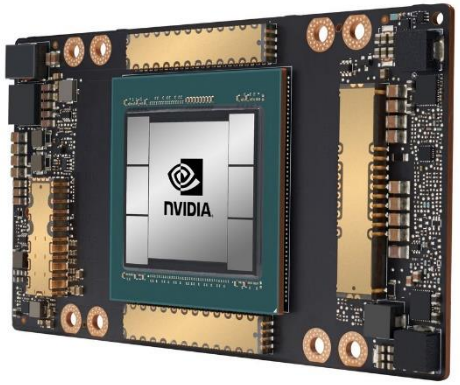
CSCB58: Computer Organization



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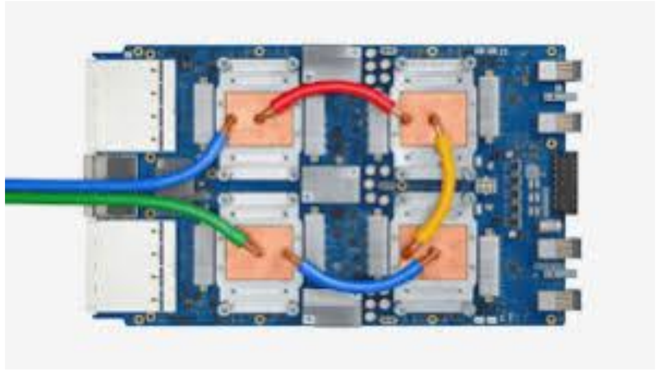
Fall 2020

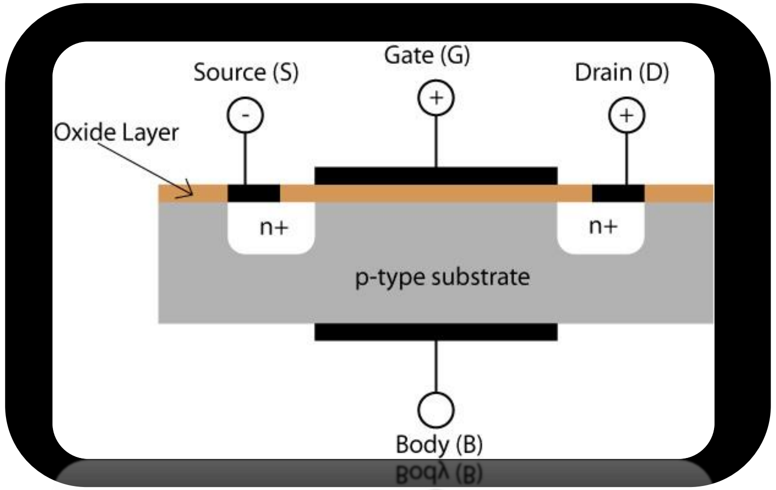


The content of this lecture is adapted from the lectures of Larry Zheng and Steve Engels

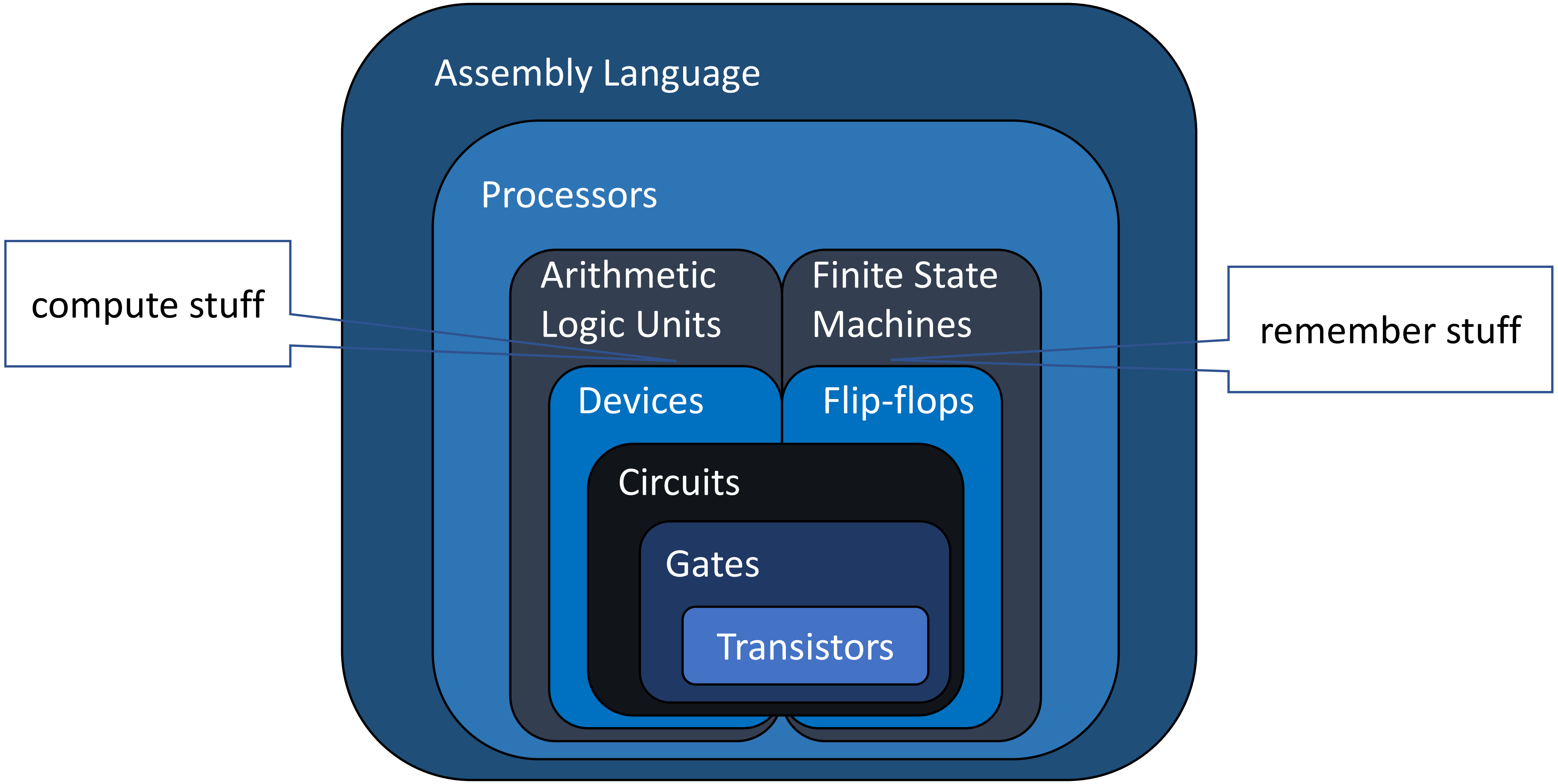
CSCB58 Week 1: Summary

Week 1 Review

- Properties of electricity
- Semiconductor materials
  - Doping (n-type and p-type)
- p-n junctions
- Transistors
  - MOSFETs



The architecture of a computer **hardware**, level by level, bottom-up

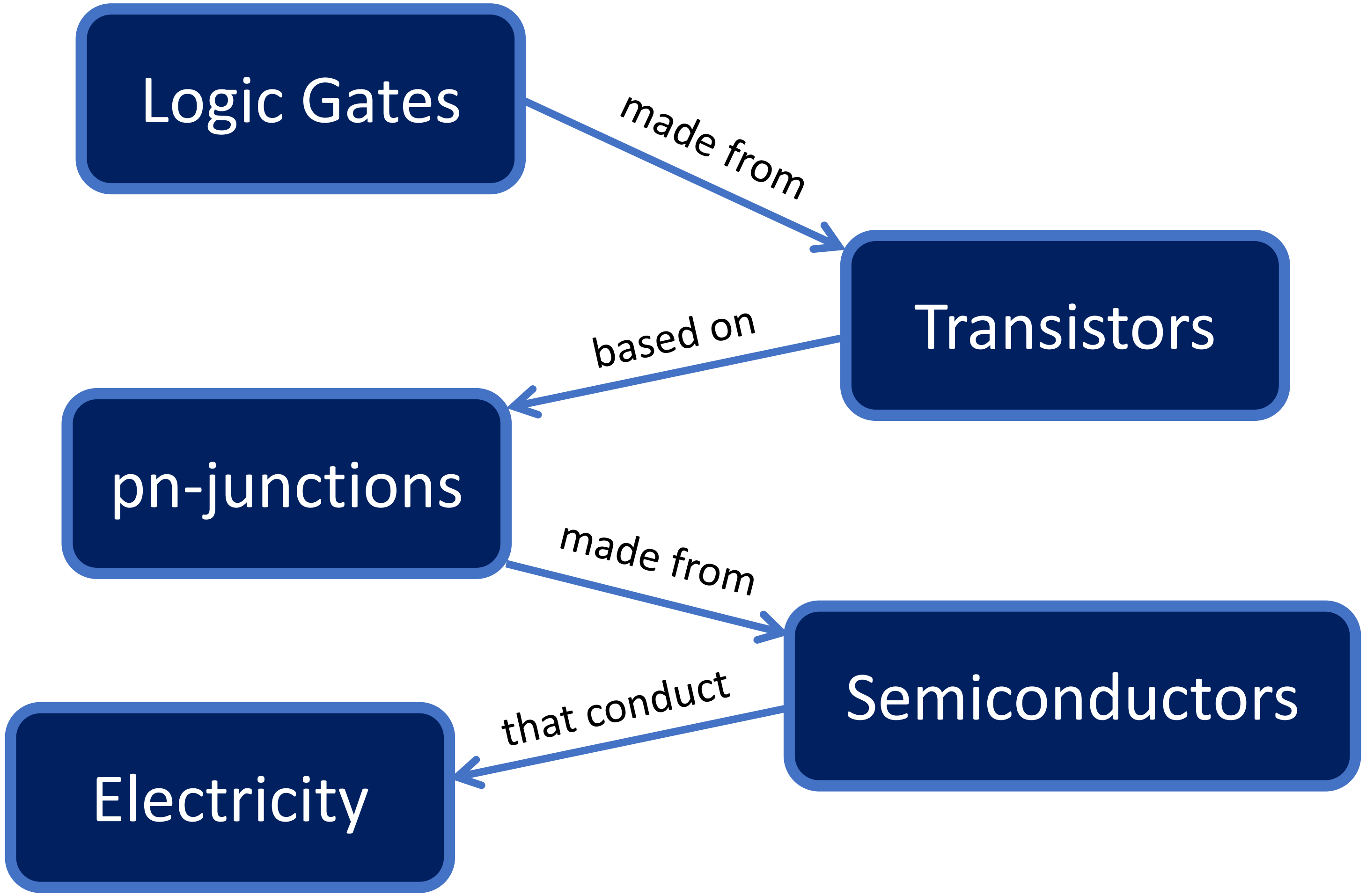


Transistors

Outline of the story

- Electricity, basic concepts
- Insulators, conductors, in between …, **Semiconductors**
- Impure semiconductors, **p-type / n-type**
- Put p-type and n-type together -- **pn-junction**
- Apply voltage to a pn-junction – **principle of transistors**
- A real-world manufacturing of transistor -- **MOSFET**

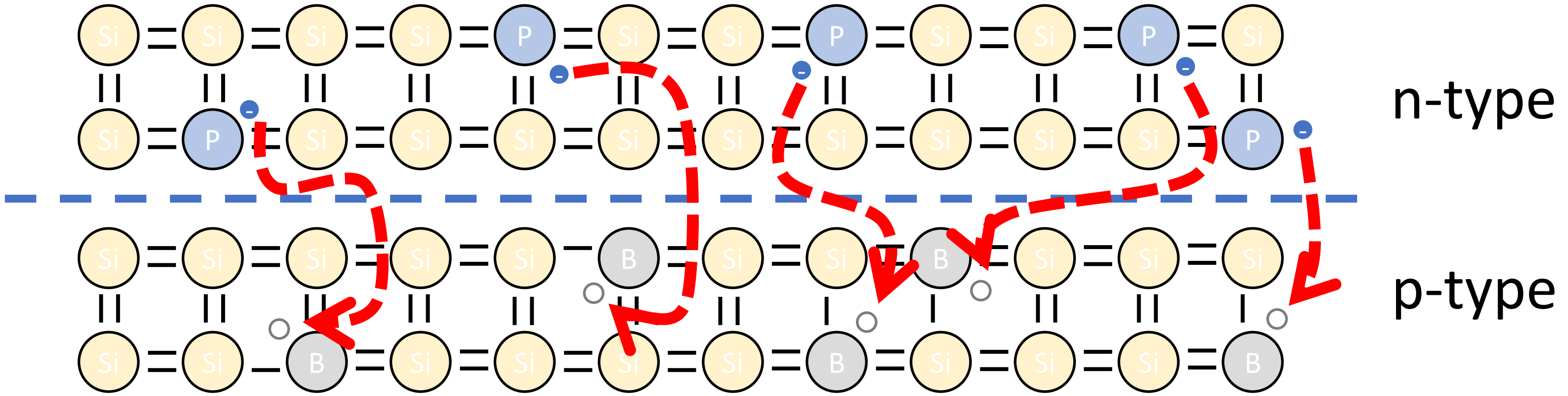
Where do transistors fit?



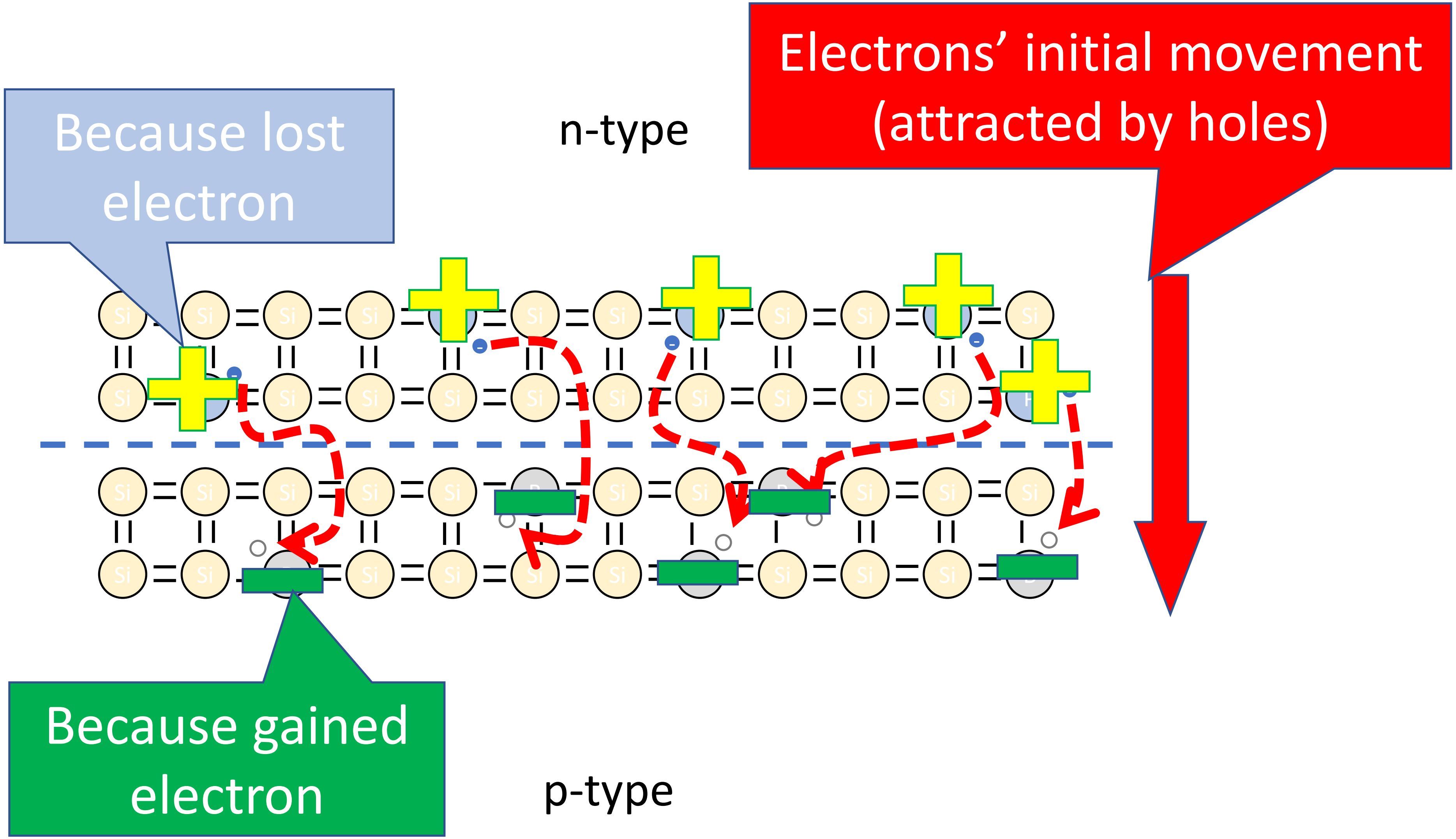
PN-junctions

Bringing p and n together

- What happens if you brought some p-type material into contact with some n-type material?



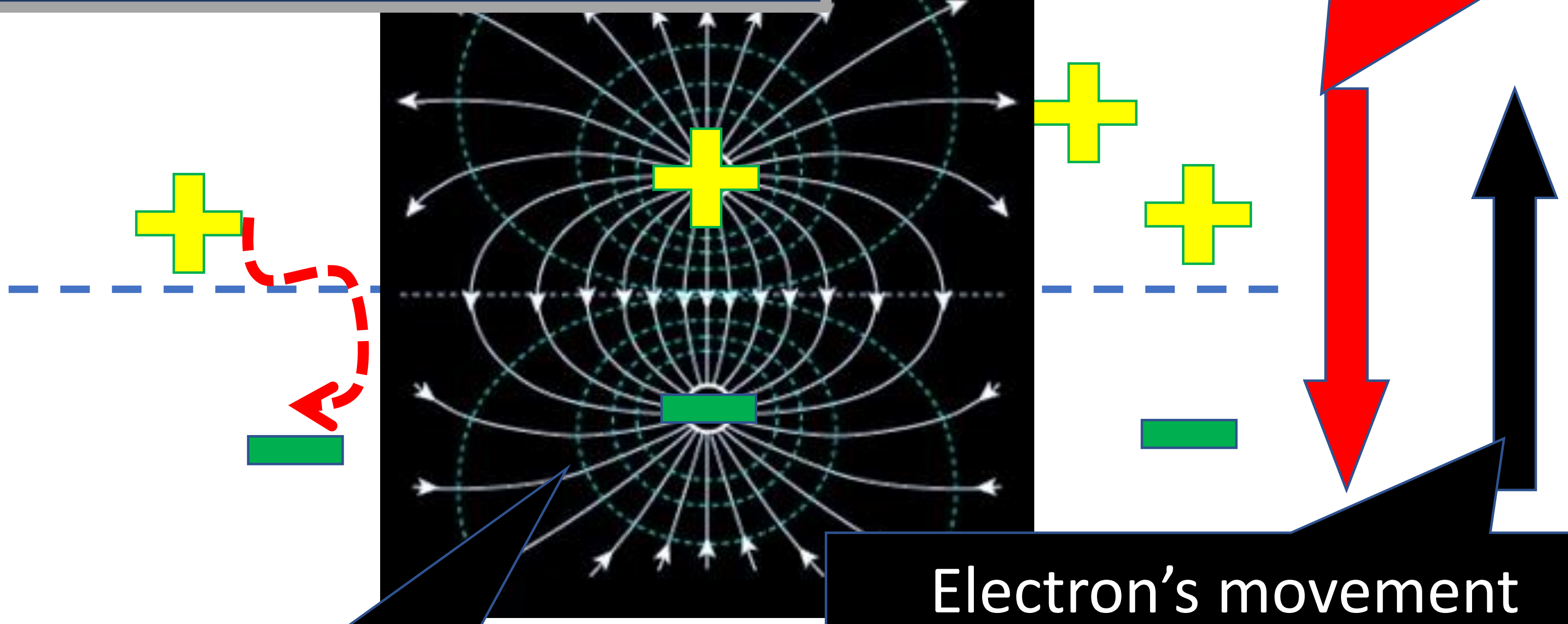
- The **electrons** at the surface of the n-type material are **drawn** to the **holes** in the p-type.


Because lost electron
n-type
Electrons' initial movement (attracted by holes)
Because gained electron
p-type

Diffusion increases the width of depletion layer, and drift draws it back. An **equilibrium** is reached, when the depletion layer is of a certain width.

"Diffusion"

Electrons' initial movement (attracted by holes)



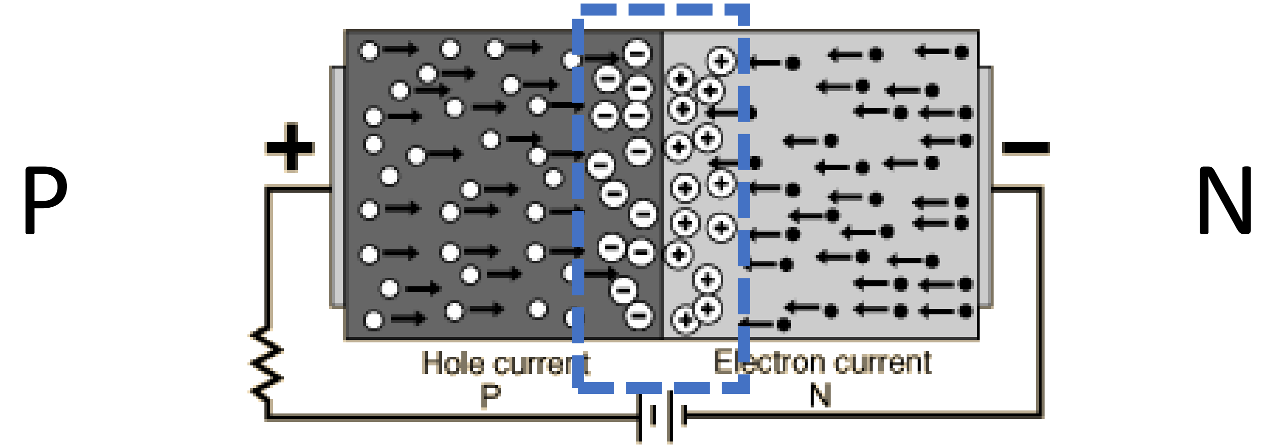
Electric field

p-type

Electron's movement drawn by the electric field

"Drift"

Summary of pn-junction



When we put **p** and **n** together, they will form a depletion layer with electric field in it.

The depletion layer grows up to a certain **width**, until equilibrium is reached.

Apply voltage to a PN-junction

It could be applied in two possible directions

- **P**ositive voltage to the **P** side
- **P**ositive voltage to the **N** side

Apply forward bias

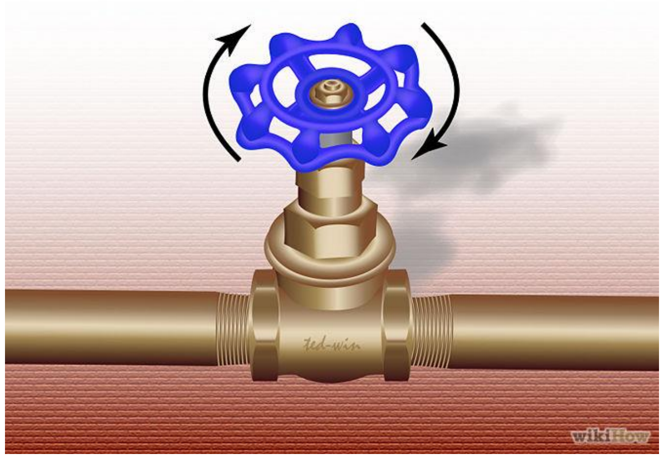
- Depletion layer narrower
- Easier to travel through
- Better conductivity
- Like switch **connected**

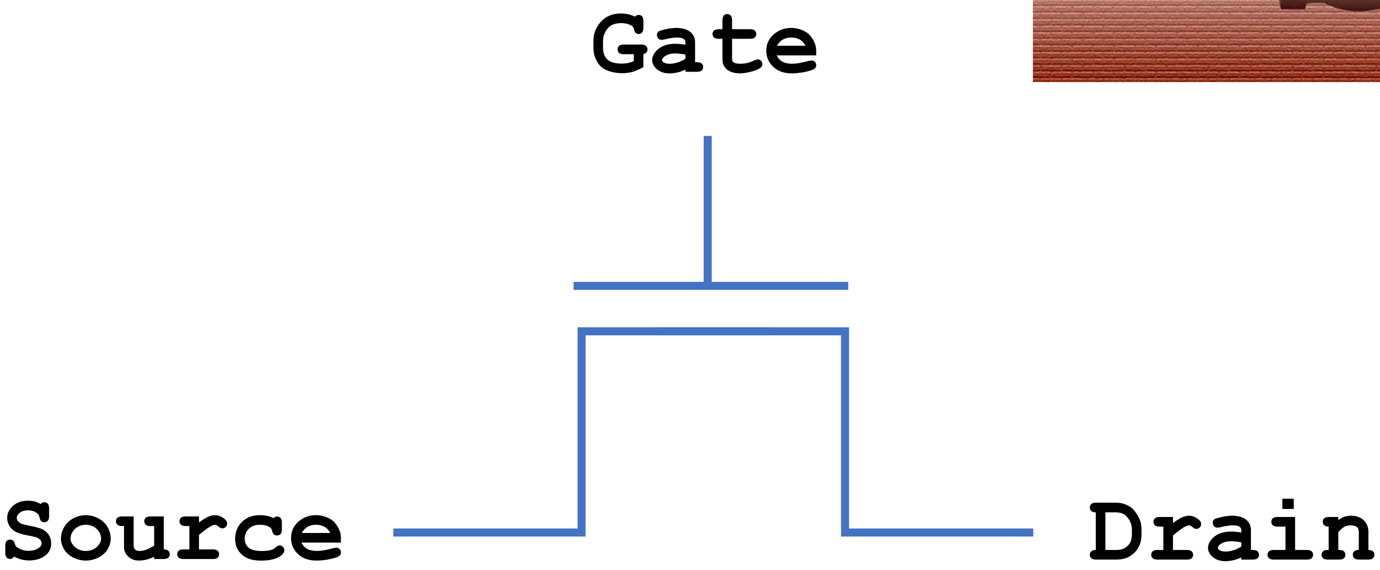
Apply reverse bias

- Depletion layer wider
- Harder to travel through
- Worse conductivity
- Like switch **disconnected**

That’s how transistors work!

Metal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor




Gate
Source
Drain

Metal

Oxide

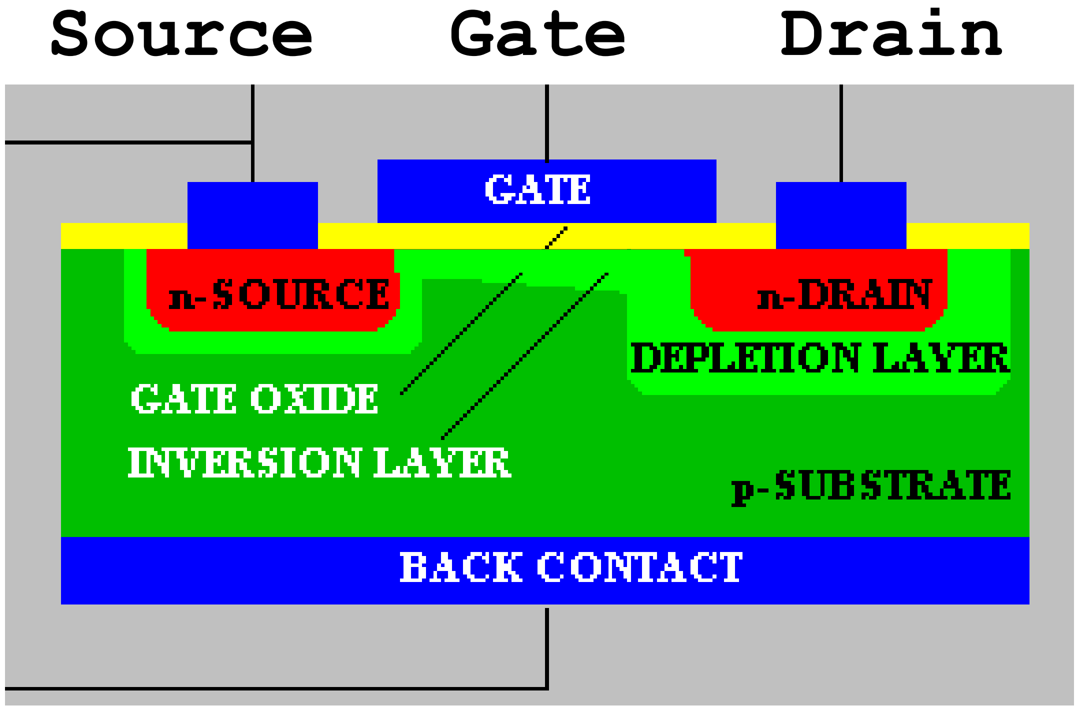
Insulator

Conductor, can apply electric charge to it

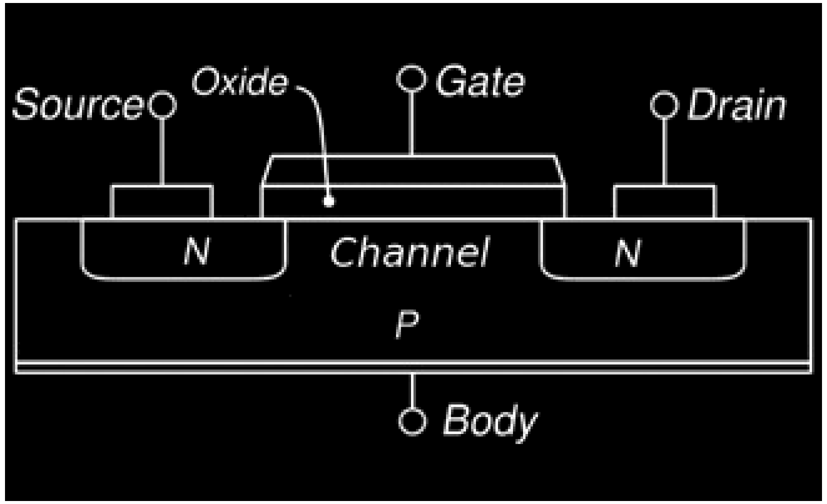
N-type

P-type

Semiconductors, doped



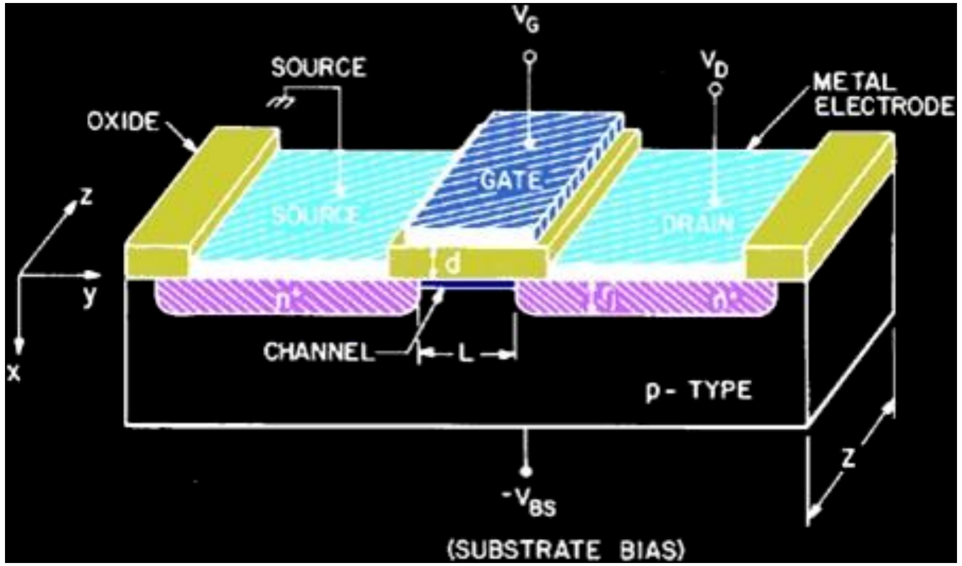
The MO of MOSFETs



- Metal Oxide Semiconductor Field Effect Transistors are composed of a layer of semiconductor material, with two layers on top of the semiconductor:
  - An oxide layer that doesn’t conduct electricity,
  - A metal layer (called the gate), that can have an electric charge applied to it
  - These are the M and O components of MOSFETs.

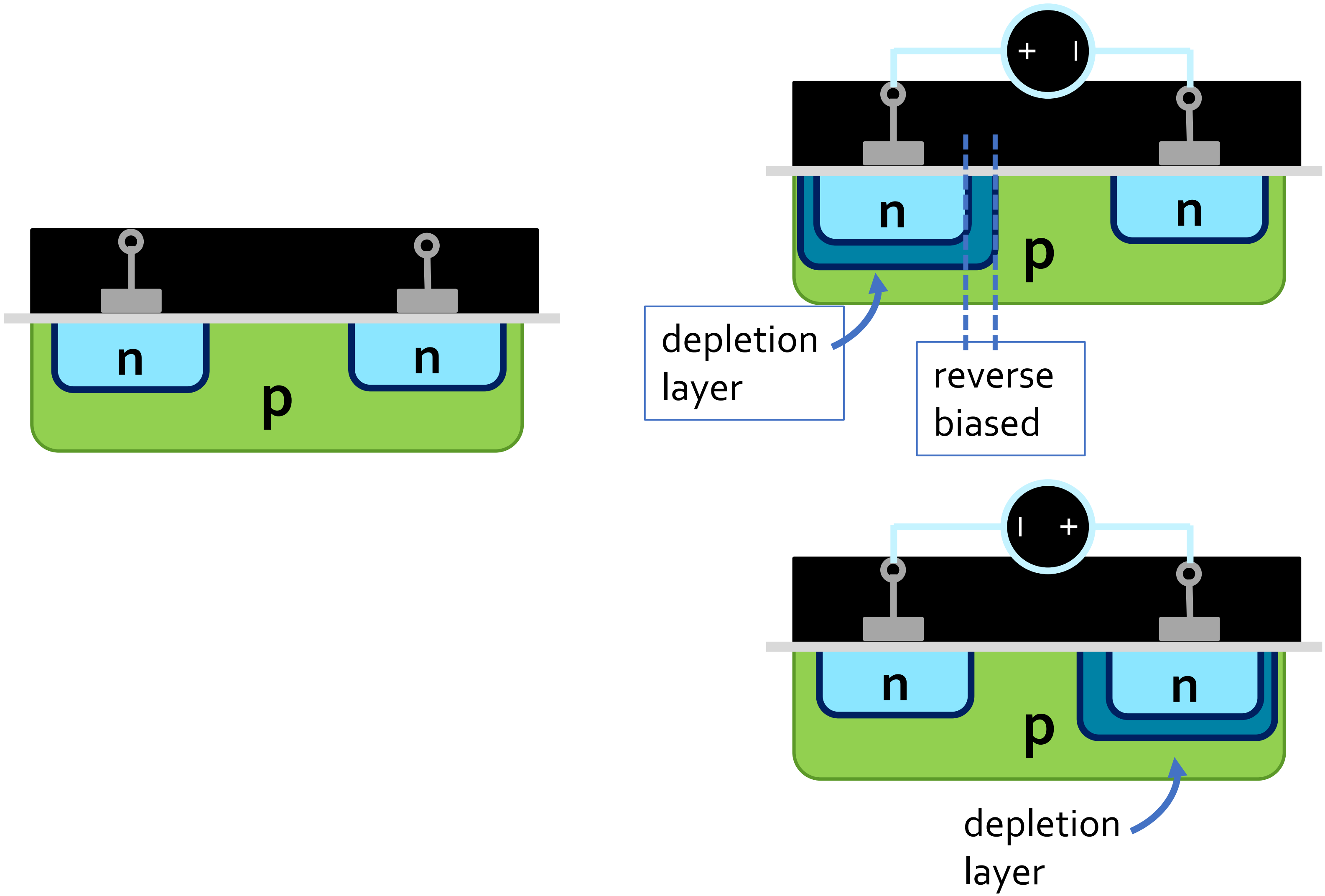
The S of MOSFETs

- The semiconductor sections are two pockets of n-type material, resting on a **substrate** layer type material.



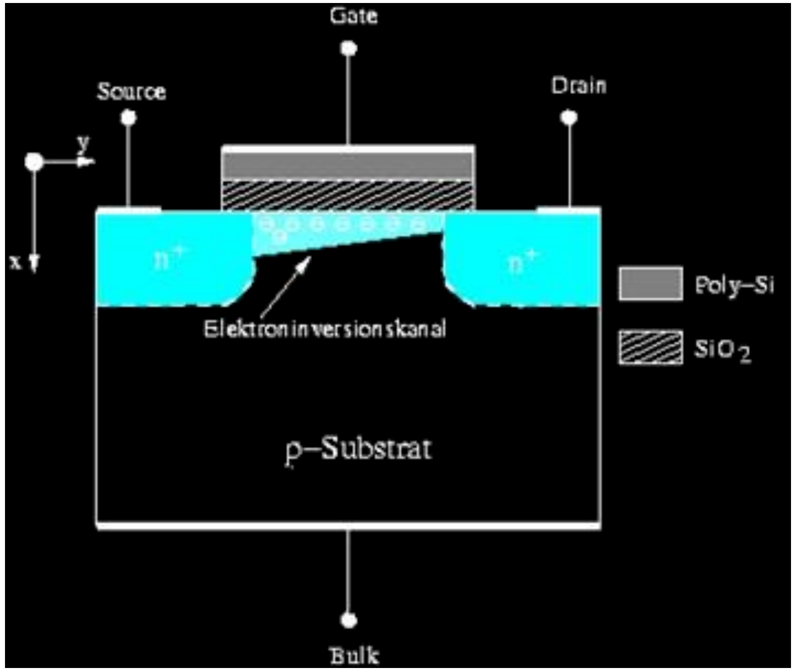
- A voltage is applied across the two n-type sections, called the **drain** and the **source**. No current will pass between them though, because the p section in between creates at least one reverse-biased pn junction.

Applying voltage to NPN



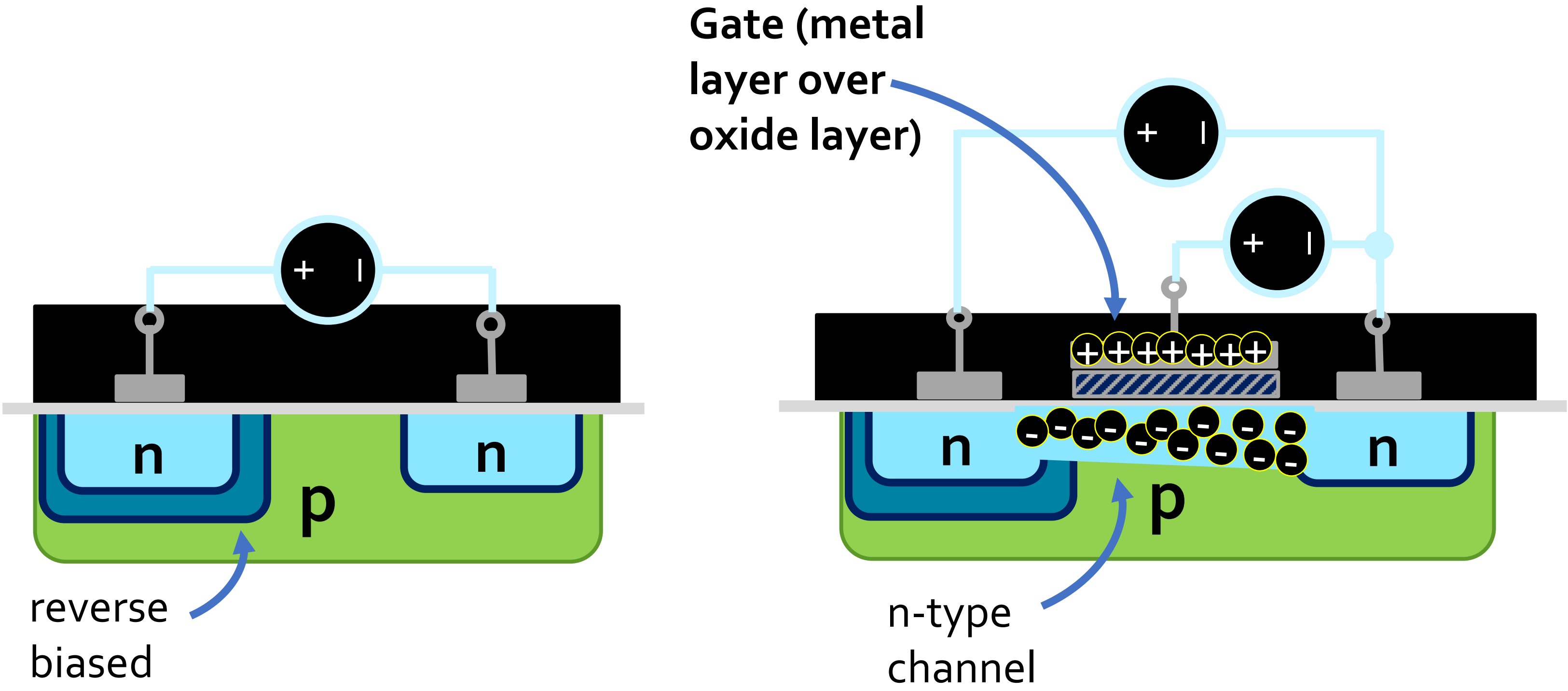
n-channel MOSFETs

- However, when a voltage applied between the source and the metal plate (the **gate**), positive charges are built up in the metal layer, which attracts layer of negative charge to surface of the p-type material.



- This layer of electrons creates an n-type channel between the drain and the source, connecting the two and allowing current to flow between them.
  - the wider the channel, the higher the current

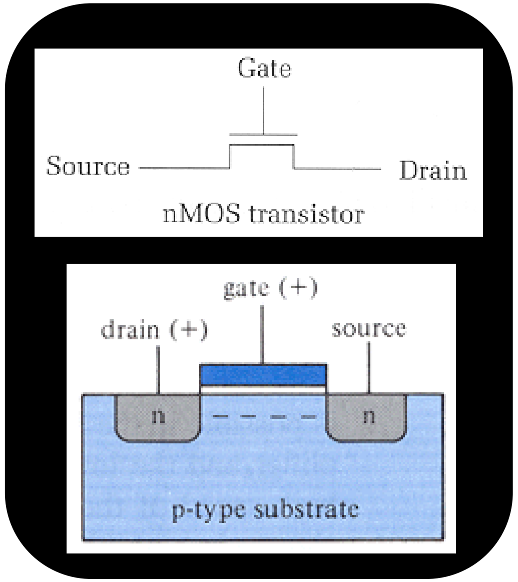
Applying voltage to NPN

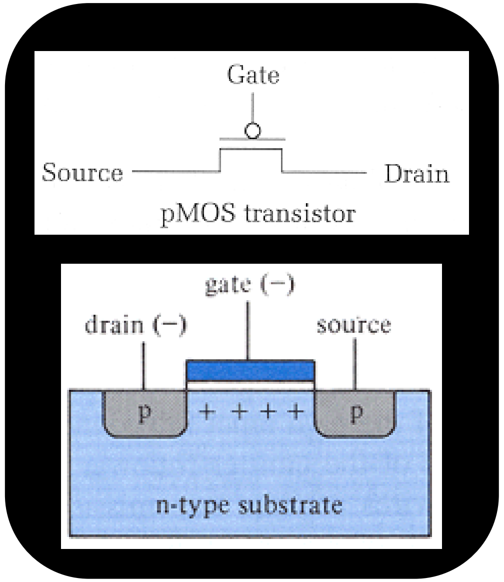


n-type channel creates path between source and drain for current to conduct!

nMOS vs pMOS

- Two types of MOSFETs exist, based on the semiconductor type in the drain and source, and the channel formed.
  - nMOS transistors (the design described so far) conduct electricity when a positive voltage (5V) is applied to the gate.
  - pMOS transistors (indicated by a small circle above the gate) conduct electricity (i.e., act as a closed switch) when the gate voltage is logic-zero.





Transistors to Logic Gates

Transistors to Gates

- MOSFETs can make current flow, based on the voltage values in the gate and drain.
  - i.e. the truth table on the right.
- One final step: combining MOSFETS to create high and low voltage outputs, based on high and low voltage inputs.
  - General approach: create transistor circuits that make current flow to outputs from high or low voltage, based on transistor input values.

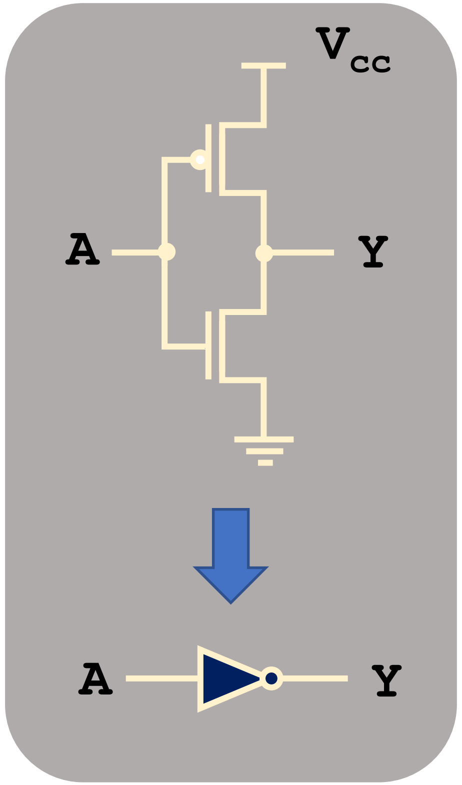
MOSFET Truth Table

V_{DS}	V_{GS}	I_{DS}
Low	Low	Low
Low	High	Low
High	Low	Low
High	High	High

Create gates using a combination of transistors

Physical data:

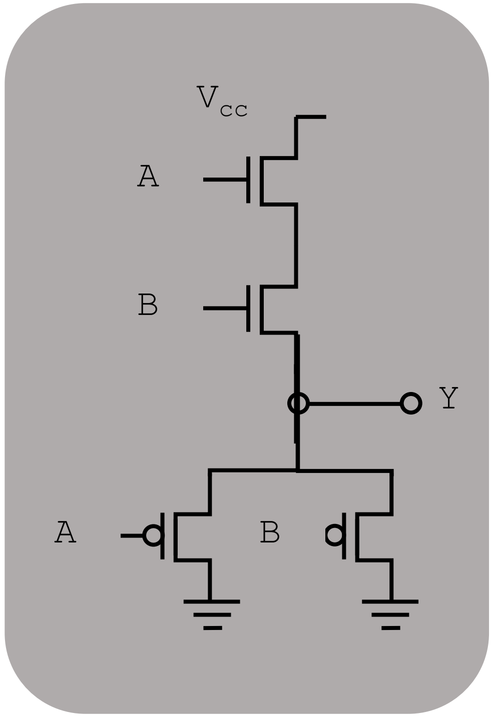
- "High" input = 5V (aka V_{cc})
- "Low" input = 0V
- Switching time: ~20 picoseconds
- Switching interval ~10 ns



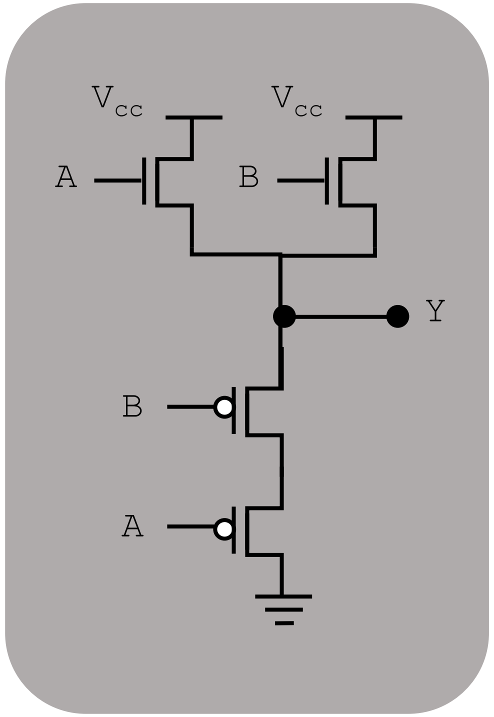
NOT Gate

Transistors into gates

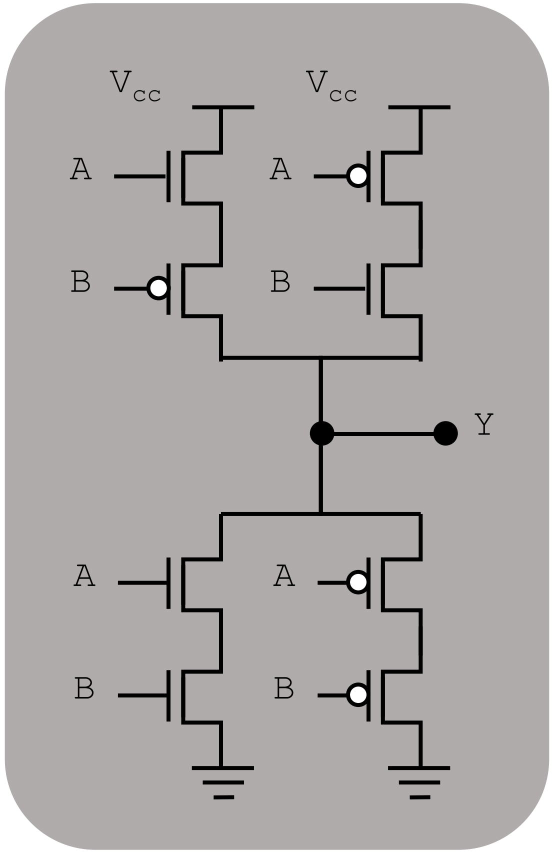
Note: `Vcc` = "Common Collector Voltage"
= high voltage `(5 V)`



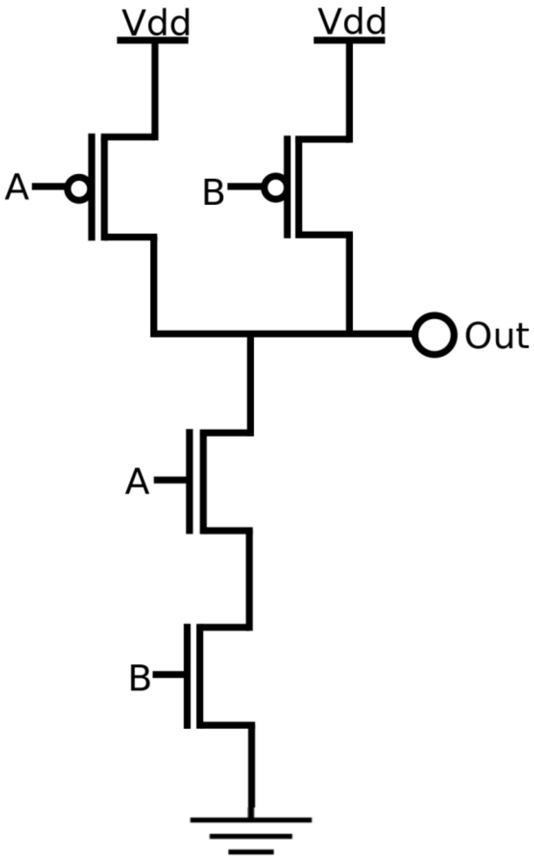
AND



OR



XOR



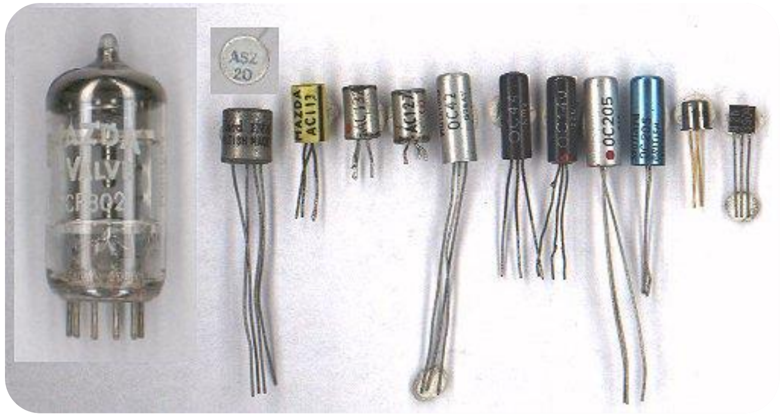
NAND is the most awesome logic gate

- It's cheaper to build
- All other logic functions (AND, OR, …) can be implemented using only NAND, i.e., it is functionally complete

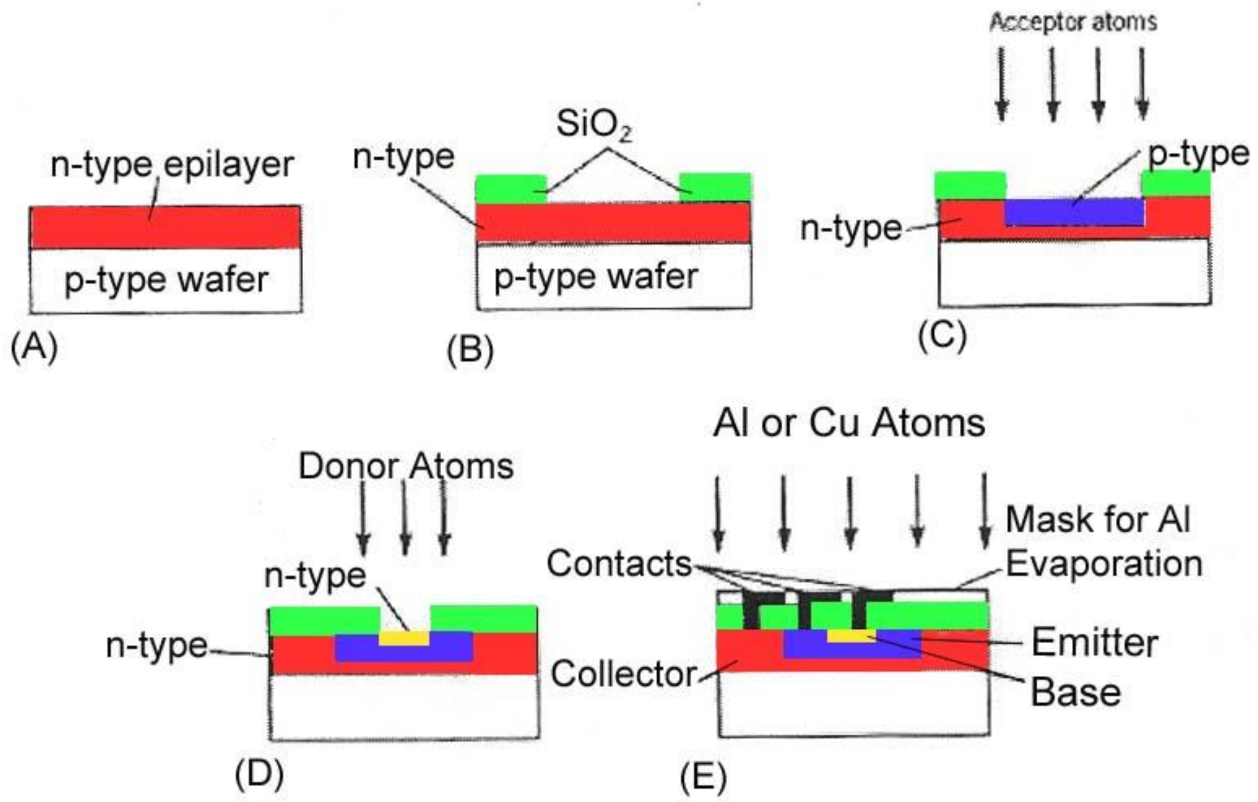
Challenge for home: implement AND, OR, NOT, XOR using only NAND.

Transistor Fabrication

- Transistors are not formed by pushing large chunks of n- and p-type semiconductors together.
- Transistors are now made by bombarding silicon with doping substances to create the layers for each junction
  - Surface is oxidized in between stages to ensure that only the necessary sections are doped.



Fabrication Process



Example Questions

Short Answer Q’s

- True or False? Doping gives a semiconductor an overall positive or negative charge.

  False

- What kind of bias on a pn junction causes the depletion layer to expand?

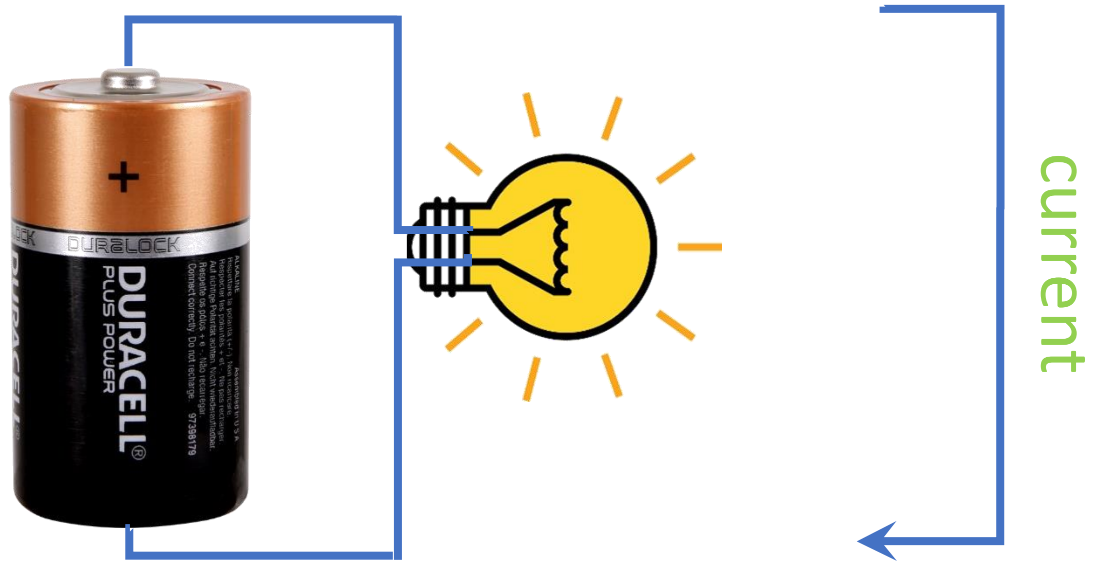
  Reverse bias

- Phosphorus has 5 electrons in its outer valence shell. When added in small amounts to silicon, the result is a ____________ semiconductor.

  Doped or N-Type

Electricity review

- If electrons are traveling from the bottom of the battery to the top, which way is current said to be traveling?
  - Current is measured as the movement of positive charges.

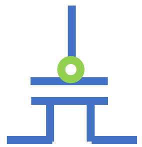


Transistor review

- Logic gates are built from <u>transistors</u>

This transistor is called <u>nMOS</u>

It conducts (i.e., acts as a closed switch) if we apply <u>5</u> Volts (logic-1) at its gate.

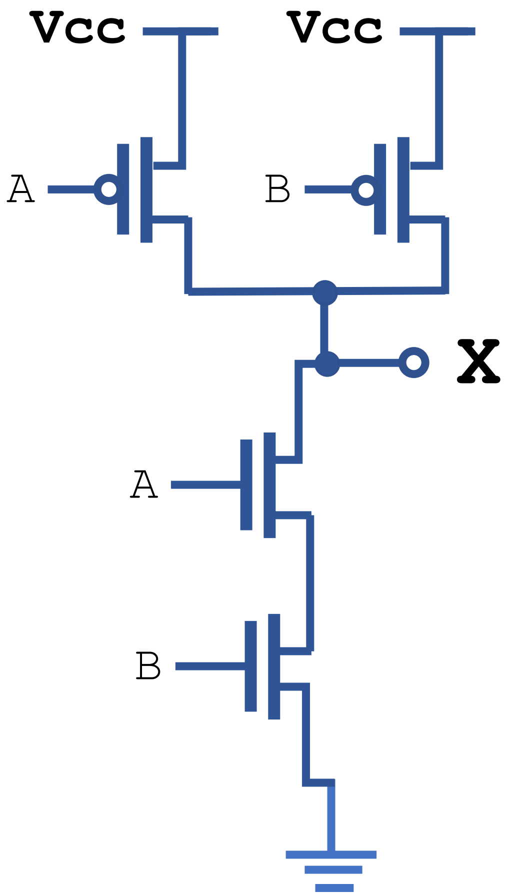


This transistor is called <u>pMOS</u>

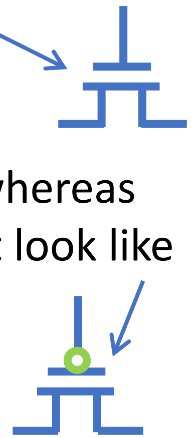
It conducts (i.e., acts as a closed switch, if we apply <u>0</u> Volts (logic-0 , Gnd) at its gate.

More Transistor Questions

- What gate is created by the following?



<u>Remember</u>: transistors that look like are activated when the gate input is high, whereas transistors that look like are activated when the gate input is low.



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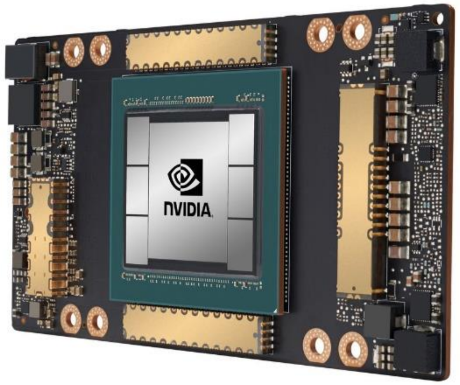

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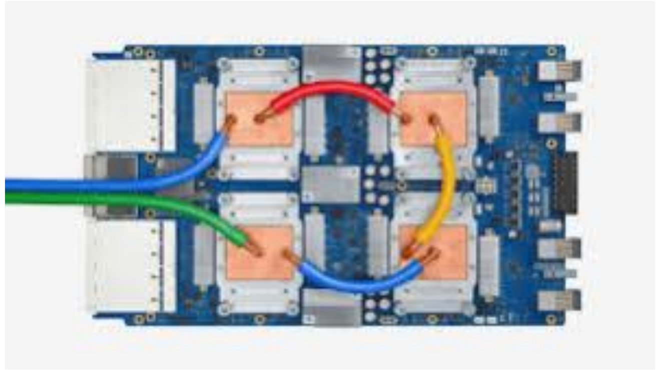

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