Homework #4 Solutions, EE/MSE 486, Spring 2017

Problem 1

From simulation result of problem 3 of homework 3, we can get the average oxidation rate for the first half hour, dx_O/dt=13.6nm/0.5hr=0.027um/h; Also for second hour the oxidation rate is dx_O/dt=(31.6nm-13.6nm)/(2hr-0.5hr)=0.012um/h.

From the Fig. 11 in the supplement notes for oxidation, we have for

$$\frac{dx_O}{dt} = \begin{cases} 0.027\mu m/h \\ 0.012\mu m/h \end{cases} \rightarrow \frac{D}{D^*} = \begin{cases} 4.3\ for\ the\ first\ 30\ mins \\ 3.9\ for\ the\ final\ 90\ mins \end{cases}$$

The above diffusion enhancement is for phosphorus, so we have

$$\frac{D}{D^*} = \frac{D_P}{D_p^*} = f_I^P \frac{C_I}{C_I^*} + f_V^P \frac{C_V}{C_V^*}, \quad where\ f_I^P + f_V^P = 1 \tag{1}$$

Since the I/V recombine is assumed near equilibrium, so

$$C_I * C_V = C_I^* * C_V^* \rightarrow \frac{C_V}{C_V^*} = \frac{C_I^*}{C_I} \tag{2}$$

Combine (1) and (2), we can get

$$\frac{C_I}{C_I^*} = \begin{cases} 4.5\ for\ the\ first\ 30\ mins \\ 4.1\ for\ the\ final\ 90\ mins \end{cases}$$

For Arsenic, f_I^{As}=0.4, so we have

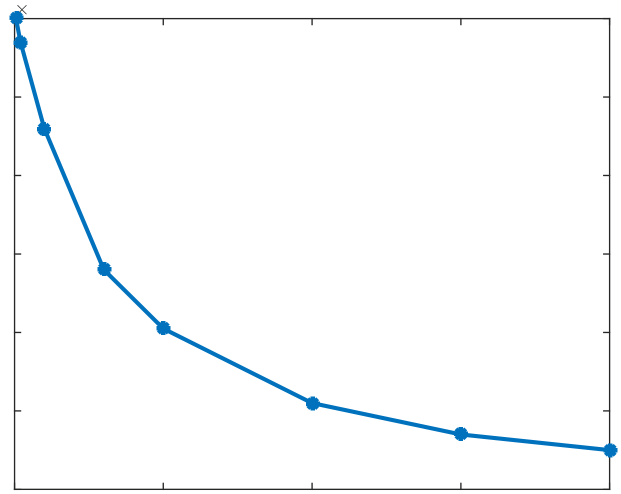
$$\frac{D_{As}}{D_{As}^*} = 0.4\frac{C_I}{C_I^*} + 0.6\frac{C_I^*}{C_I} = \begin{cases} 1.93\ for\ the\ first\ 30\ mins \\ 1.79\ for\ the\ final\ 90\ mins \end{cases}$$

For Antimony, f_I^{As}=0.05, so we have

$$\frac{D_{As}}{D_{As}^*} = 0.05\frac{C_I}{C_I^*} + 0.95\frac{C_I^*}{C_I} = \begin{cases} 0.44\ for\ the\ first\ 30\ mins \\ 0.44\ for\ the\ final\ 90\ mins \end{cases}$$

In Sentaurus simulation, the equilibrium interstitial concentration at 1000C is $7.7*10^{11}$ cm^{-3}.

The output of timedependent interstitial concentration during oxidation is shown below:



For first 30 minutes oxidation at 1000 C, the average interstitial concentration is about $2.2*10^{11}$ cm^{-3}, and C_I/C_I^* =2.85.

For final 90 minutes oxidation at 1000 C, the average interstitial concentration is about $1.6*10^{11}$ cm^{-3}, and C_I/C_I^* =2.08.

Problem 2

According to the Range Statistics plot, we can get Rp and ΔRp for SiO2 and photoresist for B implantation with 5keV.

For SiO2, Rp=18 nm, and ΔRp=11nm

For photoresist, Rp=40nm, and ΔRp=11nm

The relation between penetrated dose and film thickness is

$$Q_P = \frac{Q}{2} erfc(\frac{x_m - R_P}{\sqrt{2}\Delta R_P})$$

In this problem, $Q=10^{14}cm^{-2}$, and $Q_P=2*10^{12}cm^{-2}$.

$$erfc\left(\frac{x_m - R_P}{\sqrt{2}\Delta R_P}\right) = 0.04 \quad => \left(\frac{x_m - R_P}{\sqrt{2}\Delta R_P}\right) = 1.45$$

For SiO2, the above equation can be solved to get x_m=40.5nm

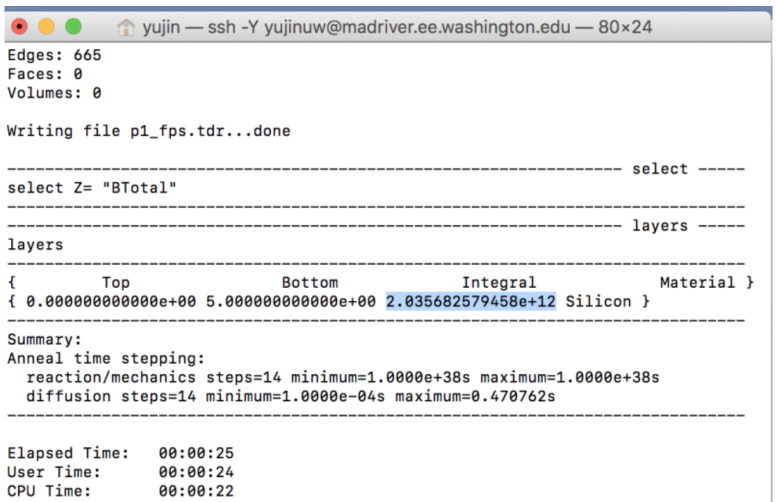
For photoresist, the above equation can be solved to get x_m=62.5nm

The Sentaurus input is as follows:

```
line x location=0 spacing= 0.001 tag=SiDevTop
line x location=1 spacing=0.01
line x location=5 spacing=0.01  tag=SiDevBot
region silicon xlo=SiDevTop xhi=SiDevBot
```

```
init concentration=1e14<cm-3> field=Phosphorus wafer.orient=100

deposit material=photoresist type=isotropic thickness=0.0974
grid remesh

implant Boron energy=5<keV> dose=1e14<cm-2> tilt=7

strip photoresist
diffuse temperature=750<C> time=1<s>
#diffuse temperature=1000<C> time=0.5<s>

struct tdr=p1
select z=BTotal
layers
```

The simulated thickness to obtain required penetrated dose is 42.5 nm for oxide and 97.4 nm for photoresist.



```
yujin — ssh -Y yujinuw@madriver.ee.washington.edu — 80×24
Edges: 665
Faces: 0
Volumes: 0

Writing file p1_fps.tdr...done

----------------------------------------------------------------- select -----
select Z= "BTotal"
------------------------------------------------------------------------------
----------------------------------------------------------------- layers -----
layers
------------------------------------------------------------------------------
{         Top                Bottom               Integral            Material }
{ 0.000000000000e+00 5.000000000000e+00 2.035682579458e+12 Silicon }
------------------------------------------------------------------------------
Summary:
Anneal time stepping:
  reaction/mechanics steps=14 minimum=1.0000e+38s maximum=1.0000e+38s
  diffusion steps=14 minimum=1.0000e-04s maximum=0.470762s
------------------------------------------------------------------------------

Elapsed Time:   00:00:25
User Time:      00:00:24
CPU Time:       00:00:22
```

Problem 3

If the beam is aligned with the channels, then nuclear stopping will be minimized and electronic stopping will dominate. The range will be

$$R = \frac{1}{N}\int_0^E \frac{dE}{S_e(E)} = \frac{1}{N}\int_0^E \frac{dE}{k\sqrt{E}}$$

The value of k is given by $k = 0.2\times10^{15}\, eV^{1/2} cm^2$ while $N = 5\times10^{22}\, cm^{-3}$ is the atom density in silicon, so that the range is given by

$$R \approx 20\sqrt{E}\ Angstroms \approx 282\ nm$$

This is about four times the range from the range tables (Rp=74 nm and delta Rp=31nm), because there is a nuclear stopping component which contributes along with the electronic stopping. However, the calculation does indicate the range of a well-channeled ion.
For a 10^{14} cm^{-2} dose implantation, the implantation profile with 50% ions channeled is shown below: