Silicon: Child and Progenitor of Revolution

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Antoine Lavoisier, the pioneering French chemist who (together with Joseph Priestley in England) identified oxygen as an element and gave it its name, in 1789 concluded that quartz was probably a compound with an as-yet undiscovered but presumably extremely common element. That was also the year in which the French Revolution broke out. Five years later, the Jacobins accused Lavoisier of offences against the people and cut off his head, thereby nearly cutting off the new chemistry. It was not until 1824 that Jöns Berzelius in Sweden succeeded in confirming Lavoisier’s speculation by isolating silicon. Argument at once broke out among the scientific elite as to whether the newly found element was a metal or an insulator. It took more than a century to settle that disagreement decisively: As so often, when all-or-nothing alternatives are fiercely argued, the truth turned out to be neither all nor nothing.

Silicon and oxygen are in fact the most abundant elements in the earth’s crust and are also very common in our galaxy. Why in particular is silicon so common? Our modern understanding of nucleosynthesis got under way at about the same time as the invention of the transistor. The great British astronomer Fred Hoyle in 1946 [1] took the first steps in working out how hydrogen first fused to generate helium and how multiple helium nuclei might then fuse to produce carbon, which in turn would fuse with more helium nuclei to progressively generate heavier elements (all of which astronomers simply call ‘metals’). An apparently insoluble energy barrier turned up against the combination of beryllium and helium to generate carbon; Hoyle proposed a possible way around this roadblock and in one of the great triumphs of modern astronomy he combined with several American colleagues to prove in detail that this escape route was indeed correct [2]. The synthesis of elements up to silicon and iron proceed in the interior of stars at temperatures exceeding $10^9$ K. Further nucleosynthesis, of heavier elements, mostly takes place in supernovas which are even hotter. Silicon is one of the stablest elements against both fusion and fission, which is very appropriate for an element that has proved so crucial for humanity.

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is in fact often used by astronomers as a reference standard when they estimate the cosmic abundances of different elements.

Nucleosynthesis is today sometimes utilised for the improvement of semiconducting devices. The minority silicon isotope $^{30}{\text{Si}}$ can be transmuted into $^{31}{\text{P}}$ by bombardment at ambient temperature with thermal neutrons. This was first discovered by Lark-Horowitz in 1951 [3] and later applied to practical devices requiring extremely uniform phosphorus doping; the recent history of this approach, with its benefits and drawbacks, is set out by Wilkes [4].

Towards the end of the nineteenth century, silicon found a growing role as an alloying element for iron. The British metallurgist Robert Hadfield discovered some interesting properties in iron–silicon alloys with a few mass per cent of silicon and very little carbon. Systematic experiments at the end of the century by William Barrett in Dublin, Ireland, culminated in the single-phase iron–silicon alloys that for more than a century have been used for transformer laminations, saving significant money because transformers made with this alloy had very low core losses. The American metallurgist T.D. Yensen (who later introduced the use of vacuum melting for these alloys) estimated as early as 1921 [5] that in the first 15 years of silicon–iron, the use of this alloy family had returned savings in electrical power generation and transmission sufficient to finance the building of the Panama Canal – and this was before the mastery of crystallographic textures further improved the performance of silicon–iron transformer laminations. This early use of silicon thus foreshadowed the extraordinary financial savings and untold applications resulting from the introduction of transistors and integrated circuits, half a century later. A detailed account of the development of silicon-iron was written by J.L. Walter of the GE (Central) Research Laboratory [6].

The electrical uses of silicon began hesitatingly. Crystal rectification, making use of cat’s whisker counter-electrodes, developed into early detectors for wireless telegraphy, and coarse-grained silicon of merely “metallurgical-grade purity” (99%) was used until World War I when vacuum tubes began to take over the role of detectors. According to a brilliant historical overview of electronic developments involving silicon [7], Jürgen Rottgardt in Germany in 1938 reported on extensive research into the possible use of cat’s whisker crystal rectifying junctions in the microwave region, which was becoming important for the incipient development of radar. Rottgardt concluded that the combination silicon–tungsten was particularly promising as a detector in this wavelength range. This was developed into a practical detector by Herbert Skinner in Britain during World War II, and independently by Russell Ohl and George Southworth at the Bell Telephone Laboratories in America. This approach gradually gained ground against the devotees of vacuum tubes due to its higher operating frequency; each advance in this field was fiercely resisted by the exponents of the preceding orthodoxy. Seitz and Einspruch [7] tell us that in 1941 Skinner wrote a bitter little poem, which included the words: “And so alone / we, fighting every inch of the way, / against those ingrained elephants of inertia / against...p rejudice and hardened pride... / we fought (through forests thick with self-satisfaction) / to shorter electromagnetic wavelengths.”