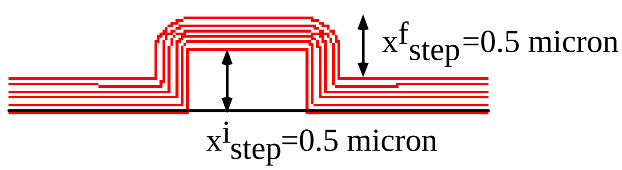
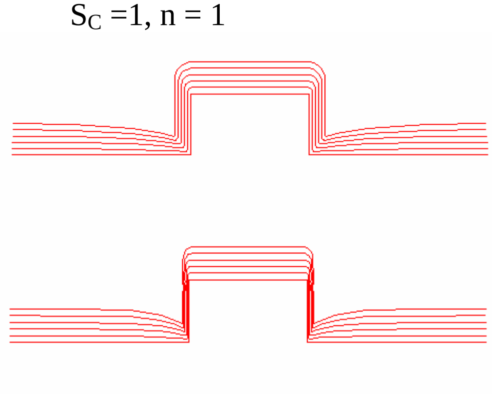
10.6. It is found that a certain plasma etch chemistry in a certain RIE etch system produces vertical sidewalls with zero etch bias when etching a particular film. Adding chemical A to the etch chemistry results in non-vertical sidewalls, and an etch bias. Adding chemical B to the original etch chemistry results in non-vertical sidewalls, but with zero etch bias. Explain what may be going on.

Answer:

Adding A results in a higher active species to inhibitor ratio (either by increasing free radical production or decreasing inhibitor/polymer formation), reducing the sidewall inhibitor formation relative to the etch rate, and leading to more isotropic etching. Adding B results in a lower active species to inhibitor ratio, increasing the the sidewall inhibitor formation relative to the etch rate. This increases the inhibitor deposition to etch ratio, enough so that excess inhibitor forms. This leads to sloped sidewalls, as illustrated in Figure 10-14 or 10-24c, with no undercutting, or etch bias.



S_C =1, n = 1 S_C =1, n = 5



10.11. We want to see how the etch rate in the vertical direction might depend on pressure assuming that the etch follows the saturation/adsorption model. Assume that for a particular etch system that the chemical flux is directly proportional to the pressure, while the ion flux is inversely proportional to the pressure. That is $F_c=F_c'*P$ and $F_i=F_i'/P$. (P is normalized to 1 atm and unitless.) Also assume that density = 1 atom/nm^3, and that $K_iF_i' = S_cF_c' = 1$ atom/nm^2/sec.

a. Plot the vertical etch rate versus pressure, P, from P = 0 to 10.

b. Repeat with $K_iF_i' = 40$ atoms nm^{-2} sec^{-1} and $S_cF_c' = 1$ atom nm^{-2} sec^{-1}.

Answer:

In the vertical direction, the etch rate will have contributions from both the chemical and ionic etch components, but acting an a synergistic fashion. For the saturation/adsorption etch model (ion enhanced etching):

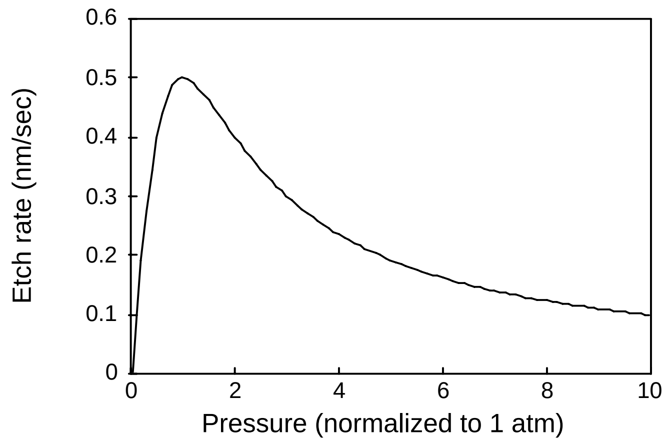
$$\text{Etch Rate} = \frac{1}{\text{density}} \frac{1}{\left(\frac{1}{K_i F_i} + \frac{1}{S_c F_c}\right)}$$

Plugging in $F_i=F_i'/P$ and $F_c=F_c'*P$, the density = 1 atom/nm^3, and that $K_iF_i' = S_cF_c'$ = 1 atom/nm^2/sec gives:

$$\text{Etch rate} = \frac{1}{\text{density}} \frac{1}{\left(\frac{1}{K_i F_i'/P} + \frac{1}{S_c F_c' * P}\right)}$$

$$= \frac{1}{1 \ \text{atom/nm}^3} \frac{1 \ \text{atom/nm}^2/\text{sec}}{\left(\frac{1}{1/P} + \frac{1}{1*P}\right)}$$

$$= \frac{1}{\left(P + \frac{1}{P}\right)} \text{nm/sec}$$



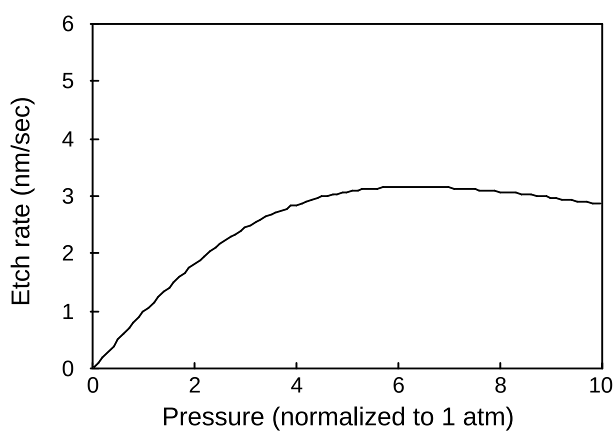
b. For K_iF_i' = 40 atoms/nm^2/sec and S_cF_c' = 1 atom/nm^2/sec:

Etch rate

$$= \frac{1}{\text{density}} \frac{1}{\left(\frac{1}{K_i F_i'/P} + \frac{1}{S_c F_c' * P}\right)}$$

$$= \frac{1}{1\ \text{atom}/\text{nm}^3} \frac{1\ \text{atom}/\text{nm}^2/\text{sec}}{\left(\frac{1}{40/P} + \frac{1}{1 * P}\right)}$$

$$= \frac{1}{\left(\frac{P}{40} + \frac{1}{P}\right)}\ \text{nm}/\text{sec}$$



4. (a) No loading ⇒ surface reactions do not reduce C_{Cl}

In steady state then,

$$0 = \frac{\partial C_{Cl_2}}{\partial t} = \frac{F_{Cl}}{V} - k_1 n C_{Cl_2} - \frac{S C_{Cl_2}}{V}$$

$$C_{Cl_2} = \frac{F_{Cl_2}/V}{k_1 n + S/V} \qquad (1)$$

$$0 = \frac{\partial C_{Cl}}{\partial t} = 2 k_1 n C_{Cl_2} - \frac{S C_{Cl}}{V}$$

$$C_{Cl} = \frac{2 k_1 n C_{Cl_2}}{S/V} = \frac{2 F_{Cl_2} k_1 n}{(k_1 n + S/V) S} \qquad (2)$$

(b) Near equilibrium ⇒

$$\frac{C_{Cl} N_{*Si*}}{N_{*SiCl}} = K_3(T) \qquad (3)$$

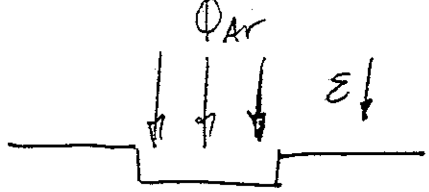
$$\frac{C_{Cl} N_{*SiCl}}{N_{ClSiCl}} = K_4(T) \qquad (4)$$

There are a fixed number of surface silicon atoms (N_{Si}) in the three possible states:

$$N_{*Si*} + N_{*SiCl} + N_{ClSiCl} = N_{Si} \qquad (5)$$

Solve (3), (4), (5) for $N_{ClSiCl} = \dfrac{N_{Si}}{1 + \dfrac{K_3}{C_{Cl}} + \dfrac{K_3 K_4}{C_{Cl}^2}}$

Etch rate w/o Ar^+ $= k_5 N_{ClSiCl} \Omega_{Si} = \dfrac{k_5 N_{Si} \Omega_{Si}}{1 + \dfrac{K_3 S (k_1 n + S/V)}{2 F_{Cl_2} k_1 n} + \dfrac{K_3 K_4 S^2 (k_1 n + S/V)^2}{(2 F_{Cl_2} k_1 n)^2}}$

(c) 

Due to $\mathcal{E}$-field, argon ion flux is primarily normal to surface and enhances etching vertically

Fraction of sites w/ 2 Cl's attached is $\dfrac{N_{Cl-Si-Cl}}{N_{Si}}$.

so vertical etch rate $= \left(\phi_{Ar}\dfrac{N_{ClSiCl}}{N_{Si}} + k_5 N_{ClSiCl}\right)\Omega_{Si}$

$$= \left(\frac{\phi_{Ar}}{N_{Si}} + k_5\right) N_{ClSiCl}\,\Omega_{Si}$$

$$\frac{\text{vertical rate}}{\text{lateral rate}} = \left(\frac{\phi_{Ar}}{N_{Si}} + k_5\right)\Big/ k_5 = \frac{\phi_{Ar}}{k_5 N_{Si}} + 1$$