Solutions
INEL 6055 Midterm Exam

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1. For forward-biased current in an ideal pn-junction diode, show that the ratio of hole current to total current is independent of the applied voltage and can be controlled by varying the relative doping on the two sides of the junction. Derive an expression of the ratio as a function of $\frac{N_A}{N_D}$. (25 points)

   ANSWER:

   From the class notes, the electron current density is given by

$$J_n = \frac{qD_n n_{pe}}{L_n}(1 - e^{\frac{qV_D}{kT}})$$

   n_{pe} is equilibrium concentration of electrons in p-type side. The equivalent expression for the hole current is

$$J_p = \frac{qD_p p_{ne}}{L_p}(1 - e^{\frac{qV_D}{kT}})$$

   p_{ne} is equilibrium concentration of electrons in p-type side.

   The total diode current density is $J = J_n + J_p$. Thus

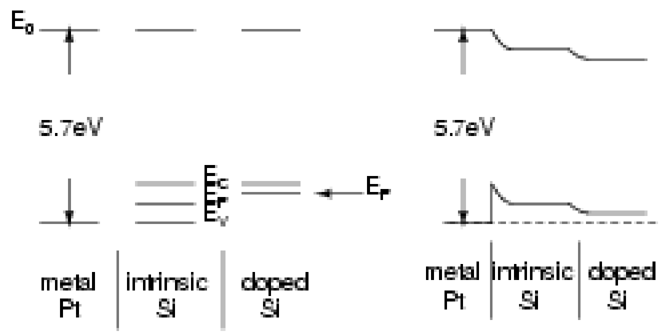
$$\begin{aligned} \frac{J_p}{J} &= \frac{1}{\frac{J_n}{J_p} + 1} \\ &= \frac{1}{\frac{\frac{qD_n n_{pe}}{L_n}}{\frac{qD_p p_{ne}}{L_p}} + 1} \\ &= \frac{1}{\frac{qD_n n_{pe} L_p}{qD_p p_{ne} L_n} + 1} \end{aligned}$$

   Substituting $n_{pe} = \frac{n_i^2}{N_A}$ and $p_{ne} = \frac{n_i^2}{N_D}$ yields the desired relationship,

$$\frac{J_p}{J} = \frac{1}{\frac{qD_n N_D L_p}{qD_p N_A L_n} + 1}$$

2. A system is composed of a metal, an intrinsic silicon region, and a doped silicon region The impurity concentration in the doped region is $N_D = 10^{16} cm^{-3}$. The metal is Platinum (chemical symbol Pt, work function equal to 5.7eV). Assume room temperature and that the three regions are large enough so that band bending at the two interfaces are independent of each other.

   (a) Sketch an *energy versus position* diagram, such as the one shown in your textbook's figure 2.6, for this system. (15 points)
   ANSWER:



(a) (b)

   (b) Find the magnitude of the energy band bending at the two interfaces.(20 points)
   ANSWER:
   To find the amount of band bending, observe that at thermal equilibrium the Fermi levels must allign through the system.
   The work functions at the metal and intrinsic silicon are $\phi_{Pt} = 5.7eV$ and $\phi_{Si_intrinsic} = \frac{1}{2}E_g + q\chi_s = 4.61eV$, respectively. Thus the band bending at this interface is $5.7eV - 4.61eV = 1.09eV$.
   For the doped silicon region, the work function is $q\phi_{Si_doped} = q\chi_s + E_C - E_F$. From the chapter 1 notes,

$$E_C - E_F = kTln\frac{N_C}{N_D} = 0.025eVln\frac{2.86 \times 10^{19}}{10^{16}} = 0.2eV$$

   and

$$q\phi_{Si_doped} = 4.05eV + 0.2eV = 4.25eV$$

   The band bending at the intrinsic Si-doped Si interface is thus equal to $4.61eV - 4.25eV = 0.36eV$.

3. Find the missing result in the following table. (40 points)

V_D (V)	0.70	0.72	0.74
I_D (mA)	0.6	?	2.3

ANSWER:

From the diode's equation

$$I_D = I_S exp(\frac{V_D}{nV_T})$$

we see that we can find n from the ratio $I_D(0.74V)/I_D(0.70V)$. After a few operations, this yields $n = 1.19$. Solving the diode equation for I_S and using one of the two data points given in the table, we get $I_S = 3.6 \times 10^{-14}A$. We then can use the above equation once more to calculate the missing data and obtain $I_D(0.72V) = 1.17mA$.