2021 Source Workshop (online), Oct. 23 - 28, 2021

Fabrication of EUV light source with cold cathode electron beam (C-beam)

Sung Tae Yoo, and Kyu Chang Park

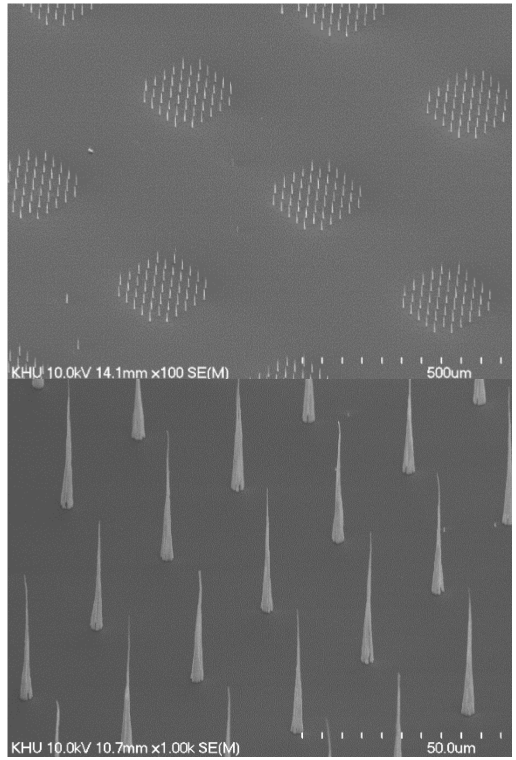
Department of Information Display, Kyung Hee University, Dongdaemun-gu, Seoul, 02447, Korea

Kyung Hee University

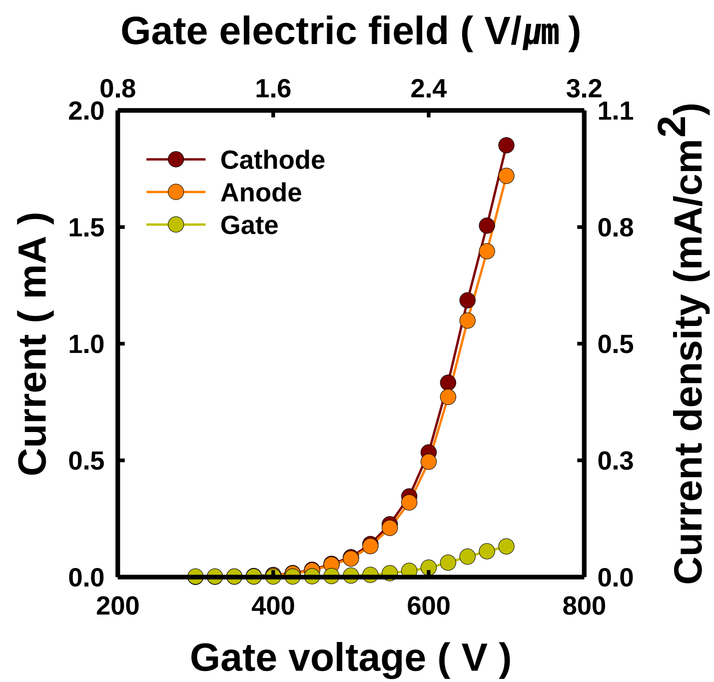
C-BEAM Research Laboratory

Why C-beam for EVU lighting?

- 01 Instantaneous operation
- 02 High output power
- 03 Large area
- 04 Eco-friendly



[SEM image of CNTs]

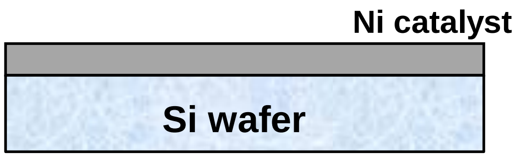


[I-V characteristics of C-beam]

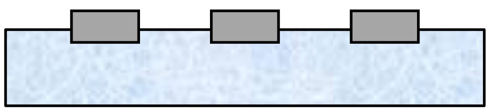
The SEM image & I-V characteristics of C-beam

- **Carbon nanotube (CNT)-based cold cathode electron beam (C-beam) was manufactured for EUV lighting.**

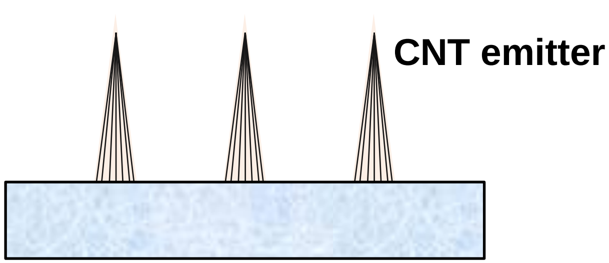
Fabrication process of the CNT emitters



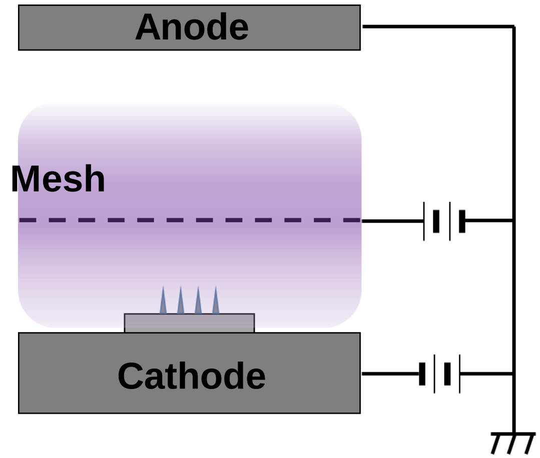
Ni sputtering

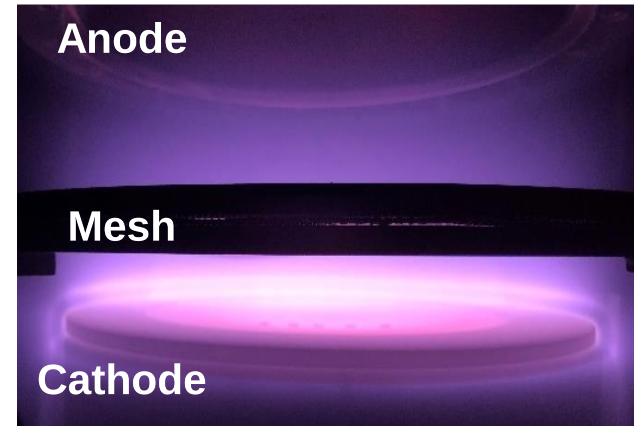


Photolithography &
Ni etching

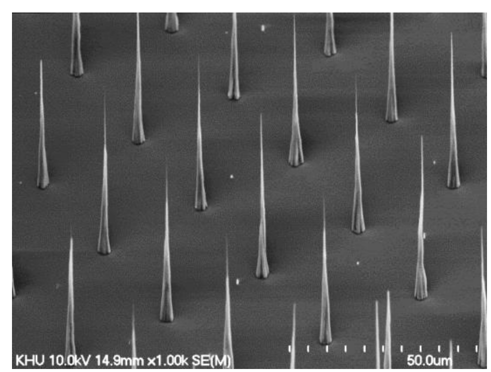


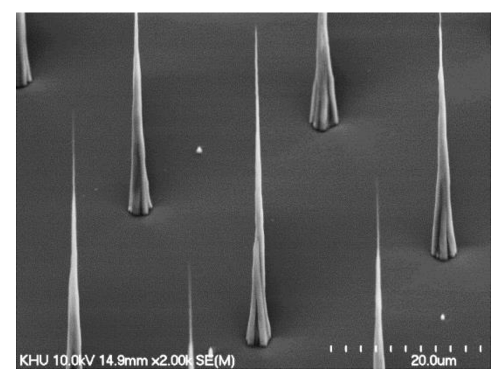
CNT growing with
DC-PECVD





Triode DC-PECVD system

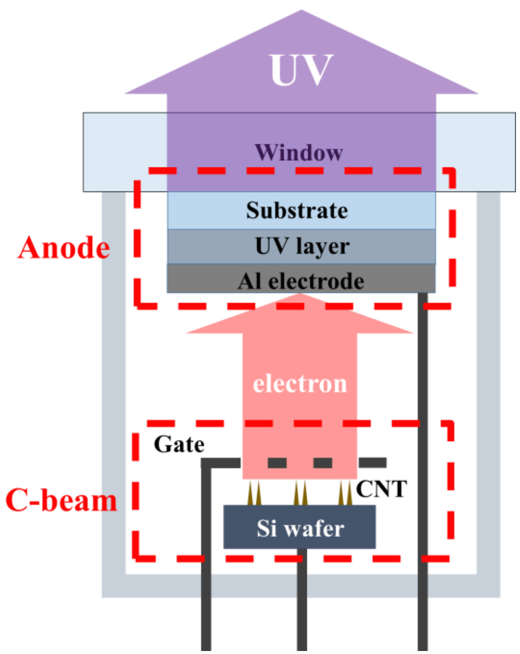


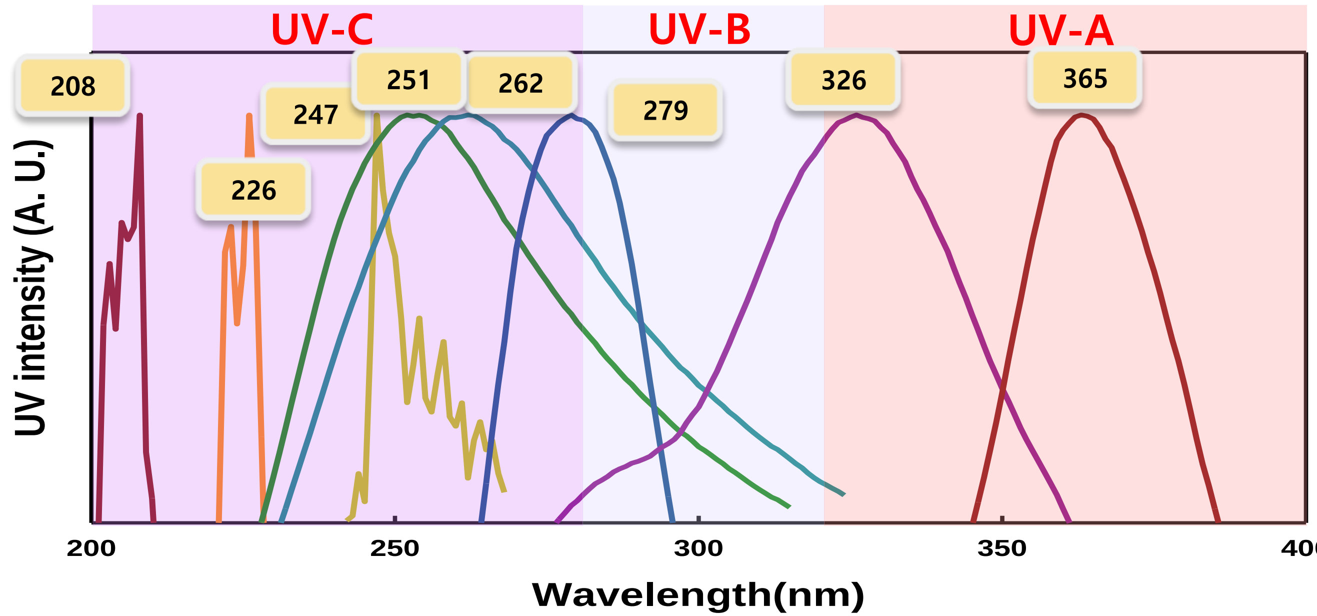


Vertically aligned CNT emitters

- **The CNT emitters have fully vertically aligned structure and grown pre-defined selective area.**

UV Light developed at Kyung Hee University (UV-A to UV-C)



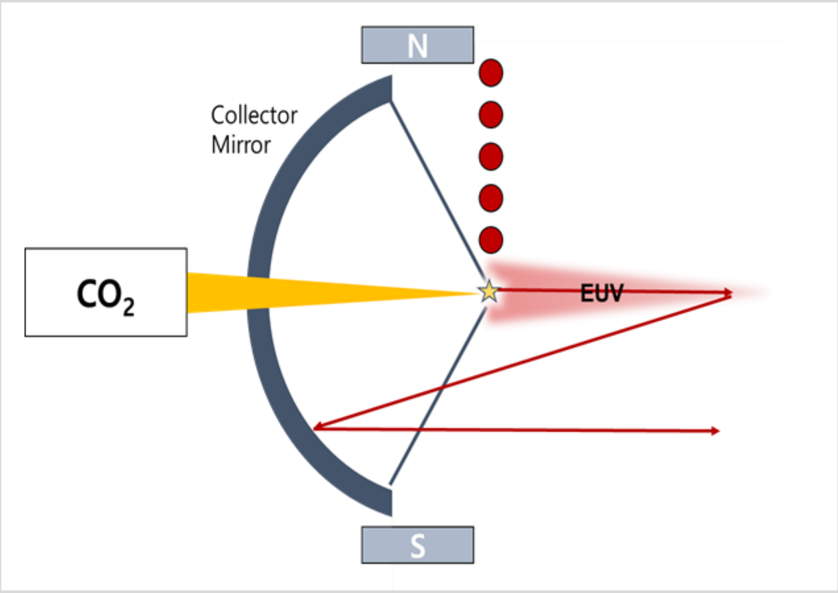


Peak WL 226 nm | 230 nm | 240 nm | 260 nm | 286 nm | 302 nm | 365 nm

UV spectrum & captured image of UV light generation using C-beam

- **UV generation was confirmed with C-beam pumping technology.**

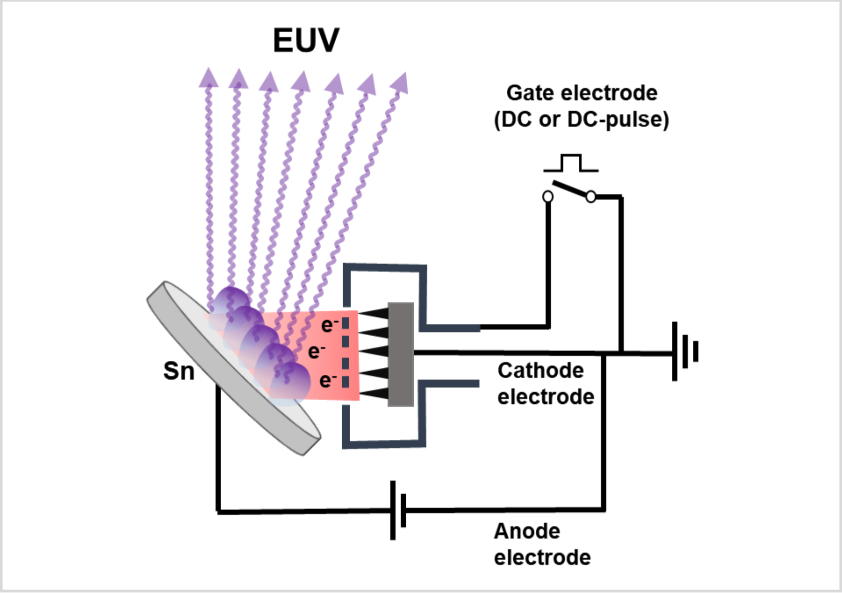
Comparison btw LPP and C-beam



Laser produced plasma (LPP) source

- **High power CO_2 laser**
- **High-temperature plasma**
  - An average electron temperature of 76.6 eV

    [Appl. Sci. 9, 2827 (2019)]
- **Ultrahigh pulse driving (100 kHz)**
- **Very expensive**

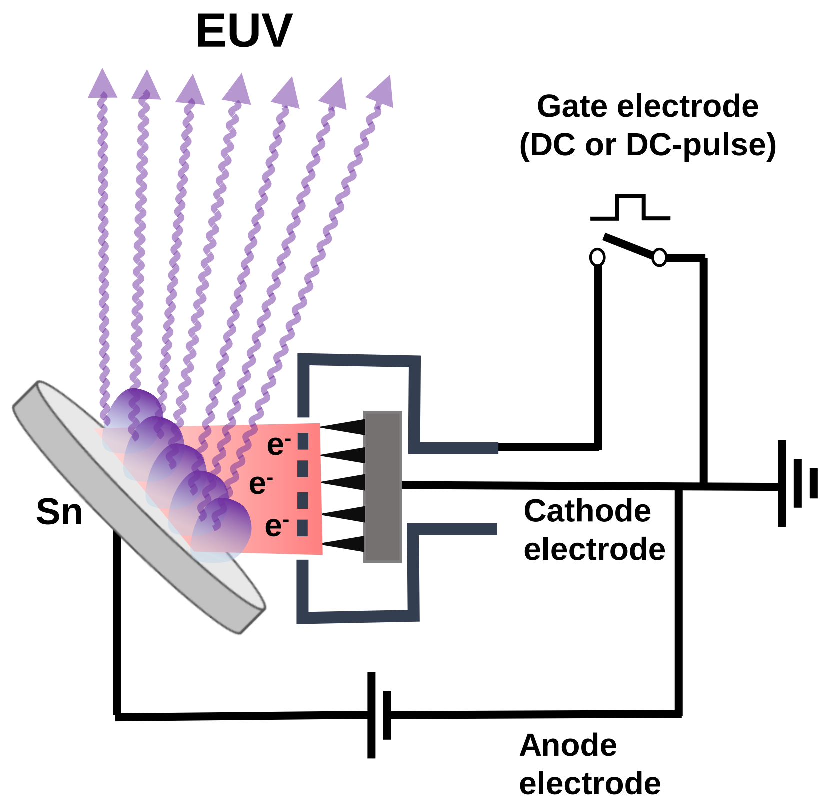


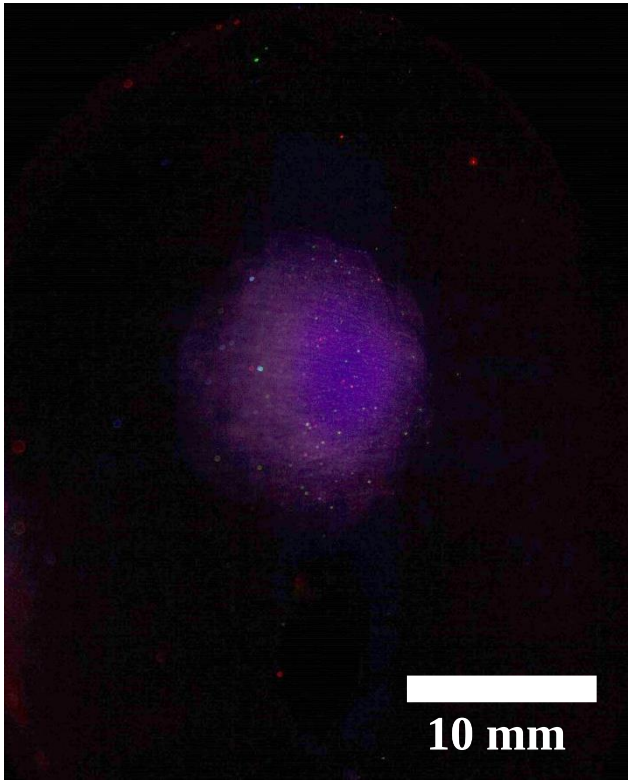
C-beam pumping technology

- **Electron bombardment using C-beam**
- **Cold plasma**
  - Less than 1 eV

    [J. Appl. Phys. 110, 093304 (2011)]
- **Multi-beam irradiation is possible**
- **Adjustable size of C-beam from micrometer to centimeter scale**
- **DC & DC-pulse power supply**

Configuration of EUV generation using C-beam



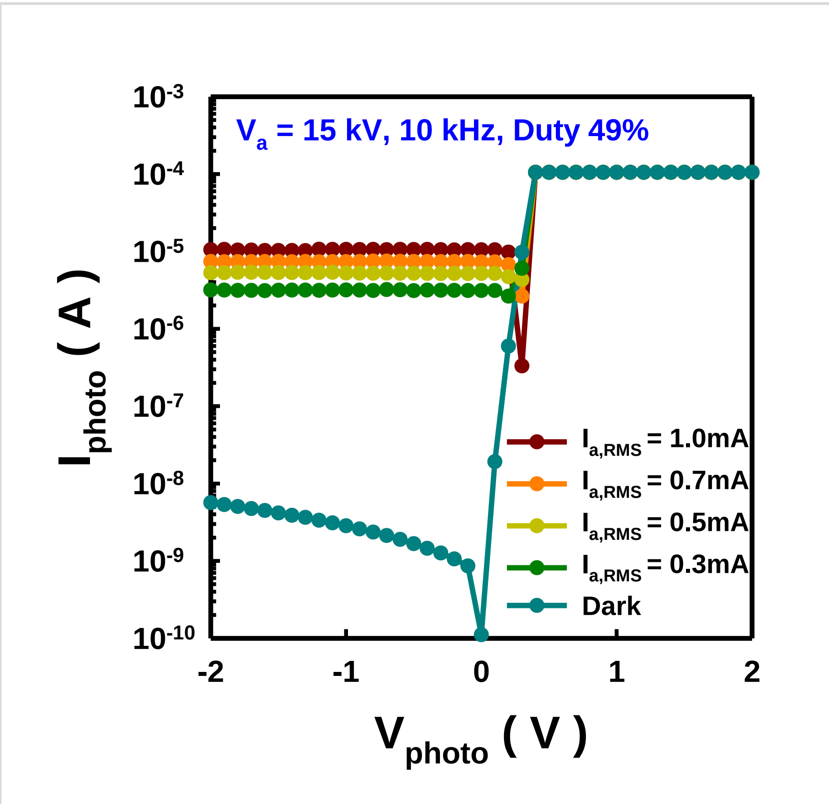


Schematic of EUV generation with C-beam

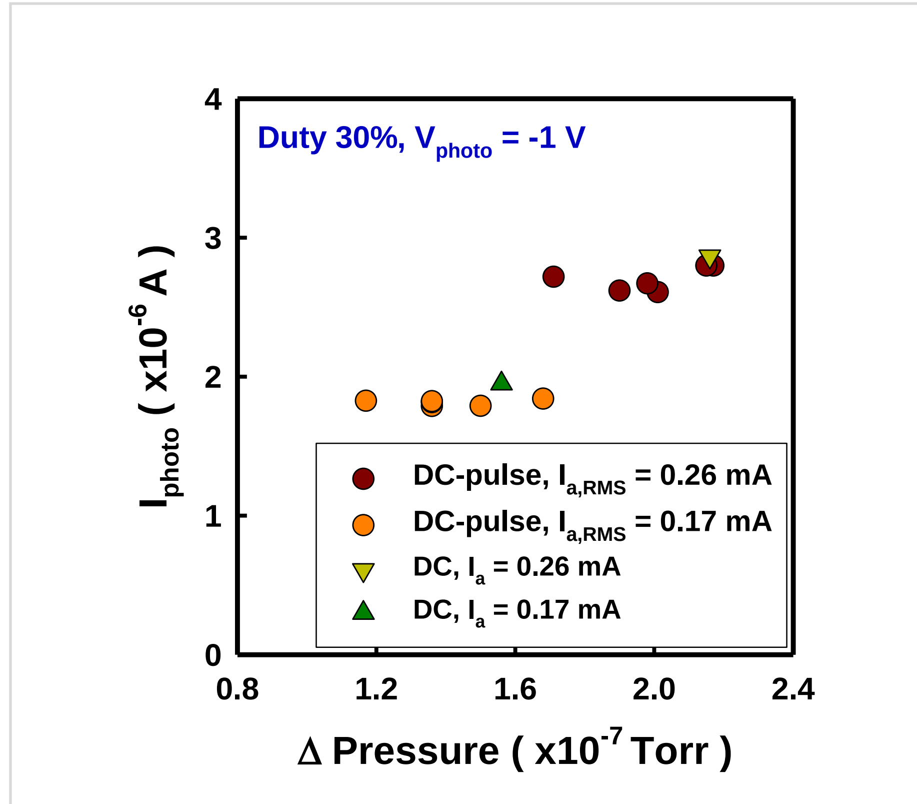
Photo of EUV-emitting plasma

- Electrons emitted from the C-beam directly collide with Sn, excitation and ionization of Sn atoms evaporated by electron bombardment, resulting in EUV-emitting plasma.

Controlling the intensity of EUV light



Photocurrent response



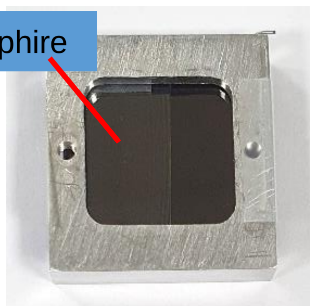
EUV intensity and Δpressure with different driving

※ EUV photodiode equipped with a 150 nm thick Zr filter

- **EUV intensity depends on C-beam parameters with anode impact power and driving.**
- **Unlike DC driving, DC-pulse driving generates EUV light with minimal pressure change by changing the frequency.**

EUV lithography using PMMA photoresist

C-BEAM Research Laboratory



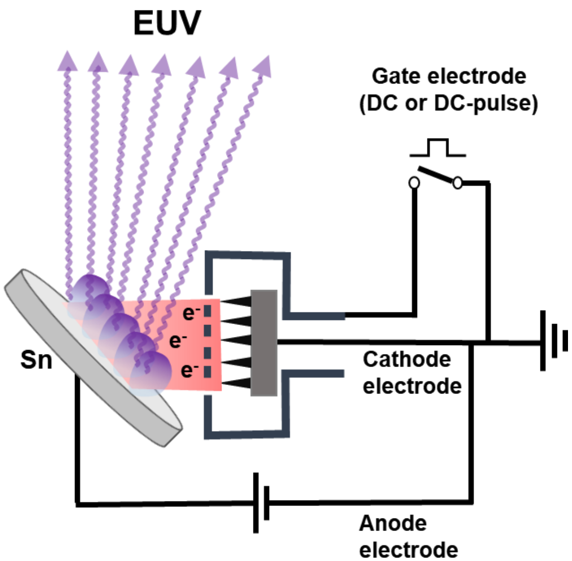
C-beam pumping

- V_a: 15 kV, 1 kHz, $I_{a,RMS}$: 0.4 mA
- Exposure time: 30 s

Optical microscope image after exposure and develop

- **When observed with an optical microscope at 500 times magnification, the part covered by the sapphire and the part not covered by the sapphire can be accurately distinguished.**

Summary



- **EUV light generated by direct irradiation of C-beam was verified using a photodiode equipped with Zr filter and PMMA photoresist.**
- **EUV intensity depends on C-beam parameters with anode voltage, current, and DC-pulses.**

References

- Yoo, S. T., & Park, K. C. "Sapphire Wafer for 226 nm Far UVC Generation with Carbon Nanotube-Based Cold Cathode Electron Beam (C-Beam) Irradiation" *ACS omega* 5.25, 15601-15605 (2020).
- Yoo, S. T., Lee, H. I., & Park, K. C. "Optimization of Zn_2SiO_4 Anode Structure for Deep Ultraviolet Generation With Carbon Nanotube Emitters" *IEEE J. Electron Devices Soc. 7*, 735-739 (2019).
- Yoo, S. T., Lee, H. I., & Park, K. C. "363 nm UVA light generation with carbon nanotube electron emitters" *Microelectron. Eng. 218*, 111142 (2019).
- Yoo, S. T., Hong, J. H., Kang, J. S., & Park, K. C. "Deep-ultraviolet light source with a carbon nanotube cold-cathode electron beam" *J. Vac. Sci. Technol. B 36*(2), 02C103 (2018).
- Yoo, S. T., So, B., Lee, H. I., Nam, O., & Park, K. C. "Large area deep ultraviolet light of $Al_{0.47}Ga_{0.53}N/Al_{0.56}Ga_{0.44}N$ multi quantum well with carbon nanotube electron beam pumping" *AIP Adv. 9*(7), 075104 (2019).
- Lee, J., Yoo, S. T., So, B., Park, K. C., & Nam, O. "Large-area far ultraviolet-C emission of $Al_{0.73}Ga_{0.27}N/AlN$ multiple quantum wells using carbon nanotube based cold cathode electron-beam pumping" *Thin Solid Films 711*, 138292 (2020).

E-mail: kyupark@khu.ac.kr