A model to describe surface physics in EUVL optics mirror contamination

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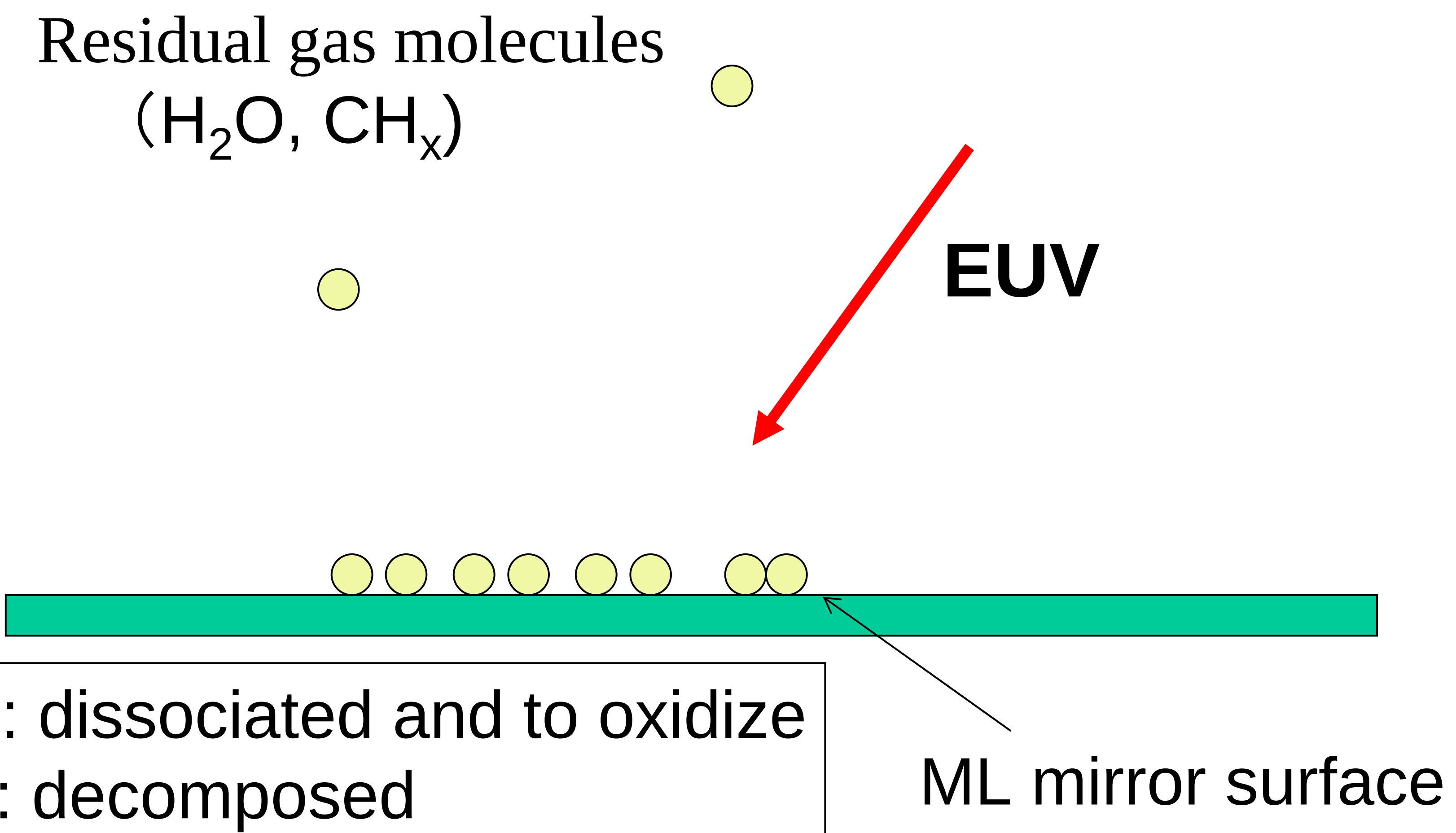
Purpose

Describe surface physics in mirror contamination.

Analyze the condition of acceleration test.

Estimate the difference in irradiation results between pulse and more continuous irradiation conditions.

Schematics of surface Physics



H_2O: dissociated and to oxidize
CH_x: decomposed

Model

Adsorption of residual gas species is described by

$$d\sigma_i/dt = S_i\Gamma_i - \sigma_i/\tau_i - \eta_i P \qquad (1)$$

σ_i: surface areal density of i-th residual gas molecules ($/cm^2$)
S: sticking probability
Γ: arriving rate of residual gas molecules ($/cm^2.s$)

$$\Gamma = n_i v_{thi}/4$$

τ: mean residence time (s)
η: photon-induced desorption coefficient (molecules/photon)
P: EUV photon flux ($/cm^2.s$)

When P is large, the second term can be neglected.
If not, σ_i is determined by thermal process: thus it does not depend on P.

In continuous irradiation, steady state is given by

$$S_i\Gamma_i = \eta_i P \qquad (2)$$

In pulse irradiation,

$$S_i\Gamma_i\Delta t_f = \eta_{mi}P_{mp}\Delta t_p \qquad (3)$$

$\Delta t_f/\Delta t_p$: pulse-to-pulse/pulse duration, P_p: pulse power

Photon-induced desorption is expressed by

$$\eta_i = \eta_{i0}(\sigma_i/\sigma_{i0})^n \qquad (4)$$

η_{i0} is η_i @ σ_{i0}. In both cases, using mean power P_m

$$\sigma_{im} = \sigma_{i0}(S_i\Gamma_i/P_m\eta_{i0})^{1/n} \qquad (5)$$

Acceleration test

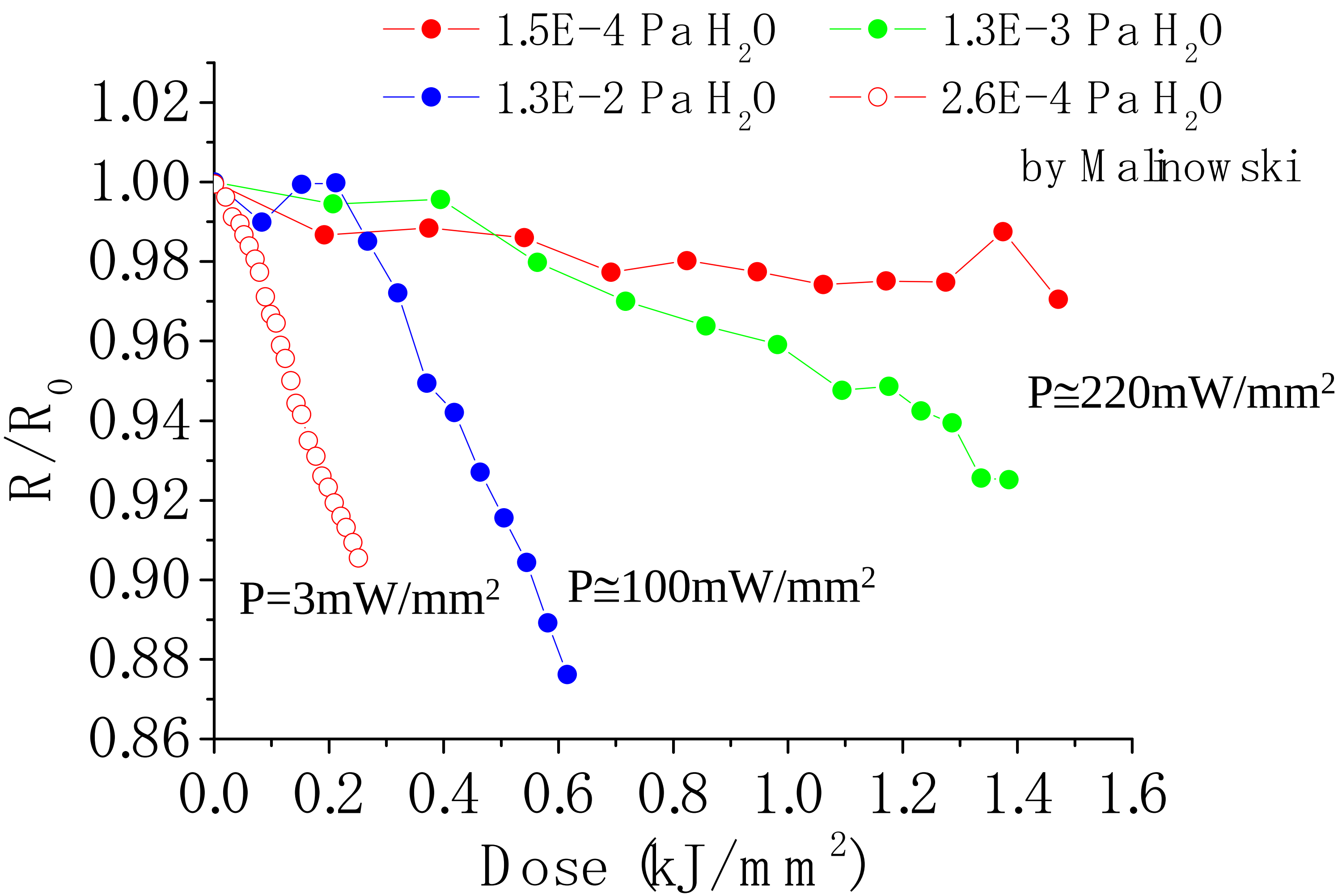
We assume that EUV-exited process is proportional to $\int P\sigma_i dt$. Using Eq. (5),

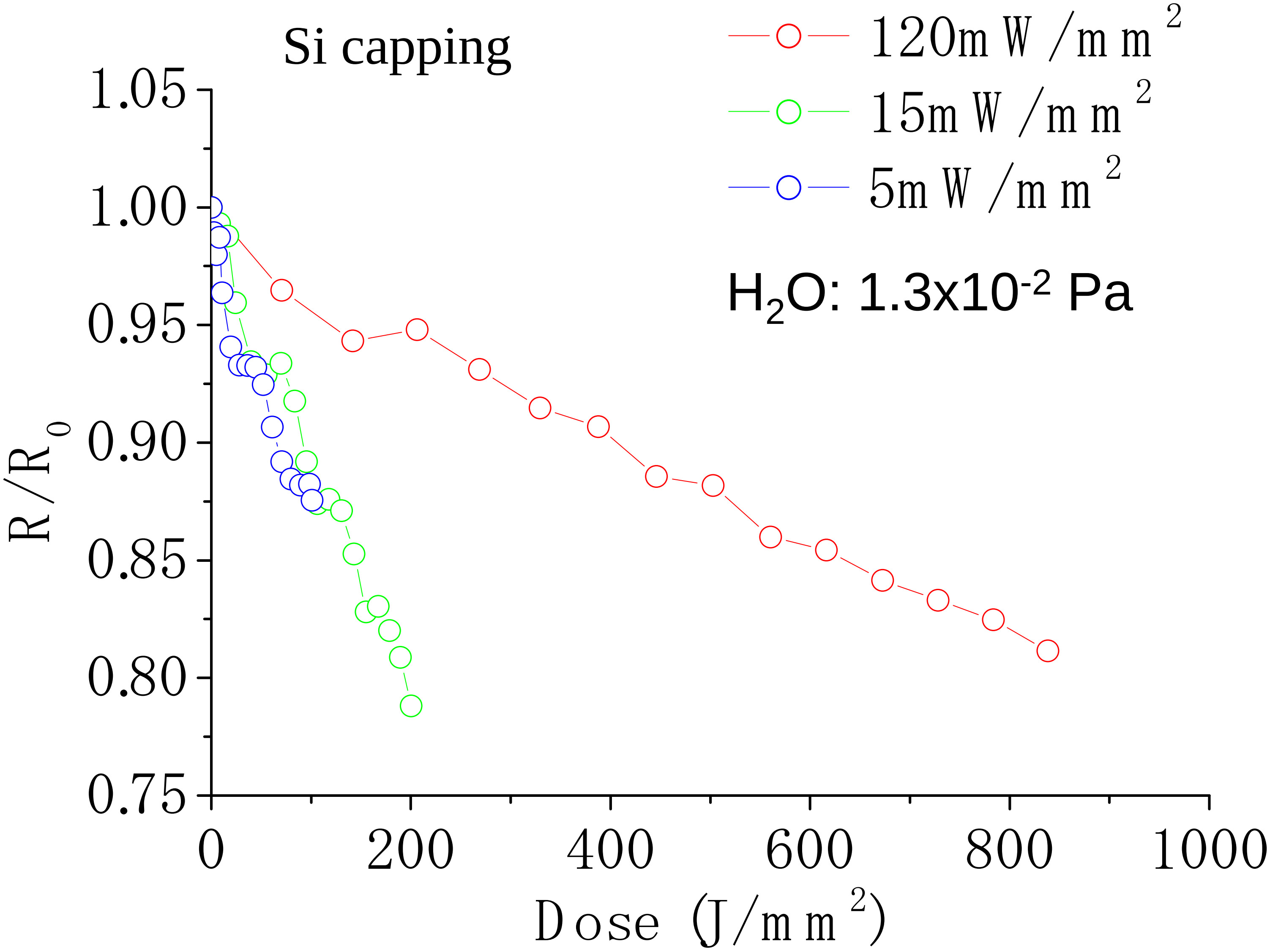
$$\int P\sigma_i dt \propto \Gamma_i^{1/n} P^{(1-1/n)}, \qquad (6)$$

suggesting that if we increase P by a factor of M, we should also increase Γ_i or the corresponding residual gas pressure by M.

This is somewhat obvious from Eq. (2) or (3). Namely, σ_i does not change in this condition, and $\int P\sigma_i dt$ is resultantly proportional to P.

Si capping


1.5E-4 Pa H2O
1.3E-3 Pa H2O
1.3E-2 Pa H2O
2.6E-4 Pa H2O
by Malinowski
P≅220mW/mm2
P≅100mW/mm2
P=3mW/mm2
R/R0
Dose (kJ/mm2)
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

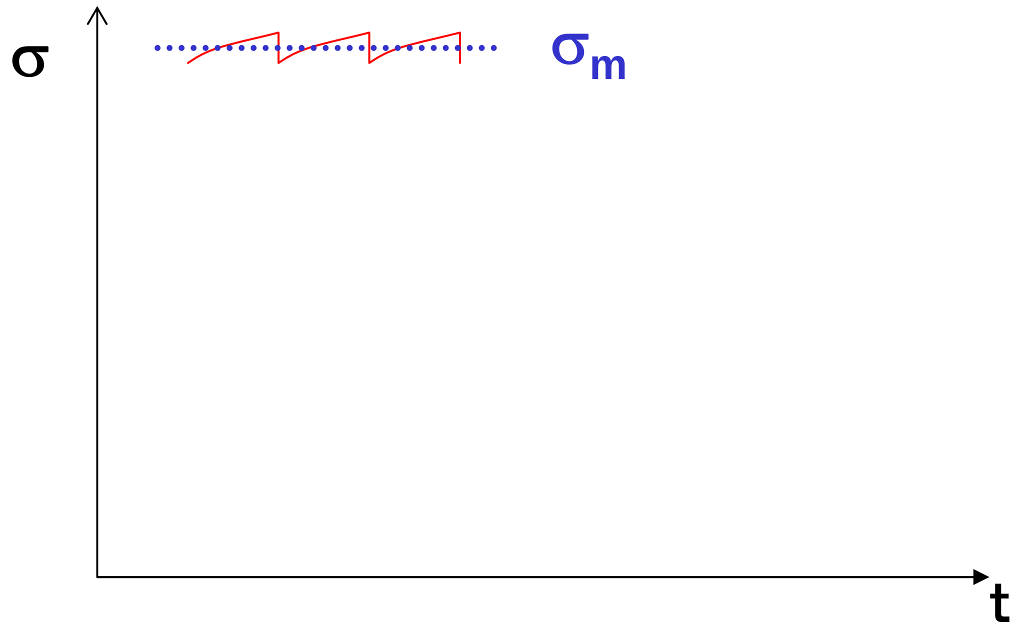

Si capping
120mW/mm2
15mW/mm2
5mW/mm2
H2O: 1.3x10-2 Pa
R/R0
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0
200
400
600
800
1000
Dose (J/mm2)

Pulse and more continuous operation

If photon-induced desorption is not dominant, σ is almost constant.
Even when photon-induced desorption is dominant,

$$\sigma_{im} = \sigma_{i0}(S_i\Gamma_i/P_m\eta_{i0})^{1/n} \quad (5)$$

$$\sigma_{im} >> S_i\Gamma_i\Delta t_f$$



Typical estimation

Pulse frequency: 10kHz

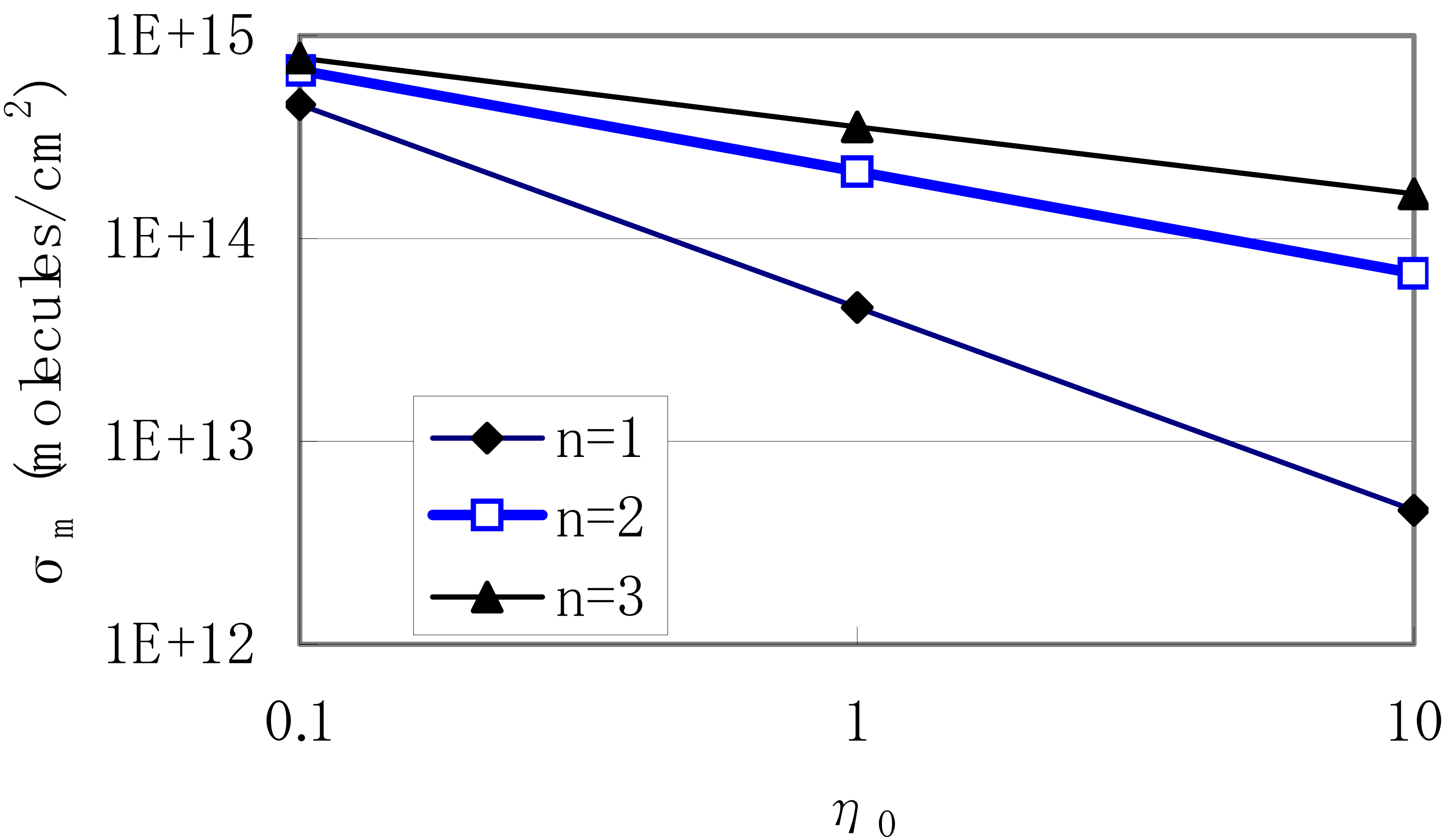
P_m: 2000mW/cm^2

H_2O: 3x10^{-3} Pa

S=0.5

$$S\Gamma\Delta t_f = 6.2\times10^{11}\ (\text{molecules/cm}^2).$$

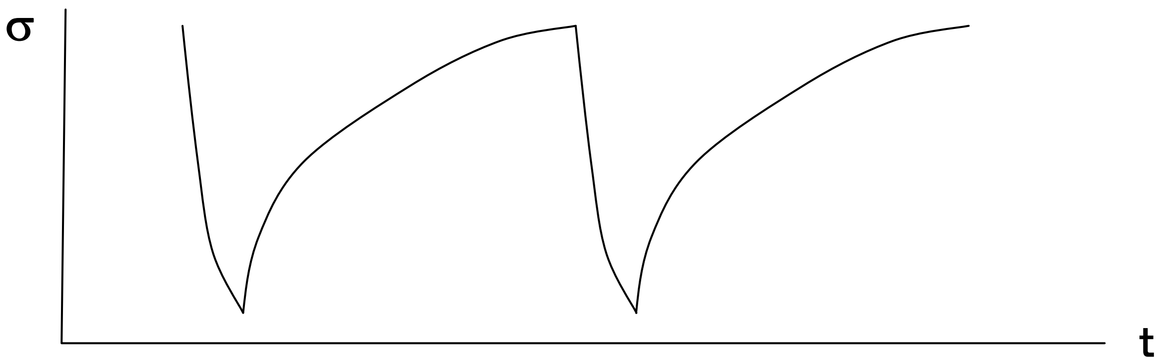
$$\sigma_i = \sigma_{i0}(S_i\Gamma_i/P_m\eta_{i0})^{1/n} \qquad (5)$$



η_0: η for monolayer ($\sigma_0 = 10^{15}$ molecules/cm^2)

$S\Gamma\Delta t_f = 6.2 \times 10^{11}$

When do we have difference by pulse irradiation?



This happens when (1) the pulse frequency is small and (2) the corresponding residual gas pressure is high.

Summary

The surface physics model tells:

1. In acceleration test, the pressure of the corresponding gas should be increased proportionally to the photon intensity (P) increase when P is large.

2. Pulse irradiation in typical EUVL tools can be simulated by using more continuous irradiation as far as $\int P\sigma_i dt$ describes reaction.

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