3.155J/6.152J
Microelectronic Processing Technology
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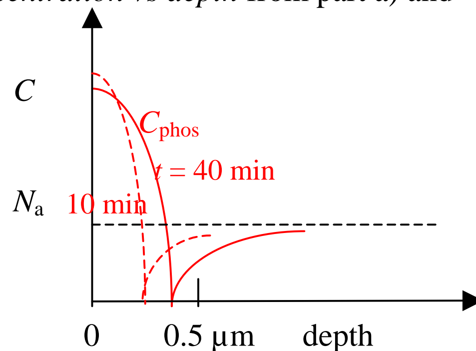
Ion implantation, diffusion [15]

1.

a) Two identical *p*-type Si wafers ($N_a = 10^{17}$ cm^{-3}) have a phosphorus pre-deposition of Q_0 applied by ion implantation. A junction is created at a depth of 0.4 µm by heating the first wafer for 40 min at 1000^{0}C. You want the junction depth at 0.2 microns. How long a *time* would you heat treat your second wafer if you used the same temperature? [5]

Ans: Using the diffusion length, $x = 2(Dt)^{1/2}$, you would have to cut the time to ¼th, or 10 min in order to reduce the diffusion length by a factor of 2.

b) Sketch on the figure at right the *carrier concentration vs depth* from part a) and label all the curves. [10]
Ans: Curves, labels at right in red.



Gas kinetics, vacuum technology [5]

2. Describe in one or two sentences the *molecular-scale process* that accounts for *pressure* (e.g. in a vacuum chamber) mentioning the properties of the molecules that determine the pressure. [5]

Ans: Pressure is due to the *number* of molecular collisions per unit area on a surface times the *momentum* of each molecule.

Chemical vapor deposition [25]

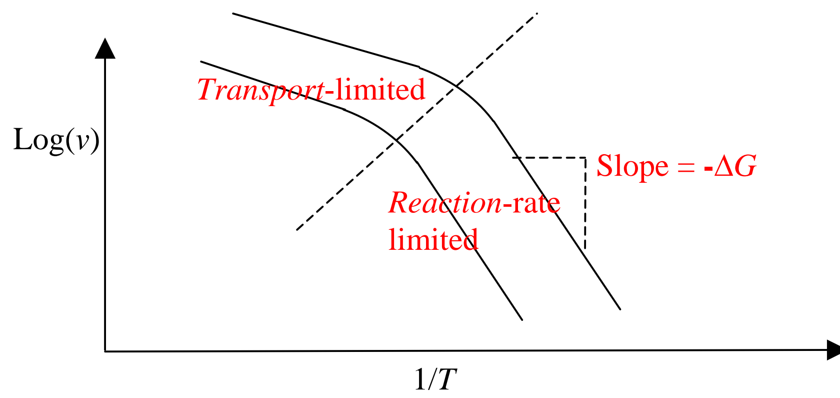
3.

a) Briefly *describe the processes* implied by each term in the equation for the velocity of CVD film growth: $v_f = \dfrac{C_g / N_f}{\dfrac{1}{h_g} + \dfrac{1}{k_s}}$ [10]

b) Which of the processes in this equation are *thermally activated*? [5]

c) Label on the CVD growth-vs.-1/T figure below the *transport*-limited regime and the *reaction*-rate limited regime. [5]

d) From what part of this figure would you calculate the *activation energy* for this reaction? [5]



Ans:

a) C_g is the concentration in the carrier gas of the species to be deposited; it sets an upper limit on the transport process. N_f is the number of molecules per unit area in the film. h_g is the gas transport coefficient governing the flow rate of gas across the boundary layer above the substrates. k_s is the reaction rate coefficient at the film surface.

b) The *reaction-rate constant* is thermally activated, $k_s = k_0 \exp[-\Delta G/kT]$.

c) See red in figure above.

d) The activation energy is given by the *slope* in the reaction-limited regime.

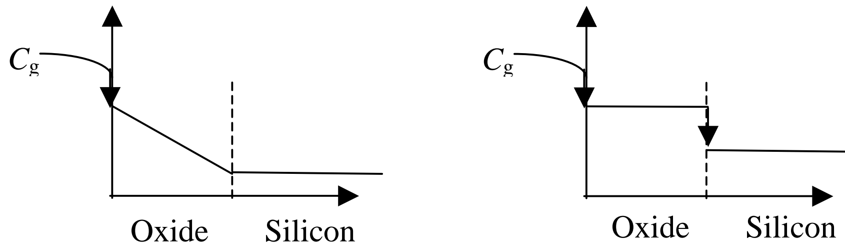
Oxidation [25]

4.

a) Using what you know about the Deal-Grove model of Si oxidation,

$$v_{\text{oxide}} = \frac{HP_g / N_f}{\frac{1}{h_g} + \frac{x_{\text{oxide}}}{D} + \frac{1}{k_s}}$$

, label the figures below as either *diffusion* limited or *reaction*-rate limited and briefly explain why. [10]



b) Given the growth-rate equation $x_0^2 + Ax_0 = B(t + \tau)$, write the equation for the oxide thickness, x_{ox}, as a function of time for *thin* and *thick* oxide layers. [5]

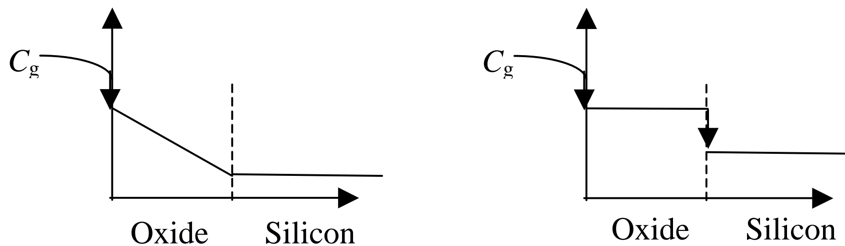
c) Does Si oxidation occur *faster* or *slower* in the presence of water vapor ? [5]

d) Which method of Si oxide growth, *wet* or *dry*, is better suited for the *gate* oxide? [5]

Ans:

a) *Diffusion* or *transport limited* because slope in oxide is not zero, all oxygen reaching interface reacts quickly

Reaction rate limited because flat slope in oxide means there is a backup at reaction interface



b) Thin oxide: $x_{ox} = (B/A)(t + \tau)$

Thick oxide: $x_{ox} = [B(t + \tau)]^{1/2}$

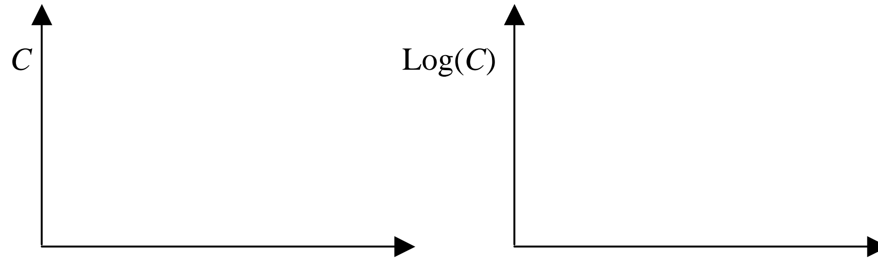
c) Oxidation is faster in H_2O.

d) Dry-grown SiO_2 is of higher quality, therefore better for gate oxide.

Ion implantation, diffusion [25]

5.

a) Sketch the form of the *implanted concentration* vs. *depth* for a typical ion implant. [5]



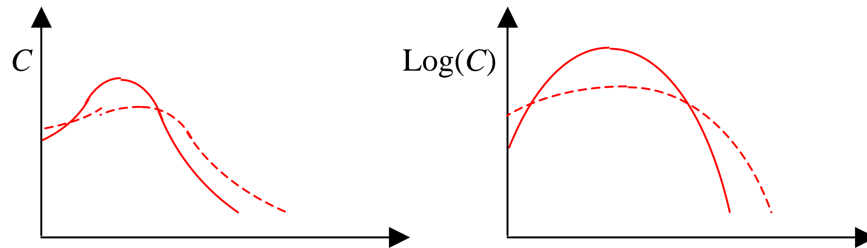
b) Overlay on your solution to part a) a dashed line to show what happens to the distribution upon *annealing* after the implant is complete. [5]

c) Consider the three mechanisms for implanted ions to give up their energy to a target: i) *electronic viscosity*, ii) local *electronic excitations* of target atoms, and iii) *nuclear collisions*. Which of these mechanisms is most responsible for the *lateral broadening* (perpendicular to the direction of implant) of the implanted profile? [5]

d) Describe the *difference in the range of implant* and the *damage* done to the target (assume Si) for boron and arsenic ions implanted at the same voltage and dose? [10]

Ans:

a,b)



c) The third mechanism, momentum transfer by *nuclear collisions*, is most effective in changing the direction of the incident ions.

d) *Boron* implantation has a much *greater range* than arsenic (for similar voltage and dose) because its smaller mass is less effective in transferring energy to the target nuclei. In terms of damage, the same amount of kinetic energy is given up by each implant. Because boron is lighter, its kinetic energy is expressed in a greater velocity and hence a greater fraction of its energy is given up to electron viscosity, so overall *B produces less damage* than As.

Sputter deposition [25]

6. You are sputter depositing Al over an SiO_2 layer on a Si wafer.
   a) Which condition, P_{ar} = 15 mTorr or P_{ar} = 5 mTorr (all other parameters equal), would give a *denser Al film* (and therefore better electrical conductivity)? [5]
   b) Which substrate bias voltage would more likely give *better step coverage*, -100 V or -40 V (all else equal)? [5]
   c) You want to deposit a SiN layer. Would you use *RF* or *DC* sputter deposition? [5]
   d) You want to increase your sputter deposition rate for a silver (Ag, 108 amu) electrical contact. You had been using Ar (40 amu) sputtering gas. Which of the following changes would help *increase Ag deposition rate*: [10]
      i) Switch sputtering gas to Kr (83 amu).
      ii) Switch sputtering gas to Ne (20 amu).
      iii) Increase the anode-cathode potential difference.
      iv) Reduce the pressure in the chamber.

Ans:

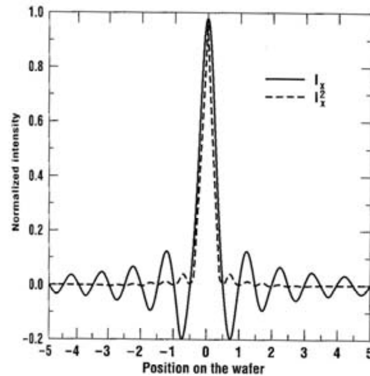
a) Lower pressure means fewer collisions for the Ag atoms drifting toward the substrate. They therefore arrive with greater kinetic energy and are able to diffuse to lower-energy sites, making a denser, higher-quality film.
b) Better step coverage is achieved with a broader angular distribution of incoming Ag target atoms approaching the substrate. This occurs when the incoming species have lower energy, hence lower bias voltage is better.
c) SiN is not a conductor so you cannot use DC sputtering. Use RF.
d) i), iii) and iv) increase Ag deposition rate.
   i) Switching to Kr (better mass match to Ag) will increase the sputtering yield of Ag at the target. iii) Increasing the anode-cathode potential difference will increase the rate of sputtering from the target and increase the deposition rate.
   iv) Reduced pressure in the chamber increases the deposition rate because there are fewer collisions for Ag between the target and substrate.

Lithography and etching [??? – maybe 25]

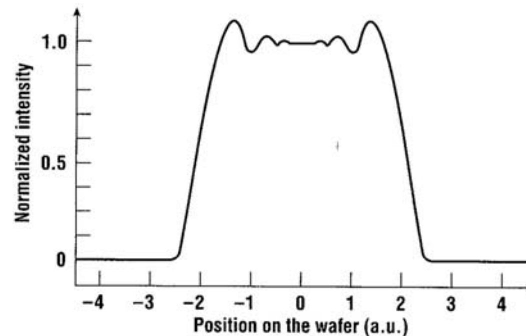
7.

a) For which type of lithography systems do Fraunhofer and Fresnel diffraction theory apply? Sketch the intensity profiles on a wafer for both types of lithography systems. [5]

Ans: Fraunhofer = Projection   Fresnel = Contact/Proximity



Source: Campbell p.157



Source: Campbell p.156

b) Explain (using a sketch) how the Rayleigh criteria for resolution limit in a projection system is determined. [5]

Ans: Determined as the distance between features when the peak of one projection lands on the first zero of the other.

c) In a projection lithography system, does an increase in spatial coherence of the source cause an increase or decrease in resolution if the CMTF of the resist is constant. Explain. [5]

Ans: Could increase or decrease depending upon the CMTF of the resist.

d) Why does the addition of O_2 change etch rate in a CF_4-based plasma etch. [5]

Ans: Oxygen is added to CF_4 plasma to increase the amount of reactive F species (O reacts with CF_3 and CF_2 and hence reduces the recombination rate of F.).

e) The CH_3COOH:HF:HNO_3 system is commonly employed to wet etch silicon. Explain the steps of this chemical etch process, i.e. explain the function of each chemical in the process. [5]

Ans: HNO_3 acts as an oxidant to the silicon, HF etches the oxidized silicon. CH_3COOH is used to dilute the solution.