

3.155J/6.152J
Microelectronic Processing Technology
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SOLUTIONS

Quiz I

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OXIDATION [25]

- 1) **[10]** A bare silicon wafer is oxidized for 120 minutes at 1100C in O₂ followed by 30 minutes at 920^oC in wet O₂. What is the final thickness? If the oxide is patterned (i.e. etched away in certain areas) between the first and second oxidation, what will be the thickness of the oxide in the patterned region?

After 2 hours at 1100C: Oxide thickness = 196nm

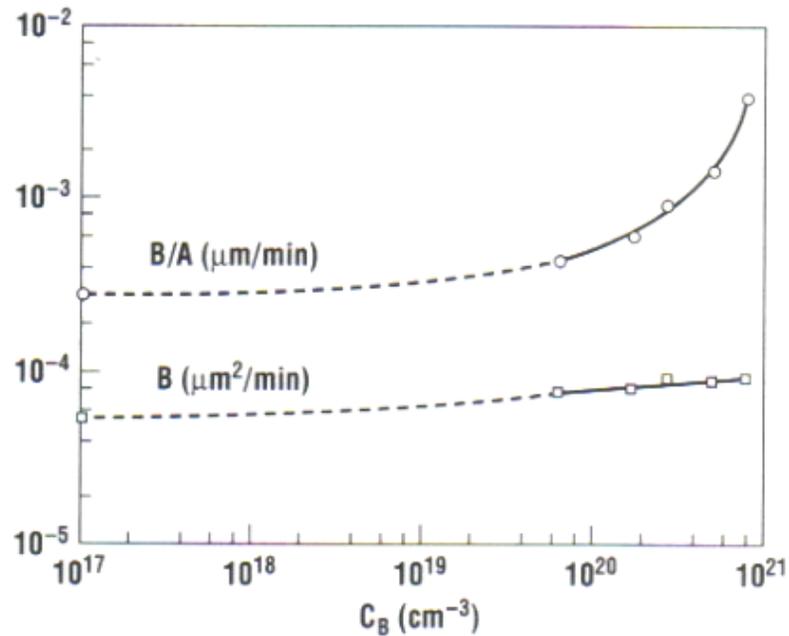
After and additional 30 min. at 920C: Oxide thickness = 298nm

Thickness in the patterned region (due to just 30min at 920C): Thickness = 155nm

- 2) **[8]** One micron of silicon dioxide is grown on a wafer. You subsequently determine that the oxidation step has caused the doping concentration near the surface to rise (compared to the bulk). Explain why this has happened, and what this means about the segregation coefficient and the diffusion constant of this dopant.

A rise in concentration of dopant at the surface (of the silicon) relative to the bulk is a result of the segregation coefficient (m) being greater than one, and the diffusion of the dopant in the oxide being relatively slow (refer to p. 83-84 of Campbell). Note: some interpreted this question as the rise in concentration to be in the oxide, which would be a result of segregation coefficient less than one.

- 3) [7] The linear and parabolic growth constants have the characteristics shown in the Fig. below. Explain why they are a function of doping concentration.



The linear rate, B/A , rises rapidly because the doping causes an enhancement in the surface reaction rate. The parabolic rate, B , rises slightly, which would be a result of an increase in diffusion of oxidant through the oxide as a result of the dopant changing the silicon dioxide.

Diffusion [30]

4. [20] You want to create a shallow $p-n$ junction near the surface of a doped Si wafer and need to maintain the highest possible dopant concentration near the wafer surface. You have access to B and P sources for CVD deposition or doping from the vapor/gas phase and a suitable reaction chamber.

a. [4] Would you prefer to use B or P as a dopant? Explain.

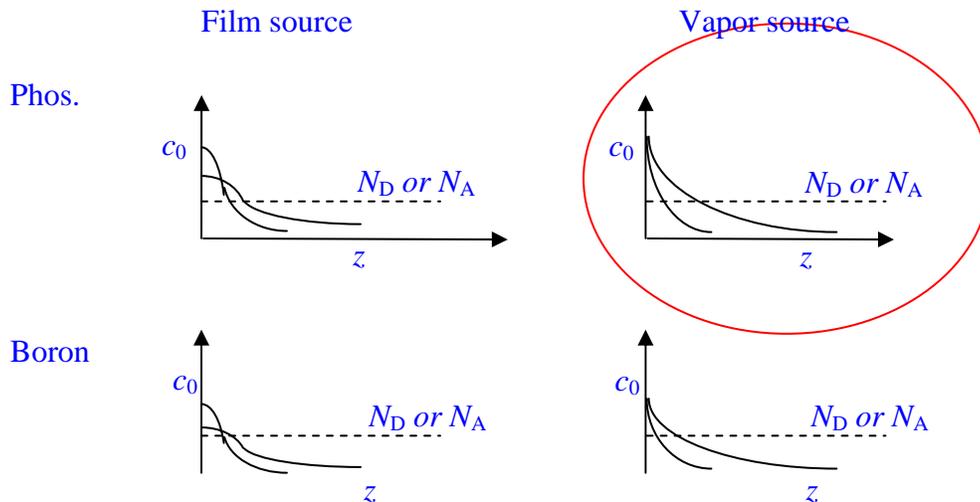
P because it has a higher solubility than B at 1100 K.

b. [2] Which type of Si wafer would you then start with, p -type or n -type?

P is donor so you need an acceptor-doped, p -type Si wafer. [Wrong answer, B, in a) would require n -type wafer]

c. [10] Would you prefer to use a predeposited film (B or P) then diffuse it in at 1100 K or expose the wafer to the appropriate gas phase (diborane or phosphene) while diffusing at 1100 K? Explain and sketch profiles in each case (below) showing profiles in each figure for 2 different diffusion times.

Prefer to diffuse from a constant vapor source (if you can get vapor dopant concentration, c_0 , as high as its solubility limit in Si) so surface concentration in Si remains at c_0 for all times; complementary erf solution.





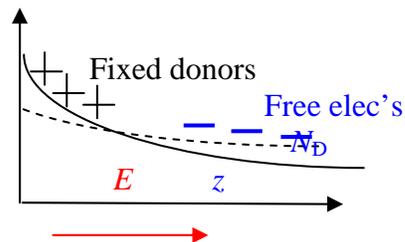
- d. [4] Your first effort involved a 10-minute diffusion process and put the junction depth at twice the desired depth. On your next run at the same temperature, how long should your diffusion process last? Why?

The junction depth advances with time like the diffusion length, $a = 2(Dt)^{1/2}$. So you would decrease your time four-fold to get half the junction depth, namely to $t = 2.5$ min instead of 10 min.

5. [10]

- a. [5] Explain in a few words and with a sketch why diffusion is generally accelerated in a region that is already highly doped with that species.

Separation of mobile and fixed charges in highly doped region results in an internal electric field that always acts to drive the dopant farther into the material.



- b. [5] Explain briefly how this effect might be relevant to your desire to create a high dopant concentration at the surface while maintaining a shallow junction depth.

This effect always results in a more square diffusion profile, i.e. greater diffusion length at high concentrations and smaller a at lower concentration. This makes it easier to maintain a high surface

concentration of dopant with a sharp dropoff to keep the junction as shallow as possible.

Ion Implantation [10]

6. [10] One of your colleagues later told you that she had read about a device like your shallow junction/high-surface concentration one, but made instead using ion implantation and getting a junction depth considerably less than yours. She could not recall the species implanted.
- a. [5] Was the implanted species more likely B, P, or As? Explain.

Most likely used As ion implantation, because it has the shortest range of the three at a given ion energy (see figure).

- b. [5] Describe the likely dominant stopping mechanism (nuclear or electronic) for your answer in a) and explain why.

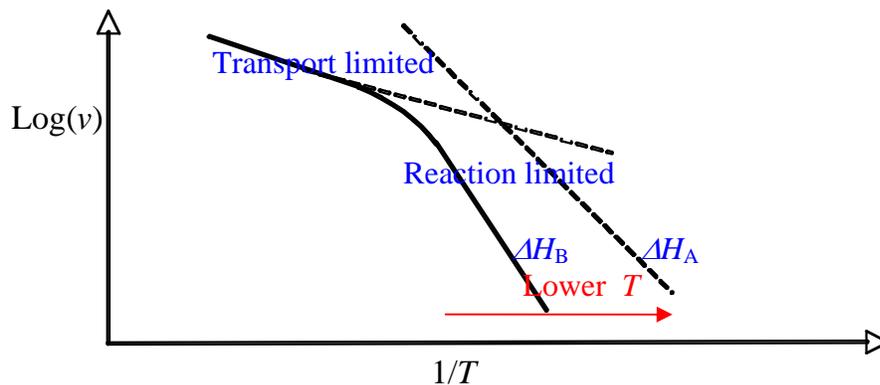
As implants are stopped mainly by nuclear scattering because of its large mass relative to P or B. The latter reach a higher velocity at a given energy and so are more dominated by electronic stopping, especially so for B.

Chemical Vapor Deposition [25]

7. You are about to grow a film by CVD and want good process control.
- a. [15] Briefly explain the advantages of film growth in the regime that is limited by *gas transport* (as opposed to reaction limited). Mention factors that control *film growth rate* and the *stability* of this growth rate. (A good sketch that supports your answers will get you easier points).

Transport limited growth

- is always faster than reaction-kinetic-limited growth,
- it can be controlled by reactant gas pressure and flow rate, as well as depending weakly on temperature ($T^{1/2}$), and
- it is more stable against thermal drift because it depends more weakly on temperature than does reaction-limited growth.



- b. [10] You want to lower the CVD deposition temperature to protect the integrity of prior-deposited components. Which species would you choose to deposit that would more likely allow you to control the growth rate by transport parameters (all else being equal): species A with a heat of formation ΔH_A or species B with a heat of formation $\Delta H_B = 2\Delta H_A$? Explain.

You want to use the smaller ΔH_A species because it has a higher reaction rate at a given temperature and this expands the transport-limited regime (all else, such as pre-exponential factor, being equal). This allows you to still control by transport parameters while operating at lower temperature.