



CMOS INTEGRATED CIRCUITS FABRICATION PROCESSES

Outline

■ Fundamental processes

- Wafer manufacture
- Thermal oxidation
- Doping processes
 - Ion implantation
 - Solid-state diffusion
- Photolithography
- Thin-film removal
- Thin-film deposition



■ CMOS process sequence (process flow)

Fundamental processes: Wafer manufacture

■ Wafer production requires three processes:

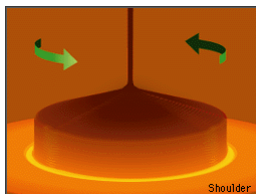
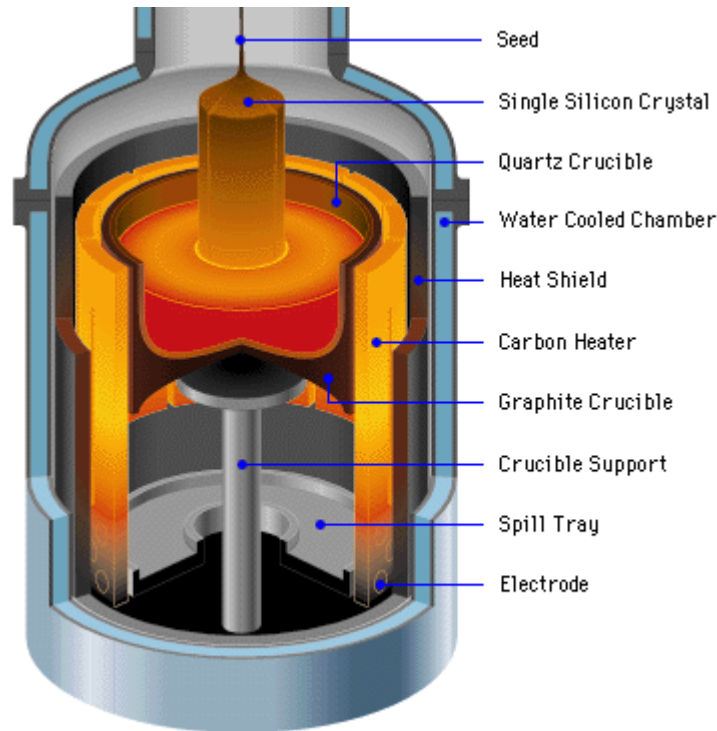
- **Silicon refinement**: Several processes are necessary in order to obtain polycrystalline chunks of silicon with the enough purity.

- Silica in a furnace at 2000°C with carbon source
$$\text{SiO}_2(\text{solid}) + 2\text{C}(\text{solid}) \rightarrow \text{Si}(\text{liquid}) + 2\text{CO}(\text{gas})$$
- Chemical reduction processes

- **Crystal growth**: Czochralski method

- **Wafer formation**: 1 mm thick (thickness increases with wafer diameter)

Fundamental processes: Wafer manufacture



Process of monocrystalline silicon ingot creation

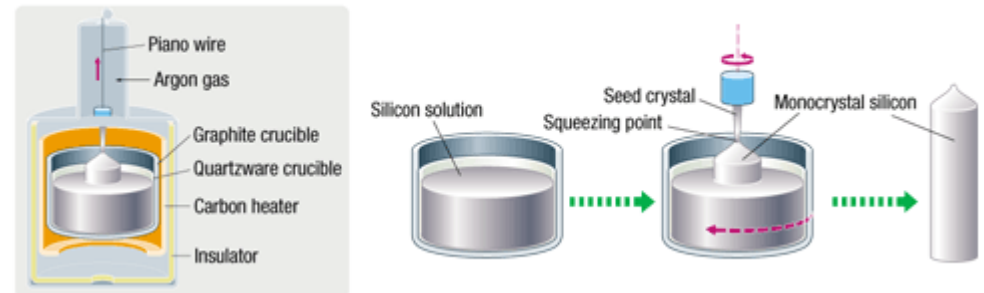
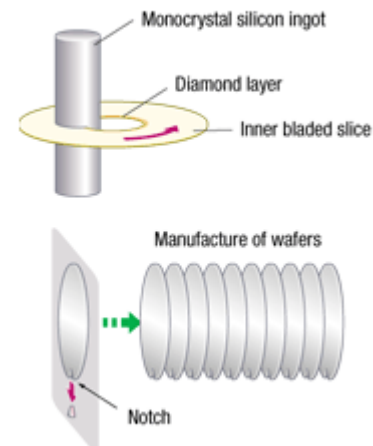
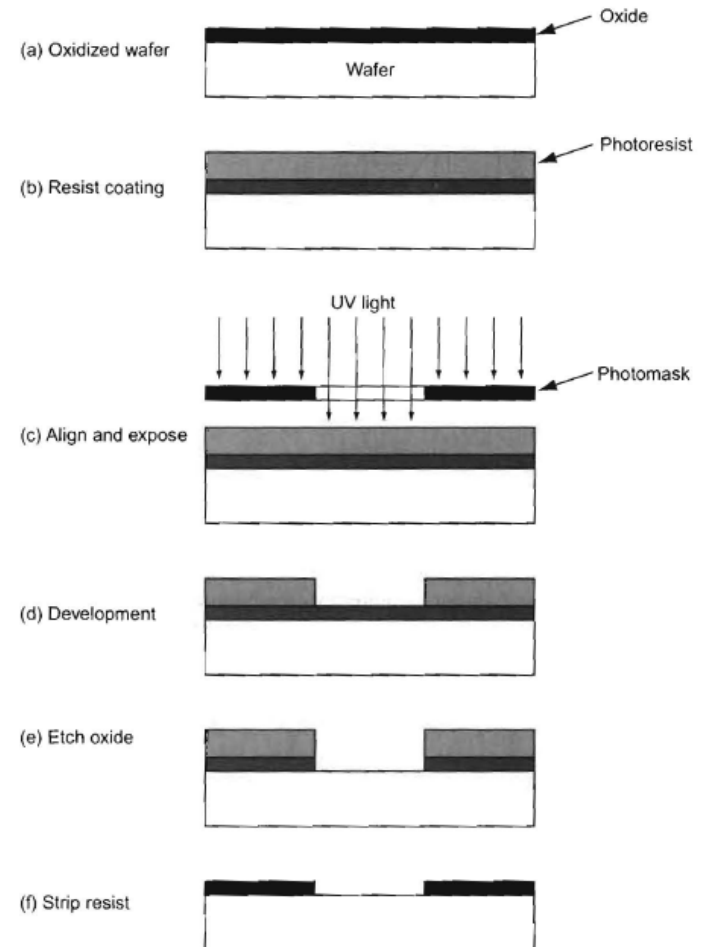


Fig. 1 Cutting of silicon wafer

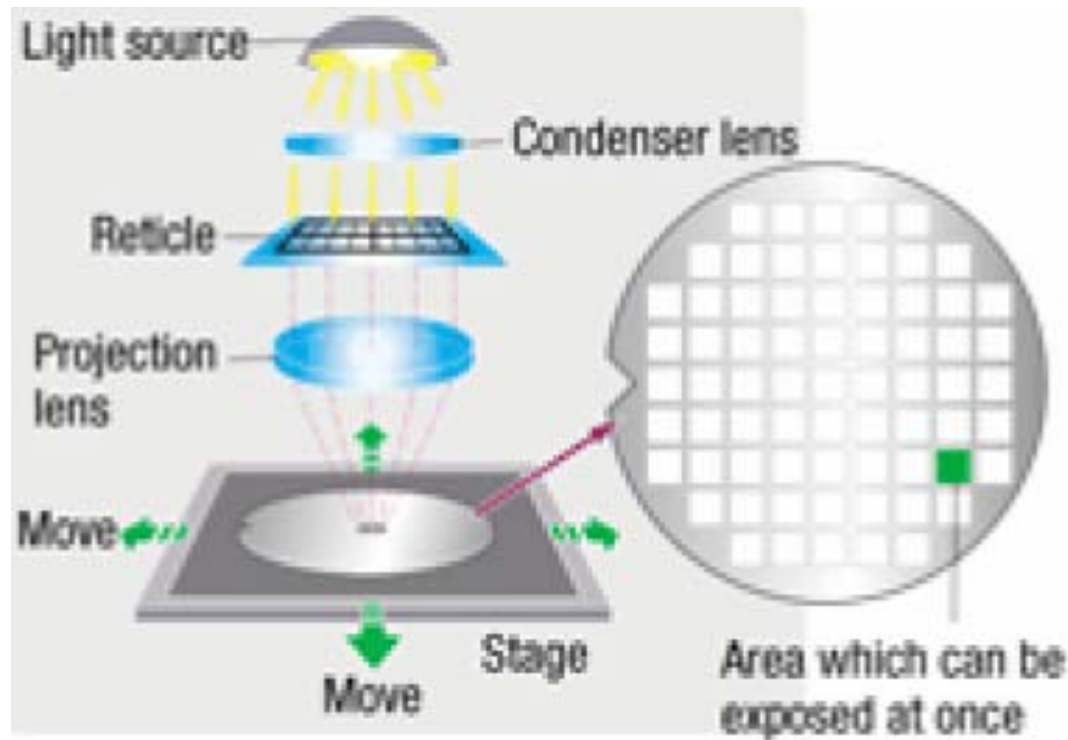


Fundamental processes: Photolithography

- Process used to select the parts in a wafer that must be affected by a given fabrication process
- A light-sensitive polymer called photoresist serve as ion implantation masks and etch masks
- Photoresist can be negative (insoluble (hardened) after exposure to UV) or positive (soluble after exposure to UV light). Positive photoresists present a higher resolution
- Resolution: diffraction of light limits the minimum printable feature size
 - Electron beam

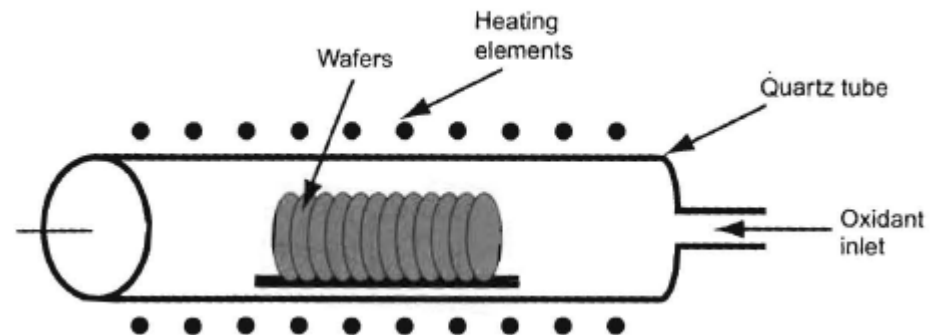


Fundamental processes: Photolithography



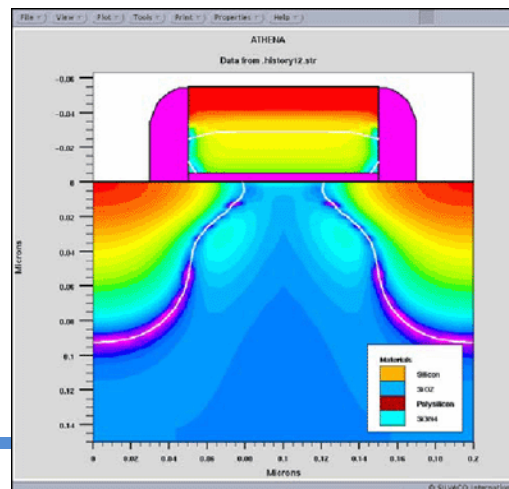
Fundamental processes: Thermal oxidation

- Silicon within an oxidant at elevated temperatures will form a thin layer of oxide (SiO_2) on all exposed surfaces.
- SiO_2 is an essential element in CMOS technology:
 - High quality dielectric such as gate oxides
 - Used for implantation, diffusion and etch masks
 - Near ideal silicon-oxide interface
- The silicon wafer is exposed at high temperatures (900-1200°C) to a gaseous oxidant:
 - O_2 : dry oxidation
 - water vapor: wet oxidation



Fundamental processes: Doping processes

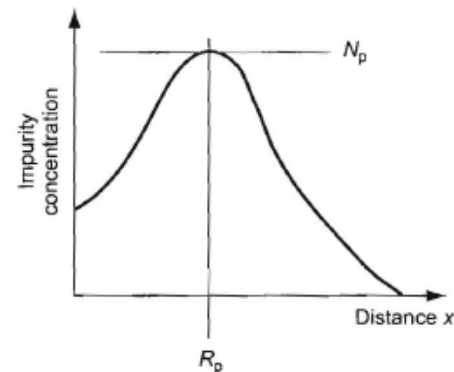
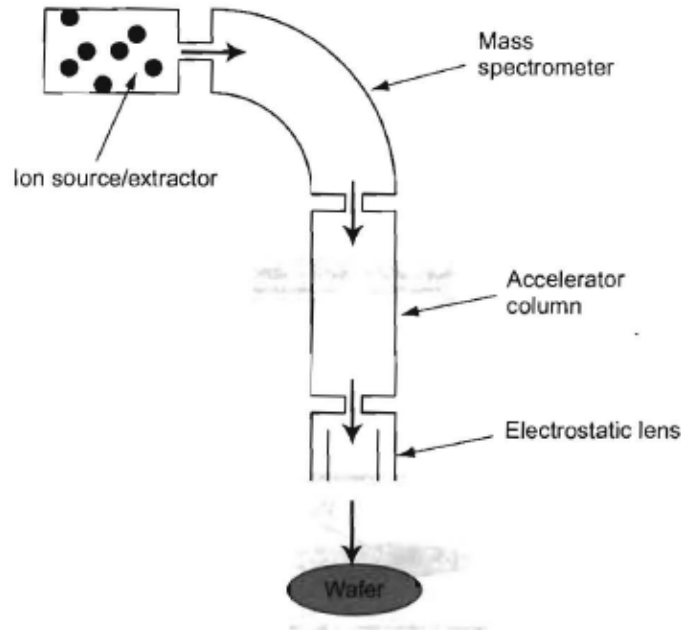
- Controlled introduction of dopant impurities into silicon
 - N-type dopants: P, As, Sb (Phosphorus, Arsenide, Antimony)
 - P-type dopant is B (Boron)
- Solid state diffusion has been the traditional doping process. Diffusion is directly proportional to the concentration gradient and thermal energy



Lateral diffusion

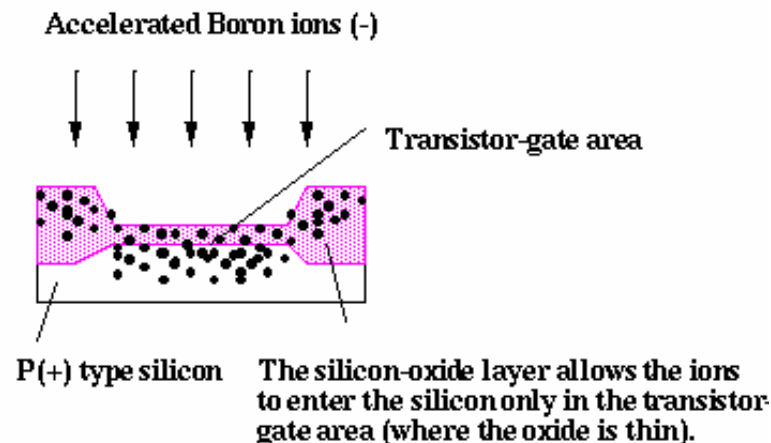
Doping process: Ion implantation

- Ion implantation is the most used method in modern CMOS fabrication
- Dopant atoms are ionized, then accelerated through a large electric potential (few kilovolts to megavolts) toward a wafer. The highly energetic ions bombard and implant into its surface.



Doping process: Ion implantation

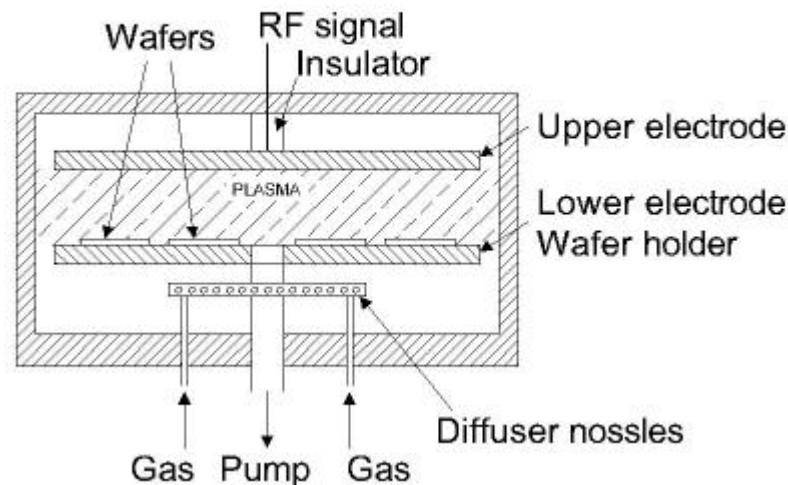
- High degree of lattice damage. It is repaired with annealing at high temperatures agitating dopant impurities into lattice sites.
- Compared with solid-state diffusion, ion implantation has the advantages of being a low-temperature and a highly controlled process.
- Nowadays, diffusion is used to redistributing dopants after the ion implantation



Fundamental processes: Thin-film removal

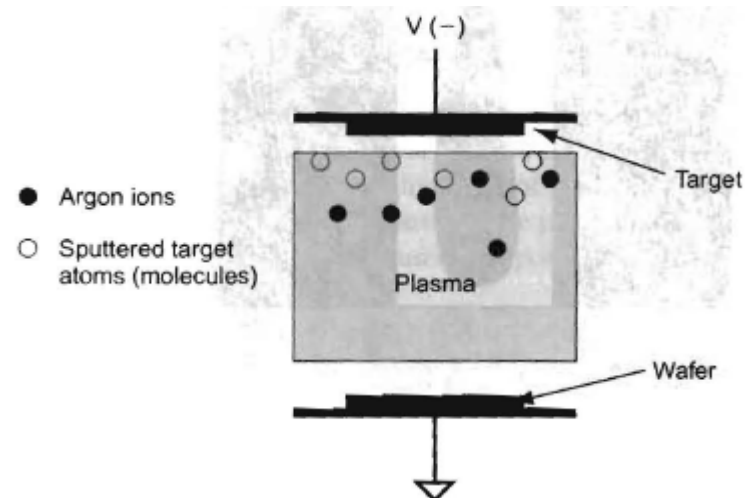
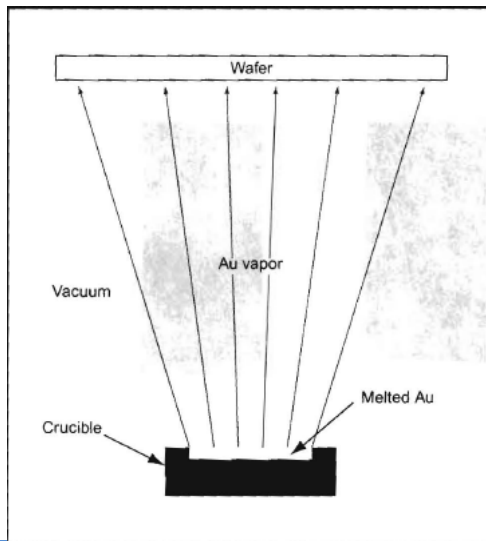
■ Processes to remove thin films

- Wet etching. A chemical solution is used to remove material. Highly selective compared with the dry-etch processes
- Dry etching.
 - The wafer is bombarded by charged ions that cause material to be ejected off the surface



Fundamental processes: Thin-film deposition

- Methods of depositing thin films of insulators, conductors and semiconductors on the wafer
 - Film thickness uniformity $< \pm 5\text{nm}$
- Physical vapor deposition (PVD). Atoms or molecules pass through a low-pressure gas phase and then condense on the surface of the substrate:
 - Evaporation
 - Sputter deposition (similar to dry etching)



Fundamental processes: Thin-film deposition

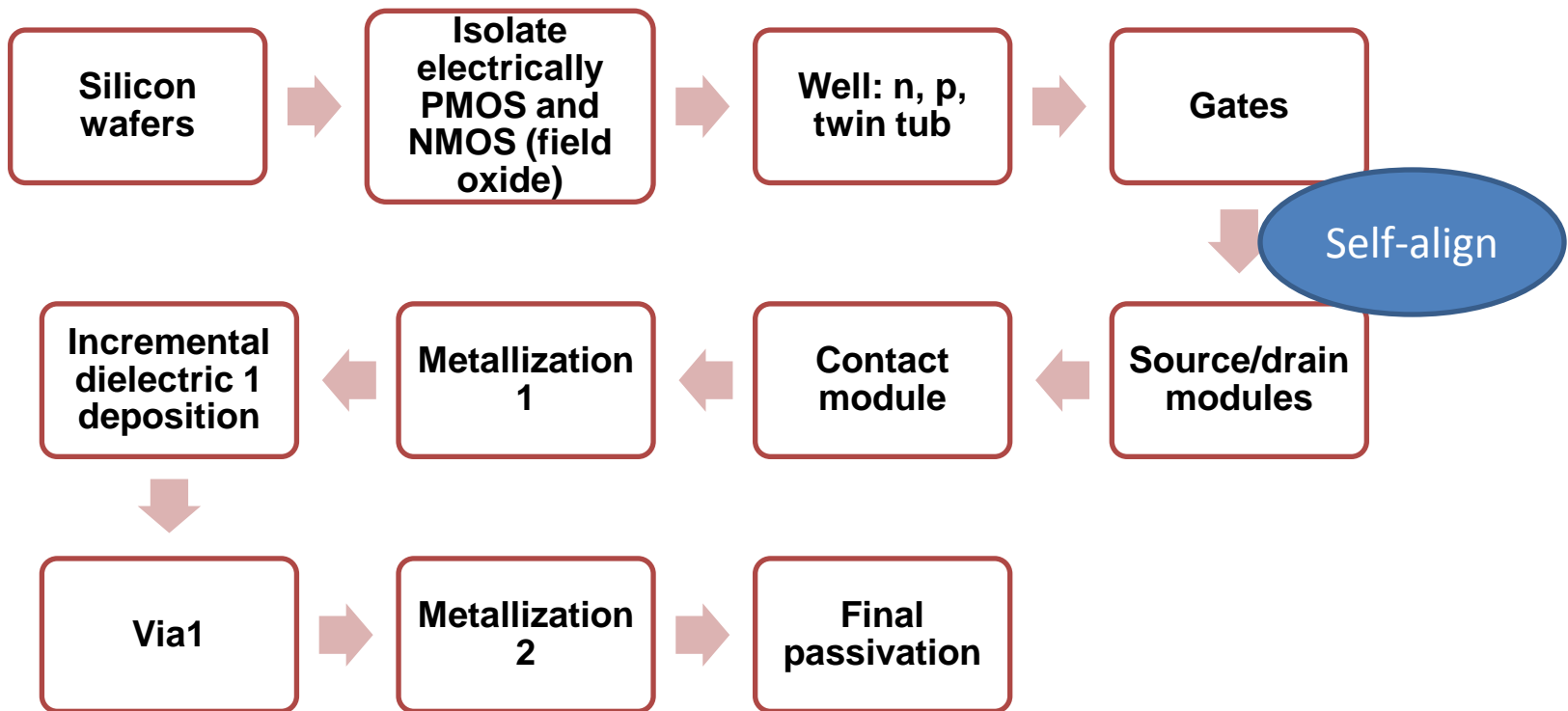
- Chemical vapor deposition (CVD). Reactant gases are introduced into a chamber where chemical reactions between the gases at the surface of the substrate produce the desired film.
- At atmospheric pressure at relatively low temperatures CVD can be applied in a reactor similar to an oxidation tube furnace
- At low pressure the process can yield better films but at the expense of a higher deposition temperature.

Polysilicon → Thin-film deposition of silicon on SiO_2

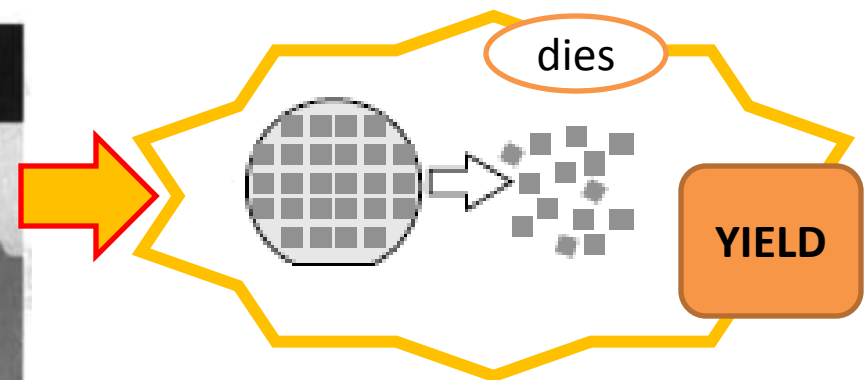
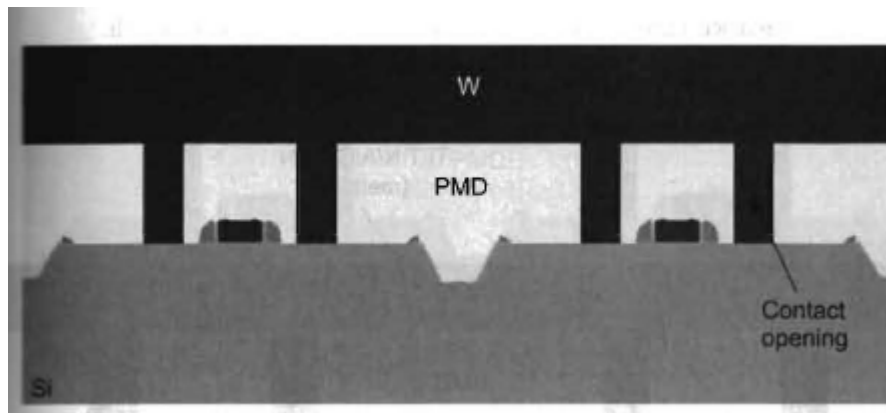
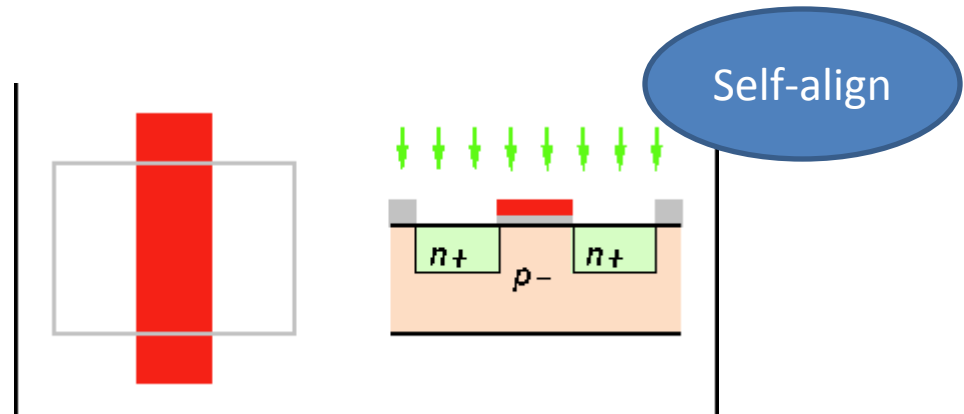
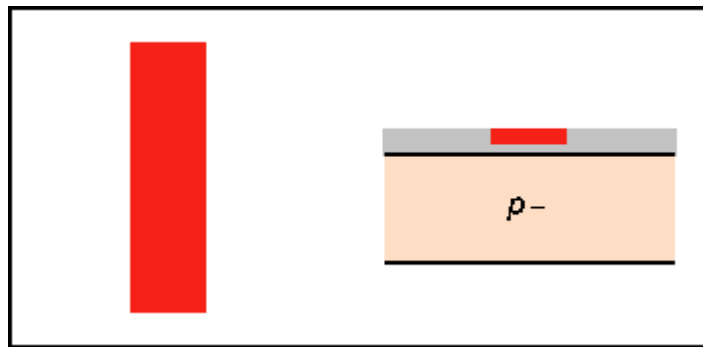
Metallization → AlCu/Ti

CMOS process sequence

- Several hundred steps are required to manufacture ICs on a silicon wafer.



CMOS process sequence



Bibliography

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