

Photons are absorbed by pumping electrons from the VB to the CB through the process known as electron–hole pair generation. However, as required by the detailed balance, the opposite mechanism is also produced so that a CB electron can decay to the VB and emit a photon, leading to what is called a *radiative recombination process*, responsible for luminescent light emission. In fact, many of such luminescent photons whose energy is slightly above the band gap are reabsorbed, leading to new electron–hole pair generations and balancing out the recombinations. Only the recombination processes leading to the effective emission of a photon out of the semiconductor produce a net recombination. Taking into account that the luminescent photons are emitted isotropically, only those photons emitted near the cell faces, at distances in the range of or smaller than the inverse of the absorption coefficient, and directed towards the cell faces with small angles (those reaching the surface with angles higher than the limit angle will be reflected back) have chances to actually leave the semiconductor, and thus to contribute to the net radiative recombination. The rare device analyses that account for this re-absorption – not yet very common as they are rather involved and the radiative recombination is small in silicon and in many thin-film cells – are said to include photon recycling [15].

In the ideal SQ cell any non-radiative recombination mechanism, which is an entropy-producing mechanism, is assumed to be absent.

The difference between the electrons pumped to the CB by external photon absorption and those falling again into the VB and effectively emitting a luminescent photon equals the current extracted from the cell. This can be presented in an equation form as

$$I/q = \dot{N}_s - \dot{N}_r = \int_{\varepsilon_g}^{\infty} (\dot{n}_s - \dot{n}_r) d\varepsilon \quad (4.19)$$

where $\varepsilon_g = \varepsilon_c - \varepsilon_v$ is the semiconductor band gap and \dot{N}_s and \dot{N}_r are the photon fluxes entering or leaving the solar cell, respectively, through any surface. When the cell is properly contacted, this current is constituted by the electrons that leave the CB through the highly doped *n*-contact. In a similar balance, in the VB, I/q are also the electrons that enter the VB through the highly doped *p*-contact. Note that the sign of the current is the opposite to that of the flow of the electrons.

Using the nomenclature in Table 4.1, the terms in equation (4.19) for unit-area cells are $\dot{N}_s = a\dot{N}(T_s, 0, \varepsilon_g, \infty, \pi \sin^2 \theta_s)$ for the cell facing the sun directly or $\dot{N}_s = a\dot{N}(T_s, 0, \varepsilon_g, \infty, \pi)$ for the cell under full concentration and $\dot{N}_r = \xi\dot{N}(T_a, qV, \varepsilon_g, \infty, \pi)$ where a and ξ are the absorptivity and emissivity of the cell. T_s is the sun temperature and T_a is the room temperature. Full concentration means using a concentrator without losses that is able to provide isotropic illumination; this is the highest illuminating power flux from a given source. The conservation of the étendue requires this concentrator to have a concentration C fulfilling the equation $C\pi \sin^2 \theta_s = \pi n_r^2$, that is, $C = 46050n_r^2$. This concentration is indeed unrealistic, but it does lead to the highest efficiency. Furthermore, it can be proven [16] that when the quasi-Fermi level split is uniform in the semiconductor bulk, then $a = \xi$. We shall assume – from now on in this chapter – that the solar cell is thick enough and perfectly coated with antireflection layers so as to fully absorb any photon with energy above the band gap energy so that $a = \xi = 1$ for these photons.