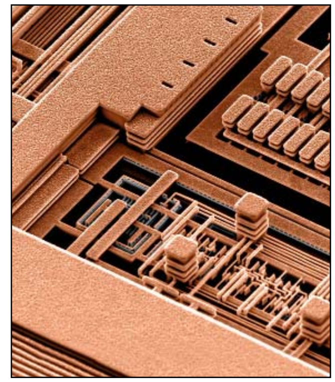
about Plasmas

from the Coalition for Plasma Science

Computer Chips and Plasma

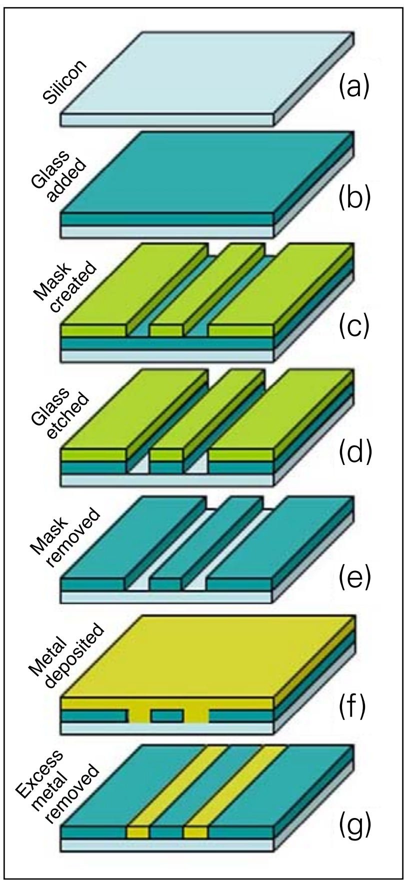
Today almost all electrical devices rely on electronic chips. Not just our computers, but our cars, our microwave ovens, our alarm clocks, even that singing birthday card – all these gadgets have chips inside. And none of these chips could be manufactured without using plasma. That's because plasma technology is capable of forming transistors and wires that are much smaller than the width of a single hair. Without plasma, the transistors would have to be made much bigger, making the chips more expensive, slower, and much less powerful.



In this microscope photo of the wiring on a chip the smallest wires are more than 100 times thinner than a single hair.

Many people are not aware of the full economic significance of using plasmas to make chips for electronics. For example, in 2005 the total global revenue generated by semiconductor chip manufacturers, like Intel Corporation and Samsung, was approximately $227 billion dollars. In the following paragraphs we will show how scientists and engineers at these companies harness the unique properties of plasma to make computer chips, and why plasma is indispensable to the continued success of the information age.

Plasma can be created by taking an ordinary gas — like air — and adding energy until electrons are stripped from the gas atoms and molecules. Usually plasma is formed by using electricity to strip electrons from these gas particles. Those electrons become very hot, typically more than 20,000°F! The hot electrons collide with gas particles, breaking many of them apart and knocking off electrons to create electrically-charged particles called ions. One of the most common plasmas is within the fluorescent light. When the light is off, that tube is filled with argon gas and mercury, but turn on the power, and the gas inside the tube is converted to glowing plasma! Plasma is also used to make computer chips. Before learning how plasma is used, it's helpful to understand how chips are made.



Stages of computer chip manufacture.

Chips are made like a layer cake, but with the unwanted parts of each layer removed before the next layer is applied. To create a complex, three-dimensional chip structure layer-by-layer, the two basic steps of adding a thin layer of material and then removing its unwanted parts are repeated many times. To begin, we use a flat piece of silicon (Left, Figure (a)). A thin layer of glass is added to the entire wafer as shown in (b). Next, a layer of light-sensitive film ("photoresist") is applied to the wafer. Laser light is used to remove parts of the film. The remaining film is called a "mask"(c). It protects parts of the wafer's surface from being removed during the "etch" step (d), which is the plasma process discussed below. Once the etching is complete, the mask is stripped away (e). Next, a thin film of metal is deposited on top of the wafer (f). Finally, the extra metal is polished from the wafer, leaving a layer of metal wires and glass insulation (g). More glass is added to coat the top of that layer, and the entire process is repeated over and over, creating an intricate three-dimensional network of circuit wiring. Connections between layers are made by etching small holes in the glass and filling the holes with metal.

So chips are made by depositing thin layers of glass and metal, then removing the parts of each layer that are not needed for the final chip. But how is plasma used

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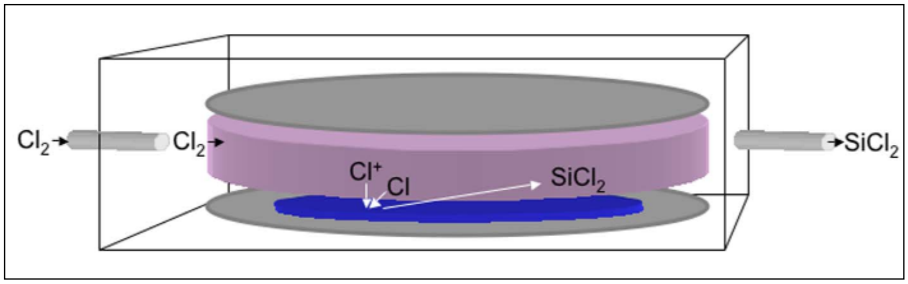
in this process? Some of the ions and fragments of molecules in the plasma are eager to react chemically with the wafer surface. These reactive components of plasma are what make it possible for engineers to create the intricate layers of a chip.



A schematic of a silicon wafer (blue) in a vacuum chamber between two metal plates (gray). The plasma is shown as purple.

As an example, let's look at etching silicon (Si) using plasma. A silicon wafer is placed in a vacuum chamber between two metal plates. The gas between the plates is removed by a vacuum pump and a small amount of chlorine gas (Cl_2) is allowed into the vacuum chamber. The metal plates are connected to a high voltage source that turns on and off about 10 million times per second. The high voltage on the plates causes the chlorine to become electrically charged, and a glowing plasma is formed directly above the wafer. The chlorine molecules are broken apart by the plasma into chlorine atoms (Cl) and ions (Cl^+). These fragments attach to the silicon atoms at the surface of the wafer and create $SiCl_2$ gas. This gas is pumped out of the plasma, removing silicon atoms in the process. A pre-patterned photoresist mask is used to protect portions of the silicon surface from Cl atoms, preventing specific regions of the wafer from being removed, as shown in steps (c)-(d) above.

A technician prepares a plasma etcher, placing the wafer on the lower metal plate. In a large commercial manufacturing environment, the wafers are handled by robots, not humans.

The process of depositing thin films on a wafer is the opposite of etching. To deposit solid material on a wafer, the input gas must contain the atoms to be deposited. For example, silane gas (SiH_4) can be used to deposit silicon using a plasma. The plasma's electrons break SiH_4 into silicon, SiH_x (x can have different values to represent different molecules), and hydrogen atoms. The silicon sticks to the surface of the wafer, and the extra hydrogen is pumped from the plasma. Within a few minutes, the silicon atoms accumulate to form a solid film of material across the entire wafer. This uniform layer of silicon then needs to be patterned with photoresist and etched to form useful devices.

Thirty years ago many of these manufacturing steps used liquid chemicals or hot gases instead of plasma. For example, simple acids were used for etching. As chips have become more sophisticated, however, the size of the transistors has become extremely small. Because acids will etch not only into the wafer but also under the mask, it is impossible to use acids to etch very small circuit patterns. Plasma, on the other hand, can etch straight into the wafer because the ions are accelerated straight from the plasma to the wafer by the high voltage used to energize the plasma. Also, since plasmas create far less hazardous waste than chemical processes, plasma-based manufacturing is much less damaging to the environment.

These are only two examples of how plasmas help create electronic chips. Plasmas are also used within the lasers needed to pattern the photoresist, and they are used to strip the photoresist from the wafer. Finally, plasmas can create "dopant" ions that modify the electrical properties of silicon, creating transistors. In fact, about half of the manufacturing steps used to make a computer chip rely on plasma. Without these vital plasma technologies, many of today's modern conveniences could not exist.

Suggested Reading:
50 Years of Science, Technology and the AVS, "Plasma Science and Technology," J. Cecchi and L. Cecchi, editors, in Journal of Vacuum Science and Technology A, vol. 21(5), pp S129-S157 (2003).
Brian Chapman, Glow Discharge Processes (John Wiley & Sons, New York, 1980).

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