Ch intro

2.1 SILICON MANUFACTURE

In this chapter we will consider only silicon-based (Si) technologies. Although other

compound materials in groups III through V, such as gallium arsenide (GaAs) and aluminum

gallium nitride (AlGaN), are also used to implement VLSI chips, silicon is still the most

popular material, with excellent cost–performance trade-off. The mineral quartz consists entirely of silicon dioxide, also known as silica. Ordinary sand is chiefly composed of tiny grains of quartz and is therefor also silica.

Despite the abundance of its compounds, elemental silicon doesn't occur naturally. The element can be artificially produced by heating silica and carbon on an electric furnace. The carbon unites with the oxygen contained in the silica, leaving more-or-less pure molten silicon. As this cools, numerous minute crystals form and grow together into a fine-grained gray solid. This form of silicon is said to be poly-crystalline because it contains a multitude of crystals. Impurities and a disordered crystal structure make this metallurgical-grade polysilicon unsuited for semiconductor manufacture.

Metallurgical-grade silicon can be further refined to produce an extremely pure semiconductor-grade material. Purification begins with the conversion of the crude silicon into a violent compound, usually trichlorosilane. After repeated distillation, the extremely pure trichlorosilane is reduced to elemental silicon using hydrogen gas. The final product is exceptionally pure, but still poly-crystalline. Practical integrated circuits can only be fabricated from single-crystal material, so that the next step consists of growing a suitable crystal.

2.1.1 Crystal Growth

The principles of crystal growing are simple and familiar. Suppose a few crystals of sugar are added to a saturated solution that subsequently evaporates. The sugar crystals serves as seeds for the deposition of additional sugar molecules. Eventually the crystals grow to be very large. Crystal growth would occur even in the absence of a seed, but the product would consist of a welter of small intergrown crystals. The use of a seed allows the growth of larger, more perfect crystals by suppressing undesired nucleation sites.

In principle, silicon crystals can be grown in much the same manner as sugar crystals. In practice, no suitable solvent exists for silicon, and the crystals must be grown from the molten element at temperatures in excess of 1400°C. the resulting crystals are at least a meter in length and ten centimeters in diameter, and they must have a nearly perfect crystal structure to be useful to the semiconductor industry. These requirements make the process technically challenging.

The usual method for growing semiconductor-grade silicon crystal is called Czochralski process. This process, illustrated in figure 2.1, use a silica crucible charged with pieces of semi-grade polycrystalline silicon. An elective furnace raises the temperature of the crucible until all the silicon melts. The temperature is then reduced slightly and a small seed crystal is lowered into the crucible. Controlled cooling of the melt causes layers of silicon atoms to deposit upon the seed crystal. The rod holding the seed slowly rises so that only the lower portion of the growing crystal remains in contact with the molten silicon. In this manner, a large silicon crystal can be pulled centimeter-by-centimeter from the melt. The shaft holding the crystal rotates slowly to ensure uniform growth. The high surface tension of molten silicon distorts the crystal into a cylindrical rod rather than expected faceted prism.

Figure 2.1

The czochralski process requires careful control to provide crystals of the desired purity and dimensions. Automated systems regulate the temperature of the melt and the rate of crystal growth. A small amount of doped polysilicon added to the melt sets the doping concentration in the crystals. In addition to the deliberately introduced impurities, oxygen from the silica crucible and carbon from the heating elements dissolve in the molten silicon and become incorporated into the growing crystal. These impurities subtly influence the electrical properities of the resulting silicon. Once the crystal has reached its final dimensions, it is lifted from the melt and is allowed to slowly cool to room temperature. The resulting cylinder of monocrystalline silicon is called an ingot.

Since integrated circuits are formed upon the surface of a silicon crystal and penetrate this surface to no great depth, the ingot is customarily sliced into numerous thin circular sections called wafers. That are 400μm to 600μm thick. Each wafer yields hundreds or even thousands of integrated circuits. The larger the wafer, the more integrated circuits it holds and the grater the resulting economies of scale.

2.2

**Deposition** • Chemical-vapor deposition (CVD)  
 • Low-pressure chemical-vapor deposition  
 • Plasma-assisted chemical-vapor deposition  
 • Sputter deposition  
 • Materials deposited  
 – Silicon nitride (Si3N4)  
 – Silicon dioxide (SiO2)  
 – Aluminum  
 – Polysilicon

**Chemical Vapor Deposition**  
 Chemical vapor deposition (CVD) is a process by which gases or vapors are chemically  
reacted, leading to the formation of solids on a substrate. CVD can be used to deposit various  
materials on a silicon substrate including SiO2, Si3N4, polysilicon, and so on. For instance, if  
silane gas and oxygen are allowed to react above a silicon substrate, the end product, silicon  
dioxide, will be deposited as a solid film on the silicon wafer surface. The properties of the  
CVD oxide layer are not as good as those of a thermally grown oxide, but they are sufficient  
to allow the layer to act as an electrical insulator. The advantage of a CVD layer is that the  
oxide deposits at a faster rate and a lower temperature (below 500°C).  
If silane gas alone is used, then a silicon layer will be deposited on the wafer. If the  
reaction temperature is high enough (above 1000°C), the layer deposited will be a crystalline  
layer (assuming that there is an exposed crystalline silicon substrate). Such a layer is called  
an epitaxial layer, and the deposition process is referred to as epitaxy instead of CVD. At  
lower temperatures, or if the substrate surface is not single-crystal silicon, the atoms will not  
be able to aligned along the same crystalline direction. Such a layer is called polycrystalline

**Resourses:**

* [[Semiconductor Glossary] Deposition | Samsung Semiconductor USA](https://semiconductor.samsung.com/us/support/tools-resources/dictionary/semiconductor-glossary-deposition/#:~:text=%5BDeposition%5D%20A%20semiconductor%20fabrication%20process%20wherein%20a%20thin,of%20a%20wafer%2C%20giving%20the%20wafer%20electrical%20characteristics.)