20.3: Applications of Diffusion

Diffusion is a key process in much of materials science. We will examine some applications more closely here:

Carburisation

Carburisation is the process by which carbon is diffused into the surface of steel in order to increase its hardness. The carbon forms carbide precipitates (particularly if the steel contains carbide forming elements such as manganese or molybdenum) which pin dislocations and prevent slip, thus making the material harder. However, the increased carbon content reduces the toughness of the material. In most applications it is important that the surface of the steel is hard, but the bulk material can remain softer without detriment to the properties of the component. Thus, carbon is often diffused in from the outer surfaces to obtain a material that is hard on the surface but tough in the bulk.

A carburised steel, showing increased carbon content on the outer surface See Micrograph No 289
This is done by heating the steel in a carbon atmosphere, so that there is a concentration gradient of carbon across the interface. Carbon diffuses into the steel, and the elevated temperature speeds up the process. The concentration profile of carbon is governed by Fick’s second law, as there is effectively an infinite source of carbon.

Nuclear Waste

In this case diffusion causes a problem that needs to be solved. Radioactive waste from nuclear energy production must be stored in such a way that the radioactive atoms do not diffuse out of the container until the radioactivity levels have sufficiently dropped. This can be a very long time indeed: often around 1000 years. Thus, the container must be made of a material in which the diffusivity of the atoms is very low (and the container must be very thick, to increase the diffusion distance). This will ensure that the time taken for atoms to diffuse out of the container is as long as possible.

Generally, the radioactive atoms are suspended in a glass matrix, such as borosilicate glass. The diffusivity of the atoms in this glass is low, thus the atoms are less likely to diffuse out of the glass before they have ceased to be radioactive. The glass is then sealed inside steel containers and buried deep in the ground under rocks, in remote areas away from populated regions.

Semiconductors

Semiconductors can be made by doping one material (often silicon) with a small number of atoms of another material of a different valency. This is known as doping, and means that there is an excess of charge carriers in the material (electrons if the valency of the dopant is greater than that of the silicon, or holes if it is less). For more details on this see the TLP on semiconductors.

The doping is often carried out by diffusion methods: the silicon is placed in a gas of the dopant atoms and heated to high temperatures. The dopant atoms diffuse down the chemical potential gradient into the silicon. As with carburisation, this process follows Fick’s second law.

In practice, the diffusion process occurs in two steps. After the initial diffusion described above, the atoms will be concentrated mainly on the surface of the silicon. The sample must therefore be annealed in order to “drive in” the atoms, so that they penetrate beyond the surface.