EECS 320 Exam 2 Spring 2012

Print Name:_____

Uniquename:_____

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 two 8.5x11" pages 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.

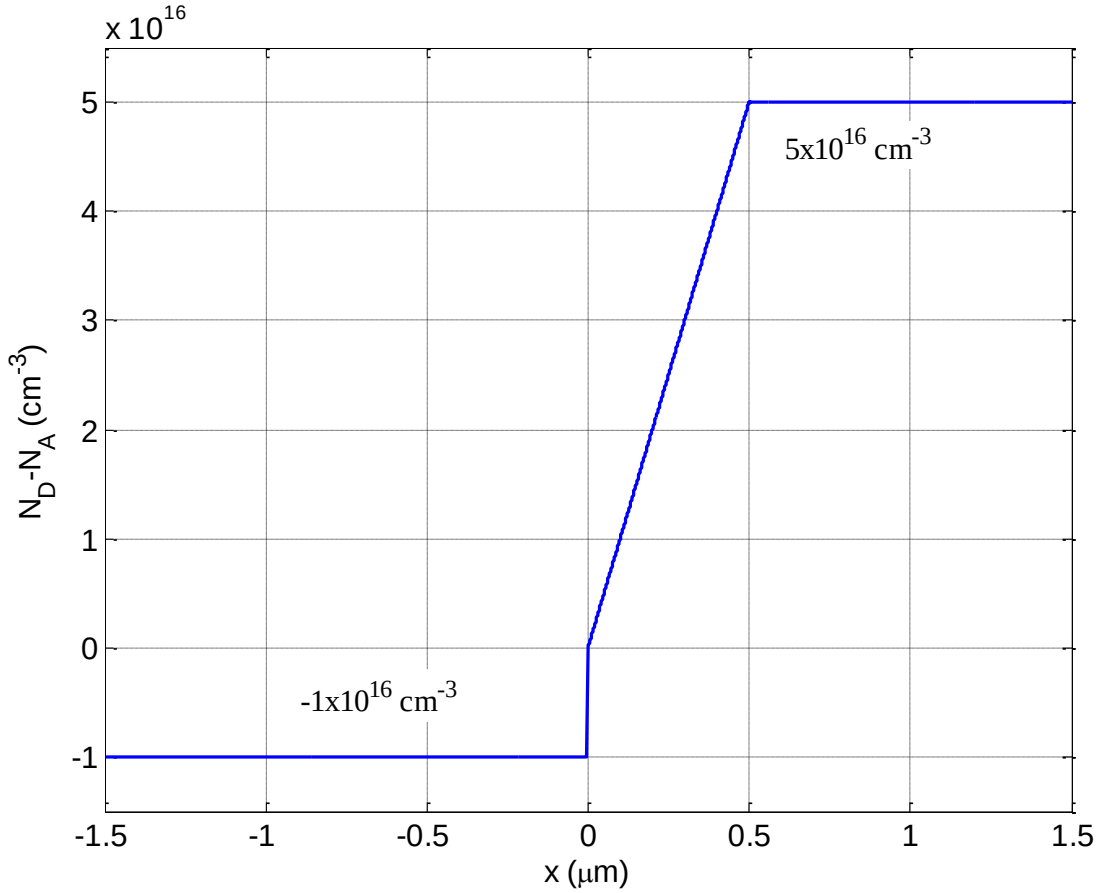
Honor pledge:

Signature:_____

Parts (# pts)

Depletion Approx.	1 (25)	
Electrostatics	2 (25)	
Abrupt Diode	3a (5)	3b (5)
	3c (10)	3d (10)
	3e (5)	
Schottky Diode	4a (5)	4b (5)
	4c (5)	

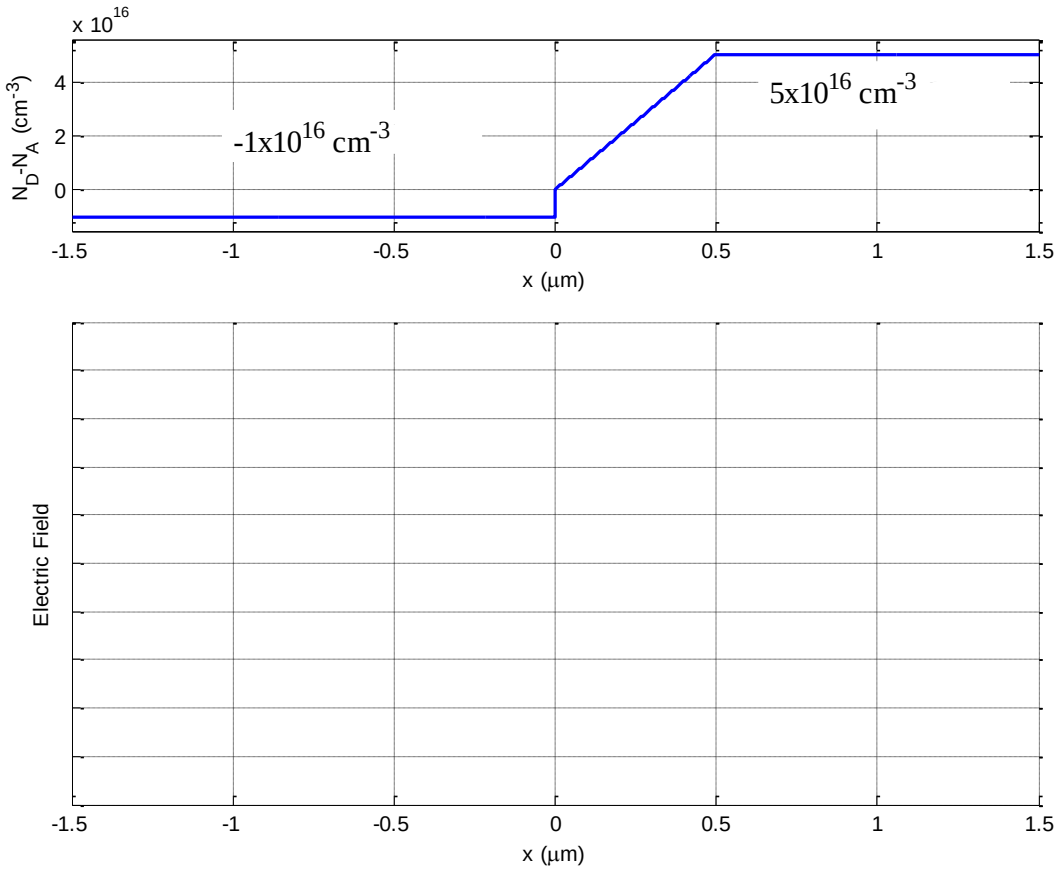
Problem 1: PN Junctions and Depletion Approximation (1 part, 25 pts)
We have a Si pn junction at 300K with the doping profile shown below.



When the depletion width on the n-side x_n=0.55 μm, find the depletion width on the p-side x_p, the value of the electric field at x=0, the electric field at x=0.5μm, and sketch the electric field vs. x.

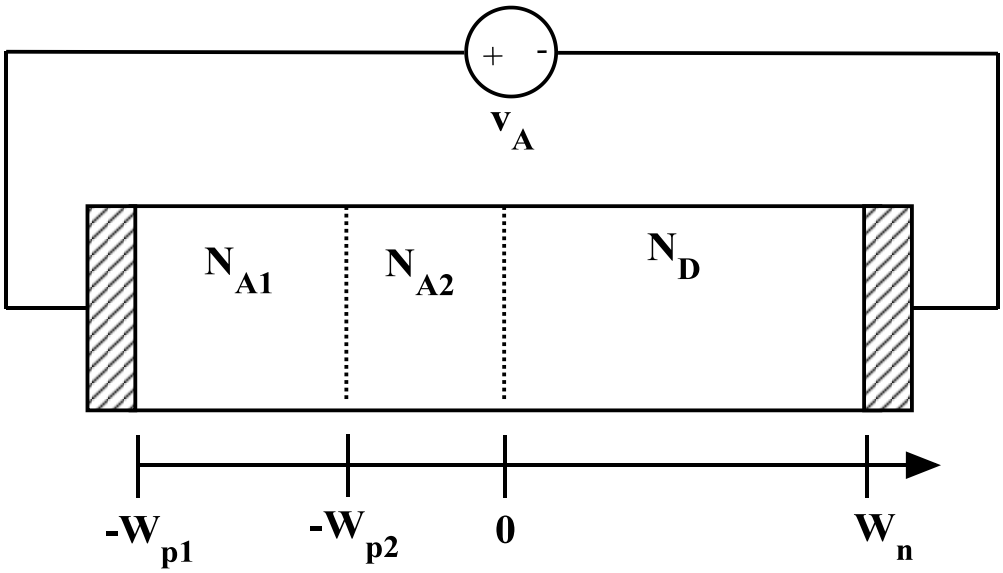
x_p=	_____	nm
$\mathcal{E}(0)$=	_____	V/cm
$\mathcal{E}(0.5\mu m)$=	_____	V/cm

Workspace for problem 1



Additional workspace for problem 1

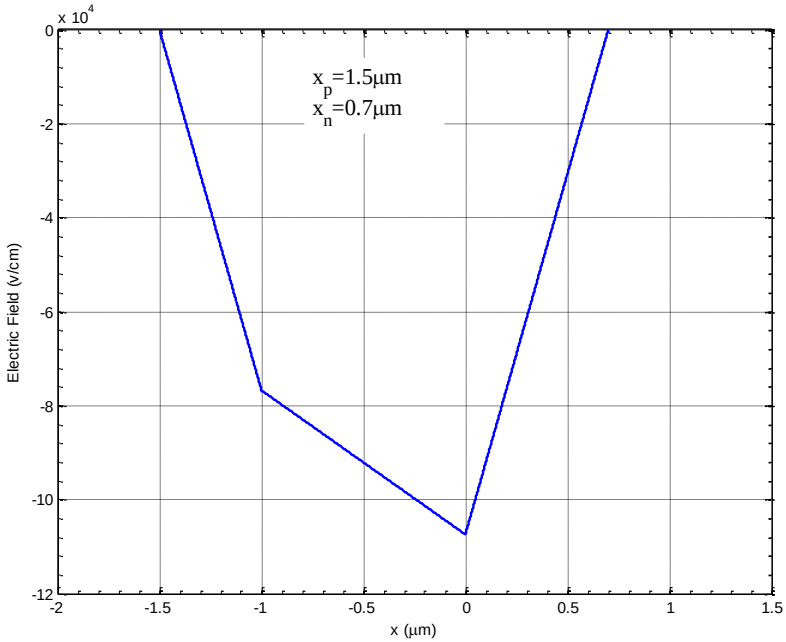
Problem 2: Electrostatics (1 part, 25 pts)
We have a Si pn diode at 300K with the doping situation shown below.



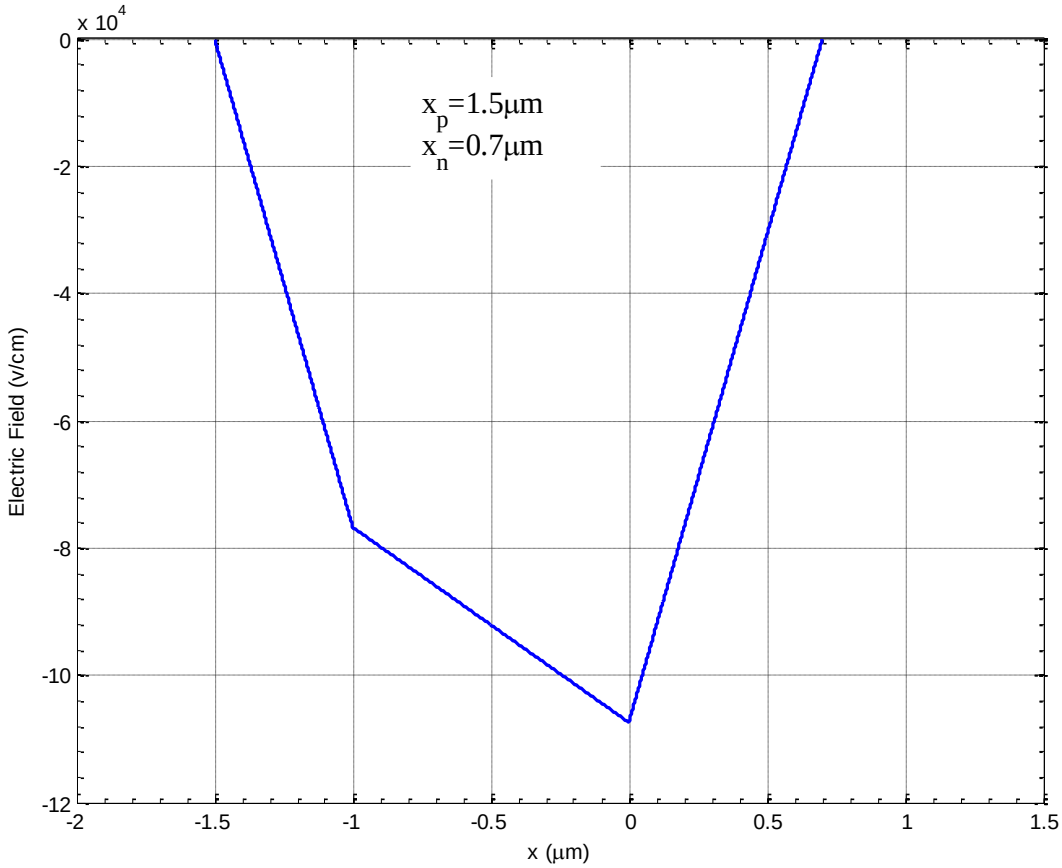
$N_{A1} = 1x10^{16} cm^{-3}$ $W_{p1} = 10\mu m$ $N_{A2} = 2x10^{15} cm^{-3}$ $W_{p2} = 1\mu m$ $N_D = 1x10^{16} cm^{-3}$ $W_n = 10\mu m$

We are biased so that the electric field profile is as shown below. Find the applied voltage that yields this field profile.

v_a= _____V

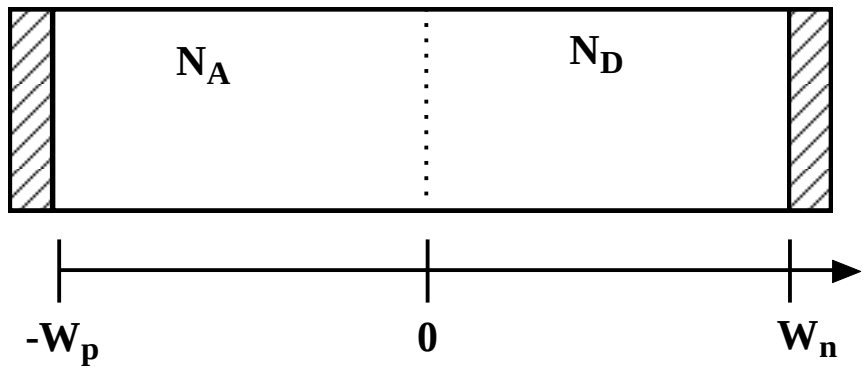


Workspace for problem 2



Additional workspace for problem 2

Problem 3: Abrupt PN Junction (a-e)
We have a uniform, abrupt **Ge** diode at 300K. Assume 100% dopant ionization and perfect ohmic contacts.



	Doping (cm^{-3})	μ_p (cm^2/v-s)	μ_n (cm^2/v-s)	Width	$\tau_{minority}$
p-side	2.7×10^{17}	500	2500	W_p=2μm	20ns
n-side	5×10^{17}	360	2100	W_n=30μm	20ns

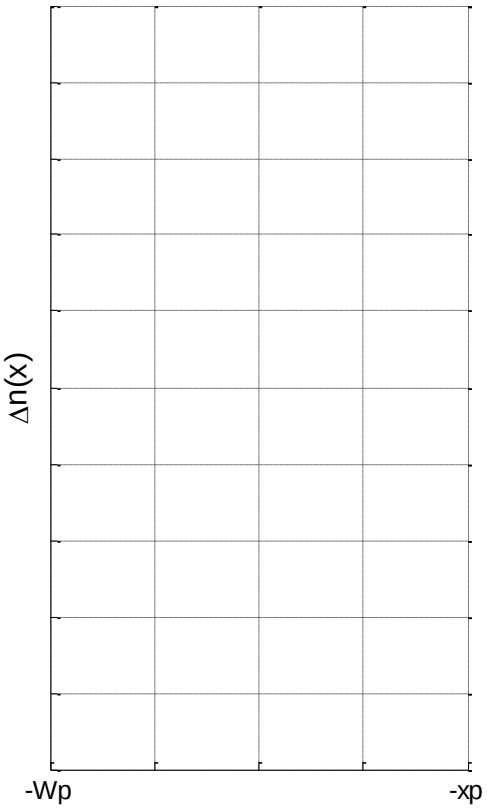
a) The built-in potential V_{bi}. (5pts)

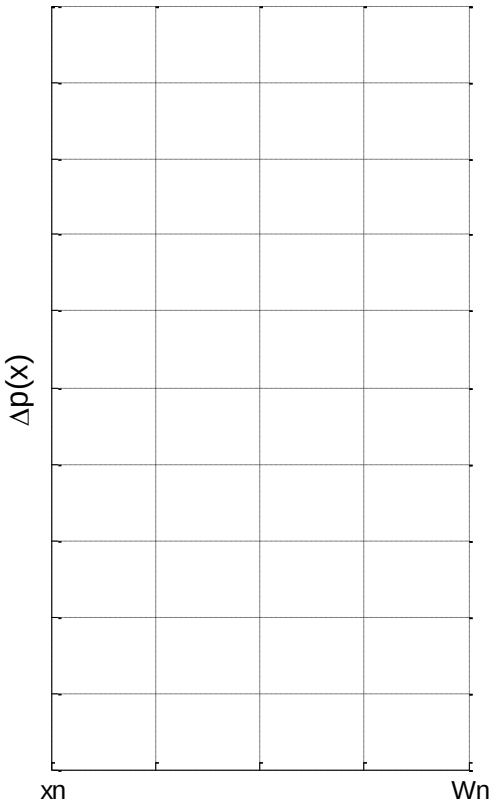
V_{bi}= _____V

b) The forward bias potential at which the low level injection (LLI) assumption would begin to fail. (5pts)

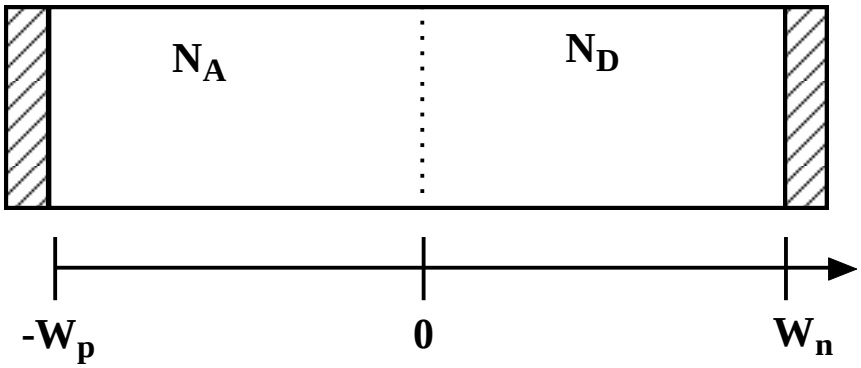
v_a= _____V

c) Sketch the excess minority carrier concentrations vs. x under forward bias conditions. (10 pts)





d) Find an expression for the current density for this diode assuming LLI applies and that we can ignore G-R in the depletion region. (10 pts)



	Doping (cm^{-3})	μ_p (cm^2/v-s)	μ_n (cm^2/v-s)	Width	$\tau_{minority}$
p-side	2.7×10^{17}	500	2500	W_p=2μm	20ns
n-side	5×10^{17}	360	2100	W_n=30μm	20ns

J= _____ A/cm^2

Additional workspace for 3 d

e) Find the capacitance per unit area for a reverse bias of 5V. (5pts)

C= _____ F/cm^2

Problem 4: Schottky Diode (a-c)

We have a metal with a work function of ϕ_m=4.6V. We use it to make a metal semiconductor diode on $N_D=1x10^{17}cm^{-3}$ Si (χ=4.05V) at 300K.

a) Sketch the equilibrium band picture. (5 pts)

b) Find the built-in potential and the equilibrium depletion width. (5pts)

V_{bi}= _____V

W= _____nm

c) For a forward bias of 0.3V, find the current density (assuming $A^{**}=112 A/cm^2/K^2$) and the depletion width in the Si. (5pts)

J=	_____ A/cm^2
W=	_____ nm

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}	2.26×10^{13}	2.19×10^{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