The open-circuit current expression, equation (3.140), can be rearranged and the temperature dependence explicitly included to give

$$I_{SC} \approx I_{o1} e^{qV_{OC}/kT} \approx BT^{\zeta} e^{-E_G(0)/kT} e^{qV_{OC}/kT} \tag{3.159}$$

where B is a temperature-independent constant and $T^{\zeta} e^{-E_G(0)/kT}$ accounts for the temperature dependence of the saturation current. The short-circuit current is relatively unaffected by temperature under typical operating conditions, so by differentiating with respect to T, the temperature dependence of the open-circuit voltage can be expressed as [15]

$$\frac{dV_{OC}}{dT} = -\frac{\frac{1}{q} E_G(0) - V_{OC} + \zeta \frac{kT}{q}}{T} \tag{3.160}$$

which for silicon at 300 K corresponds to about −2.3 mV/°C. Equation (3.159) can be rearranged as follows:

$$V_{OC}(T) = \frac{1}{q} E_G(0) - \frac{kT}{q} \ln\left(\frac{BT^{\zeta}}{I_{SC}}\right). \tag{3.161}$$

V_{OC} varies roughly linearly and inversely with temperature and an extrapolation of V_{OC} to $T = 0$ is approximately the band gap since $\lim_{T\to 0}[T \ln T] = 0$.

3.5.5 Concentrator Solar Cells

Operating solar cells under concentrated illumination offers two main advantages. The first is that since fewer solar cells are required to collect the sunlight falling on a given area, their cost of manufacture can be higher than that for cells designed for nonconcentrated illumination, and they are therefore presumably of higher quality (efficiency). The second is that operation under concentrated illumination offers an advantage in the solar cell efficiency. If sunlight is concentrated by a factor of X (X sun illumination), the short circuit at that concentration is

$$I_{SC}^{\mathrm{Xsuns}} = \mathrm{X} I_{SC}^{\mathrm{1sun}}. \tag{3.162}$$

This is assuming that the semiconductor parameters are unaffected by the illumination level and that the cell temperature is the same at both levels of illumination – not necessarily valid assumptions especially at very large X, that is, X > 100. However, these assumptions will allow the demonstration of the potential efficiency of concentrator solar cells. Substituting equation (3.162) into equation (3.135) gives

$$\eta = \frac{FF^{\mathrm{Xsuns}} V_{OC}^{\mathrm{Xsuns}} I_{SC}^{\mathrm{Xsuns}}}{P_{in}^{\mathrm{Xsuns}}} = \frac{FF^{\mathrm{Xsuns}} V_{OC}^{\mathrm{Xsuns}} \mathrm{X} I_{SC}^{\mathrm{1sun}}}{\mathrm{X} P_{in}^{\mathrm{1sun}}} = \frac{FF^{\mathrm{Xsuns}} V_{OC}^{\mathrm{Xsuns}} I_{SC}^{\mathrm{1sun}}}{P_{in}^{\mathrm{1sun}}} \tag{3.163}$$

From equation (3.131),

$$V_{OC}^{\mathrm{Xsuns}} = V_{OC}^{\mathrm{1suns}} + \frac{kT}{q} \ln \mathrm{X}. \tag{3.164}$$