Crystal Growth

Crystal Growth

Semiconductor wafers are cut from large crystals of the semiconducting material. These crystals, also called ***ingots***, are grown from chunks of the intrinsic material, which have a polycrystalline structure and are undoped. The process of converting the polycrystalline chunks to a large crystal of single-crystal structure, with the correct orientation and the proper amount of N- or P-type, is called ***crystal growing***.

Three different methods are used to grow crystals:

- 1. ***Czochralski***,
- 2. ***Float Zone,*** &
- 3. ***Liquid Encapsulated Czochralski***

Crystal Growth:
1. Czochralski (CZ) method

The majority of silicon crystals are grown by the CZ method (Fig. 3.8). The equipment consists of a quartz (silica) crucible that is heated by surrounding coils that carry radio frequency (RF) waves or by electric heaters.

The crucible is loaded with **chunks of polycrystalline** of the semiconductor material and small amounts of **dopant**. First, the poly and dopants are heated to the liquid state at 1415°C (Fig. 3.9).

Next, a seed crystal is positioned to just touch the surface of the liquid material (called the *melt*). The seed is a small crystal that has the same crystal orientation required in the finished crystal. Seeds can be

Czochralski (CZ) method....

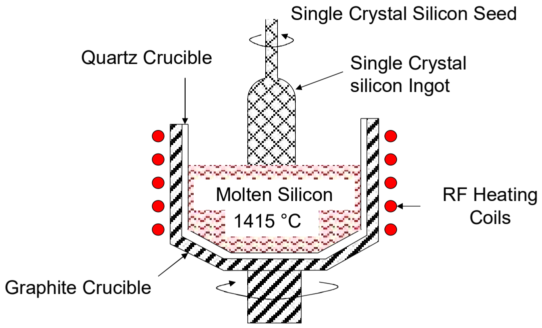
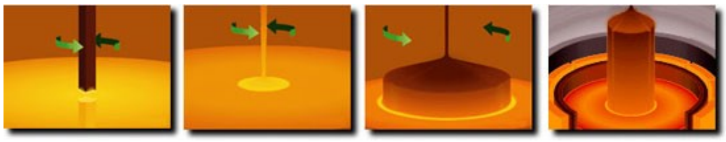


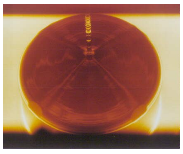
Figure 3.8 Czochralski crystal-growing system.

CZ Method.......

- Crystal growth starts as the seed is slowly raised above the melt. The surface tension between the seed and the melt causes a thin film of the melt to adhere to the seed and then to cool. During the cooling, the atoms in the melted semiconductor material orient themselves to the crystal structure of the seed.
- To achieve doping uniformity, crystal perfection, and diameter control, the seed and crucible (along with the pull rate) are rotated in opposite directions during the entire crystal-growing process.
- The CZ method is capable of producing crystals several feet in length and with diameters up to 12 or more inches.

CZ Crystal Pulling





Source:
http://www.fullman.com/semiconductors/_crystalgrowing.html

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2. Float zone technique

- A drawback to the CZ method is the inclusion of oxygen from the crucible into the crystal.
  - For some devices, higher levels of oxygen are intolerable. For these special cases, the crystal might be grown by the float zone technique, which produces a lower oxygen content crystal.
- This limits the resistivity to ~20Ωcm, while intrinsic Si is 230kΩcm.

Float-zone Technique: overview

- These crystals are more expensive and have very low oxygen and carbon.
- Carrier concentrations down to 10^{11} atoms/cm^3 is possible to achieve.
- It is far less common, and is reserved for situations where oxygen and carbon impurities cannot be tolerated.
- Float-zone does not allow as large Si wafers as CZ does (200mm and 300mm) and radial distribution of dopant in FZ wafer is not as uniform as in CZ wafer.
- It is good for solar cells, power electronic devices (thyristors and rectifiers) that use the entire volume of the wafer not just a thin surface layer, etc.

Float Zone (FZ)

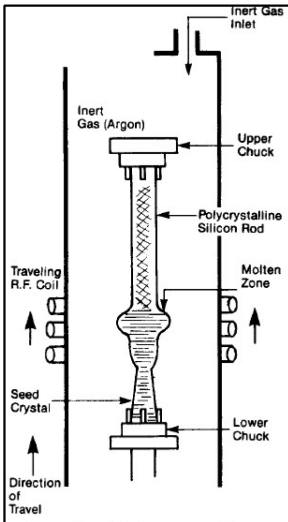
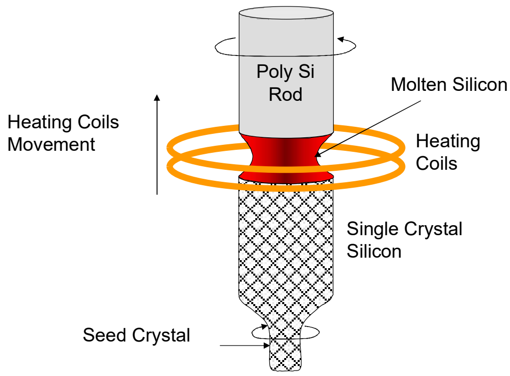


Figure 3.11 Float zone crystal-growing system.

* Float zone (FZ) crystal growth requires a bar of the polysilicon. The seed is fused to one end of the bar and the assemblage placed in the crystal grower.
* Crystal growing starts when an RF coil heats the interface region of the bar and seed.
* The coil is then moved along the axis of the bar, heating it to the liquid point a small section at a time.
* Within each molten region, the atoms align to the orientation started at the seed end.

Float Zone Method



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Comparison between CZ and FZ method

- CZ method is more popular
  - Cheaper
  - Larger wafer size (300 mm in production)
  - Reusable materials
- FZ method
  - Pure silicon crystal (no crucible)
  - More expensive, smaller wafer size (150 mm)
  - Mainly for power devices.

3. Liquid encapsulated Czochralski (LEC)

LEC crystal growing is used for the growing of gallium arsenide crystals. It is essentially the same as the standard CZ process but with a major ***modification*** for gallium arsenide.

The modification is required because of the evaporative property of the ***arsenic*** in the melt. At the crystal growing temperature, the ***gallium and arsenic*** react, and the arsenic can evaporate, resulting in a ***nonuniform*** crystal.

Two solutions to the problem are available.

- ***Pressurize*** the crystal growing chamber to suppress the evaporation of the arsenic.
- ***Use a layer of boron trioxide*** (B_2O_3) floating on top of the melt to suppress the arsenic evaporation.

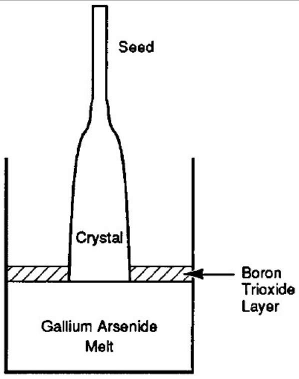

Figure 3.10 LEC system of crystal growth.

A seed crystal is then dipped, through the boron trioxide layer, into the melt & is rotated and slowly withdrawn and a single crystal propagates from the seed.

LEC…..

The pre-synthesised polycrystalline GaAs (or elemental Ga & As) are placed in the growth crucible along with a pellet of boron trioxide. The crucible is placed inside a **high pressure** crystal puller & heated up.

At 460°C the boron trioxide melts to form a thick, viscous liquid which coats the entire melt.

This layer, in combination with the pressure in the crystal puller, prevents sublimation of the volatile group V element

Crystal and Wafer Quality

- Semiconductor devices require a high degree of crystal perfection. But even with the most sophisticated techniques, a perfect crystal is unobtainable.
- The imperfections, called crystal defects cause an uneven silicon dioxide film growth, poor epitaxial film deposition, uneven doping layers in the wafer, and other problems.
- In finished devices, the crystal defects cause unwanted current leakage and may prevent the devices from operating at required voltages.

There are three major categories of crystal defects:

- 1. Point defects
- 2. Dislocations
- 3. Growth defects