describes in detail the problems and challenges associated with silicon production and purification.

An important advance in solar cell fabrication was the demonstration that solar cells with high efficiency can be fabricated from wafers containing hundreds of large-grain (1–10 mm) multicrystals, called multicrystalline (multi-Si) or polycrystalline (poly-Si), although this later term is less favored because it may cause confusion with the feedstock (polysilicon). The multi-Si growth procedure is much faster and the wafer is cheaper. The loss of efficiency of a few percent (absolute) caused by the random orientation of crystalline grains in a multi-Si wafer compared to a single c-Si wafer is balanced by the lower cost so that the price per watt peak is the same on a module basis. But the simplicity of the multi-Si wafer-growing equipment and process is producing a clear trend towards the use of the multicrystalline option as seen in Figure 1.9.

An interesting option in Si solar cell manufacturing is the growth of ribbons [62, 63]. Ribbons do not require the expensive sawing process. However, the growth of the ribbon crystal is slower because they usually grow in the plane perpendicular to the ribbon surface, with very small area (the ribbon width times the thickness). In contrast, wafers grow in the plane of the wafer surface whose area is the wafer area. The standard ingot solidification process is a very effective purification process due to the preferential segregation of impurities to the molten silicon. However, in ribbon Si the plane of solidification moves faster (although with very small area), so the segregation is less effective. In summary, the ribbon cells are almost as good as the multicrystalline bulk-grown cells and possibly cheaper. Challenges lie in increasing the growth speed and the resulting cell efficiency.

Although the solar cell manufacturing process represents a relatively small fraction of the total cell cost, it strongly affects the overall cost in $\$/W_P$ because it determines the cell and module efficiency. This efficiency depends on the quality of the wafer or ribbon utilized but it also greatly depends on the cell process itself.

As a matter of fact, an efficiency of 25% has been achieved for laboratory cells in a long complex process where every possible efficiency-improving detail has been implemented to produce a complicated but nearly ideal device structure. This is explained in Chapter 7. However, most factories use some variation of the wafer and cell fabrication process described above, including the screen-printing process, that leads to 15% single crystal cells or 13% multicrystal cells. In modules, these efficiencies are reduced to 14% or 12%, mainly due to the redefinition of area that now includes the module frame. This process is considered the best compromise between costs and performance.

The existence of the large efficiency gap between laboratory and commercial cells, together with the increasing markets, suggest that novel, high efficiency commercial cell processes will appear in the next years. Some companies (BP Solar or Sanyo, for instance) are already on this path and have different processes leading to 17 to 18% cells in production. It is worth noting, that the ribbon technology is incompatible (see Chapter 7) with the ubiquitous screen-printing processing, so that a new processing, which may not be so cheap, is required to fabricate cells with this material.

An additional factor very seriously affecting the cell cost is the production yield. In the fabrication of any semiconductor device, not every unit introduced into the production