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Development of low-pressure UV cleaning technique for carbon contaminated EUV optics

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Abstract

➢ Carbon contamination is one of the serious issues of EUVL. We have developed some methods which can easily remove contamination from optics.

➢ UV cleaning method utilizing a low pressure mercury lamp was a great success for carbon-contaminated EUV optics. Multilayer after the UV cleaning showed no significant degradation of reflectivity. Cleaning rate was evaluated by recovery factor of reflectivity. Our carbon contamination samples prepared with the EUV1 exposure tool showed much higher cleaning rate than that for sputtered carbon. Thus it suggests they consist of not closed packed structure but polymer-like deposit.

➢ For possible application on future exposure tools, low pressure UV cleaning technique is also studied. If cleaning sample is placed at several ten mm away from the UV source in atmosphere, the cleaning rate will dramatically decrease in general due to low UV transmission. Therefore reduced pressure condition helps cover this weak point. We observed strong pressure-dependency of cleaning efficiency through the experiments using actual carbon contaminated samples. Cleaning efficiency is determined by UV transmission, and by the life time of oxygen radical.

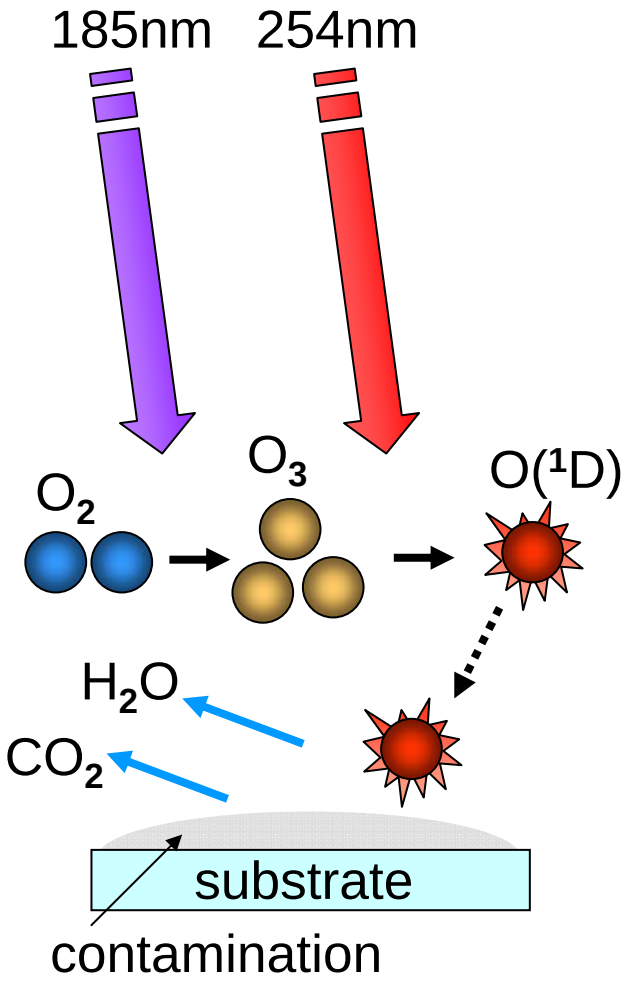
Cleaning Methods

- UV dry cleaning has
  high cleaning rate
  high applicability to EUV1

Cleaning methods	Reaction	Cleaning Rate	Heat Road	Damage	Applicability to EUV1
UV	Oxidation	○	○	○	◎
H*(radical)	Reduction	△	×～△	△	×
O*(radical)	Oxidation	○	×～△	×	×
EUV+O2/O3	Oxidation	△	○	○	○

Principle of UV Cleaning

- Utilizing a low pressure mercury lamp



i) $O_2 + h\nu\,(185nm) \Rightarrow O(^3P) + O(^3P)$

ii) $O(^3P) + O_2 \Rightarrow O_3$

iii) $O_3 + h\nu\,(254nm) \Rightarrow O(^1D) + O_2$

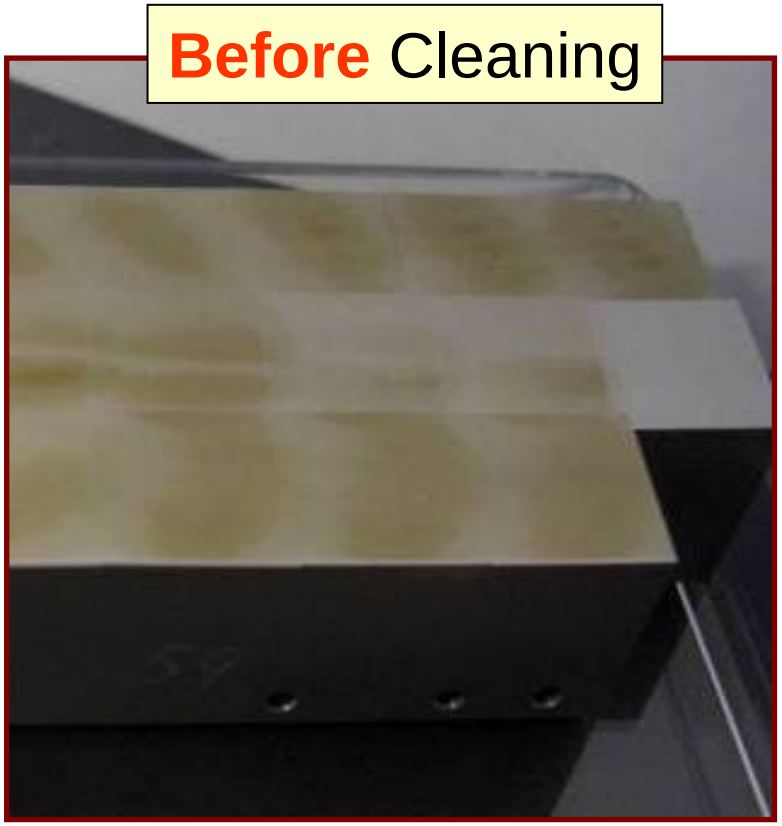
iV) Carbon can be removed by $O(^1D)$

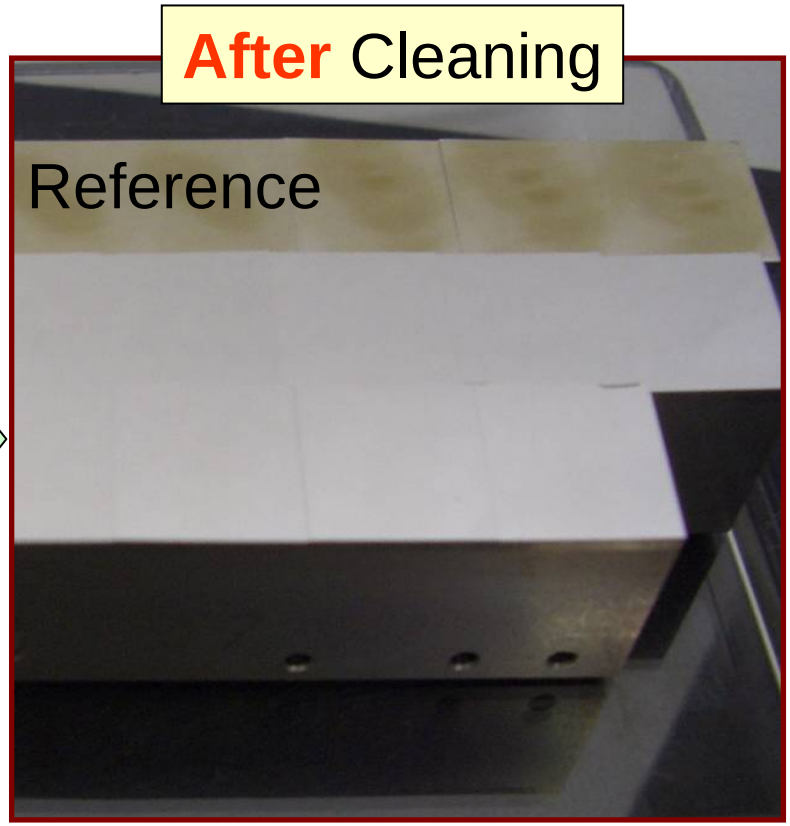
Cleaning Power ∝ UV Irradiance

✓ *SHORT path length*
✓ *LOW-pressure*
are important.

Cleanability

➢ Carbon contamination on EUV optics can be removed using a commercially available UV cleaner.

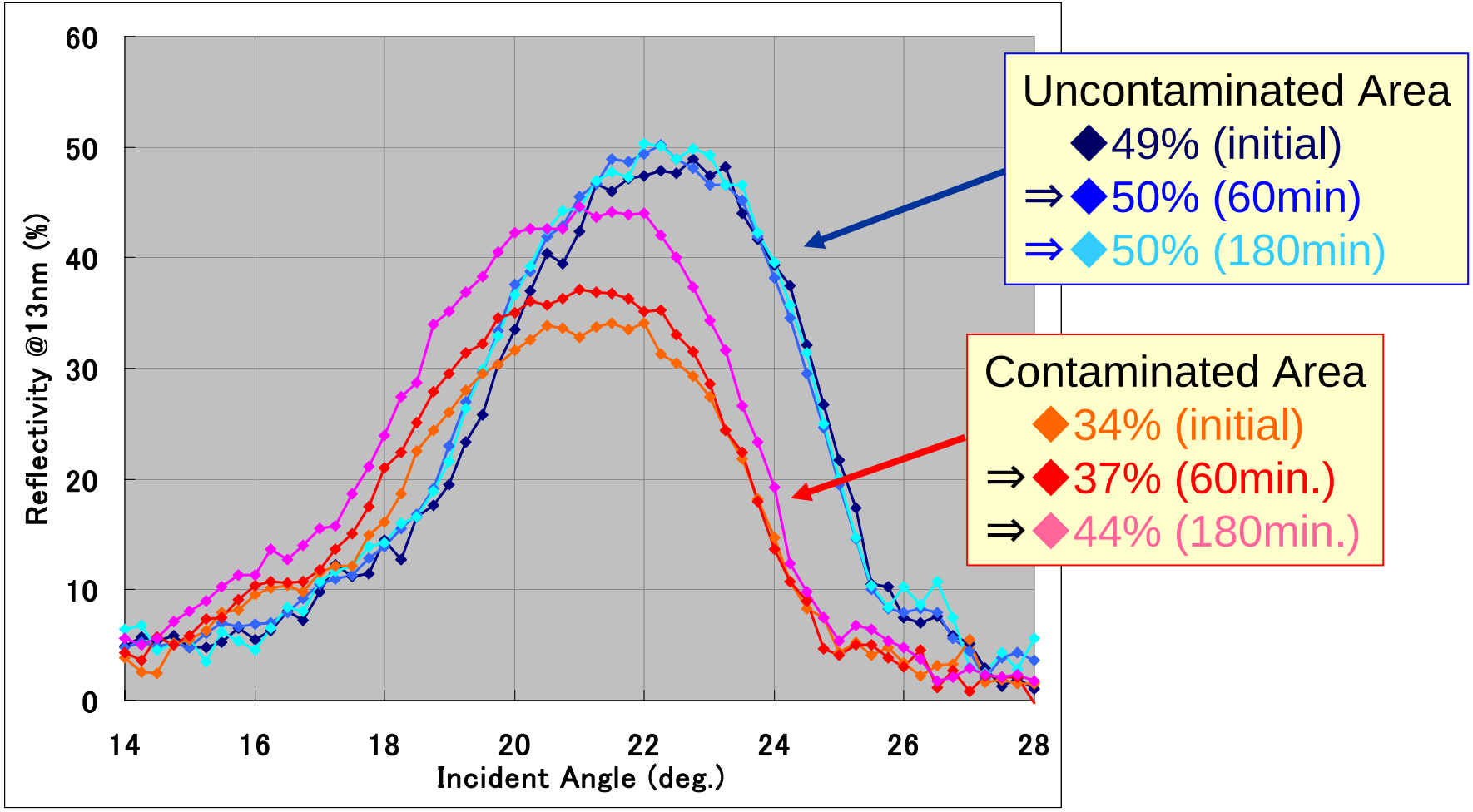




✓ 13mW cm^{-1} @ λ =254nm
✓ 180 min. irradiation

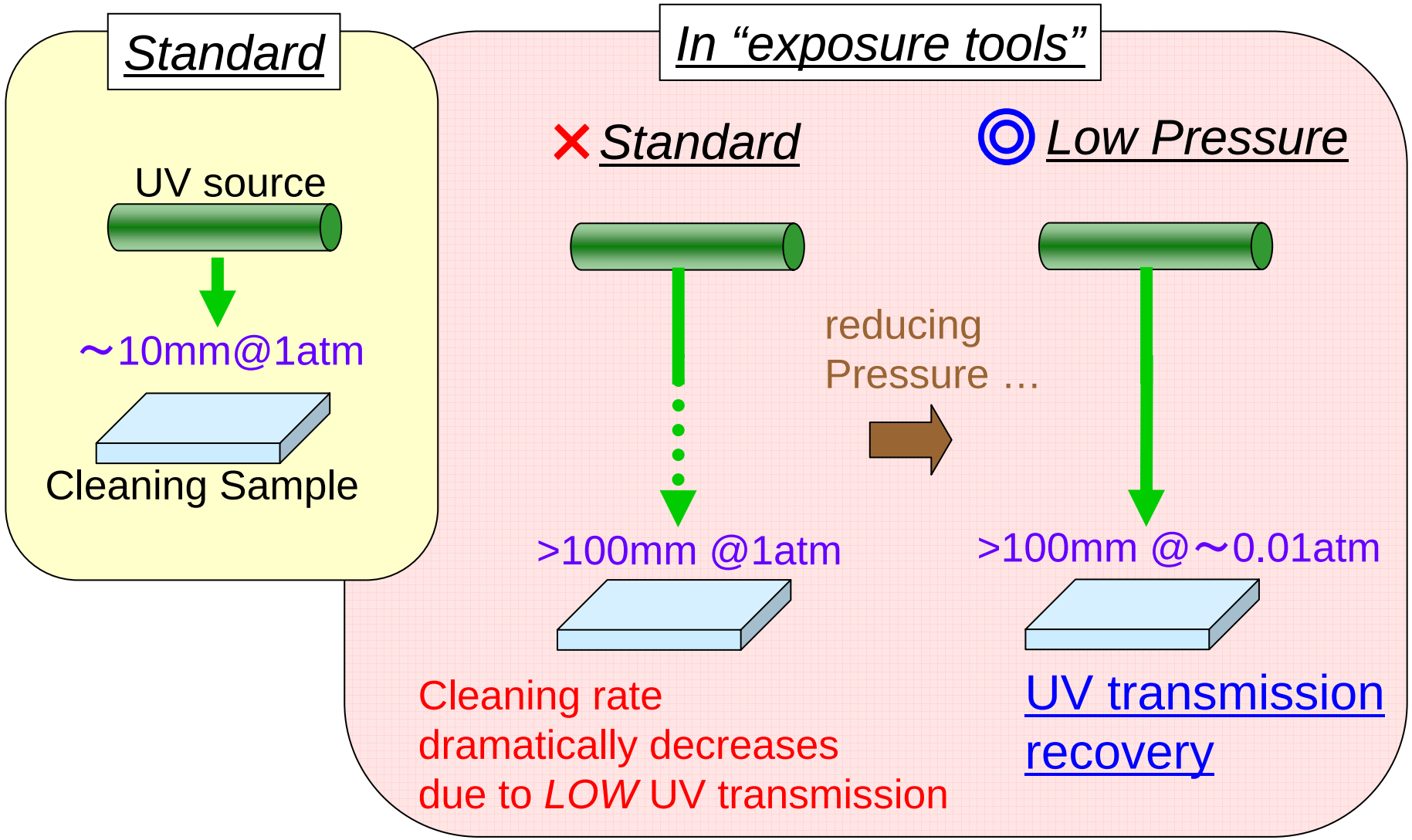
Reflectivity

- Initial reflectivity was recovered by UV cleaning.
- Over exposure does not degrade reflectivity.

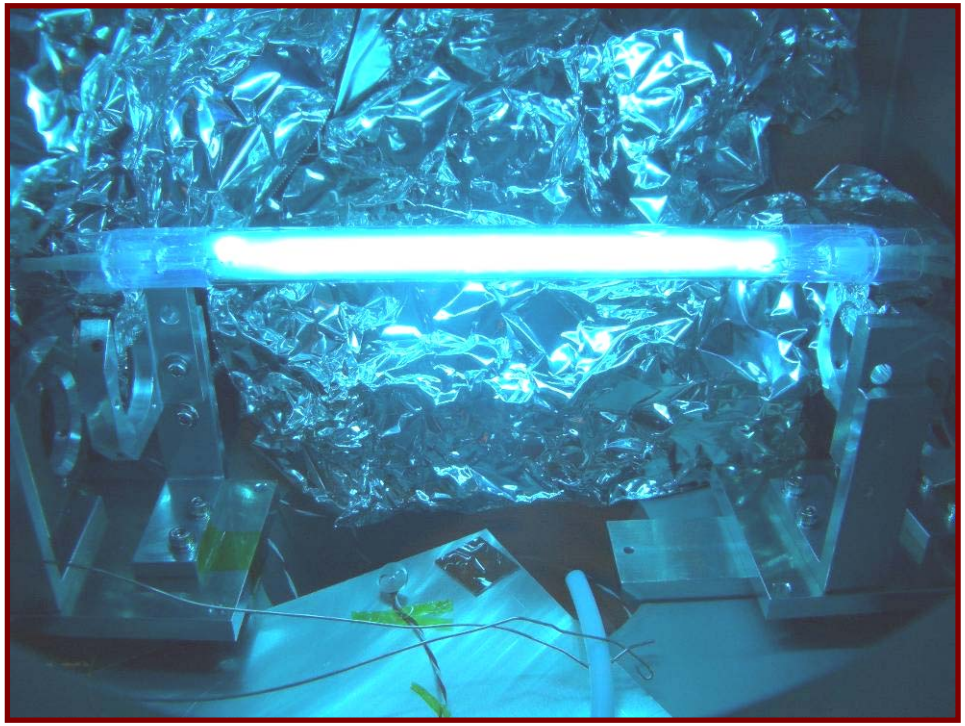


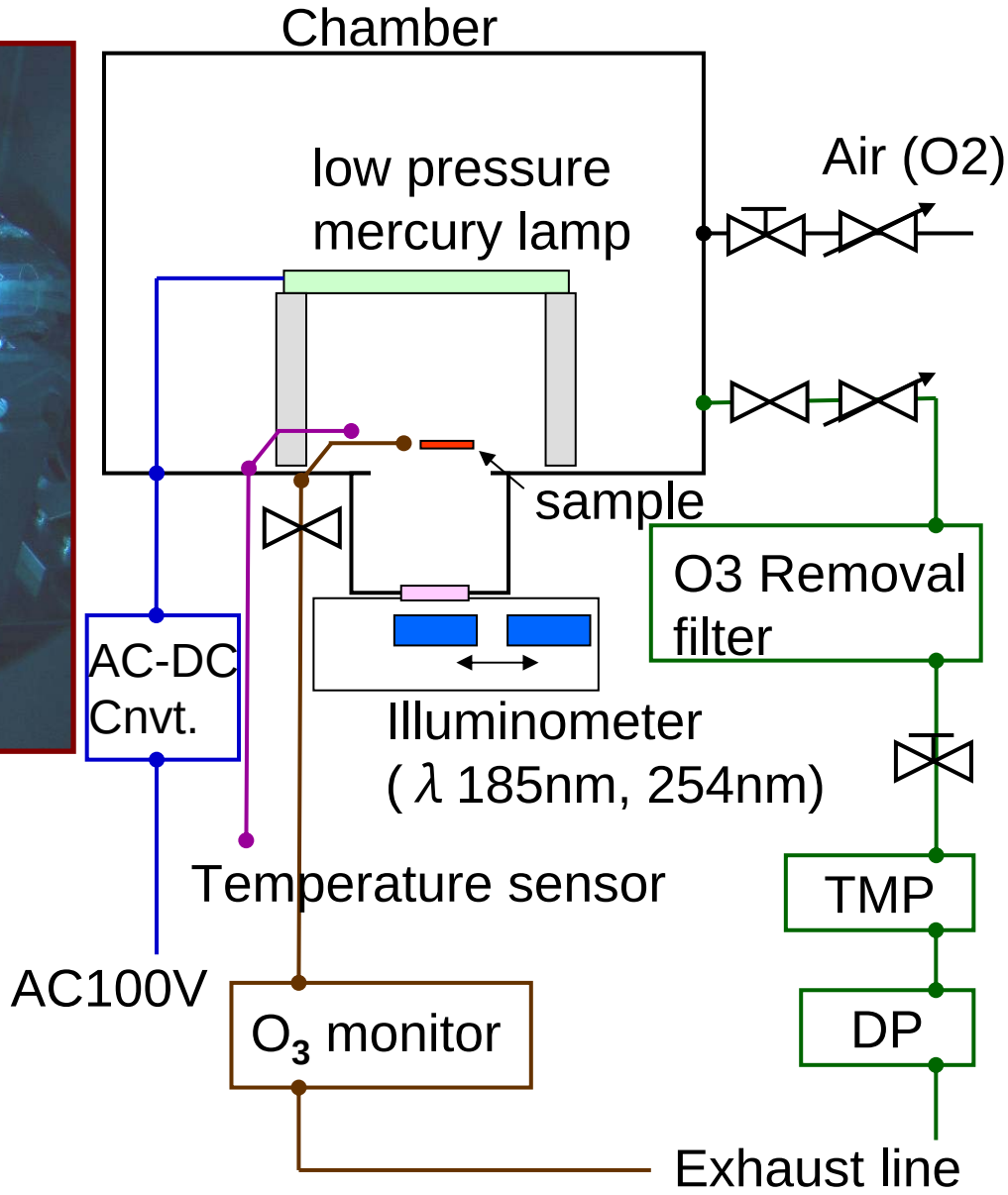
“Low Pressure” UV Cleaning

➢ Motivation (For possible application on future exposure tools)



Experimental Setup



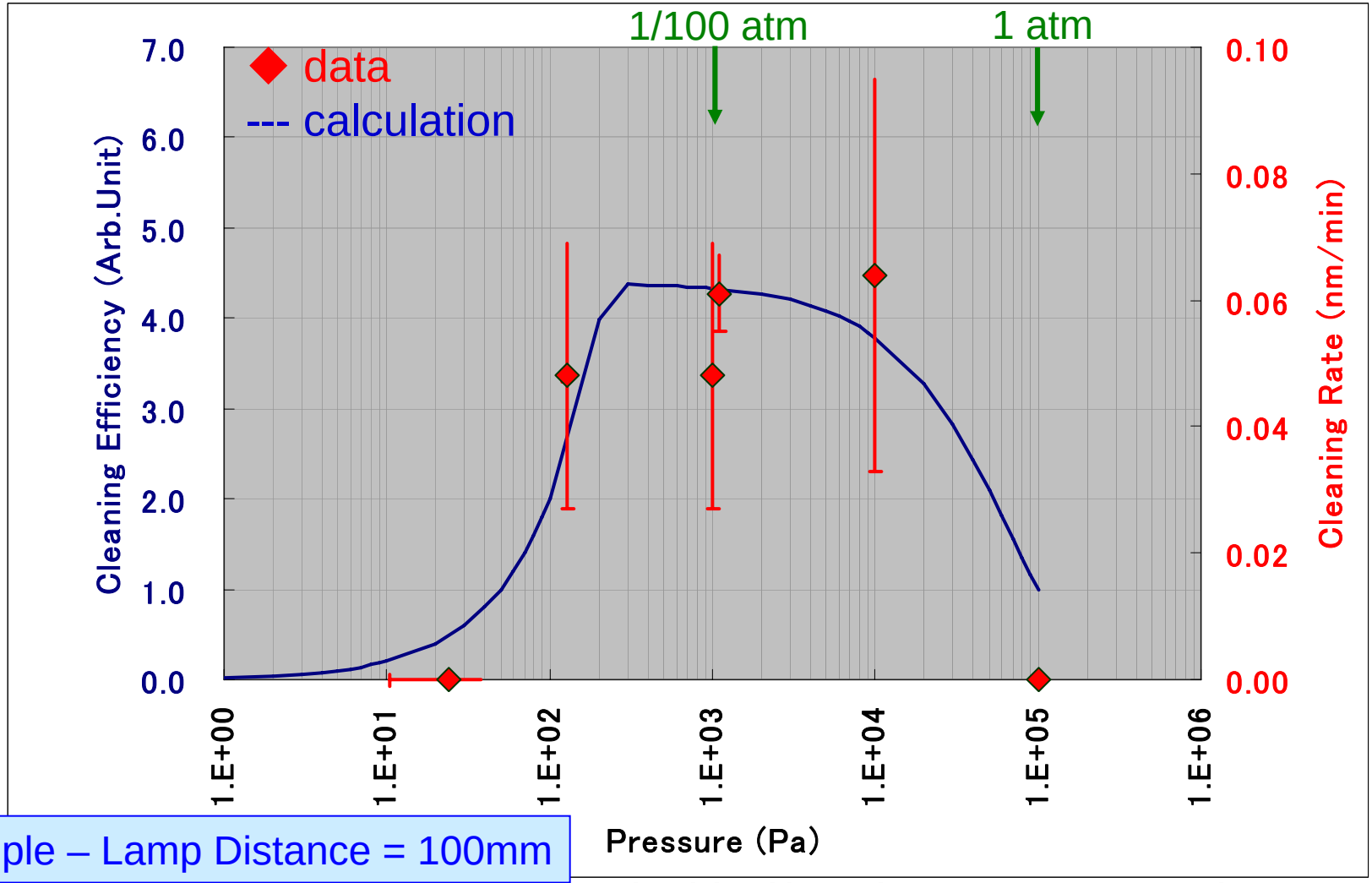


Experimental Items

- Measurement
  - Cleaning efficiency as a function of surrounding pressure.
  - Cleaning rate for carbon contamination prepared with the EUV1 exposure tool under the low pressure condition.
  - The above cleaning rate under the condition filled with N_2 (Keep low O_2 partial pressure)
  - Experimental absorption cross section of O_2 and O_3 at λ = 185nm and 254nm.
- Evaluation
  - EUV reflectivity (Using our in-house reflectometer with LPP source of CO_2 gas target)
    - Cleanability test, Damage test, Estimation of contamination thickness

Results; Cleaning Efficiency

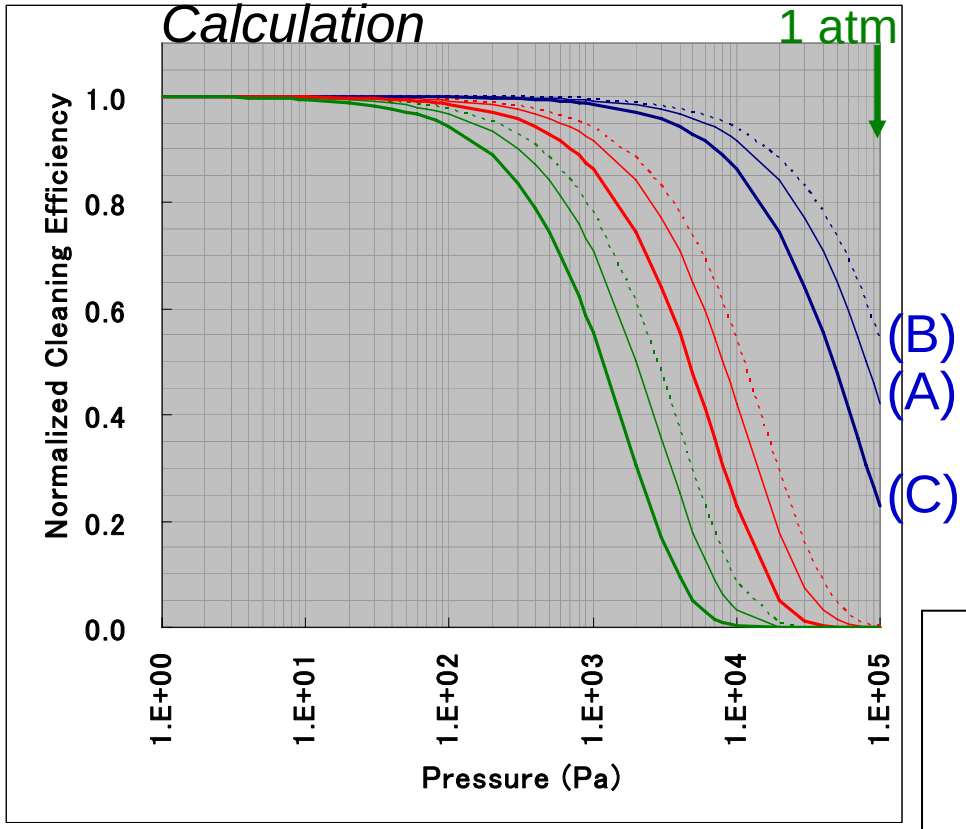
- Higher cleaning rate by reducing the pressure
- Strong pressure dependency



Sample – Lamp Distance = 100mm

High-pressure region

➢ Cleaning efficiency is determined by UV transmission, and increases greatly in proportion to the UV transmission.



Sample – Lamp Distance = 10mm

(A) O2 transmission @ λ =185nm
(B) O3 transmission @ λ =254nm
(C) = (A) × (B)

D= 100mm

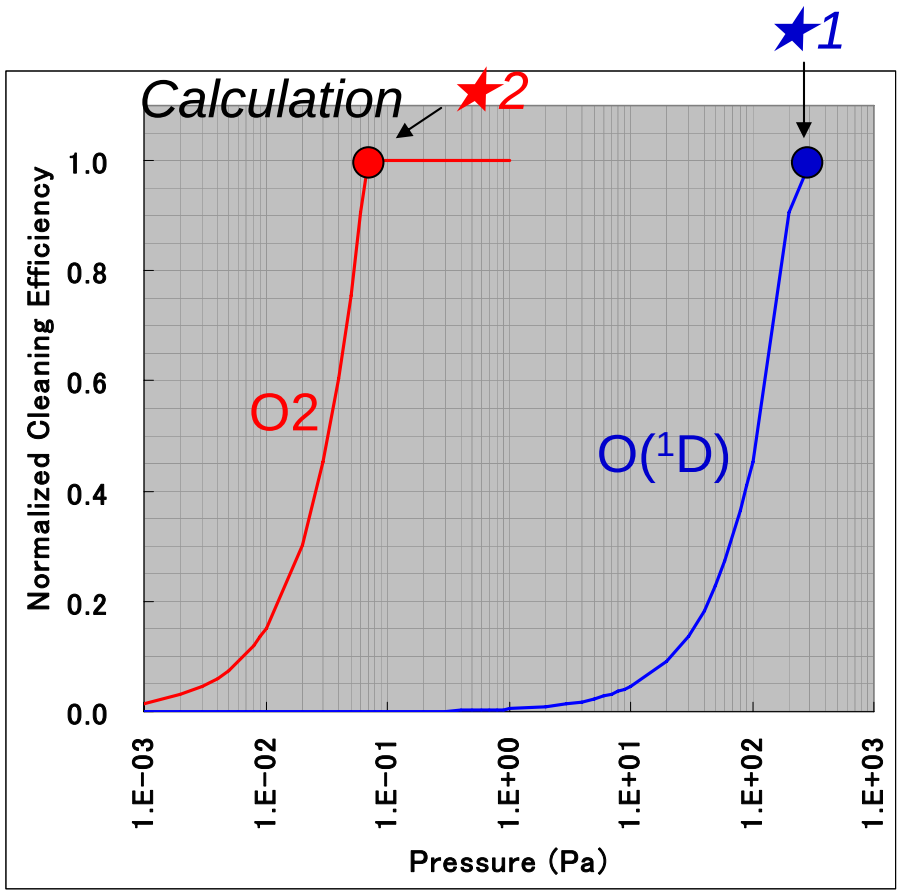
D= 400mm

◆ To keep up the efficiency,

greater distance
needs
lower pressure

Low-pressure region

➢ Cleaning efficiency is roughly determined by *not* the amount of O2 *but* the life time of oxygen radical (O1D).



O(^{1}D)

- ✓ Lifetime ～ 10^{-7} s
- ✓ Velocity ～ 300 m s^{-1}
- ✓ Distance ～ 30 um
- ✓ Pressure that mean free path equals 30 um ⇒ ～220 Pa ★1

O2

- ✓ Sample - Lamp distance ～ 100mm
- ✓ Pressure that mean free path equals 100mm ⇒ ～6.6E-2 Pa ★2

Schematic View

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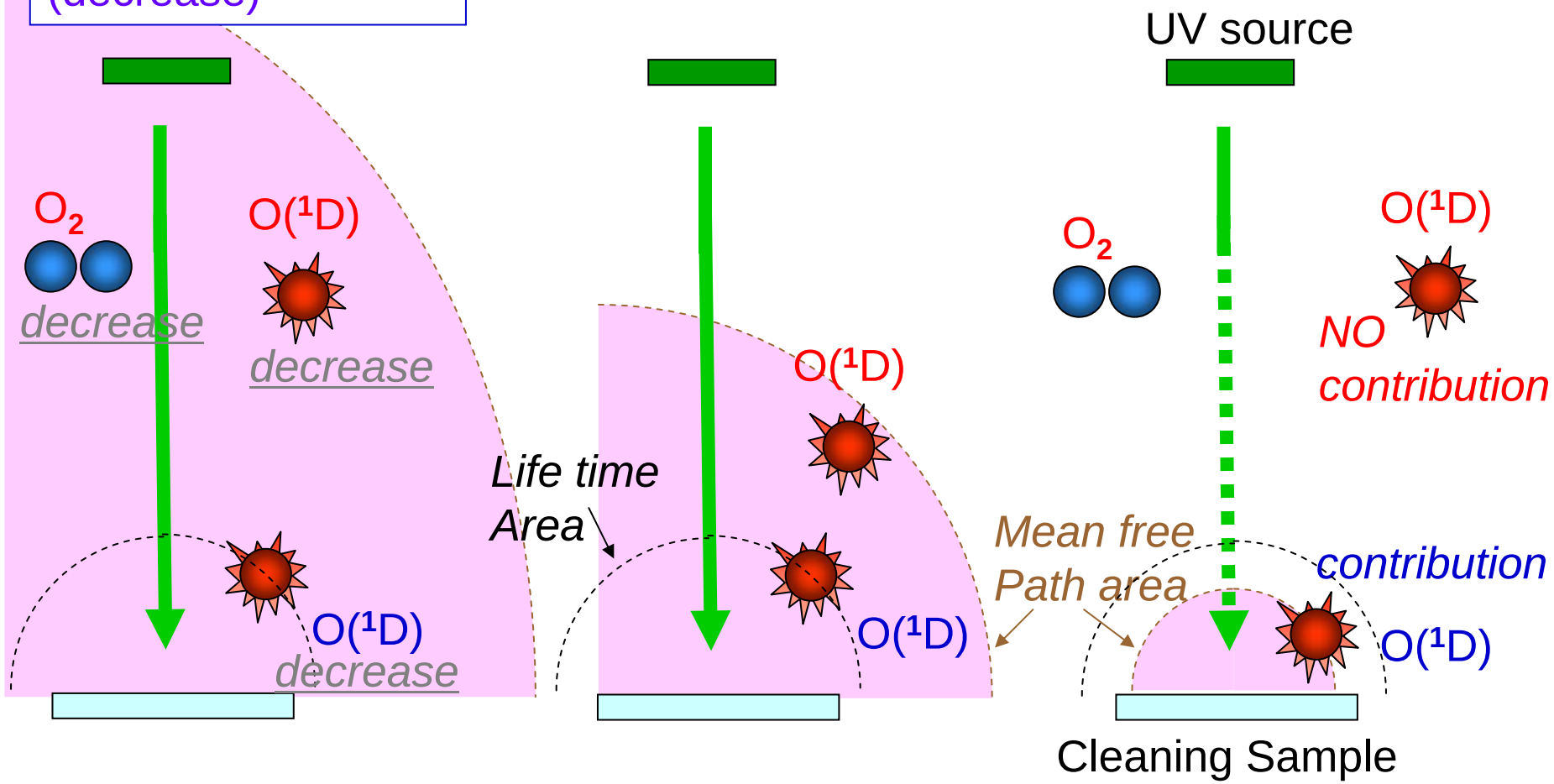
P ~ 5E-2 [Pa]
λ ~ 130 [mm]
Dominated by O(^{1}D) (decrease)

P ~ 1E+2 [Pa]
λ ~ 70 [um]
Dominated by O(^{1}D)

P ~ 1E+5 ~1E+3 [Pa]
λ << 1
Dominated by UV transmission



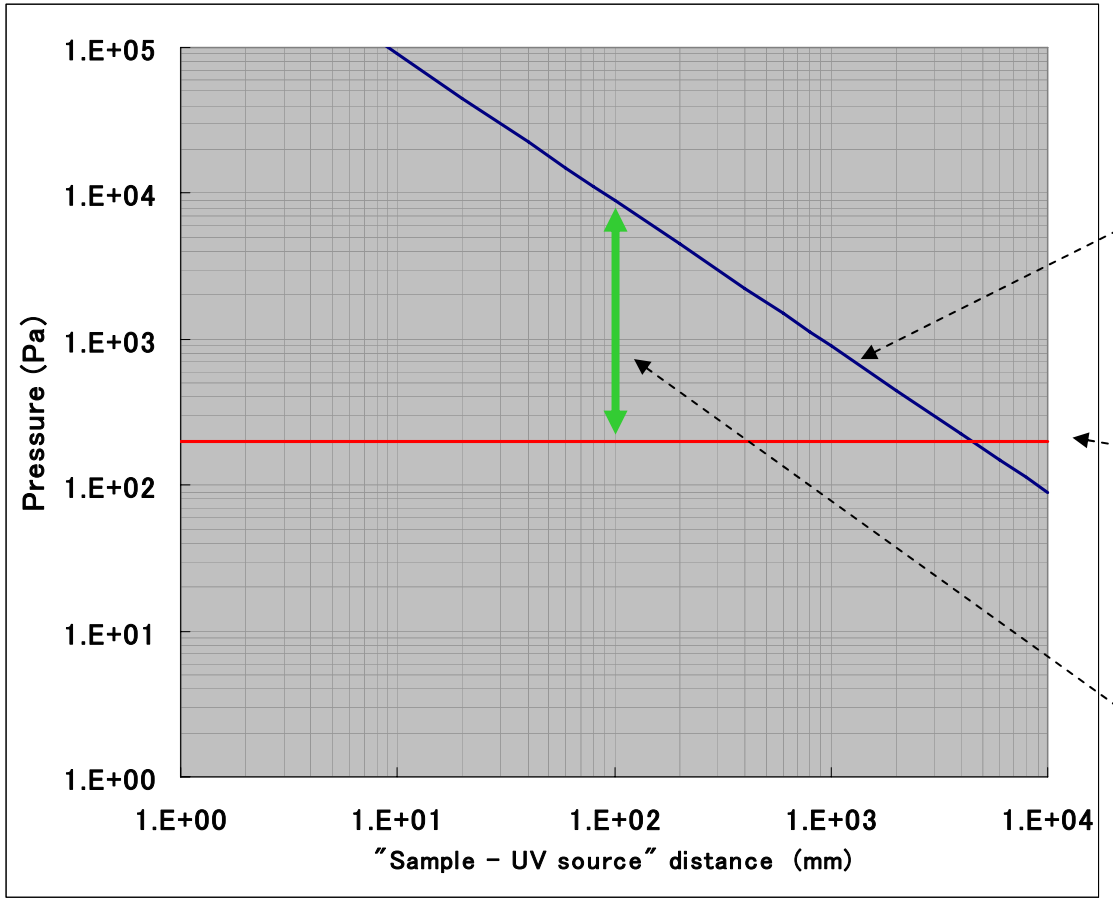
Cleaning rate

- Low-pressure UV cleaning
  - cleaning rate: 0.061±0.006 [nm/min.]
  - UV irradiance:
    - 1.60 mW cm^{-2} @ λ 254nm, 0.21 mW cm^{-2}@ λ 185nm
    - aperture: ϕ 6mm, UV source size: 140mm × ϕ 15mm
  - @0.01atm, @100mm distance
  - Carbon contamination samples prepared with EUV1

- Low-pressure UV cleaning filled with N2(1atm)+O2(0.01atm)
  - cleaning rate: 0.031±0.004 [nm/min.]
  - Extinction of the oxygen radical due to N2 on optical path.

Appropriate Pressure Range

- Parameters: Sample – UV source distance *ONLY*
  ※ UV transmission automatically determined



∝ UV transmission

Threshold:
>90% cleaning efficiency
(100% = UV cleaning
@1atm, @10mm distance)

∝ lifetime of O(^{1}D)

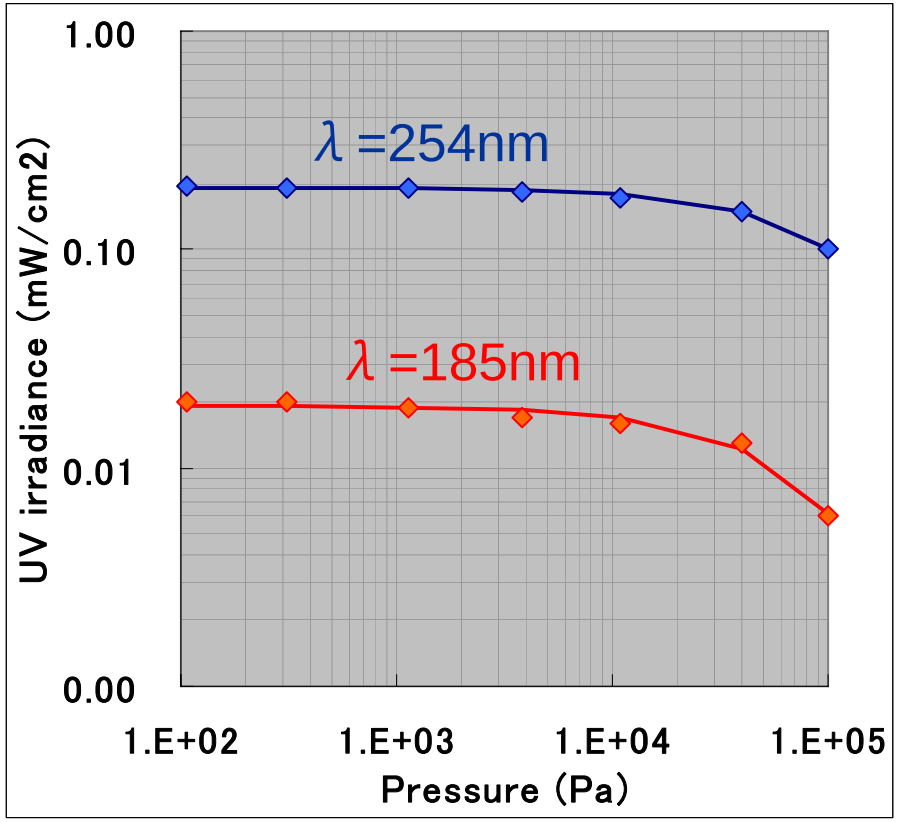
UV source distance
= 100mm

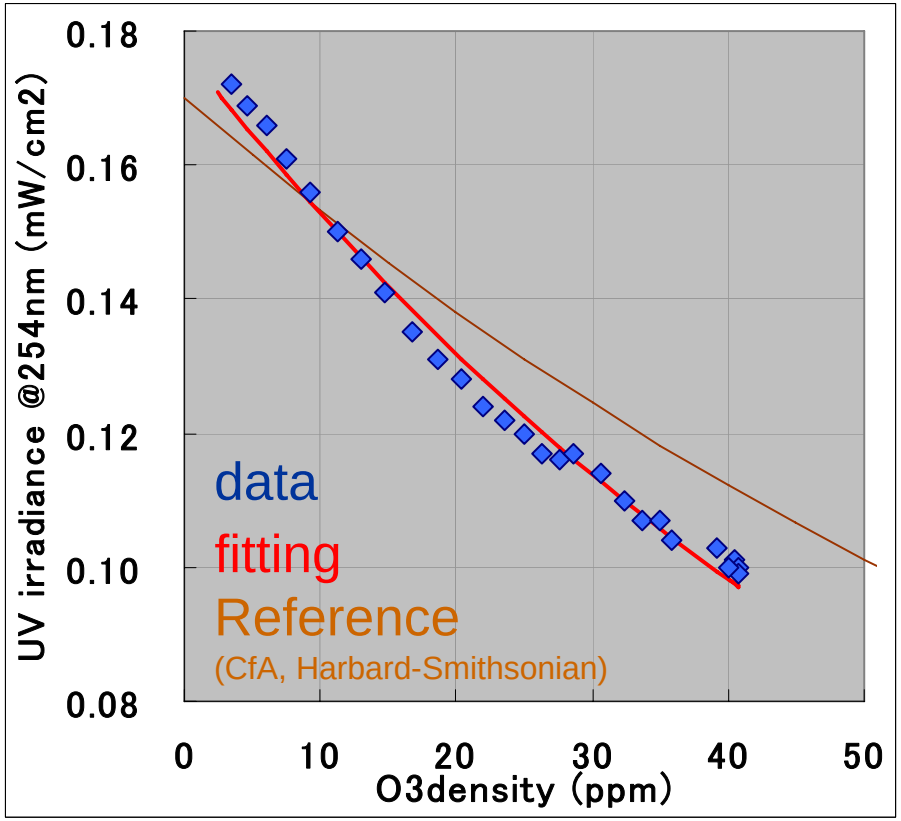
⇓

Pressure range
⇒ 2E+2 ～ 9E+3 [Pa]

Absorption cross section

➢ UV irradiance are measured as functions of the pressure and density.



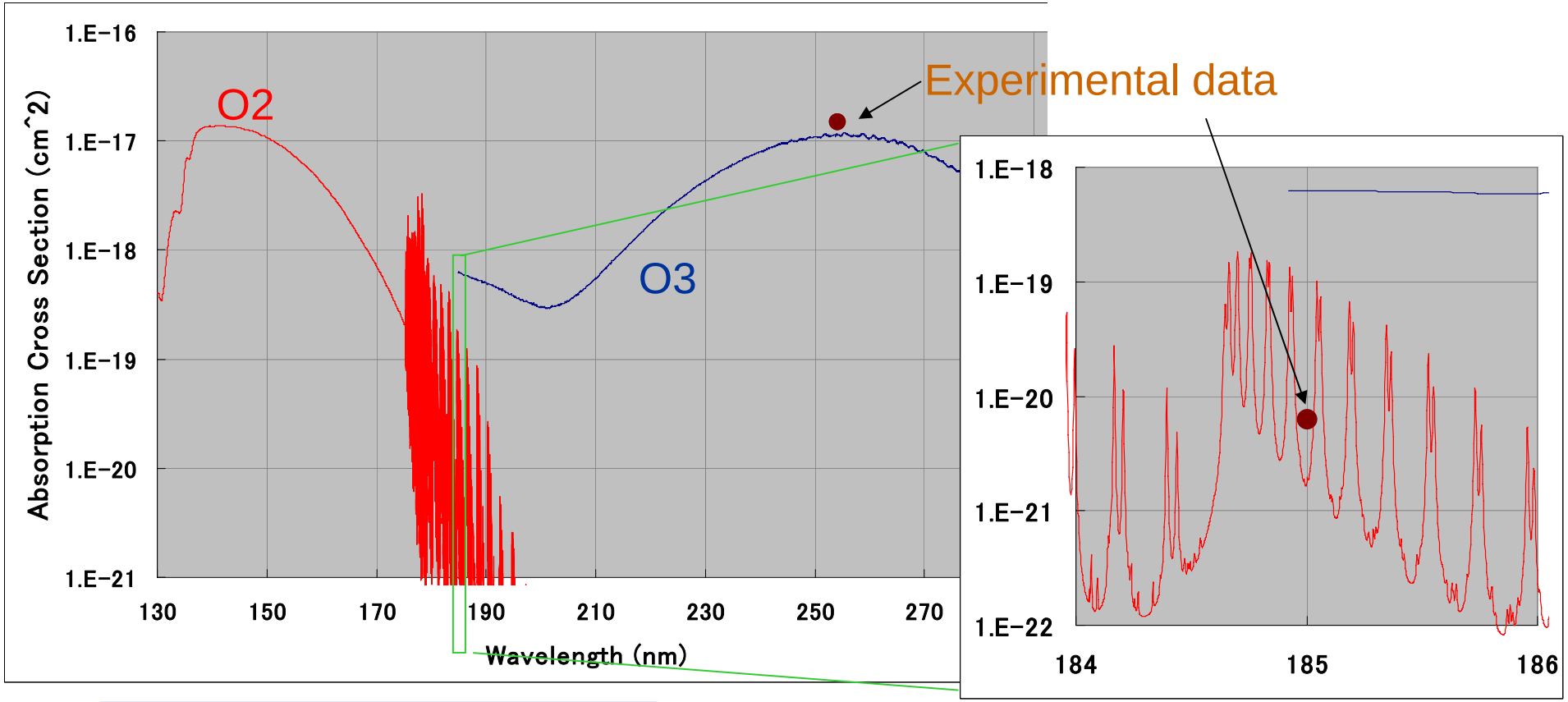


$$E = E_0 \exp(-\mu prx)$$

E: irradiance *r*: density
p: Pressure *x*: path length
μ: Absorption coefficient

Absorption cross section

- Absorption cross section of the O2 in the Schumann-Runge band was experimentally derived.



O3@254nm : 1.5E-17 cm^{-2}
O2@185nm : 6.3E-21 cm^{-2}

Summary

- UV dry cleaning utilizing a low pressure mercury lamp has high cleaning rate and high applicability to EUV1.
- Carbon contamination on EUV optics can be removed using a commercially available UV cleaner.
  - Initial reflectivity was recovered.
  - Over exposure didn't degrade reflectivity.
- "Low-Pressure" UV cleaning has higher cleaning rate by reducing the pressure, and strong pressure dependency.
  - High-pressure region: Cleaning efficiency is determined by UV transmission, and increases greatly in proportion to the transmission.
  - Low-pressure region: Cleaning efficiency is roughly determined by *not* the amount of O2 *but* the lifetime of oxygen radical.
- "Low-Pressure" UV cleaning rate: 0.061±0.006 [nm/min.]

  @0.01atm, @100mm, when 1.6mWcm^{-2}@ λ 254nm
- Absorption cross section of the O2 in the Schumann-Runge band was experimentally derived.