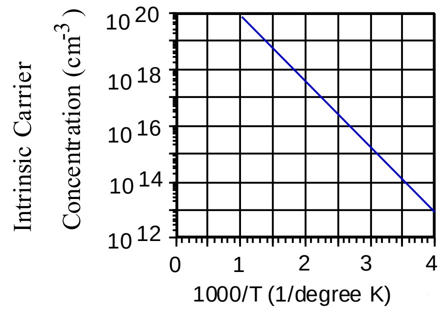
NENG 452

Home assignment # 6 **Due: April 18, 2014**

1. The figure below shows the dependence of the intrinsic carrier concentration on inverse temperature for a semiconductor material. What is the energy gap of this semiconductor?
Hint: you may neglect the temperature dependence of the densities of states for an estimate of the energy gap based on this graph.



2. Two degenerate GaAs samples #1 and #2 have electron concentrations n_1 and n_2 such that $n_2/n_1 = 2$. The Fermi level in sample #1 is 40 meV above the bottom of the conduction band. The sample temperature is 77K (low so that k_BT/q << 40 meV).
   (a) What is the position of the Fermi level in sample #2 with respect to the bottom of the conduction band?
   (b) Calculate n_1.

3. Show that in a semiconductor with quasi-Fermi levels for electrons and holes E_{Fn} and E_{Fp}, respectively, the non-equilibrium carrier concentrations in the non-degenerate case follow

$$np = n_i^2 \exp\left(\frac{E_{Fn} - E_{Fp}}{k_B T}\right)$$

4. Derive the equations for surface concentration of the two dimensional electron gas, n_S, in one subband depends on $\eta_C = (E_F - E_C)/k_BT$ (where E_F is the Fermi level and E_C is the bottom of the subband) as follows:

(a) $n_s = \frac{m_e^*}{\pi\hbar^2}(k_BT)\ln\left(1+\exp(\eta_c)\right)$, and approximately

(b) $n_s = D_2\left(E_F - E_C\right)$ for η_C >>1 (degenerate case) and

(c) $n_s = D_2 kT \exp\left(\frac{E_F - E_C}{k_B T}\right)$ for $-\eta_C$ >>1 (non-degenerate case)

where $D_2 = \frac{m_e^*}{\pi\hbar^2}$ - 2-dimensional density of states

5. A piece of non-uniformly doped silicon has a built-in electric field of 10^4 V/cm and an electron gradient (dn/dx) at x = 0 which equals -10^{20} cm^{-4}. Assuming the semiconductor is in thermal equilibrium, calculate the electron and hole density as well as the hole gradient at x = 0. Use μ_n = 1000 cm^2/V-s and μ_p = 300 cm^2/V-s.

6. n-MOSFET channel can be considered as a two-dimensional electron gas (quantum confined in the normal-to-the-substrate direction). At some gate voltage, the density of electrons in a Si n-MOSFET channel is $1\text{x}10^{13}$ cm^{-2}.

(a) Find the Fermi-level (in eV) with respect to the bottom of the quantum-confined subband. Consider a single subband is occupied.

(b) Estimate the channel mobility and sheet resistivity if the scattering time is 0.03 ps.

(c) Estimate the electron density in the second subband, if it is elevated by 50 meV from the first subband.

Note: consider equal occupation of six conduction band valleys of Si. It will be helpful to draw the 2D density of states vs. energy and indicate energies.

Electron effective masses are given in the table:

	m_ℓ^*	m_t^*	$\bar{m}_{\ell h}^*$	$\bar{m}_{hh}^*$
Si	0.92	0.19	0.16	0.52
Ge	1.59	0.082	0.043	0.34