$$C = \frac{Q}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(x-R_P)^2}{2\sigma^2}\right)$$

(a) Peak at $x=R_P$, the damage can be calculated by

$$Damage = \frac{E_n}{2E_d}C = \frac{20keV}{2 \times 20eV}C = 555.6C$$

The amorphization threshold is $5*10^{21}$ cm⁻³, so the minimum peak concentration should be

$$C = \frac{5 \times 10^{21}}{555.6} cm^{-3} = 0.9 \times 10^{19} cm^{-3} = \frac{Q}{\sqrt{2\pi\sigma}}$$
(*)

We can calculate the minimum dose

$$Q = \sqrt{2\pi}\sigma^*C = 1.8 \times 10^{13} cm^{-3}$$

(b) To get continuous amorphization to surface, we should have

$$0.9 \times 10^{19} cm^{-3} = \frac{Q}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(0-R_p)^2}{2\sigma^2}\right)$$

So
$$Q = 1.8 \times 10^{13} cm^{-2} \exp(\frac{R_p^2}{2\sigma^2}) = 1.33 \times 10^{14} cm^{-2}$$

If the energy deposition profile is skewed towards surface, an ion particle can generate more I/V pairs near the surface region than in the bulk region. So less dose than our calculation is required to make surface region amorphous.

(c) At the amorphous crystalline interface, C_{damage}=5*10²¹cm⁻³ independent of dose, so the net interstitial concentration is also independent of dose which is 10¹⁹cm⁻³. Using assumption of (a), we can obtain the amorphous crystalline interface using the following equation,

$$0.9 \times 10^{19} \, cm^{-3} = \frac{Q}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(x-R_P)^2}{2\sigma^2}\right)\Big|_{x=x_{a/c}}$$

Combining result of (a) and equation (*), we can get

$$x_{a/c} = R_{P} + \sigma \sqrt{2 \ln\left(\frac{Q}{1.8 \times 10^{13} cm^{-2}}\right)}$$
$$\frac{\partial C_{I}^{net}}{\partial x}\Big|_{x=x_{a/c}} = \frac{Q}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(x_{a/c} - R_{P})^{2}}{2\sigma^{2}}\right) \left(-\frac{x_{a/c} - R_{P}}{\sigma^{2}}\right) = 0.9 \times 10^{19} cm^{-3} \left(-\frac{x_{a/c} - R_{P}}{\sigma^{2}}\right)$$

Thus net interstitial drops faster as $x_{a/c}$ goes up as Q goes up, so Net excess I below $x_{a/c}$ drops as dose increase.

From the plot in page #23 in the notes, the interstitial supersaturation is about 10000 at 750C, and is about 800 at 1000C;

From the plot in page #24 in the notes, the duration to remove damage is about 1000s at 750C and is about 0.5s at 1000C.

The effective Dt should be

$$(Dt)_{TED} = D_B f_I \frac{C_I}{C_I^*} \tau_{enh}$$

f_I=1 for boron. For simplicity, the intrinsic boron diffusivity is used here.

At 750C,
$$D_B = 1.0 \times \exp(-\frac{-3.5eV}{k_BT}) = 5.8 \times 10^{-18} cm^2 / s$$

So $(Dt)_{TED} = D_B f_I \frac{C_I}{C_I^*} \tau_{enh} = 5.8 \times 10^{-18} cm^2 / s * 10000 * 1000s = 5.8 \times 10^{-11} cm^2$

At 1000C,
$$D_B = 1.0 \times \exp(-\frac{-3.5eV}{k_BT}) = 1.4 \times 10^{-14} \, cm^2 \, / \, s$$

So
$$(Dt)_{TED} = D_B f_I \frac{C_I}{C_I^*} \tau_{enh} = 1.4 \times 10^{-14} cm^2 / s * 800 * 0.5s = 5.6 \times 10^{-12} cm^2$$

The junction depth can be obtained using the following equation

$$2 \times 10^{17} \, cm^{-3} = \frac{Q}{\sqrt{2\pi(\Delta R_p^2 + 2Dt)}} \exp\left(-\frac{(x_j - R_p)^2}{2(\Delta R_p^2 + 2Dt)}\right)$$

Here, $R_p{=}140nm$ and $\Delta R_p{=}55nm$ from the plot in page 3-4 40keV boron implantation. $Q{=}2{*}10^{14}cm^{-2}.$

The calculated junction depth at 750C is $x_j=0.460\mu m$. At 1000C the junction depth is $x_j=0.325 \mu m$.

The alternative method to calculate the effective Dt is by using the following formula

$$(Dt)_{TED} = D_B \left(\frac{QR_P}{d_I C_I^*} \right)$$

where $d_I C_I^* = 5*10^{25} exp(-4.88 eV/kT) cm^{-1}s^{-1}$.

The Sentaurus input file is:

line x location=0 spacing= 0.001 tag=SiDevTop line x location=1 spacing=0.01 line x location=5 spacing=0.1 tag=SiDevBot region silicon xlo=SiDevTop xhi=SiDevBot init concentration=2e17<cm-3> field=Phosphorus wafer.orient=100

```
implant Boron energy=40<keV> dose=2e14<cm-2> tilt=7
struct tdr=implant
```

```
#diffuse temperature=750<C> time=1000<s> diffuse temperature=1000<C> time=0.5<s>
```

struct tdr=p1

The output plots for boron distribution is shown below.



The initial junction depth at $2*10^{17}$ cm⁻³ after implantation is about 395nm.

The junction depth after 0.5s 1000C RTA is 403nm.

The junction depth after 1000s 750C furnace annealing is 454 nm.

By Equation in the notes:
$$v = \frac{k_S h_G}{k_S + h_G} \frac{C_T}{N} Y = \frac{1}{\left(\frac{1}{h_G} + \frac{1}{k_S}\right)} \frac{C_T}{N} Y$$

 $h_G = 0.2 \text{ cm sec}^{-1}$

 $k_{\rm S} = 2 \times 10^6 \exp(-1.5 \text{ eV/kT}) \text{ cm sec}^{-1}$ where $T = T^{\circ}C + 273$

 $C_T/N = 1/10,000$

 $Y = P_g/P_{total} = 1 \text{ torr} / 760 \text{ torr}$

For low pressure case, only h_g changes (increased by 100 times). C_T/N times P_g/P_{total} remains constant since n and P_g each remains constant, and the C_T/P_{total} ratio stays constant as stated above.

The plot of v for each case versus 1/T below. For the 1 atm total pressure case, curve v, the transition between surface reaction controlled and diffusion controlled is at about 800°C, while for the low pressure case ("low P"), the transition occurs at somewhere above 1200°C.



Problem 5

From equation in the notes, but assuming an ideal cosine emission behavior from the small area source, the flux emitted from a small area planar source to an area facing the source is:

$$F_{ik}^{\ \ p} = \frac{R_{evap}}{\pi r^2} \cos \theta_i$$

The deposition rate, v, is just that flux divided by the film density, so that

$$v = \frac{R_{evap}}{\pi r^2 N} \cos \theta = \frac{3x 10^{-3} \ gm \ \sec^{-1}}{\pi (10 cm)^2 10 \ gm \ cm^{-3}} \cos \theta$$

= 2.83×10⁻⁷ cos $\theta \ cm / \sec = 2.83 \cos \theta \ nm / \sec^{-1}$

(Or one could just use the deposition rate for small area source with $\cos\theta_k = 1$ to get the same result.) A plot of v versus θ_i will be a cosine function, with a value of v at $\theta_i = 0^\circ$ equal to 2.83 nm/sec, and value of 0 at $\theta_i =$ plus or minus 90°. No, uniform deposition will not occur.