1. (a) From the figure we have $R_p = 50nm$, $\Delta R_p = 18nm$ for both Si and Si_3N_4.

Since the thickness of Si_3N_4 layer is 10nm, the implanted peak is $50nm - 10nm = 4$

away from the Si/Si_3N_4 interface.

The implanted profile can be expressed as

$$C(x) = C_p \exp\left(-\frac{(x-R_p)^2}{2\Delta R_p^2}\right) = \frac{Q}{\sqrt{2\pi}\,\Delta R_p} \exp\left(-\frac{(x-R_p)^2}{2\Delta R_p^2}\right)$$

$$= 4.43 \times 10^{19}\,cm^{-3} \exp\left(-\frac{(x-50nm)^2}{2\times(18nm)^2}\right)$$

The implanted does in Si is: $\int_{10nm}^{\infty} C(x)\,dx = \frac{Q}{2}\operatorname{erfc}\left(\frac{X_{SiN} - R_p}{\sqrt{2}\,\Delta R_p}\right)$

$$= \frac{Q}{2}\operatorname{erfc}(-1.57) = \frac{Q}{2}\times 1.97$$

$$= 1.97 \times 10^{14}\,cm^{-2}$$

(b)

The effective Dt ~~for~~ in TED is

$$(Dt)_{TED} = D_B\left[\frac{Q R_p}{d_I C_I^*}\right] f_I \times 1.5 \qquad , \qquad f_I = 1 \text{ for boron.}$$

The effective anneal time for boron under equilibrium conditions should be

$$\frac{(Dt)_{TED}}{D_B} = 1.5\times\left[\frac{Q R_p}{d_I C_I^*}\right] = \frac{1.97\times10^{14}\,cm^{-2} \times 50\times10^{-7}\,cm \times 1.5}{5\times10^{25}\exp\left(\frac{-4.88}{8.62\times10^{-05}\times(1273.15)}\right)} \times 1$$

$$= \frac{1.97\times 50 \times 10^{7}\,cm^{-1}\times 1.5}{2.44\times10^{6}\,cm^{-1}\,s^{-1}} = 604.5\,s$$

The alternative metod is by using $t_{eff} = \tau_{enh} \frac{C_I^{max}}{C_I^*} \cdot 1.5$

Here τ_{enh} is the duration of TED which is about 0.5s in the plot;

C_I^{max}/C_I^* is the supersaturation of interstitial which is about 800 in the plot;

2. $\langle 111 \rangle$ wafer

In steam at 1000 °C we have

$$B = 3.86\times10^{2}\ \mu m^{2}\,hr^{-1}\ \exp\left(-\frac{0.78}{8.62\times10^{-5}\times1273.15}\right)$$

$$= 0.3162\ \mu m^{2}/hr$$

$$\frac{B}{A} = 1.63\times10^{8}\ \mu m/hr\ \exp\left(\frac{-2.05}{8.62\times10^{-5}\times1273.15}\right)$$

$$= 1.2582\ \mu m/h$$

$$\Rightarrow A = 0.2513\ \mu m$$

$$\tau = \frac{X_i^2}{B} + \frac{X_i}{B/A} = \frac{(0.2\mu m)^2}{0.3162\mu m^2/hr} + \frac{0.2\mu m}{1.2582\mu m/h} = 0.2855\ hr$$

The final oxide thickness is

$$X_o = \frac{A}{2}\left[\sqrt{1+\frac{t+\tau}{A^2/4B}}-1\right] = 0.1256\mu m\left[\sqrt{1+\frac{(2+0.2855)}{0.2513^2/(4\times0.3162)}}-1\right]$$

$$= 0.1256\mu m\left[\sqrt{1+45.77}-1\right] = 0.733\ \mu m$$

3. If an initial 200nm oxide on a <100> wafer is further oxidized in pure O_2 at 1000°C, what would be the interstitial supersaturation near the beginning of the growth process and the resulting diffusion enhancement factor (D/D*) for As? (20)

$$\frac{dx_o}{dt} = \frac{B}{2x_o + A}$$

$$= \frac{0.0105\ \mu m^2/hr}{2(0.2\mu m) + 0.233\mu m}$$

$$= 0.0166\ \frac{\mu m}{hr}$$

$$B_{100} = B_{111} = 7.72\times10^2 \exp\left(-\frac{1.23eV}{kT}\right)\frac{\mu m^2}{hr}$$

$$= 0.0105\ \mu m^2/hr$$

$$\frac{B}{A}_{100} = \frac{B}{A}_{111}/1.68 = \frac{6.23\times10^6}{1.68}\exp\left(-\frac{2.0\,eV}{kT}\right)\frac{\mu m}{hr}$$

$$= 0.045\ \mu m/hr$$

$$A_{100} = \frac{B}{B/A} = \frac{0.0105\ \mu m^2/hr}{0.045\ \mu m/hr} = 0.2333\ \mu m$$

From $\frac{\langle D_p\rangle}{D_p^*}$ vs $\left(\frac{dx_o}{dt}\right)$ plot

$$\frac{\langle D_p\rangle}{D_p^*} \cong 4 = f_I^P\frac{C_I}{C_I^*} + f_V^P\frac{C_V}{C_V^*}$$

Assuming $\frac{C_V}{C_V^*} = \frac{C_I^*}{C_I}$

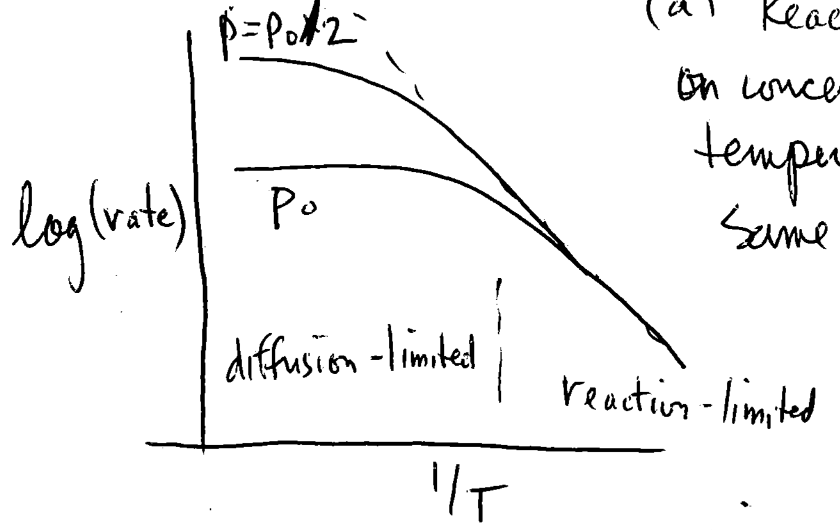
and using $f_I = 0.98$

$$\frac{C_I}{C_I^*} = 4.08$$

$$\frac{\langle D_{As}\rangle}{D_{As}^*} = f_I^{As}\left(\frac{C_I}{C_I^*}\right) + f_V^{As}/\left(\frac{C_I}{C_I^*}\right) = 0.4(4.08) + \frac{0.6}{4.08}$$

$$= \underline{\underline{1.76}}$$

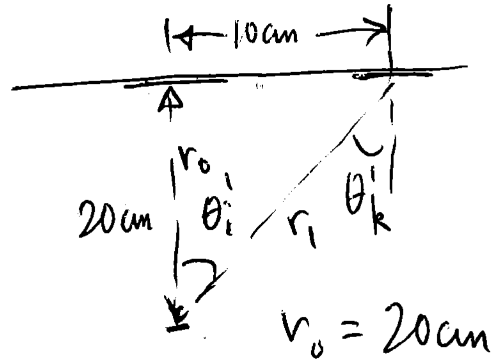
4. Sketch the deposition rate versus temperature for an LPCVD polysilicon deposition process with SiH_2Cl_2/H_2 source gasses. If the pressure is dropped by a factor of 2, but the SiH_2Cl_2 partial pressure is kept the same, what will happen to the deposition rate (increase, decrease, no change) if the process is (a) reaction limited and (b) diffusion limited. Briefly explain answer in each case. (18)



(a) Reaction limited process depends only on concentration of reactant(s) and temperature. These both remain the same, so no change.

(b) Mass transport in gas phase depends on total pressure inversely ($D \propto 1/P_{total}$) and h(gas phase mass transfer rate) is proportional to D. Thus if pressure is dropped, growth rate will increase. Increase will be a factor of 2 if thickness of stagnant layer (which varies much less strongly with pressure) is unchanged.

5. In an evaporation chamber, wafers are attached to a flat wafer holder parallel to and 20 cm away from the small area source. If the angular distribution of the source is ideal (n=1), what would be the ratio of deposition rates on a flat wafer surface between the center of the wafer holder (directly opposite source) and 10 cm away from the center. (12)



$$\text{rate} \propto \frac{1}{r^2} \cos^n \theta_i \cos\theta_k \qquad n=1$$

$$\frac{\text{rate}(x=0)}{\text{rate}(x=10cm)} = \frac{1/r_0^2 \cos(0)\cos(0)}{1/r_1^2 \cos(\theta_i')\cos(\theta_k')}$$

$r_0 = 20cm$

$r_1 = \sqrt{(20cm)^2 + (10cm)^2}$

as $\theta_i = \theta_k$, $\cos\theta_k' = \dfrac{20cm}{\sqrt{(20cm)^2 + (10cm)^2}}$

$$\frac{\text{rate}(x=0)}{\text{rate}(x=10)} = \frac{1/(20cm)^2 \,(1)\,(1)}{1/(500cm^2)\ \frac{400cm^2}{500cm^2}} = \left(\frac{5}{4}\right)^2 = \frac{25}{16} = 1.5625$$