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

EE 130/230M — Spring 2013
Integrated Circuit Devices — Prof. Liu & Dr. Xu

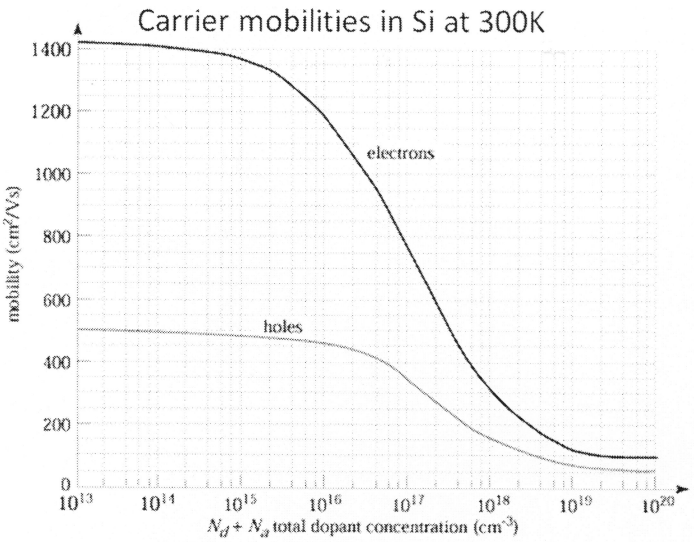
QUIZ #1
Time allotted: 25 minutes

NAME: SOLUTIONS _____ _____ _____
(print) Last First Signature

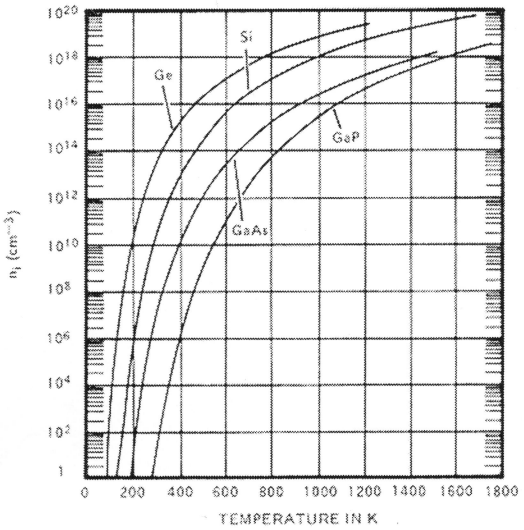
STUDENT ID#: _____

Properties of silicon (Si) at 300K

Description	Symbol	Value
Energy band gap	E_G	1.12 eV
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}



Intrinsic Carrier Concentration *vs.* Temperature



Problem 1 [8 points]

a) Why is it important to keep track of crystallographic planes and directions within a Si crystal? [2 pts]

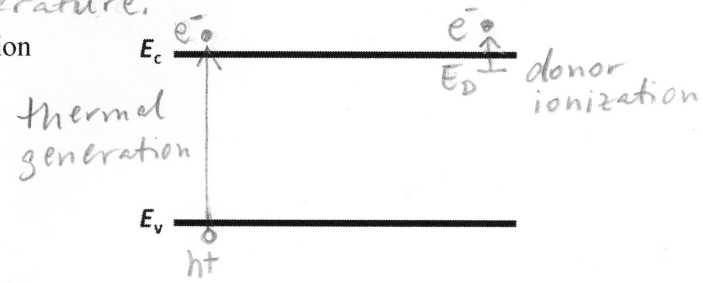
Electron and hole mobilities (hence IC device performance) vary with the crystallographic plane and direction of current flow, due to differences in atomic and bond densities.

b) Does the conductivity of intrinsic Si vary significantly with temperature near 300K? Briefly explain your answer. [3 pts]

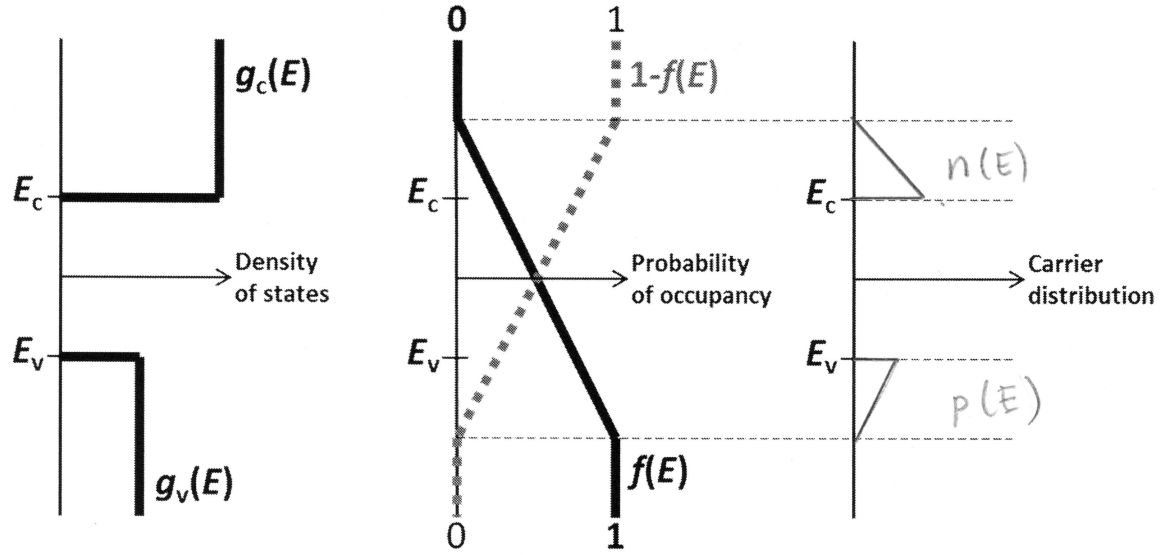
conductivity $\sigma = q n_i (\mu_n + \mu_p)$ for intrinsic Si.

Yes. Intrinsic carrier concentration increases with $T^{3/2} e^{-E_a/2kT}$ while mobility decreases with $T^{-3/2}$, so their product increases rapidly with increasing temperature.

c) Illustrate thermal generation and donor atom ionization on the energy band diagram [3 pts]



Problem 2 [6 points]
Sketch the electron and hole distributions within the conduction and valence bands, respectively, for a semiconductor with the given density of states and occupancy functions [4 pts]



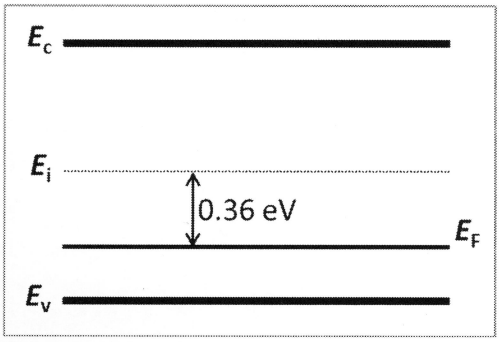
Is this material n-type or p-type? Justify your answer. [2 pts] n-type

$\int_{E_c}^{\infty} n(E)\,dE > \int_{-\infty}^{E_v} p(E)\,dE$ so $n > p$

Problem 3 [11 points]
The energy band diagram for a uniformly doped Si sample maintained at T=300K is shown below.

a) Is this sample n-type or p-type? [1 pt]

p-type, since $E_F < E_i$



b) What are the carrier concentrations (n and p)? [4 pts]
(Remember that $kT \cdot ln(10) = 0.060$ eV at 300K)

$E_i - E_F = 0.36\,eV = 6 \times kT\ln(10) = kT\ln 10^6 = kT\ln\left(\frac{p}{n_i}\right)$

$\Rightarrow \frac{p}{n_i} = 10^6 \Rightarrow p = 10^{16}\,cm^{-3}$ $\quad n = \frac{n_i^2}{p} = 10^4\,cm^{-3}$

c) Roughly estimate the resistivity of this sample. [4 pts] $\mu_p = 450\,cm^2/V\cdot s$

$\rho \simeq \frac{1}{q\mu_p p} = \frac{1}{(1.6\times10^{-19})(450)(10^{16})} = \frac{1}{720\times10^{-3}} = 1.4\,\Omega\text{-cm}$

d) Estimate the temperature at which this sample becomes intrinsic. [2 pts]

n_i exceeds $10 \times 10^{16}\,cm^{-3}$ at $T = 800K$