H3 Part 2: Practice Questions (Set 2)

1. The built-in voltage of an abrupt, uniformly doped p^+n junction diode is 0.75 V. At 0 V bias, the junction capacitance is 10 pF. The cross-sectional area of the diode is 2×10^{-4} cm^2 and the relative permittivity of the semiconductor is 10.5.

   (a) Sketch, with reasonable accuracy, a *labelled* energy band diagram of the junction diode at thermal equilibrium.

   (b) Determine the maximum *built-in* electric field across the junction.

   (c) If the maximum allowable junction electric field is 3.2×10^5 V/cm to ensure proper operation of the junction diode, determine the maximum voltage that may be applied. Assume the width of the space charge region in the p^+ region, x_p to be negligibly small.

   [8.06×10^4 V/cm; 11.0 V]

2. An abrupt Ge p-n junction diode has moderately doped p and n regions. The doping concentration on the p-side is twice that of the n-side. The desired built-in voltage is 0.32 V. The intrinsic carrier concentration is 2.4×10^{13} cm^{-3} and the critical electric field is 1×10^5 Vcm^{-1}. Assume $kT = 0.0259$ eV.

   (a) Determine the required doping concentration of the p- and n-side.

   (b) A reverse bias voltage of -2 V is applied across the diode. Sketch, to reasonable accuracy, a *labelled* energy band diagram of the diode under this biasing condition. Calculate and write down clearly the position of the Fermi energy, relative to the center of the bandgap, on the p- and n-side.

   (c) Further increasing the reverse bias voltage will eventually result in a large current flowing through the diode. Give a possible explanation for this observation.

   [8.18×10^{15} cm^{-3}; 1.64×10^{16} cm^{-3}]

3. An Ohmic contact is formed on an n-type semiconductor doped to a concentration of 5×10^{16} cm^{-3}. The bandgap of the semiconductor is 1.2 eV; intrinsic carrier concentration at 300 K is 1×10^{10} cm^{-3}; electron affinity is 4.1 eV.

   (a) Determine the maximum allowable work function of the metal.

   (b) A metal of work function smaller than that in part (a) is used. Sketch, to reasonable accuracy, a *labelled* energy band diagram of the contact under thermal equilibrium.

   (c) What potential barrier must electrons in the metal overcome before they can get to the semiconductor side?

   [4.30 eV; 0.201 eV]

4. A metal contact is to be formed on an n-type semiconductor, doped moderately to a concentration of 1×10^{16} cm^{-3}. The work function of the semiconductor is 3.80 eV. Assume $N_C = 1.2\times10^{19}$ cm^{-3}; $kT = 0.0259$ eV.

The following are available choices of metals:

Metal	**Work function (eV)**
Aluminum	4.1
Silver	4.5
Titanium	4.3

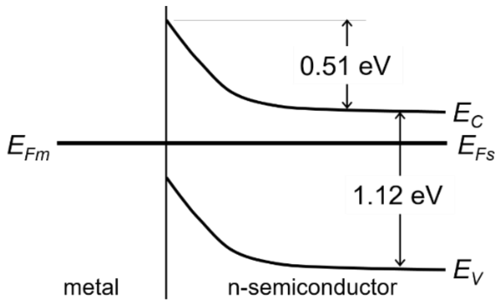
(a) Determine the electron affinity of the semiconductor.

(b) If it is desired to have a Schottky contact with the lowest reverse saturation current density, which metal would you choose? Briefly justify your choice.

(c) Determine the reverse saturation current density for the metal chosen in part (b). The Richardson constant for this contact is 120 A K^{-2}cm^{-2}.

[3.62 eV; 18.9 nA/cm^2]

5. The figure below shows the energy band diagram of a metal to n-semiconductor contact at 300 K. The semiconductor is uniformly doped to a concentration of 7×10^{15} cm^{-3}. The intrinsic carrier concentration is 1.5×10^{10} cm^{-3} and the electron affinity is 4.1 eV.



(a) Is the contact Schottky or Ohmic? Explain your answer very briefly.

(b) Determine the work function of the metal and the metal-to-semiconductor potential barrier.

[4.83 eV; 0.73 eV]

6. An AlGaAs n$^+$p light emitting diode, of cross-sectional 5×10^{-2} cm^2, is doped uniformly to a concentration of 5×10^{15} cm^{-3} on the lightly doped side. A 10-mA current flows through the diode when it is forward biased at 1.1 V. The mobility of the electrons and holes are 8500 cm^{2}V^{-1}s^{-1} and 400 cm^{2}V^{-1}s^{-1}, respectively. The intrinsic carrier concentration is 2×10^5 cm^{-3}. Assume $kT = 0.0259$ eV.

(a) Determine the lifetime of the electrons. State clearly any assumption(s) made.

(b) If the optical power output of the LED at the said bias condition is 7 mW, determine the bandgap energy of AlGaAs. The radiative recombination efficiency is 42%.

(c) What is the color of the light emitted?

[70 ns; 1.67 eV]

7. An N^+P light-emitting diode (LED) is fabricated using a direct bandgap semiconductor ($E_g = 1.7$ eV), doped uniformly to a concentration of 6.2×10^{15} cm^{-3} on the p-side. The intrinsic carrier concentration is 1.8×10^{4} cm^{-3}. The LED is forward biased with a 1.25 V battery at 300 K. The electron and hole mobility are 8500 cm^{2}V^{-1}s^{-1} and 400 cm^{2}V^{-1}s^{-1}, respectively. The corresponding lifetimes are 0.01 and 0.05 μs. The diode cross-sectional area is 5×10^{-3} cm^{-3}.

(a) Calculate the current flowing through the LED.

(a) Determine the optical power output if the radiative recombination efficiency is 0.4.

(b) The optical power measured is usually lower than the value determined in part (b). Give a very brief explanation.

[6.09 mA; 4.14 mW]