was extensively used by thick-film technology in hybrid circuits. The character of the industries being different, their requirements for equipment differ, and it is to be expected that substantial improvements of photovoltaics will take place, now that the business volume makes it attractive for equipment manufacturers to get involved in.

A modern fabrication line is capable of processing around 1000 wafers h^{-1}, that is, an operation in a cell takes 2 to 3 s. Of course, the slowest operation along the flow line will limit the overall throughput. In order to get an estimate of how this translates into yearly production, let us consider $10 \times 10\ cm^2$ cells with 15% efficiency (1.5 Wp power per cell). If the line operates without interruption and all wafers are successfully processed, during one year it will produce

$$1.5\ \text{Wp/cell} \times 1000\ \text{cells/h} \times 24\ \text{h/day} \times 365\ \text{days/year} \cong 13\ \text{MWp/year}$$

This number has to be decreased by (1) the downtime of the equipment due to maintenance, repair, and so on and (2) the yield, that is, the percentage of defective or broken wafers. Allowing for both would give a throughput in the range of 5 to 10 MWp/year per production line with available, commercial equipment.

Yield is a most important parameter for cell production: it can be defined as the ratio of successful finished cells to starting wafers. Since PV technology is material-intensive, yield has a strong influence on cost. Breakage and poor electrical performance are the causes of low yield, which is, generally speaking, benefited by automation. In this respect, in-line quality control acquires a great relevance to quickly detect and amend problems affecting yield.

For a given time per operation per cell, the throughput increases if the power of the cell increases. This is achieved by increasing the cell's area and the efficiency, which also helps in decreasing the cost. The standard wafer size is shifting from $10 \times 10\ cm^2$ to $12.5 \times 12.5\ cm^2$ and $15 \times 15\ cm^2$. Series resistance and the uniformity of the obtained layers (emitter, AR coating), that may compromise the electrical performance, become important issues. Besides, larger cells are more difficult to handle without breaking and the yield may be affected.

There is a lot of room for efficiency improvement of industrial solar cells and the processes to realize it are proved in the laboratory. The question is how to implement them in an industrial environment so that they are cost-effective.

7.5 VARIATIONS TO THE BASIC PROCESS

This section introduces some variations to the basic process described above that aims at improving the efficiency, the throughput or the cost. While some modifications are already in production, most of these improvements are still being developed at the laboratory.

7.5.1 Thin Wafers

Wafering and sheet-growth techniques improve and produce thinner substrates, with wafer thickness below 200 μm being envisaged for the near term [78]. When processing these thin cells, several relevant issues appear.