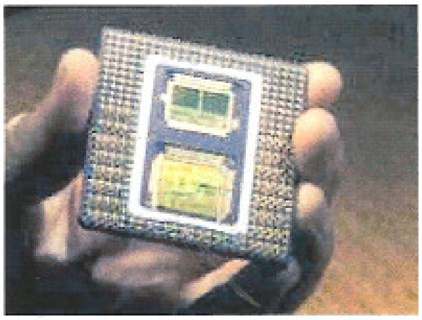
# Infinity in a Grain of Sand

*By Adam Quest*

When William Blake wrote of finding "infinity in a grain of sand," he was not thinking about the computer chip. But perhaps the man who invented the microprocessor was thinking about Blake. Sand is the raw material of silicon, the "chip" part of the processor. And the computer chip, a.k.a. integrated circuit or semiconductor, looks toward infinite possibility and the expanses of human consciousness. The chip is the central processing unit of the computer, the soul of the machine.

The manufacture of these wondrous tiny machines is an intricate process befitting such a portentous invention. Chip fabrication combines the precision of microengineering with the massive scale of industrial production (it's a $100-billion industry).



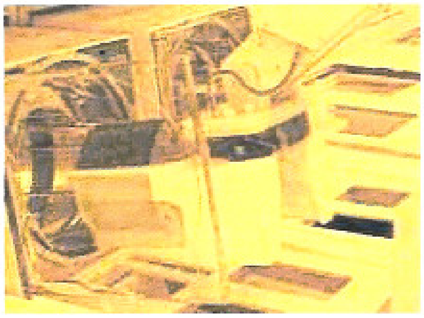
The first step in manufacturing most computer chips is to extract silicon from common sand. Silicon is a natural semiconductor (i.e., a material that can be either a conductor or an insulator) and the second most abundant element on earth. Heating sand to 2000 degrees C in a furnace frees the silicon, which then reacts with carbon in the form of wood chips or coal. The resulting silicon is chemically processed until it is 99.9999999% pure-- THE purest material ever made commercially in bulk quantities-- and then heated to a molten liquid.

Dipping a seed crystal into the molten silicon and slowly pulling it out creates a crystal that repeats the structure of the seed. The cooling silicon crystallizes around the seed and forms a cylindrical ingot, which is ground to a uniform diameter. Following this step, a diamond saw blade cuts the crystal ingot into wafers about .01 inch thick, which are ground smooth and chemically polished. A single wafer forms the base for hundreds of copies of an integrated circuit. Wafer fabrication is a key process in the 100-plus steps required to manufacture semiconductors and usually takes from 10 to 30 days.

Unlike most forms of manufacturing, which combines a series of discrete components manufactured individually, making a chip entails building up the individual circuit patterns in layers. This involves a variety of processes in which portions of conducting and nonconducting compounds are repeatedly added and stripped away.

Initially, an insulating layer of silicon dioxide is applied to the blank wafer. Then a light-sensitive film called **photoresist** is applied over the silicon dioxide. The next step, a process known as photo-masking or photolithography, involves placing a mask over the photoresist layer and directing ultraviolet light through the spaces in the mask, exposing the photoresist with the mask pattern.

In the etching process that follows, the exposed photoresist is removed. The masked-out photoresist is heated to solidify the remaining pattern. Then chemicals or a plasma discharge etch away the areas not covered by hardened photoresist. To ensure that the image transfer from the mask to the top layer is correct, other chemicals eat away the photoresist, leaving the wafer ready for inspection. The next process, called doping, introduces chemical impurities-- positive or negative conductors-- to areas exposed by the etching process to alter the electrical character of the silicon.



The masking, etching and doping steps are repeated until the chip pattern is complete. Then a conducting material, typically aluminum, is added to create pathways for electricity to flow throughout the chip. Finally, a diamond saw slices the wafer into hundreds of single chips. These chips are inspected and either discarded or sealed in a protective package.

The dimensions of computer chips and their components are extraordinarily small, down to sizes less than one micron-- one hundred times smaller than the diameter of a human hair. Because these devices are so minuscule, one speck of dust during manufacturing can ruin a chip. As a result, all processing must be done in a strictly monitored clean room facility, where the air carries fewer than one airborne particle per cubic foot of air and those particles are no larger than half a micron. To protect the purity of the environment, the workers manning these facilities have to wear full-body "bunny suits" that filter particles out of the air they exhale. The bunny suit has become a familiar symbol of the semiconductor industry through a recent series of Intel TV commercials that show supposed microchip workers disco-dancing around in wildly colored suits. (In real life, the suits are usually white, and the workers rarely funky.)

Discussing anything related to computer chips is not unlike talking about that other mythic area of science, space, because so many aspects of the processes involved can be described with superlatives: the smallest, the purest, the most. This is not incidental because scale plays a crucial role in every aspect of the semiconductor: its origins, production, and impact on society.

Computers have evolved from the daunting, room-sized machines of the fifties to their present ubiquity mainly because scientists have discovered how to fit more transistors on chips, which allows the computers to process more information faster. Semiconductors themselves have become cheaper to manufacture because new methods allow larger wafers and smaller transistors. The lower cost of chips, in concert with increased consumer demand, has drastically reduced the price of computers. Economies of scale drive the whole process, and "smaller, faster, cheaper" is the unofficial industry mantra.

---

To think that the computer chip-- so complex and so intertwined with practically all human endeavor (work, leisure, communication, etc.)-- is formed from ordinary, seemingly inert sand is to face a towering paradox. The microchip, embodiment of the man-made, exists through the good graces of nature; yet it's at the forefront of our attempts to undermine nature at every turn.

Think about **that** the next time you go to the beach.