Topic: Semiconductors

Synthesising information from different sources

- **Using information from all excerpts, write a paragraph of not more than 170 words (not less than 150 and not more than 190) discussing the properties and types of semiconductors.**

Remember that you need to:

- **Use information from all sources.**
- **Cite your sources appropriately.**
- **Use your own words! You must not plagiarise!**

Excerpt 1

Characteristic properties of metals include: (1) electrical conductivity, (2) opaqueness and (3) malleability. A very simple model in which the metallic crystal is viewed as a lattice of positive ions surrounded by a "gas" of free electrons provides a crude understanding of the first and third properties. If the crystal has a gas of free electrons, it is easy to see why the application of an electric field will result in the motion of these electrons and thus for the high electrical conductivity. This model also allows one to explain the malleability of metals, as shown in fig. 1b. When a metallic crystal is subject to forces that displace one plane of atoms with respect to another, the environment of the charged species is left unchanged. In contrast, the displacement of neighboring planes in an ionic crystal as a result of a distorting force will lead to cleavage, largely because of changes in the interaction of the charged species…

From the large electrical conductivity of metals, it appears that at least some of the electrons can move freely through the bulk of the metal. Since even lithium with only one valence electron has eight nearest neighbors (crystallizes in a body-centered cubic lattice), it is clear that the atoms cannot be bonded to each other by localized electron-pair bonds (for in that case the lithium atom, which altogether has only three electrons, would have to supply eight or even fourteen valence electrons to establish bonding with the nearest and next-to-nearest neighbor atoms). [1, pp. 2-3]

Excerpt 2

The beginnings of modern electronics lay in the control of current rectification by the cathode-ray diode. However, the cathode-ray tube did not provide the first case in which rectification was observed. It was seen independently by Braun (1874) and by Schuster (1874). Braun conducted experiments in which a crystal such as ferrous sulfide was contacted with a very thin wire, and the resistance was measured as a function of the direction in which current was flowing. Such point junctions do rectify current, although the effect is quite small and had no immediate practical consequences…

Semiconductors are bad insulators. At zero temperature all electrons lie within completely filled valence bands separated from conduction bands by an energy gap of magnitude *Eg.* Because thermal excitation provides exponentially growing numbers of mobile charge carriers, the electrical conductivity of semiconductors grows exponentially with temperature, in contrast with metals where scattering generally reduces conductivity as temperature goes up. As the band gap *Eg* sinks below 1eV, thermal excitation becomes a sufficiently important source of carriers that the semiconductors conduct at room temperature. More important is the fact that the electrical properties of semiconductors are enormously sensitive to the presence of certain types of impurities, which make their presence felt even at concentrations on the order of one part in 10^{10}. Before the role of impurities was understood, semiconductors seemed capricious and unreliable. Now that they are not only understood but can be controlled, the impurities are employed to give semiconductors tremendously interesting and variable electrical transport properties, with which the electronics industry has developed and grown for over four decades. [2, pp. 574-76]

Excerpt 3

A semiconductor, such as silicon or germanium, is a material that has an electrical conductivity intermediate between that of a metal and that of an insulator. To understand the electrical properties of semiconductors, let's look first at the bonding in insulators. Take diamond, for example, a covalent network solid in which each C atom is bonded tetrahedrally to four other C atoms. In a localized description of the bonding, C - C electron-pair bonds result from the overlap of sp^3 hybrid orbitals. In a delocalized description, the 2*s* and the 2*p* valence orbitals of all the C atoms combine to give bands of bonding and antibonding MOs—a total of four MOs per C atom. As is generally the case for insulators, the bonding MOs, called the valence band, and the higher-energy antibonding MOs, called the conduction band, are separated in energy by a large band gap. The band gap in diamond is about 520 kJ/mol.

The conductivity of a semiconductor can be greatly increased by adding small (ppm) amounts of certain impurities, a process called doping. Consider, for example, the addition of a group 5A element such as phosphorus to a group 4A semiconductor such as silicon. Like diamond, silicon has a structure in which each Si atom is surrounded tetrahedrally by four others. The added P atoms occupy normal Si positions in the structure, but each P atom has five valence electrons and therefore introduces an extra electron not needed for bonding. [3, pp. 864-66]

Excerpt 4

Intrinsic semiconductors

In the macromolecular structures of diamond, silicon, germanium and α-tin, each atom is tetrahedrally sited. An atom of each element provides four valence orbitals and four valence electrons, and, in the bulk element, this leads to the formation of a fully occupied band and an unoccupied band lying at higher energy.

Each of Si, Ge and α-Sn is classed as an *intrinsic semiconductor*, the extent of occupation of the upper band increasing with increasing temperature. Electrons present in the upper *conduction* band act as charge carriers and result in the semiconductor being able to conduct electricity. Additionally, the removal of electrons from the lower *valence* band creates *positive holes* into which electrons can move, again leading to the ability to conduct charge. [4, p. 161].

Extrinsic (n- and p-type) semiconductors

The semiconducting properties of Si and Ge can be enhanced by *doping* these elements with atoms of a group 13 or group 15 element. Doping involves the introduction of only a minutely small proportion of dopant atoms, less than 1 in 106, and extremely pure Si or Ge must first be produced. The reduction of SiO2 in an electric furnace gives Si, and the Czochralski process is used to draw single crystals of Si from the melt. [4, p. 161]

The number of electrons in the conduction band of the doped silicon is much greater than the number in pure silicon, and the conductivity of the doped semiconductor is therefore correspondingly higher. When just one of every one million Si atoms is replaced by P, the number of electrons in the conduction band increases from ~*1010/cm3* to ~*1017/cm*3 and the conductivity increases by a factor of ~*107*. Because the charge carriers are electrons, which are *negatively* charged, the silicon doped with a group VIIA element is called an *n*-type semiconductor. [4, pp. 7-9]

References

[1] D. Sadoway, Class lecture 3, "Bonding in metals, semiconductors and insulators – band structure", Massachusetts Institute of Technology, Massachusetts, Fall 2010.
[2] M. P. Marder, *Condensed Matter Physics* (2nd ed.). Hoboken, New Jersey: John Wiley, 2010.
[3] J. E. McMurry & R. C. Fay, *Chemistry*, (6th ed.). Prentice Hall: Upper Saddle River, New Jersey, 2011.
[4] C. A. Housecroft & A. G. Sharpe, *Inorganic Chemistry*, (3rd ed.). Prentice Hall: Upper Saddle River, New Jersey, 2007.