ECSE-2210 Microelectronics Technology
Class Activity 13 – Solution

1. Answer the following questions. Give reasons.

$$W = \left[\frac{2K_s \varepsilon_0}{q} \left(\frac{N_A + N_D}{N_A N_D} \right) (V_{bi} - V_A) \right]^{1/2}$$

   a. In a p^+-n junction, most of the depletion layer will be in the (choose one: **n-side** or p-side) of the junction.

   b. The depletion layer will (choose one: **increase** or decrease) with the applied reverse voltage.
      From the above equation it can be seen that the $(V_{bi} - V_A)$, turns out to be a positive value with increasing reverse bias. As the bias in the reverse direction is increased the width of the depletion region also increases as they are directly proportional to each other.

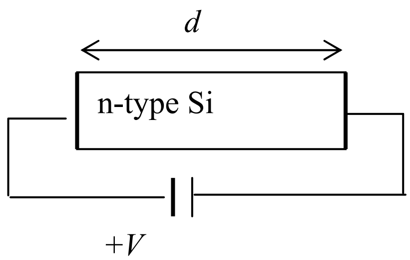
   c. The forward bias current is associated with what type of carrier activity? (choose one; **diffusion**, drift or generation-recombination)
      Diffusion current increases exponentially as applied voltage is increased.

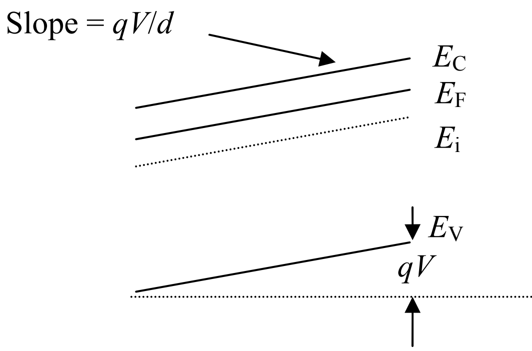
   d. The reverse-bias current is associated with what type of carrier activity? (choose one; diffusion, **drift** or generation-recombination)
      The drift current is not dependent on the $\mathcal{E}$-field since the $\mathcal{E}$-field is so large that any small number of minority carriers, which comes near the depletion layer, will be swept across the junction in no time. So, the number of minority carriers, which cross over to the other side depends on the generation rate.

   e. Why is the reverse-bias current expected to be small in magnitude and to saturate at a small reverse voltage?
      The reverse current depends on the rate at which the minority carriers are generated up to a distance of one diffusion length from the depletion layer edge. These carriers are swept across the depletion region and are responsible for the reverse saturation current. This rate is small and depends on the number of minority carriers wandering into the depletion region per second.

   f. Why can't the minority carrier diffusion equation be used to determine the minority carrier concentrations and currents in the depletion layer of a diode?
      The minority carrier diffusion equation assumes zero electric field. The $\mathcal{E}$-field is not zero inside the depletion layer. There is a finite $\mathcal{E}$-field that is caused due to the built-in potential (V_{bi}).

2. Sketch the energy band diagram for an n-type Si piece shown below. (Note that the slope of the band gives the $\mathcal{E}$-field and the Fermi-level difference gives the applied voltage).





When an external voltage is applied to the semiconductor the material is disturbed from its equilibrium position. Hence all the bands including the Fermi level will bend. The amount of bend is directly proportional external voltage that is applied.

3. Sketch the energy band diagram for an ideal p^+-n step junction diode. Assume that the Fermi-level is at the valence band in the p^+-side, and the n-side doping is 10^{16} cm^{-3}. Draw the diagrams for the following conditions: (a) $V_A = 0$ (b) $V_A = 0.5$ V (c) $V_A = -5$ V (These diagrams should illustrate why the forward current is large, whereas the reverse current is negligibly small).

See figure 6.1 in the text.

With an applied forward bias the barrier for the electrons to move from the n-side to the p-side is decreased. As a result the number of carriers crossing the junction also increases and also the current increases exponentially with the applied bias. Also the width of the depletion region decreases as the voltage ($V_{bi} - V_A$) is now less.

With an applied reverse bias the potential for the carriers from the n-side to the p-side increases greatly. None of the carriers can overcome the potential barriers. Only those carriers that are generated within one diffusion length from the depletion region are swept across the depletion region and contribute to the reverse saturation current. Also under the reverse bias case the depletion layer width increases.

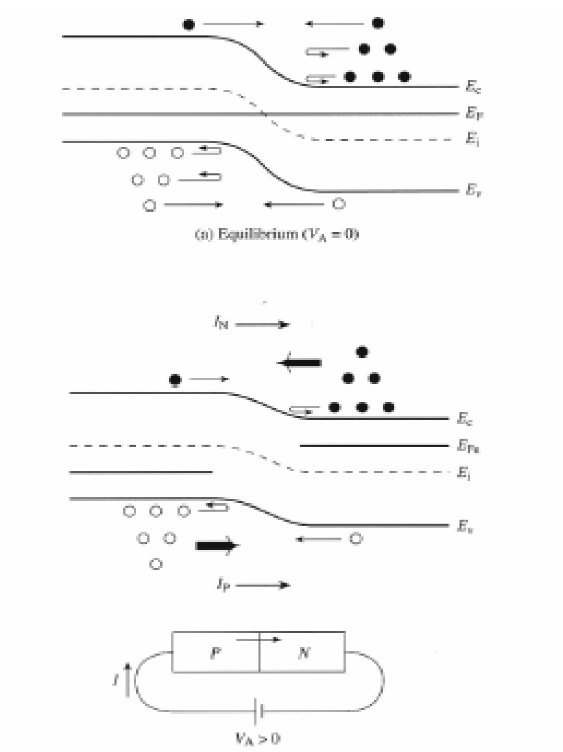


Fig. 6.1(Pierret, 1996)

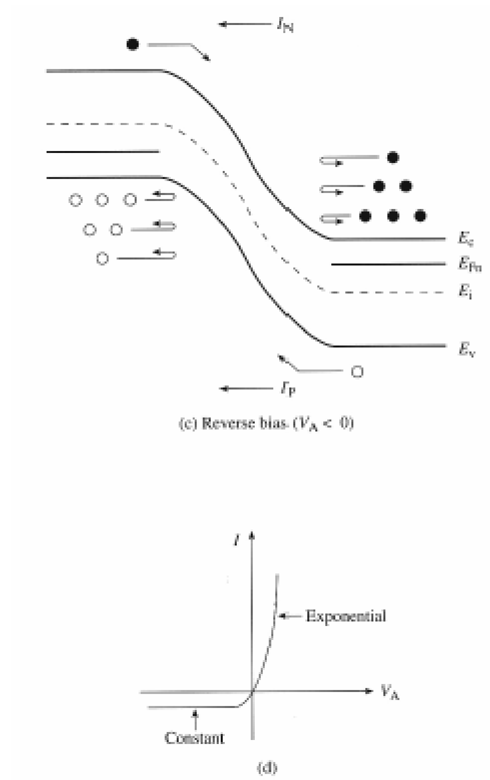
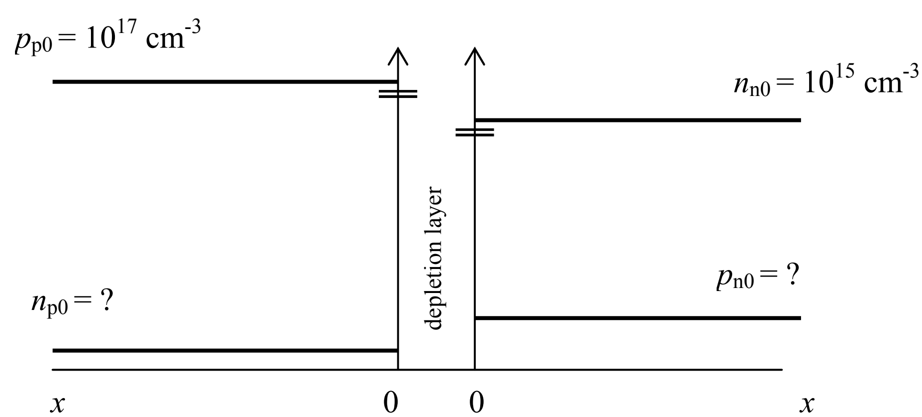
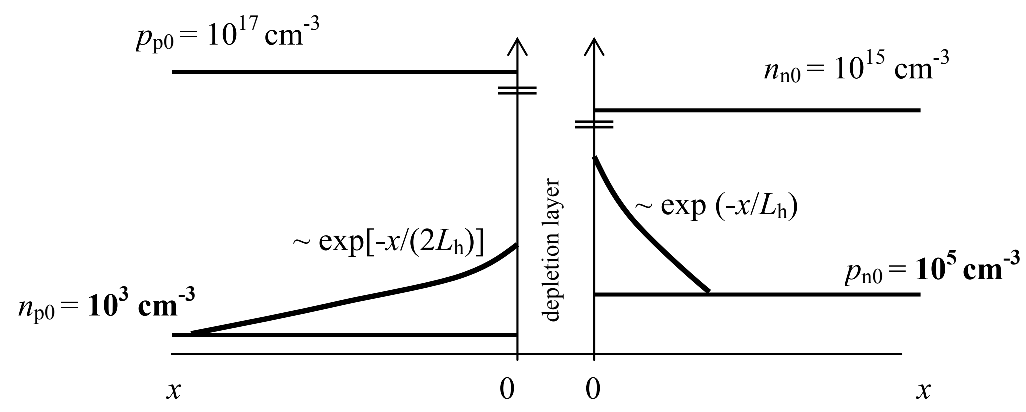


Figure 6.1 *Continued.*

4. The following diagram shows the equilibrium carrier concentration on either side of the p-n junction.



   a. Calculate the equilibrium minority carrier concentrations on each side and mark them in the figure below.



On the n-side of the junction

$$p_{no} = \frac{n_i^2}{n_{n0}} = \frac{10^{20}}{10^{15}} = 10^5\,\text{cm}^{-3}$$

On the p-side of the junction

$$n_{p0} = \frac{n_i^2}{p_{p0}} = \frac{10^{20}}{10^{17}} = 10^3\,\text{cm}^{-3}$$

b. A forward voltage of 0.3 V is applied to this diode. Plot the minority carrier concentration profile on either side of the diode. Assume the electron diffusion length L_n is twice that of the hole diffusion length L_h.

The ratio of minority carrier concentration at the edge of the depletion layer under applied bias to the concentration at equilibrium is the same on both sides:

$$p_n(0) / p_{n0} = n_p(0) / n_{n0} = \exp(0.3/0.0256)$$

Since the electron diffusion length is larger, the diffusion distance on p-side is larger.