

Homework Assignment #3 Solutions

Problem 1

a.) 100 keV Phosphorus → Si ⇒ $R_p = 0.12 \text{ mm}$ and $\Delta R_p = 0.045 \text{ mm}$

$$\therefore \text{Peak concentration } C_p = \frac{\phi}{2.5\Delta R_p} = \frac{1.2 \times 10^{13}}{2.5 \times 0.045 \times 10^{-4}} = 1.05 \times 10^{18} / \text{cm}^3$$

Using $\mu_n(\text{at } C_p) \sim 270 \text{ cm}^2/\text{V-sec}$ $\therefore R_s \cong \frac{1}{q\phi\mu} = \frac{1}{1.6 \times 10^{-19} \times 270 \times 1.2 \times 10^{13}} = 1929 \text{ W/ square}$

b.) $C_p \exp\left[-\frac{(x_j - R_p)^2}{2(\Delta R_p)^2}\right] = N_B = 10^{15} \Rightarrow \left[-\frac{(x_j - R_p)^2}{2(\Delta R_p)^2}\right] = \ln \frac{10^{15}}{1.05 \times 10^{18}} = -6.96 \Rightarrow x_j = 0.288 \text{ mm}$

Problem 2

140 keV boron will have $R_p = 0.4 \text{ }\mu\text{m}$ and $\Delta R_p = 0.081 \text{ }\mu\text{m}$

With $N_p = 0.4\phi/\Delta R_p$, $R_s \cong 1/q\mu\phi$ and the mobility curve for holes, we can solve the required dose by trial-and-error to obtain:

$N_p = 10^{19}/\text{cm}^3$, $\mu_p = 60 \text{ cm}^2/\text{V-sec}$ and $f = 2 \times 10^{14}/\text{cm}^2$ to give $R_s = 520 \text{ }\Omega/\text{square}$.

Problem 3

(a) Peak concentration $C_p = \frac{0.4 \cdot \text{ion dose} \cdot (\# \text{ atoms/ion})}{\Delta R_p}$

	Ion Energy	Effective B+	Implant energy	Atoms/ion	DRp (Angstrom)	Cp (atoms/cm3)
(1) B(+)	50keV		50 keV	1	500	8.0E+19
(2) B (2+)	100keV		100keV	1	700	5.7E+19
(3) B2 (+)	50keV		25 keV	2	330	2.4E+20

(b) $x_j = R_p + [2(\Delta R_p)^2 \cdot \ln \frac{C_p}{N_B}]^{\frac{1}{2}}$

The B^{2+} (doubly charged ion) has the largest R_p (~3000 Å) and the largest ΔR_p (~700 Å), it **will have the largest x_j** .

[Note : The sqrt [ln (C_p/N_B)] term only changes by 20% even C_p changes by 4 times]

(c) Using $\mu_p \sim 75 \text{ cm}^2/\text{V-sec}$ at a concentration of $5.7 \times 10^{19}/\text{cm}^3$ from mobility curves

$$R_s \cong \frac{1}{q\phi\mu_p} = \frac{1}{1.6 \times 10^{-19} \times 75 \times 1 \times 10^{15}} = 83 \text{ W/ square}$$

Problem 4

(a) **dose** = number of O atoms/cm² for the 0.1 μm thick SiO₂ = $2 \times 2.3 \times 10^{22} \times 0.1 \times 10^{-4} = 4.6 \times 10^{17}/\text{cm}^2$

[Note: This problem only needs conservation of oxygen atoms to get the required dose. Details on placement of the final SiO₂ layer will depend on ion energy (R_p and ΔR_p) and annealing conditions]

(b) Using an implantation area of 20cm × 20 cm to cover the whole 8" wafer ~ 400 cm²

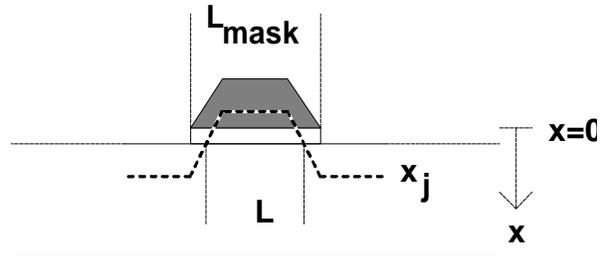
$$\text{dose} = \frac{(\text{current}/q) \times (\text{implantation time})}{\text{implantation area}} = \frac{10 \times 10^{-3} \times (\text{implantation time})}{400 \times 1.6 \times 10^{-19}}$$

⇒ **implantation time = 2944 sec = 49 min**

[Note: Typical implantation time for dopants with dose $<10^{15}/\text{cm}^2$ is less than 1 min per wafer. For a high dose implantation situation like SIMOX (mid 10^{17} dose range), it take a long time to complete the implantation process and increase cost of the implantation step.]

Problem 5

(a)



Parameter	Channel Length L
Implant Dose \uparrow	\downarrow
Ion Energy (E) \uparrow	\downarrow
Substrate conc. N_B \uparrow	\uparrow
Sidewall Angle θ \uparrow	\uparrow
Ion Mass (M) \uparrow	\uparrow

(b) (i) $R_p=0.1114 \mu\text{m}$, $\Delta R_p=0.0374 \mu\text{m}$

$$x_j=R_p+\Delta R_p\left[2 \ln \left(\frac{\phi}{\sqrt{2 \pi} \Delta R_p N_B}\right)\right]^{1 / 2}=0.29 \mu\text{m}$$

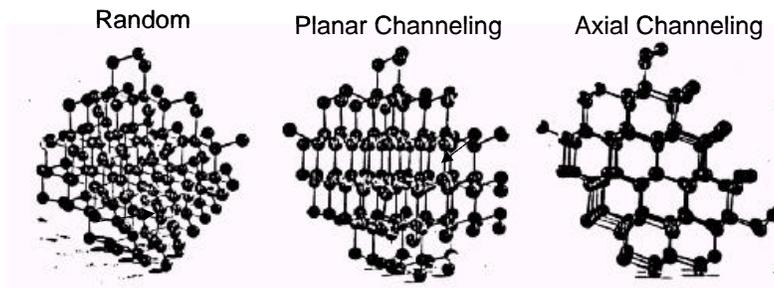
$$L=L_{\text {mask }}-2\left(x_j-0.05\right) \tan 45^{\circ}=2-2 \times 0.24=1.52 \mu\text{m}.$$

(ii) **With finite DR_p, L will decrease further** due to additional lateral spreading of dopant implantation.

Problem 6

(a)

1) For some particular angles of incidence along crystallographic axis or planes, the substrate crystalline atoms appear as strings of atoms or planes of atoms to the highly-directional trajectory of ions.



A fraction of the incident ions can trasverse the crystalline substrate with little nuclear scattering, and hence less energy loss . This fraction of ions will give a deeper implantation profile component than that of an amorphous substrate. The resultant junction depth will be deeper than that of an amorphous substrate.

2) Although a tilt-and-rotate geometry can minimize the primary channeling effect of the incident ions, we can still have a small fraction of the scattered ions (**the “lucky” ions**) bouncing into various axis or planes of the crystalline substrate, giving a tiny “channeling tail” of the doping profile.

(b) For typical energy range of ions (~ several keV to 200 keV) used in IC manufacturing, the energy loss mechanism for boron ions is primarily electronic stopping while the energy loss mechanism for arsenic is dominated by nuclear stopping. **A much higher dose of boron is needed to make its small nuclear stopping component to exceed a critical *energy density/unit volume* to transform crystalline Si into amorphous Si.**