experimental measurements, as $J_{ph} = 24.5$ mA/cm^2, $J_{01} = 3.6 \times 10^{-5}$ mA/cm^2, $J_{02} = 4.5 \times 10^{-8}$ mA/cm^2 [...]. These low-performing devices, constituting 20% of the total device elements, are now randomly distributed in our network model. The resultant I–V curve for the total cell is also shown in Figure 8.21 (solid line). The parameters of the total cell with defects are $V_{OC} = 620$ mV, $J_{SC} = 32.7$ mA/cm^2, $FF = 75.8\%$, and Efficiency = 16.7%.

It is seen that all the parameters of the "defected" cell are lower than that of the "defect-free" cell. However, the major reduction is in the V_{OC} and the FF. The reduction in V_{OC} is 30 mV whereas J_{SC} is reduced by 1.45 mA/cm^2. It should be pointed out that in a "defect-free" cell, a reduction of 30 mV in V_{OC} would require a large reduction in J_{SC} (in accordance with the cell equation). This disproportionate reduction in the voltage is caused by increased recombination, which manifests as shunting, due to defected regions. Such shunts represent sources of internal power dissipation within the cell. The network model is directly applicable to multigrain solar cells, if the distribution of defects in various grains is known.

The extent of influence of a GB on the photovoltaic properties of the grains constituting the GB depends on several parameters of the grains themselves. These parameters include density of defects, barrier height, and the carrier density of the grains. In a small-grain material, the grain size can be of the same order as the size of "influence" of a GB. Thus, grains and GBs are modeled as regions with different properties. It is important to note that each region (whether a grain or a GB) is characterized by defects. All grains and the boundaries between adjacent grains can be modeled using categorization developed by Chen [19]. This categorization of various grains (or regions) is based on the properties of defects, summarized below.

Type I: These regions have very low defect densities and may be considered as standard regions where the recombination of the majority carriers can be neglected, and the density of extra charges introduced by defect levels is negligibly small.

Type II: The recombination of majority carriers can be neglected, but the extra charges introduced by defect levels in these regions cannot be.

Type III: These are heavily defected, effectively "dead" regions in which almost all the carriers (both majority and minority carriers) will recombine. In the modeling, the details of carrier distribution inside this type of region are ignored because these regions do not contribute any free carriers to the system. This type of region can include GBs or other defect-rich regions such as heavily diffused emitters.

Type IV: A highly defected region in which a significant fraction of the majority carriers recombine. As a result, the Fermi levels in this region will be different from the Type I regions with the same doping concentrations. Because of the high density of defect levels, it is likely that these regions also have extra charges.

In Type I regions, the electric field $E(x, y)$ is 0. But in the regions of Type II or Type III, which have extra charges, these charges will induce internal electric fields; hence, $E(x, y)$ will not be 0.

An important feature of the characterization of regions into four types is that it includes defect-free regions, defected regions, as well as GBs. In particular, one can appropriately define GB in terms of the properties of adjacent grains (see a later part of this Section 8.3.3.1).