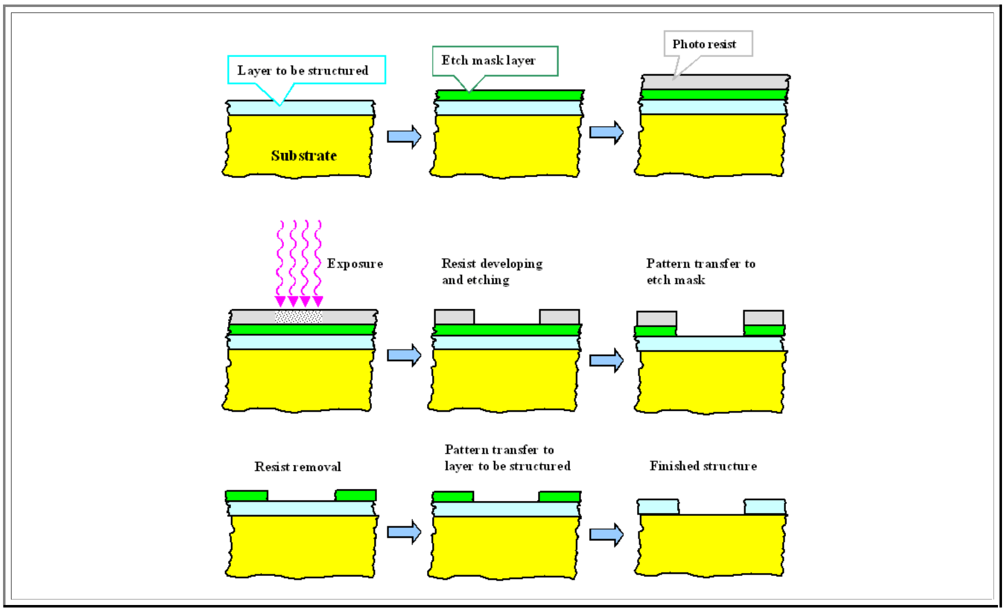
6.5 Lithography

6.5.1 Basic Lithography Techniques

Process flow of Lithography (and Pattern Transfer)

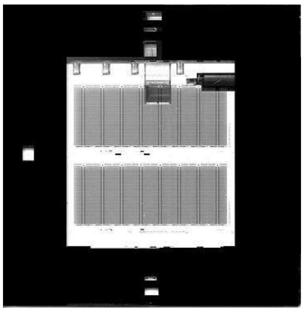
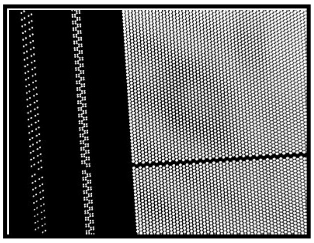
- Lets start by considering the basic processes for the complete structuring module.
  - Shown is a more complex process flow with a special etch mask layer (usually **SiO_2**).
  - Often, however, you just use the *photo resist as masking layer for etching*, omitting deposition, structuring, and removal of the green layer. A photo resist mask generally is good enough for ion implantation (provided you keep the wafer cool) and many plasma etching processes.



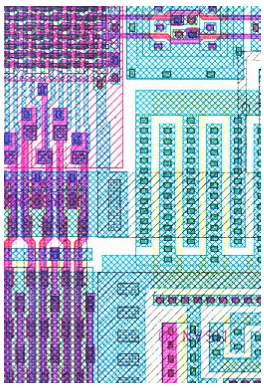
- As far as lithography is concerned, it is evident that we need the following key ingredients:
  - A **photo resist** [1)], i.e. some light sensitive material, not unlike the coating on photographic film.
  - A **mask** (better known as **reticle** [2)]) that contains the structure you want to transfer - not unlike a slide.
  - A **lithography unit** that allows to project the pattern on the mask to the resist on the wafer. Pattern **No. x** must be *perfectly aligned* to pattern **No. x - 1**, of course. Since about **1990** one (or just a few) chips are exposed at one time, and than the wafer is moved and the next chip is exposed. This step-by-step exposure is done in machines universally known as **steppers**.
  - Means to **develop** and structure the resist. This is usually done in such a way that the *exposed* areas can be removed by some etching process (using **positive resist**). For some special purpose, you may also use **negative resists**, i.e. you remove the *unexposed* areas.
- In principle, it is like projecting a slide on some photosensitive paper with some special development.
  - However, we have some very special requirements. And those requirements make the whole process very complex!
  - And with *very complex* I mean *really* complex, super-mega-complex - even in your wildest dreams you won't even get close to imagining what it needs to do the lithography part of a modern chip with structures size around **0,13 µm**.
- But relax. We are not going to delve very deep into the intricacies of lithography, even though there are some advanced material issues involved, but only give it a cursory glance.

Reticles

- For any layer that needs to be structured, you need a ***reticle***. Since the projection on the chip usually reduces everything on the reticle fivefold, the reticle size can be about **5** times the chip size
  - A reticle then is a glass plate with the desired structure etched into a **Cr** layer. Below, a direct scan of an old reticle is shown, together with a microscope through-light image of some part.
  - "Obviously", the regular lattice of small opening in the non-transparent **Cr** layer is the array for the trenches in a memory chip. The smallest structures on this reticle are about **5 µm**.

	
Typical reticle, about original size	Enlargement (**x 100**)

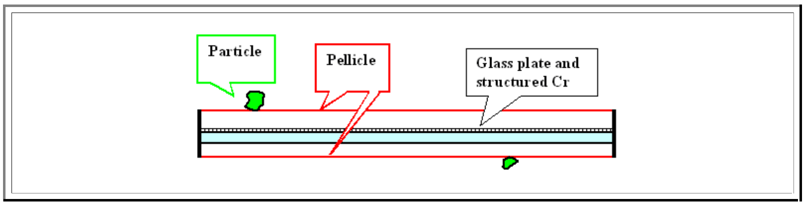
- Before we look at the requirements of reticles and their manufacture, lets pause for a moment and consider how the structure on the reticle comes into being.



- First, lets look at these structure, or the **lay-out** of the chip. Shown on the left is a tiny portion of a **4 Mbit DRAM**.
- Every color expresses *one* structured layer (and not all layers of the chip are shown).
- A print-out of the complete layout at this scale would easily cover a soccer field.
- The thing to note is: it is *not* good enough to transfer the structure on the reticle to the chip with a resolution *somewhat better* than the smallest structures on the chip, it is also necessary to superimpose the various levels with an **alignment accuracy** *much better* than the smallest structure on the chip!
- And remember: We have about **20** structuring cycles and thus reticles for one chip.

- The *lay-out* contains the *function* of the chip. It established where you have transistors and capacitors, how they are connected, how much current they can carry, and so on.
  - This is determined and done by the product people - electrical engineers, computer scientists - no materials scientists are involved.
  - The *technology*, the making of the chip, determines the *performance* - speed, power consumption, and so on. This is where material scientists come into their own, together with semiconductor physicists and specialized electrical engineers (who e.g., can simulate the behavior of an actual transistor and thus can tell the process engineers parameters like optimal doping levels etc.).
  - In other words, the reticles are the primary input of the product engineers to chip manufacturing. But they only may contain structures that can actually be made. This is expressed in **design rules** which come from the production line and must be strictly adhered to. Only if *all* engineers involved have some understanding of *all* issues relevant to chip production, will you be able to come up with aggressive and thus competitive design rules!

- What are the requirements that reticles have to meet (besides that their structures must not contain mistakes from the layout. e.g. a forgotten connection or whatever).
  - Simple: They must be *absolutely* free of defects *and* must remain so while used in production! Any defect on the reticle will become transferred to *every* chip and more likely than not will simply kill it.
  - In other words: Not a single particle is ever allowed on a reticle!
- This sounds like an impossible request. Consider that a given reticle during its useful production life will be put into a stepper and taken out again a few thousand times, and that every mechanical movement tends to generate particles.
  - Lithography is full of "impossible" demands like this. Sometimes there is a simple solution, sometimes there isn't. In this case there is:
  - First. make sure that the freshly produced reticle is defect free (you must actually check it pixel by pixel *and* repair unavoidable production defects).
  - Then encase it in **pellicles** [3] (= fully transparent thin films) with a distance of some mm between reticle and pellicle as shown below.



  - One of the bigger problems with steppers - their very small (about **1 µm**) *depth of focus* - now turns to our advantage: Unavoidable particles fall on the pellicles and will only be imaged as harmless faint blurs.
- How do we make reticles?
  - By writing them pixel by pixel with a finely focussed electron beam into a suitable sensitive layer , i.e. by direct writing **electron-beam lithography**.
  - Next, this layer is developed and the structure transferred to the **Cr** layer.
  - Checking for defects, repairing these defects (using the electron beam to burn off unwanted **Cr**, or to deposit some in a kind of e-beam triggered **CVD** process where it is missing), and encasing the reticle in pellicles, finishes the process.
- Given the very large pixel size of a reticle (roughly $\mathbf{10^{10}}$), *this takes time* - several hours just for the electron beam writing!
  - This explains immediately why we don't use electron beam writing for directly creating structures on the chip: You have at most a few seconds to "do" one chip in the factory, and e-beam writing just can`t deliver this kind of throughput.
  - It also gives you a vague idea why reticles don't come cheap. You have to pay some **5000 $ - 10 000 $** for *making* one reticle (making the lay-out is not included!). And you need a set of about 20 reticles for one chip. And you need lots of reticle sets during the development phase, because you constantly want to improve the design. You simply need large amounts of money.

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[1] Something as a protective coating that resists or prevents a particular action (Webster, second meaning)

[2] A system of lines, dots, cross hairs, or wires in the focus of the eyepiece of an optical instrument (Webster)

[3] A thin skin or film, especially for optical uses