The Journey Inside[SM]: Technology and Society

# Student Handout: Making of a Silicon Chip

## Making of a Silicon Chip

by Michael S. Malone, courtesy of *One Digital Day* (1998)

It comes from one of the most common elements on earth: sand. Just as steel and coal powered our past, silicon made from sand has become the foundation of our future. After undergoing an extraordinary transformation, this simple element, mined from the earth, eventually becomes the silicon wafers from which microchips are built.

Beginning deep in the earth, quartz, which is believed to make up 28 percent of the earth's crust, is mined in quarries and then shipped to one of the few companies that specializes in processing this element into purified silicon. One of these companies is Wacker Siltronic in Germany, where electric arc furnaces transform the quartz to metallurgical-grade silicon. In a process designed to further weed out impurities, the silicon is converted to a liquid, distilled, and then re-deposited in the form of semiconductor grade rods, which are, at that point, 99.999999 percent pure. These rods are then mechanically broken into chunks and packed into quartz crucibles, where they are melted at 2,593 degrees Fahrenheit.

A monocrystal seed is introduced to the melted silicon, and as the seed rotates in the melted silicon, a crystal grows. After a few days, the monocrystal is slowly extracted, resulting in a 5-foot-long ingot of silicon which, depending on its diameter, is worth from $8,000 to $16,000. These pure silicon ingots, weighing up to 264 pounds each, are then sliced by diamond saws into wafers, which are washed, polished, cleaned, and inspected both visually and mechanically. The wafers are then scanned with lasers to find surface defects and particles less than 1/300th the width of a human hair before being shipped to customers. Every week, Wacker Siltronic produces around 800 ingots, enough to create more than 500,000 wafers.

In Hillsboro, Oregon, chip architects are developing the latest circuit designs in a never-ending quest to fit more transistors on a chip, thus increasing performance. Intel's first microprocessor, shipped in 1971 for Japanese calculators, held 2,300 transistors; the 1.3 gigahertz Pentium® 4 processor cartridge, released in 2000, contained over 42 million. To check the location of transistors on a multilayered microprocessor, Intel layout experts examine a diagram of a chip on a computer screen. A magnified diagram, or die plot, shows the complexity of these microcircuits.

The architect's completed designs are then transferred to a mainframe computer and processed through an electron beam that "writes" these designs into a metal film on a piece of quartz glass, to make a mask. The making of a chip is a combination of repeating steps consisting of the application of a thin film, followed by photolithography and then etching, in which the mask acts much like a negative. Of paramount importance is the precise alignment of each mask: if one mask is out of alignment more than a fraction of a micron (one millionth of a meter), the entire wafer is useless.

When light is shone through the mask, circuitry designs are "printed" onto a wafer. Each newly designed chip requires approximately 20 masks that are positioned as overlays at different points throughout the process—a journey that includes several hundred steps from wafer to finished chip. The primary steps include coating the wafer with an emulsion called "photoresist" under a special yellow light designed to avoid premature exposure; exposing the wafer to ultraviolet light through a mask to transfer the first layer of pattern onto the wafer; etching the pattern into the wafer and removing the photoresist so the next layer of circuitry can be applied; storing the wafers, before the next mask is applied, with alignment references notched on their edges; and loading the wafers, in lots of 25, into a "boat" for transport to an area where they'll be implanted with various elements to change each layer's particular electrical properties. An eight-inch wafer, seen here under inspection light, will host more than 200 Pentium® II processor chips.

Each chip is tested throughout the entire process—both while part of a wafer and after separation. During a procedure known as "wafer sort," an electrical test is conducted to eliminate defective chips. Needle-like probes conduct over 10,000 checks per second on the wafer. A chip that fails a test for any reason in this automated process is marked with a dot of ink that indicates it will not be mounted in packaging.

When the chip-making process is complete, wafers are cut with a diamond saw in order to separate each individual chip, which at this point can be referred to as a "die." Once each die is separated, it is placed on a static-free plate to be transported to the next step—the "die attach"—where the chip is inserted into its "packaging." Chip packaging protects the die from environmental elements and provides the electrical connections needed for the die to communicate with the circuit board onto which it will later be mounted.

At an Intel plant in Penang, Malaysia, after a battery of sophisticated tests, a technician visually inspects a tray of finished processors before they are sent to a warehouse and used to fulfill customer orders.

The culture behind the scenes of chip fabrication is perhaps the most fascinating element of the process. The world's largest "fab," or chip fabrication factory, is in Rio Rancho, New Mexico, where production never stops, and the clean rooms alone cover the area of three football fields. In this otherworldly atmosphere, the technicians spend their 12-hour shifts encased in GORE-TEX® "bunny suits." Workers wear this required garb over their clothes to keep minute particles such as dead skin cells from contaminating the microscopic circuits.

To further minimize the presence of airborne particles, technicians wear helmets that pump their expelled breath through a special filter package. Powerful pumps in the ceiling also continually pour filtered air into the fab, replacing the air in the room eight times a minute.

Technicians take two stretch breaks before their day is done. These stretch sessions also become general meetings between shifts so that as one crew finishes up, technicians share production updates with the new crew coming on.

With quality control done, the chips are ready for market. From wafer to chip to market, the process takes up to 45 days and is divided among Intel employees in more than a dozen countries around the world—a global high-tech relay in which microchips, precious cargo of our age, are the baton.