CHE323/384 Chemical Processes for Micro- and Nanofabrication
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Homework #14 Solutions

1. The time required to process a wafer in an EUV lithography tool is the sum of the actual time spent exposing and the overhead time (to load and unload the wafer, move between scans, etc.). Suppose that a tool has an overhead time of 8 seconds per wafer. Further suppose that this tool has a throughput of 60 wafers per hour when the photoresist requires an exposure dose of 15 mJ/cm^2. How much will the throughput be reduced if the required dose increases to 25 mJ/cm^2? What will the throughput improve to if the required dose decreases to 10 mJ/cm^2?

At a throughput of 60 wph, that gives 60 seconds per wafer. With an overhead of 8 seconds, the exposure time is 52 seconds per wafer at a 15 mJ/cm^2 dose. Assuming the scan speed is does-limited rather than stage limited, an increase to 25 mJ/cm^2 dose will cause an increase in exposure time to 52(25/15) = 86.67 s. Add back the 8 seconds of overhead, and that gives a processing time of 1.5778 minutes per wafer, or a throughput of 60/1.5778 = 38 wph.

A similar calculation for the 10 mJ/cm^2 dose gives a throughput of 87 wph.

2. Explain the main advantages and disadvantages of EUV lithography versus 193-nm double patterning for the production of 25 nm lines and spaces.

The most important factor is cost, assuming a process that achieves the same yield. If EUV can achieve 125 wph at a dose that enables good LER (and thus good yield), it should be about the same cost as 193-nm lithography using double patterning. Then EUV will be preferred because of the easier design and maskmaking associated with single patterning. On the other hand, 193-nm immersion lithography is well understood with good resists, reliability, etc. There are almost no unknowns. Thus, it is the same bet.

3. Consider a wafer with a mean dopant concentration of 7×10^{18} cm^{-3} in the channel region of the transistor. If the channel length is 30 nm, the channel width is 60 nm, and the channel depth is 15 nm, what is the mean and standard deviation of the number of dopant atoms in the channel. Assume the dopant number of atoms follows a Poisson distribution.

The mean number of dopants is the concentration times the volume.

$$\langle n \rangle = CV = \frac{7 \text{ X } 10^{18}}{cm^3}\left(\frac{cm}{1 \text{ X } 10^7 nm}\right)^3 (30nm)(60nm)(15nm) = 189$$

For a Poisson distribution, and variance equals the mean. Thus, the standard deviation in the number of dopants is $\sqrt{189} = 14$.

4. Assuming that a certain amount of acid is required to achieve a desired lithographic effect (that is, assuming the mean concentration of photogenerated acid is fixed), how low can the mean number of photons go before photon shot noise exceeds the PAG loading shot noise for an EUV resist and for a 193-nm resist? Assume for both cases that $\langle h \rangle$ = 0.3, the PAG loading is $\rho_{PAG} = \langle n_{0-PAG} \rangle / V$ = 0.05 /nm^3, and the region of interest is (10 nm)^3. Also, assume typical values for EUV resist parameters: ϕ_e = 0.9, α = 6.5 μm^{-1}.

For an EUV resist:

$$\frac{\sigma_h^2}{\langle h \rangle^2} = \frac{1}{\langle h \rangle \langle n_{0-PAG} \rangle} + \left(\frac{(1-\langle h \rangle)\ln(1-\langle h \rangle)}{\langle h \rangle} \right)^2 \frac{1}{\langle n_{photoelectrons} \rangle}, \quad \langle n_{photoelectrons} \rangle = \phi_e \langle n_{photons} \rangle \left(1 - e^{-\alpha D}\right).$$

From the problem, we have $\langle n_{0-PAG} \rangle = \rho_{PAG} V = 0.05(10)^3 = 50$. Also,

$$\left(\frac{(1-\langle h \rangle)\ln(1-\langle h \rangle)}{\langle h \rangle} \right)^2 = 0.693\,.$$

Our goal is to find the number of photons that makes the two terms in this equation equal:

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

Plugging in the numbers, we get $\langle n_{photoelectrons} \rangle = 10.4$. Then, using D = 10 nm (from the volume of interest), we have

$$\langle n_{photons} \rangle = \frac{\langle n_{photoelectrons} \rangle}{\phi_e \left(1 - e^{-\alpha D}\right)} = 184.$$

For a 193-nm resist, $\frac{\sigma_h^2}{\langle h \rangle^2} = \frac{1}{\langle h \rangle \langle n_{0-PAG} \rangle} + \left(\frac{(1-\langle h \rangle)\ln(1-\langle h \rangle)}{\langle h \rangle} \right)^2 \frac{1}{\langle n_{0-PAG} \rangle \langle n_{photons} \rangle}$. Thus, we get, as above, $\langle n_{0-PAG} \rangle \langle n_{photons} \rangle = 10.4$ and thus $\langle n_{photons} \rangle = 0.2$.

In other words, it is almost impossible for a 193-nm resist to be photon shot-noise limited. For an EUV resist, however, it is likely that the acid uncertainty will be photon shot-noise limited.