Diamonds out-sparkle silicon

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There is a gold rush on to master the use of diamond in the microchip industry. While De Beers makes evasive moves to protect its market for the ‘natural’ diamond, it is the synthetic, single crystal diamond wafers that may be the greater prize.

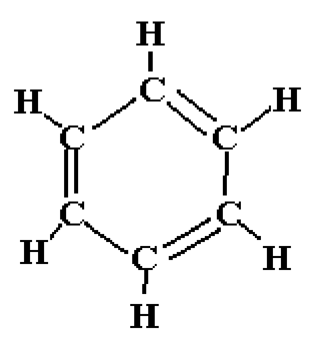
The silicon revolution, with transistors, integrated circuits and the Pentium chip seems to be reaching a plateau, as higher demands on computers drive higher currents through electronic components. Silicon, with its low thermal conductivity and melting point seems to be reaching the limit of how hot it can get. Diamond, which is the best-known conductor of heat and also withstands scorching temperatures, could be the glittering platform to launch a new age of computing.

Atomic structure

Diamond, which is a form of carbon, and silicon have similarities in atomic structure that makes them candidates to steal each other’s roles. The similarity is in the ‘outer shell’ electrons of the atoms. All atoms consist of a positively charged core, surrounded by a cloud of tiny, negatively charged electrons, distributed in concentric shells. A rule in atomic structure is that the first shell can have no more than 2 electrons and the last shell can have no more than 8 electrons. In the last shell, in fact, the best condition is when there are all of 8 electrons. Atoms thus like to combine, so that they exchange or ‘share’ electrons, to come down or rise as close to an ‘octet’ as they can.

For instance, the calcium atom has 2 outer shell electrons and oxygen has six. Hence, in calcium oxide, the calcium atom gives up its two ‘extra’ electrons, to be left with a ‘complete’ outer shell, while oxygen ‘borrows’ 2 electrons to complete its own outer shell.

In the case of carbon, the atom has 4 electrons in the outer shell and is located ‘half way’. It can thus both give up 4 electrons and also accept 4 electrons. Or even ‘share’ electrons with 2 or 4 atoms of carbon, hydrogen, oxygen, nitrogen, etc., or even combinations of atoms, and so on. This 4-way combining property enables carbon to be the base of an assortment of ‘organic’ chemicals, plastics, polymers, the material of living tissue, even of genes and the bases of life itself.

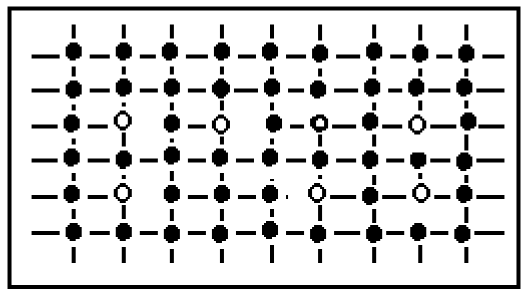


a complex carbon compound

Silicon's answer

Another atom that has 4 outer shell electrons is Silicon, an element of great abundance as silica, or common sand. It is found that crystals of silicon, with this 4-electron property, form a regular lattice of atoms, each atom 'holding hands', as it were, with four others. Silicon crystals are also found exhibit useful electrical properties.

The interesting property is when the material of the crystal is 'doped' with an impurity of atoms that have 3 or 5 outer shell electrons. These atoms occupy places in the lattice, but because they form 3 or 5 bonds, they either leave 'holes', which are the lack of an electron, or give rise to loosely bound, 'extra', fifth electrons. These result in the silicon crystal suddenly becoming a conductor of electricity, through the passing, from atom to atom, of either 'holes' or the 'free' electrons.



Holes in the lattice

If a crystal with 'holes' and a crystal with extra electrons are brought together, electrons form the second crystal rush to fill the 'holes' in the first. Some electrons do cross over and create a thin region of 'neutralised' holes, which prevents this process from continuing. But the reverse cannot happen, as there is no way that 'holes' on one side can cross over to the other side. The junction of the two crystals thus behaves as a 'one-way' street for electric currents. Applying a small voltage to the junction, to 'drain' or 'push back' electrons now controls the motion of currents through the junction, and this is the basis of diodes, transistors, integrated circuits and the whole electronics revolution!

Silicon based life?

Apart from this use in electronics, the 4-way structure of silicon also suggests the possibility of silicon combining with hydrogen, sulphur, nitrogen, just like carbon. The possibility is there, in principle and in fact there is a whole family of 'silicones', silicon-based chemicals, with structures like organic chemicals and with remarkable properties. A disconcerting thought is that if there were 'organic'-type chemicals based on silicon then there could be life based on silicon too. If such a life form should invade the earth, it would find abundant food in the expanse of silica, in the form of sand in deserts and in the sea. Our familiar, carbon based life may be wiped out!

The reason that this has not happened may be largely thanks to the fact that the chemicals in life forms need an extent of mobility that calls for the materials to be in the liquid state. For silicon, this would need high temperatures, at which the delicate molecular forms, for cells and genetic material, cannot exist. There is also the difficulty of silicon-based life having to dispose of waste, not as carbon dioxide gas, but as silicon dioxide, which is hard, rock ysand!

Now its carbon's turn

Conversely, it is the same property of not being rigid at higher temperatures that has kept carbon away from being a candidate for semiconductors and electronics. Except that in diamond, a crystalline form of carbon, this difficulty is not there at all. The problem is that diamonds are rare and the synthetic kind, manufactured by subjecting graphite to very high pressures, creates small diamonds, not a wafers of single crystals..

All this has been altered with recent developments where diamond wafers are being grown by spraying a plasma, or a disintegrated vapour of carbon-rich methane molecules, over a bed of ordinary industrial diamonds. Given the right conditions, the sprayed carbon atoms link to form a firm, high quality diamond film.

Diamond itself, like silicon, is not a conductor if electricity, but methods have been found to slip in 'dopants' of boron or nitrogen, to make the diamond a 'semi'-conductor, like doped silicon. Boron has 5 outer shell electrons, while nitrogen has 3. Both kinds of semiconductors, the kind with 'holes' as well as the kind with 'free' electrons, are thus possible, and thus the gamut of possibilities.

The diamond film technology has reached some perfection with Robert Linares of Spectrum Technology bagging a patent last June. His company was a pioneer in semiconductor technology and has the credit of developing the gallium arsenide chip that is used in cell phones. Jan Isberg and others of the ABB Group Services Center in Västerås, Sweden, have also developed the technique. Japan is said to be investing a billion dollars in research and Intel, the silicon giant, may need to take the plunge too.