For this problem please use the information in the class notes for Lecture 9.0. For a particular transistor on a 30 cm wafer, we need peak phosphorous dopant concentration of 0.001 at % at a depth of 0.3 m.

A)Detethe implantation conditions (current, time and applied voltage) necessary to achieve this phosphorous dopant concentration profile.

B)A Si3N4 thick film is grown on the bare Silicon wafer as a mask for this implantation. How thick does the Si3N4 film need to be to be an effective implantation mask? Assume that the standard deviation of the implantation depth is 26.7% of the peak depth.

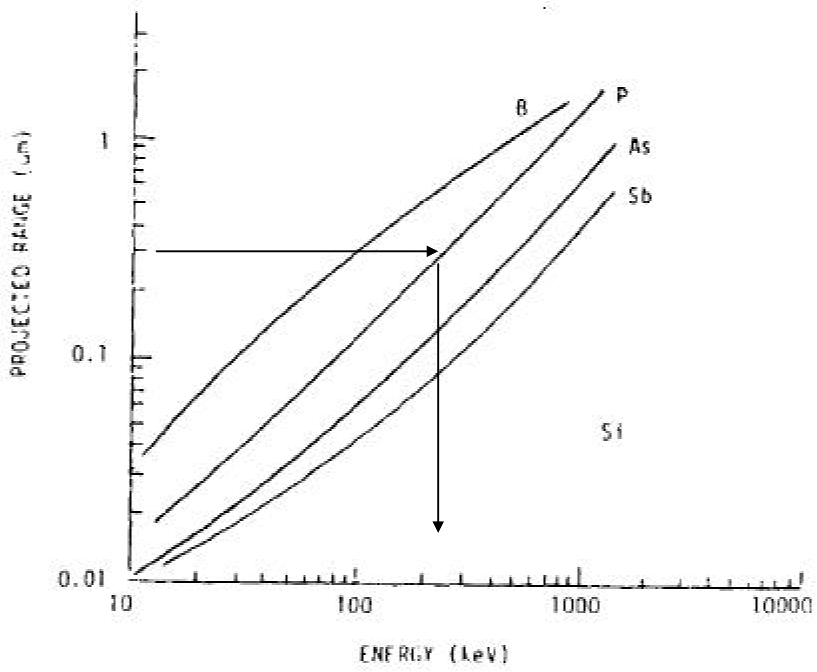
C)The Si3N4 film is grown by reacting the Silicon wafer with pure N2 gas at a pressure of 0.0001 atm. and a temperature of 1100K.3/2 Si(s)+ N2(g) ½ Si3N4(s)

Determine the time needed for the wafer in the reaction furnace to grow this Si3N4 film assuming that the chemical reaction is the rate-controlling step and that the reaction rate is given by:
Flux= koexp(-EA/RgT) (CN2-CN2-eq)
where ko= 1.2x105 cm/s, EA=23 kcal/mole.

DATA:	Density(gm/cm3)	Mole Weight		
Si	2.33	28.08		
Si3N4	3.44	140.28		
	Hof	Gof	So	Cp
N2	0	0	45.77	6.961
Si(s)	0	0	4.5	4.78
Si3N4	-179.3	-154.7	22.4	23.84
	kcal/mole	kcal/mol	cal/(mole*K)	cal/(mole*K)

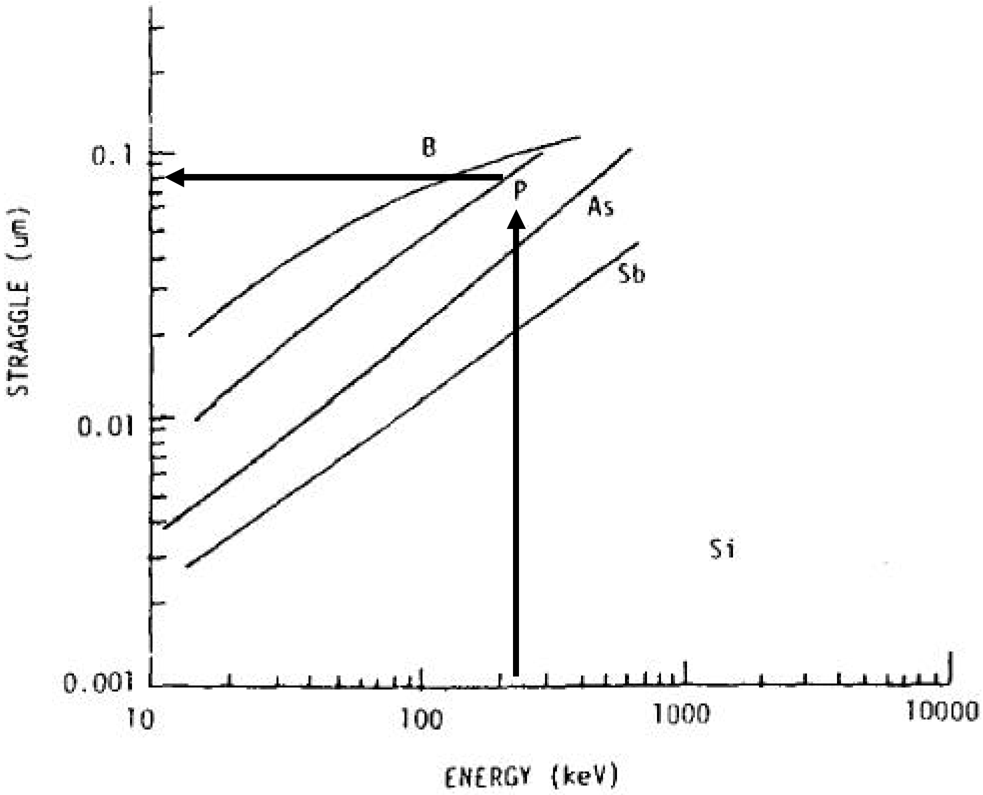
Implantation

$\mu m := 10^{-6} \cdot m$



A) Implantation Energy from figure is 250 keV

$$N_{Av} := 6.023\cdot 10^{23}\cdot\frac{1}{\text{mole}}$$



Standard Deviation of Projected Range σx=0.08 µm

$$\frac{0.08\cdot\mu m}{0.3\cdot\mu m} = 0.267$$

$\sigma_x := 0.08\cdot\mu m$ taken from figure above

Silicon Data

$D_{wafer} := 30 \cdot cm$

$\rho := 2.33 \cdot \frac{gm}{cm^3}$ $Mw := 28 \cdot \frac{gm}{mole}$

$C_{eq} := \frac{\rho \cdot N_{Av}}{Mw}$ $C_{eq} = 5.012 \times 10^{22} \frac{1}{cm^3}$ # atoms/cm^3

Dopant Dose Calculation

$N_{max} := 0.00001 \cdot C_{eq}$

$N_{max} = \frac{N_{dose}}{\sqrt{2\pi} \cdot \sigma_x}$

$N_{max} = 5.012 \times 10^{17} \frac{1}{cm^3}$ # atoms/cm^3

$N_{dose}(N_{max}, \sigma_x) := N_{max} \cdot \left(\sqrt{2\pi} \cdot \sigma_x\right)$

$N_{dose}(N_{max}, \sigma_x) = 1.005 \times 10^{13} \frac{1}{cm^2}$ Ions/cm^2

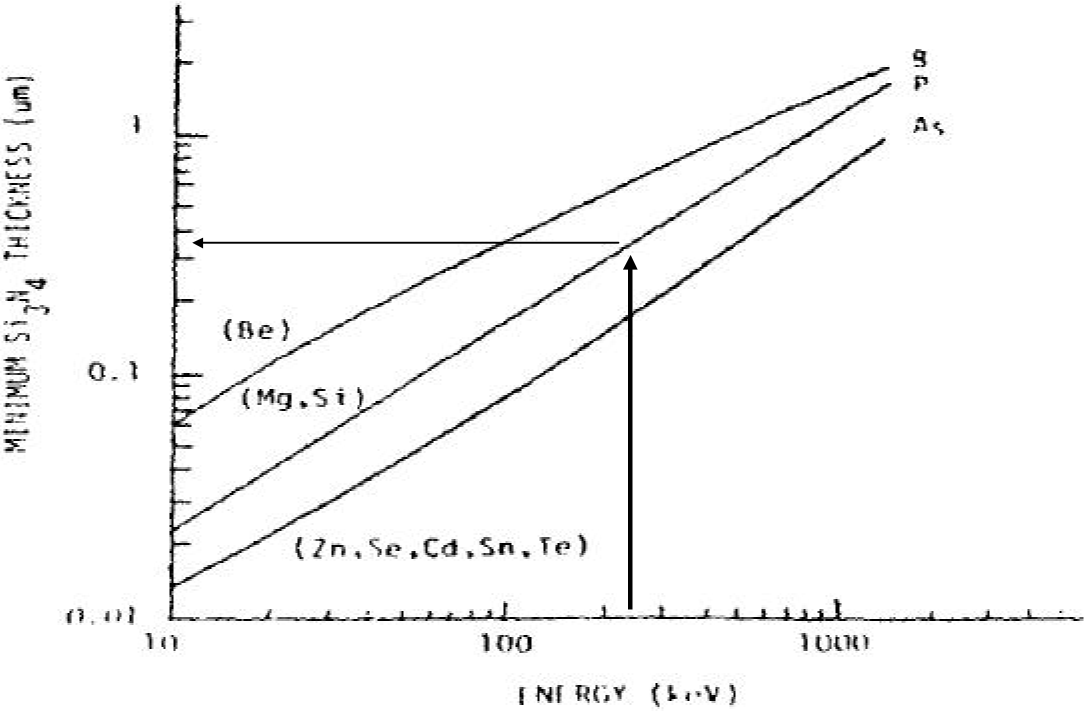
$Q_{dose}(N_{max}, \sigma_x) := N_{dose}(N_{max}, \sigma_x) \cdot \left(1.602 \cdot 10^{-19} \cdot coul\right) \cdot \left(\frac{\pi}{4} \cdot D_{wafer}^{2}\right)$

$Q_{dose}(N_{max}, \sigma_x) = 1.138 \times 10^{-3} A \cdot s$

Notice this is a short time!!

Remember the Video where
the wafers are put into a high
speed carriage and passed in
and out of the implantation zone
for many ver short period of times.

3C) Si3N4 Mask Layer Growth



Minimum Si3N4 thickness = 0.37 µm

3/2 Si(s)+ N2(g) <--> ½ Si3N4(s) HoRXN = +89.65 kcal/mole

$T := 1100\cdot K$

$P := 0.0001\cdot atm$

$\rho_{Si} := 2.33\cdot\frac{gm}{cm^3}$ $\rho_{Si3N4} := 3.44\cdot\frac{gm}{cm^3}$

$Mw_{Si} := 28.08\cdot\frac{gm}{mole}$ $Mw_{Si3N4} := 140.28\cdot\frac{gm}{mole}$ $k_o := 1.2\cdot 10^5\cdot\frac{cm}{s}$

$E_A := 23000\cdot\frac{cal}{mole}$

$H_{fSi} := 0\cdot\frac{cal}{mole}$ $G_{fSi} := 0\cdot\frac{cal}{mole}$ $S_{Si} := 4.5\cdot\frac{cal}{mole\cdot K}$ $Cp_{Si} := 4.78\cdot\frac{cal}{mole\cdot K}$

$H_{fSi3N4} := -179300\cdot\frac{cal}{}$ cal cal

$H_{fSi3N4} := -179300 \cdot \frac{cal}{mole}$ $G_{fSi3N4} := -154700 \cdot \frac{cal}{mole}$ $S_{Si3N4} := 22.4 \cdot \frac{cal}{mole \cdot K}$ $Cp_{Si3N4} := 23.84 \cdot \frac{cal}{mole \cdot K}$

$H_{fN2} := 0 \cdot \frac{cal}{mole}$ $G_{fN2} := 0 \cdot \frac{cal}{mole}$ $S_{N2} := 45.77 \cdot \frac{cal}{mole \cdot K}$ $Cp_{N2} := 6.961 \cdot \frac{cal}{mole \cdot K}$

$$\Delta H_{rxn}(T) := \left[\frac{1}{2} \cdot H_{fSi3N4} - \left(\frac{3}{2} \cdot H_{fSi} + H_{fN2}\right)\right] \ldots$$
$$+ \left[\frac{1}{2} \cdot Cp_{Si3N4} - \left(\frac{3}{2} \cdot Cp_{Si} + Cp_{N2}\right)\right] \cdot (T - 298.15 \cdot K)$$

$$\Delta H_{rxn}(298.15 \cdot K) = -8.965 \times 10^{4} \frac{cal}{mole}$$

$$\Delta G_{rxn}(T) := \Delta H_{rxn}(T) - T \cdot \left[\frac{1}{2} \cdot S_{Si3N4} - \left(\frac{3}{2} \cdot S_{Si} + S_{N2}\right)\right]$$

$$\Delta G_{rxn}(298 \cdot K) = -7.734 \times 10^{4} \frac{cal}{mole}$$

$$K(T) := \exp\left(\frac{-\Delta G_{rxn}(T)}{R_g \cdot T}\right) \qquad P_{N2eq}(T) := \frac{P}{K(T)}$$

$$Flux = \frac{\rho_{Si3N4}}{Mw_{Si3N4}} \cdot Area \cdot \frac{dy}{dt} = \frac{Rate}{Area} = (2) \cdot k_o \cdot \exp\left(\frac{-E_A}{R_g \cdot T}\right) \cdot \left(C_{N2} - C_{N2eq}\right)$$

Film Growth Equation

$$C_{N2} := \frac{P}{R_g \cdot T} \qquad C_{N2} = 1.111 \times 10^{-3} \frac{mole}{m^3}$$

$$C_{N2eq}(T) := \frac{P_{N2eq}(T)}{R_g \cdot T} \qquad C_{N2eq}(T) = 7.571 \times 10^{-13} \frac{mol}{m^3} \qquad P_{N2eq}(T) = 6.814 \times 10^{-14} atm$$

Integrate Flux equation

$$y(t, T) := \frac{Mw_{Si3N4}}{\rho_{Si3N4}} \cdot \left[(2) \cdot k_o \cdot \exp\left(\frac{-E_A}{R_g \cdot T}\right) \cdot \left(C_{N2} - C_{N2eq}(T)\right)\right] \cdot t$$

Rearrange

$$t(T) := \frac{0.37 \cdot \mu m}{\frac{Mw_{Si3N4}}{\rho_{Si3N4}} \cdot \left[(2) \cdot k_o \cdot \exp\left(\frac{-E_A}{R_g \cdot T}\right) \cdot \left(C_{N2} - C_{N2eq}(T)\right)\right]}$$

$$t(T) = 2.187 \, min$$

$$R_g := 1.98 \cdot \frac{\text{cal}}{\text{mole} \cdot \text{K}}$$