Another important figure of merit is the collection efficiency, which can be defined relative to both optical and recombination losses as an *external* collection efficiency

$$\eta_C^{ext} = \frac{I_{SC}}{I_{ph}} \tag{3.136}$$

where

$$I_{ph} = qA \int_{\lambda<\lambda_G} f(\lambda)\,d\lambda \tag{3.137}$$

is the maximum possible photocurrent that would result if all photons with $E > E_G$ ($\lambda < \lambda_G = hc/E_G$) created electron–hole pairs that were collected. The collection efficiency can also be defined with respect to recombination losses as the internal collection efficiency

$$\eta_C^{int} = \frac{I_{SC}}{I_{gen}} \tag{3.138}$$

where

$$I_{gen} = qA(1-s) \int_{\lambda<\lambda_G} [1 - r(\lambda)] f(\lambda)(1 - e^{-\alpha(W_N+W_P)})\,d\lambda \tag{3.139}$$

is the light-generated current. This represents what the short-circuit current would be if every photon that is absorbed is collected and contributes to the short-circuit current. $I_{gen} = I_{inc}$ when there is no grid shadowing, no reflective losses, and the solar cell has infinite optical thickness.

3.4.6 Properties of Efficient Solar Cells

Using these figures of merit, the properties of a good (efficient) solar cell can be ascertained. From equation (3.135), it is clear that an efficient solar cell will have a high short-circuit current, I_{SC}, a high open-circuit voltage, V_{OC}, and a fill factor, FF, as close as possible to 1.

$I_{SC} = \eta_C^{int} I_{gen}$ is directly proportional to both the internal collection efficiency and the light-generated current, I_{gen}. The internal collection efficiency is solely dependent on the recombination in the solar cell and will approach 1 as $\tau \to \infty$ and $S \to 0$. To maximize I_{gen} (i.e. $I_{gen} \to I_{inc}$), the solar cell should be designed with a minimum amount of grid shadowing (s), minimum reflectance ($r(\lambda)$), and be optically thick enough such that nearly all the photons with $E > E_G$ are absorbed.

The open-circuit voltage

$$V_{OC} \approx \frac{kT}{q} \ln \frac{I_{SC}}{I_{o1}} \tag{3.140}$$

is logarithmically proportional to the short-circuit current and to the reciprocal of the reverse saturation current, I_{o1} (the same is true for I_{o2}). Therefore, reducing the saturation