Homework Assignment #4 (Due Oct 6 Thur 9:40am)

Note: Different textbooks use either C(x) or N(x) to represent the concentration and Q or ϕ to represent the dopant dose.

Reading Assignment

1)**Jaeger**, Chapter 4 on diffusion [Van der pauw's Method (section 4.7.4) for sheet resistance and junction profile measurement (section 4.8) are optional.]
2) **EE143 Reader** : Wolf and Tauber , Chapter 9, "Diffusion in Silicon" Read the whole chapter. However, you only need to have **qualitative** understanding of the following sections:
Section 9.3 Atomistic Models of Diffusion
Section 9.4 Diffusion Modeling
Section 9.8 Diffusion Systems and diffusion sources
Section 9.9 Measurement Techniques for Diffused Layers
3) **Handout** : Notes on Mathematics of Doping Diffusion

Problem 1 Simple predep calculation

A boron predeposition step is performed into an n-type Si substrate with a background concentration C_B of $1 \times 10^{16}/cm^3$. The predeposition thermal cycle is 975 °C for 15 minutes.
Given: Boron solid solubility at 975 °C = $3.5 \times 10^{20}/cm^3$
Boron diffusion constant at 975 °C = 1.5×10^{-14} cm^2/sec
(a) Calculate the junction depth x_j.
(b) Calculate the incorporated boron dose Q.

Problem 2 Predep and Drive-in

A pn junction is to be formed 2 μm from the surface in n-type Si substrate which has a doping concentration of 10^{16} phosphorus atoms per cm^3. The junction is formed by a two-step diffusion of boron:
1) the predep is solid-solubility limited at 900°C
and
2) the drive-in is at 1100 °C. After the drive-in step , the sheet resistance is 150Ω/ square.
Find out the appropriate diffusion times for both predep and drive-in steps.

Given :D_o=10.5 cm^2 /sec and E_a=3.69 eV for Boron diffusion constant
Solid solubility limit of boron at 900°C (predep temp) $\approx 1.1\times10^{20}/cm^3$

Problem 3 Thermal budget – Multiple Drive-in steps

Boron is diffused into n-type Si substrate with a background concentration of $10^{15}/cm^3$. After a **drive-in** step (i.e., half-gaussian profile) , you obtain a sheet resistance R_S of 44 Ω/square and a junction depth of 6 μm. This junction depth is shallower than what you want and you put the wafers back into the furnace and heat them at 1150°C for an additional 6.5 hours. **Calculate the final junction depth**. Show all calculations. [GIVEN: D of boron at 1150°C = 7.2×10^{-13} cm^2 / sec]
[Hint: You have to use the Irvin Curves]

Problem 4 Implantation plus Drive-in

The n-type Si substrate has a uniform concentration of 10^{16} /cm^3. B+ ions are implanted into the substrate with 1000 keV energy and a dose of 10^{13} /cm^2. The post-implant heat-treatment is 1000°C for 30 minutes.
Given: Diffusion constant of B at 1000°C = 1.6×10^{-6} μm^2/sec

(i) Calculate the junction depths
(ii) Calculate the sheet resistance of the implanted p-layer using the Irvin's curves. [Hint: Make a rough sketch of the p-dopant profile.]

Problem 5 High Concentration Diffusion effects

(a) In class, we illustrated how a boron diffusion profile will generate a built-in electric field which can enhance the boron diffusion constant. Repeat the same argument here for the case of **arsenic** diffusion.

(b) For *high concentration* Arsenic drive-in diffusion, the diffusion profile is not half-gaussian but is approximately a rectangular profile. If we assume the electron mobility has a constant value for high doping concentrations, qualitatively sketch the Irvin Curve [i.e., log C_S versus log (R_S x_j)] for low background concentrations N_B. Also derive the numerical value of the slope of this plot.

(c) **Assume** the diffusion mechanism of Boron in Si is **completely dominated** by the singly-charged positive vacancy concentration : $D \approx h \times D_i^{+} \frac{p}{n_i}$

At 1000 °C, the diffusion constant of low concentration (<< n_i) B in Si is 1×10^{-14} cm^2 /sec.
Calculate the diffusion constant at 1000 °C when the boron concentration is 10^{20}/cm^3.
[Hint: you may want to look up the numerical value of n_i at 1000 °C]

Problem 6 Why difficult to form ultra-shallow junctions

To form the source/drain regions of a state-of-the-art MOSFET by in ion implantation followed by an annealing step, it is required to have : (1) very shallow junction depths x_j ; AND (2) very low sheet resistance R_S.

(i) Discuss two major physical mechanisms which limit the formation of ultra-shallow junction depths.
(ii) Discuss one major physical mechanism which limits the formation of low sheet resistance source/drain layers.

(iii) Discuss the difficulty to satisfy both the shallow junction depths x_j AND low sheet resistance R_S requirements.