by $E_V(x) = E_C(x) - E_G$, and the intrinsic energy by equation (3.19). E_0, defined as the vacuum energy, serves as a convenient reference point and is universally constant with position. An electron at the vacuum energy is, by definition, completely free of influence from all external forces. The electron affinity, χ, is the minimum energy needed to free an electron from the bottom of the conduction band and take it to the vacuum level. The electric field is a result of the uncovered ionized donors and acceptors and opposes the diffusion of electrons and holes in the quasi-neutral regions. The charge density plot illustrates the balance of charge between the two sides of the depletion region. In heterojunctions, both the band gap and the electron affinity are position-dependent – making the calculation of the junction electrostatics and energy band diagram more involved.

The basic solar cell structure has now been established (Figure 3.13). It is simply a *pn*-junction diode consisting of two quasi-neutral regions on either side of a depletion region with an electrical contact made to each quasi-neutral region. Typically, the more heavily doped quasi-neutral region is called the *emitter* (the *n*-type region in Figure 3.13) and the more lightly doped region is called the *base* (the *p*-type region in Figure 3.13). The base region is also often referred to as the *absorber region* since the emitter region is usually very thin and most of the light absorption occurs in the base. This basic structure will serve as the basis for deriving the fundamental operating characteristics of the solar cell.

3.4 SOLAR CELL FUNDAMENTALS

The basic current–voltage characteristic of the solar cell can be derived by solving the minority-carrier diffusion equation with appropriate boundary conditions.

3.4.1 Solar Cell Boundary Conditions

At $x = -W_N$, the usual assumption is that the front contact can be treated as an ideal ohmic contact. Hence,

$$\Delta p(-W_N) = 0. \tag{3.95}$$

However, since the front contact is usually a grid with metal contacting the semiconductor on only a small percentage of the front surface, modeling the front surface with an effective surface recombination velocity is more realistic. This effective recombination velocity models the combined effects of the ohmic contact and the antireflective passivation layer (SiO_2 in silicon solar cells). In this case, the boundary condition at $x = -W_N$ is

$$\frac{d\Delta p}{dx} = \frac{S_{F,\text{eff}}}{D_p}\Delta p(-W_N) \tag{3.96}$$

where $S_{F,\text{eff}}$ is the effective front surface recombination velocity. As $S_{F,\text{eff}} \to \infty$, $\Delta p \to 0$, and the boundary condition given by equation (3.96) reduces to that of an ideal ohmic contact (equation 3.95). In reality, $S_{F,\text{eff}}$ depends upon a number of parameters and is bias-dependent. This will be discussed in more detail later.