HOMEWORK 8

April 20, 2009
Homework is due in the class on April 27, 2009

Chapter 8

Answer the following questions:

Q1: A 30-keV implant of B^{11} is done into bare silicon. The dose is 10^{12} cm^{-2}.
   a. What is the depth of the peak of the implanted profile?
   b. What is the concentration at this depth?
   c. What is the concentration at a depth of 300 nm?
   d. The measured concentration is found to be an order of magnitude larger than the value predicted in part (c), although the profile agrees with answers (a) and (b). Give a possible explanation, assuming that the measured value is correct.

Q2: A MOSFET threshold voltage adjust implant is done through a gate oxide of 150 Angstroms. The implant species is boron at 30 keV. Estimate the fraction of boron implanted in the oxide. (You may have to use the approximation that x<< R_p for the Gaussian.)

Q3: A mass spectrometer as described in the chapter is used for element extraction in an implanter. Calculate the magnetic field necessary to extract silicon (mass 28) if the extraction potential is 20-keV and the radius of curvature for the analyzer is 30 cm. Explain why one might also see some N_2 in the implant profile if the source cabinet has small vacuum leak.

Q4: Arsenic is implanted into a lightly doped p-type Si substrate at an energy of 75keV. The dose is 1 \times 10^{14} / cm^2. The Si substrate is tilted 7^\circ with respect to the ion beam to make it appear amorphous. The implanted region is assumed to be rapidly annealed so that complete electrical activation is achieved. What is the peak electron concentration produced?

Q5: Arsenic is implanted into a lightly doped p-type Si substrate at an energy of 75keV. The dose is 1 \times 10^{14} / cm^2. The Si substrate is tilted 7^\circ with respect to the ion beam to make it appear amorphous. The implanted region is assumed to be rapidly annealed so that complete electrical activation is achieved. What is the peak electron concentration produced?
Q6: An 80 keV, $5 \times 10^{13} \text{cm}^{-2}$ boron implant is performed into bare silicon. A subsequent anneal at 950°C ($D_B = 4.24 \times 10^{-15} \text{cm}^2 \text{sec}^{-1}$) is performed for 60 min.

(a) Can the annealed profile evolution be described by the formula

$$C(x, t) = \frac{Q}{\sqrt{\pi D_B t}} \exp\left(-\frac{x^2}{4D_B t}\right)$$

(b) Assume that all the dopant remains in the silicon and that none evaporates to the ambient. By considering a virtual or imaginary image profile on the ambient side of the interface (a reflecting boundary), calculate the surface concentration after a 60 min, 950°C anneal.

Q7: An implant machine for 300 mm wafers is required to have a throughput of 60 wafers per hour. What beam current is required in order to implant a source/drain region in a CMOS device with a dose of $1 \times 10^{15} \text{cm}^{-2}$?

Q8: An engineer investigating solid phase epitaxial regrowth after amorphizing ion implants of various species (P, B, Si, Ge, As, Sb) makes the following observations:

1. N-type dopants of very different size or atomic radius (e.g. antimony versus phosphorus) show identical regrowth rates, approximately an order of magnitude faster than the regrowth of silicon implanted and amorphized with silicon ions.

2. P-type and N-type ion implanted regions have much faster regrowth rates than Si or Ge implanted regions, although they are not identical.

3. B-doped regions compensated with an equal dose of an arsenic implant show identical regrowth rates to Ge implanted and amorphized regions.

Construct a unified physical explanation of all three phenomena, considering possibilities such as size or stress effects, dopant charge or electric field effects, or point-defect based effects (no calculation required).

Q9: In two separate experiments, As and then B are implanted through a thin SiO$_2$ layer into the underlying substrate. As a result of the implantation, some of the oxygen atoms in the SiO$_2$ layer are knocked into the silicon substrate. Would you expect the As or the B to produce more oxygen knock-ons? Why?

Q10: An NMOS transistor is being built and an ion implantation is done after the gate oxide is grown and before the gate polysilicon deposition, in order to adjust the threshold voltage by +1 volt.

(a) Which dopant should be used?

(b) Calculate the dose of the dopant if the oxide thickness is 10 nm.