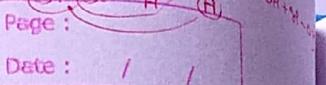


© Time
 Domain CVD
 Supreme Society
 of students

MINOR-2

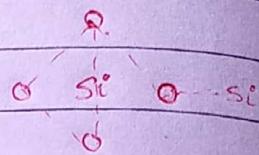
February 8



Structure

→ Tetrahedral

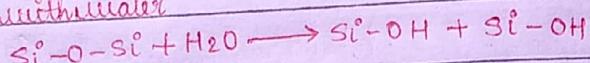
- Each Si do four O
- Each O do two Si



→ Single crystal quartz (density 2.6 g/cm^3)

→ fused silica

→ React with water



→ $\text{Si}^{\circ}-\text{OH}$ termination is stable

- structure is more porous than $\text{Si}^{\circ}-\text{O}-\text{Si}$

which one is
(porous-
(wet)
since

$\rightarrow \text{H}_2$ gas
diffused
as a byproduct
 \rightarrow is not a good
thing

(acts as a
local trapping
of electrons
(charge)
quality
hampers)

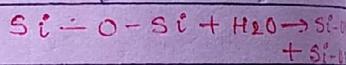
Thermal Oxidation -

Dry oxidation (slower)

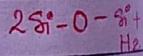
$\text{Si} + \text{O}_2 \rightarrow \text{SiO}_2$
- Dense oxide
formed

Wet oxidation
(faster)

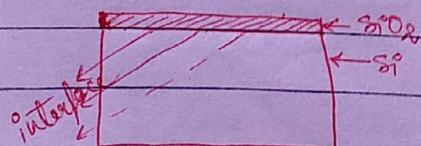
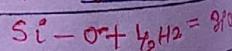
Mechanism :- Hydration near surface



Oxidation : $2 \text{Si}^{\circ}-\text{OH} + 2\text{O} = 2\text{Si}^{\circ}-\text{O} + \text{H}_2$



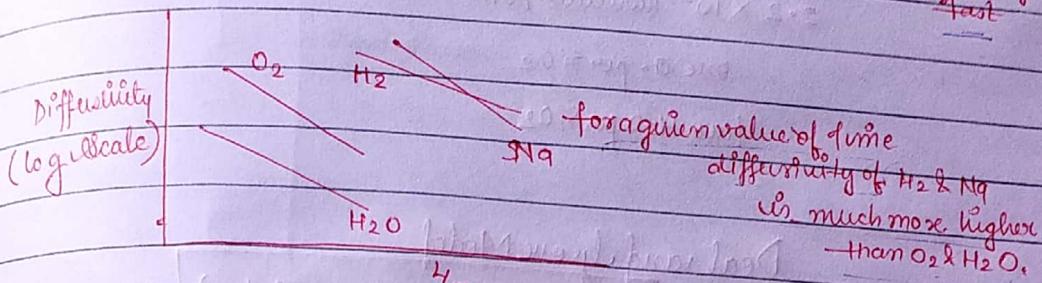
→ Hydrogen will diffuse
→ Some hydrogen many may
form hydroxyl groups



Diffusivities in Oxide

Oxygen diffuses faster than the water

Sodium & Hydrogen diffuse very fast



Oxygen, H₂O ... diffused on $\text{Si}^{\circ}\text{O}_2$ (The graph shows this)
purpose : (+ to thicken the $\text{Si}^{\circ}\text{O}_2$)

Oxidation Kinetics -

→ At a steady state

$\text{Oxygen diffusion through oxide} = \text{Reactn rate at the } \text{Si}^{\circ}/\text{Si}^{\circ}\text{O}_2 \text{ interface}$

(Intermediates, OH ion in
(Metastable) (bulichrome effects
water molecule
occupy larger
area. Hence
wet oxide
faster)

→ Oxygen diffuses faster than water
However, water solubility is very high (1000 times)
⇒ Effectively water concn at the
interface is higher

Diffusion

$$J = -D \frac{dN}{dx} \approx D \frac{(N_0 - N_i)}{x}$$

Reactn

$$\text{Rate} = k_i N_i$$

$$N_i = D \frac{N_0}{k_i + D}$$

flux at
steady
Rate

$$J = D \frac{N_0}{x + D/k_i}$$

→ Oxide Growth Rate $\frac{dx}{dt}$

Oxidizing species per unit volume of $\text{Si}^{\circ}\text{O}_2$

$$n = 2.2 \times 10^{22} \text{ cm}^{-3} \text{ for O}_2$$

$$n = 4.4 \times 10^{22} \text{ cm}^{-3} \text{ for H}_2\text{O}$$

$$\text{Eqn} = \frac{dx}{dt} = \frac{D N_0}{x + D/k_i}$$

$$x = x_{\text{initial}} t = 0$$

T/n

(3)

Page:

Date: / /

$$6.023 \times 10^{23} \text{ molecules}$$

$$= 1 \text{ mol of oxide} = x \text{ g of oxide}$$

$$= y \text{ cm}^3 \text{ of oxide (from density)}$$

$$2.02 \times 10^{22} \text{ molecules/cm}^3$$

$$\text{One O}_2 \text{ per } \text{SiO}_2$$

$$\text{Two H}_2\text{O per } \text{SiO}_2$$

Deal and Grove Model

$$\left[x^2 + \frac{2D}{K_i} x = \frac{2DNO}{n} (t + \tau) \right] \text{ OR}$$

$$t = \frac{x^2 + \frac{2x}{(B/A)} - \tau}{\frac{2D}{K_i}}$$

where

$$\tau = \frac{x_i^2 + 2x_i}{B/A}$$

$$A = \frac{2D}{K_i}$$

$$B = \frac{2DNO}{n}$$

to τ is time needed to grow the initial oxide.

A and B will depend on 'D'

① Diffusivity

② Solubility

③ Oxidizing species per unit volume, (n)

Deal Grove model

- Time for initial oxidation dep(A & B)

- A & B will depend on wet or dry oxidation

wet oxidation will have less thickness, than wet oxidation, wet for a fixed dry of time

wet or dry
wet oxidation

We discussed for Layer of Si_2O_5 , Now

Si_3N_4 like vapor

SiO_2 layer develop

Now what which

parameter will change

'D' will change (depends upon type of material) D of Si_3N_4

τ depends upon
 n

A

B

gi

Time

Linear And Parabolic Regimes

$$x = 0.5A \left\{ \left(1 + \frac{4B}{A^2} (t + \tau) \right)^{\frac{1}{2}} - 1 \right\}$$

$t = \text{thickness of oxide}$
mili-gauge
given
specimen

If one starts with thin oxide (or Bare metal)

Very short time $x = \frac{B}{A} (t + \tau)$ $t + \tau \propto \frac{A^2}{4B}$

$x \propto t$ if t is small

Longer time $x^2 = B (t + \tau)$ $(t + \tau) \propto \frac{A^2}{4B}$

Linear vs Parabolic Regimes.

Kinetic Controlled vs Mass Transfer Controlled

Initial faster growth rate, then slower growth rate

→ Surface never pure; always there will be a layer of native oxide

Hence oxidation falls in 2 categories:
parabolic & linear
at the beginning oxidation is faster later (kinetic model)
saturation slower (mass transfer)

Exponential Regime :-

If one starts with Bare oxide

- for dry oxidation, one finds that τ is not zero in the model fit

- A τ corresponding to an initial thickness of 25 nm provides good fit.

- Initial growth at very high rate

Hypothesis: Approximated by exponential regime

Charge species form

Holes diffuse faster / set up E

diffusion + drift \Rightarrow effective diffusion length high
space charge regime control

length = 15 nm for oxygen, 0.5 nm for water

wet oxidation not affected (since no charge species present);

- Hypothesis - 2 -

In dry oxidn, many open areas exist

oxygen diffuses fast in silicon

Hence more initial growth rate

once covered by silicon dioxide,
slow diffusion

[Initially, oxidation
exponent k₀ will
be higher than
beginning &
slowing down -]

There are voids
inside Si_xO_y will
allow diffusion

- Hypothesis 3 -

Even before reactn (at high temp), oxygen
dissolved in silicon (reasonable diffusion)

once temp is increased, 5 nm quick oxide formed?

* (property of oxygen dissolved in silicon before already)

Effect of Doping -

- increases oxidation rate

Segregation

- ratio of dopant in silicon / dopant in oxide

Extrinsic doping faster;

∴ we always have, light-dopant (higher rate of oxidn)
↳ extrinsic

Intrinsic ki conductivity kam

- By e.g. Boron incorporated in oxide

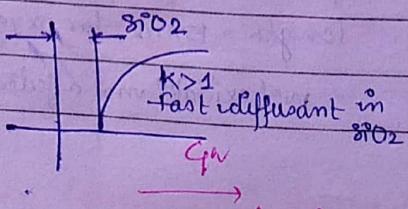
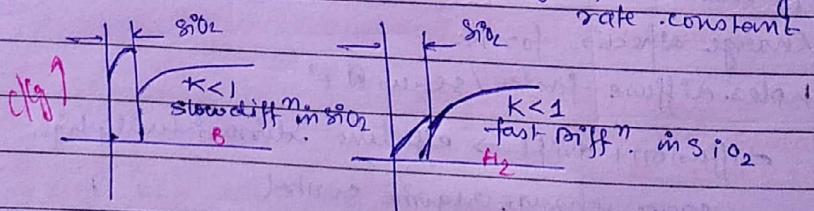
More porous oxide

more diffusion

parabolic rate constant is higher

P not incorporated in oxide

no significant change in parabolic



6

When we have a doped-type of material - the porosity of the material would increase leading to more gases; porosity & gases & diffusivity. Hence wetoxid

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Issues -

- Na diffuses fast in oxide (trapped charge problem)
- Use Al during "oxidat"
 - Helps trap Na
 - Helps create volatile compounds of heavy metals (contamination from surface etc)
- use 3% HCl or tri chloroethylene (TCE)
 - It diffuses in oxide; reach inside Bulk & produce trap charge; post treated (as contamination?)
 - How to avoid this problem
 - Use Cr₂O₃ chlorine (it traps Na; not allows Na to diffuse)
 - How will Al prevent Na to diffuse?
 - It will trap it by making complex compounds that is - large in size not suitable to diffuse easily;
Na is - smaller, insize diffusely.

Electrochemical -

Use neutral solution and apply potential
Pt as counter electrode (hydrogen evolution);

Assign-1

What is VLSI & ASIC, Explain with examples.

" " MEMS, Compare it with VLSI fab'n & Design

✓ Mention few VLSI & MEMS CAD Tools, Also explain their application with suitable ex -

✓ Name any 5 Research labs in India working in chip design. Briefly describe their working thematic area

Repeat above question of international laboratory

Name 5 international general conferences in the field of chip designing

Name 3 regular international conferences in chip design

Diffusion

is the redistribution of atoms from regions of high concn of mobile species to regions of low concn. It occurs at all temperatures, but the diffusivity has an exponential dependence on T.

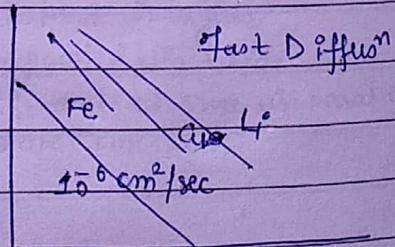
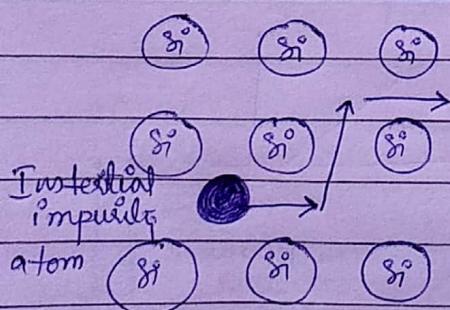
Predeposit - Doping often proceeds by an initial spread step to introduce the required dose of dopant into the substrate.

Drive-In: In subsequent drive-in anneal then redistribution of the dopant giving the required junction depth and surface concentration.

Mechanism -

(a) Interstitial Diffusion

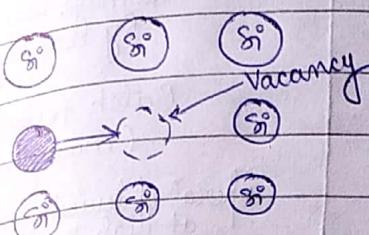
Ex - Cu, Fe, Li, H



→ Hydrogen, Lithium (light atoms) can fit easily in the gap

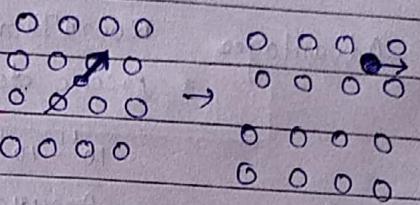
(b) Substitutional Diffusion

Ex - Dopeants in Si (e.g. B, P, As, Sb)



Silicon is displaced &
a vacancy is created
Due to strain within Bonds

(c) Interstitial Diffusion



In interstitially, diffusion
an interstitial impurity
displaces a subst. impurity,
driving it to an
interstitial site

where it diffuses
some distance
Before it returns
to a substitu-
+ lated site.

Two step dopant Diffusion -

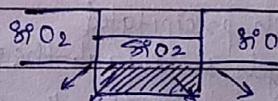
(1) Predeposition

dose control SiO_2 Si
pre material

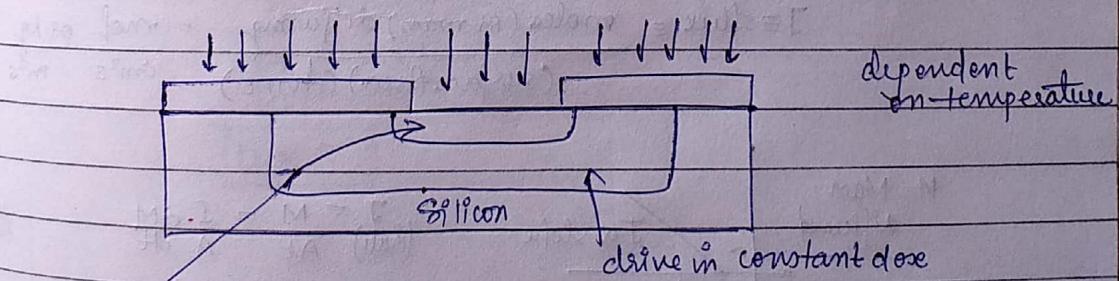
Dopant gas
Si material deposited

(2) Drive-in

profile control

(juncⁿ depth;
concⁿ)

Turn off dopant gas

or seal surface
withoxide.prede
controlled
dose

→ concentratⁿ at the surface
is more, than inside
the depth of Bulk.

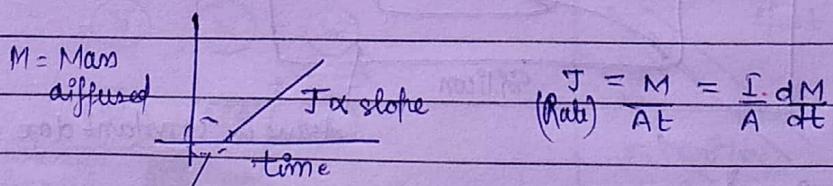
Ion Implantation & Annealing		Solid Gas Phase Diffusion
Advantages	Room Temp Mask Precise dose control $10^{11} - 10^{16}$ atoms cm^{-2} dose Accurate depth control	No damage created by doping Batch fabrication (many substrates) Area of device affected at high-temp (500°C)
Disadvantages	Implant damage enhances diffusion Dislocations caused by damage may cause junction leakage. Implant channeling may affect profile	Usually limited to solid solubility Low surface concn hard to achieve without a long drive-in Low dose profile very difficult.

Dopants are soluble in Bulk up to a max value. Before they precipitate into another phase.

Temp ↑ solid gets precipitated
gets solidify at the surface & doesn't get diffused
inside the Bulk.

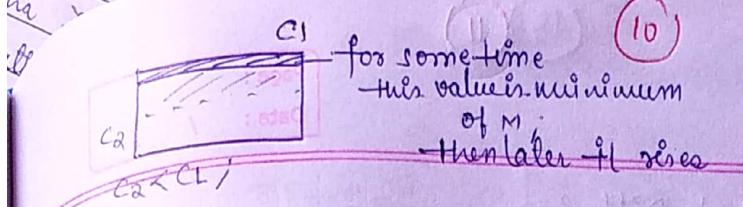
Differ Rate of Diffusion?

$$J = \text{flux} = \frac{\text{moles (or mass) diffusing}}{(\text{surface Area})(\text{time})} = \frac{\text{mol}}{\text{cm}^2 \text{s}} \text{ or } \frac{\text{kg}}{\text{m}^2 \text{s}}$$



pedeposition time
this is Mass diffused

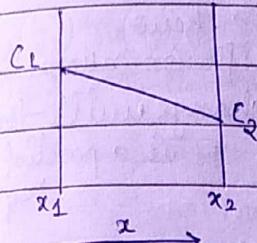
- Make thin film (membrane) of known surface area
- Impose conc gradient
- Measure how fast atoms or molecules diffuse through the Membrane



Page : / /
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Steady State Diffusion - (Rate of diff^n independent of time)

(flux proportional to conc gradient = dC/dx)



Fick's first law of diffusion

$$J = -D \frac{dc}{dx}$$

Diff^n coefficient

some
solids
do not penetrate
middle 89% Bulk

$$\text{if linear, } \frac{dc}{dx} = \frac{\Delta C}{\Delta x} = \frac{C_2 - C_1}{x_2 - x_1}$$

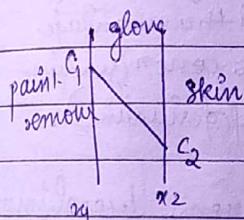
Chemical Protective Clothing (CPC)

gloves made up of Butyl Rubber of $x \rightarrow 0.04 \text{ cm}$

$$D = 110 \times 10^{-8}$$

$$C_1 = 0.44 \text{ g/cm}^3$$

$$C_2 = 0.02 \text{ g/cm}^3$$



$$J = -D \frac{dc}{dx} \cong -D \frac{C_2 - C_1}{x_2 - x_1} = \frac{(0.02 - 0.44)}{0.04} \times 110 \times 10^{-8}$$

$$= 1.016 \times 10^{-5} \text{ g/cm}^2 \text{s}$$

- assuming linear conc. gradient

Diffusion & Temp ✓

$$[D \propto T]$$

$$D = D_0 \exp\left(-\frac{Q_d}{RT}\right)$$

value of D will rise exponentially with increase in temperature.

$$T \quad D = m^2/s \quad (\text{Diffusion coefficient})$$

$$D_0 = \text{pre-exponential} (m^2/s)$$

$$Q_d = \text{Activation Energy} [J/mol \text{ or } \text{eV/atom}]$$

$$R = \text{gas constant} [8.314 \text{ J/mol} \cdot \text{K}]$$

$$T = \text{absolute Temperature [K.]}$$

$$T = 300 \\ D = ?$$

$$D \propto e^{4T}$$

$$\log D \propto \frac{1}{T}$$

(ii)

(ii)

Page :

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Non-steady state Diffusion

Fick's Second Law :-

Predicts how

- diffusion causes the concn to change with time.

It is a partial differential eqn.

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}$$

(Concn depends on time & concn of diffusing species.)

$$c = c(x, t)$$

Fick first Law - relates the diffusive flux to the concn (in pñjuncⁿ) under the assumption of steady state

It postulates that the flux goes from regions of high concn to regions of low concn, with a magnitude that is proportional to the concn gradient (spatial derivative).

To model transport processes in foods, neurons, biopolymers, pharmaceuticals, porous soils, population dynamics, nuclear materials, semiconductor doping processes, etc.

Ion Implantation - (Low temp process)

Wafer is target in High Energy Accelerator Impurities "shot" into wafer. Preferred method of adding impurities to wafers -

- Wide range of Impurity species - (Almost anything can be doped)
 - Tight Dose Control (A few % vs 20-30% for high)
 - Temperature free "deposit" processes
 - Low Temp. Process
- (Expensive systems & Vacuum system) -

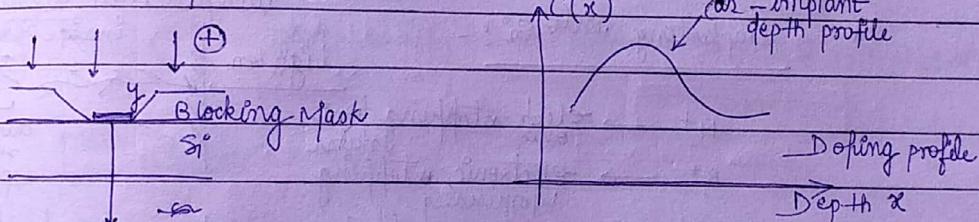
$$\text{Force on charged particle } \vec{F} = q(\vec{v} \times \vec{B})$$

$$\text{Magnetic field } |\vec{B}| = \frac{\sqrt{2mV}}{q\vec{v}^2}$$

(Temperature is ambient. Implanted Dose = $\Phi = \frac{1}{nqA_0} \int I(t) dt$)

post-implant annealing $> 900^\circ\text{C}$ is required to anneal out defects

Ion Implantation -



Advantages of Ion Implantation -

Precise control of dose and depth profile

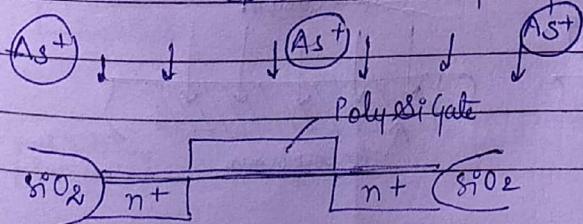
Low-temp process

Wide selection of masking materials

e.g. photoresist, oxide, poly-Si, metal

Less sensitive to surface cleaning procedures

Excellent lateral uniformity



MOSFET Schematic

Threshold voltage depends upon thickness of device

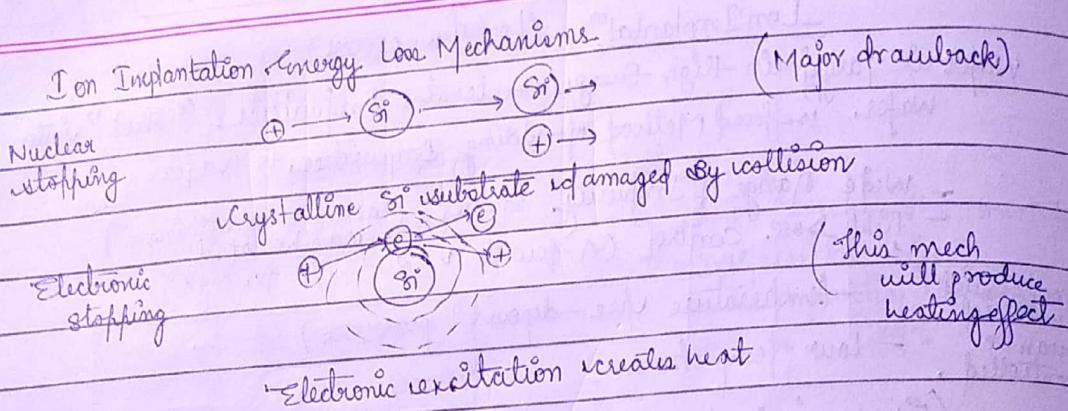
— Due to self-alignment

(Due to SiO2 Mask;

jahan se As^{+} ko

uniform miljumetru

implant ho gya.



Ion Energy Loss Characteristics -

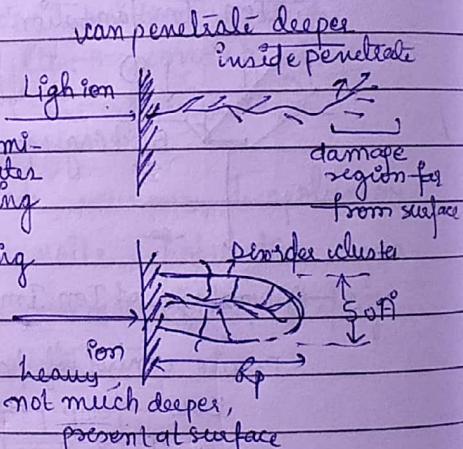
Light Ions / at higher Energy → more electronic stopping

Heavier ions / lighter energy → more nuclear stopping
not given higher energy

Because more mass,
more K.E.,
bombarding
more damage

E_V - Implanting into Si° :-

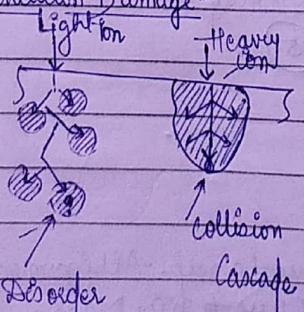
- H⁺ → Electr. stopping dominates
- B⁺ → Electronic stopping dominates
- As⁺ → Nuclear stopping dominates



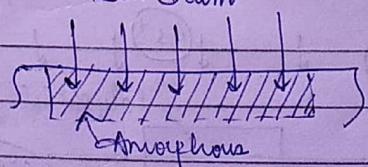
Simulation of 50 KeV Boron with Si

After certain time, it will begin to settle & hence distribute/spread.

Implantation Damage -



Ion Beam



→ dislocations trap charges, and overall hampers the functionality of the device.

→ traps act as a local fixed charge point (pits) capacitor effect operates at higher

frequency which results in short circuit of the device, high current flows, & in the device ~~leads~~, making ten current flow in load.

Post Implantation Annealing Summary -

- After implantation, we need an annealing step.

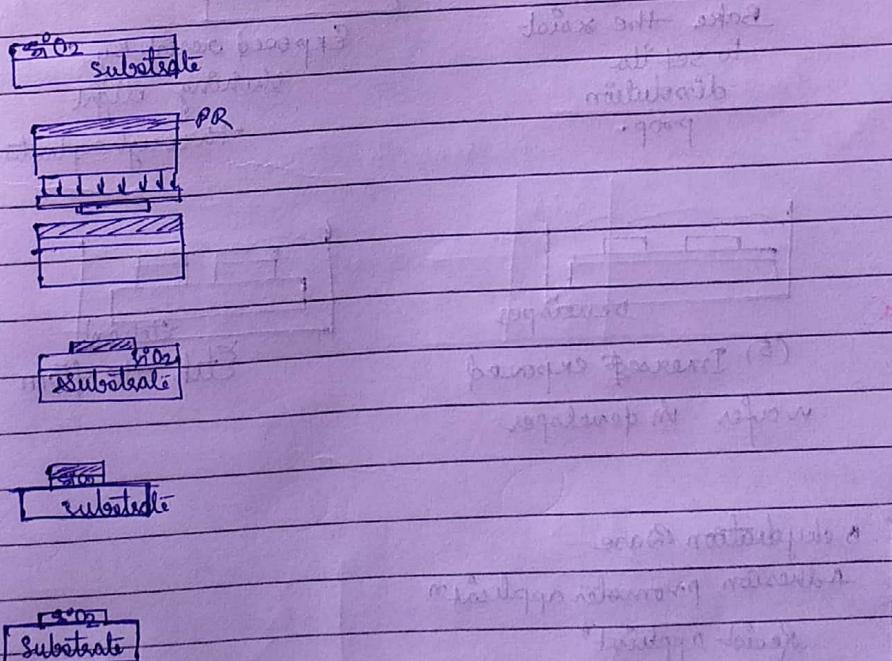
- (1) Restore Si crystallinity
- (2) Place dopants into Si₀ substitutional sites for electrical activation.

The lithographic process -

Design \Rightarrow Mask \Rightarrow Wafer

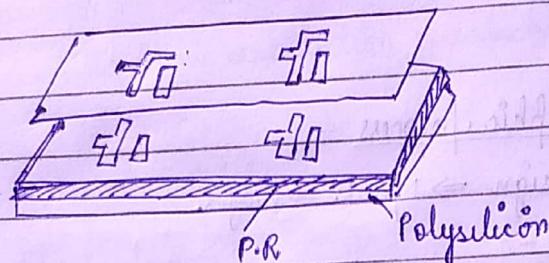
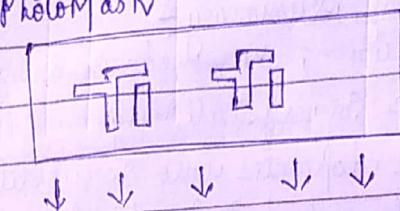
Photolithographic process -

- (a) Substrate covered with silicon dioxide Barrier layer
- (b) The photoresist applied to wafer surface
- (c) Mask in close proximity to surface
- (d) Substrate following resist exposure and development
- (e) Substrate after etching of oxide layer
- (f) Oxide barrier on surface after resist removal
- (g) View of substrate with silicon dioxide pattern on the surface



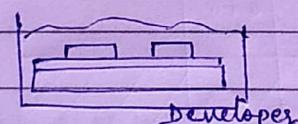
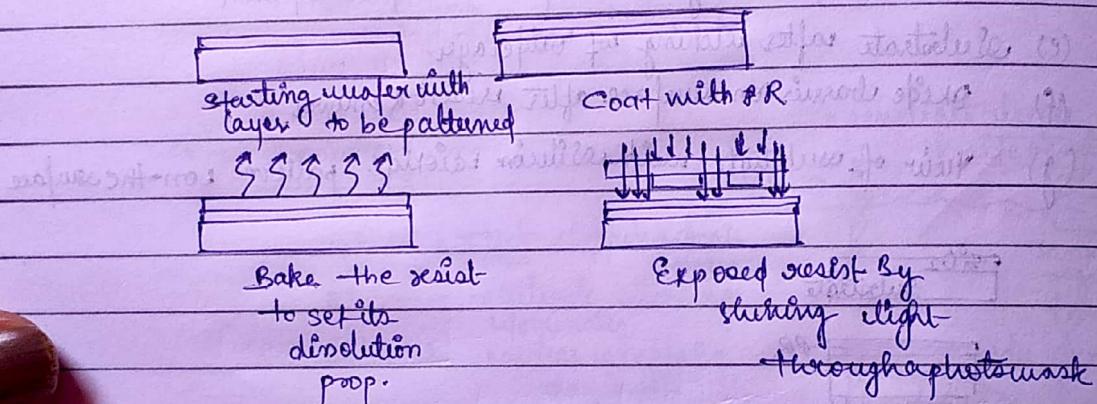
* Photomasks - CAD layout

PhotoMask

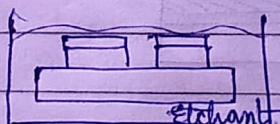


further, we remove P.R., and transferred onto substrate,

Lithographic Process. (Disadvantage - Difracⁿ)



(5) Immerse exposed wafer in developer



Etch the film

After initial steps

Dry etching base
Adhesion promoter applicatⁿ
Resist applicatⁿ

Softbake

Exposure

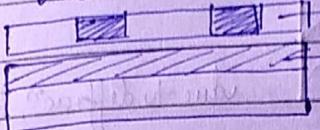
Post exp. Bake

Develop cycle

Hardbake \rightarrow Resist stabilization.

Contact Printing

SSSSS

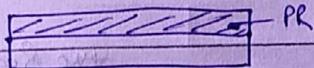
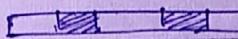


Marks | Both are close to each other

Resolⁿ $R < 0.5 \mu\text{m}$

mask plate is easily
damaged or
accumulates defects

Proximity Printing

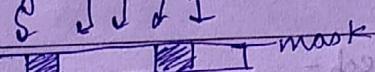


$R \propto$ to (λg)
gap
wavelength
of light

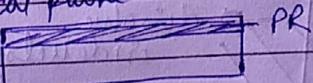
$\sim 1\text{mm}$ for visible photons

much smaller for X-Ray lithography

Projecting Printing



focal plane



lens → through this

focus light

so that we
can have
many
types of
magnification

But expensive

$\sim 0.2 \mu\text{m}$ of resolⁿ (deep UV photons)

trade off : optics. complicated and expensive

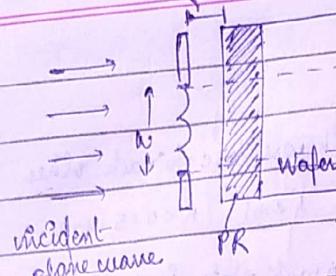
De-Magnificatⁿ \times : 10x stepper

4X

1X

Separation depends
on type of system

Aerial Images



proximity effect

Contact

due to diffraction, it may distort our pattern

Resists for Lithography

Exposure Sources

- Light

- Electron Beam

- X-ray sensitive

Resists

+ve &

- ve

Two Resist types

- ve Resist

- Composit^m

. Polymer (MW ~ 65000)
volatile solvents

- Light breaks N-N in light
sensitive additive

- Sensitive, hard,
swelling during
Develop.

the Resist

- Comp^m

Polymer (~ 5000)

photoactive dissol^m
inhibitors

(< 5%)

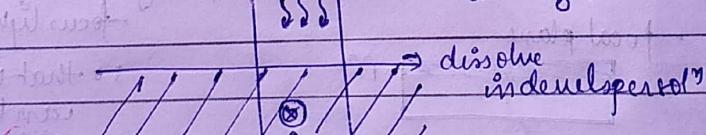
- volatile solvents
Inhibitor losses N₂

⇒ Alkaline soln.
Acid

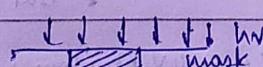
- Develops by
"etching"
No swelling

Positive PR Mech -

photons deactivate
sensitizer



polymer + photosensitizer



exposed

removed

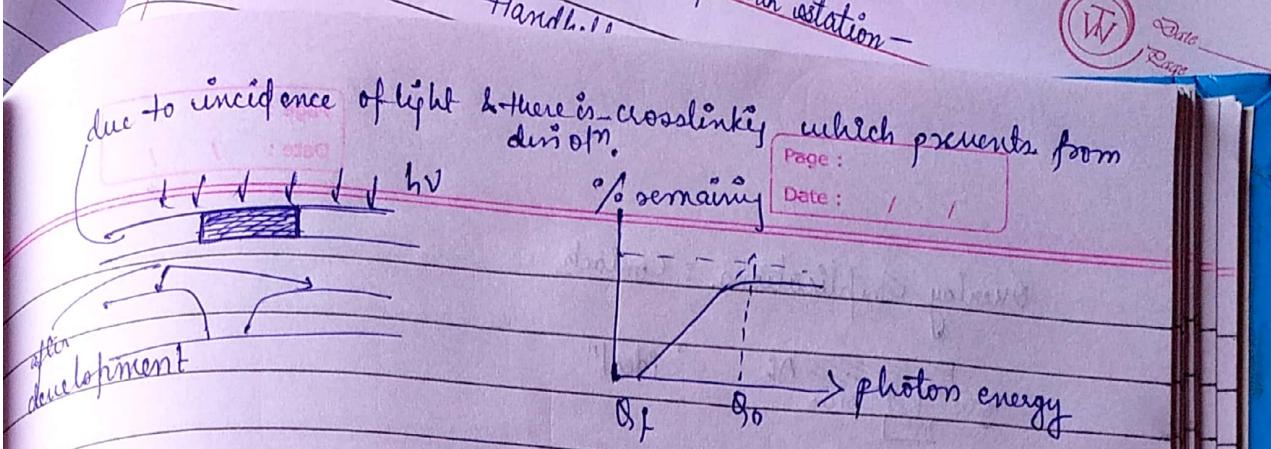
100% ↑

resist thickness remaining

Q₀ Q_f of exposure

Resist contrast

$\frac{1}{Q_{T,0}} \left(\frac{Q_f}{Q_0} \right)$



$h\nu \rightarrow$ crosslinking \rightarrow insoluble in developer

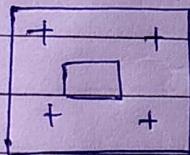
+ve PR
- higher Resolⁿ
requires aqueous-based solvents

* - less sensitive

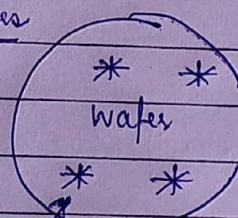
-ve PR

- more sensitive \Rightarrow higher exposure throughout
- less expensive
- X - lower Resolⁿ
- X - requires organic-based solvents
- relatively tolerant of developing conditions
- Better chemical resistance \Rightarrow better Mask Material

Overlay Errors



Photomask
mask



Alignment
marks

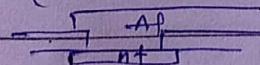
are not properly
placed;

(cross-cross match
nhi kija)

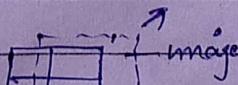
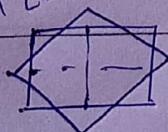
Toh
error.

Rotational/Translational Errors

(2) T.E

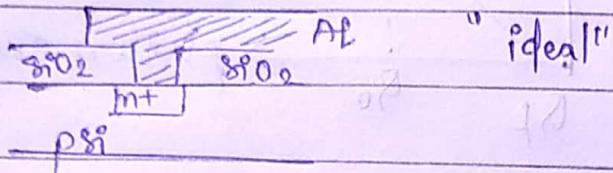


P (3) R.E.

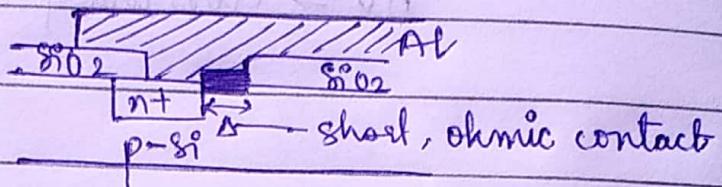


Reference

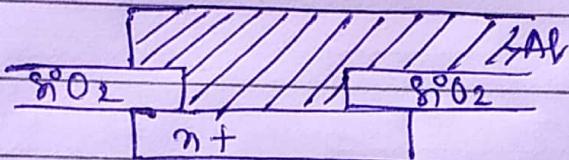
Overlay Implications : Contacts



- Alignment error

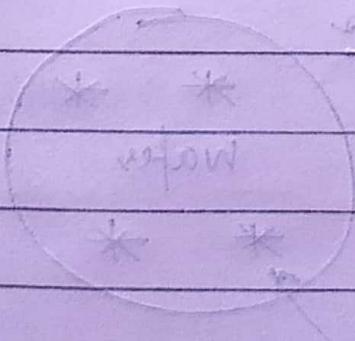


80% : Design $n+$ region larger than contact hole



- larger contact area -
- facilitates p-n junction -
- facilitates electron transport -

- contact $n+$ added to contact p junction -



MOSFET

