**Selective doping - Ion Implantation Machine**

- (1) Gas source of material, such as BF3 or AsH3 at high accelerating potential; valve controls flow of gas to ion source
- (2) Power supply to energize the ion source
- (3) Ion source containing plasma with the species of interest (such as +As, +B, or +BF2), at pressures of ~ 10-3 torr
- (4) Analyzer magnet: allows only ions with desired charge/mass ratio through
- (5) Acceleration tube through which the beam passes
- (6) Deflection plates to which voltages are applied to scan the beam in x and y directions and give uniform implantation
- (7) Target chamber consisting of area-defining aperture, Faraday cage, and wafer feed mechanism
Selective doping - Ion Implantation

Principles of Ion Implant

- Generation of ions
  - dopant gas containing desired species
  - BF3, B2H6, PH3, AsH3, AsF5
- plasma provides positive ions
  - (B11)+, BF2
  - (P31)+, (P31)+
- Ion Extraction
  - Ions are extracted from the source due to a high electric field
- Ion Selection
  - Magnetic field mass analyzer selects the appropriate ion (mass & charge)
- Ion Acceleration
  - Further accelerate ions giving the ions their final kinetic energy.
Selective doping - Ion Implantation

Multi-Wafer chuck

Ref: Dept. EE
STU, Iran
Selective doping - Ion Implantation - Plasma source

Variable extraction voltage (typically ~30KV)

Pressure: $10^4$ to $10^2$ Torr

Ion source is characterised by

Ion current density

$$J_{\text{ion}} = \frac{5.5 \times 10^{-8} V_{\text{ext}}^{3/2}}{d^2 \cdot M^{1/2}} \text{ Amp/cm}^2$$
Selecting doping - Ion Implantation-Mass analyzer

The ions are extracted from the source and analyzed in a magnetic field. The Lorentz force makes the ions take a curved path with a radius of curvature that depends on the mass of each ionic species. By adjusting the magnetic field strength, only the selected ions will enter the accelerating column.

Mass to charge ratio of the selected ions:

\[ \frac{M}{q} = \frac{R^2 B^2}{2 V_{ext}} \]

Conclusion:

For a Magnet, \( R \) is fixed. Hence for a given Extractor Voltage \( B \propto \sqrt{M} \)

\( B \) is controlled by coil current, which can then fix species of one mass.

Ref: Deft. PE, STU, Iran
Magnetisation Curve for a Magnet

1. Permanent Magnet
2. Electromagnet
3. Temporary Magnet

Hysteresis is seen in B-H curve of Magnet
Selective doping - Ion Implantation - Mass analyzer

BF$_3$ Gas Spectrum

PH$_3$ Gas Spectrum
Selective doping - Ion Implantation - Accelerator

Ion Acceleration

Final Kinetic Energy of the ion = $q \left( V_{\text{ext}} + V_{\text{acc}} \right)$

Example: $V_{\text{ext}} = 30 \text{ KV}$  $V_{\text{acc}} = 70 \text{ KV}$

Energy of the ion = 100 KeV

Column length = 3
Selective doping - Ion Implantation - Scanner

Beam Scanning

Electrostatic scanning (low/medium beam current implanters ($I < 1\text{mA}$))

Vertical Scan

Horizontal Scan

Scan Patterns

This type of implanter is suitable for low dose implants. The beam current is adjusted to result in $t > 10$ sec/wafer. With scan frequencies in the 100 Hz range, good implant uniformity is achieved with reasonable throughput.
Selective doping - Ion Implantation-Wafer cage (Faraday cup)

In-situ Dose Control

End Station

secondary electrons

ion beam

wafer

back plate

$V_{\text{suppression}}$ (-500 V)

$V_{\text{Faraday cup}}$ (-180 V)

DOSE MONITORING

$\int I \, dt = Q = A \, q \, \phi$

$N_s = \text{Dose} = \frac{1}{qA} \int_0^t I(t) \, dt$
Silicon Integrated Circuit Process Flow for CMOS Technology
CMOS PROCESS FLOW (BASIC PROCESS)

1. Choice of Substrate:
   \[ \begin{align*}
   \text{MOS Circuits:} & \quad <100> \text{ Oriented} \\
   \text{Bipolar Circuits:} & \quad <111> \text{ Oriented}
   \end{align*} \]

(ii) Doping: 5-50 \( \text{j2cm} \)

(iii) P-type (Boron) Doped Wafers
   - Typical conc. \( \geq 10^{15} \text{ /cc} \) for 0.25\( \mu \) Technology Node
   - EDP Count \( < 1 / \text{cm}^2 \)

(iv) Wafers Size & Thickness as per Technology Node.
2. Active Area Creation:

Active areas are those regions where MOS Transistors will be created.

All transistors need to be separated and process which allows this is called Isolation. '1st Mask' is used here to delineate Active areas, and hence called "Active Area Mask".

Isolation is provided by thick oxide and there are two ways it is created in an MOS ICs.

(i) LOCOS Process used to create Bird’s Beak or Bird’s Crest.

(ii) LOCOS is used to create "Shallow Trench Isolation" also popularly called 'STI'.
A Typical basic CMOS transistor cross-section

Mask for above figure
1. Thermal Growth
   \[ \text{Si} + \text{O}_2 \rightarrow \text{SiO}_2 \] (90 nm)

2. Photoresist (Deposition + Spin)

3. Photoresist thickness 0.6 \( \mu \text{m} \) to 1.0 \( \mu \text{m} \)

4. Si\text{3N}_4 Deposition
   \[ 3 \text{SiH}_4 + 4 \text{NH}_3 \xrightarrow{\text{LPCVD}} \text{Si}_3\text{N}_4 + 12 \text{H}_2 \]
   Typical Thickness (800 Å)

5. 1st Mask – Lithography
   Clear field for PPR
Pattern etched in Photoresist (Development) and Silicon Nitride

\[ \text{Si}_3\text{N}_4 + 12 \text{F} \rightarrow 3 \text{SiF}_4 + 2 \text{N}_2 \]

Etching

Keeping Resist & Si₃N₄ in areas which are active areas
Then Resist is stripped

Si₃N₄ → Oxidation

LOCOS
Dry - Wet - Dry Oxidation
Magnified pattern looks like Bird's Beak after etching Si₃N₄.

If we don't have initial 'PAD-oxide', but directly deposit Si Nitride, then we see, after Patterning we have Edge Lifts.

Due to Mismatch of Thermal Coeff. & Expansion, Si₃N₄ lifts from edges during patterning & removal & resist followed Thermal Cycle after Oxidation Si₃N₄ is etched out.
Shallow Trench Isolation (STI)

First 4 steps are identical to normal LOCOS process. Even 5th step is also same.

Now we do silicon etching through created windows.

Initial Silicon Surface
Shallow Trench in Silicon.
After etching of Trenches in Silicon, one removes resist by stripping.

Then wafers are subjected to Dry Oxidation for creation of good quality thin layers on all sides of Trenches. Oxide thickness is around 100 Å to 200 Å.

The wafer status is shown below:

Then Thick Silicon Dioxide is Deposited after Removal of Si₃N₄ or many a times. This is not done.

Now Upper Surface which has undulation, is given Chemical Mechanical Polish (CMP), which planarizes that top layer.
Recessed Trench Oxide Isolation (STI)