Homework Assignment #4 (Due Feb 23, Thur 8am)

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 (how to use the erfc function)
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 ^oC for 15 minutes.
Given: Boron solid solubility at 975 ^oC = $3.5 \times 10^{20}/cm^3$
Boron diffusion constant at 975 ^oC = 1.5×10^{-14} cm^2/sec
(a) Calculate the junction depth x_j.
(b) Calculate the incorporated boron dose Q.

Problem 2 Predep followed by Drive-in

A pn junction is to be formed 1μm from the surface in n-type Si substrate, which has a doping concentration of 10^{17} phosphorus atoms per cm^3.

The junction is formed by a two-step diffusion of boron:
The predep is solid-solubility limited at 1000°C and the drive-in is at 1100°C.
After the drive-in step, the sheet resistance is 50Ω/square.
(Given: D_0=10.5 cm^2/sec and E_a=3.69eV for Boron diffusion. Use the solid solubility limit curve in Fig 4.6 and Irvin's curves in Fig. 4.16 of Jaeger as neccesary).

Find out the appropriate diffusion times for both the (1) predep and (2) drive-in steps.

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.

[GIVEN: D of boron at 1150°C = 7.2×10^{-13} cm^2 / sec]
Calculate the final junction depth. Show all calculations.
[Hint: You have to use the Irvin Curves]

Problem 4 Implantation followed by drive-in diffusion

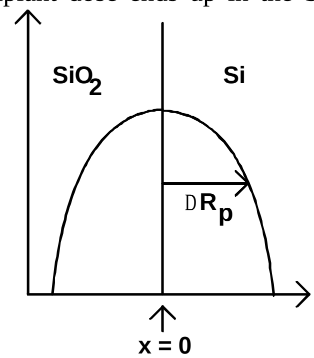
We would like to form an n-type region on a p-type Si substrate (p-type concentration is $10^{16}/cm^3$), with phosphorus implantation followed by a drive-in step (e.g. the N-well of a CMOS process).

The phosphorus implantation is done with a 0.1 μm of SiO_2 present over Si substrate.

(a) What implant energy should be chosen such that one half of the implant dose ends up in the Si? Assume SiO_2 has the same implantation stopping power of Si.

(b) If the phosphorus concentration at the Si surface is 10^{18} /cm^3, what is the required implant dose?

(c) The phosphorus implantation profile in Si is mathematically equivalent to a drive-in profile with an effective Dt which can be used in subsequent drive-in calculations. What is the value of this effective Dt?



(d) What is the junction depth x_j after implantation but before the drive-in step?

(e) What drive-in time is required to achieve a junction depth of 2 μm at 1200°C. Given: D (phosphorus at 1200°C) = 0.5 μm^2 / hour. [Hint: Phosphorus diffusion is SiO_2 is negligible. The phosphorus implant inside SiO_2 does not affect the phosphorus diffusion in Si.]

(f) Calculate sheet resistance of the phosphorus-doped n-layer after the drive-in step described in part(e) ?

(g) Is **high concentration diffusion** effects significant in this diffusion problem? Explain.

(h) To obtain the same phosphorus dose in Si [see part (b)], it is proposed that the phosphorus implantation step is replaced by a predeposition diffusion step at 950°C (D for phosphorous ≈10^{-15}cm^2/sec at 950°C) performed directly on a blanket p-Si substrate (no oxide). ***Do you think the required predep time is controllable using a diffusion furnace?***

Problem 5 High Concentration Diffusion effects

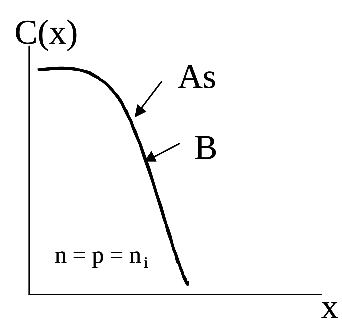
(a) In class, we illustrated how a boron diffusion profile will generate a built-in electric field which can enhance the boron diffusion constant. Repeat the same argument here for the case of **arsenic** diffusion.

(b) With high concentration diffusion effects, the diffusion profile resembles a rectangular profile (i.e., constant concentration from surface to the junction depth). Analogous to the Irvin's Curves, plot log C_S versus log (R_S x_j) for this rectangular profile. What is the numerical value of the slope of this plot ?

(c) The surface region of a Si wafer contains **two identical concentration depth profiles** of Boron and Arsenic. Both profiles can be considered as having high concentration (~10^{20}/cm^3 near the peak region)

(i) Do you expect to observe ***high concentration diffusion effects*** when the wafer is heated at 1000°C for short diffusion times? Explain with a sketch.

(ii) Do you expect to observe ***high concentration diffusion effects*** when the wafer is heated at 1000°C for longer diffusion times? Explain with a sketch.



[Hint: Boron has a higher diffusivity than Arsenic]

Problem 6 Why difficult to form ultra-shallow junctions

To form the source/drain regions of a MOSFET by ion implantation followed by an annealing step, it is desirable to have :

(1) very shallow junction depths x_j ;

AND

(2) very low sheet resistance R_S.

(i) Discuss how **ion channeling**, **high concentration diffusion effects**, and **transient enhanced diffusion** will limit the formation of ultra-shallow junction depths.

(ii) Discuss the key physical mechanism which limits the formation of low sheet resistance source/drain layers of a MOSFET when junction depth is very shallow.

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