Course Title: Processing & Fabrication Technology
Course No.: EEE 707

Class lecture -1

Introduction to Fabrication

Basic Fabrication Steps

There are more than 200 processing steps. In IC fabrication the major steps are followed:

- Wafer preparation
- Lithography
- Oxidation
- Etching
- Ion Implantation and
- Metallization

Basic Fabrication Steps...

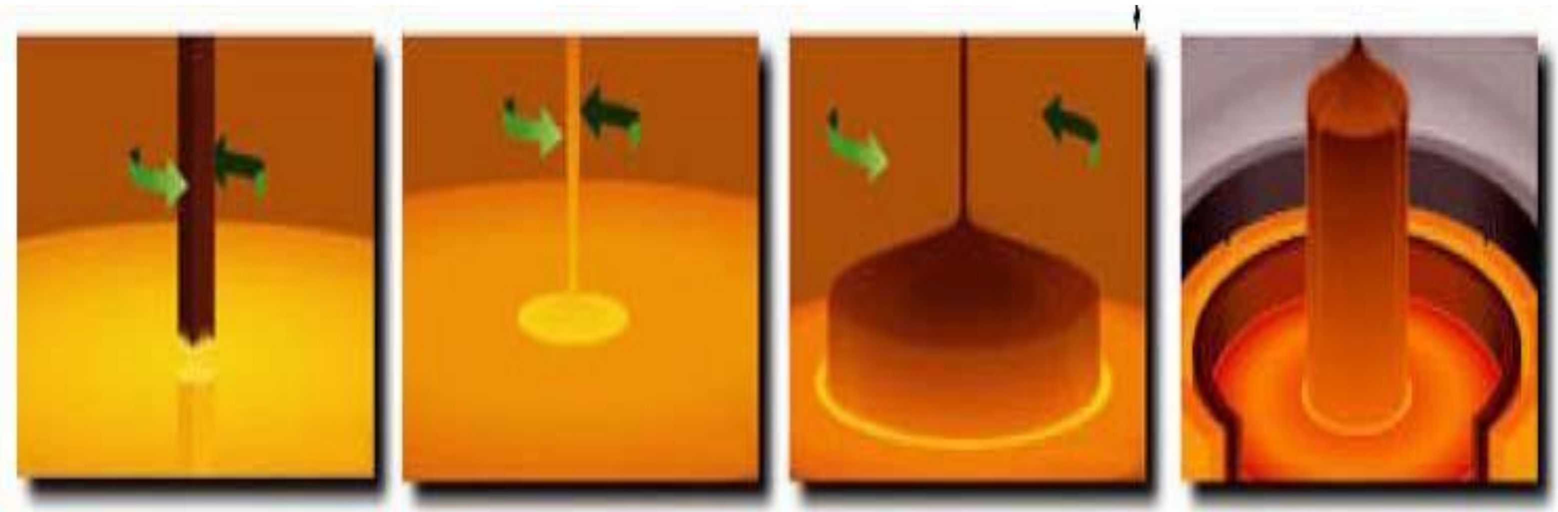
- Wafer processing is to produce the proper type of substrate.
- Lithography is used to precisely define of each region.
- Oxidation, deposition and ion implantation is used to add materials to the wafer.
- Etching is used to remove materials from the wafer.
- Metallization is used to form ohmic contacts and interconnections.

Introduction to Wafer preparation

Wafer Processing

The starting wafer in a CMOS technology must be created with a very high quality. i.e. the wafer must be grown as a single crystal silicon body having a very small number of defects. Furthermore, the wafer must contain the proper type and level of doping so as to achieve the required resistivity. This is accomplished by the “Czochralski method”, whereby a seed of crystalline silicon is immersed in molten silicon and gradually pulled out while rotating. As a result, a large single crystal cylindrical “ingot” is formed that can be sliced thin into wafers.

Wafer Processing…



Single Crystal Silicon Ingot

Introduction to Lithography

Lithography Techniques

- Optical/Photo Lithography
- Electron Lithography
- X-ray Lithography
- Ion-radiation Lithography

Photolithography

- In each processing steps a certain area on the chip is masked out using the appropriate optical mask so that a desired processing step can be selectively applied to the remaining regions. The processing steps include (i) oxidation, (ii) etching, (iii) metal, polysilicon and buffer material deposition, and (iv) diffusion and ion implantation.
- The technique to obtain/accomplish the selective masking is called photolithography.
- This process transfers hundreds of millions of patterns to the semiconductor surface simultaneously.

Photolithography Process

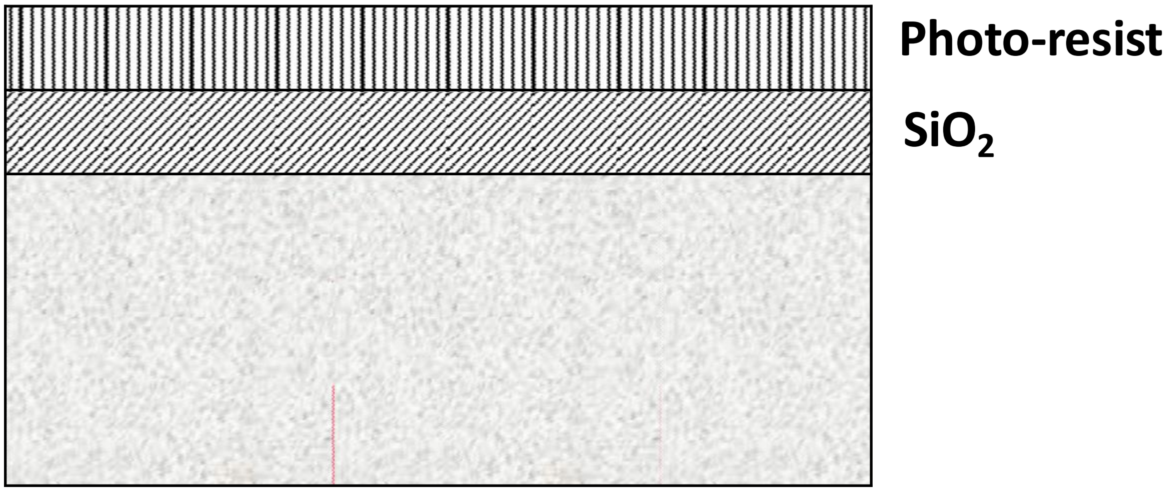
The typical operations involved in photolithography are:

1. Photo-resist coating
2. Stepper exposure
3. Photo-resist development
4. Etching
5. Spin, rinse and dry
6. Photo-resist removal or ashing

Step-1: Photo-resist coating

A light sensitive polymer (photo-resist) is evenly applied while spinning the wafer to a thickness of approximately 1 μm. This material is originally soluble in a chemical solvent, but has the property that polymers cross-link when exposed to light, making the affected region insoluble. A photo-resist of this type is called a negative photo-resist. A positive photo-resist has the opposite property.

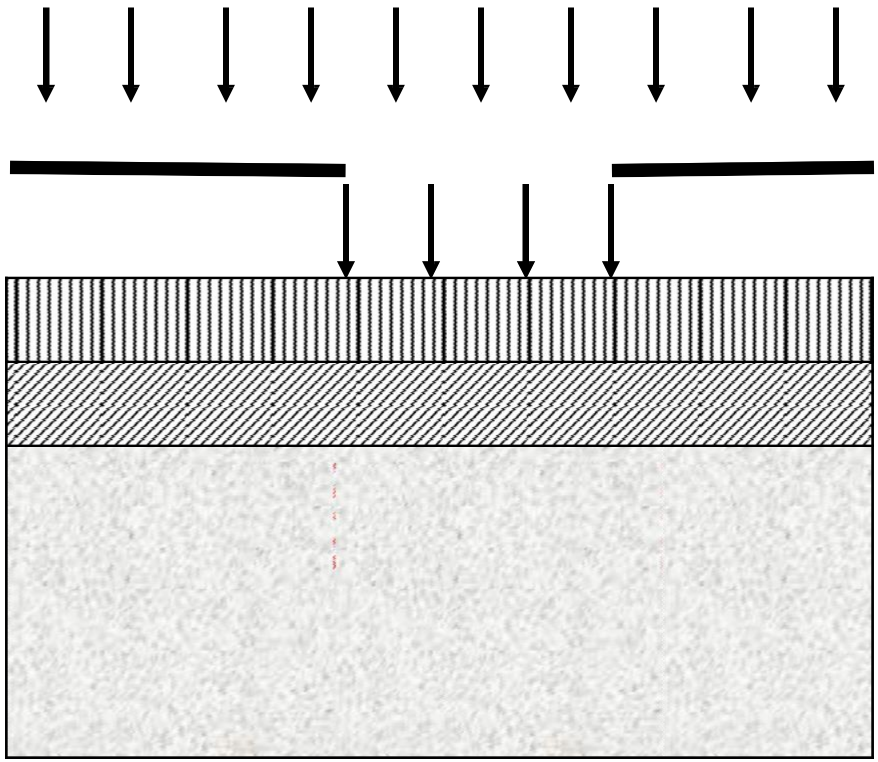
Step-1: Photo-resist coating…



Step-2: Stepper exposure

A glass mask containing the patterns that we want to transfer to the silicon, is brought in close proximity to photo-resisted wafer. The mask is opaque in the regions that we want to process, and transparent in the other region (in case of negative photo-resist). The combination of mask and wafer is now exposed to ultra-violet light. Where the mask is transparent, the photo-resist becomes insoluble.

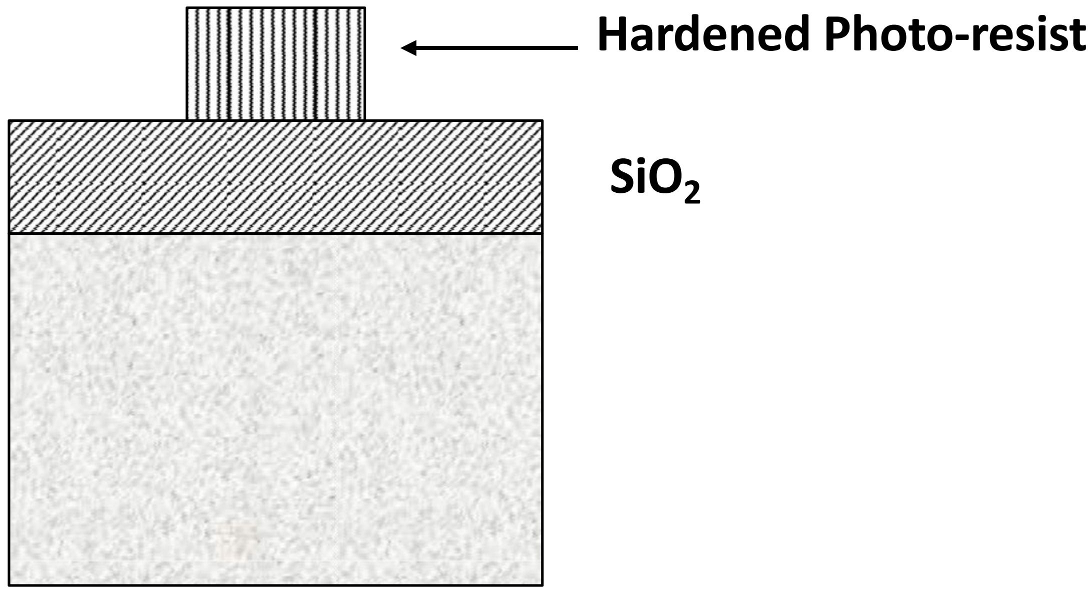
Step-2: Stepper exposure…



Step-3: Photo-resist development

The wafer is developed in an acid or base solution to remove the resist from the non-exposed areas. Once the non-exposed photo-resist is removed, the wafer is “soft-baked” at a low temperature to harden the remaining photo-resist.

Step-3: Photo-resist development…



Step-4: Etching

Material is removed from the areas of the wafer that are not covered by the photo-resist through etching process. Two types of etching usually performed (i) Wet etching, and (ii) Dry etching.

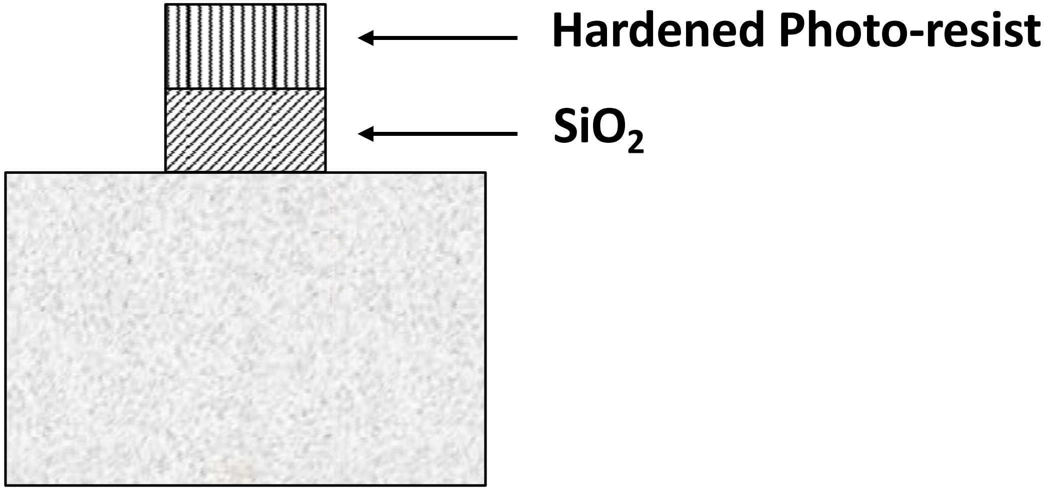
Wet etching is accomplished by using many different types of acid, base and caustic solutions as a function of material that is to be removed. For instance, hydrochloric acid buffered with ammonium fluoride is typically used to etch SiO2.

Step-4: Etching…

In dry or plasma etching, the wafer is placed into the etch tool's processing chamber and the negative electrode attached to the region to be etched. The chamber is heated to 100°C and brought to a vacuum level of 10 mTorr. The chamber is then filled with a positively charged plasma by supplying a mixture of chlorine and boron trichloriide.

Plasma etching offers a well-defined directionality to the etching action, creating patterns with sharp vertical contours.

Step-4: Etching…

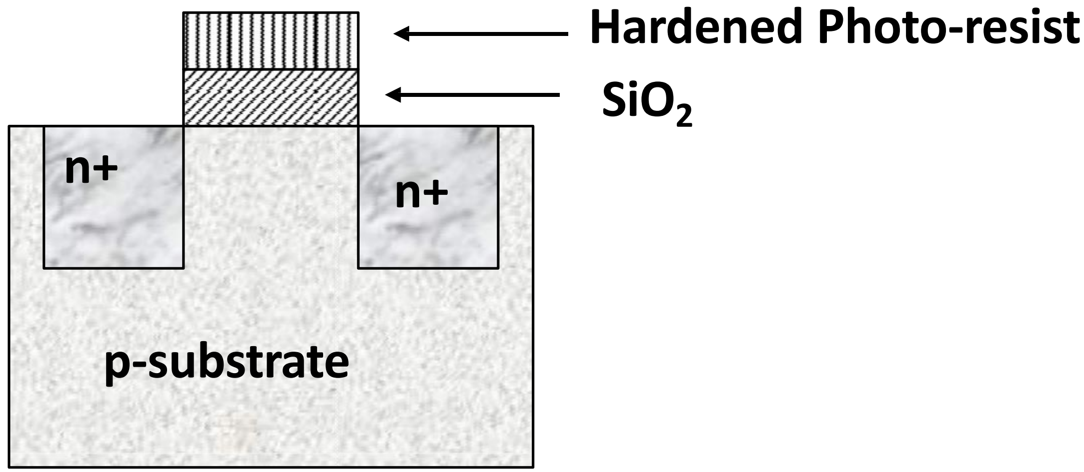


After plasma etching SiO_2 is removed

Step-5: Spin, rinse and dry

A special tool (called SRD) is used to clean the wafer with

de-ionized water and dries it with nitrogen.

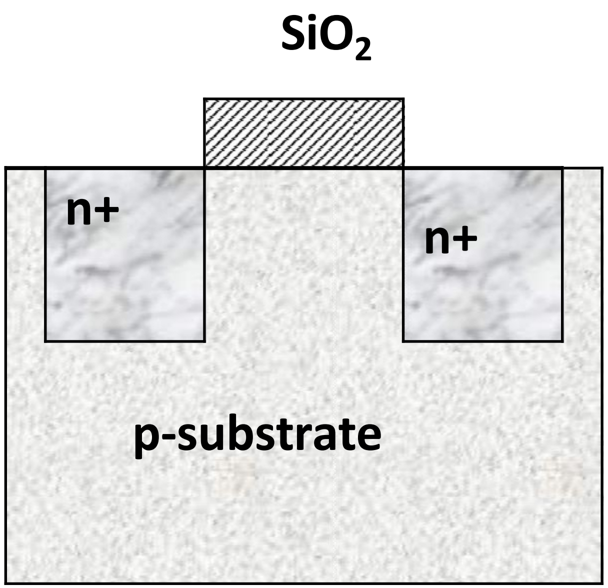


After diffusion/ion implantation, n+ source and drain is produced

Step-6: Photo-resist removal or ashing

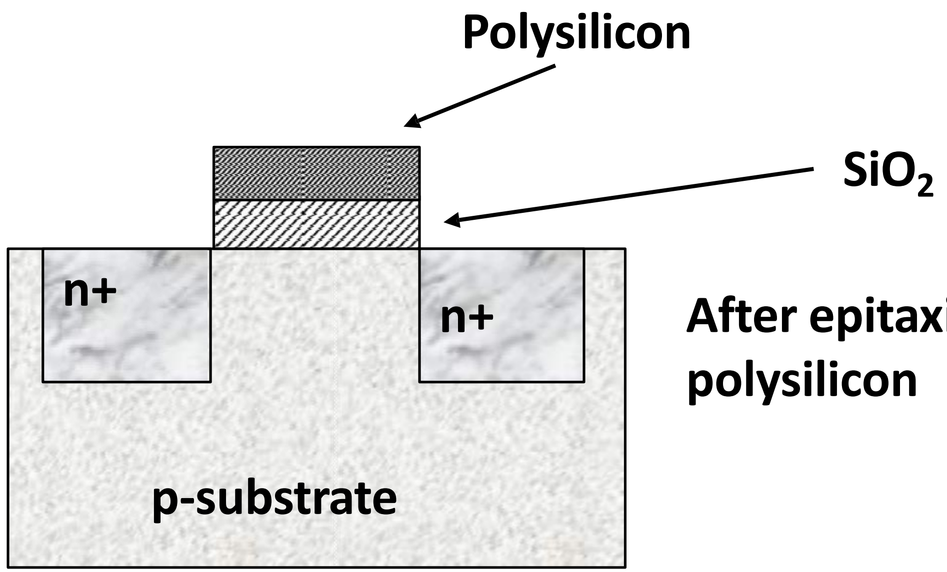
After completing the recurring process steps (such as diffusion or ion implantation, deposition and dry etching), a high temperature plasma is used to selectively remove the remaining photo-resist without damaging the device layers.

Step-6:



After ashing remaining photo resist is removed

Step-7: Development of Gate

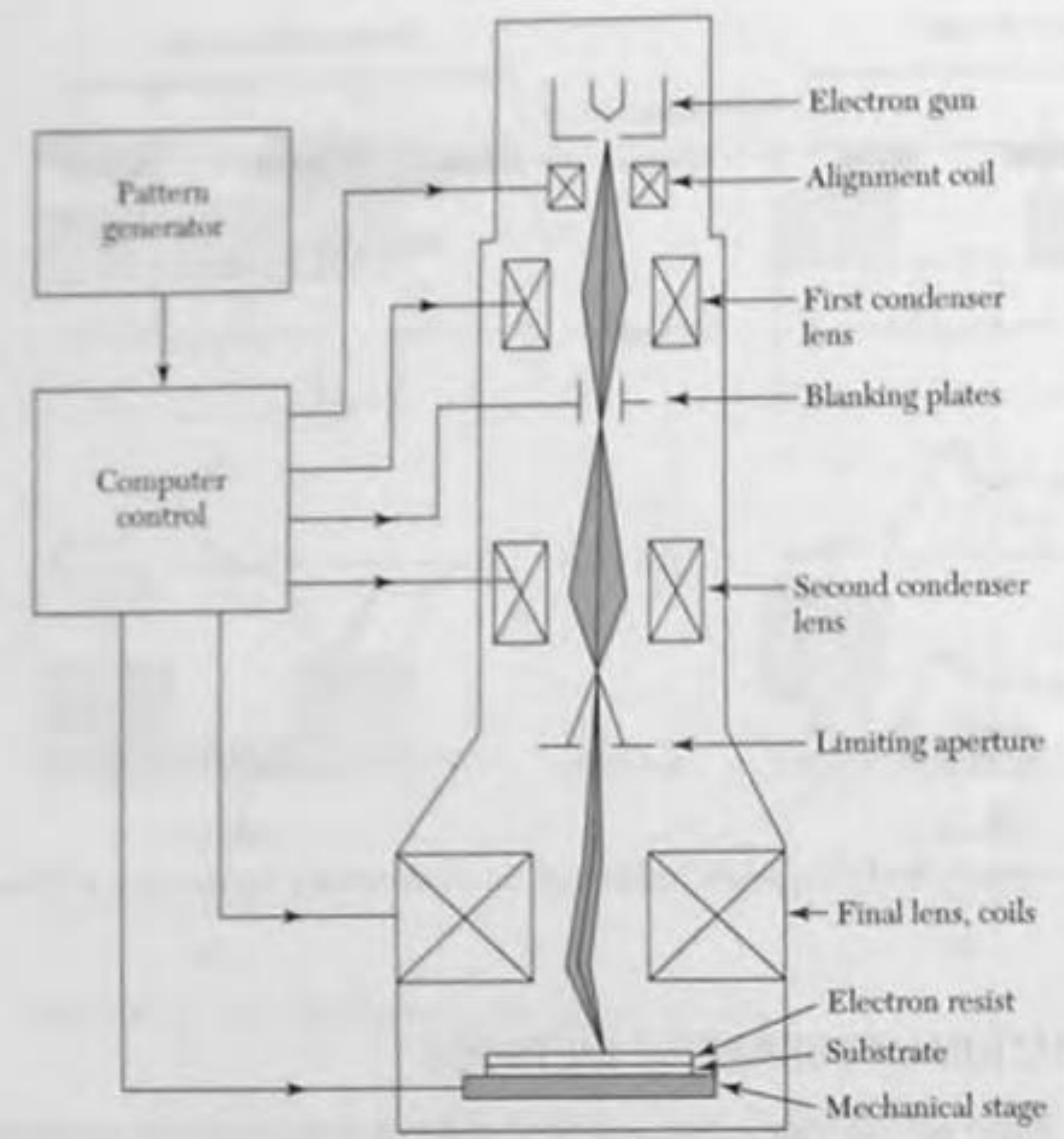


After epitaxial growth of polysilicon

After this step, aluminum contacts are made from source, drain and gate.

Electron Beam Lithography (e-beam)

- Electron beam (e-beam) lithography is primarily used to produce photomasks. Relatively few tools are dedicated to direct exposure of the resist by a focused electron beam without a mask.



Schematic of an Electron beam lithography machine

Electron Beam lithography…

- The electron gun is a device that can generate a beam of electrons with suitable current density. A tungsten thermionic emission cathode or single-crystal lanthanum hexaboride (LaB_6) is used for the electron gun.
- Condenser lenses are used to focus the electron beam to a spot size 10 to 25 nm in diameter.
- Beam blanking plates, which turn the electron beam on and off and beam deflection coils are computer controlled and operated at MHz or higher rates to direct the focused electron beam to any location in the scan field on the substrate. Because the scan field is much smaller than the substrate diameter, a precision mechanical stage is used to position the substrate to be patterned.

Electron Beam lithography…

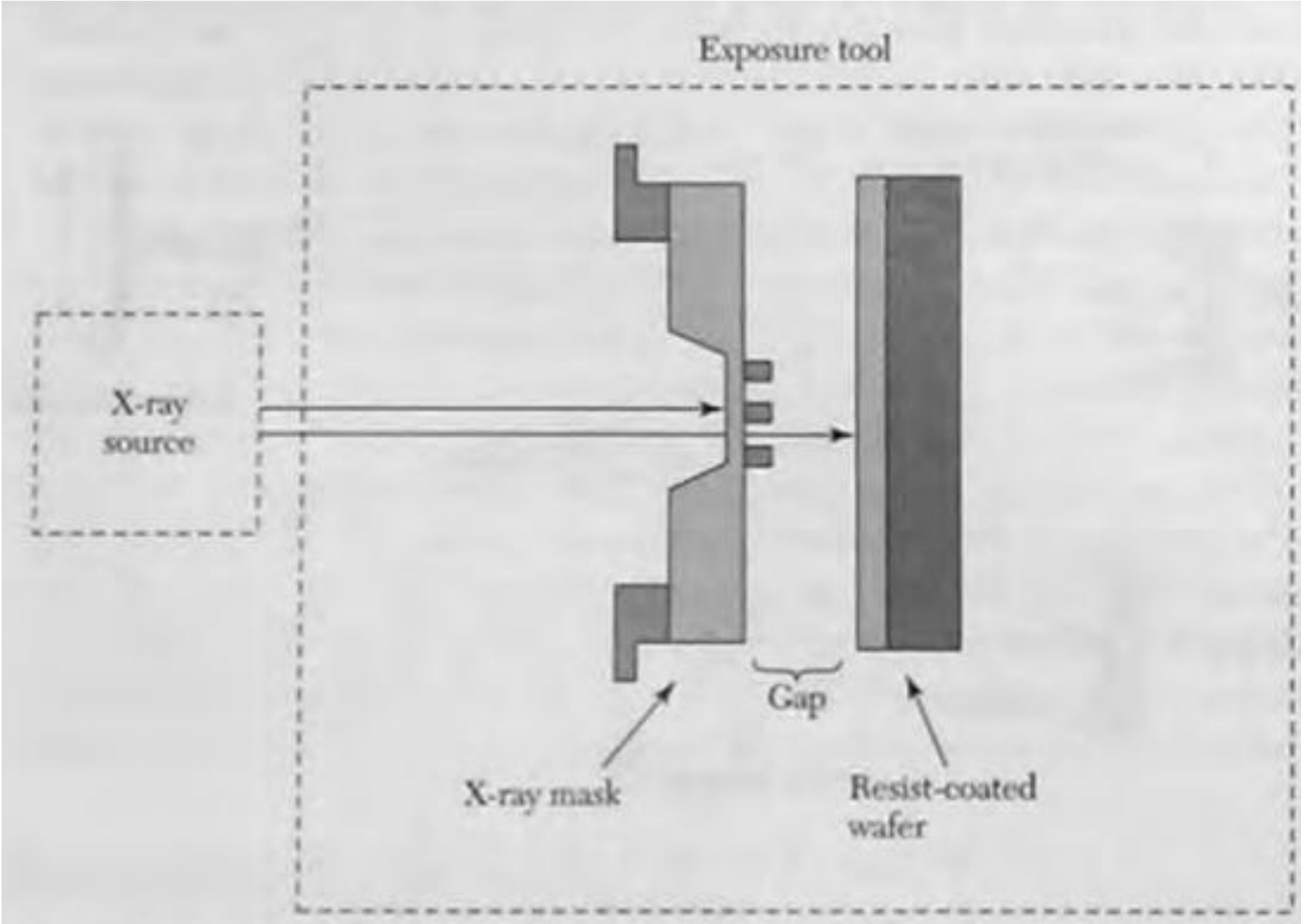
- The advantages of electron beam lithography include the generation of submicron resist geometrics, highly automated and precisely controlled operation, greater depth of focus than that available from optical lithography and direct patterning on a semiconductor wafer without using a mask.
- The disadvantage is that electron beam lithography machines have low throughput - approximately 10 wafers per hour at less than 0.25 μm resolution.

X-Ray Lithography (XRL)

- X-ray lithography (XRL) is a potential candidate to succeed optical lithography for the fabrication of integrated circuits at 100 nm. The synchrotron storage ring is the choice of x-ray source for high-volume manufacturing. It can provide a large amount of collimated flux and can easily accommodate 10 to 20 exposure tools.

X-Ray Lithography…

- XRL uses a shadow printing method similar to optical proximity printing.
- The x-ray wavelength is about 1 nm and the printing is through a 1 x mask in close proximity (10-40 μm) to the wafer. Since x-ray absorption depends on the atomic number of the material and most materials have low transparency at λ≡1nm, the mask substrate must be a thin membrane (1-2 μm thick) made of low atomic number material, such as silicon carbide or silicon.
- The pattern itself is defined in a thin (≈0.5 μm), relatively high atomic number material such as tantalum, tungsten, gold or one of their alloys, which is supported by the thin membrane.



Schematic of a X-Ray lithography system

X-Ray Lithography…

- Masks are the most difficult and critical element of an XRL system and the construction of an x-ray mask is much more complicated than that of a photomask.
- To avoid absorption of an x-rays between the source and mask, the exposure generally takes place in a helium environment. The x-rays are produced in vacuum, which is separated from the helium by a thin vacuum window.
- The mask substrate will absorb 25% to 35% of the incident flux and must therefore be cooled. An x-ray resist 1 μm thick will absorb about 10% of the incident flux. There are no reflections from the substrate to create standing waves, so antireflection coatings are unnecessary.

Ion Beam Lithography

- Ion beam lithography can achieve higher resolution than optical, x-ray or electron beam lithographic techniques because ions have a higher mass and therefore scatter less than electrons.
- However, ion lithography may suffer from random space-charge effects, causing broadening of the ion beam.
- There are two types of ion beam lithography systems: a scanning focused-beam system and a mask-beam system.