

QUICK QUESTION 4.1

A plastic, helium-filled balloon, with no flaws that would cause leakage, will fairly soon lose its helium and deflate. Explain this in terms of the concepts discussed above. *Hint:* Helium forms one of the smallest possible molecules. Oxygen molecules are much larger. Would an oxygen-filled balloon deflate faster or slower than a helium-filled balloon?

REAL-WORLD EXAMPLE 4.1: GROWING SILICON CRYSTALS FOR COMPUTER CHIPS

A nearly perfect silicon (Si) crystal is needed to begin the making of the electronic circuit in a computer chip. These are called integrated circuits, or ICs. Crystals for making ICs are grown by a natural process in which atoms find their way from a liquid onto the surface of a crystal, which constantly increases in size. You might be familiar with crystal growth from grade-school days, where a common experiment is to grow sugar crystals from a highly concentrated solution of sugar in water. A string is placed into the solution and small crystals grow onto the surface of the string. To make ICs, we need to grow large Si crystals, up to 16 inches in diameter. The surface of a crystal of this size can hold hundreds of ICs, which are then separated by cutting the crystal.

The common method to grow large, pure Si crystals is to start with clean sand (silicon dioxide, SiO_2). The sand is purified by chemical reactions and then melted at a high temperature in a furnace to produce a liquid of SiO_2 that is pure to a few parts per billion. A large crystal is grown from this hot liquid by starting from a small Si crystal, called a seed crystal. This seed is grown by other techniques. As in **Figure 4.6**, the seed is lowered into the melted SiO_2 , and the seed begins to grow larger by the growth of new material onto its surface. The atoms that attach themselves to the seed crystal do so in a way that maintains the perfect regularity of the seed crystal structure. As the seed crystal grows larger, it is slowly pulled away from the liquid SiO_2 , while still maintaining contact. A typical growth rate is a few millimeters per minute. This leads to a long, cylinder-shaped Si crystal. This method of “pulling” a crystal is called the Czochralski method, after its inventor, Jan Czochralski, a Polish chemist, discovered the method in 1916 when he accidentally dipped his pen into a crucible of molten tin rather than his inkwell. He pulled his pen out to discover that a thin thread of solidified metal was hanging from it.

After the crystal is grown and cooled, a diamond saw is used to slice it into thin wafers 0.5 to 0.7 mm thick. Each wafer surface is then polished to be extremely flat and smooth, as shown in **Figure 4.7**.

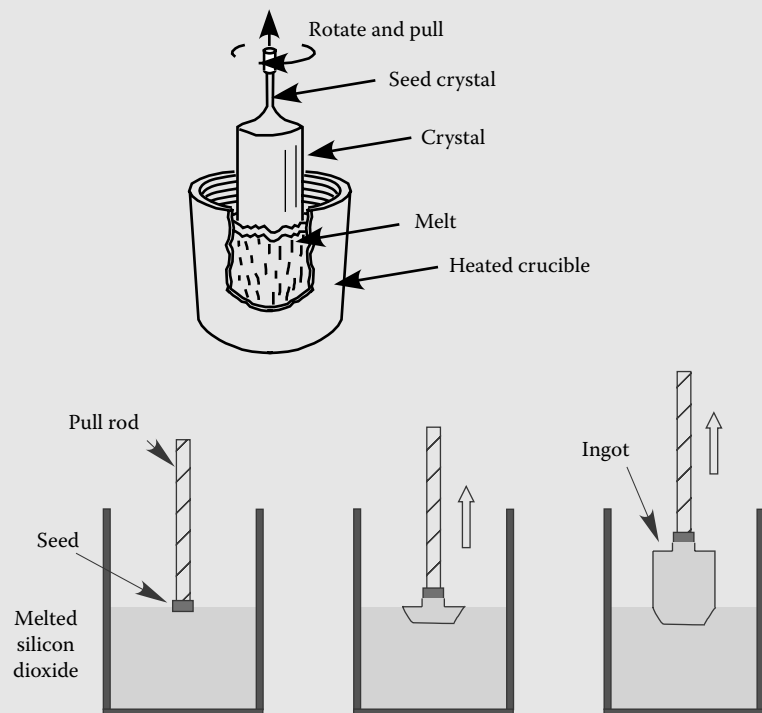


FIGURE 4.6 The method for growing silicon crystals.



FIGURE 4.7 Silicon crystals (ingots), and wafers sliced from an ingot and polished. (Courtesy of SUMCO Corporation, Japan.)

4.4 PRESSURE IN A GAS

If you are in a very tall elevator that begins to descend rapidly, sometimes your ears will “pop,” or even feel pain. This happens because the air pressure changes with altitude. What, precisely, is *pressure*?

Pressure is the steady net force exerted on a single surface by a gas, liquid, or solid, divided by the area of the surface. As an equation:

$$\text{pressure} = \frac{\text{net force}}{\text{area}}, \quad \text{or} \quad p = \frac{F_{NET}}{A}$$

Net force means the total *force* exerted by all of the atoms or molecules striking just one side of an object. **Figure 4.8** shows the eardrum, with surface area equal to A (about 10 mm^2). When the molecules in the air (primarily oxygen and nitrogen) impinge on the eardrum, each momentarily exerts a force on its surface. The number of atoms that hit the eardrum’s surface each second is a very large number, far greater than can be illustrated in the figure. As many molecules bounce from the surface, a nearly steady force is exerted on it. This means that any gas, liquid, or solid exerts a pressure on a surface that it contacts. Pressure is force per unit area.

The units of pressure are newtons (N) per square meter (m^2). That is,

$$\text{pressure} = \frac{\text{net force}}{\text{area}} = \frac{\text{newtons}}{\text{square meter}} = \frac{\text{N}}{\text{m}^2}$$

A force of 1 newton acting on an area of 1 square meter creates a pressure that is called 1 pascal, which is given the symbol Pa. That is,

$$1 \text{ Pa} = 1 \text{ N/m}^2$$