current will increase the open-circuit voltage. From equations (3.127) and (3.128), it is obvious that $I_{o1} \to 0$ as $\tau \to \infty$ and $S \to 0$.

From equation (3.134) it is clear that increasing V_{OC} will increase the fill factor, FF. Thus, the design and the operation of an efficient solar cell has two basic goals:

1) Minimization of recombination rates throughout the device.
2) Maximization of the absorption of photons with $E > E_{\mathrm{G}}$.

It is evident that, despite the apparent complexity of the expressions describing the operation of solar cells, the basic operating principles are easy to understand. Electron–hole pairs are created inside the solar cell as a result of absorption of the photons incident on the solar cell from the sun. The objective is to collect the minority carriers before they are lost to recombination.

3.4.7 Lifetime and Surface Recombination Effects

The solar cell characteristics previously derived (equations 3.118 through 3.128) allow examination of the dependence of the solar cell performance on specific sources of recombination. Figure 3.17 shows how the base minority-carrier lifetime affects V_{OC}, I_{SC}, and the FF. Unless otherwise stated, the parameters of Table 3.2 are used to compute the solar cell performance. Short lifetimes mean that the diffusion length in the base is much less than the base thickness and carriers created deeper than about one diffusion length in the base are unlikely to be collected. When this is true ($L_n \ll W_P$), the contribution to the dark saturation current in the base (equation 3.128) becomes

$$I_{o1,n} = qA\frac{n_{\mathrm{i}}^2}{N_{\mathrm{A}}}\frac{D_n}{L_n} \tag{3.141}$$

and is commonly referred to as the *long-base approximation*. In this case, the BSF has no effect on the dark saturation current. On the other hand, when the base minority-carrier lifetime is long ($L_n \gg W_P$), the carriers readily come in contact with the BSF and the dark saturation current is a strong function of S_{BSF}

$$I_{o1,n} = qA\frac{n_{\mathrm{i}}^2}{N_{\mathrm{A}}}\frac{D_n}{(W_P - x_P)}\frac{S_{\mathrm{BSF}}}{S_{\mathrm{BSF}} + D_n/(W_P - x_P)} \tag{3.142}$$

When S_{BSF} is very large (i.e. no BSF), this reduces to the more familiar short-base approximation

$$I_{o1,n} = qA\frac{n_{\mathrm{i}}^2}{N_{\mathrm{A}}}\frac{D_n}{(W_P - x_P)}. \tag{3.143}$$

Figure 3.18 shows how S_{BSF} affects V_{OC}, I_{SC}, and the FF. Notice that the break point in the curves occurs when $S_{\mathrm{BSF}} \approx D_n/W_P = 1000$ cm/s, as can be inferred from equation (3.142).