Homework #6 Solutions

1. (5.14)

$$S_e = \left[\frac{2q^2 a_0 Z_1^{1/6} Z_2 N}{\epsilon_0 (Z_1^{2/3} + Z_2^{2/3})^{3/2}}\right]\frac{v}{v_0}$$

$a_0 = 0.53\times10^{-8}$ cm (Bohr radius) $= 5.3\times10^{-11}$ m

$q = 1.6\times10^{-19}$ C

v_0 = Bohr velocity $= 2.2\times10^{6}$ m/s

$\epsilon_0 = 8.85\times10^{-12}$ F/m

$N = 5\times10^{22}\ \text{cm}^{-3} = 5\times10^{28}\ \text{m}^{-3}$

$E = \frac{1}{2}mv^2$, so $v = \left(\frac{2E}{m_1}\right)^{1/2}$

$m_H = 1.67\times10^{-27}$ kg

B	
Z_1	5
$\frac{m_1}{m_H}$	10.8

$Z_2 = 14$

$$S_e = \left[\frac{2q^2 a_0 N}{\epsilon_0 v_0}\right]\left(\frac{2}{m_H}\right)^{1/2} E^{1/2}\left[\frac{Z_1^{7/6} Z_2}{(Z_1^{2/3}+Z_2^{2/3})^{3/2}}\right]\frac{1}{m_1^{1/2}} \qquad J = \frac{kg\,m^2}{s^2}$$

$$= 0.24\left(\frac{E}{m_1}\right)^{1/2}\left[\frac{Z_1^{7/6} Z_2}{(Z_1^{2/3}+Z_2^{2/3})^{3/2}}\right] \qquad \underbrace{\frac{C^{2}\, m\, m^{-3}}{(C/Vm)\, m/s\,(kg)^{1/2}}}_{J^{1/2}/m}$$

$$= 0.24\left(6.25\times10^{18}\,eV\right)^{1/2}\frac{1}{100\,cm}\left(\frac{E}{m_1}\right)^{1/2}$$

$$= 6\times10^{6}\left(\frac{E}{m_1}\right)^{1/2}\frac{eV^{1/2}}{cm}\left[\frac{Z_1^{7/6} Z_2}{(Z_1^{2/3}+Z_2^{2/3})^{3/2}}\right] = 6.5\times10^{6}\,E^{1/2}\,\frac{eV^{1/2}}{cm}\ (B)$$

$$S_e = -\frac{dE}{dx} \qquad dx = -\frac{dE}{S_e} \qquad \int_0^{L_{max}} dx = \int_{30keV}^{0} -\frac{dE}{AE^{1/2}} \qquad AE^{1/2}$$

$$L_{max}^{B} = -\frac{2E^{1/2}\,cm}{6.5\times10^{6}\,eV^{1/2}}\Bigg|_{30keV}^{0} = 5.33\times10^{-5}\,cm = \underline{\underline{0.53\,\mu m}}$$

2. 100keV B $\qquad$ 300nm $TiSi_2$, 300nm poly

$R_p = 215.4\,nm, \Delta R_p = 56.3\,nm$; $R_p = 296.8\,nm, \Delta R_p = 73.5\,nm$

<u>R_p scaling:</u>

Scale to $TiSi_2$: $x_{poly}^{eff} = 300\,nm \left(\frac{215.4}{296.8}\right) = 217.7$

Stack is equivalent to 517.7nm of $TiSi_2$

<u>Eq. 8.10</u> $\quad$ Fraction penetrating $= \frac{1}{2}\,\mathrm{erfc}\left(\underbrace{\frac{517.7-215.4}{\sqrt{2}(56.3)}}_{3.8}\right)$

$= 3.86\times10^{-8}$

Scale to poly (Si): $x_{TiSi_2}^{eff} = 300\,nm\left(\frac{296.8}{215.4}\right) = 413.37$

Fraction penetrating $= \frac{1}{2}\,\mathrm{erfc}\left(\underbrace{\frac{713.37-296.8}{\sqrt{2}\,73.5}}_{4.01}\right)$

$= 7.1\times10^{-9}$

<u>Dose matching:</u>

$$n(x) = \begin{cases} n_{TiSi_2}(x) & 0 < x < 300\,nm \\ \alpha n_{Si}[x-(413.4-300)] & 300\,nm < x < \cancel{600\,nm}\ \infty \end{cases}$$

$$\int_{-\infty}^{\infty} n(x)\,dx = \underbrace{\frac{1}{2}+\frac{1}{2}\,\mathrm{erf}\left(\underbrace{\frac{300-215.4}{\sqrt{2}\,56.3}}_{1.06}\right)}_{0.933} + \frac{\alpha}{2}\,\mathrm{erfc}\left(\underbrace{\frac{413.4-296.8}{(73.5)\sqrt{2}}}_{1.21}\right) = 1$$

$$0.933 + \alpha(4.35\times10^{-2}) = 1$$

$\alpha = 1.54$

Fraction penetrating $= \frac{1.54}{2}\,\mathrm{erfc}\left(\overbrace{\frac{713.4-296.8}{\sqrt{2}\,73.5}}^{4.01}\right) = 1.1\times10^{-8}$

Intermediate value. Differences are due to $\frac{\Delta R_p}{R_p}$ not being equal.

8.16. Calculate the change in junction depth for a 40 keV boron threshold adjust implant of $5\times10^{13}\text{cm}^{-2}$ annealed at 750˚C in a furnace or at 1000˚C in an RTA for a time just long enough to remove all the damage that causes TED. Assume a uniform well doping of $5\times10^{16}\text{cm}^{-3}$.

Answer:

The primary formula we will use gives the enhancement in diffusivity while TED lasts

$$Dt_{eff} = D^* \frac{I}{I^*}\tau_{enh}$$

For 40 keV boron,

$$R_p \approx 0.14\mu\text{m} \quad \Delta R_p \approx 0.055\,\mu\text{m}$$

The initial junction is given by

$$C_B = \frac{Q_{Si}}{\sqrt{2\pi\Delta R_p^2}}\exp\left(-\frac{\left(x-R_p\right)^2}{2\Delta R_p^2}\right)$$

$$x = 0.3\mu\text{m}$$

$$D_B = 0.76\exp\left(-\frac{3.46}{kT}\right)$$

At 750˚C, the equilibrium boron diffusivity is

$$D_B = 6.9\times10^{-18}\,\text{cm}^2\,\text{sec}^{-1}$$

and it is enhanced by 7500 (Fig. 8.38) for a time of 400 seconds (Fig. 8.40)

giving

$$Dt_{eff}^{750\,C} = 2.07\times10^{-11}\text{cm}^2$$

At 1000˚C, the equilibrium boron diffusivity is

$$D_B = 1.5\times10^{-14}\,\text{cm}^2\,\text{sec}^{-1}$$

and it is enhanced by 400 for 0.2 seconds

$$Dt_{eff}^{1000\,C} = 1.2 \times 10^{-12}\ cm^2$$

Clearly, the effective Dt is higher at 750˚C than at 1000˚C, and we can calculate the new junction depths from

$$x = R_p + \sqrt{-2\left(\Delta R_p^2 + 2Dt_{eff}\right)\ln\left[\frac{C_B}{Q}\sqrt{2\pi\left(\Delta R_p^2 + 2Dt_{eff}\right)}\right]}$$

$$x = 0.14 + 0.23 = 0.37\mu m \text{ at } 750˚C$$

$$x = 0.14 + 0.17 = 0.31\mu m \text{ at } 1000˚C$$

The 1000˚C is deeper by

$$\Delta x_j = 0.06\mu m$$

4 (a) $$C_{As}(x) = \frac{Q}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{(x-R_p)^2}{2\sigma^2}\right)$$

$$E_n = 80\,\text{keV} * C_{As}(x)$$

$$C_{damage} = \frac{E_n(x)}{30\,\text{eV}} = \frac{80{,}000}{30}\,\frac{Q}{\sqrt{2\pi}\,(25\times10^{-7}\,\text{cm})}\exp\left(-\frac{(x-60)^2}{2(25)^2}\right)$$ (x in nm)

Amorphization at peak when $C_{damage}(60\,\text{nm}) = 5\times10^{21}\,\text{cm}^{-3}$

$$Q = \frac{5\times10^{21}\,\text{cm}^{-3}\sqrt{2\pi}\,(25\times10^{-7}\,\text{cm})\,30\,\text{eV}}{80{,}000\,\text{eV}} = \underline{\underline{1.2\times10^{13}\,\text{cm}^{-2}}}$$

(b) Amorphization at surface when

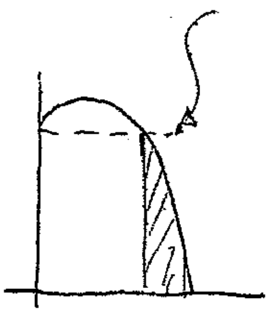
$$C_{damage}(0) = 5\times10^{21}\,\text{cm}^{-3}$$

$$Q = 1.2\times10^{13}\,\text{cm}^{-2}\exp\left(\frac{(60)^2}{2(25)^2}\right) = \underline{\underline{2.1\times10^{14}\,\text{cm}^{-2}}}$$

(c) Location of a/c interface is when $C_{damage}(x) = 5\times10^{21}\,\text{cm}^{-3}$

$$x_{a/c} = 60\,\text{nm} + 25\,\text{nm} * \sqrt{2\ln\left(\frac{5\times10^{21}\,\text{cm}^{-3}}{1.7\times10^{8}\,\text{cm}^{-1}\,Q}\right)}$$

Remaining dose is $\int_{x_{a/c}}^{\infty} C_{damage}(x)\,dx$ at $x_{a/c}$ C_{damage} is the same

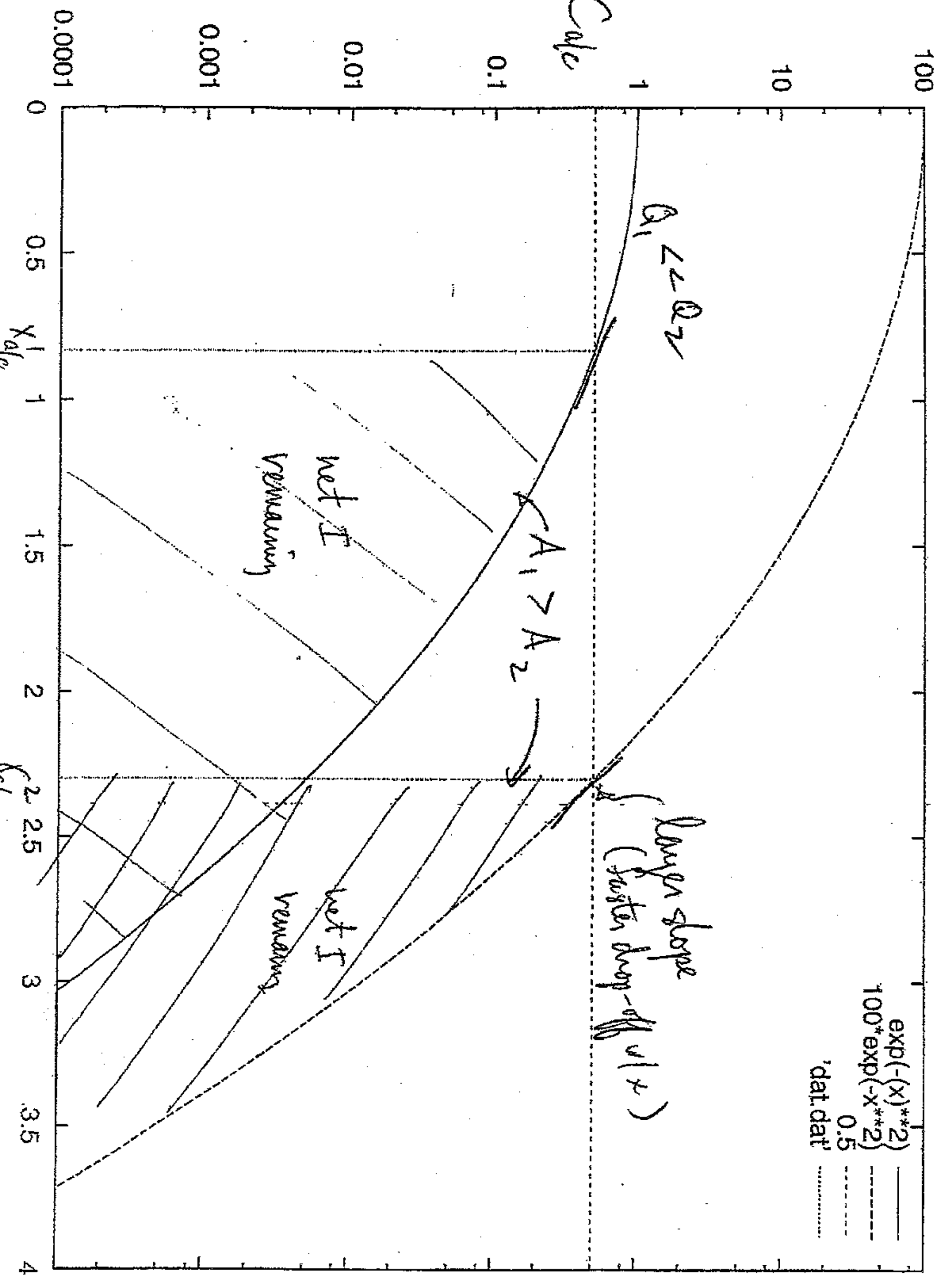


$$\left.\frac{dC_{damage}}{dx}\right|_{x=x_{a/c}} = -1.7\times10^{8}\,\text{cm}^{-1}\,Q\left(\frac{2(x_{a/c}-60)}{2(25)^2}\right)\exp\left(-\frac{(x_{a/c}-60)^2}{2(25)^2}\right)$$

$$= -\frac{2(x_{a/c}-60)}{2(25)^2}\,5\times10^{21}\,\text{cm}^{-3}$$

Thus, C_{damage} drops faster when $x_{a/c}$ is larger (larger dose)

Total Damage dose decreases w/ implant dose (Q) due to increased slope (as shown on plot).



5.3. An X-ray exposure system uses photons with an energy of 1 keV. If the separation between the mask and wafer is 20 µm, estimate the diffraction limited resolution that is achievable by this system.

Answer:

The equivalent wavelength of 1 keV x-rays is given by

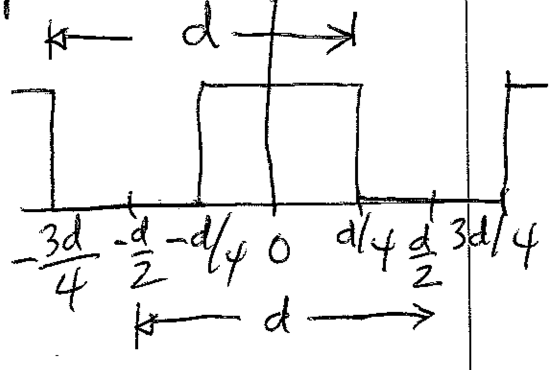
$$E = h\nu = \frac{hc}{\lambda} \quad \therefore \quad \lambda = \frac{hc}{E} = \frac{\left(4.14x10^{-15}\,\mathrm{eV\,sec}\right)\left(3x10^{10}\,\mathrm{cm\,sec^{-1}}\right)}{10^{3}\,\mathrm{eV}}$$

$$= 1.24x10^{-7}\,\mathrm{cm} = 1.24\ \mathrm{nm}$$

X-ray systems operate in the proximity printing mode, so that the theoretical resolution is given by Eqn. 5.12:

$$\mathrm{Resolution} = \sqrt{\lambda g} = \sqrt{\left(1.24x10^{-3}\,\mu\mathrm{m}\right)\left(20\mu\mathrm{m}\right)} = 0.15\mu\mathrm{m}$$

6. The Fourier decomposition of square wave with unitheight and period d is:



$$\frac{1}{2} + \frac{2}{\pi}\left[\cos\frac{2\pi x}{d} - \frac{1}{3}\cos\frac{6\pi x}{d} + \frac{1}{5}\cos\frac{10\pi x}{d} - \frac{1}{7}\cos\frac{14\pi x}{d} + \dots\right]$$

Maximum spatial frequency allowed by the pupil function is: $\frac{NA}{\lambda} = \frac{0.8}{193\,nm} = 0.0044\ nm^{-1}$

the spatial frequencies are $\frac{n}{d}$, where $n = 1, 3, 5, \dots$

$\frac{1}{d} = \frac{1}{260\,nm} = 0.0038$, so only 1^{st} order term passes through pupil function. The resulting intensity is: $I = I_0\left[0.5 + 0.637\cos\left(\frac{x}{41.4\,nm}\right)\right]^2$

$$\frac{I}{I_0} = \begin{cases} 0.6 \text{ @ } x = \pm 46.57\,nm \\ 0.4 \text{ @ } x = \pm 56.34\,nm \end{cases}$$