CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

Lecture 66
Line-Edge Roughness, part 2

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Stochastic Exposure

- Exposing a resist to generate acid is a stochastic process
- For a given volume V, there is a random number of:
  - Photoacid Generators (Poisson distribution)
  - Absorbed photons (Poisson distribution)
  - Exposure events (1st order kinetics)
- Defining the probability of each event, we can calculate the uncertainty in the acid concentration

Stochastic 193-nm Resist Acid Uncertainty

$$\frac{\sigma_h^2}{\langle h\rangle^2} = \frac{1}{\langle h\rangle\langle n_{0-PAG}\rangle} + \left(\frac{(1-\langle h\rangle)\ln(1-\langle h\rangle)}{\langle h\rangle}\right)^2 \frac{1}{\langle n_{0-PAG}\rangle\langle n_{photons}\rangle}$$

(Mean relative acid concentration: $\langle h\rangle$; Mean initial number of PAGs: $\langle n_{0-PAG}\rangle$)

$$\langle n_{photons}\rangle = A\langle E\rangle \frac{\lambda}{hc} \qquad \langle h\rangle = 1 - e^{-C\langle E\rangle}$$

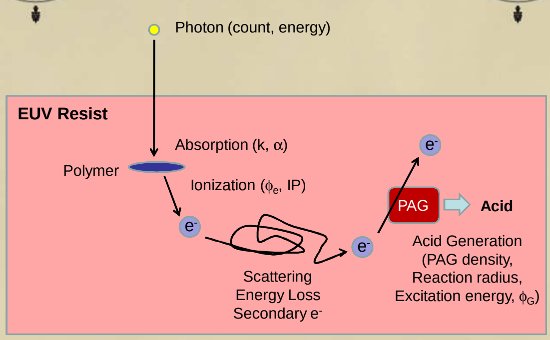
(Mean number of incident photons: $\langle n_{photons}\rangle$; Area: A; Mean exposure dose: $\langle E\rangle$)

Planck's constant h = 6.62606957 X 10^{-34} Js
Speed of light c = 2.99792 X 10^{8} m/s

For λ = 193 nm,

$$\frac{hc}{\lambda} = 1.03\text{x}10^{-18}\ J/photon$$

EUV Stochastic Resist Model



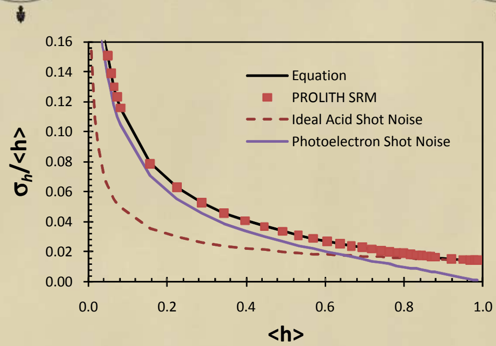
Stochastic EUV Resist Acid Uncertainty

$$\frac{\sigma_h^2}{\langle h\rangle^2} = \frac{1}{\langle h\rangle\langle n_{0-PAG}\rangle} + \left(\frac{(1-\langle h\rangle)\ln(1-\langle h\rangle)}{\langle h\rangle}\right)^2 \frac{1}{\langle n_{photoelectrons}\rangle}$$

$$\langle n_{photoelectrons}\rangle = \phi_e\langle n_{photons}\rangle\left(1-e^{-\alpha D}\right) \qquad \langle h\rangle = 1 - e^{-C\langle E\rangle}$$

Typical Values: ϕ_e = 0.9, α = 6.5 µm^{-1}, D = 50 nm, C = 0.08 cm^2/mJ

Components of Acid Uncertainty



How to Reduce EUV Acid Uncertainty?

(Assume dose is held constant)

Increase PAG Loading

$$\frac{\sigma_h^2}{\langle h\rangle^2}=\frac{1}{\langle h\rangle\langle n_{0-PAG}\rangle}+\left(\frac{(1-\langle h\rangle)\ln(1-\langle h\rangle)}{\langle h\rangle}\right)^2\frac{1}{\langle n_{photoelectrons}\rangle}$$

Increase Photoelectron Generation Efficiency

$$\langle n_{photoelectrons}\rangle=\phi_e\langle n_{photons}\rangle\left(1-e^{-\alpha D}\right)$$

Increase Absorption

$$\langle h\rangle=1-e^{-C\langle E\rangle}$$

Increase C

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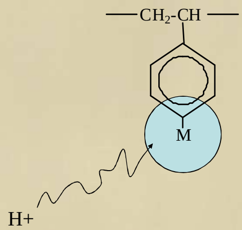
Stochastic View of Reaction-Diffusion

- Reaction is catalyzed by the diffusing species:



von Smoluchowski Trap:

Reaction can occur once acid approaches the blocking group within its capture radius, *a*.

$$Rate \propto a$$

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Stochastic View of Exposure + Reaction-Diffusion

- Final expression for the uncertainty in deblocked polymer concentration (for EUV resist):

$$\left(\frac{\sigma_m}{\langle m\rangle}\right)^2=\frac{1}{\langle n_{0-blocked}\rangle\langle m\rangle}+\left(K_{amp}t_{PEB}\right)^2\left(\frac{2a}{\sigma_D}\right)^2\left(\frac{\langle h\rangle}{\langle n_{0-PAG}\rangle}+\frac{\left[(1-\langle h\rangle)\ln(1-\langle h\rangle)\right]^2}{\langle n_{photo-electron}\rangle}\right)$$

Deblocking reaction — Reaction-diffusion — PAG concentration, exposure — Photon shot noise

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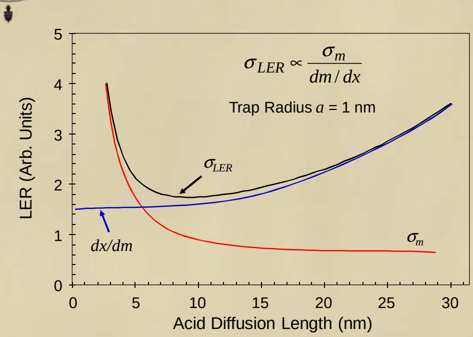
Line-Edge Roughness and Acid Diffusion



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Lecture 66: What have we Learned?

- What three stochastic components contribute acid uncertainty after exposure?
- Be able to use the 193-nm and EUV resist stochastic equation to work problems
- How can acid uncertainty in an EUV resist be reduced?
- Why is there an optimum acid diffusion length for minimizing LER?

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