- **Diffusion**:
- Process of introducing dopants into selected areas on an IC
- **Example**:

diborone gas → (B_2H_6) + O_2 @ high temperature ~ 800°C — 1200°C

SiO_2 B B B B B SiO_2

p

n-Si substrate

① Form borosilicate glass w/ high B concentration
② Boron diffuses in → this becomes p-type

⇒ diffusion requires:
① concentration gradient
② movement (velocity)

→ Example. Fish Tank

① When separator removed...
② Fish will go to the other side
③ Until the concentration is the same on both sides

highly concentrated

But they can't if they're dead!

It's similar for an impurity in silicon:

Si Si Si Si
Si B Si
Si Si Si Si

need temperature for this to happen

Need higher T for this vacancy to exist.

Just one mechanism for diffusion → we'll look at others, too

substitutional diffusion:
⇒ impurity moves along vacancies in the lattice
⇒ substitutes for a Si atom in the lattice

For movement to occur:

① Vacancies must exist.
② The B must have enough energy to move.

} Both require high temperature!

must heat to induce diffusion of impurities in Si!

Definitions.

① Predeposition: diffusion w/ dopant source present
② Drive-in: diffusion in an inert ambient, e.g., N_2 w/ no dopant gases present

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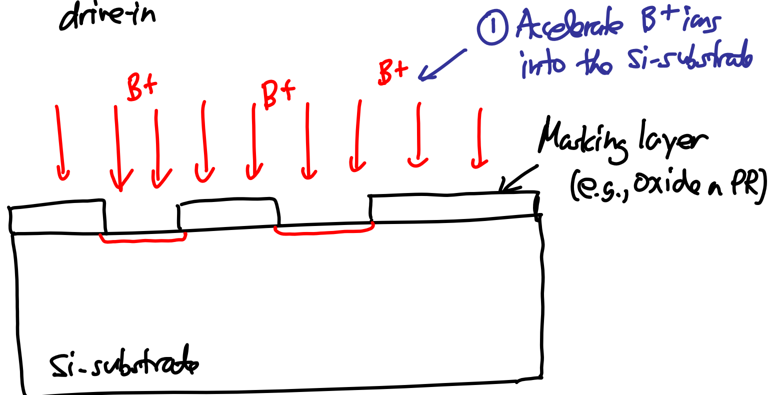
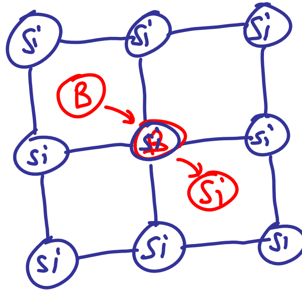
Ion Implantation

⇒ a more accurate way to introduce dopants before drive-in



② B+ punches into the Si



③ Raise T to move the B into the lattice → only when it's in the lattice is it active & can contribute to the doping level

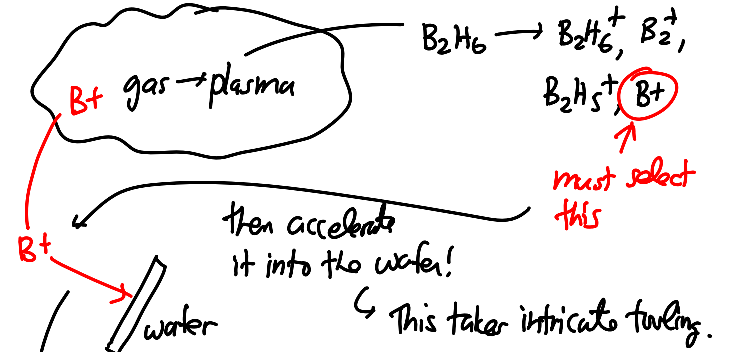
④ Keep T up to drive the dopants in to the desired depth.

Advantages:

1. accurate dose
2. change depth by setting ion energy
3. no need for high temperature

Problem: COST!

An ion implanter is quite a sophisticated piece of equipment! → and expensive! (> $1 million)



Energy Range: 20 keV – 100 keV

Penetration Depth: fraction of a μm

⇒ larger ions don't go as far as smaller (heavier ions penetrate shallower than smaller)

Dose: $10^{11} - 10^{15}\ cm^{-2}$

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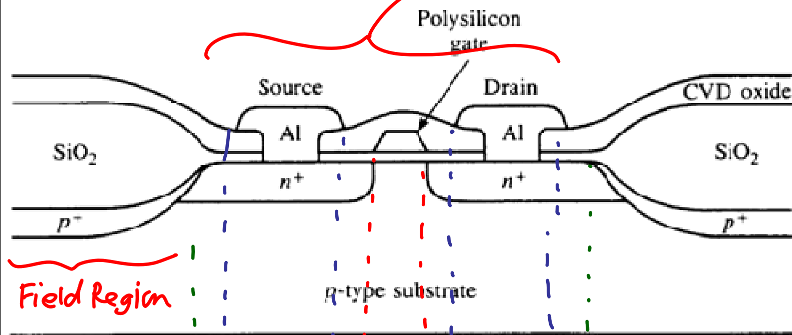
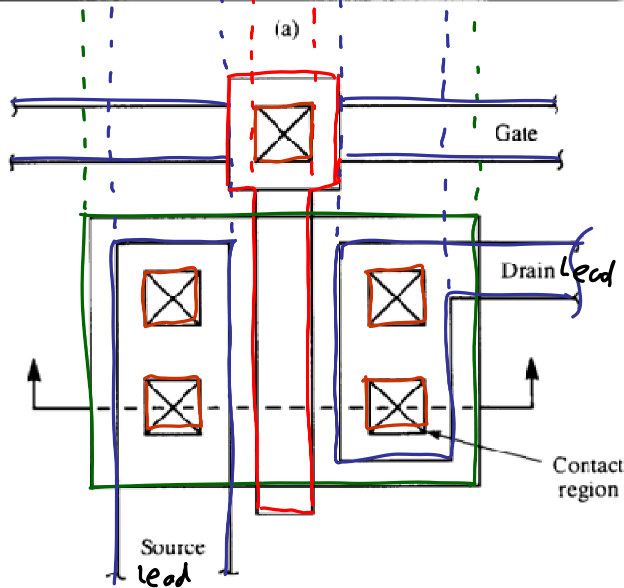
- **Process Integration**:
- e.g., Standard NMOS Process
- Similar to EE143 process, but a bit more advanced
- Difference:
  - 5 masks (vs. 4 for EE143)
  - LOCOS oxidation (local oxidation) (oxidation and etch back for EE143)
- The Goal: NMOS device





5 Masks

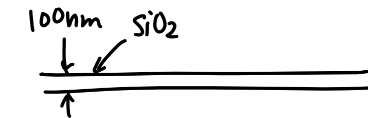
- Gate Polysilicon Mask (cf)
- Active Area Mask (df)
- Contact Mask (df)
- Metal Mask (cf)
- Bond Pad Opening Mask (df) → not shown

clear field → box indicates regions of PR that remain after lithography (for (+) PR)

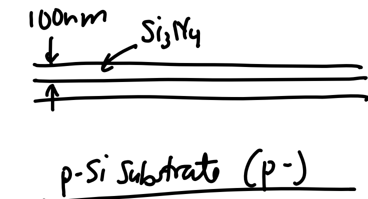
dark field → box indicates region of PR removed after lithography (for (+) PR)

NMOS Process Flow

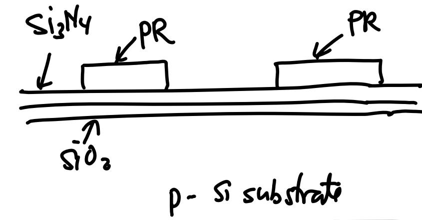
Silicon Oxidation thickness = 100nm



LPCVD Si_3N_4 (100nm)



Mask I: Active Region



over →

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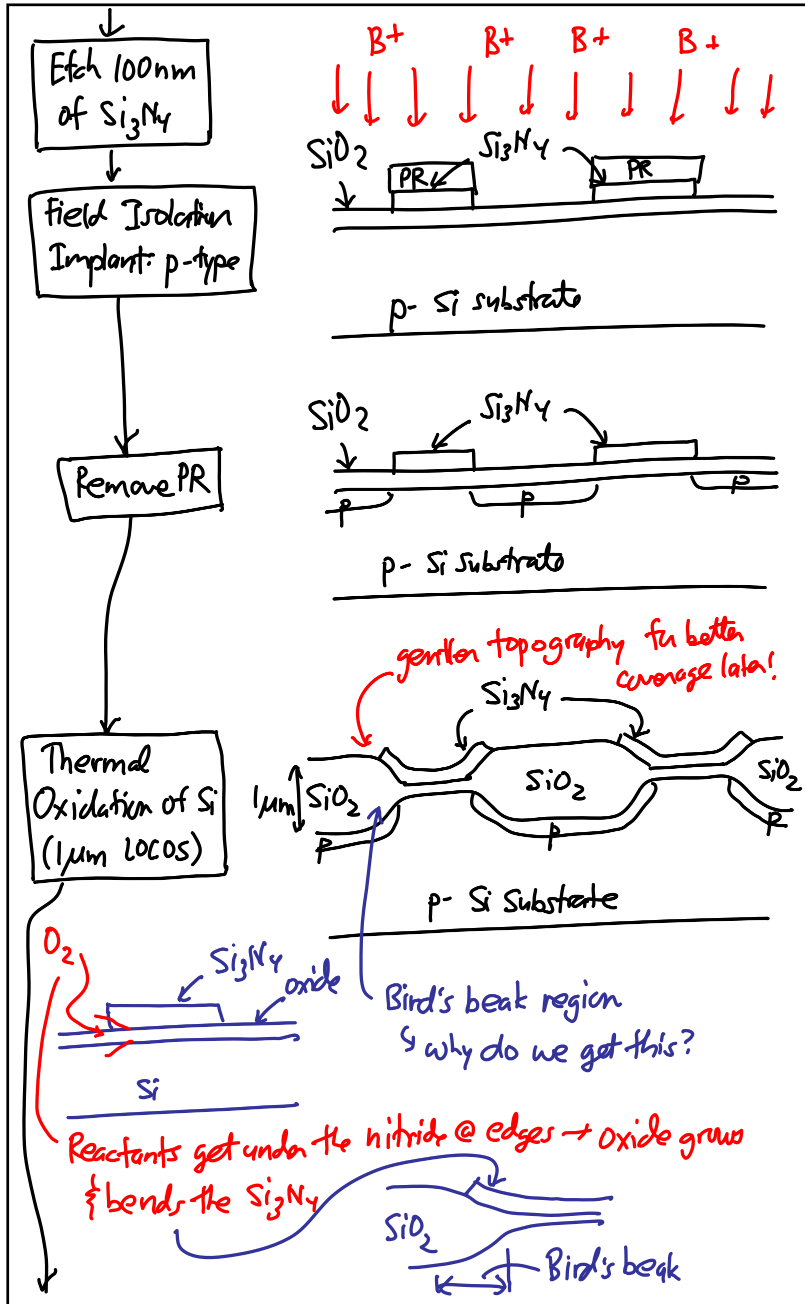

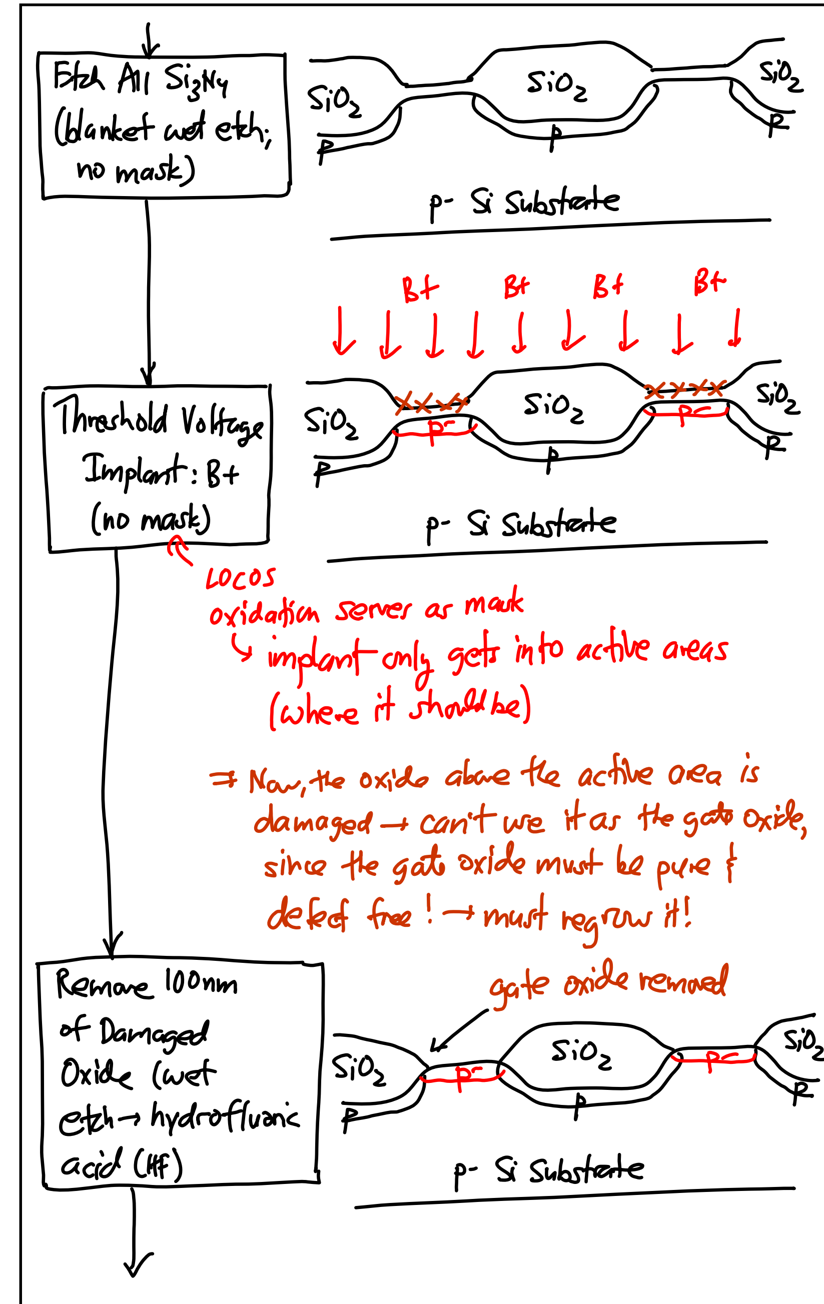

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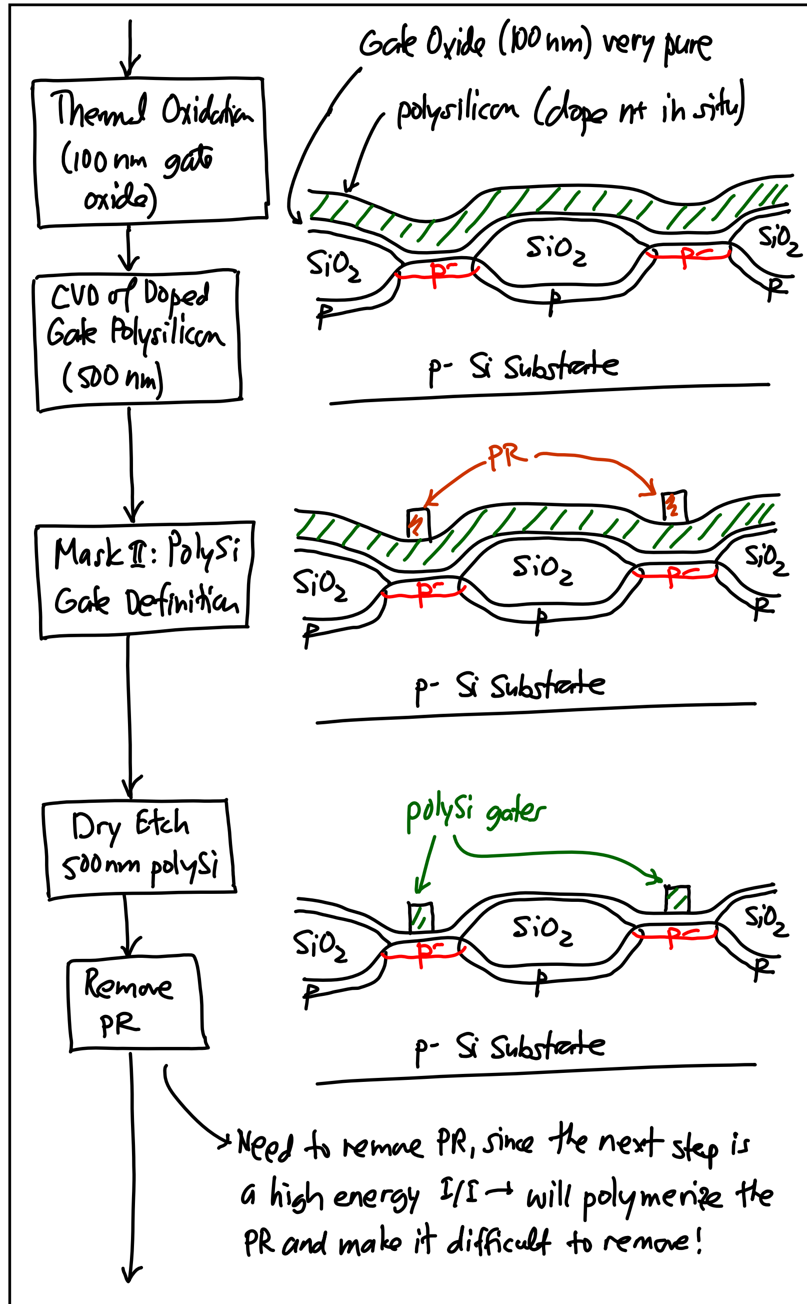

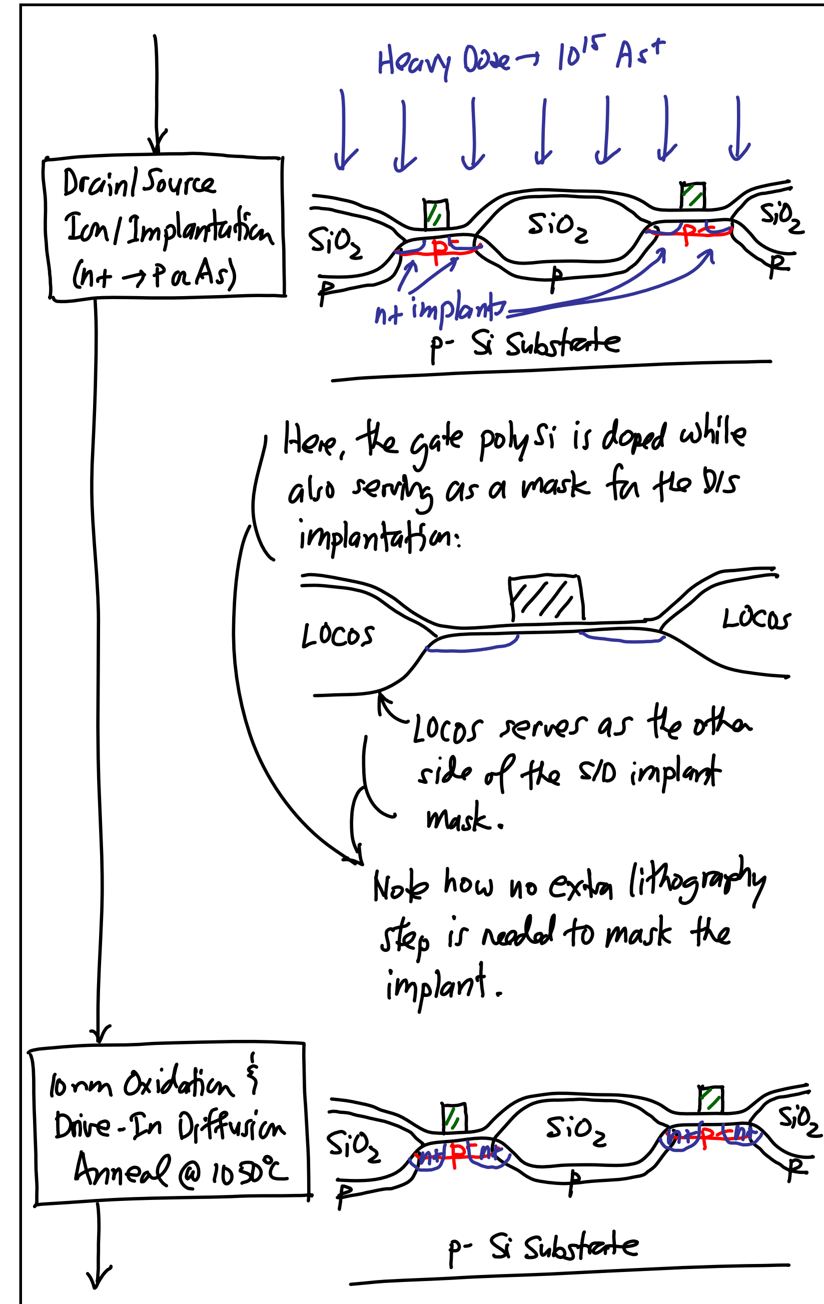

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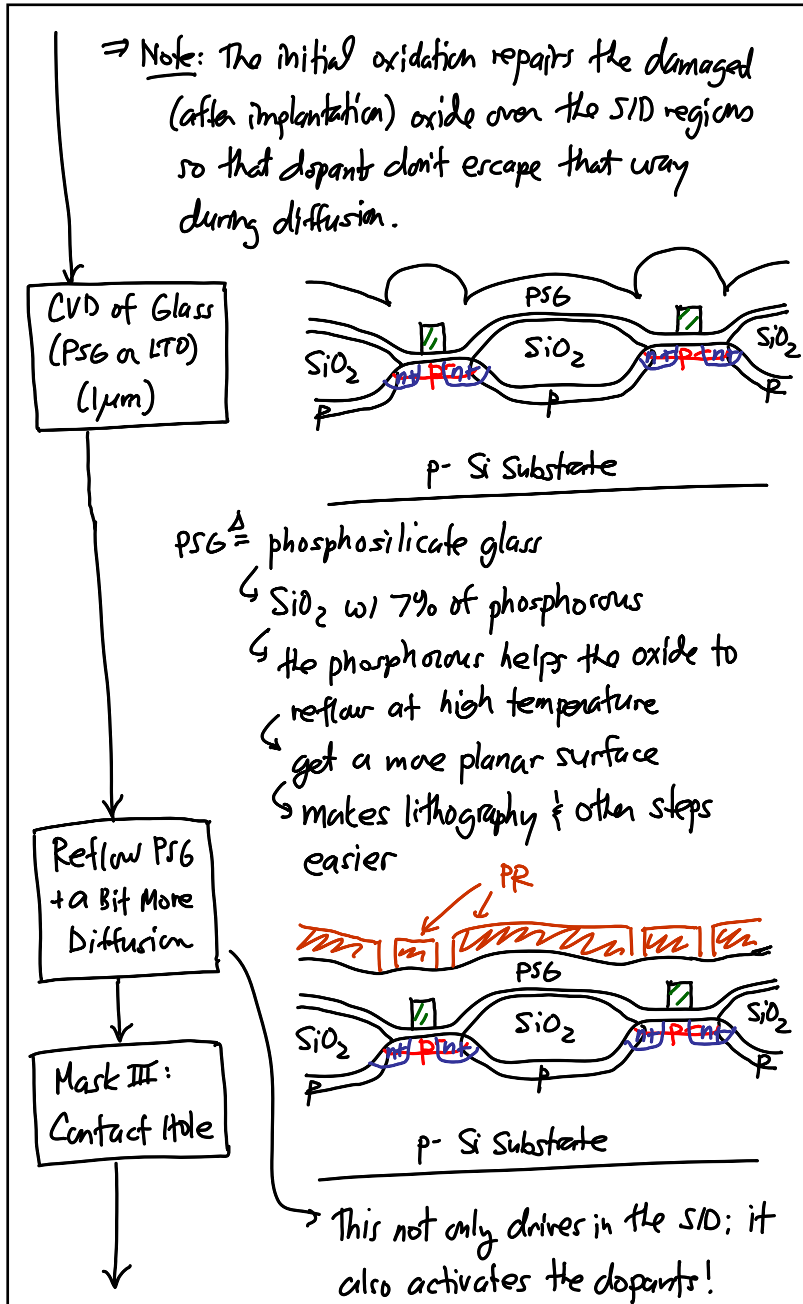

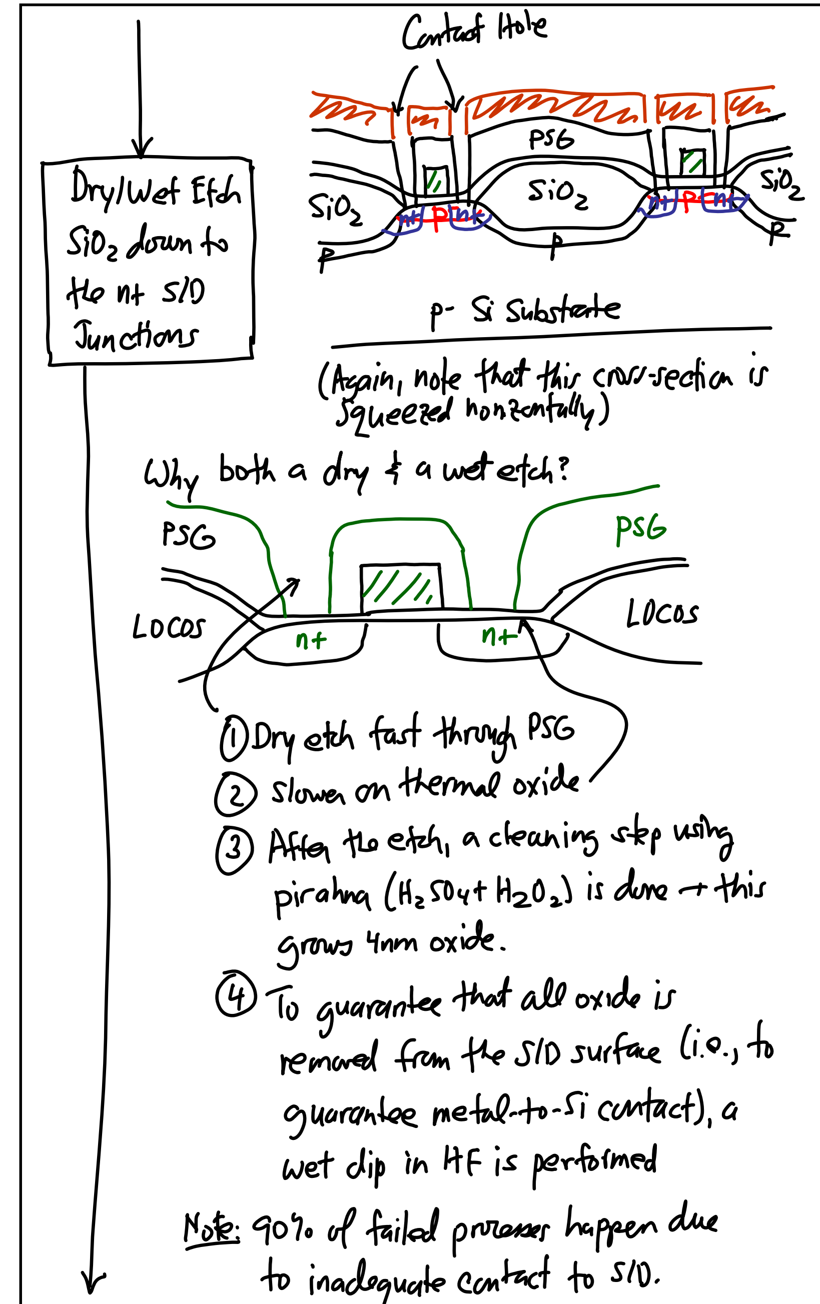

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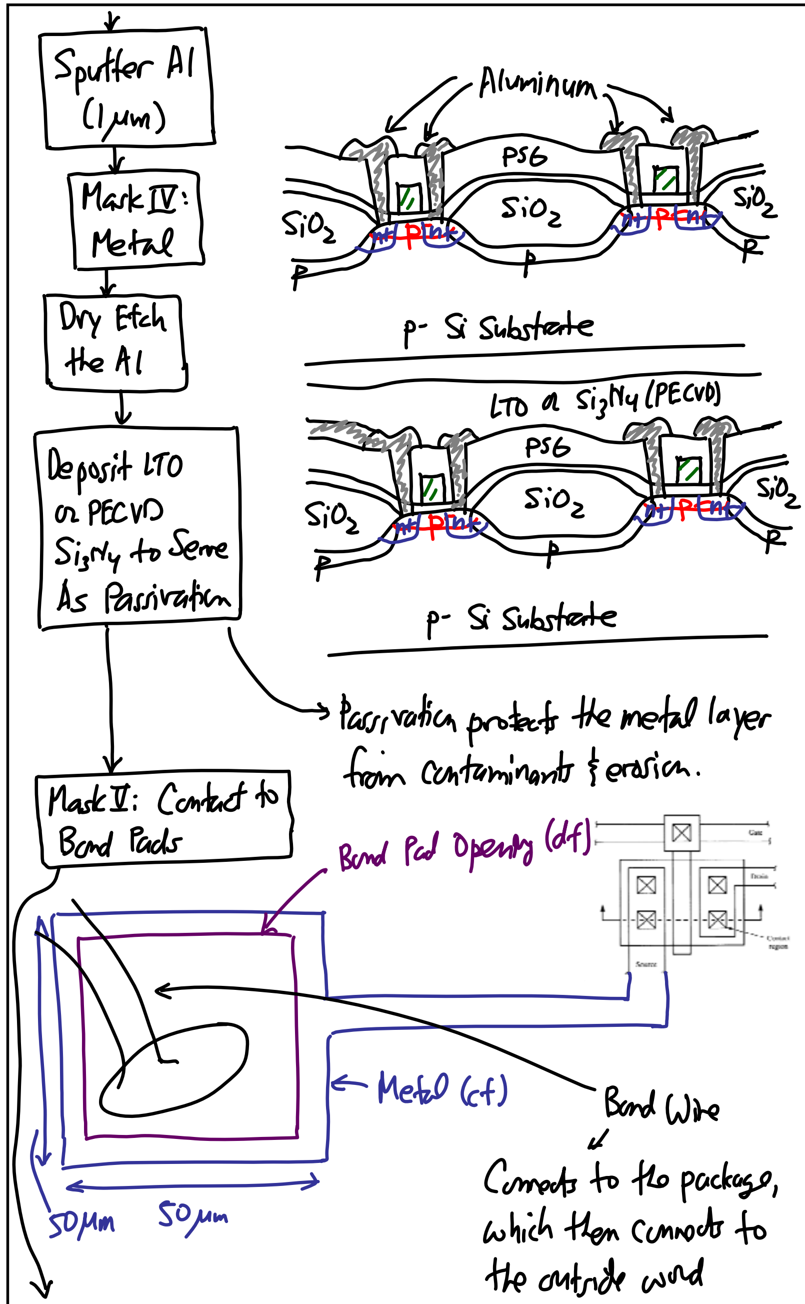

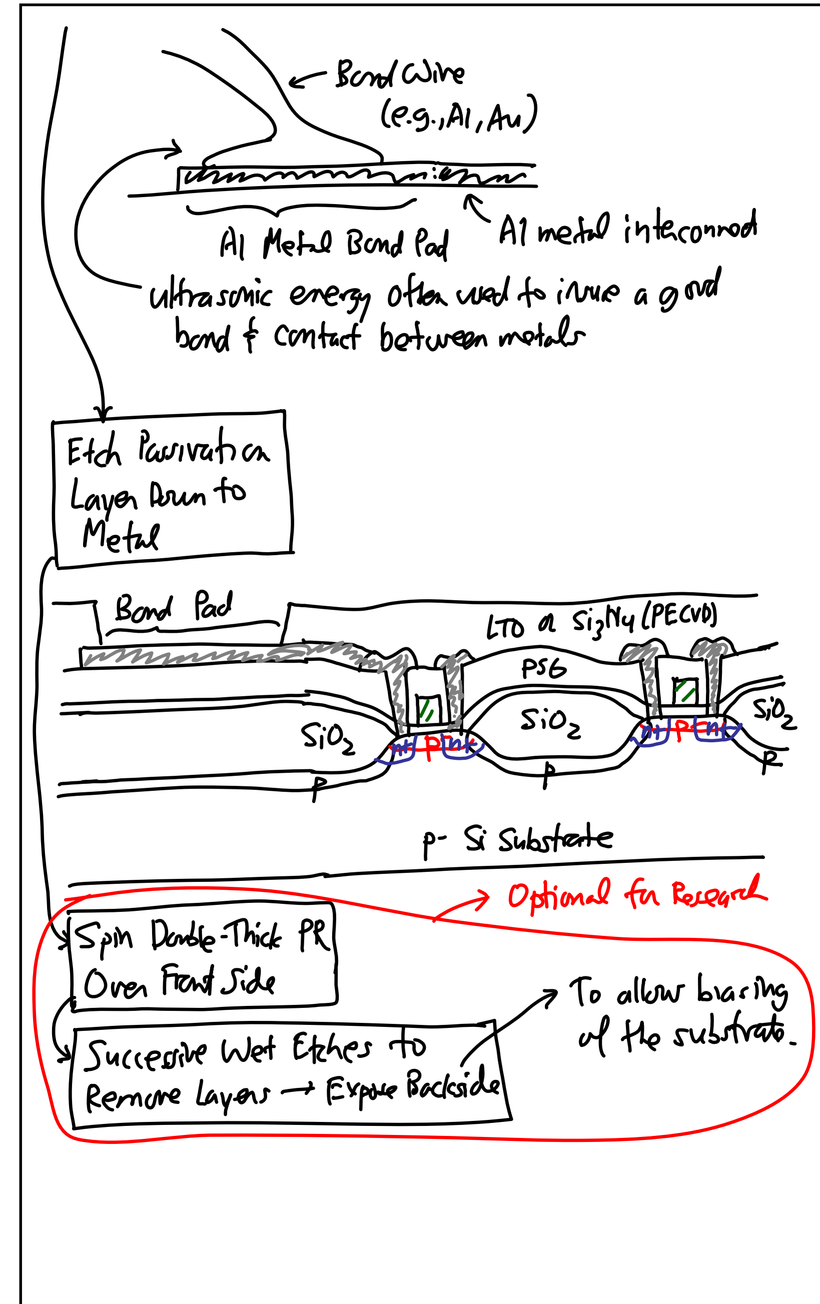

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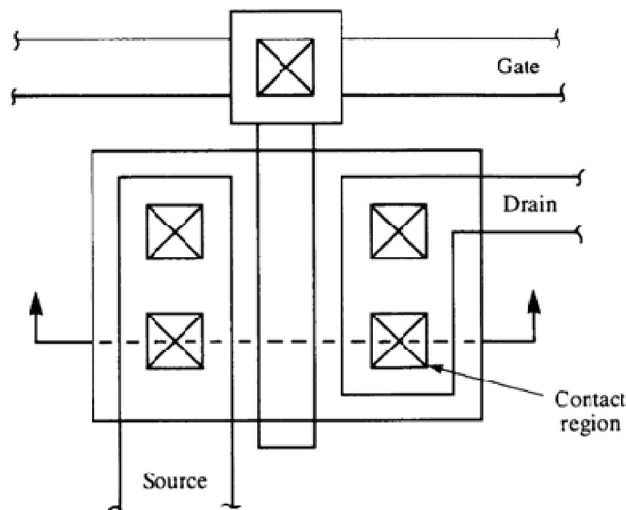
Mark to Cross-Section

⇒ one skill you must learn:

Given: ① Process Flow
② Mask Layout

Draw the cross-section along various lines and at various steps in the process flow.

- Example: NMOS Process
- Layout:



- Process Flow:
  1. Silicon oxidation: target = 100nm
  2. LPCVD Si_3N_4: target = 100nm
  3. Lithography: Mask I (active area)
  4. Etch Si_3N_4 to clear it in field areas
  5. Field isolation implant: B+ (p-type)
  6. Remove PR
  7. Grow 1mm of SiO_2 by thermal oxidation (LOCOS oxidation)
  8. Blanket etch all Si_3N_4 in hot phosphoric acid wet etchant
  9. Threshold voltage implant: B+ (no mask)
  10. Remove 100nm of damaged oxide via a timed wet etch in hydrofluoric acid (HF)
  11. Grow 100nm of gate thermal oxide in an ultra-clean furnace
  12. LPCVD situ phosphorous-doped gate polysilicon
  13. Lithography: Mask II (gate polysilicon)
  14. Dry etch polysilicon to clear the field areas
  15. Remove PR
  16. D/S ion implantation: P or As (n-type)
  17. Oxidize a bit (10nm) and anneal at 1050°C to activate dopants and drive-in diffusion
  18. LPCVD PSG: target = 1μm
  19. Reflow PSG (& a little bit of diffusion) at 950°C
  20. Lithography: Mask III (contact hole)
  21. Dry/wet etch SiO_2 down to n+ S/D regions
  22. Sputter Al: target = 1μm
  23. Lithography: Mask IV (metal)
  24. Dry etch Al
  25. Deposit via LTO or PECVD Si_3N_4 to serve as passivation
  26. Lithography: Mask V (bond pad contacts)
  27. Etch passivation layer down to metal
  28. (optional) spin double-thick PR over the front side

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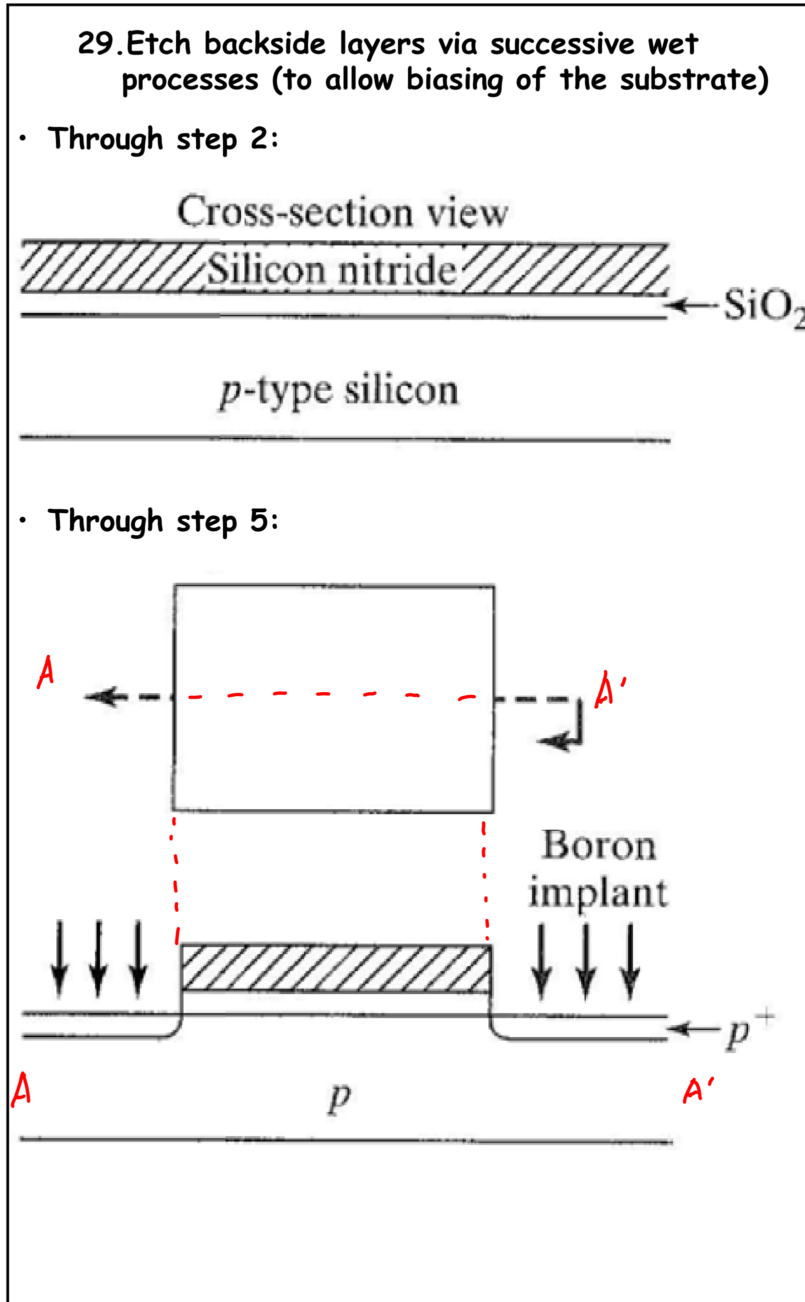

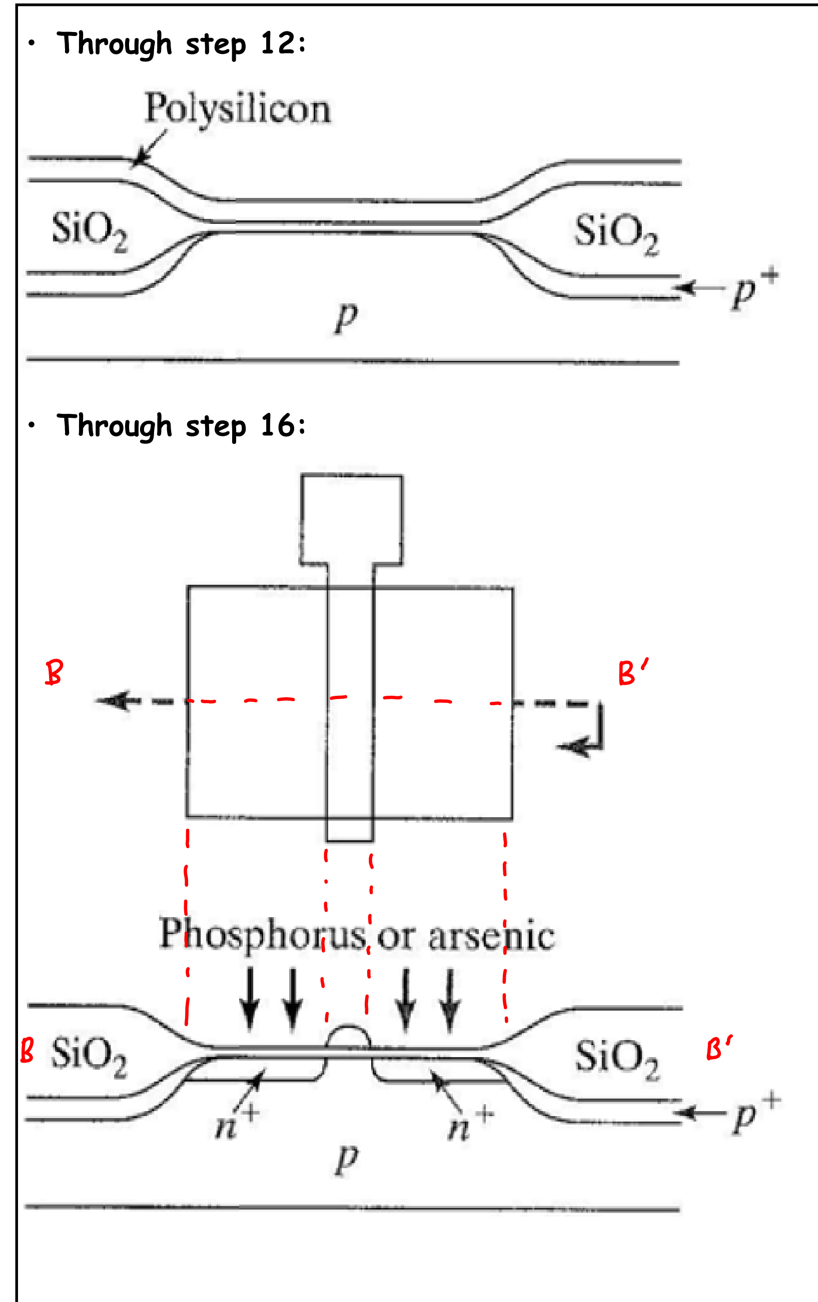

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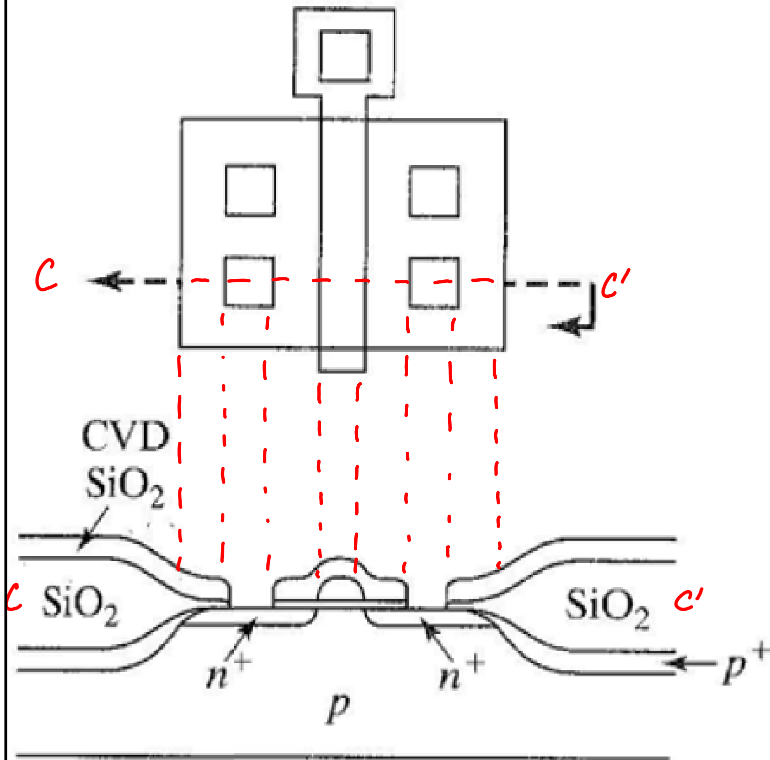
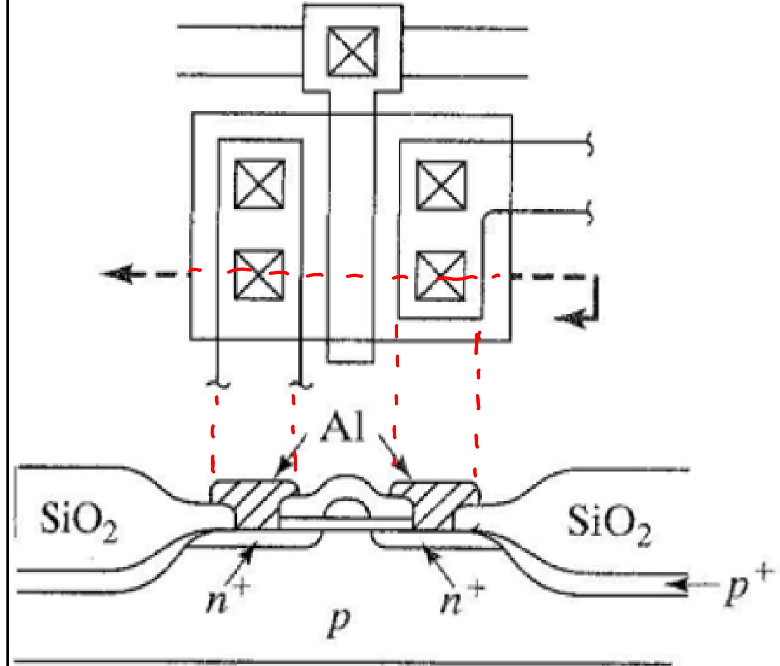
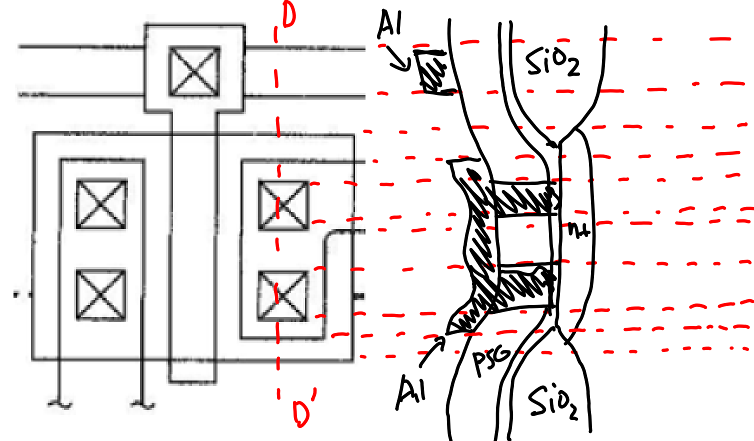
- Through step 21:



- Through step 24:



How about a sideways cross-section?



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