

Homework Assignment #4 Solutions

Problem 1

a.) 100 keV Phosphorus \rightarrow Si $\Rightarrow R_p = 0.12 \mu\text{m}$ and $\Delta R_p = 0.045 \mu\text{m}$

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

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

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

Problem 2

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

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 $\phi = 2 \times 10^{14}/\text{cm}^2$ to give $R_s = 520 \Omega/\text{square}$.

Problem 3

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

	Ion Energy	Effective B+	Implant energy	Atoms/Ion	ΔR_p (Angstrom)	C_p (atoms/cm ³)
(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

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

The **B²⁺** (doubly charged ion) has the largest R_p ($\sim 3000 \text{ \AA}$) and the largest ΔR_p ($\sim 700 \text{ \AA}$), 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]

Problem 4

(a) **dose** = number of O atoms/cm² for the 0.1 μm thick $\text{SiO}_2 = 2 \times 2.3 \times 10^{22} \times 0.1 \times 10^{-4} = 4.6 \times 10^{17}/\text{cm}^2$

[Note: This problem only needs conservation of oxygen atoms to get the required dose. Details on placement of the final SiO_2 layer will depend on ion energy (R_p and ΔR_p) and annealing conditions]

(b) Using an implantation area of $20\text{cm} \times 20 \text{ cm}$ to cover the whole 8" wafer $\sim 400 \text{ cm}^2$

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

$$\Rightarrow \text{implantation time} = 2944 \text{ sec} = 49 \text{ min}$$

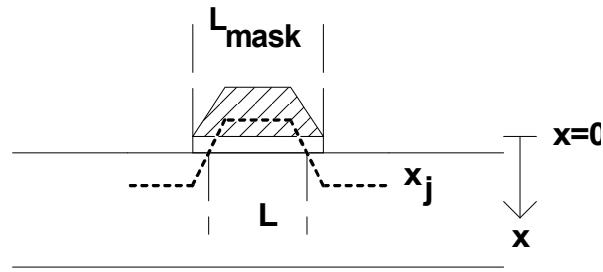
[Note: Typical implantation time for dopants with dose $< 10^{15}/\text{cm}^2$ is less than 1 min per wafer. For a high dose implantation situation like SIMOX (mid 10^{17} dose range), it take a long time to complete the implantation process and increase cost of the implantation step.]

(c) Power = $200\text{kV} \cdot 10\text{mA} = 2 \text{ kilowatts}$!! With an implant time of ~ 1 hour, Si wafer will be red hot if there is no cooling.

Problem 5

(a)

Parameter	Channel Length L
Implant Dose ↑	↓
Ion Energy (E)↑	↓
Substrate conc. $N_B \uparrow$	↑
Sidewall Angle $\theta \uparrow$	↑
Ion Mass (M)↑	↑



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

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

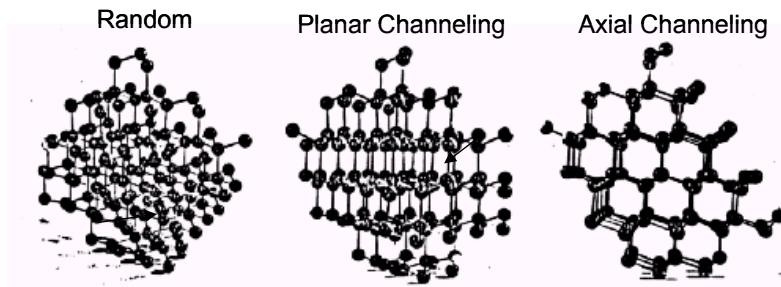
$$L = L_{\text{mask}} - 2(x_j - 0.05) \tan 45^\circ = 2 - 2 \times 0.24 = 1.52 \mu\text{m}$$

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

Problem 6

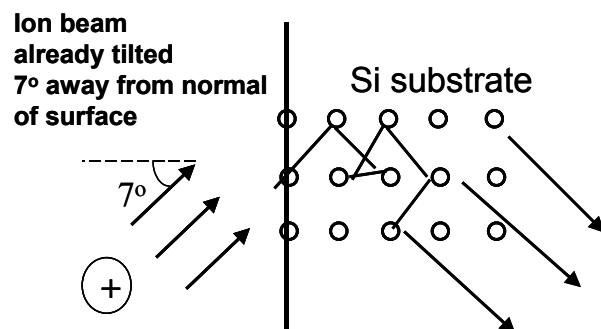
(a)

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 traverse 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 (\sim 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.**