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

Lecture 67
Line-Edge Roughness, part 3

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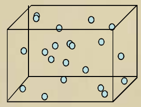
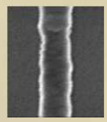
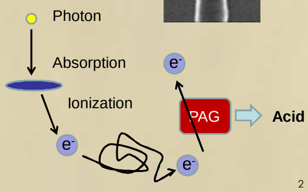
Randomness in Lithography

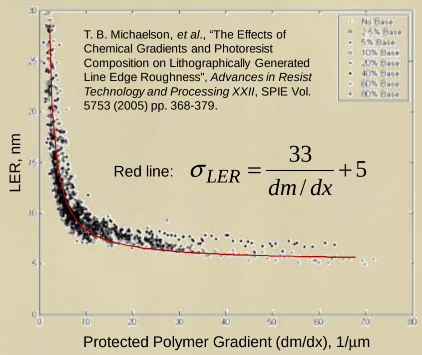
- Photon count
- PAG positions
- Absorption/acid generation
- Polymer chain length
- Blocking position
- Reaction-diffusion
- Dissolution







Impact of Gradient on LER



Line-Edge Roughness (Simple Model)

- Consider a small deviation in resist development rate. The resulting change in resist edge position will be approximately

$$\Delta x = \frac{dx}{dR}\Delta R$$

- For some variation in development rate σ_R,

$$\sigma_{LER} = \frac{\sigma_R}{dR/dx} \approx \frac{\sigma_m}{dm/dx}$$

Line-Edge Roughness (A Simple Model)

- Add the finite size of a resist molecule, σ_0

$$\sigma_{LER} = \frac{\sigma_m}{dm/dx} + \sigma_0 \quad = \frac{noise}{gradient} + pixel\ size$$

- What affects the three terms of this model?
  - Molecular size
  - Acid diffusion length
  - Dose
  - Image NILS
  - Others…

Stochastic View of Exposure + Reaction-Diffusion

- Uncertainty in deblocked polymer concentration:

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

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

Effect of Polymer Size

- As polymer size increases ($\uparrow$):

$$\sigma_{LER} = \frac{\sigma_m \downarrow}{dm/dx} + \sigma_0 \uparrow$$

- Solubility of the polymer is a function of the total number of deprotection events associated with that polymer
- These events are averaged over the volume of one polymer
- There is an optimum polymer size

Effect of Diffusion

- As diffusion length increases ($\uparrow$):

$$\sigma_{LER} = \frac{\sigma_m \downarrow}{dm/dx \downarrow} + \sigma_0$$

- Smoothing is caused by the diffusion of a catalyst
- This catalyst diffusion leads to correlation
- Diffusion also smears away the image

Effect of Dose

- As dose increases ($\uparrow$):

$$\sigma_{LER} = \frac{\sigma_m \downarrow}{dm/dx \uparrow} + \sigma_0$$

- Increasing dose improves the chemical gradient (to a point)
- Increasing dose reduces uncertainty (to a point)
- Diminishing returns for higher dose (in fact, there is an optimum), but we are a long ways away from that for EUV

Optimizing LER

- There is an optimum polymer size
  - Current materials are probably close to optimum
- There is an optimum diffusion length
  - Current materials probably diffuse too much
  - Optimum diffusion length scales with feature size
  - There is a dose penalty for lower diffusivity
- There is an optimum dose
  - The best dose is higher than what we now use (definitely true for EUV)

Conclusions

- LER is the ultimate limiter to resolution in optical lithography (for both EUV and 193i)
  - Current best LER results for EUV is not good enough
- A good LER model is needed to optimize resist process and material properties and to find the minimum possible LER
  - Progress is being made, but a predictive LER model does not yet exist
  - How low can LER go? What is the ultimate resolution limit? Will we understand LER before it is too late?

Lecture 67: What have we Learned?

- What are the three terms of our basic LER model?
- How does polymer size affect those three terms?
- How does diffusion length affect those three terms?
- How does dose affect those three terms?