UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EECS 130 Professor Ali Javey
Fall 2006

Midterm I

Name:

Closed book. One sheet of notes is allowed.

Show all your work in order to receive partial credit.

Include correct units when appropriate.

Make sure everything is on the exam papers. Work on additional papers will *NOT* be accepted.

There are a total of 10 pages of this exam including this page. Make sure you have them all.

Problem 1	30
Problem 2	15 & 5 extra credit
Problem 3	28
Problem 4	27
Total	100

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	1.12 eV
Intrinsic Carrier Concentration in Si at 300K	n_i	10^{10} cm^{-3}

1. Carriers Concentrations [30 pts]

This problem concerns a specimen of gallium arsenide, GaAs, which has 2×10^{17} cm^{-3} donors and an unknown number of acceptors. A measurement is made on the specimen and it is found that it is p-type with an equilibrium hole concentration, p_o, of 5×10^{17} cm^{-3}.

At room temperature in GaAs, the intrinsic carrier concentration, n_i, is 10^7 cm^{-3}, the hole mobility, μ_h, is 300 cm^2/V-s, and the electron mobility, μ_e, is 4000 cm^2/V-s. The minority carrier lifetime, t_{min}, is 10^{-9} s.

a) [6 pts] What is the net acceptor concentration, N_A (= N_a - N_d), in this sample, and what is the total acceptor concentration, N_a?

N_A =_______________cm^{-3}

N_a=

________________cm^{-3}

b) [6 pts] What is the equilibrium electron concentration, n_o, in this sample at room temperature?

n_0=

_________________cm^{-3}

c) [6 pts] Calculate $E_F - E_i$ in this sample at room temperature.

$E_F - E_i =$ ____________ eV

d) [6 pts] What is the electrical conductivity, σ_0, of this sample in thermal equilibrium at room temperature?

$\sigma_0 =$ ______________ S/cm

e) [6 pts] This sample is illuminated by a steady state light which generates hole-electron pairs uniformly throughout its bulk, and the conductivity of the sample is found to increase by 1% (that is, to 1.01 σ_0). What are the excess hole and electron concentrations, Δp and Δn, in the illuminated sample, assuming that the illumination has been on for a long time?

Δn = ____________________ cm^{-3}

Δp =
____________________ cm^{-3}

2. Temperature Dependence of Carrier Concentrations and Mobility [15 pts]

A silicon wafer is moderately doped with arsenic. The plots in parts (a)-(c) show the relationship between ln(*n*) and 1/*T* for this Si wafer, where n is the electron density in the conduction band and T is the temperature. In each case, clearly mark any pertinent shift in the curve and/or the slopes of the two non-flat regions as various properties of the semiconductor is changed.

[5 pts] Draw a second curve that would correspond to an intrinsic (undoped) Si wafer.

[5 pts] Draw a second curve that would correspond to using a Ge (E_g~0.67) wafer with the same dopant density instead of a Si (E_g~1.1) wafer. Assume the same ($E_D - E_C$).

[5 pts] Draw a second curve that would correspond to another Si wafer, but doped with a different donor such that $(E_D - E_C)_{NEW\_DONER} = 4 \times ((E_D - E_C)_{As}$, where E_D is the donor energy level.

[5*pts extra credit*] Draw a second curves that would correspond to a heavily doped Si wafer. Hint: when doping density is high, the impurity energy level splits into a band of available states due to Pauli exclusion principle. This impurity band crosses E_c.

3. Band Model [28 pts]

A silicon device maintained at 300 K is characterized by the following band diagram. Use the cited energy band diagram in answering parts (a)-(e)

[8 pts] Sketch the electric field inside the semiconductor.

[5 pts] Do equilibrium conditions prevail (yes, no, or cannot determine)?

[5 pts] Is the semiconductor degenerate at any point? If so, specify one point where this is the case.

[5 pts] What is the electron current density (J_N) flowing at $x = x_1$?

[5 pts] What is the kinetic energy of the hole shown in the diagram?

4. [27 pts] Assume a Si PN junction with the following dopant density profiles for the two segments:

N **P**

[6 pts] Find V_{bi}.

V_{bi}= _______________V

[7 pts] Draw a band diagram for the structure with a forward bias of V_A=0.5 V. Label V_A, V_{bi}, E_v, E_c, and Fermi (or quasi-Fermi) levels.

[4 pts] For part b, using arrows, indicate direction of $I_{n,diff}$, $I_{p,drift}$, I_n, and I_{total} (Redraw the band diagrams from b here).

[10 pts] So far, we have been assuming that there is no series resistance (and therefore, no potential drop) in the neutral P and N regions of our diodes. However, when lightly doped (~<5e16cm^{-3}), the resistivity of the P and N type regions are often high, leading to series resistance or potential drop in the P and N regions under an applied voltage. Draw a band diagram for this PN junction in equilibrium and then under forward bias, this time including the effect of the series resistance (qualitatively) of the N segment. Hint: assume the series resistance is constant throughout the N segment.

$N_D = 2 \times 10^{16}\ cm^{-3}$ $N_A = 1 \times 10^{17}\ cm^{-3}$

$N_A = 1 \times 10^{16}\ cm^{-3}$ $N_D = 1 \times 10^{13}\ cm^{-3}$