7.8.5.3 Modules with back contact cells

Several cell structures have been proposed that bring both contacts to the back face, which is usually accomplished by implementing phosphorus diffusions at both faces that are internally connected through processing. They fit the scheme in Figure 7.1(d) [131]. Back contact cells are interconnected without tabs by soldering them to a layer with the connection paths printed, similar to PCB practice in electronic circuits. These experimental designs offer simplified module fabrication and enhanced visual appeal.

7.9 ELECTRICAL AND OPTICAL PERFORMANCE OF MODULES

7.9.1 Electrical and Thermal Characteristics

The voltage of the module is, in principle, the number of series-connected cells times the voltage of the single cell, and the module current the number of paralleled cells times the single cell current. Whatever the combination, the module power equals the power of a single cell times the number of them. Mass-produced modules offered in the catalogues of manufacturers show power ratings that typically range from 50 to 200 Wp, delivered at current levels between 3 and 8 A and at voltages between 20 and 40 V. Lower and higher values are possible for special applications.

The manufacturer usually provides values of representative points (short-circuit, open-circuit and maximum power) of the module $I-V$ curve measured at standard cell conditions (STC), that is, 1 $kW{\cdot}m^{-2}$ irradiance (=0.1 $W{\cdot}cm^{-2}$), AM1.5 spectral distribution and 25°C cell temperature. The maximum power of the module under STC is called the peak power and given in watts-peak (Wp). While efficiency has the greatest importance for a solar cell, for a module it has the less relevant meaning since part of the area is not occupied by the expensive solar cells.

The conditions in real operation are not the standard ones; instead, they vary strongly and influence the electrical performance of the cell, causing an efficiency loss with respect to the STC nominal value. This loss can be divided into four main categories [132]:

1. *Angular distribution of light*: Because of the movement of the sun and the diffuse components of the radiation, light does not fall perpendicular to the module, as is the case when measurements are done and the nominal efficiency is determined.
2. *Spectral content of light*: For the same power content, different spectra produce different cell photocurrents according to the spectral response. And the solar spectrum varies with the sun's position, weather and pollution and so on, and never exactly matches the AM1.5 standard.
3. *Irradiance level*: For a constant cell temperature, the efficiency of the module decreases with diminished irradiance levels. For irradiances near one sun, this is primarily due to the logarithmic dependence of open-circuit voltage on photocurrent; at very low illumination the efficiency loss is faster and less predictable.
4. *Cell temperature*: The ambient temperature changes and, because of the thermal insulation provided by the encapsulation, light makes cells in the module heat over it;