Semiconductor Technology from A to Z

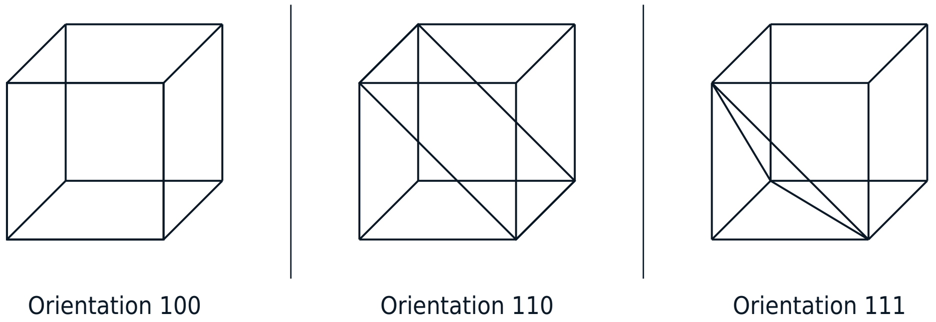
Wafer Fabrication

Fabrication of the single crystal

The Single Crystal

A single crystal (monocrystal), as required in semiconductor manufacturing, is a regular arrangement of atoms. In addition, there is polycrystalline silicon (composed of many small single-crystal grains) and amorphous silicon (disordered structure). Depending on the orientation of the lattice in space, silicon wafers exhibit different surface structures, which influence various device parameters, such as charge carrier mobility.

Crystal orientations



Chip manufacturing uses almost exclusively (100)-oriented silicon. The reason lies at the interface with the gate oxide: unsaturated bonds remain there after oxidation, and their number is lowest for this orientation. The (111) orientation has the densest arrangement of bonds and therefore the most defects; however, it oxidizes the fastest.

Crystal orientation is also of particular importance in micromechanics. For instance, microchannels with vertical walls can be produced on (110) silicon, whereas (100) orientation results in sidewall angles of 54.74°.

Czochralski Crystal Growing Process

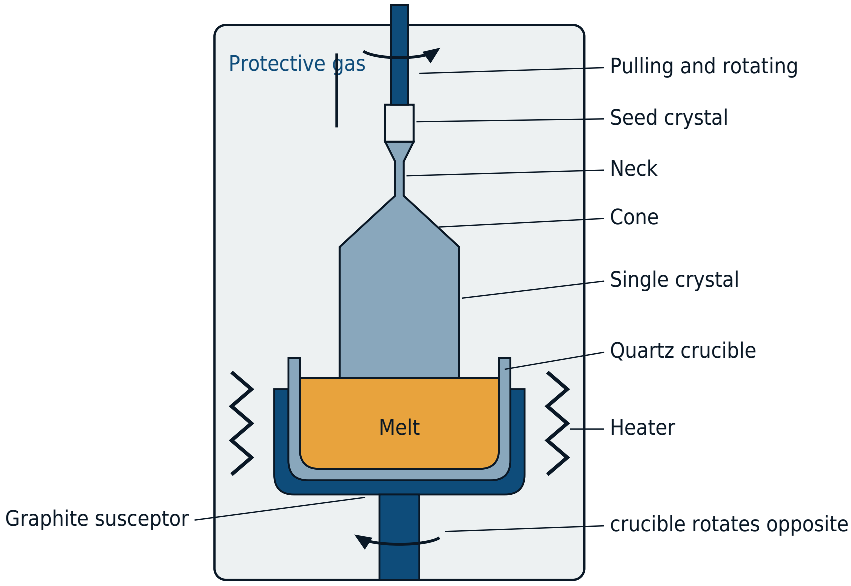
The polycrystalline silicon obtained after zone refining is melted in a quartz crucible just above the melting point of silicon. Dopants (e.g. boron or phosphorus) can now be added to the melt in order to achieve the desired electrical properties of the single crystal.

A seed crystal (a single crystal) mounted on a rotating rod is brought into contact with the surface of the silicon melt. This seed determines the orientation of the crystal. Upon contact between the seed and the melt, silicon deposits onto the seed and adopts its crystal structure. Because the crucible temperature is only slightly above the melting point of silicon, the deposited silicon solidifies immediately on the seed, and the crystal grows.

The seed is slowly pulled upward while being continuously rotated, maintaining constant contact with the melt. The crucible rotates in the opposite direction to the seed crystal. Constant temperature control of the melt is essential to ensure uniform growth. The diameter of the single crystal is determined by the pulling speed, which ranges from 2 to 25 cm/h. The faster the pulling speed, the thinner the crystal becomes. The entire apparatus is enclosed in a protective gas atmosphere to prevent oxidation of the silicon.

Czochralski Crystal Growth

The seed crystal sets the orientation of the crystal



Diameter is set via pulling speed and melt temperature.

A significant disadvantage of this process is that the melt becomes increasingly enriched with dopants during the process, since the dopants dissolve more readily in the melt than in the solid. As a result, the dopant concentration is not constant along the length of the silicon rod. In addition, impurities or metals can dissolve out of the crucible and become incorporated into the crystal lattice.

The advantages of this process are its low cost and the ability to produce larger wafers than is possible with the float-zone process (see below).

Crucible-Free Float-Zone Growing

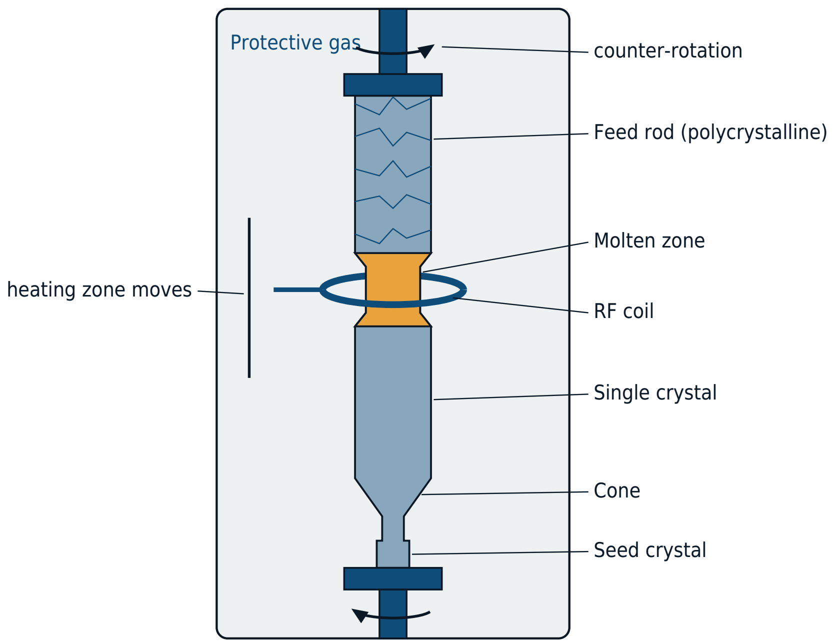
In contrast to the Czochralski crystal growing process, crucible-free float-zone growing does not melt the entire polysilicon rod; instead, as with zone refining, only a small region (a few millimetres) is melted.

Here too, a seed crystal, brought into contact with the end of the polycrystalline silicon rod, determines the crystal structure. The polycrystal is melted and adopts the structure of the seed. The heating zone is slowly moved along the rod, and the polycrystalline silicon rod gradually transforms into a single crystal.

Since only a small region of the polycrystalline silicon is melted, very few impurities can accumulate (as with zone refining, the foreign atoms migrate to the end of the silicon rod). Doping is achieved here by adding dopants (e.g. diborane or phosphine) to the protective gas that flows around the apparatus.

Float-Zone Process

Only a few millimeters of the rod are molten



No crucible means no contact with foreign material; doping is introduced via the protective gas.