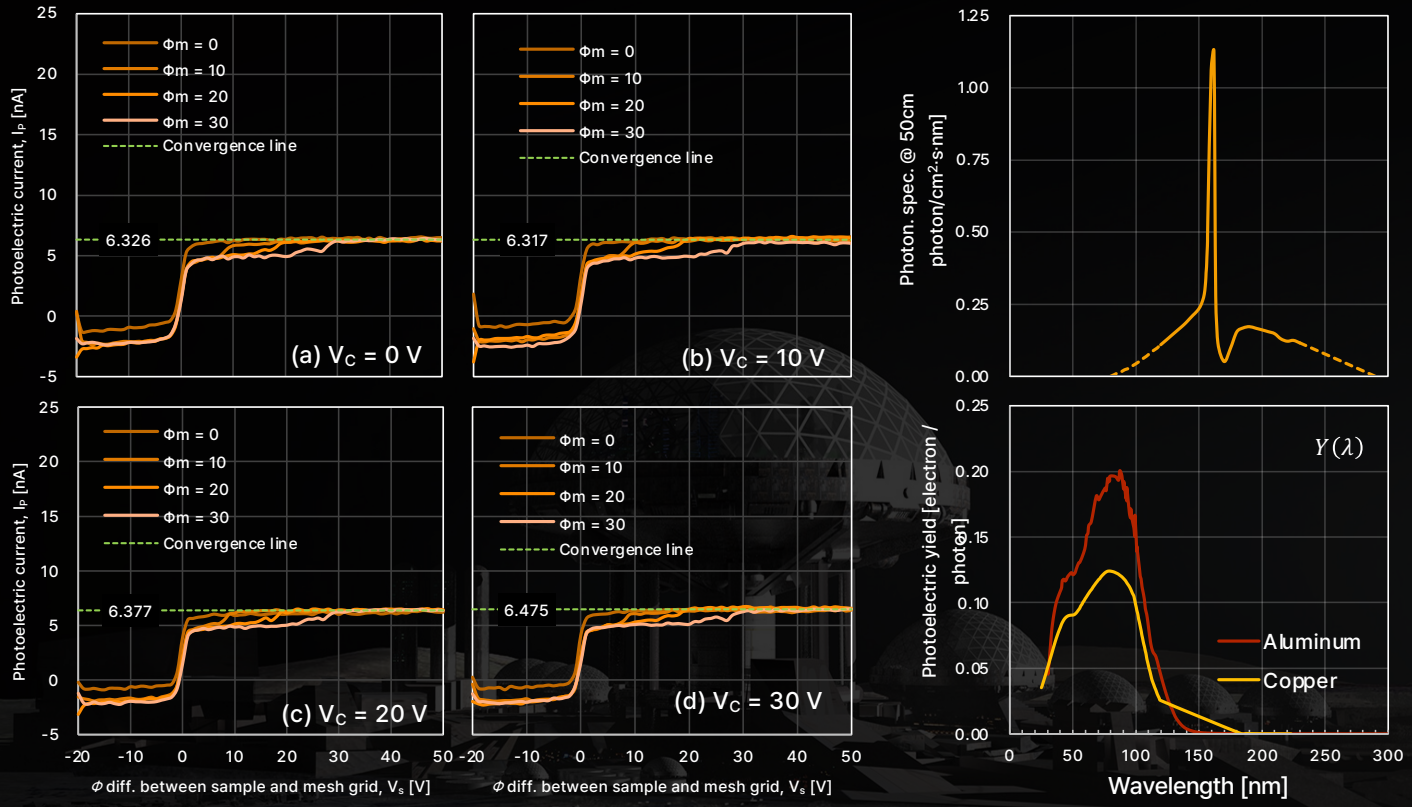
$$J_{pc} = e \cdot \int_{\lambda_a}^{\lambda_b} S(\lambda) Y(\lambda) d\lambda = 0.169 \times 10^{-3}\ [\mathrm{A \cdot m^{-2}}]$$

$$J_{pm} = 0.160 \times 10^{-3}\ [\mathrm{A \cdot m^{-2}}]$$



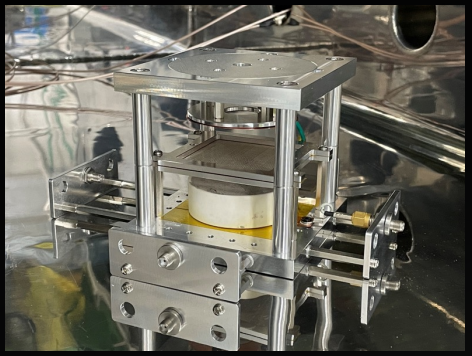
Result

- Case of copper

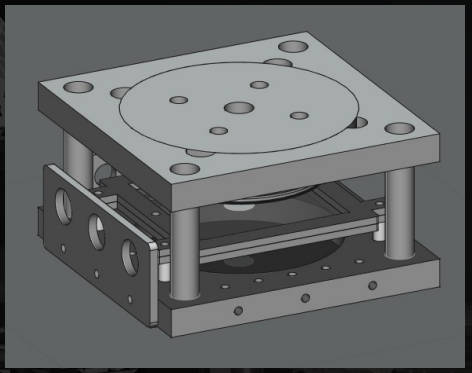


Summary & Future works

- A specific unit was devised to measure photoelectric current density.
- The connection between the operating variable and the resulting photoelectric current was analyzed.
- A comparative analysis was conducted between the current density obtained from the designed measuring unit and the calculated values derived from information regarding light sources and target materials.
- Future works include:
  - Expanded setup for measuring photoelectron density and temperature (Langmuir probe?)
  - Setting up for plasma environment in the chamber (for J_e and J_i)
  - Photoelectric current measurement for Lunar simulant KLS-1
  - Photoelectric current measurement in Pilot scale DTVC (Dirty Thermal Vacuum Chamber)



Measurement unit with KLS-1 within it



Measurement unit with on the soil bed (graphic)

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박 승 수

Park, Seungsoo

Research / Ph.D.
Korean institute of CIVIL ENGINEERING and BUILDING TECHNOLOGY
Department of Future & Smart Construction Research

Address: (10223) 283, Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si
E-mail: ssglenpark@kict.re.kr
Mobile: +82-10-3334-3039
Office: +82-31-910-0765