

the supercooling decreases owing to a nucleation of new grains on the substrate surface, which leads to a more columnar growth of the silicon sheet. Both crystallisation modes depend on the surface of the substrate and on the heating power controlled temperatures of the substrate and the melt. Numerical simulations allow investigating this crystal-growth tendency as well as the temperature field at the contact region of the ribbon on the substrate. In Figure 6.34 an example of the simulation of single silicon grain growth on the substrate is given [96]. In this way, numerical simulations can study the grain growth under various temperature conditions and grain-selection mechanisms of silicon crystals.

6.7 CONCLUSIONS

At the present time, the PV industry relies on solar cells made on crystalline silicon wafers, which provide around 90% of the total PV power installed. It is expected that monocrystalline and multicrystalline solar cells will continue dominating the industry for the next 10 years.

With rejects from the microelectronic industry as feedstock, the PV industry grows monocrystalline ingots by the Czochralski technique. Owing to more relaxed specifications than in microelectronics, the throughput of PV Cz pullers can be increased and still produce high-quality silicon, allowing the achievement of 15 to 17% efficient solar cells.

Tri-crystalline silicon (tri-Si) can be grown in standard production Cz growers using a quasi-continuous pulling with multiple recharging with high productivity and feedstock usage. Tri-Si allows slicing of ultra-thin wafers with higher mechanical yield than monocrystalline Si and obtaining solar cells of similar performance.

Multicrystalline Si can be manufactured at a lower cost than monocrystalline Si, but produces less efficient cells, mainly owing to the presence of dislocations and other crystal defects. With the introduction of new technologies, the gap between multicrystalline and monocrystalline solar cells is reducing.

Si ingots are sliced into thin wafers with multi-wire saws, with throughputs of about 500 to 700 wafers per day and per machine. Sawing is responsible for high material losses, and amounts to a substantial part of the wafer production cost. Understanding the microscopic processes of wire sawing allows optimising the technique and improving the sawing performance.

Silicon ribbon wafer/foil technologies have matured in the past decade to where they are serious contenders for competing on a scale equal to that of conventional silicon wafers. Several ribbon technologies have already demonstrated robust and reproducible processes, which have been scaled up to megawatt levels. The next round of expansion will probably reach the 50 to 100 MW factory size for individual technologies within 5 years. Factories of this scale will require considerable development of automated equipment and infrastructure in addition to continuous improvement on the basic process control and material quality. EFG and SF ribbon technologies are most notably in a position today to manufacture wafers on this scale and lead the anticipated growth of the photovoltaic industry.

During the last decade, computer power has been increasing strongly and there is a high progress in the modelling of physical phenomena and in the development of