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

Lecture 65
Line-Edge Roughness, part 1

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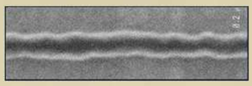
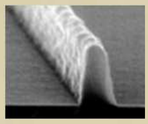
What is LER?

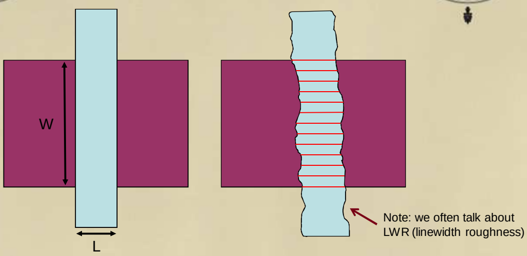
- Line-edge roughness (LER) - The deviation of a feature edge (as viewed top-down) from a smooth, ideal shape. That is, random (stochastic) edge deviations of a feature.





From: Chris A. Mack, Fundamental Principles of Optical Lithography: The Science of Microfabrication, John Wiley & Sons, (London: 2007).

Simple Device Model for LER



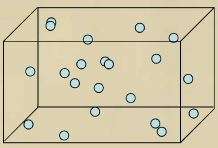
Break the transistor into many small 1D devices of different lengths, then sum up their currents to get the full device current.
Result: 1) increased leakage current for the rough gate
2) average CD error affects transistor speed/leakage

Continuum Approximation

- The real world is discrete (photons, atoms, etc.), but most macroscopic models (e.g., litho simulation) make the *continuum approximation*
  - Matter and energy are described with continuous mathematical functions
  - Ex: aerial image intensity, acid concentration after exposure, resist dissolution
- What are the implications of making the continuum approximation?
  - Line-edge roughness cannot be predicted

Continuum Approximation: Chemical Concentration

- Concentration: The number of atoms or molecules of a certain type per unit volume
  - By necessity, an average over a volume
- What is the meaning of H(x,y,z) – the concentration of acid at a specific point in space?



Stochastic View of Chemical Concentration

- Model atom/molecule as a point located at its center of mass
- Consider a volume V – is the molecule in the volume or not?
  - This is a binary proposition, governed by the binomial distribution: $P(n)$ = probability of finding n molecules in V

$$P(n) = \binom{N}{n}(CdV)^n(1-CdV)^{N-n} = \frac{N!}{(N-n)!n!}(CdV)^n(1-CdV)^{N-n}$$

$N = V/dV$, C = average number of molecules per unit volume

- These statistics do not apply if the concentration is very high (atom is not a point), or if there are intermolecular interactions that affect position (e.g., agglomeration)

Stochastic View of Chemical Concentration

- The binomial probability distribution can be well approximated a Poisson distribution

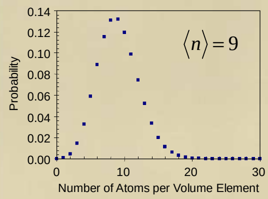
$$P(n) = \frac{(CV)^n}{n!} e^{-CV}$$

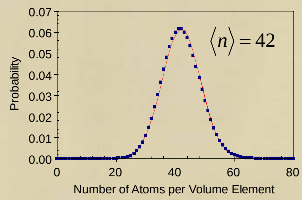
$$\langle n \rangle = CV \qquad \sigma_n^2 = CV$$

$$\frac{\sigma_n}{\langle n \rangle} = \frac{1}{\sqrt{\langle n \rangle}} = \frac{1}{\sqrt{CV}}$$

Stochastic View of Chemical Concentration

- Also, if CV > 20, the Poisson probability distribution can be well approximated a Gaussian distribution





(Gaussian: solid red line)

Stochastic View of Chemical Concentration

- Example: for a typical 193nm resist formulation, G_0N_A = 0.042 /nm^3 (G_0 = the initial concentration of PAG, N_A = Avogadro's number)

For V = (3 nm)^3 $\langle n \rangle = 1.13$ $\sigma_n / \langle n \rangle = 94\%$

For V = (6 nm)^3 $\langle n \rangle = 9$ $\sigma_n / \langle n \rangle = 33\%$

For V = (10 nm)^3 $\langle n \rangle = 42$ $\sigma_n / \langle n \rangle = 15\%$

Photon Shot Noise (Also Poisson)

- Example: for a typical 193nm resist with 10 mJ/cm^2 dose to clear,

For A = (1 nm)^2 $\langle n \rangle = 97$ $\sigma_n / \langle n \rangle = 10\%$

For A = (10 nm)^2 $\langle n \rangle = 9700$ $\sigma_n / \langle n \rangle = 1\%$

- Example: for an EUV resist with 5 mJ/cm^2 dose to clear,

For A = (1 nm)^2 $\langle n \rangle = 3$ $\sigma_n / \langle n \rangle = 58\%$

For A = (10 nm)^2 $\langle n \rangle = 300$ $\sigma_n / \langle n \rangle = 6\%$

Lecture 65: What have we Learned?

- Define line-edge roughness (LER)
- What is the continuum approximation?
- Photon and concentration shot noise follow what probability distribution?
- How are the mean and variance related for a Poisson distribution?