UNIVERSITY OF CALIFORNIA
College of Engineering
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EECS 130 Professor Chenming Hu
Spring 2009

Midterm I

Name: ______________________________

Closed book. One sheet of notes is allowed.
There are ten pages of this exam including this page.

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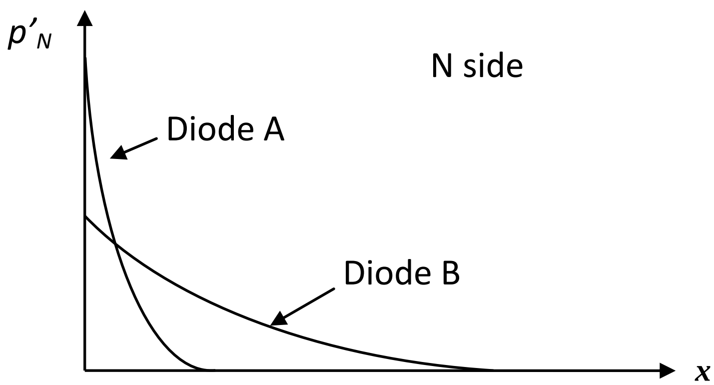
Physical Constants

Electronic charge	q	1.602×10^{-19} C
Permittivity of vacuum	ε_0	8.845×10^{-14} F cm^{-1}
Relative permittivity of silicon	$\varepsilon_{Si}/\varepsilon_0$	11.8
Boltzmann's constant	k	8.617×10^{-5} eV/ K or
		1.38×10^{-23} J K^{-1}
Thermal voltage at T = 300K	kT/q	0.026 V
Effective density of states	N_c	2.8×10^{19} cm^{-3}
Effective density of states	N_v	1.04×10^{19} cm^{-3}
Silicon Band Gap	E_G	1.1 eV
Intrinsic carrier concentration of Si at 300K	n_i	$10^{10}cm^{-3}$

Problem 1

Minority carrier concentration versus position plots are often used to describe the situation inside semiconductor devices. A linear plot of the excess minority carrier concentration on the N-side of two ideal P^+-N diodes maintained at room temperature is pictured below. The P-side doping (N_a), N-side doping (N_d) and the cross-sectional area are the same in both diodes. Assume low-level injection conditions prevail.



(a) Are both diodes forward, zero, or reverse biased? [3pts]

Forward bias

(b) Which diode has higher bias? Briefly explain. [5pts]

Diode A. $p'_N(0) = p_{N0}\left(e^{\frac{qV}{kT}} - 1\right)$, since $p'_{NA}(0) > p'_{NB}(0)$ and $p_{N0A} = p_{N0B} \rightarrow V_A > V_B$

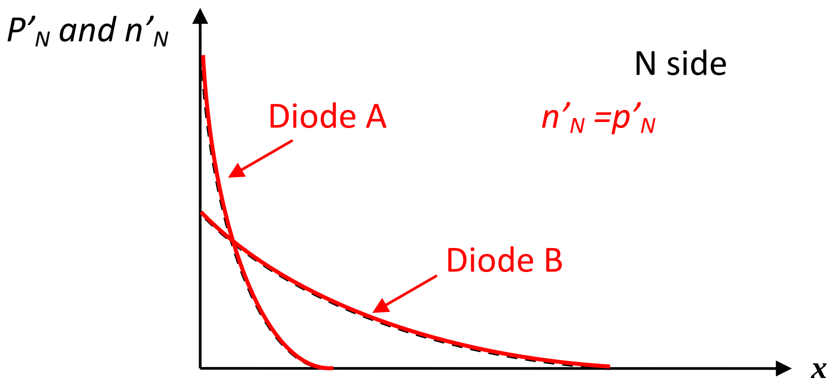
(c) Which diode has higher minority carrier lifetime on the N-side? Assume that the hole mobility of diode A and B are the same. Briefly explain. [5pts]

Diode B. $L = \sqrt{D\tau}$, since $L_B > L_A$ and $D_A = D_B$ ($\mu_A = \mu_B$) $\rightarrow \tau_B > \tau_A$

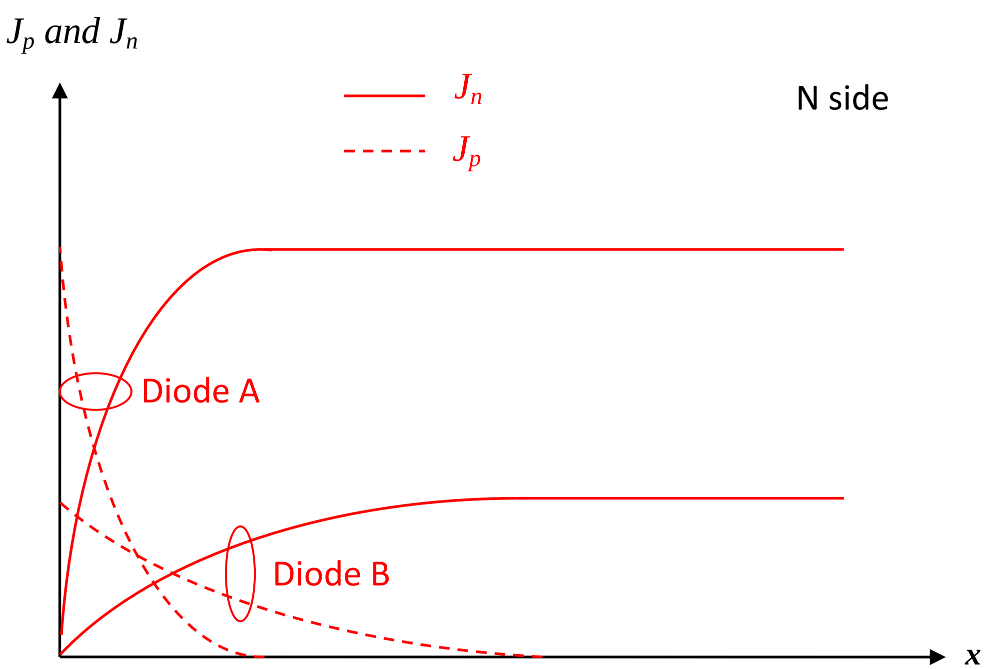
(d) Which diode has higher current? Briefly explain. [5pts]

Diode A. $J_p = -qD\frac{dp'}{dx}$, since $D_A = D_B$ and $\left|\frac{dp_A'}{dx}\right| > \left|\frac{dp_B'}{dx}\right| \rightarrow J_{pA} > J_{pB}$

(e) Given the plot of p'_N in dashed lines in the following figure, add n'_N in solid lines for diode A and B and label them. [4pts]



(f) Qualitatively draw J_p and J_n for diode A and B. Label them clearly. [8pts]

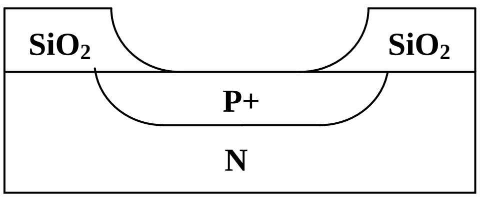


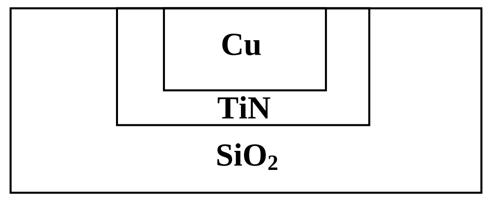
Problem 2

(a) Given below is a menu consisting of various fabrication processes you are familiar with. Using only these given processes, complete the sequence of steps to fabricate the structure given below. (Hint: All given processes may or may not be required, and the same process maybe used multiple times.)

Processes Available:

Thermal annealing (diffusion)	Epitaxy	Anisotropic Etching
CVD (Chemical Vapor Deposition)	Isotropic Etching	Nanoimprint
CMP (Chemical-mechanical polishing)	Lithography	Thermal oxidation
ALD (Atomic layer deposition)	Ion implantation	Sputtering





Starting from a N-type silicon wafer [5pts]

Thermal oxidation
Lithography
Isotropic Etching
Ion implantation
Thermal annealing

Starting from SiO_2 [5pts]

Lithography
Anisotropic Etching
Sputter TiN
CVD Cu
CMP

(b) Briefly explain the difference between positive and negative photoresists. [4pts]

The exposed regions are removed for positive photoresist, while the unexposed regions are removed for negative photoresist.

(c) Why does wet lithography provide better resolution? Briefly explain. [3pts]

When light enters the water, its wavelength is reduced by the refraction index of water, 1.43, and therefore the lithography resolution is improved. (lithography resolution = $k\lambda$)

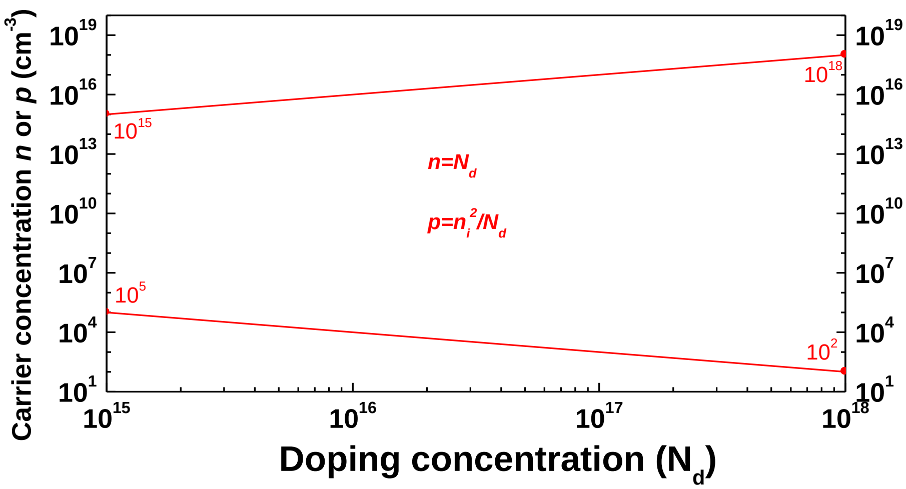
(d) What motivates the IC industry to use increasingly larger silicon wafer size? Briefly explain. [3pts]

More dies of chip can be sliced out of a larger wafer size. Therefore the cost per chip is reduced.

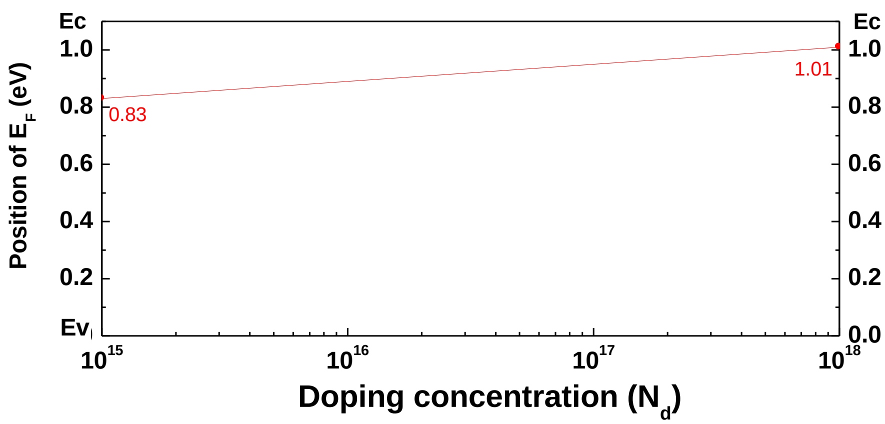
Problem 3

Doping concentration plays an important role in changing the physical and electrical properties of a doped semiconductor. You are given an N-type silicon semiconductor:

(a) Draw carrier concentrations *n* and *p* versus doping concentration in T=300K. Do the calculation to specify the left and right intercept of the line. [4pts]



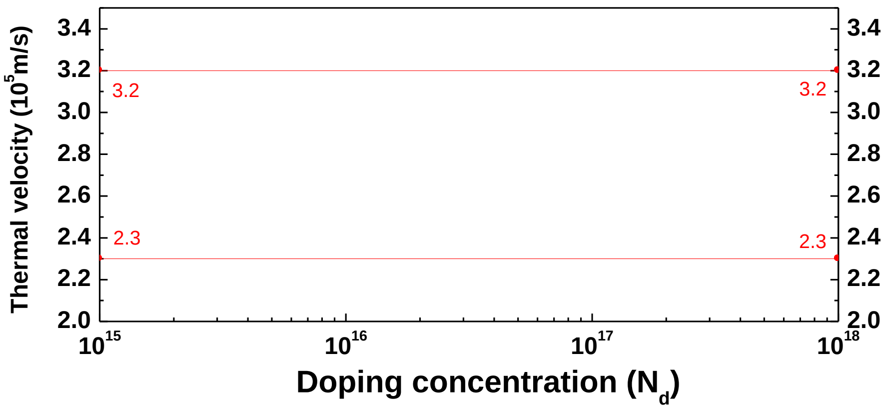
(b) Draw the position of Fermi level versus doping concentration in T=300K. Do the calculation to specify the left and right intercept of the line. [7pts]



$$n = N_d = N_c \exp\left(\frac{E_F - E_c}{kT}\right)$$

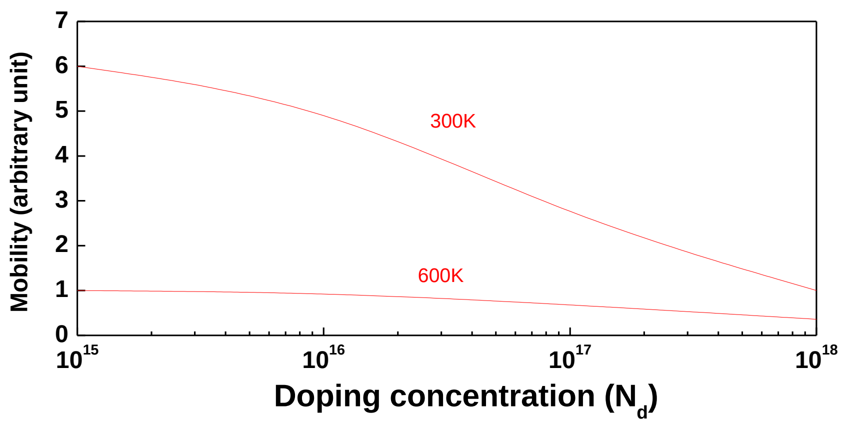
$$\Rightarrow E_F = E_c + kT \times \ln\left(\frac{N_d}{N_c}\right)$$

(c) Thermal velocity at T=300K and $N_d=10^{15}$ cm^{-3} is 2.3×10^5 m/s. Draw thermal velocity versus doping concentration in 300K and 580K. Do the calculation to specify the intercepts of the lines. [4pts]



$v_{th} = \sqrt{\frac{3kT}{m}} \propto \sqrt{T}$, therefore it's independent of doping concentration

(d) i. Qualitatively draw electron mean free time versus doping concentration at 300K and 600K, given that τ_{mn} at 300K, 10^{15}cm^{-3} is six times of τ_{mn} at 600K, 10^{15}cm^{-3}. (No need to do calculations) [4pts]

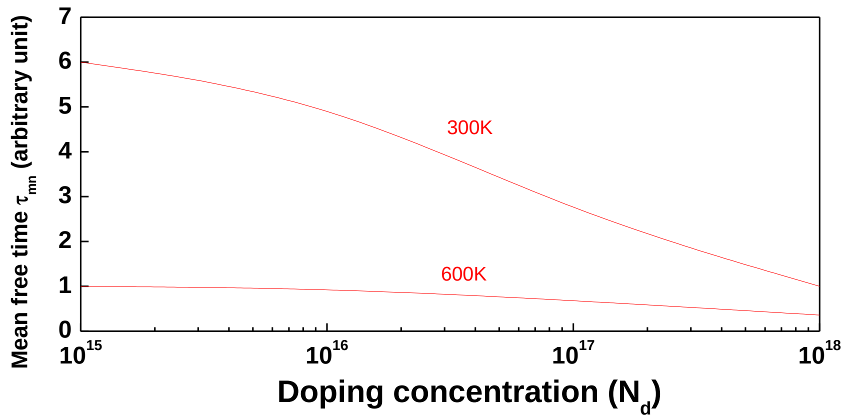


ii. At 300K, what scattering mechanism dominates at low (10^{15}cm^{-3}) and high (10^{18}cm^{-3}) doping concentration respectively? [3pts]

Low (10^{15}cm^{-3}) : Phonon scattering
High (10^{18}cm^{-3}): Columbic (impurity) scattering

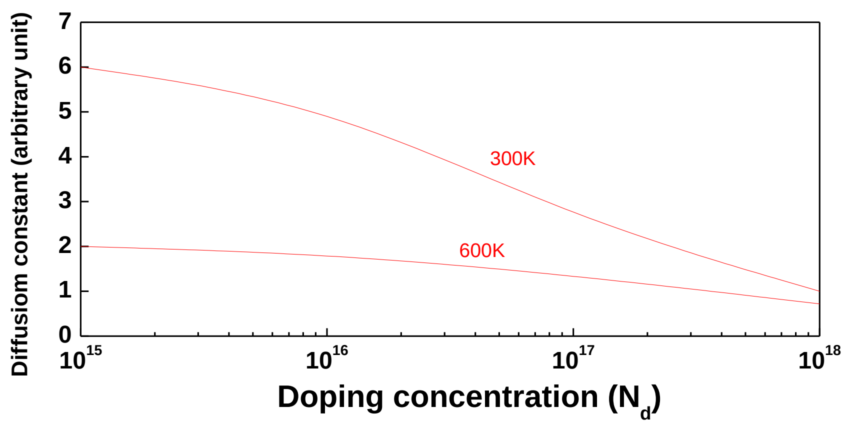
iii. At 600K, what scattering mechanism dominates at low (10^{15}cm^{-3}) and high (10^{18}cm^{-3}) doping concentration respectively? [3pts]
Low (10^{15}cm^{-3}): Phonon scattering
High (10^{18}cm^{-3}): Phonon and impurity both have effect (free 1.5 points !)

(e) <u>Qualitatively</u> draw electron mobility versus doping concentration at 300K and 600K. Briefly explain how you get the curves. (No need to do calculations) [4pts]



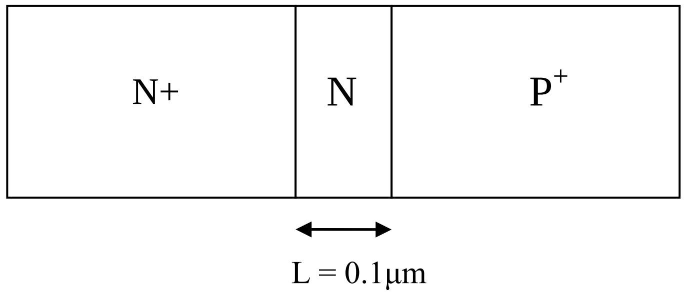
$\mu_n = \frac{q\tau_{mn}}{m_n}$, therefore mobility curves are the same shape of mean free time.

(f) <u>Qualitatively</u> draw electron diffusion constant versus doping concentration at 300K and 600K. Briefly explain how you get the curves. [6pts]



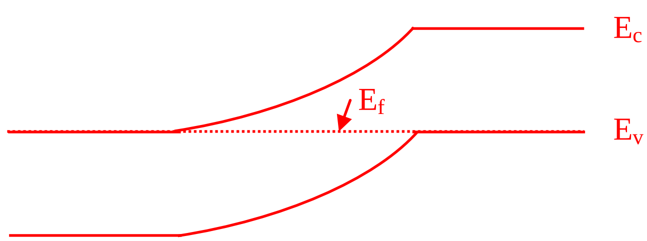
$D_n = \frac{kT}{q}\mu_n$, therefore, the diffusion constant curves are the same shape except the one at 600K should be doubled up the value.

Problem 4



Consider the above silicon diode. Assume that N^+ and P^+ regions are heavily doped that $E_c = E_f$ in the N^+ region and $E_F = E_V$ in the P^+ region. The doping in the N-type region is 5×10^{16} cm^{-3}. Assume that the N layer is thin enough that it is completely depleted.

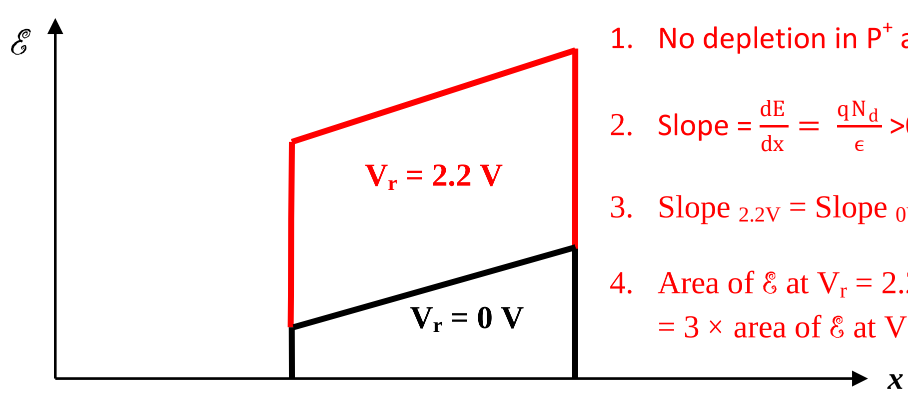
(a) Sketch the energy band diagram for this diode. Do not be concerned with the exact shape of $E_c(x)$ in the depletion region. [2pts]



(b) Find the built in potential (φ_{bi}) of the given diode in Volts. [2pts]

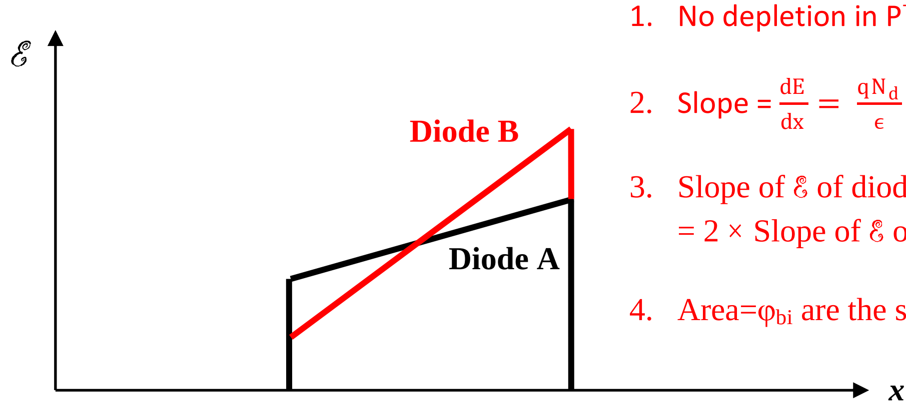
Built in potential (φ_{bi}) = Bandgap = E_g/q = 1.1V

(c) Qualitatively draw the electric field in the semiconductor as a function of x under the condition of (i) V=0V (ii) V_r (reverse bias) = 2.2 V on the same plot. (Hint: You may assume that the depletion region is entirely contained in the N region only. No need to do calculation) [4pts]



1. No depletion in P^+ and N^+ region
2. Slope = $\frac{dE}{dx} = \frac{qN_d}{\epsilon} > 0$
3. Slope $_{2.2V}$ = Slope $_{0V}$
4. Area of ℰ at V_r = 2.2 V = 3 × area of ℰ at V = 0 V

(d) Call the diode in part (a) "diode A". Now consider another "diode B" with the identical N^+-N-P^+ structure except doping of N region is 10^{17} cm^{-3}. Qualitatively draw the electric field at V=0V of diodes A and B as a function of x in the same plot. [4pts]



1. No depletion in P^+ and N^+ region

2. Slope = $\frac{dE}{dx} = \frac{qN_d}{\epsilon} > 0$

3. Slope of ℰ of diode B = 2 × Slope of ℰ of diode A

4. Area=φ_{bi} are the same

(e) Does diode A or B has higher breakdown voltage? Briefly explain why. [3pts]

Diode A has a higher breakdown voltage.
Because diode A has a lower peak electric field at a given bias.
Therefore, diode A has to reach E_{crit} ($E_{critA} = E_{critB}$) at a higher voltage.