and

$$I_{o1,n} = qA\frac{n_i^2}{N_A}\frac{D_n}{L_n} \times \left\{\frac{D_n/L_n \sinh[(W_P - x_P)/L_n] + S_{BSF}\cosh[(W_P - x_P)/L_n]}{D_n/L_n \cosh[(W_P - x_P)/L_n] + S_{BSF}\sinh[(W_P - x_P)/L_n]}\right\} \quad (3.128)$$

These are very general expressions for the dark saturation current and reduce to more familiar forms when appropriate assumptions are made, as will be seen later.

I_{o2} is the dark saturation current due to recombination in the space-charge region,

$$I_{o2} = qA\frac{W_D n_i}{\tau_D} \quad (3.129)$$

and is bias-dependent since the depletion width, W_D, is a function of the applied voltage (equation 3.89).

3.4.5 Solar Cell I–V Characteristics

Equation (3.118), repeated here, is a general expression for the current produced by a solar cell.

$$I = I_{SC} - I_{o1}(e^{qV/kT} - 1) - I_{o2}(e^{qV/2kT} - 1) \quad (3.130)$$

The short-circuit current and dark saturation currents are given by rather complex expressions (equations 3.119, 3.128, and 3.129) that depend on the solar cell structure, material properties, and the operating conditions. A full understanding of solar cell operation requires detailed examination of these terms. However, much can be learned about solar cell operation by examining the basic form of equation (3.130). From a circuit perspective, it is apparent that a solar cell can be modeled by an ideal current source (I_{SC}) in parallel with two diodes – one with an ideality factor of “1” and the other with an ideality factor of “2”, as shown in Figure 3.15. Note that the direction of the current source is opposed to the current flow of the diodes – that is, it serves to forward-bias the diodes.

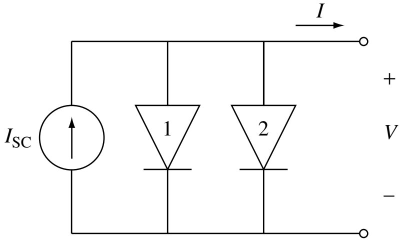

Figure 3.15 Simple solar cell circuit model. Diode 1 represents the recombination current in the quasi-neutral regions ($\propto e^{qV/kT}$), while diode 2 represents recombination in the depletion region ($\propto e^{qV/2kT}$)