EECS 179

Scaling $L \propto$ capacitance, Turbulent current, Re

$L^3 \propto$ Vol, Mass, heat cap $1/L^4 \propto$ heat flow

$L^2 \propto$ surface, strength, force, power

$1/L \propto R$, accel, freq, $\vec{E}$, power density

HEAT → heat flows through small devices very quickly

Contamination

- Ruin devices, poison equipment
- Particle (org, inorg), film, atomic

$D_0 = \dfrac{\text{No of defects}}{\text{No of chip} \times \text{Area}}$

Cleanroom ⇒ class 10000 → Medical, packaging

class 1000, class 100 — MEMS · class 10 – IC

Crystaline – spatially arranged.

Amorphous – no long term structure

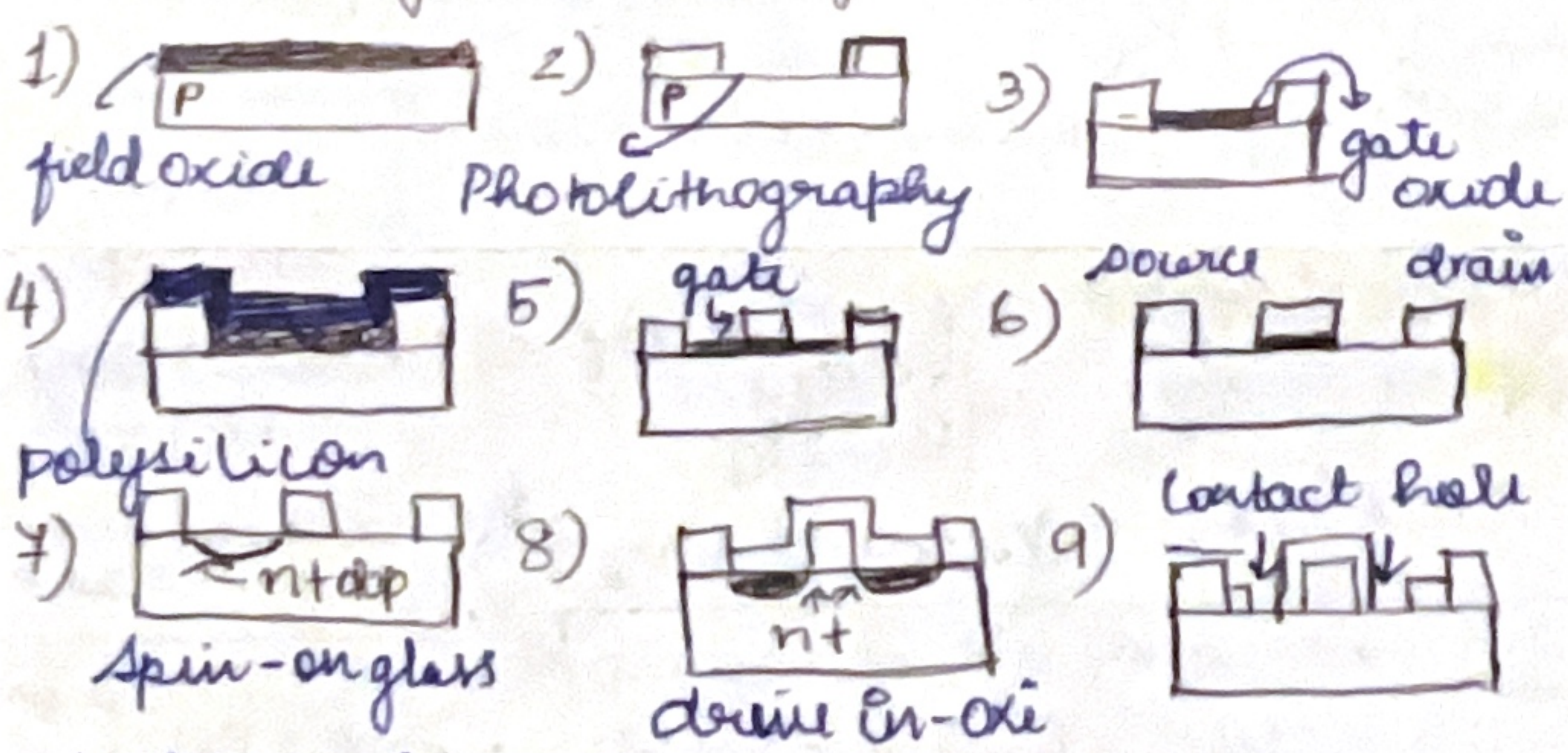
Silicon – grey (RI $n = 3.4$), not transparent to UV. strong & brittle. $E_g = 1.12$ eV

Dopants grp 5 → Donor → n-type – P, As, Sb.

grp 3 → Acceptor → p-type – B, Al, Ga, In

Purity → 11 9's

+ve PR → Region exposed gets dissolved



Metalization & Metal definition.

4 lithograph steps: active area, gate electrode, contacts, metal interconnect

Mosfet: TO (pad oxide), Si_3N_4, lithography, Boron implantation, field oxide, removal of Si_3N_4 & pad, TO (gate oxide), poly-si (CVD), poly-si gate electrode, P or As ion implantation, SiO_2, contact holes, Al, Al patterning

Photolithography Coat, protect, expose, etch

- Where light hits, portion erode → +ve else –ve
- light blocking → chrome or IO → soda lime
  MASK

- Dark field does not transmit light

Clear Mask + PPR = develop (Most area) Weaken bond
" + NPR = stay * Metal, Burned

Dark Mask + PPR = develop (Small area)
" + NPR = stay (~~Most area~~) strength

Misalignment – Thermal exp, print or error
- Make n well or p well bigger PR – Nitride

PR Consist – Resin (adhesion), Sensitizer, solvent
Photoactive compd Resist liq

Deposition

a) Spin on ⓑ Spray on $t = KS^{1/2}(V/w^2 \cdot R^2)$

exposure energy E = Intensity × time $= 1/\log(E_f/E_i)$ contrast ratio →

PPR – PMMA, DQN, Phenolic Novalak Resin

NPR – rubber

$MTF = (I_{light} - I_{dark})/(I_{light} + I_{dark})$ image / object

Process: clean substrate, dry sub, spin coat, softbake, exposure, post exp bake

Contact $\delta = \frac{\lambda}{(NA)^2}$	Proximity	Projection
• Best Reso • cheap, fast • exposed at once • contamination • Mask is exp $2b_{min} = 3\sqrt{\lambda \cdot \frac{z}{2}}$ z = thickness of PR $2b_{min}$ = Gap $\lambda = 400$ nm ↓	• Fast • exposed at once • No mask contamination • less Res n • Mask large & exp $= 3\sqrt{\lambda \cdot (s + \frac{z}{2})}$ S – Space	• No contact • tolerate ↑ temp. • longer time to expose • complex & exp • each die exposed seper. Numerical Aper $= n \sin(\theta_{max})$

$\frac{NA}{n} = \frac{D/2}{\sqrt{(D/2)^2 + f^2}}$ D = lens dia n = RI

$2b_{min} \sim (0.6\lambda)/NA$ Rayleigh Resolution

depth of focus degrades image resolution

How improve Resolution
- Phase shift mask • optical proximity corr rounding corners.
- Immersion

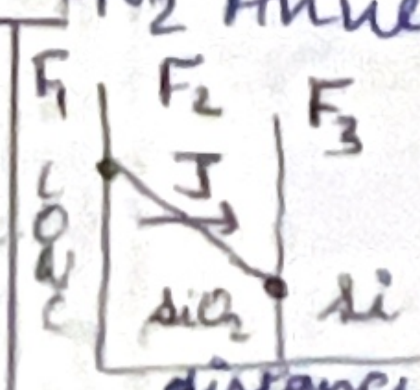
Thermal Oxi

Wet – iso – dry

Thermal SiO_2 prop ★ Si_3N_4 ⇒ Mask

- $\rho > 1e^{20}$ • $E_g = 9$ eV • high breakdown E field
- Stable SiO_2/Si interface • $D_{SiO_2} \ll D_{Si}$
- dopant barrier

Oxi cycle
- push: low temp, O_2 to prevent nitride
- Dry ox → High Quality → slow → thin (gate)
  (O_2 + HCl) $Si + O_2 \to SiO_2$
- Wet ox → low Quality → fast – thick (field)
  ($O_2 + H_2O$)
- N_2 Anneal • Ramp down.



Oxidation growth rate will fall with ↑ time & oxide thickness

$J = F_2 = -D \cdot \frac{dN}{dx}$ | $J = (D \cdot N_0)/(x_0 + D/k_s)$

$x_{ox}(t) = \frac{1}{2}A\left[\left(\sqrt{1 + \frac{4B}{A^2}(t+\tau)}\right) - 1\right]$

reduces to (next pg)

$A = \frac{2D}{k_s}$, $B = \frac{2DN_0}{N_{ox}}$ $N = 2.3e^{22}$

$x_{oi}^2 + Ax_{oi} = B(t+\tau)$

$\tau = \frac{x_i^2}{B} + \frac{x_i}{(B/A)}$ (Multiple Oxidation)

for diff temp & type of Oxi, = diff thickness and Oxi time

$x_{ox}(t) = \frac{B}{A}(t+\tau) \rightarrow$ linear term $\cdot$ growth rate $(t+\tau) < \frac{A^2}{4B}$

$X_{ox}(t) = \sqrt{B(t+\tau)} \rightarrow$ para $(t+\tau) > \frac{A^2}{4B}$

Reaction rate – $B(T) = B_0 \cdot e(-Ea(b)/KT)$

$B/A(T) = (B/A)_0 \cdot e(-Ea(b/a)/KT)$ Arrhenius

Diffusion controlled contamination

- ficks 1st law – +ve flux, -ve slope cancel – sign.

$k = 1.38 \times 10^{-23}$

$D = D_0 \cdot e^{-(Ea/KT)}$ diffusion const

- ficks second law $\frac{dN}{dt} = D \cdot \frac{d^2N}{dx^2}$

incom, accumulation, outgoing

- Fast diffuser
- slow diffuser $\rightarrow$ useful.

Boundary cond

1. const source $N(x=0,t) = N_0$
2. const dose or fixed dopants $\int N(x,t) \cdot dx = Q \rightarrow$ const

(1) $\rightarrow N(x,t) = N_0 \, \mathrm{erfc}\left(\frac{x}{2\cdot\sqrt{Dt}}\right)$

const source – longer time higher diffusivity

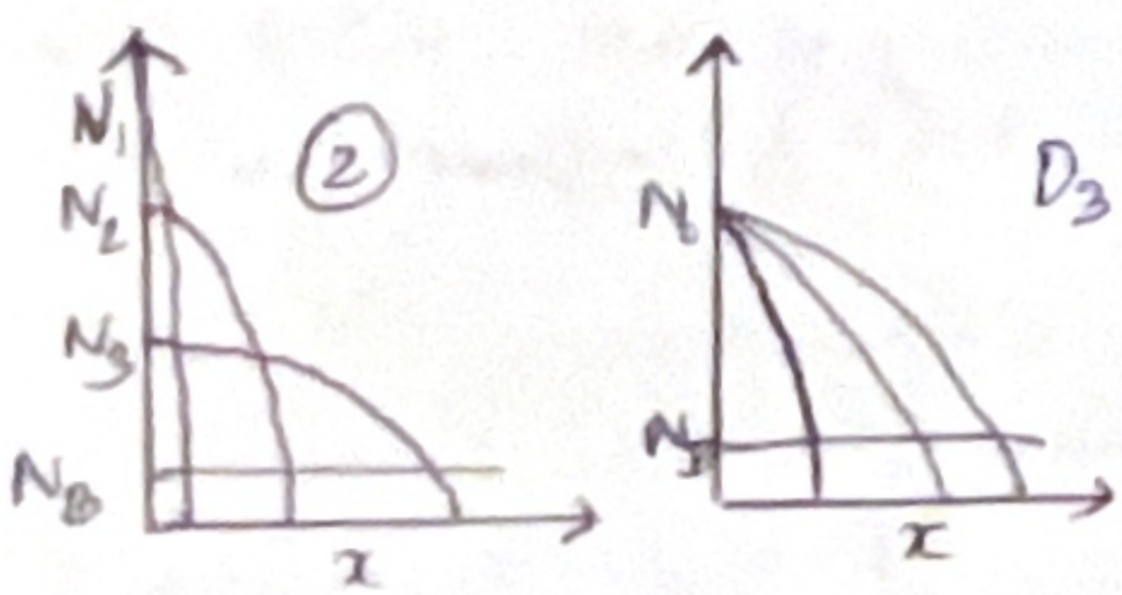
$\boxed{\text{Total dose } Q(t)} = \int_0^\infty N(x,t) \cdot dx = \boxed{2N_0\sqrt{\frac{Dt}{\pi}}}$

Junction depth — Breaks dissociation of HNO_3 / isotropic HNA $\rightarrow$

intersection of $N(x,t)$ with background conc $\therefore N(x,t) = N_B$

(2) $N(x,t) = \frac{Q}{\sqrt{\pi Dt}} \cdot e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$ no of dopant fix

Gaussian



$D_3 t_3 > D_2 t_2 > D_1 t_1$

$(D \cdot t)_{total} = \sum_i D_i t_i$ $+ \frac{1}{2}(\Delta R_p)^2$

- isotropic diffusion can diffuse under mask

source

Spin on glass or previous deposit film

Sheet resistance $R_s = \rho / \text{thickness}$

IR curve : x_j, N_B, N_0, R_s

ION implantation : low temp, instant on off precise, good depth $\boxed{\text{disadv}}$ exp, channelin crystaline damage $q = 1.6 \times 10^{-19} C$

$\boxed{Q_{dose}} = \int_0^T (I\,dt)/\eta \cdot q \cdot A$ η = valence.

distribution $= \int_0^\infty N(x) \cdot dx$ of overall — straggle

$\boxed{N(x)} = N_p \cdot e^{-1/2((x-R_p)/\Delta R_p)^2}$

fully below surface $\boxed{Q = \sqrt{2\pi} \times N_p \times \Delta R_p}$

implantation parameter: Current

Ion energy (depth), conc (dose), Mask shape (geometry)

Ion species (n or p) $R_s = \frac{1}{q \mu_{N_p} Q_{dose}}$

$\boxed{\text{Bombardment} > 10\text{ KeV}}$

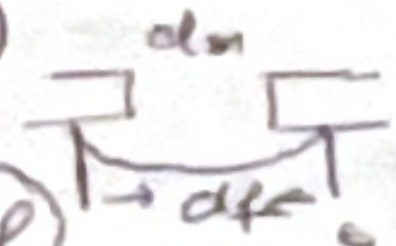
$N_{redist}(x,t) = \frac{N_p}{\sqrt{1 + \frac{Dt}{1/2(\Delta R_p^2)}}} e^{-\frac{x-R_p}{2\sqrt{\frac{1}{2}\Delta R_p^2 + Dt}}}$

Etching • isotropic – undercut the mask

Parameter : etch rate – rate of material removal

Arrhenius $\rightarrow X(T) = X_0 e^{-Ea/KT}$

selectivity, geometry (anisotropy)



d_m, $\rightarrow d_f$, isotropic

etch bias – $B = d_f - d_m$ or $B = 2h_f$

degree of anisotropy $0 \leq A_f \leq 1$ Anisotropy

$A_f = 1 - \frac{|B|}{2h_f}$ Isotropy $|B| = 2h_f$ $|B| = 0$

$x = x_1 + x_2 = (V_v \cot\theta + V_l)$ V_v : vertical etch rate V_l =

$SiO_2 \rightarrow$ etched HF $\rightarrow$ isotropic $\rightarrow$ 120nm/min

HF $\rightarrow 10:1 H_2O \rightarrow$ highly selective $\rightarrow$ but PR

BHF $\rightarrow 5 NH_4F : HF$ (Maintain conc)

Si $\rightarrow$ Nitric acid & HF $\rightarrow$ diluted by CH_3COOH; H_2O

CH_3COOH preferred. HNO_3 oxidises $Si \rightarrow SiO_2$

silicon nitride $\rightarrow$ phosphoric acid

H_3PO_4 attacks metals $\rightarrow$ Tough mask

Piranha $\rightarrow H_2SO_4$ 5 : 1 H_2O_2

clean organic residue

RCA Cleaning – Remove organic film, organic particle ($NH_4OH : H_2O_2$: DI), remove metal ions (H_2O : HCl : H_2O_2), spindry

Orientation dependent etch (KOH) alkaline

- PR wont survive $\rightarrow$ ECP

etch rate $\{110\} > \{100\} > \{111\}$ aniso

Oxide attacked slowly, nitride not attack

$X_{Si} = 0.46 X_{ox}$ $N_{Si} * X_{Si} = N_{ox} * X_{ox}$

$(X-1) = 0.46 X_{ox}$ $5 \times 10^{22} \times \pi(100^2 - \pi^2) = 2.3 \times 10^{22}(\pi + 100^2 - \pi^2)$

$X = 1.85$ um