- Planar Technology 0. [11, 12] Songyu [Figure]

1. n-type Si wafer
2. oxidation → SiO_2
   - dry: ① thin oxides ② good Si-SiO_2 interface
   - wet: ① thick layer ② higher growth rate
3. photolithography → geometry of P-N junction

   spin, coat, photoresist → bake, harden → exposure, mask, UV → polymerized, develop

4. etching

   bake → etch → strip away

5. diffusion & ion implantation
6. metallization → ohmic contacts & interconnections

   physical / chemical vapor deposition → front & back contact → low-temperature anneal

- Crystal Growth 1. [3] Calculation: 1. [20, 21, 22, 34]

1. The Czochralski Technique (Si, GaAs) 1. [9]

   ① Czochralski crystal puller
   - furnace (CW)
   - seed holder (CCW)
   - an ambient control

   ② dopant: B & P for Si

   ③ equilibium segregation coefficient k_0: $k_0 \equiv \frac{C_s}{C_l}$

   ④ doping distribution: $C_s = k_0 C_0 \left(1 - \frac{M}{M_0}\right)^{k_0 - 1}$

   $k_0 < 1 \rightarrow \frac{C_s}{C_0} \uparrow$; $k_0 > 1 \rightarrow \frac{C_s}{C_0} \downarrow$; $k_0 = 1 \rightarrow$ uniform

④ effective segregation coefficient k_e: $k_e \equiv \frac{C_s}{C_l} = \frac{k_0}{k_0+(1-k_0)e^{-v\delta/D}}$

⑤ GaAs compared to Si: + liquid encapsulation method; fused-silica crucible → graphite crucible

2. Silicon Float-Zone Process (Si) 1.[26]

① no contamination; high-resistivity → high-power, voltage

② doping distribution: $C_s = C_0[1-(1-k_e)e^{-k_e x/L}]$

3. Bridgman System (GaAs) 1.[46]

- Wafer Processing 1.[50]

shaping → slicing → lapping & polishing

- Crystal Defects

1. Point Defects 1.[63]

① substitutional impurity ② interstitial impurity

③ lattice vacancy ④ Frenkel-type detect

2. Line Defects 1.[65]

① edge dislocation ② screw dislocation

3. Area Defects 1.[67]

① intrinsic stacking fault ② extrinsic stacking fault

4. Volume Defects

- Silicon Oxidation

1. functions: ① FEOL ② BEOL ③ packaging

2. groups: ① grown directly on silicon → oxidation process

② deposited from gas phase → deposition process (CVD)

3. thermal oxidation 2.[6]

4. chemical reactions

① dry oxidation: in oxygen ② wet oxidation: in water vapor

5. structures:

SiO_2: tetrahedral

Si: ① crystalline (e.g. quartz) ② amorphous 2.[13,14]

- Kinetics of Growth 2.[15] Calculation: 2.[29-33]

1. flux $F_1 = D\frac{dC}{dx} \cong \frac{D(C_0-C_s)}{x}$ $F_2 = kC_s$

steady state: $F_1 = F_2 = F$ $F = \frac{DC_0}{x+(D/k)}$

2. oxide thickness: $x = \frac{D}{k}\left[\sqrt{1+\frac{2C_0k^2(t+\tau)}{DC_1}} - 1\right]$ $\left(\tau = \frac{(d_0^2+\frac{2Dd_0}{k})C_1}{2DC_0}\right)$

① small t: $x \cong \frac{C_0k}{C_1}(t+\tau)$ ② large t: $x \cong \sqrt{\frac{2DC_0}{C_1}(t+\tau)}$

3. $A = \frac{2D}{k}$ $B = \frac{2DC_0}{C_1}$ $\frac{B}{A} = \frac{C_0k}{C_1}$ $x^2 + Ax = B(t+\tau)$ $\left(\tau = \frac{d_0^2+Ad_0}{B}\right)$

① linear rate constant $\frac{B}{A}$: $x = \frac{B}{A}(t+\tau)$

dependence of crystal orientation

② parabolic rate constant B: $x = \sqrt{B(t+\tau)}$

independence of crystal orientation

- Impurity Redistribution 2.[36] factors

- Photolithography 3.[4,13] Calculation 3.[11,12,51-53]

1. Exposure:

① performance $\begin{cases} \text{resolution} \\ \text{registration} \\ \text{throughout} \end{cases}$

② techniques: contact printing & proximity printing

③ critical dimension CD: $CD \approx \sqrt{\lambda g}$

④ projection printing 3.[23]

resolution $l_m = k_1 \frac{\lambda}{NA}$ $DOF = k_2 \frac{\lambda}{(NA)^2}$

⑤ photoresist: positive & negative

2. Liftoff technique

① positive resist

② image reversal 3.[63]

3. Next-Generation Lithographic Methods pros

① electron beam $\begin{cases} \text{raster scan system} \\ \text{vector scan system} \end{cases}$ proximity effect

② extreme ultraviolet

③ X-ray

④ ion beam $\begin{cases} \text{scanning focused-beam system} \\ \text{mask-beam system} \end{cases}$

- Etching

1. Wet Chemical Etching

① mechanisms 4.[6]

② $\text{etch rate uniformity}(\%) = \frac{\text{max. etch rate} - \text{min. etch rate}}{\text{max. etch rate} + \text{min. etch rate}} \times 100\%$

③ immersion etching & spray etching

④ ohoton inversion

⑤ SiO_2 & SiN & Al etching

2. Dry Etching

① capacitively coupled (rf) plasma etcher

② physical sputtering

③ reactive ion etching (RIE)

④ chemical etching

⑤ polymer deposition

- Diffusion 5. [6]

1. atomic diffusion models 5. [12]

$\begin{cases} \text{vacancy diffusion} \\ \text{interstitial diffusion} \end{cases}$

2. flux $F = -D\frac{\partial C}{\partial x}$

Fick's diffusion equation: $\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$

$D = D_0 \exp\left(\frac{-E_a}{kT}\right)$ (E_a: activation energy in eV)

3. diffusion profiles

① constant surface concentration 5. [24]

$C(x,t) = C_s \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$ (erfc: complementary error function)

$Q(t) = \frac{2}{\sqrt{\pi}} C_s \sqrt{Dt} \cong 1.13 C_s \sqrt{Dt}$

② constant total concentration 5. [28]

$C(x,t) = \frac{S}{\sqrt{\pi D t}} \exp\left(-\frac{x^2}{4Dt}\right)$

4. intrinsic & extrinsic diffusion 5. [31]

5. concentration-dependent diffusivity: $D = D_s\left(\frac{C}{C_s}\right)^{\gamma}$ 5. [33]

- Ion Implantation

1. medium-current ion implantor 6.[7]

2. ion distribution: Gaussian

3. ion stopping { ① transfer its energy to the target nuclei
② interaction of the incident ion with the cloud of electrons around the target's atoms

$$\frac{dE}{dx} = S_n(E) + S_e(E)$$

4. ion channeling → the exponential tail

minimized techniques { ① blocking amorphous layer
② misorientation of the wafers
③ pre-damage the wafer

5. implant damage 6.[49] heavy & light ions

6. annealing

• Epitaxial Growth { chemical vapor deposition (CVD)
molecular beam epitaxy (MBE)

1. CVD 7.[7]

① vapor-phase epitaxy (VPE)

② { at atmospheric pressure (APCVD)
at low pressure (LPCVD)

③ susceptors { horizontal
pancake
barrel

7.[5]

2. MBE 7.[18]

① molecular impingement rate { $\phi = P(2\pi mkT)^{-\frac{1}{2}}$

$$\phi = 2.64 \times 10^{20}\left[\frac{P}{\sqrt{MT}}\right] \text{ molecules}/cm^2\text{-}s$$

② lattice-matched & strained-layer epitaxy 7.[28]

3. Dielectric Deposition

- atmospheric-pressure CVD
- low-pressure CVD (LPCVD) 7.[33]
- plasma-enhanced chemical vapor deposition (PECVD) 7.[34]

4. Step Coverage

conformal step coverage vs. nonconformal step coverage 7.[44]

5. SiN deposition:

① intermediate-temperature (750°C) LPCVD process

② low-temperature (300°C) plasma-assisted CVD process

6. Physical Vapor Deposition (PVD)

- evaporation 7.[5-7]
- sputtering 7.[5-9]

7. Al metallization → aluminium junction spiking & electromigration