Microlithography For The Masses

Chapter 1

Introduction:

Microchips are everywhere nowadays, in cell phones, washing machines, fax machines, PDAs TVs, air conditioners, and most importantly in computers. You name it - they are in it.

First came the transistor: invented in 1947 by John Bardeen, Walter H. Brattain, and William B. Shockley, engineers and scientists at Bell Telephone Laboratories.

Second came the naked Integrated Circuit (IC). In August and September of 1958, Jack S. Kilby, previously at Centralab and now at Texas Instruments, assembled and demonstrated the first integrated circuits; an oscillator and a flip-flop.

Then the first microchip came to be in 1971. Ever since then the microchip has been getting smaller, smarter, more dense and much more cheaper for the end user.

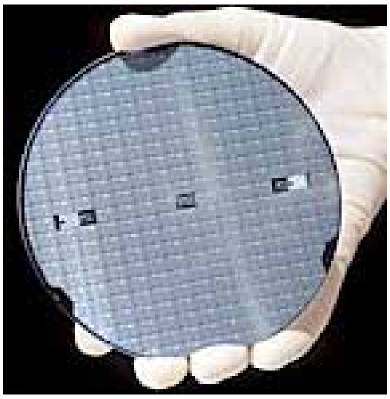
Some microchips perform only simple **logic** functions, some are way more smarter, like the (arguably) most popular microprocessor now- the Pentium 4. Others just store **data** and are commonly known as **memory** microchips, even referred to as 'sticks of RAM' (to be honest - even the memory chips perform logic functions also).

The design and amount of the components on the microchip will determine it's function. The first microchips had a very small amount of components on them, around 10-100. Along with the semiconductor industry growth so did the demand for constant improvements on previous versions and generations of microchips. Today we have the Intel Pentium 4 with over 42 Million transistors onboard consuming 60-75 watts of power consumption with critical layer line width at 0.18micron.

The demand for these performance boosts led a constant ongoing technological struggle to design, mass produce and supply the cutting edge precision tools to the semiconductor industry necessary to fabricate microchips.

Microlithography has the main stage in this industry. And advances in microlithography has been the key for achieving the constant scaling down in line width, imperative for speed increase and lowering power consumption (and keeping Moore's Law relevant..).

Before I give an overview of microlithography we must briefly look at the entire process of microchip manufacturing.



Manufacturing Process

Silicon

Silicon is the material used for the microchip surface. It's electrical conductivity properties are needed for the microchip. Silicon is where the whole manufacturing story begins. A silicon crystal with a miniscule percentage of impurities is grown, processed and sliced into round slices called wafers. The diameter of the wafers started out in 1980 as 3" then every few years the semiconductor industry adopted and adapted to larger diameters of wafers: 1986 6" wafers, 1990 8" wafers and today the new fabrication plants built are ready for the huge 300mm diameter size of wafers. Some older fabs will be upgraded.(The downturn in the semiconductor industry has greatly delayed the ramping up of the 300mm process) The wafers then have a notch or a 'flat' marked into one side (done before slicing). The notch marks the crystal plane orientation, which is very important for the final cutting of the individual dies that will be built up upon the wafer.

Next the wafer is polished to a mirror like flat surface, tested for electrical conductivity and sent to an oxidization process, with involves growing a silicon di-oxide (SiO_2) coating on the wafer. This will be the foundation of all subsequent layers.

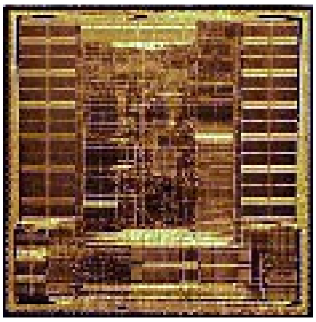
Microlithography

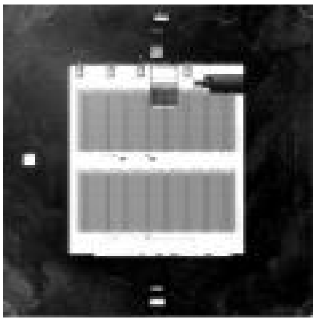
The next step is the Microlithography process. This is the process of building up several layers upon a single wafer. We can break down this part into three:

1) Wafer surface preparation: coating the wafer with light sensitive photo-resist.
2) Exposure of the resist with a projected image through a patterned reticle.
3) Developing of the resulting pattern on the wafer.

Depending upon the type of resist type used the resist will be either softened or hardened due to the exposure to the light. This is also known as a 'positive' or a 'negative' process. The softened resist will be removed in the chemical process of developing. Voila! we are left with the image that we projected and onto the wafer.

All we need now is to make this pattern a permanent pattern.





Etching

This brings us to the next part - Etching. This involves removing the layer of silicon di-oxide (SiO_2) through the openings left in the resist by the previous developing. The remaining resist no longer plays any useful part and can now be removed. What we are left with now is one layer of many which will be added to this wafer.

Doping

Part of the wafer surface are treated with chemicals that change the areas electrical conductivity. This is achieved by replacing some of the original silicon atoms with dopant atoms. The addition of impurities adds charge carrying elements to the semiconductor. The two classes of doping are p-type and n-type which refer to the introduction of positive and negative charge carriers. This is the construction of diodes, for example.

Metal Interconnections

A conductive metal substance is used for the connections between layers and within devices (transistors) on the microchip. Vertical and horizontal interconnections are made.

Insulation

An insulating layer of glass based material is spread over the metal layer isolating the layer from other layers.

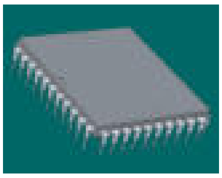
Round and round it goes

The complete process can be repeated up to 30 times or more to build up a multilayered microchip.

The End ?

The final 'wrapping up' processes consist of:

- **Passivation layer. This is the sealing of the microchip with a protective layer, to keep out humidity and guard from damage and contamination.**
- **Sorting. This is the testing of each die on the wafer to test its functionality, speed etc.**
- **Packaging. Each microchip is placed in a plastic, ceramic, or metal case and is connected to the outside world via bonding to the package's pins or legs. Some microchips are not even packaged, but directly surface mounted to a printed circuit board (pcb) and covered with a nice dollop of epoxy.**



In the next chapter we will look more closely at the Microlithography part of the above manufacturing process and discover the challenges which must be met and overcome to achieve the super fast microchips we take for granted today.

Chapter 2

The Isolated Heart

To fully comprehend a microlithography machine's performance, one has to comprehend the accuracy required to create an accurate pattern upon a silicon wafer at a **sub micron** level. A human hair is 20-40 microns thick! To achieve this the heart of the machine, the **exposing** module, has to be isolated from the vibrations and 'noise' of the outer world, and literally float in space, suspended in a totally undisturbed universe of its own.

A simple example: Try and draw a perfect vertical line with a length of 30 cm and a width of 2mm on a flat piece of paper. Can you do it? Not likely. If you look under a microscope at your resulting line you could even say it was a pathetic attempt. Why is your result so bad? Many reasons: Your muscles slightly tremble, your breathing rhythm interferes, your heart beat vibrates and your eyesight and coordination have limitations. These are some of the obvious reasons. The other non obvious causes, are the vibrations caused by **sound waves** from the TV in the living room, the **unflatness** of the paper, the refrigerator motor vibrations coming up through the floor etc. etc. You start to get the idea.

Now, imagine the unacceptable results of exposing a 0.13 micron wide line, 25 microns in length on a silicon wafer, placed on your your dining room table. *The Horror*!!! The Litho police would be kicking down the door before you even got to the microscope to look at the results.

What is in the Exposing Module ?

-The Optical Projection Lens. This is the most critical part of the microlithography machine. The make and break of it all. If a microchip manufacturer demands a 0.18micron process then the projection lens must be able to recreate images at this resolution. Every single element of the machine is built around the lens. The purpose of the lens is the projection of the pattern on the reticle onto the wafer. What properties do we demand of our lens? Predefined optical characteristics with minimal optical distortions, extremely accurate physical dimensions. Also, the lens manufacturer must identically be able to create many of these lens, as they will be used in many machines. It is common to see in a fabrication plant up to 30 of a certain type or types of microlithography machines 'pumping' out production wafers. Typically today the lens will have a 4:1 or 5:1 reduction (the resulting image on the wafer will be smaller than on the reticle).

-The reticle support system. This part supports the reticle and positions it accurately above the lens during the exposure sequence. This part is also known as the **Reticle Stage.**

- The wafer support system. This part supports the silicon wafer and positions the wafer correctly under the lens during the exposure sequence. Also known as the Wafer Stage.

-The wafer loading system. We have to place and remove wafers from the system, right? This part of the machine loads and unloads the wafers.

- The reticle loading system. Each layer of the final microchip product has a different pattern. A reticle 'holds' this pattern. So when its time to move on to the exposure of a subsequent layer we need to unload the previous reticle and load the next one. Also switching between different products, running calibration tests etc. will require different reticles.

- Alignment system. In order to project the reticle image onto the **correct** position upon the wafer we need to align the reticle and wafer prior to the exposure sequence. The system performing this task of alignment must also be isolated from vibrations and noise. Keep in mind that if we attempt to build up a multi layered microchip all layers **must** be overlayed with a minimal misalignment. Otherwise...your microchip will not function as required or expected.

- Illumination delivery system. We have the exposure light source (...used to soften the parts of the light sensitive resist coating on the silicon wafers - remember...?) This source of light depends on the light wavelength required (This is a whole other subject, deserving an article of its own...). It could be 365nm, 248nm or 193nm.

Anyway, this light needs to get to the reticle somehow, in a very accurate manner, with predefined light uniformity, telecentricity and polarisation. The illumination delivery system does exactly this. Another task taken care of by the illumination delivery system is to make sure we give the correct dose during the exposure. This simply means what length of time shall each exposure take. Defined, amongst various parameters, by the sensitivity level of the photo resist used. To start an exposure we open a very fast exposure shutter and close this shutter to finalize an exposure. Just like a camera!

How do we isolate it?

Well, this is real tricky for sure. Why? Because we are talking about a few tons of weight. And we must be able to use the isolation system also in a way that can compensate for vibrations and noise. In other words it must be a **dynamic isolation** system.

Very weak springs can also be used to suspend the **exposure module**, but they are just not accurate or reliable enough and you cannot 'tweak' them too much for performance. Another way is through magnetic coupling. Ever seen those super fast Bullet trains in Japan? They 'levitate' with the force of a magnetic field as they magnetically propel themselves forward. This is a fairly good solution, since we all know the equation F=BIL (right...? anyone...?) and we can control the performance (Forces) of this system with electrical current (I).

Another very good way is seating the **exposing module** on top of a 'balloon' or 'air cushion'. The basic idea is used in a certain way to suspend burn patients in hospitals. This requires a good pneumatic control system. But is very stable and controllable. Depending on the type of Microlithography machine, all of these solutions are used, in combination or independently.

Temperature Monitoring and Control

OK. We have isolated all the critical components in the microlithography machine from the vibrationous world outside, but now we need to control its environment. This simply means keep the critical modules and systems and a predefined temperature and humidity. Why is this necessary? Lets take an example: the Projection Lens.

If the lens heats up (and it will heat up - 248nm light is **Ultra Violet** light and gives us sunburn and dried tomatoes) then it expands, and if it **expands** the 4:1 reduction lens property is no longer true and we can no longer expose our wafers with confidence that all will be OK. Hmm....problem, eh? Nothing we cannot deal with.

Solutions:

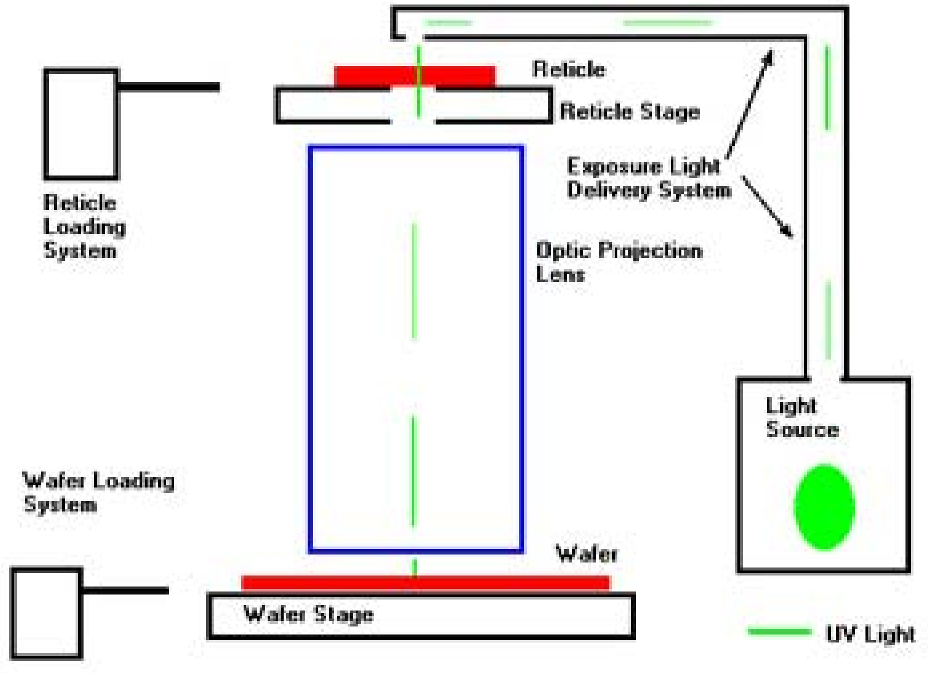
- Keep the lens at a certain constant temperature in a closed monitoring loop. Good cooling agents are water and air.
- Immediately compensate for the lens expansion with a adjustable **magnification** lens controlled by a thermometer.

Environment

We need a very clean environment for the production of micrcohips. A single 1micron dust particle can kill your microchip. Today a Class 1 (one 0.5 micron particle per every cubic foot specification - cleaner than the cleanest hospital operating theatre) cleanroom environment is mandatory. Huge filters filter the air and maintain laminar air flow. **Humidty** is also a big concern. We are not interested in condensation anywhere inside or outside of our exposure module.

Human/Machine Interfacing

Now we have our system nicely prepared for work how do we tell it what to do? You guessed. A computer interface. Software controls all aspects of the microlithography machine. From monitoring temperatures to unloading a wafer and also self calibration tests to a complete shutdown and restart. Through this software interface we will also load production jobs, that hold all the information needed by the microlithography machine to know what reticle to use, how many wafers to expose and at what dose, how many individual exposures per wafer and at what coordinates to place these exposures upon the wafer.



The Exposing Sequence of a Batch

1) Load the correct job into the software.
2) load the reticle.
3) load the first wafer.
4) Align wafer and reticle to each other.
5) Position wafer at the 1st die position on the wafer.
6) Expose the die.
7) Move to next die position and repeat exposure until the complete wafer exposed (total number of dies on the wafer will vary according to each die size).
8) Unload wafer.
9) Repeat steps 4,5,6,7,8 until all wafers in this batch are completed.

Jim Adkins