(a) (b)

Figure 6.1 Cz pullers in a PV-production environment (a) and growing Cz crystal (b) in a quartz crucible

is pulled upwards to grow a "crystal neck". Since dislocations propagate on (111) planes that are oblique in an <100>-oriented crystal, the dislocations grow out of the crystal neck after a couple of centimetres so that the rest of the crystal grows dislocation-free even if the growth was started from a dislocated seed. The dislocation-free state of the grown crystal manifests itself in the development of "ridges" on the crystal surface. If this state is achieved, the diameter of the crystal can be enlarged by slower pulling until it reaches the desired value. The transition region from the seed node to the cylindrical part of the crystal has more or less the shape of a cone and is therefore called the "seed cone". This cone can be pulled differently, either flat or steep.

Shortly before the desired diameter is reached, the pulling velocity is raised to the specific value at which the crystal grows with the required diameter. Owing to the seed rotation, the crystal cross section is mostly circular. In general, the pulling velocity during the growth of the cylindrical part is not kept constant, but is reduced towards the bottom end of the crystal. This is mainly caused by the increasing heat radiation from the crucible wall as the melt level sinks. The heat removal of the crystallisation thus becomes more difficult and more time is needed to grow a certain length of the crystal. Standard pull speeds in the body range from 0.5 to 1.2 mm/min. The diameter of the crystal in PV is often chosen between 100 and 150 mm. This is due to the short-circuit current of big solar cells where values of 6 A per cell are exceeded. It is difficult to provide a proper contacting scheme in screen print technology that can handle such high currents in the front contacts without high series-resistance losses. With even larger cell sizes, this effect becomes more problematic.

To complete the crystal growth free of dislocations, the crystal diameter has to be reduced gradually to a small size, whereby an end cone develops. For this purpose, the pulling speed is raised and the crystal diameter is decreased. If the diameter is small enough, the crystal can be separated from the melt without a dislocation forming in the cylindrical part of the crystal. The withdrawal of the crystal from the residual melt can be done with a rather high velocity, but not too fast, because thermal shock would cause plastic deformation called "slip" in the lower part of the crystal. The final crystal length is dependent on the crucible charge and varies between 40 and 150 cm.