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A model to describe surface physics in EUVL optics mirror contamination

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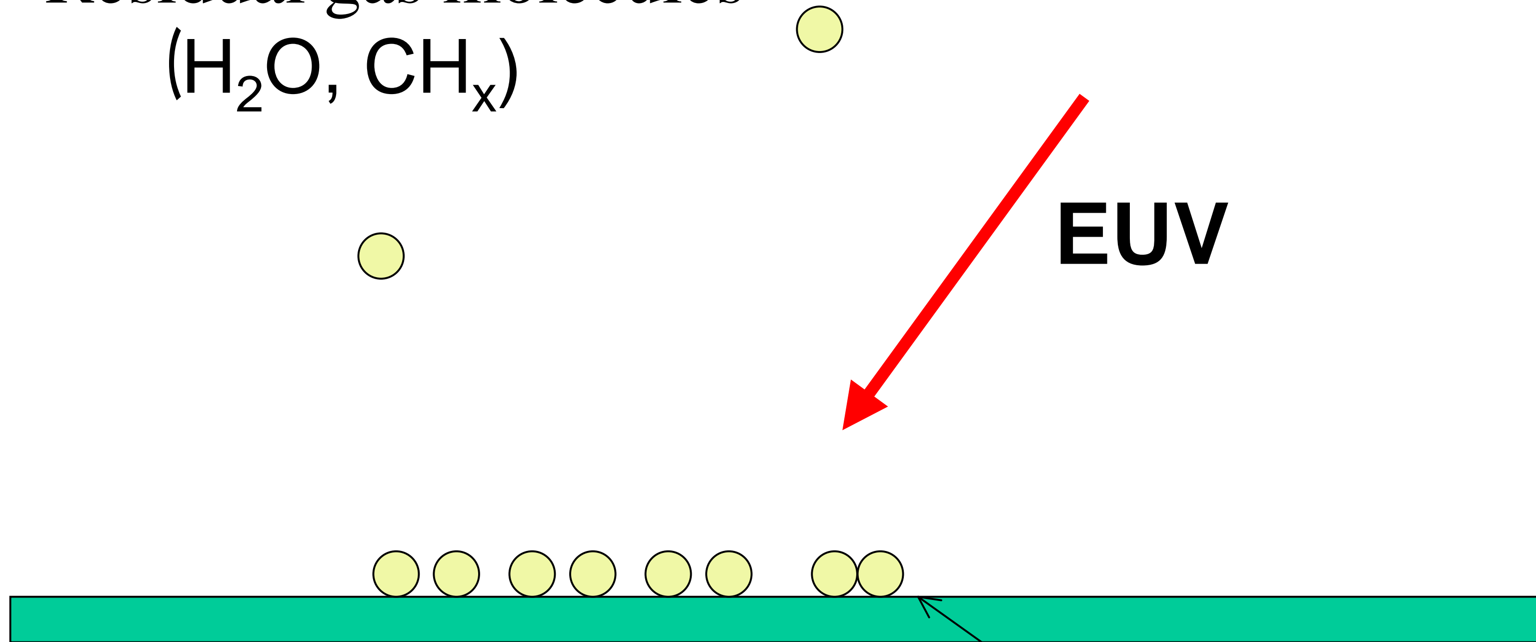
Backgroud

Multilayer (ML) mirror of projection optics in EUVL tools is oxidized by the influence of H_2O in residual gases and carbon deposition may also take place. Resultantly, EUV reflection rate is reduced.

Purpose

To propose a model to describe surface physics in mirror contamination, analyze the condition of acceleration test, and estimate whether or not we have difference in irradiation results between pulse and more continuous irradiation conditions.

Schematics of surface Physics



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.

In continuous irradiation, steady state is given by

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

In pulse irradiation,

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

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

Photon-induced desorption is expressed by

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

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

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

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

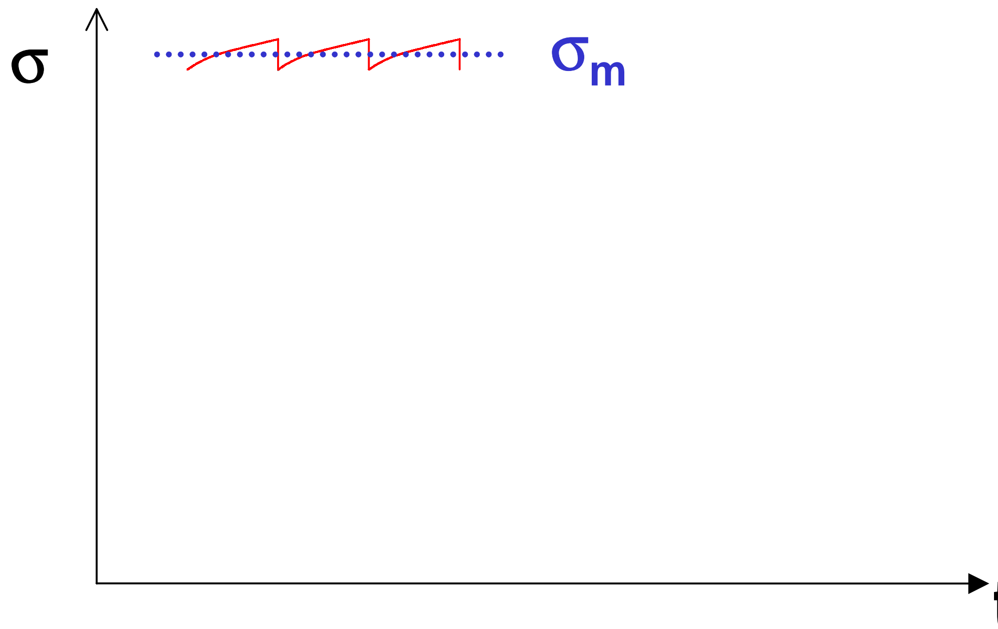
$$\int P\sigma_i dt \propto \Gamma_i^{1/n} P^{(1-1/n)}, \qquad (6)$$

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.

Pulse and more continuous operation

If the condition $\sigma_{im} >> S_i \Gamma_i \Delta t_f$ is satisfied, it implies that difference between pulse and more continuous operation is small. This is because the arriving quantity during the pulse is so much smaller than the existing amount on the surface.



Typical estimation

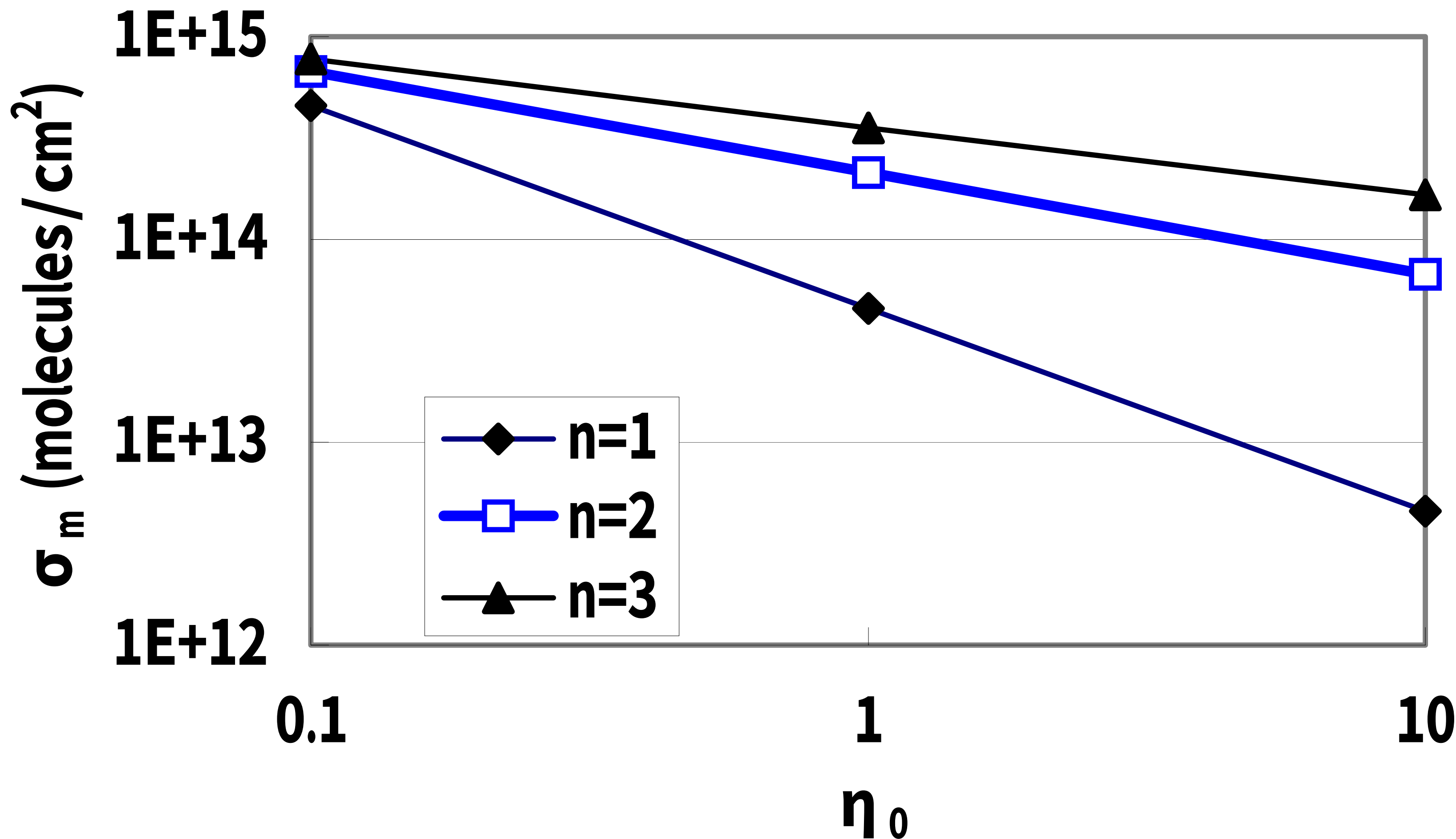
Assuming a pulse frequency of 10kHz, mean EUV irradiation power (P_m) of 20mW/cm^2 which should be converted to photon flux, H_2O pressure of $3x10^{-5}$ Pa and S=0.5, the arriving quantity during the pulse is given as

$$S\Gamma\Delta t_f = 6.2x10^9 \text{ (molecules/cm}^2\text{)}.$$

The existing amount on the surface is estimated by Eq. (5) which is

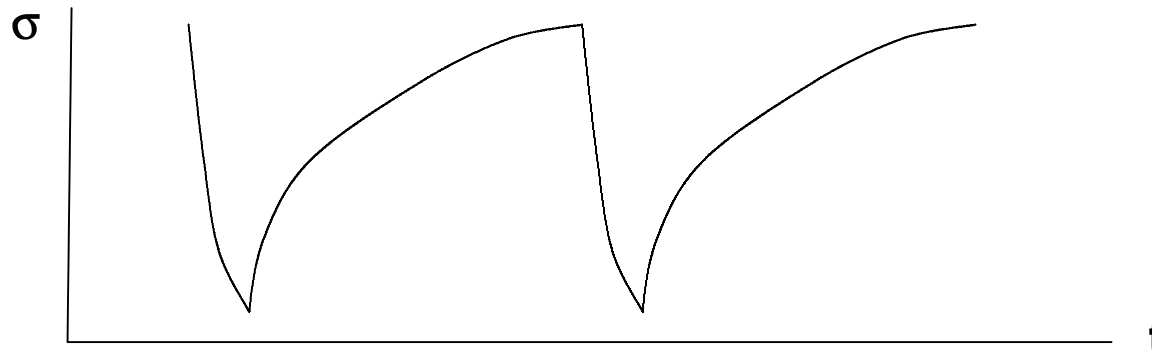
$$\sigma_i = \sigma_{i0}(S_i\Gamma_i/P_m\eta_{i0})^{1/n}, \qquad (5)$$

taking η_{i0} and n as parameters.



η_0 is the value for monolayer ($\sigma_0=10^{15}$ molecules/cm^2)

The condition $\sigma_{im} >> S_i \Gamma_i \Delta t_f$ is satisfied with a margin of more than 3 orders of magnitude. Thus, the author concludes that the difference between pulse and more continuous operations is quite small. When do we have difference?



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

Summary

The surface physics model tells:

- In acceleration test, the pressure of the corresponding gas should be increased proportionally to the photon intensity increase.
- Pulse irradiation in EUVL tools can be simulated by using more continuous irradiation.

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