

3.155J/6.152J
Microelectronic Processing
Fall Term, 2005

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Problem Set 5

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1. The Matrix Asher you use in the lab to remove photoresist from your wafers works using an oxygen plasma at a pressure of order 1 Torr. This pressure is higher than the plasma conditions for sputter deposition that we considered in class where the pressure range over which we plasmas were found to be stable was about from 1 mT to 100 mT.

a) Calculate the mean free path of an oxygen ion at 1 Torr assuming $T = 300$ K. (<http://www.iun.edu/~cpanhd/C101webnotes/modern-atomic-theory/atomic-radii.html>).

Ans. Because only a small fraction of the oxygen atoms in a plasma are ionized, the mean free path of the ions is not governed by electrostatic interactions but rather by atom size, so it can be calculated from the kinetic expression for collisions based on the impact parameter d . An oxygen O^+ ion (ionization potential 13.6 eV) has a radius of about 0.22 Å.

(<http://www.webelements.com/webelements/elements/text/O/radii.html>).

The pressure is (1 Torr $\times 10^5/760$) Pa, so mean free path $\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 P}$ is 3.7 mm.

b) Briefly describe the nature of the oxygen ions and the voltage needed to insure that they gain sufficient energy to ionize oxygen atoms? (Assume an electrode spacing in of 10 cm, 1 kW RF power at 13 MHz). Discuss.

Ans. Oxygen has an ionization potential of 13.6 eV (O^+) so we need to accelerate the oxygen ions to that kinetic energy over the distance of a mean free path.

$v_f^2 = 2ax$, $\frac{1}{2}mv_f^2 = Eq\lambda$ (Joules) = $E\lambda$ (eV). $E = 13.6$ V/3.7 mm = 3.7 kV/m, which is a voltage drop of 370 volts over 10 cm. The sheath over which the voltage drops could be much smaller than 10 cm, so the voltage applied needs to be scaled down from 370 by the ratio of the sheath thickness to the electrode spacing.

2. A typical dry CVD growth rate for gate-oxide-quality SiO_2 is about 0.1 $\mu\text{m/hr}$. For a special project, you consider that instead of dry CVD you will try reactive evaporation (evaporate Si while chamber is backfilled with a partial pressure of oxygen gas). Being cautious, you pump your chamber down to 10^{-7} T and do not backfill the chamber with any O_2 until you can measure the Si deposition rate.

a) Estimate the Si deposition rate if you heat the Si source to 1500 K and the chamber geometry is: crucible opening radius is 2 cm, chamber $r = 30$ cm (r defined in class notes).

Ans. $J_{\text{Si}} = \frac{P_{\text{vap}}}{\sqrt{2\pi m_{\text{Si}} k_B T_{\text{vap}}}} = 1.7 \times 10^{19} \text{ (Si/m}^2\text{s)}$ $v_{\text{Si}} = \frac{J_{\text{Si}}}{n_{\text{Si}}} \frac{A_c}{4\pi r^2} = 1.36 \text{ (nm/hr)}$

b) What partial pressure of O₂ would you need to use in order that the Si film grown under these conditions is fully oxidized (assume unit sticking and 100% reaction).

Ans. $P_{\text{O}_2} = J_{\text{O}_2} \sqrt{2\pi m_{\text{O}_2} k_B T}$ and the flux of oxygen ON THE SUBSTRATE should equal that of Si on substrate, $J_{\text{sub}} = n v_{\text{Si}} = 5 \times 10^{28} \text{ (m}^{-3}\text{)} \times 1.36 \text{ (nm/hr)} = 1.89 \times 10^{16} \text{ (Si or O}_2\text{/s} \times \text{m}^2\text{)}$. The result, being careful here to use $T = 300 \text{ K}$, is $P_{\text{O}_2} = 7 \times 10^{-7} \text{ Pa}$ or $5.4 \times 10^{-9} \text{ Torr}$.

c) What changes would you make to better compete with CVD?

Ans. To make this rather slow deposition rate more competitive with CVD, you might heat the Si to 1650 K, which would gain an order of magnitude in vapor pressure. You could also increase the crucible area and reduce the distance to the substrate. For example, if the ratio of r_c/r increased 4 fold, evaporation at 1650 K would result in a deposition rate of 0.21 μm/hr, competitive with CVD, 0.1 μm/hr.