process, the melting is performed in a quartz crucible without a coating, whereas – after pouring the molten silicon into a second crucible – for the crystallisation also a Si_3N_4-coated one is used.

Usually, in both production technologies, crystallisation starts at the bottom of the crucible by lowering the temperature below the melting temperature (1410°C) of silicon. Within the Bridgman process the temperature reduction is achieved by simply descending the liquid silicon-containing crucible out of the hot area of the crystallisation furnace. Contrarily, the temperature control during the block-casting process is achieved by a corresponding adjustment of the heaters, whereas the crucible itself is not moved during solidification.

After solidification starts in the bottom region, the crystallisation front, that is, the liquid–solid interphase, moves in a vertical direction upwards through the crystallisation crucible. This so-called directional solidification results in a columnar crystal growth and consequently adjacent wafers fabricated out of the ingots show nearly identical defect structures (grain boundaries and dislocations).

Common crystallisation speeds used for the Bridgman technology are in a range of about 1 cm/h (corresponding to a weight of approximately 10 kg/h for large ingots). With regard to the increase in crystallisation speed, that is, productivity, mainly cooling of the already crystallised fraction of the ingot has to be taken into account. Too high process speeds cause large thermal gradients within the solidified silicon that may result in cracks or even destruction of the ingot. For the block-casting technology, however, owing to the more versatile and sophisticated heater system, considerably higher crystallisation speeds can be achieved [18].

6.3.2 Doping

Standard multicrystalline silicon is a boron-doped p-type material with a specific electrical resistivity of about 1 Ωcm, which corresponds to a boron concentration of about $2 \times 10^{16}/cm^3$. The specific resistivity is adjusted in a way such that optimal solar cell performance is guaranteed. Naturally, the boron concentration can be varied according to the requirements of specific solar cell processes. Specific resistivities in a range of 0.1 to 5 Ωcm have been used for solar cell fabrication so far. The boron concentration is normally adjusted by adding the equivalent amount of B_2O_3 to the silicon raw material prior to melting of the silicon. Considering alternative doping elements like gallium (p-type) or phosphorous (n-type) first, the segregation coefficient governing the resistivity decrease with increasing block height has to be considered. With a segregation coefficient of 0.8, boron nearly always is the optimal doping element giving only a small resistivity change over the silicon ingot (see Figure 6.8), whereas gallium and phosphorous with segregation coefficients of 0.008 and 0.35, respectively, are less favourable.

For phosphorous as an n-type dopant, additionally the disadvantage of a lower minority charge carrier (i.e. holes) mobility and a more complicated solar cell process using, for example, higher process temperatures for boron instead of phosphorous diffusion is encountered. However, recent results indicate that the activity of extended defects in n-type multicrystalline silicon is unexpectedly low, which could render n-type material nevertheless an attractive new feedstock source for photovoltaics.