Semiconductors Explained for the RAE

The word 'semiconductor' is used in two ways: to denote **materials** (such as germanium and silicon) that have properties intermediate between those of conductors and insulators; and to denote **electronic devices** (such as transistors and integrated circuits) that use specially treated pieces of semiconductor material.

Although this duality of meaning is technically wrong (the first meaning is the only correct one), it is so widespread that even well-respected amateur radio magazines call the transistors, ICs, etc, needed for projects 'semiconductors'. Fortunately, in the vast majority of cases, which meaning is intended by 'semiconductor' is absolutely obvious from the context in which the word is used.

The RAE examination contains some questions on semiconductors – so here's a tutorial on them from Shirley Hesketh, G4HES. But old Gs need not turn the page – this would also be a good opportunity for a little brushing up on the subject!

Semiconductor materials are crystaline – that is to say, they are made up of regular arrays of atoms all tightly bonded to their immediate neighbours (see **Fig. 3**). If you think of a box tightly packed with, for example, cricket balls, you can get some idea of the evenness of atomic structure.

The bonding between atoms in a crystal is through their valence electrons; as is shown in **Figs 1** and **2**, silicon and germanium each have four electrons in their outer, valence shell, and in their crystals each will have four nearest neighbours with which it will be sharing two electrons (one from each atom).

Figure 3 is very much a diagramatisation of this bonding, as the structure involved is three-dimensional, not two-dimensional. However, there is one important point which this diagram does show, and that is that the two electrons in each bond are pair-bonded to each other. This means that quite a lot of energy is required to remove an electron from a bond.

Thermal Excitation

In any crystal, there will be thermal vibrations, and these vibrations are grouped in packets called phonons that have a certain amount of energy associated with them. The average energy of all the packets of energy depends on the absolute temperature of the crystal, but within the average, there is quite a spread. At normal 'room temperature' a few – but only a very small few – have enough energy to break the bonding of the valence electrons, knocking an electron free to move about the crystal (at higher temperatures, there will be more energetic phonons).

The result of this is that silicon and germanium have a small conductivity at room temperature; in the case of silicon, the conductivity is so small that it can usually be regarded as zero (ie, infinite resistance). Germanium is a much bigger atom and the valence electrons are consequently that much further away from the nucleus, so a lower energy is needed to liberate valence electrons. This results in a slightly larger conductivity, particularly at higher temperatures, which is one of the reasons why germanium is falling out of favour as a material for making semiconducting devices with!

Note that light also travels around in packets of energy (photons) and these generally have much more energy than phonons; as a result, semiconductors can be used as detectors for light (visible, infra-red and ultra violet).

Holes

When an electron is removed from its bond, by a phonon or a photon, the parent atom is left with a gap or **hole**, and hence a net positive electrical charge. There is already a certain amount of ambiguity about which of the two atoms involved in the now-broken bond 'owned' the electron – in fact, it is an important physical principle that all electrons are indistinguishable from one another – so the hole could belong to either atom. Additionally, with a little en-

Fig. 1 The atomic structure of silicon; note that this representation is highly diagramatic; the current picture of the atomic structure of atoms is that the electrons *all* have different 'orbits', which are not in fact orbits at all but probability fields; however, the diagram shown is rather easier to cope with, and shows the essential point, namely that there are four electrons on the outside.