Photolithography: Etching Patterns for Computer Chips

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The twenty-first century has seen the proliferation of tiny microprocessors in everything from insulin pumps to digital hearing aids to the ubiquitous cell phones and iPods. In the 1960s, computers were the size of a room in order to accommodate large vacuum tubes to perform calculations. Now that same processing can be done with a microprocessor smaller than a fingernail. This miniaturized circuitry on computer chips would not even be possible without photolithography.

Creating a microprocessor, or any other kind of integrated circuit, requires photolithography, which is the process of "etching" shapes into a piece of semi-conducting material, such as silicon, using light. Originally used for recreating works of art, such as engravings and photographs, photolithography is now primarily used for making integrated circuits (Mansuripur, 2004). Photolithography is a multi-step process, each step being partially controlled by computers, because the scale of the etching is too small for a human to properly work with. Multiple layers of semi-conducting materials are laid on top of each other, and the shapes etched into them, the actual patterns themselves, are able to function as transistors and internal data pathways (Kozierok, 2001).

The word photolithography is Latin for light-stone-writing, which is accurate because it is essentially a means to transfer a pattern onto a wafer. While the process was first used for developing large quantities of integrated circuits in the 1960s, photolithography was originally used to reproduce photographs and engravings as well as creating printing plates in the years before (Darling, n.d.; Mansuripur, 2004). It was first developed in 1826 by Joseph Nicephore Niepce by using a combination of lavender oil and mineral spirits on a pewter plate to make a

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recreation of it. The first synthetic photopolymer, known as polyvinyl cinnamate, which is the basis for negative photoresists, was developed by Louis Minsk in 1935. Five years later, the first positive photoresist is created by Otto Suess, which was diazoquinone-based, a chemical commonly used in modern photoresists (Darling, n.d.). The creation of negative and positive photoresists was key in the use of photolithography in making integrated circuits.

How the circuit is made is vital to its proper functioning. Before the main piece of silicon, also known as a wafer or substrate, is layered, it must be cleaned to get rid of any materials that may interfere with the etching process. The silicon wafer is covered with a layer of silicon oxide, then silicon nitride, and finally a material known as a photoresist, which is a polymer that reacts with light in order to create places that can be dissolved differently than other areas of the same polymer (Wilson, 2007; "How is Chemistry used to build ICs?," n.d.). With more complicated integrated circuits, such as those in microprocessors, there can be as many as a dozen layers (Kozierok, 2001). The photoresist is the layer that makes etching silicon wafers possible, and it comes in both negative and positive forms. Positive photoresist weakens when exposed to light, which makes it easier to remove. Negative photoresist, on the other hand, is just the opposite: it gets stronger when exposed to light, making it harder to remove (Wilson, 2007). The process of soft-baking, which means that the layers are exposed to high heat for a pre-determined amount of time, is done to remove solvents from the photoresist coating, which helps make it photosensitive enough for etching the designs into the silicon wafer ("Photolithography," n.d.; Wolf, 2005).

When etching a pattern into the silicon substrate, a mask must be put over the parts of the photoresist in order to prevent them from dissolving when exposed to light. The mask has

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the actual pattern, an “elaborate template,” that is used to etch shapes of transistors and wires into the silicon itself (“How is Chemistry used to build ICs?,” n.d.). What were in the past separate transistors are now simply “etched” or cut into a single tiny wafer. The wavelength of light used is the determining factor in how many shapes can fit onto a single piece of silicon wafer. The original wavelength of light used in photolithography was 365 nanometers, but it has decreased over the years (Mansuripur, 2004). More advanced methods of photolithography use direct write-on wafer systems for exposing the silicon substrate to light. Excimer lasers, electron beams, and focused ion beams are three methods that direct write on wafer systems use and do not require the use of a mask (Darling, n.d.). Higher frequencies of light are needed to etch smaller patterns into silicon wafers because the wavelength of light is the limiting factor in how small the patterns can be. The amount of miniaturization is astounding. The popular Intel Core™ 2 line of processors has between 167 million and 820 million transistors etched into them (“Microprocessor Quick Reference Guide,” n.d.). This process is key to producing tiny and fast microprocessors.

From the mid-1820s to the present day, photolithography has been used for recreating photographs and engravings as well as etching patterns into semi-conductive materials to create integrated circuits. The process of modern photolithography is broken down into several steps, each step carefully controlled by a computer. From the adding of the photoresist to the etching away of layers with light, all steps in photolithography must be done with great care. The scale of working with light to etch away patterns in silicon is so small that no human could do it without disturbing the pattern itself, which is why we need expensive photolithographic machines to do the work. It is the patterns themselves that work as the transistors and data

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pathways in microprocessors and other integrated circuits. What was once used for art has been transformed into a step in the process of computer miniaturization, little known but absolutely vital.

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