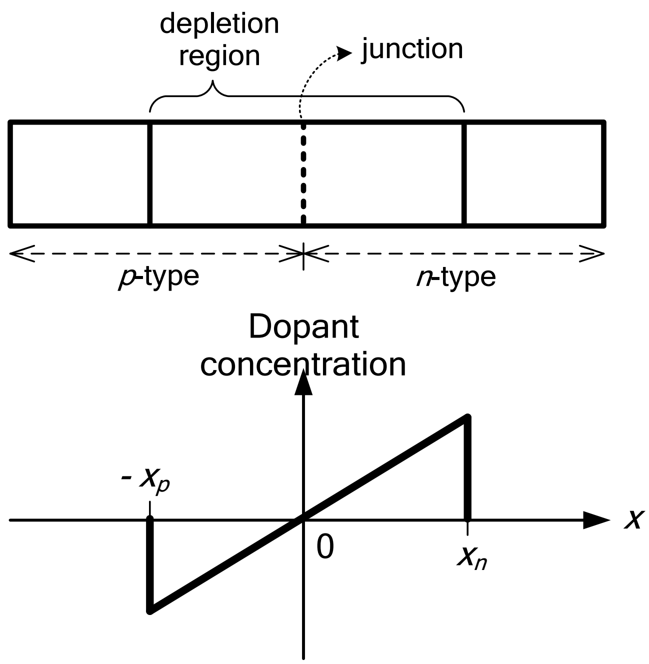
H3-Part 2: Extra Practice Questions

1. A *p*-*n* junction is non-uniformly doped such that the distribution of ionized donor and acceptor concentrations in the depletion region is of the form shown in the figure below. Sketch the electric field profile and electric potential distribution in the depletion region of this *p*-*n* junction. Explain clearly how you arrive at your answers.



2. An ideal GaAs *p*-*n* junction, maintained under thermal equilibrium condition, has doping concentrations of $N_A = 10^{17}$ cm^{-3} and $N_D = 2\times10^{16}$ cm^{-3} in the *p* and *n* regions, respectively. The bandgap energy of GaAs is $E_g = 1.43$ eV. Assume that ε_r (GaAs) = 12.9, $N_c = 4.7\times10^{17}$ cm^{-3}, $N_v = 7.0\times10^{18}$ cm^{-3} and $T = 300$ K.

   (a) Calculate the equilibrium contact potential and depletion region width.

   (b) Determine the maximum electric field in the depletion region.

   (c) Explain why the equilibrium contact potential cannot be measured with a voltmeter.

[Ans: (a) 1.24 V, 0.33 μm, (b) 75.95 kV/cm]

3. A uniform abrupt Si p-n junction has a cross-sectional area of 2.5×10^{-4} cm^2 and a built-in voltage of V_0 = 0.79 V. When a reverse bias voltage of 2 V is applied to the p-n junction, a capacitance of 5.6 pF is measured. Assume that $N_d > N_a$, T = 300 K, n_i = 1×10^{10} cm^{-3} and ε_r(Si) = 11.8.

   (a) Determine the donor and acceptor doping densities in the n- and p-regions, respectively.

   (b) Proper device operation is guaranteed if the peak electric field in the depletion region does not exceed 326 kV/cm. What is the maximum voltage that can be applied to the p-n junction?

[Ans: (a) $N_d = 9.85\times10^{16}$ cm^{-3}, $N_a = 2.02\times10^{16}$ cm^{-3}, (b) 19.87 V]

4. An ideal metal is deposited onto a p-type semiconductor (E_g = 1.1 eV, n_i = 1.5×10^{10} cm^{-3}) at 350 K. The acceptor doping concentration in the semiconductor is N_A = 10^{16} cm^{-3} and the electron affinity is 4.5 eV. The metal work function is 5.1 eV.

   (a) Is the resulting metal-semiconductor contact ohmic or rectifying?

   (b) Sketch the band diagram of the metal-semiconductor contact when a positive voltage is applied to the metal.

[Ans: (a) Rectifying]

5. A p^+n junction diode has an area = 10^{-2} cm^2. The relation between the junction capacitance C_j and applied voltage V_a is given by

$$\frac{1}{C_j^2} = 7.48\times10^{18}\left(13 - 20\ V_a\right)$$

   where V_a is positive when the diode is forward biased and negative for reverse bias conditions. Assume that n_i = 9.5×10^9 cm^{-3} and ε_r(Si) = 11.8.

   Determine, at T = 300 K,

   (a) the built-in voltage, V_{bi}.

   (b) the doping densities in the n and p regions.

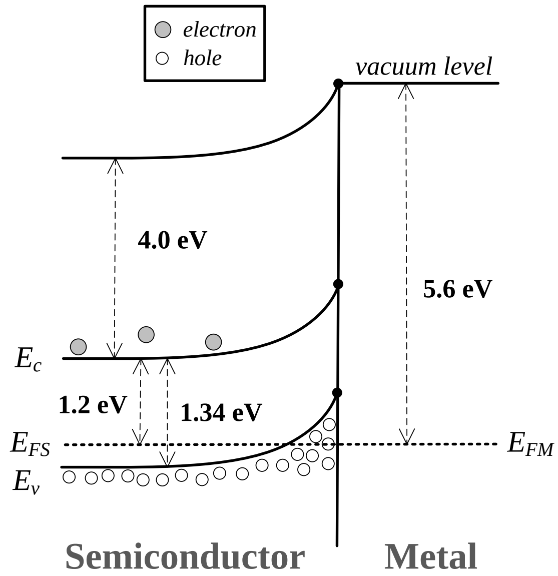
[Ans: (a) 0.65 V, (b) $N_A = 8.06\times10^{15}\,\text{cm}^{-3}, N_D = 8.88\times10^{14}\,\text{cm}^{-3}$]

6. The energy band diagram of a metal-semiconductor contact is shown in figure. The semiconductor has the following parameters:

$N_c = 5.7\times10^{17}$ cm^{-3}

$N_v = 1.1\times10^{19}$ cm^{-3}

$T = 300$ K



(a) What is the majority carrier concentration in the semiconductor?

(b) Determine the work function of the semiconductor and state whether the metal-semiconductor contact is ohmic or rectifying.

(c) A voltage is applied across the metal-semiconductor contact such that the positive polarity is on the metal. Sketch the resulting energy band diagram of the contact.

[Ans: (a) 4.88×10^{16} cm^{-3}, (b) 5.2 eV, ohmic]

7. The donor and acceptor doping concentrations in the *n*- and *p*- regions of a uniform abrupt *p*-*n* junction diode are $N_d = 9.85\times10^{16}$ cm^{-3} and $N_a = 2.02\times10^{16}$ cm^{-3}, respectively. A forward bias voltage of 0.65 V is applied to the diode. Assume that the intrinsic concentration is $n_i = 1.1\times10^{10}$ cm^{-3}, $I_0 = 1.5\times10^{-10}$ A, $\varepsilon_r = 11.8$ and $T = 300$ K. The diode has a cross-sectional area of 8×10^{-4} cm^2.

(a) Calculate the junction capacitance and the peak electric field in the depletion region of the forward biased diode.

(b) The minority carrier concentrations at both the space-charge edges, i.e. at position $x = -x_p$ and $x = x_n$, are required to be no larger than 1% of the respective majority carrier concentrations. How should the forward bias voltage be changed to meet this requirement? State the new forward bias voltage that can be applied to the diode.

[Ans: (a) 81.5 pF, 26.35 kV/cm, (b) 0.625 V]