UNIVERSITY OF CALIFORNIA

College of Engineering

Department of Electrical Engineering and Computer Sciences

EECS 143 Professor Ali Javey

Fall 2008

Exam 2

Name: _____

SID: _____

Closed book. One sheet of notes is allowed.

There are a total of 12 pages on this exam, including the cover page.

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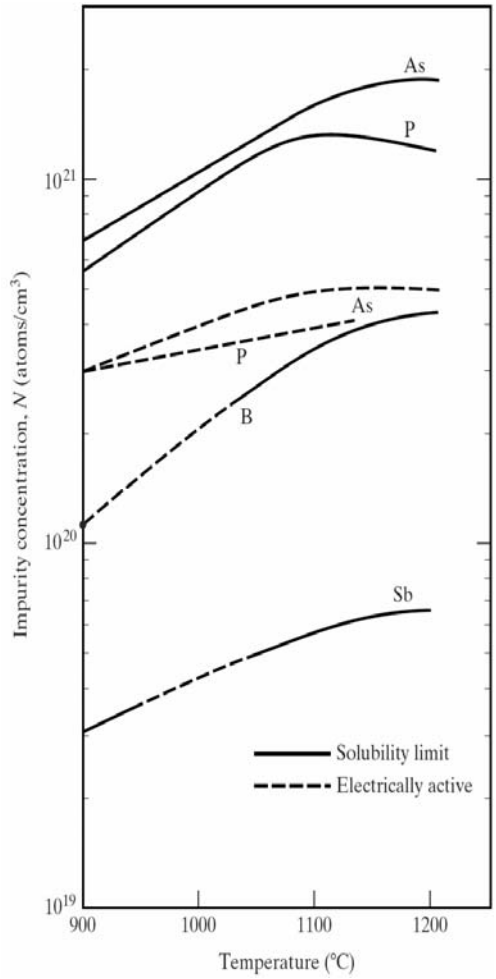
Total		100

Physical Constants

Electronic charge	q	1.602×10^{-19} C
Permittivity of vacuum	ε_0	8.845×10^{-14} F cm^{-1}
Relative permittivity of silicon	$\varepsilon_{Si}/\varepsilon_0$	11.8
Boltzmann's constant	k	8.617×10^{-5}eV/ K or 1.38×10^{-23} J K^{-1}
Thermal voltage at T = 300K	kT/q	0.026 V
Effective density of states	N_c	2.8×10^{19} cm^{-3}
Effective density of states	N_v	1.04×10^{19} cm^{-3}
Silicon Band Gap	E_G	1.12 eV

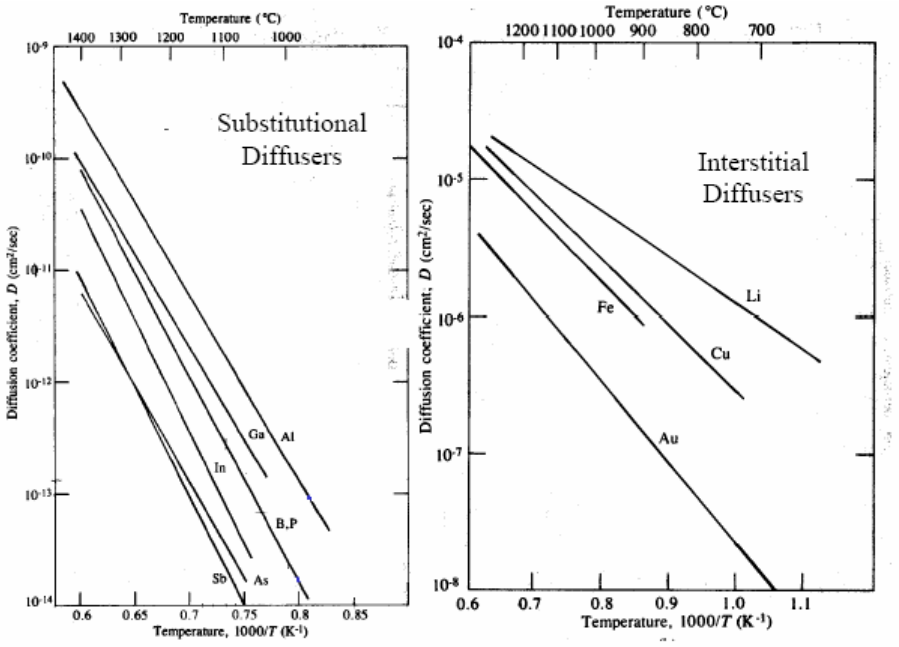
Solid Solubility Limits

Information which may be useful:



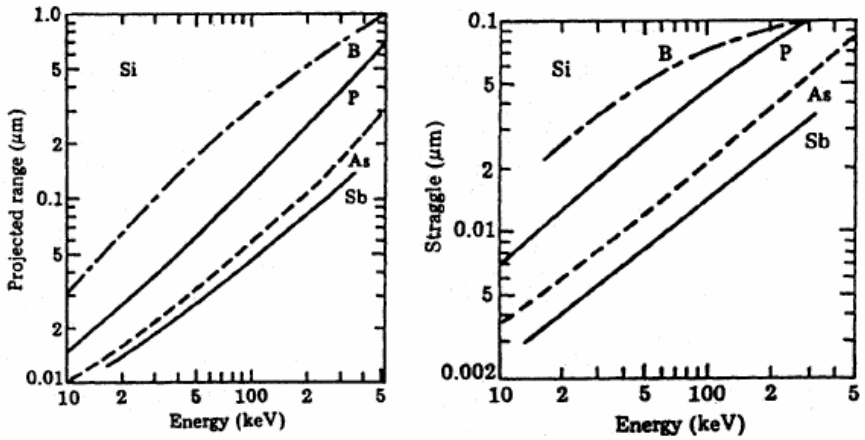
Diffusion

Information which may be useful:



Ion Implantation

Information which may be useful:

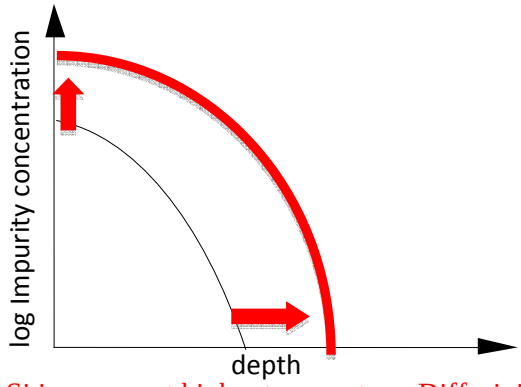


Problem 1: Diffusion (28 pts)

(a) [3 pts] An instrinsic Si sample is surface doped with boran by a thermal annealing at 900 ºC for 30 seconds in the presence of continuously flowing diborane (B_2H_6) gas. Is this an example of a constant source diffusion or limited source diffusion? Briefly explain (1 sentence max).

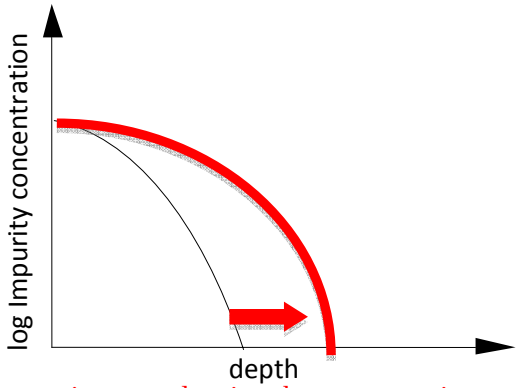
This is constant source diffusion because the diborane is flowing at a constant rate, thus fixing the supply of boron at the surface.

(b) [5 pts] The boron profile for the sample in (a) is shown below. On the same plot, draw a second curve that would correspond to the boron profile for another sample that is doped at **1000 ºC** for 30 sec in the presence of continuously flowingdiborane gas.



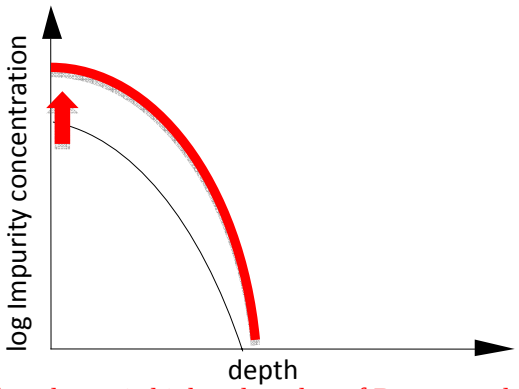
The solid solubility of boron in Si increases at higher temperature. Diffusivity also increases.

(c) [5 pts] The enabled boron profile for the sample in (a) is shown below. On the same plot, draw a second curve that would correspond to the boron profile for another sample that is doped at 900 ºC for **60 sec** in the presence of continuously flowingdiborane gas.



In this case, solid-solubility does not increase, leaving the concentration constant at the surface. Increased time, however, increases the depth of the profile.

(d) [5 pts] The enabled boron profile for the sample in (a) is shown below. On the same plot, draw a second curve that would correspond to the phosphorous profile for another sample doped at 900ºC for 30 sec in the presence of continuously flowing**phosphine (PH_3)**.



The solid-solubility for Phosphorus is higher than that of Boron, so the surface concentration increases. The diffusivity is roughly the same, making the depth increase only slightly.

(e) [5 pts] The two common donors in Si are phosphorous and arsenic. Which do you think is used more often in IC manufacturing for the n+ wells of the contacts? Briefly explain your reasoning. (2 sentences max)

Arsenic is more often used. This is because it is a slower diffuser, so it can make shallower junctions, as well as having a higher solid-solubility. Also, can mention the phosphorus kink.

(f) [5 pts] As compared to the common dopants, Au is known to diffuse very fast in Si. Briefly explain why. (3 sentences max)

Gold is an interstitial diffuser.

Problem 2: Ion Implantation (34 pts)

An ion implantation is done to implant a total dose of 10^{14} cm^{-2} of arsenic atoms into a Si/SiO_2 substrate (a Si wafer with a thermally grown SiO_2 layer). The implantation is calibrated so that the peak concentration occurs at the Si/SiO_2 interface. The oxide layer is then completely removed in HF, resulting in a Si wafer with its peak dopant concentration at the surface. Assume a Gaussian profile for the implanted dopants.

a) [4 pts] What is the effective dose of the incorporated dopants in the Si layer?

The effective dose is half of the implanted dose, because half of the dopants were removed along with the oxide layer.

$$Q_{eff} = \frac{Q_0}{2} = 5 \times 10^{13} cm^{-2}$$

b) [5 pts] Given a longitudinal straggle of 77 nm, what is the Si surface doping concentration?

Although the effective dose is reduced by half, the part of the profile that remains was nevertheless determined by the original, implanted dose. Hence we use the original dose to calculate the surface concentration.

$$N_{surf} = N_{peak} = \frac{Q_0}{\sqrt{2\pi}\Delta R_p} = \frac{10^{14} cm^{-2}}{\sqrt{2\pi} \times 77 \times 10^{-7} cm} = 5.181 \times 10^{18} cm^{-3}$$

c) [5 pts] If the Si wafer had a boron background concentration of 10^{15} cm^{-3}, what is (are) the metallurgical junction depth(s)?

There is only one junction, since the silicon only contains half of a Gaussian profile. Using the peak concentration calculated in (b), the junction depth is:

$$x_j = \Delta R_p \sqrt{2 \ln\left(\frac{N_{peak}}{N_{bgnd}}\right)} = 77 \times 10^{-7} cm \times \sqrt{2 \ln\left(\frac{5.161 \times 10^{18} cm^{-3}}{10^{15} cm^{-3}}\right)} = 318 nm$$

d) [5 pts] Immediately after completing our implantation and stripping the oxide layer, we measure the sheet resistance of our wafer and find that it is enormous. Why do you think that's the case? (2 sentences max)

Because we haven't done an anneal, the dopants are not yet activated and the crystal lattice is damaged.

e) [5 pts] What process can we use to fix the problem encountered in (d)? Briefly explain. (2 sentences max)

Annealing will activate the dopants and repair the crystal lattice.

f) [5 pts] List two main advantages and two disadvantages of ion implantation with respect to surface doping.

Advantages: precise dose control, precise depth control, good lateral uniformity, low temperature, many mask materials

Disadvantages: expensive, complex systems, damages crystal, hard to get shallow junctions

g) [5 pts] Achieving ultrashallow junctions as the source/drain extensions of nanoscaleMOSFETs is a challenging field of active research. Speculate whether enabling ultrashallow junctions is more difficult for p+ or n+ doping. Briefly justify your answer. (3 sentences max)

p+ is harder because the p-type dopants tend to be lighter, and hence go deeper upon implanting. Also, p-type dopants tend to diffuse faster during high temperature post-implant steps such as annealing.

Problem 3: Thin Film Deposition (28 pts)

a) [4 pts] We've learned several deposition methods, including sputtering, evaporation, CVD, and ALD. Arrange these four methods from most conformal to the least conformal.

ALD, CVD, sputtering, evaporation

b) [5 pts] Achieving a stoichiometrically balanced (i.e., correct atomic composition) thin film by sputtering is quite challenging for alloys. What consideration(s) do you need to apply for depositing thin films of alloys with the desired atomic composition when using a single alloyed source? Briefly justify your answer. (3 sentences max)

The sputtering yield varies for different elements in the alloy target and so its composition must be adjusted to compensate.

c) [4 pts] What common precursor(s) are used for the chemical vapor deposition of poly-Si?

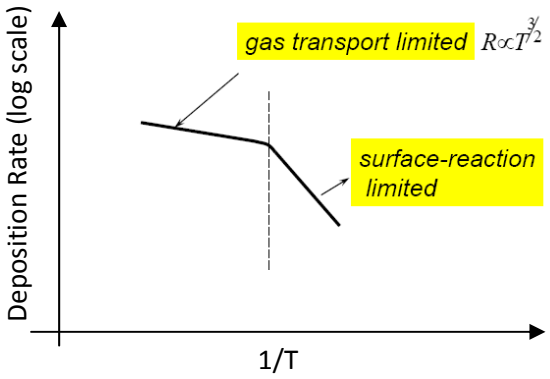
Silane (SiH_4), Dichlorosilane ($SiCl_2H_2$), etc.

d) [5 pts] List the *five* mechanistic steps involved in a CVD process. Please make sure the order is correct.

1. **Diffusion of reactant to surface**
2. **Absorption of reactant to surface**
3. **Chemical reaction**
4. **Desorption of gas by-products**
5. **Outdiffusion of by-product gas**

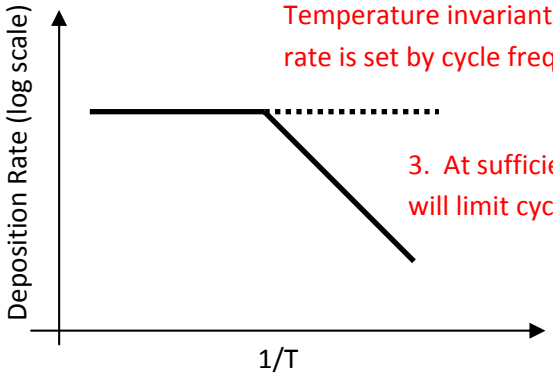
e) [5 pts] Qualitatively plot the deposition rate as a function of temperature for CVD. Label each regime on the curve and state which of the five step(s) (from part d) is (are) the rate limiting step(s) for each regime.

1. and 5.



3.

f) [5 pts] Qualitatively plot the deposition rate as a function of temperature for ALD. Label each regime on the curve and state which mechanistic step(s) (if any) is the rate limiting step for each regime.



Temperature invariant is acceptable (growth rate is set by cycle frequency).

3. At sufficiently low T, Rxn rate will limit cycling frequency.

Problem 4: Oxidation (10 pts)

We have a structure shown below. This structure is placed in a furnace and oxidized at 900ºC in the presence of dry oxygen in order to grow a thin layer of SiO_2. Draw the schematic of this structure after the dry oxidation process. In particular, make sure that your drawing emphasizes the relative thickness and the surface profile/morphology of SiO_2 obtained in different regions.