Birla Institute of Technology and Science, Pilani

MEL G611 IC Fabrication Technology Mid-Semester Test (Closed Book)

Time 90 mins **8.10.2016** **Marks 90**

Q1. Consider a silicon unit cell. Assume that all octahedral voids are filled by atoms of type "**A**". Answer the following questions:

(i) What should be exact size of "A" so that it can comfortably fit on octahedral void? **[4]**

(ii) Draw a (110) plane and show octahedral atoms. Calculate total planar density in atoms/nm^2. **[4]**

(iii) Calculate packing fraction of this unit cell occupied with 'A' atoms on all octahedral voids. **[4]**

(iv) Find total linear density for [110] direction. **[4]**

(iv) Calculate number density for "A" atoms and total atoms in atoms/cm^3 **[2+2]**

Q2. (a) A germanium-silicon alloy has concentration 90% wt% Si and 10 wt% Ge. What should be its concentration in atom % ? **[5]**

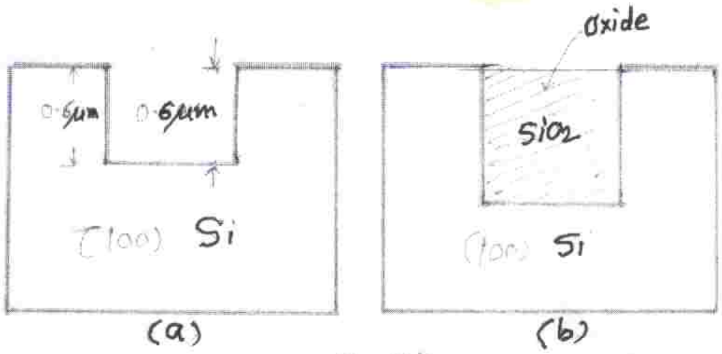
(b) Calculate surface energy for germanium (100) plane. Atomic radius of Ge = 0.122 nm. Bond energy = 300 kJ/mol **[7]**

(c) Calculate the energy for vacancy formation in a semiconductor. Given that the equilibrium number of vacancies at 1073 K is $3.6 \times 10^{23}/m^3$. The atomic weight and density is 107.9 g/mol and 9.5 g/cm^3, respectively. Further, what is the fraction of atomic sites that are vacant at 1300 K? **[5+3]**

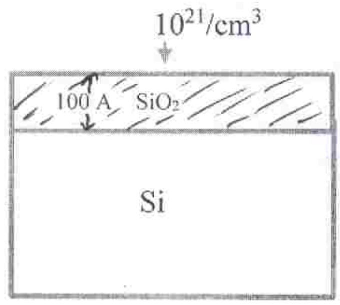
Q3. Assume that gate oxide thickness over a silicon wafer is 100 A. Concentration of Boron at the surface is maintained at $10^{21}/cm^3$. Estimate the dose of impurity that enters into silicon after 4 hr of annealing process at 1273K. For B in silicon: $D_0 = 3 \times 10^{-4}$ cm^2/s and $E_a = 3.53$ eV/atom. Also assume that B has same diffusion constant in Si and SiO_2. **[15]**

Q4. For a boron diffusion in silicon at 1273K, the surface concentration is maintained at $10^{20}/cm^3$ for 5 hr. Considering infinite source diffusion, calculate gradient of the diffusion profile at (i) x = 0 and (ii) at a place where the concentration is $10^{16}/cm^3$. Diffusion constant at 1273K is = 2×10^{-14} cm^2/s. **[10]**

Q5. It is known that there is a volume expansion during SiO_2 formation such that growing 1 micron SiO_2 consumes 0.45 micron of silicon. For the structure shown, a window is opened to make a groove of depth 0.6 micron. How long a wafer must be wet oxidized at 1273K so that the window is totally filled with oxide as shown in Fig. b. Consider, for wet oxidation at 1273K: B = 0.316 μm^2/hr and B/A = 0.75 μm/hr **[12]**



For Q 5



For Q 3

Q6. (a) At 1200 ^{0}C, the Oxidation of a 1500 A gate oxide is grown in two steps by dry oxidation. In step one- 1000 A is grown first and in second step- wafer is re-oxidized to a total thickness of 1500 A. Find the time required in the first and second process.

(b) In another experiment 1500 A gate oxide is grown in one single step by dry oxidation at 1200 ^{0}C. Find the time required to grow the oxide. **[13]**

You may use A = 0.04 μm and B = 0.045 μm^2/hr at 1200 ^{0}C.

τ = 0.027h

You may need: Atomic weight of boron = 10.81g/mol, $N_A = 6.02 \times 10^{23}$, $K_B = 1.38 \times 10^{-23}$J/K, Atomic weight of Si = 28.9 g/mol, Atomic weight of Ge = 72.64 g/mol. Atomic radius of Si = 0.118 nm, density of Si = 2.33 g/cm^3, atomic weight of SiO_2 = 60.08 g/mol. density of SiO_2 = 2.21 g/cm^3 gas constant R = 8.31 J/mol.K

$$\int_0^u erf_c\, z\, dz = u\, erf_c u + \frac{1}{\sqrt{\pi}}(1 - e^{-u^2})$$

Table 5.1 **Tabulation of Error Function Values**

z	$erf(z)$	z	$erf(z)$	z	$erf(z)$
0	0	0.55	0.5633	1.3	0.9340
0.025	0.0282	0.60	0.6039	1.4	0.9523
0.05	0.0564	0.65	0.6420	1.5	0.9661
0.10	0.1125	0.70	0.6778	1.6	0.9763
0.15	0.1680	0.75	0.7112	1.7	0.9838
0.20	0.2227	0.80	0.7421	1.8	0.9891
0.25	0.2763	0.85	0.7707	1.9	0.9928
0.30	0.3286	0.90	0.7970	2.0	0.9953
0.35	0.3794	0.95	0.8209	2.2	0.9981
0.40	0.4284	1.0	0.8427	2.4	0.9993
0.45	0.4755	1.1	0.8802	2.6	0.9998
0.50	0.5205	1.2	0.9103	2.8	0.9999

Model Solutions

Mid Sem 2016

MEL G611

Q1: 20 Marks Total

Q1 (i) A Silicon unit cell will have 4 octahedral voids at edge centers and at center of unit cell. → [2]

'A' atom can this way occupy position. exact size → it just fits the void

(100) plane

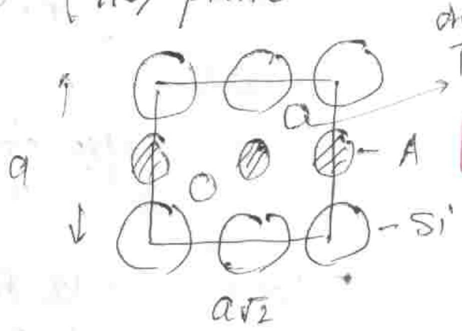
$a = 2r_{Si} + 2r_A = \frac{2 \times 4 r_{Si}}{\sqrt{3}} = \frac{8 r_{Si}}{\sqrt{3}} = 0.5450\ nm$

given $r_{Si} = 0.118\ nm$

$\Rightarrow r_A = 0.1545\ nm$ [2]

This problem is of course hypothetical! Doping is substitutional normally

(ii) (110) plane



dots at Tet positions [2]

$PD = \frac{(4+2)}{\sqrt{2}\,a^2} = 14.26/nm^2$ [2]

(iii) packing fraction

$\text{Total APF} = \frac{\left[4 \times \frac{4}{3}\pi r_A^3 + 8 \times \frac{4}{3}\pi r_{Si}^3\right]}{a^3}$ [1]

72.14%

Thus APF ≃ 72% ↳ Not asked!

→ by 'A' atoms $= \frac{4 \times \frac{4}{3}\pi r_A^3}{a^3} = 0.38$ [3]

(iv) linear density of [110]

[1] $LD = \frac{2}{a\sqrt{2}} = 2.595/nm$ [3]

(v) Number density: $4/a^3 = 24.70/nm^3$ for 'A' [4] → (2+2)

$12/a^3$ = Total = 74 n/nm³

Q2
10 Marks

(a) wt% to atom% Conversion

$$C_1 = \frac{m_1}{m_1+m_2} \times 100 \quad (wt\%)$$

$$C_1' = \frac{n_1}{n_1+n_2} \times 100 \quad (atom\%)$$

$$C' = \frac{m_1/A_1}{\frac{m_1}{A_1}+\frac{m_2}{A_2}} \times 100 = \frac{\left(\frac{m_1}{m_1+m_2}\right)/A_1}{\frac{m_1}{(m_1+m_2)A_1}+\frac{m_2}{(m_1+m_2)A_2}} \times 100$$

$$C_1' = \left(\frac{C_1/A_1}{\frac{C_1}{A_1}+\frac{C_2}{A_2}}\right) \times 100 \qquad C_1' = \frac{C_1 A_2}{C_1A_2 + C_2A_1} \times 100$$ [2]

$C_1 = 90\%$
$C_2 = 10\%$

Given $A_{Si} = 28.9$ g/mol $A_{Ge} = 72.64$ g/mol

Substitution finally gives 95.76

$$C_{Si}' = \frac{90x}{90x + 10x} \times 100 = 95.76\%$$ [3]

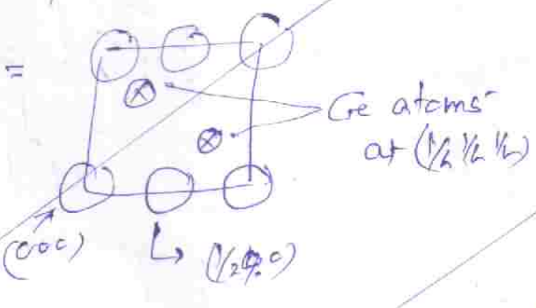
$$C_{Ge}' = 100 - C_{Si}' = 4.23\ \%$$
4.23

(b) Surface energy = bond energy per atom × $\frac{\text{no. of broken bonds}}{\text{Total bonds}}$ × PD

PD: planar density.

Ge (110) plane

planar density =



Total bonds = 12 for FCC but only 4 for Ge or even Si

Total atoms = 4

$$PD = \frac{4}{\sqrt{2}a^2}$$

$$a = \frac{8R_{Ge}}{\sqrt{3}} = 0.5634\ nm$$

$$PD = 8.91/nm^2$$

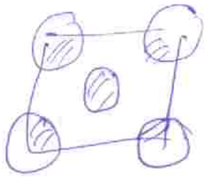
2b (7) $SE = \text{bond energy per atom} \times \dfrac{\text{Total broken bonds}}{\text{Total bonds}} \times PD$ [1]

(100) plane of Ge

Total atoms about any Ge = 4 = Total bonds

For (100) you must appreciate that 2 bonds are broken. [3]

$PD_{100}\ Ge = \dfrac{2}{a^2}$



$a = \dfrac{8}{\sqrt{3}} r_{Ge}$

$= 0.5634\ nm$

$PD = 6.30/nm^2$ [2]

$\text{Bond energy} = 300\ \dfrac{KJ}{mol} = \dfrac{300 \times 10^3 \times 1}{6.02\times10^{23} \times 1.6\times10^{-19}}\ eV/\text{particle}$

$= 3.11\ eV/\text{atom}$

$SE = 3.11\ eV \times \dfrac{2}{4} \times 6.30/nm^2$

$SE = 9.79\ eV/nm^2$ [2]

Q2C 8

$n = N e^{-E/KT}$ $\quad n = 3.6\times10^{23}/m^3 = 3.6\times10^{17}/cm^3$

atom density $\Rightarrow N = \dfrac{\rho N_A}{A} = \dfrac{9.5 \times 6.02\times10^{23}}{107.9} = 5.30\times10^{22}/cm^3$ [3]

$E = KT \ln\left(\dfrac{N}{n}\right) = 1.38\times10^{-23} \times 1273 \ln\left(\dfrac{5.30\times10^{22}}{3.6\times10^{17}}\right)$

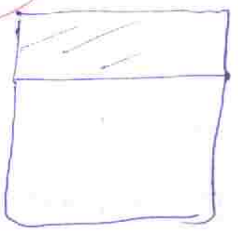
$= 1.30\ eV/\text{particle}$ [2]

Fraction at 1300K $= \dfrac{n}{N} = e^{-E/KT} = e^{-11.5942} = 9.21\times10^{-6}$

$\Rightarrow 9.21\times10^{-4}\ \%$ [3]

Q4 Q3 (15)

$C_s = 10^{21}/cm^2$



$\Phi_T = \Phi_{SiO_2} + \Phi_{Si}$

$\Phi_T = 2C_s\sqrt{\frac{Dt}{\pi}}$ [1]

$D = D_0 e^{-E/kT} = 3.26\times10^{-18}\ cm^2/s$

Diffusion length

$\sqrt{Dt} = 2.15\times10^{-7}\ cm$ [2]

Thus $\Phi_T = 2.43\times10^{14}/cm^2$ [2]

$\Phi_T = \int_0^{10^{-6}} C(x,t)\,dx + \Phi_{Si}$

$\Phi_{Si} = \Phi_T - \int_0^{10^{-6}} C(x,t)\,dx$ [2]

$\Phi_{SiO_2} = \int_0^{10^{-6}} C_s\ erfc\ \frac{x}{2\sqrt{Dt}}\ dx$

$\frac{x}{2\sqrt{Dt}} = z$

$dx = 2\sqrt{Dt}\ dz$

upper limit changes to $\frac{10^{-6}}{2\sqrt{Dt}} = 2.3255$

$\Phi_{SiO_2} = 2C_s\sqrt{Dt}\int_0^{2.3255} erfc\ z\ dz$ [2]

$\Phi_{SiO_2} = 2C_s\sqrt{Dt}\int_0^{2.3255} erfc\ z\ dz$

$= 2C_s\sqrt{Dt}\left[2.3255(erfc\ 2.3255) + \frac{1}{\sqrt{\pi}}\left(1 - e^{-(2.3255)^2}\right)\right]$

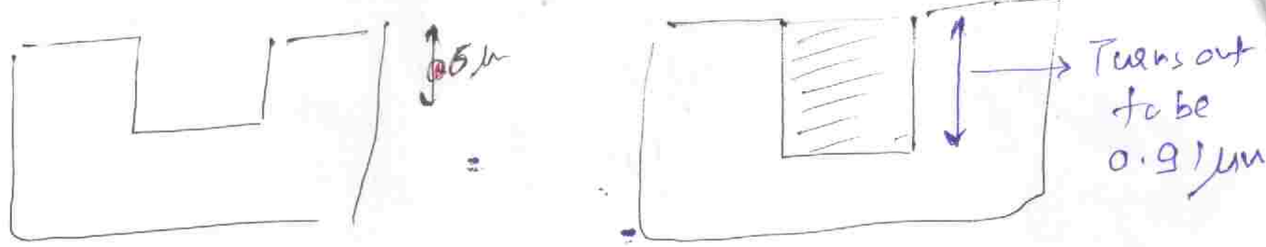
$\Phi_{SiO_2} = 2C_s\sqrt{Dt}\left[2.3255\times0.001 + \frac{1}{\sqrt{\pi}}\ 0.5618\right]$

$= 2.4257\times10^{14}/cm^2$ [2]

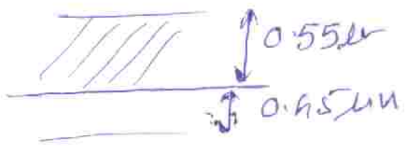
$\Phi_{Si} = \Phi_T - \Phi_{SiO_2}$

$\approx 4.3\times10^{11}/cm^2$ [4]

Q5 12



Groove is of 0.5 μm.



During oxidation vol. exp. takes place in such a way that for a bare Si surface 0.55 μm oxide grows above, and 0.45 μm grows below. This is if we oxidize Total 1 μm

We need to fill groove by oxidizing Si

∴ 0.55 μm is grown above surface if total 1 μm

∴ 0.5 μm to grow we need to grow

Total $x = \frac{0.5}{0.55} = 1.09$ μm [6]

Thus $x^2 + Ax = B(t + \tau)$ [2]

given $A = 0.421$ μm $B = 0.316 \frac{\mu m^2}{h}$

$\tau = 0$ for wet oxidation

This gives

$$t = \frac{x^2 + Ax}{B}$$

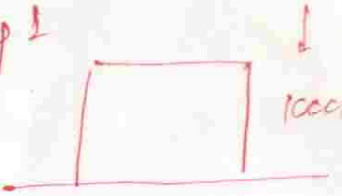
$$= \frac{(1.09)^2 + 0.421 \times 1.09}{0.316}$$

$$t = 5.21 h$$

[4]

P6 (13)

Step 1

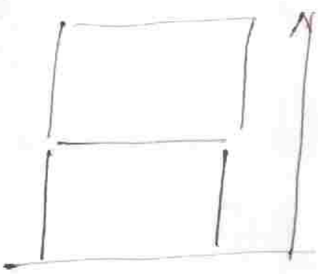


$x^2 + Ax = B(t+\tau)$ [1]

$t_1 = \dfrac{(0.1)^2 + (0.04)\times 0.1}{0.045} - 0.027$

0.284h

$t_1 = 0.0284h$ [3]



$\tau_{new} = 0.284 + 0.027$ [2]
$= 0.311h$

$x^2 + Ax = B(t+\tau)$

$t_2 = \dfrac{(0.15)^2 + (0.15)\times 0.04}{0.045} - 0.027$

$= 0.322h$ [3]

Now, to grow 0.15 µm oxide in one single dry oxidation process: $\tau = 0.027h$, $x = 0.15\mu$

$t = \dfrac{(0.15)^2 + (0.45)\times 0.15}{0.045} - 0.027$

$= 0.606 h$

$t_1 = 0.284h$

$t_2 = 0.322h$

$t = \quad h$ [4]

Thus $t = t_1 + t_2$

as expected!