secrets of Si technology. The silicon band gap, of 1.1 eV, is almost optimum to make a good solar converter, as explained in Chapters 3 and 4. The PV industry could utilize the preceding gains for their own application without having to re-create this scientific and technological infrastructure. In addition, Si is one of the most abundant minerals in the Earth's crust. Thus, there was no physical limitation to providing a huge fraction of the Earth's electricity needs with the known Si reserves.

However, for mechanical reasons (it is brittle), silicon requires relatively thick cells, with a typical wafer thickness of about 300 μm. Therefore, some of the electrons pumped by the photons to the conduction band have to travel large distances, on the order of the thickness, to be extracted by the front face through the selective contact to this band (the *pn* junction). Consequently, a good material with high chemical purity and structural perfection is required to fight the natural tendency of the conduction-band electrons to return to the valence band. This loss process is called *recombination*. To avoid this loss, the electrons must be highly mobile, as they are in perfect silicon. Impurities and imperfections must be avoided as they can absorb the extra energy of the conduction-band electrons and convert it into heat, thus eliminating the free electron from traveling through the circuit by immediately restoring it to the valence band energy. Producing heat, which is desirable in solar thermal panels, where this heat is transferred to a fluid, is undesirable in PV modules, where we try to recover the solar energy as electricity, of much higher value.

Metallurgical Grade (MG) Silicon is obtained by reduction of quartz with coke in an arc furnace. Then it is strongly purified by a method developed by and named after the Siemens Company consisting of the fractional distillation of chlorosilanes, which are obtained from the reaction of HCl with Si. Finally, silanes are reduced with hydrogen at high temperatures to produce hyperpure silicon, usually called *Semiconductor Grade* (SG) *Silicon* or just *polysilicon* (it is called *polysilicon* because it has many grains of crystalline Si, typically of about 1 mm).

The polysilicon now has the desired chemical purity (unwanted impurities below the parts per billion (ppb) level, or less than one impurity atom for every $10^{12}$ Si atoms, for some impurity atoms), but its structural quality is deficient. The structural quality is improved by melting the polysilicon ($>1400°C$) and "freezing" or allowing it to solidify very slowly around a rotating crystalline seed, usually by the Czochralski (Cz) method. In this way, a cylindrical single crystalline ingot is obtained of about 25 cm diameter and of 100 cm length. In this step, a very small number of atoms of boron are introduced in the melt to allow the appropriate metallic contacts deposited later to be selective to the valence-band electrons. This forms the *p*-type side of the *pn* junction.

The ingot is now cut in wafers with a saw. For this a very long wire (up to 500 Km) is wound many times on rotating drums cuts with slurry the silicon ingot into wafers. However, the process is slow and about half of the silicon is lost in the sawdust. The challenge here is to cut the wafers thinner so as to make more profit from the silicon. Wafers of 150 μm instead of the standard 300 μm are used in some companies. The techniques and challenges related to crystal growth and sawing are described in detail in Chapter 6.

The wafer is now etched slightly to remove the saw damage and to condition (texture) the surface for better light absorption. Then the conduction-band selective contacts