BASICS OF MANUFACTURING INTEGRATED CIRCUITS

Opportunities for filtration exist for the manufacture of very small electronic components referred to as semiconductors. This broad category includes devices such as transistors, capacitors, resistors, diodes, LED and photocells. The different types of devices can be integrated together to form integrated circuits, or VLSI (Very Large Scale Integration) devices such as microprocessors and random access memory (RAM). As more devices are stacked into a single integrated circuit, the distance between the devices, referred to as line width or geometry, is also reduced. This allows for more rapid functions while reducing the cost per chip. The processes used to make these devices therefore requires ultrapure water as well as number potentially hazardous or aggressive chemicals and chemical mixtures, all of which must be highly filter to ensure the quality of the devices and high yield.

Definitions

- **BOE (Buffered Oxide Etch):** Etch chemical composed of ammonium fluoride and hydrofluoric acid.
- **Chip:** Integrated circuit.
- **CMP slurry (Chemical Mechanical Polishing/Planarization):** Slurry of abrasives used to remove thin layers (angstrom) from a wafer via both grinding and etching.
- **Diode:** Component with two electrodes called the anode and the cathode intended to conduct electric current in only one direction.
- **Doping:** Introduction of impurities into an extremely pure semiconductor for the purpose electronic properties (increased conductivity).
- **Etching:** Chemical process used to remove layers from the surface of a wafer during manufacturing.
- **Fab:** Manufacturing plant in which raw silicon wafers are turned into integrated circuits.
- **Gallium:** Conductive chemical element (symbol Ga). Gallium arsenide and gallium nitride are the primary chemical compounds of gallium used in electronics.
- **Germanium:** Conductive chemical element (symbol Ge). For the first decade of semiconductor electronics, everything was based on germanium. Currently it is used only a fraction (2%) of silicon, mainly for solar cells.
- **HF:** Hydrofluoric acid.
- **Integrated Circuit:** Compact set of electronic circuits on one small plate of semiconductor material which is typically silicon.
- **LED:** Light-emitting diodes.
- **Moore’s Law:** The observation, named after Gordon E. Moore who was the co-founder of Intel and Fairchild Semiconductor, that the number of transistors in an integrated circuit has doubled approximately every year. In 1975, he revised the forecast to doubling every two years which holds true today.
- **NOE (Neutral Oxide Etch):** Etch chemical composed of ammonium fluoride and ethylene glycol.
- **Photoresist:** A light-sensitive material used in several industrial processes, such as photolithography to form a patterned coating on a surface. Two types: Positive resist is a type of photoresist in which the portion of the photoresist that is exposed to light becomes soluble to the developer; Negative resist is a type of photoresist in which the portion of the photoresist that is exposed to light becomes insoluble to the photoresist developer.
- **Piranha:** Stripper chemical composed of hydrogen peroxide and sulfuric acid.
• **ROM (Read Only Memory):** Type of microprocessor memory that is programmed with a permanent collection of pre-set bytes.

• **RAM (Random Access Memory):** Type of microprocessor memory that loses information when powered down.

• **RCA Clean:** Standard set of cleaning steps for wafers using SC1 and SC2.

• **SC1 (Standard Clean 1):** Stripper chemical composed of NH4OH (28%), H2O2 (30%) and dionized water.

• **SC2 (Standard Clean 2):** Stripper chemical composed of HCl (73%), H2O2 (30%), dionized water.

• **Semiconductor:** A substance, usually a solid chemical element such as silicon that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current.

• **Silicon:** Conductive chemical element (symbol Si) serves as the base of most integrated devices.

• **TOC (Total Organic Carbon):** Amount of carbon bound in an organic compound and is often used as a non-specific indicator of water quality or cleanliness of pharmaceutical manufacturing equipment.

• **Transistor:** Component with three terminals used to amplify an electronic signal.

• **VLSI:** Very Large Scale Integration.

• **Wafer:** Serves as the substrate upon which integrated circuits are built.

**Silicon Ingot**

Silicon wafers act as the main substrate for integrated circuits. The individual thin waters are cut from an ingot that is grown/formed from highly purified electronics grade silicon (99.9999999%). The ingot is started from a seed crystal immersed in a bath of molten silicon at over 1,000°C and is rotated and drawn upwards very slowly, increasing in size as it is drawn. The process takes many days, yet it is a single crystal. In a single crystal, all of the atoms are aligned and oriented in one direction. The outer diameter is ground so that it is circular. And then can be sawed (sliced) into thin discs 0.5 to 0.9 mm thick, which are the wafers. SC1 and SC2 are used to remove organics and metals. Using the silica wafer as the substrate, an insulation layer is created on the wafer under high temperature in the presence oxygen to form silicon dioxide. Since this process involves on gas, there are no liquid filtration opportunities, but rather specialized gas filters.

Companies, such as Wacker, SEH, MEMC and Hemlock Semiconductor are involved in the manufacture of silicon ingots. Due to the temperature and nature of the chemicals in the process, there are opportunities for Citadel.

**Wafer Manufacturing**

The wafer serves as the base upon which the integrated circuit is built. Wafers have been increasing in diameter over the decades as manufacturing technologies have improved. 150 mm wafers were typical until 1995, while 200 mm wafers became typical until early 2000 when 300 mm were developed. Today, 450 mm wafers are being developed. The rationale for larger wafers is that more individual integrated circuits can be built on a single wafer as the diameter increases. For instance a 200 mm wafer has an area of 31,416 mm² while a 300 mm wafer has an area of 70,686 mm². Using the same processes, output can essentially be doubled (2.25X) due to the increased area. Wafer processing involves multiple steps with layer upon layer being built on the wafer. Each layer goes through the process of photolithography, baking, developing, etching and polishing. Each layer will be a different design/pattern from the previous from the first and are interconnected at various places until the entire circuit becomes the integrated device. There may be 30 or
more layers in a single completed wafer, meaning the process of photolithography, baking, developing, etching and polishing was repeated 30 or more times.

**Photolithography**

**Photomask**: The pattern of *each* individual layer of the chip, containing the various devices (transistors, resistors, etc.), is generated in a magnified size, photographed and reduced in size to match the actual size of a wafer. The image of chips is transferred to a glass plate using electron beam and becomes the master, referred to as the photomask or mask.

**Photoresist**: The image of the pattern must be transferred to the surface of the wafer using photolithography. In this process, wafers are coated with photoresist, a photosensitive chemical which is actuated by UV light. Following the application of the photoresist, the wafers are cured at a low temperature to dry the resist (soft bake) followed by curing at higher temperature (hard bake).

- **Positive resist**: the solubility of resist covering areas exposed to the light increases and the resist can be easily rinsed off by the developer solution. This is the most prevalent type.

- **Negative photoresist**: exposed resist areas polymerize (solidify) and remain during the developing step while the non-polymerized chemical washes off.

**Expose and Develop**: The dried, resist-coated wafer is put into a camera like device which contains the photomask and beams UV light the mask at the coated wafer, exposing certain areas while others are blocked. The photoresist is now developed, similar to film. In the case of positive resist, the exposed areas can be washed away while with negative resists unexposed areas wash away. The chemicals used are referred as developers.

**Wet Etch**: Etch chemicals, typically hydrofluoric acid (HF) or BOE which contains HF, are used to etch away regions of the silica layer not protected by the patterned photoresist adhering to the wafer. Etching is usually accomplished by immersion where the wafers are placed in a holder referred to as a boat and immersed in a chemical bath. There are also acid spray processors in which wafers are sprayed with the chemical.

**Dry Etch**: As line widths have decreased in size, wet etching has become a less desirable process due to the inability to highly control the etching. In a process referred to as dry etching, ions created by plasma generation, bombard the unmasked surfaces of the wafer and create highly reactive gas compound which is then removed. Similar to the oxidative layer formation, the process involves only gas and thus there are no liquid filtration opportunities, but rather specialized gas filters.

**Stripping**: Because photoresist is used to mask the surface, it must be removed or stripped prior to further processing. There are different types of stripper depending upon the surface. For non-metal surfaces, a mixture of sulfuric acid and hydrogen peroxide is used referred to as Piranha. For metal surface, acid cannot be used. In this case, proprietary mixtures of organic based solvents, such as NMP (n-Methyl Pyrrolidone) are applied in a spraying process.
Rinsing: After chemical treatment of the wafers for cleaning, etching or stripping applications, the chemicals must be completely removed from the surface in order to stop the chemical reaction and remove any chemical residues and particles. There are several types of rinse tools in the market:

- **Overflow:** Immersion of the wafers into a rinse bath with continuous introduction of water from the bottom of the tank and overflowing at the top of the tank.
- **Spray:** Ultrapure water is dispensed through spray nozzles directly onto the wafer at variable flow, pressure or temperature.
- **Quick dump:** The wafers are placed in the rinse tank, ultrapure water is added, dumped and refilled several times.

**Doping and Deposition**

There are a number of different processes that are incorporated into making the wafer, the specific process being dependent upon the type of device being built (transistor, diode, etc). Most of the processes utilize specialize equipment that have either no filtration or in many cases specialized gas filters. These processes may be repeated or varied from layer to layer within the device and are the basis of the functioning circuit.

**Oxidation:** Using the silica wafer as the substrate, an insulation layer is created on the wafer under high temperature in the presence oxygen to form silicon dioxide.

**Doping:** Also called ion implantation is the process introducing impurities into the silicon wafer. These impurities are essential to creating electrical properties within the unmasked area of the wafer.

**Chemical Vapor Deposition:** Gases of chemical vapors are reacted to form thin film deposits on the surface of the wafer. These deposits may be metallic or conductive in nature such as tungsten, aluminum, copper, polysilicone, or silicon nitride. All of these materials undergo photolithography and etching.

**CMP**

In order for subsequent layers to be built upon the first layer, the surface must be smoothed and aligned perfectly. This process is referred to as chemical mechanical polishing/planarization. CMP is a polishing process whereby the wafer is placed on a rotating table while a rotating polishing disc moves back and forth. The process uses an aqueous slurry composed of nanometer sized abrasive particles, such as silica, alumina, ceria, suspended in various chemicals such as oxidizers, pH stabilizers, metal ion complexants and corrosion inhibitors solution to erode the surface both chemically and mechanically in order to make it flat.

**Rinse applications utilize ultrapure water at high flow rates; therefore the use of a hydrophilic membrane is required. ZTEC E 0.03 or 0.1 micron is recommended.**

**CMP slurry requires constant recirculation (global loop) and filtration. The slurry particles can agglomerate forming larger particles which result in scratching of the wafer surface, thus the destruction of the chip. Depending on the slurry, filtration may range from 0.3 micron to 10 micron. High performance melt blown filters such as the Stratum series are the main technology in use. The goal is to remove any agglomerated particles while leaving behind the nanometer sized particles.**
**Bulk Chemical Distribution Systems (BCDS)**

High purity chemicals are required in significant quantities with a Fab. Some of the chemicals are extremely dangerous and dictate minimal human interaction. Since delivering chemicals in bottles is impractical, the chemicals are supplied from storage tanks and drums through pump systems which are all part of the bulk chemical delivery system.

Since the chemicals used in BCDS are ultrapure, the filters have a long cycle life. The filters are changed out on a PM (preventative maintenance) basis up to 1 year. Due to the life and varying nature of the chemicals, all-fluoropolymer filters such as the Citadel are utilized.

**Water**

Semiconductor facilities can utilize ultrapure water at a rate of 2 MGD or ~5500 m³/day. The specifications for ultrapure water for the semiconductor industry are the most stringent. These water factories are usually stand-alone facilities operated almost independently from the Fab. Water must meet both particle and conductivity specification, requiring the use of reverse osmosis, resin beds as well as mechanical filtration technologies. Final filters rated below 0.1 micron are typical prior to sending water to the Fab, where point of use filters of similar rating may be found.

<table>
<thead>
<tr>
<th>TEST PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity, 25 °C (MΩ·cm)</td>
<td>&gt;18.18</td>
</tr>
<tr>
<td>TOC (µg/L) (on-line for &lt;10 ppb)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Dissolved oxygen (µg/L)</td>
<td>10</td>
</tr>
<tr>
<td>Particles/L (micron range) &gt;0.05</td>
<td>&lt;200</td>
</tr>
<tr>
<td></td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Non-Volatile Residue NVR (µg/L)</td>
<td>0.1</td>
</tr>
<tr>
<td>Silica – total and dissolved (µg/L)</td>
<td>0.5</td>
</tr>
<tr>
<td>Metals/Boron by ICP/MS (µg/L)</td>
<td>&lt;0.001-0.01</td>
</tr>
<tr>
<td>Ions by IC (µg/L)</td>
<td>0.05</td>
</tr>
<tr>
<td>Microbiological CFU/100 mL</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Filtration opportunities exist for pre-R.O., resin trap, tank vent, prefilter and final filter. ZTEC E PES membrane filters offers flow and performance advantages and has become the typical membrane used. Due to the critical nature of the water, high end melt blown filters are most likely to be used in pre-R.O. Prior to delivering to the Fab, the water will pass through a 0.1 micron ZTEC E filter followed by a 0.03 micron.