Print Name:_____

Uniquename:_____

EECS 320

Exam 1

Spring 2012

This exam is closed book. A list of equations and useful constants is provided. More equations and constants are provided than you may need. You are permitted one 8.5x11" page of notes and handheld calculators. Tablets or smartphones with calculator apps are NOT permitted. Notes and/or equations programmed into handheld calculators are forbidden. Please turn off your cellular phone and store them in your bag during the exam. Using or placing cellular on the table during the exam is strictly forbidden.

Show all work and ***state all assumptions*** to receive full credit. Use the space provided to answer questions. ***Use material parameters in the equation sheet provided.***

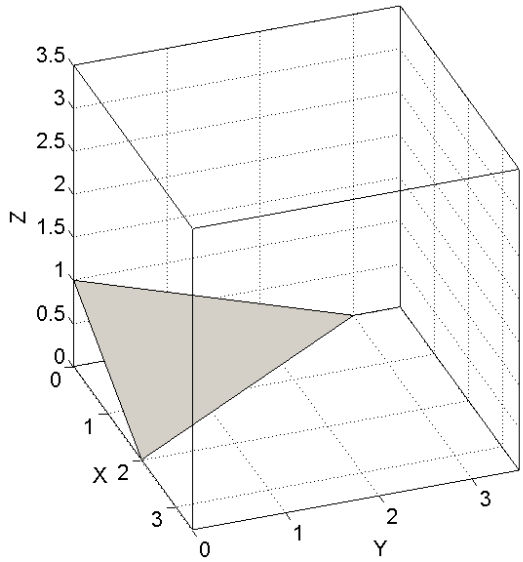
To receive credit for this examination, write the Honor Pledge "I have neither given nor received aid on this examination" and sign below.

Honor pledge:

Signature:_____

Problem 1 Miller Indices (5 points)

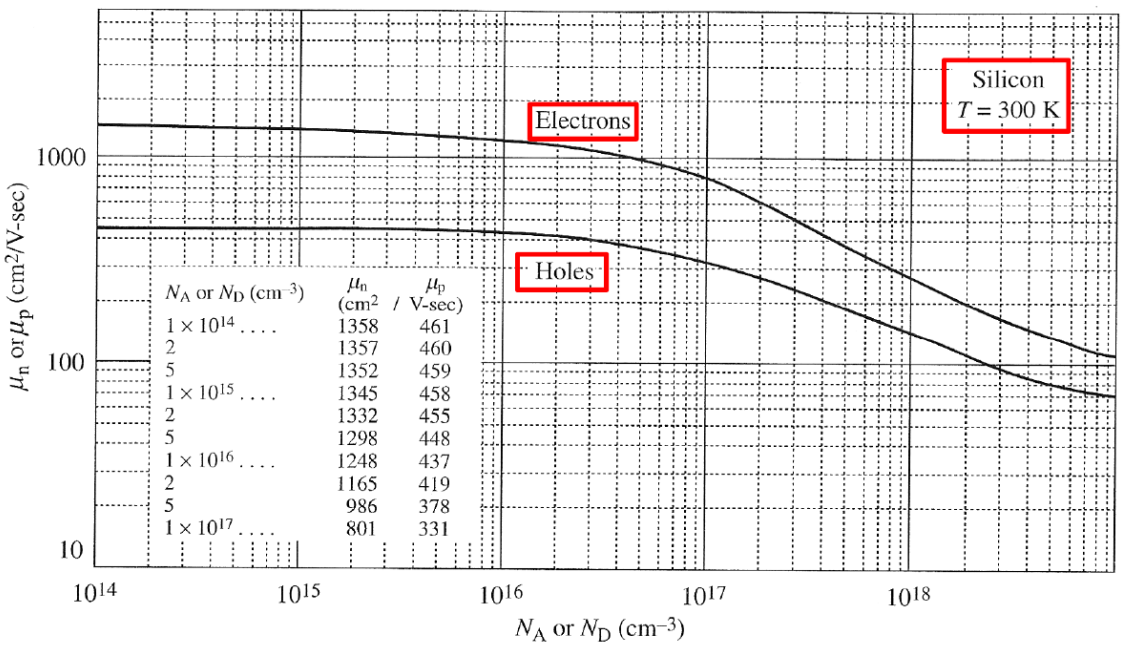
Determine the miller indices for the crystalline plane in a cubic lattice in the sketch below. Show your work.



Miller Indices of Plane: _____

Problem 2: Basic Conductivity (a 3pts ,b 4 pts)

a) Suppose we have a sample of pure Si at 300K doped only with shallow donors $N_D=1x10^{13}cm^{-3}$. Estimate the resistivity of this sample using the data from Pierret figure 3.5a reproduced below.



(a)

Pierret figure 3.5 a

b) Now we have a sample of pure Si at 300K doped with shallow donors and shallow acceptors $N_D=5x10^{16}cm^{-3}$ and $N_A=4.999x10^{16}cm^{-3}$. Estimate the resistivity of this sample and compare your result in part b.

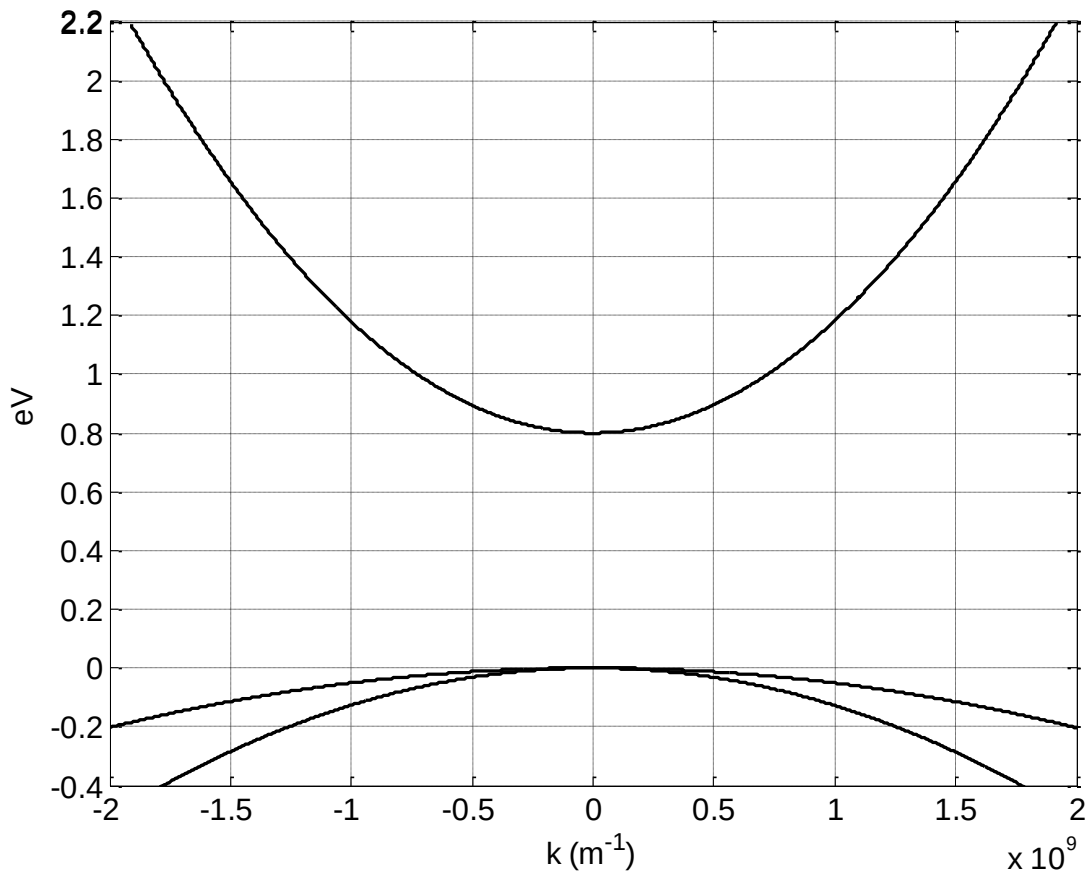
Problem 3: Doping (7 pts)

Suppose we have Si at 300K doped with Phosphorus (E_D=E_C-44meV) and Boron (E_A=E_v+44meV). If N_A=1x10^{17}cm^{-3}, what N_D is needed so that n=1x10^{18} cm^{-3}?

Problem 4: Band structure and statistics (a 3pts, b 3pts, c 15 pts)

A semiconductor has band structure show below. We have

$m_n^* = 0.1m_0$ $m_{lh}^* = 0.3m_0$ $m_{hh}^* = 0.75m_0$ at 300K



a) Is it a potential candidate for building light emitting diodes or lasers? Briefly justify your answer.

b) At what wavelength would expect to begin seeing significant optical absorption?

c) Find the effective densities of states N_c and N_v, the intrinsic carrier concentration n_i, and E_i relative to E_v.

N_c= _____

N_v= _____

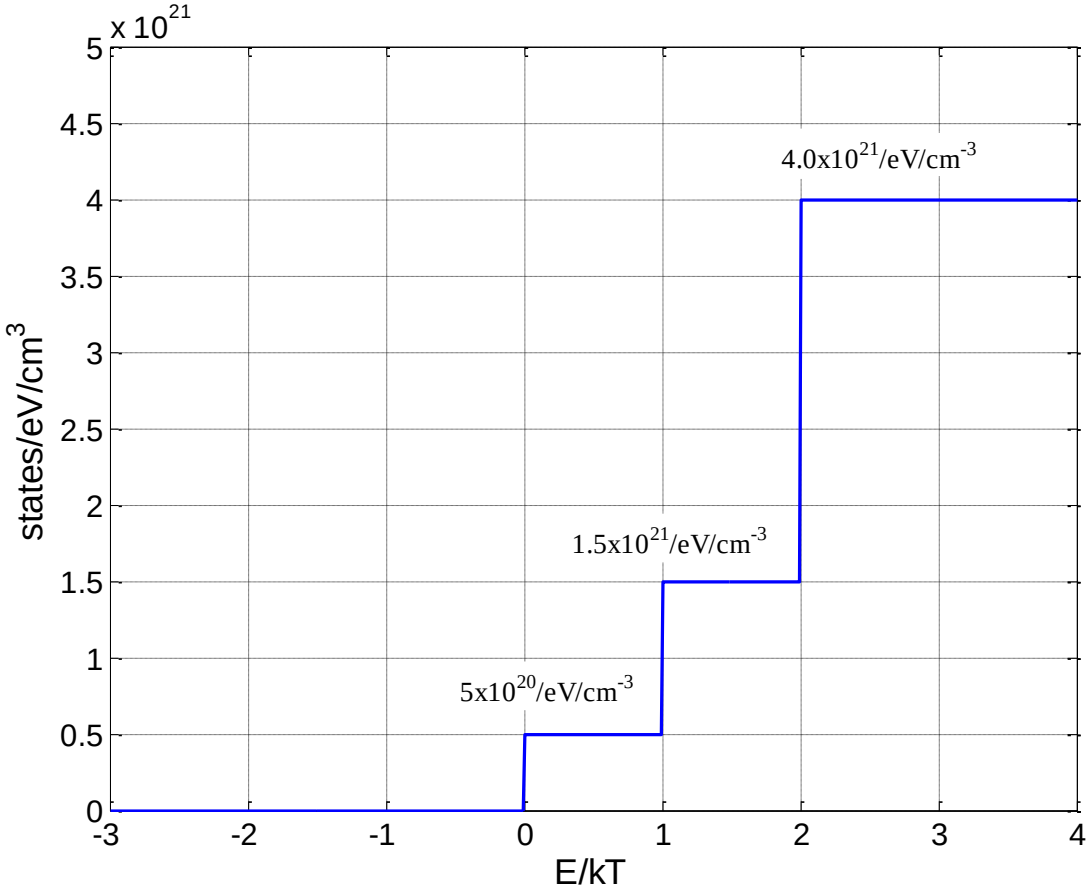
n_i= _____

E_i=E_v+_____

Additional workspace for 4c

Problem 5: Density of States and Bands (15 pts)

Suppose we have the following density of states $g_c(E)$ for a conduction band. Find the electron concentration in the band if $E_F=E_C-3kT$

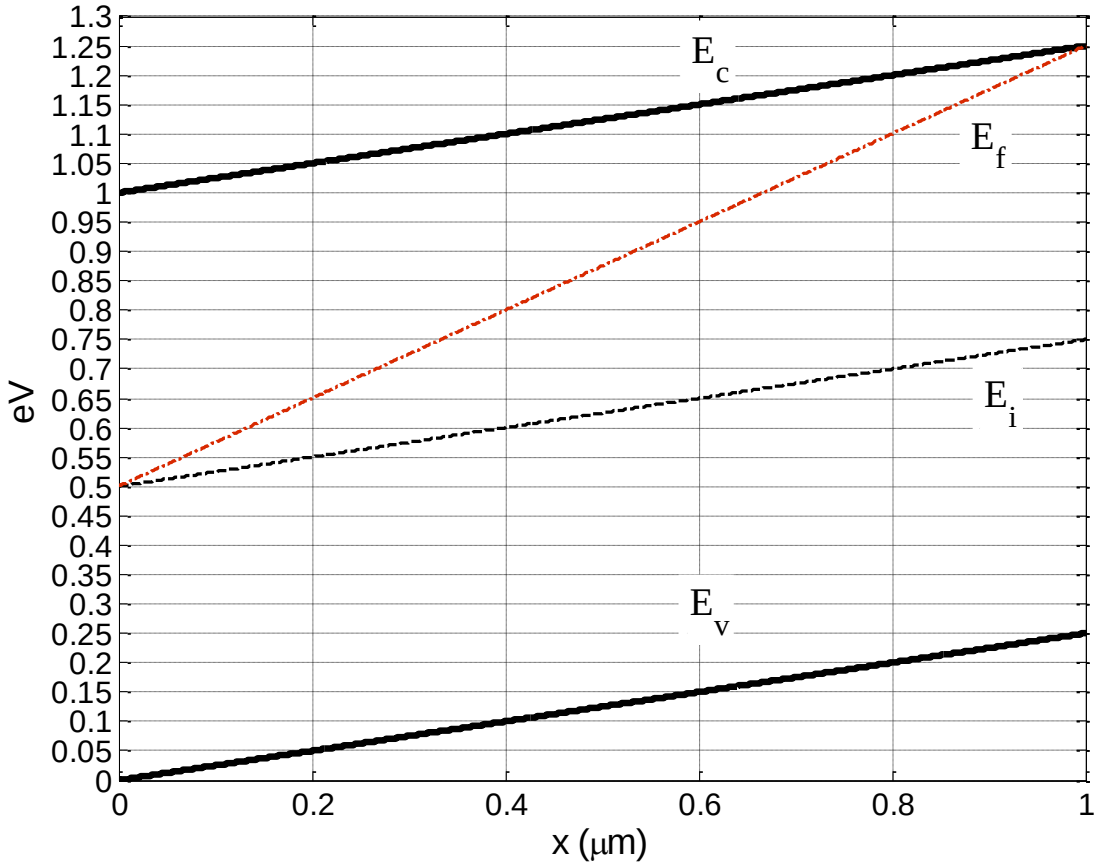


Additional workspace for problem 5

Problem 6: Drift Diffusion Transport (20 pts)

We have a semiconductor with $N_v = N_c$ $n_i = 1x10^{10}$ $E_g = 1eV$ $\mu_n = 1000cm^2v^{-1}s^{-1}$ at 300K.

A sample of this semiconductor has the band picture shown below. Find $J_{n,total}$, $J_{n,drift}$, and $J_{n,diffusion}$ at x=0.5μm.



$J_{n,total}$= _____

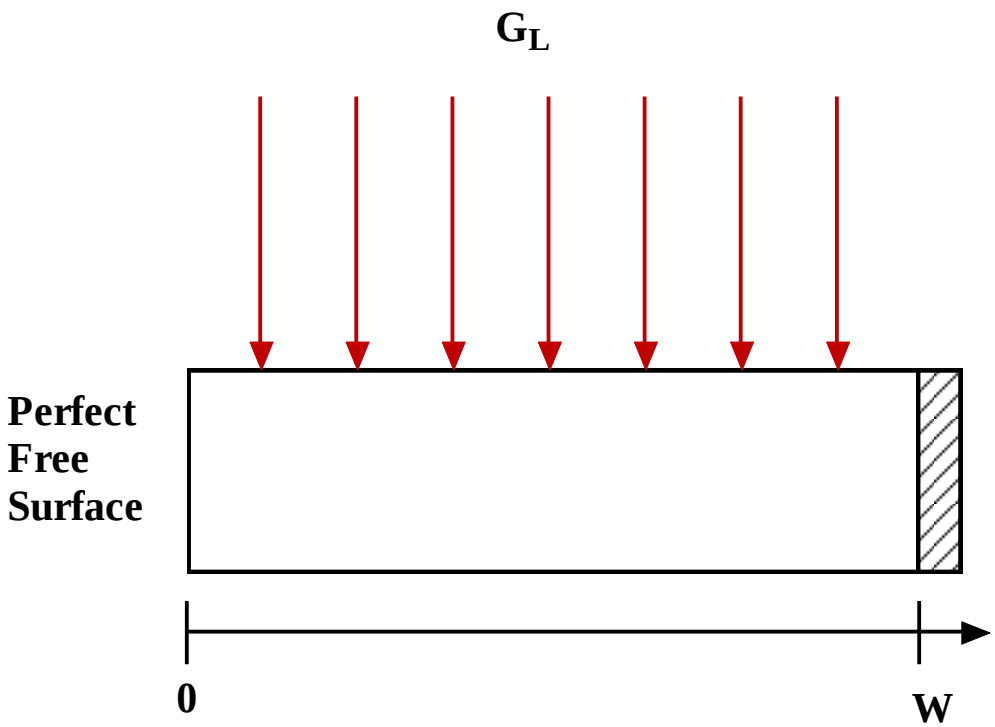
$J_{n,drift}$= _____

$J_{n,diffusion}$= _____

Additional workspace for problem 6

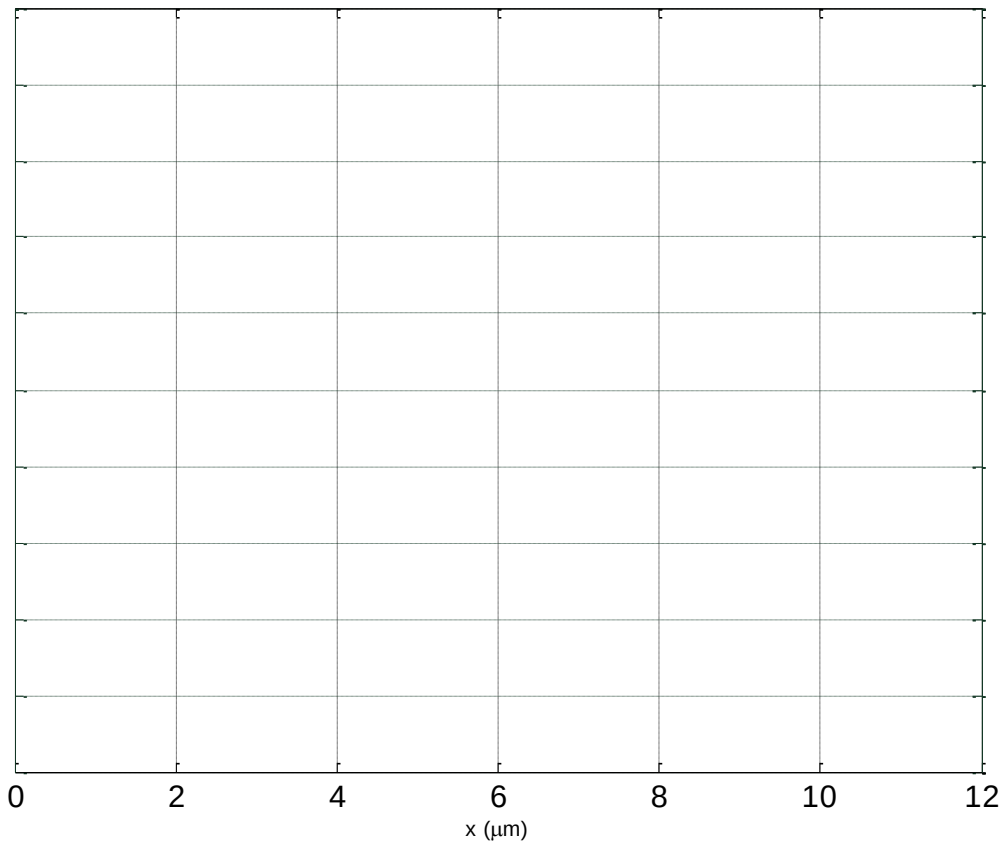
Problem 7 Generation-Recombination (a 5pts, b 20 pts)

A sample of Si is uniformly illuminated as illustrated below. The left side is a perfect free surface (x=0), the right side has a perfect ohmic contact at x=W=12μm. The sample is uniformly p-type doped with shallow acceptors $N_A=1x10^{17}cm^{-3}$, $D_n=18cm^2/s$, and $\tau_n=20ns$. Also, $G_L=6.8x10^{23}pairs/cm^3/s$.



$$N_A = 1x10^{17}\,cm^{-3} \quad D_n = 18cm^2s^{-1} \quad \tau_n = 20ns \quad G_L = 6.8x10^{23}\,pairs/cm^3/s \quad W = 12\,\mu m$$

a) Sketch the expected excess minority carrier lifetime $\Delta n(x)$ vs. x



b) Find Δn(x) assuming LLI conditions apply. Are the assumptions of LLI statisfied?

$N_A = 1x10^{17} cm^{-3}$ $D_n = 18 cm^2 s^{-1}$ $\tau_n = 20 ns$ $G_L = 6.8x10^{23}\ pairs/cm^3/s$ $W = 12 \mu m$

Additional space for 9b

$N_A = 1x10^{17} cm^{-3}$ $D_n = 18 cm^2 s^{-1}$ $\tau_n = 20 ns$ $G_L = 6.8x10^{23}\ pairs/cm^3/s$ $W = 12 \mu m$

EECS 320 Equation sheet

Physical Constants

$h = 6.626\times10^{-34}$ J - s

$\hbar = 1.054\times10^{-34}$ J-s

$q = 1.60217\times10^{-19}$ C

$eV = 1.602\times10^{-19}$ J

$m_0 = 9.11\times10^{-31}$ kg

$k = 8.617\times10^{-5}$ eV/K

$kT = 0.02585eV$ at T=300K

Electrostatics

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon}$$

$F = -\frac{dV}{dx} = \frac{1}{q}\frac{dE}{dx}$, *F* is electric field

Parabolic Band Density of States

$$g_C(E) = \frac{\sqrt{2}m_n^{*3/2}(E-E_C)^{1/2}}{\pi^2\hbar^3}$$

$$g_V(E) = \frac{\sqrt{2}m_p^{*3/2}(E_V-E)^{1/2}}{\pi^2\hbar^3}$$

Fermi Distribution Function

$$f(E) = \frac{1}{1+\exp\left(\frac{E-E_f}{kT}\right)}$$

Boltzmann approx:

$$f(E) = \exp\left(-\frac{E-E_f}{kT}\right)$$

Donor and Acceptor Statistics

$$\frac{N_D^+}{N_D} = \frac{1}{1+2\exp\left(\frac{E_f-E_D}{kT}\right)}$$

$$\frac{N_A^-}{N_D} = \frac{1}{1+4\exp\left(\frac{E_A-E_f}{kT}\right)}$$

Parabolic Band Model

$$N_C = 2\left(\frac{m_{n,dos}^* kT}{2\pi\hbar^2}\right)^{3/2}$$

$$= 2.509\times10^{19}\left(\frac{m_{n,dos}^*}{m_0}\right)^{3/2}\left(\frac{T}{300}\right)^{3/2} \text{ cm}^{-3}$$

$$N_V = 2\left(\frac{m_{p,dos}^* kT}{2\pi\hbar^2}\right)^{3/2}$$

$$= 2.509\times10^{19}\left(\frac{m_{p,dos}^*}{m_0}\right)^{3/2}\left(\frac{T}{300}\right)^{3/2} \text{ cm}^{-3}$$

$$n_i = \sqrt{N_C N_V}\exp\left(-\frac{E_G}{2kT}\right)$$

Carrier Statistics

$$n = \int g_C(E)f(E)dE$$

$$p = \int g_V(E)(1-f(E))dE$$

Calculate relative to E_C E_V

$$n = N_C\exp\left(\frac{E_f-E_C}{kT}\right)$$

$$p = N_V\exp\left(\frac{E_V-E_f}{kT}\right)$$

$$E_f = E_C + kT\ln\left(\frac{n}{N_C}\right)$$

$$E_f = E_V - kT\ln\left(\frac{p}{N_V}\right)$$

Calculate relative to E_i

$$n = n_i\exp\left(\frac{E_f-E_i}{kT}\right)$$

$$p = n_i\exp\left(-\frac{E_f-E_i}{kT}\right)$$

$$E_f - E_i = kT \ln\left(\frac{n}{n_i}\right)$$

$$E_i - E_f = kT \ln\left(\frac{p}{n_i}\right)$$

$$E_i = \frac{E_C + E_V}{2} + \frac{1}{2} kT \ln\left(\frac{N_V}{N_c}\right)$$

Doping and Charge Neutrality

$$n - N_d^+ - p + N_a^- = 0$$

$$np = n_i^2$$

$$n = \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2}$$

$$p = \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2}$$

Drift-Diffusion

$$\sigma = nq\mu_n + pq\mu_p$$

$$\mu = \frac{q\tau_{sc}}{m^*}$$

$$\frac{D}{\mu} = \frac{kT}{q}$$

$$J_n = q\mu_n nF + qD_n \frac{dn}{dx}$$

$$J_p = q\mu_p pF - qD_p \frac{dp}{dx},$$

F is electric field

Continuity Equations

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} + (G - R)$$

$$\frac{\partial \Delta n_p}{\partial t} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G$$

$$\frac{\partial \Delta p_n}{\partial t} = D_n \frac{\partial^2 \Delta p_n}{\partial x^2} - \frac{\Delta p_n}{\tau_p} + G$$

$$L_N = \sqrt{D_N \tau_n}$$

$$L_P = \sqrt{D_P \tau_p}$$

Table of properties of selected semiconductors (at 300K)

Property	Si	Ge	GaAs
N_C (cm^{-3})	2.86×10^{19}	1.04×10^{19}	4.45×10^{17}
N_V (cm^{-3})	3.10×10^{19}	6.0×10^{18}	7.72×10^{18}
n_i (cm^{-3})	1.07×10^{10}	2.3×10^{13}	1.8×10^{6}
E_G (eV)	1.1242	0.66	1.42
m_n^*/m_0	1.18	0.55	0.067
m_p^*/m_0	0.81	0.36	0.52
ε_r	11.8	16	13.1
χ (eV)	4.05	4.0	4.07