two ideal cells as a function of the two cells' band gaps, which is optimised only with respect to V_l and V_h. The generation term is in this case not the one in equation (4.52) but the one corresponding to a standard spectrum AM1.5D [18]. Power is converted into efficiency by dividing by 767.2 Wm^{-2}, which is the power flux carried by the photons in this spectrum. In the figure, we can observe that the efficiency maximum is very broad, allowing for a wide combination of materials.

A lot of experimental work has been done on this subject. To our knowledge, the highest efficiency so far achieved, 34% (AM1.5 Global), has been obtained by Spectrolab [24, 36], in 2001, using a monolithic (made on the same chip) two-terminal tandem InGaP/GaAs stuck on a Ge cell and operating at a concentration factor of 210, that is, at 21 Wcm^{-2}.

The maximum efficiency is obtained with an infinite number of solar cells, each one biased at its own voltage $V(\varepsilon)$ and illuminated with monochromatic radiation. The efficiency of this cell is given by

$$\eta = \frac{\int_0^\infty \eta_{\mathrm{mc}}(\varepsilon)\dot{e}_s \,\mathrm{d}\varepsilon}{\int_0^\infty \dot{e}_s \,\mathrm{d}\varepsilon} = \frac{1}{\sigma_{\mathrm{SB}} T_s^4} \int_0^\infty \eta_{\mathrm{mc}}(\varepsilon)\dot{e}_s \,\mathrm{d}\varepsilon = \frac{1}{\sigma_{\mathrm{SB}} T_s^4} \int_0^\infty i(\varepsilon, V)V|_{\max} \,\mathrm{d}\varepsilon \quad (4.53)$$

where $\eta_{\mathrm{mc}}(\varepsilon)$ is the monochromatic cell efficiency given by equation (4.26) and $i(\varepsilon, V)$ was defined in equation (4.23). For $T_s = 6000$ K and $T_a = 300$ K, the sun and ambient temperature, respectively, this efficiency is [34] 86.8%. This is the highest efficiency limit of known ideal converter.

Tandem cells emit room-temperature luminescent radiation. This radiation presents, however, a variable chemical potential $\mu(\varepsilon) = qV(\varepsilon)$ and therefore it is not a radiation with zero chemical potential (free radiation). In addition, the entropy produced by this array is positive since the entropy produced by each one of the monochromatic cells forming the stack is positive. None of the conditions for reaching the Landsberg efficiency (zero entropy generation rate and emission of free radiation at room temperature) is then fulfilled and, therefore, tandem cells do not reach this upper bound.

It is highly desirable to obtain monolithic stacks of solar cells, that is, on the same chip. In this case, the series connection of all the cells in the stack is the most compact solution. Chapter 9 will deal with this case extensively. If the cells are series-connected, a limitation appears that the same current must go through all the cells. For the case of two cells studied above, this limitation is expressed by the equation

$$\begin{aligned} I &= q\lfloor \dot{N}(T_s, 0, \varepsilon_{gl}, \varepsilon_{gh}, H_s) - \dot{N}(T_a, qV_l, \varepsilon_{gl}, \varepsilon_{gh}, H_r)\rfloor \\ &= q[\dot{N}(T_s, 0, \varepsilon_{gh}, \infty, H_s) - \dot{N}(T_a, qV_h, \varepsilon_{gh}, \infty, H_r)] \end{aligned} \quad (4.54)$$

This equation establishes a link between V_l and V_h (for each couple ε_l, ε_h), which reduces the value of the maximum achievable efficiency. The total voltage obtained from the stack is $V = V_l + V_h$.

Our interest now is to determine the top efficiency achievable in this case when the number of cells is increased to infinity. Surprisingly enough, it is found [37, 38] that