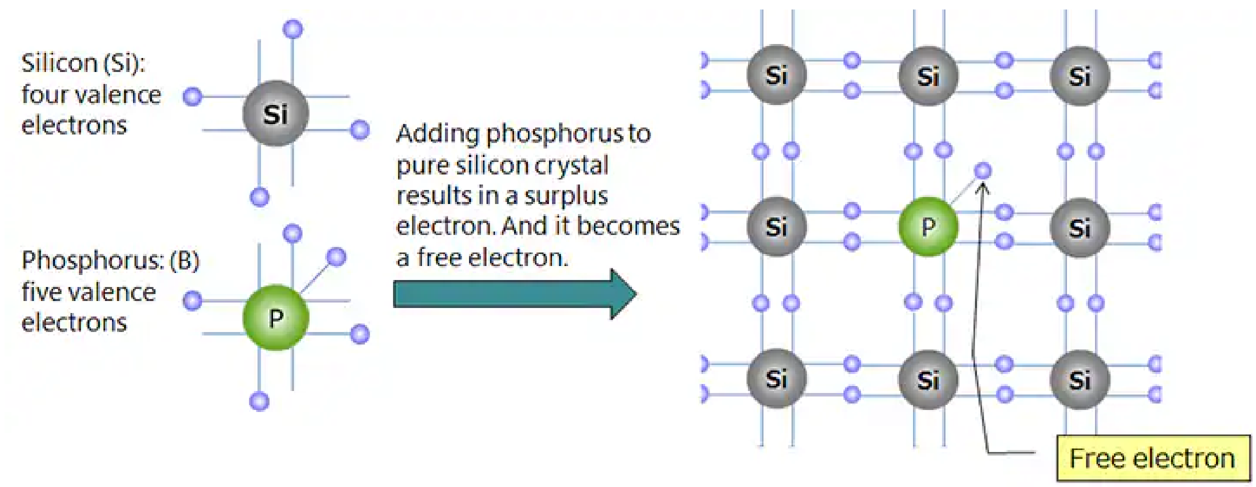
Basic of transistor

A transistor is an electronic device that can control the flow of electric current with an electric input as the control; unlike resistor and capacitor, it's not a passive but an active component. The basic principle of a transistor is just like a light switch which allows you to turn on (1) or off (0); however, transistors don't have switches and are super tiny (20 nanometers in practical use, or around 50 atoms across). Furthermore, it's semiconductors that make transistors even possible.

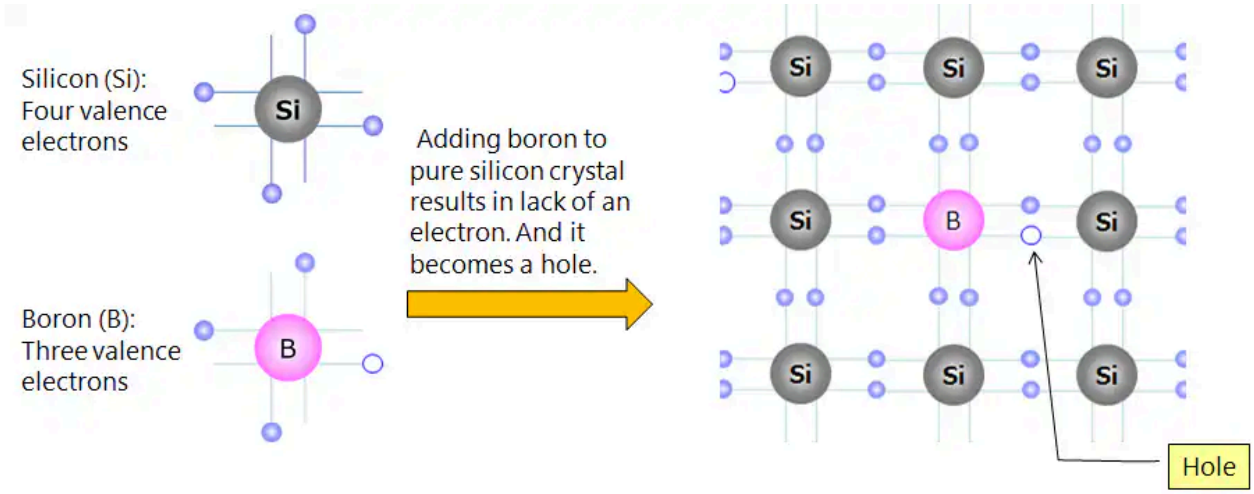
Semiconductors are the elements that are between insulator and conductor. To make current flow, the process called "doping" is necessary, which is to add impurities into existing semiconductors to "unlock" their performance.

Namely, there are two types of doping, N-type and P-type.

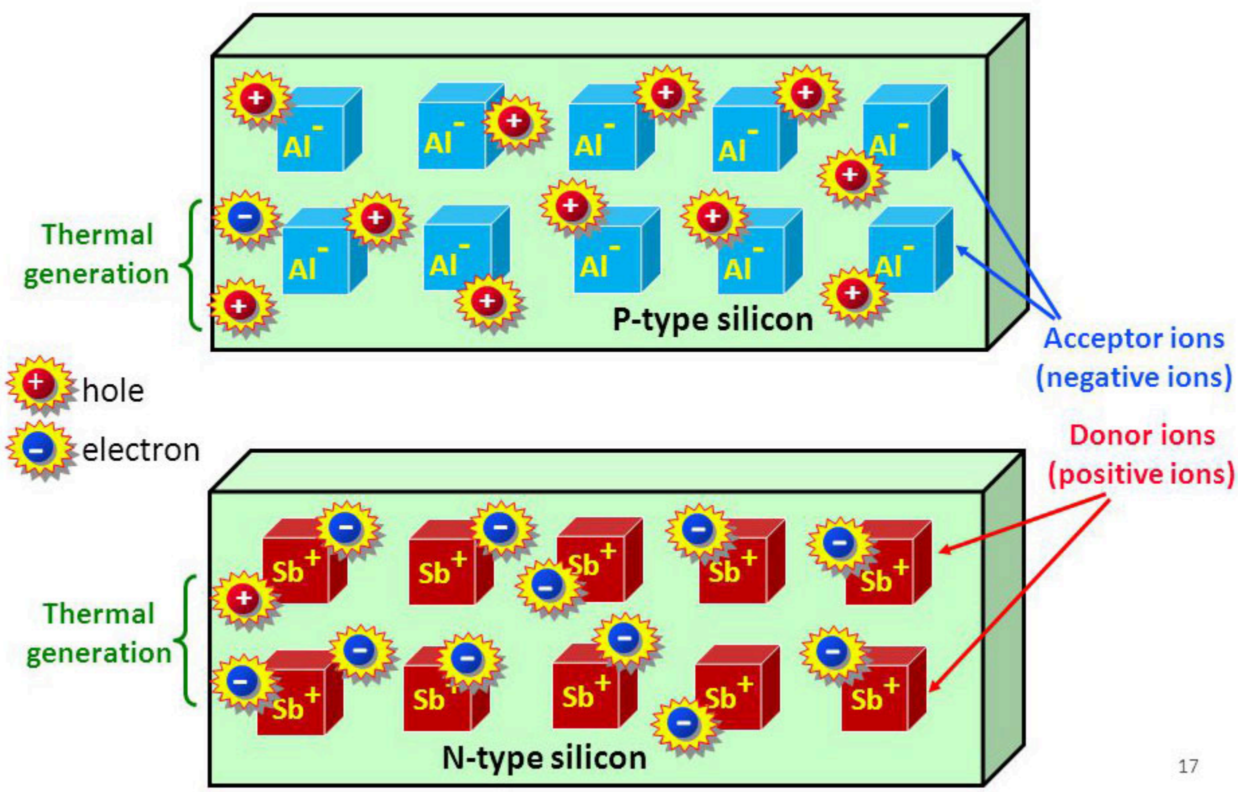
To make N-Type semiconductors, we usually take silicon and inject a small amount of an element with 5 valence electrons to the lattice. By doing so, the semiconductors now have extra charges because silicon only has 4 valence electrons, and therefore it conducts current better.

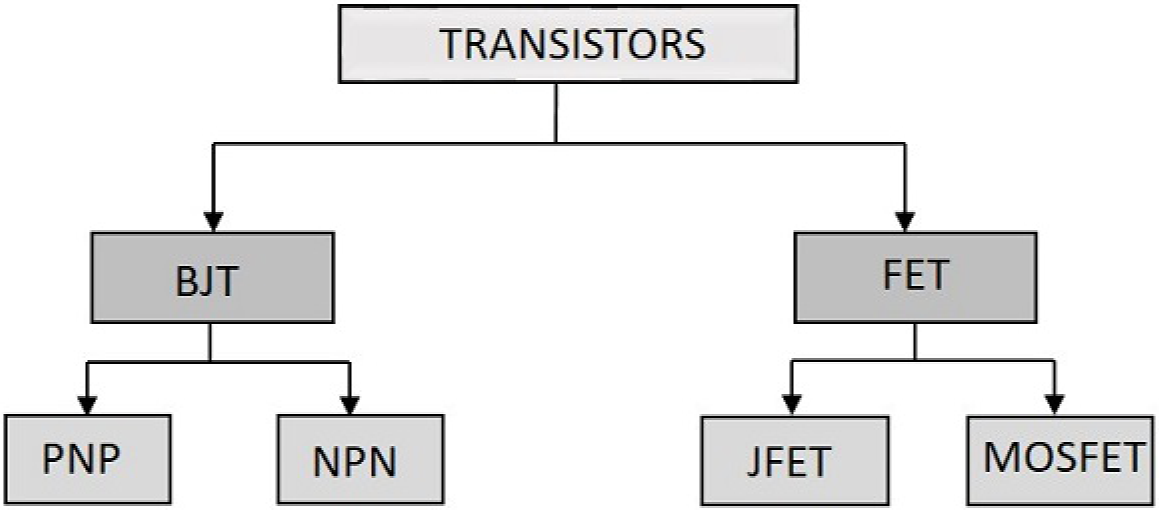


In P-Type semiconductors, it's vice versa. We take a small amount of an element with 3 valence electrons to the lattice. It'll create a "hole" because there should be 4 electrons, but it only has three for now. However, this still adds the conductivity to the semiconductors because electrons can move into the "hole". Notice here that the hole is a lack of electrons, so it acts like a positive charge, which is why the P-Type conductor is called "P-Type"(Positive).



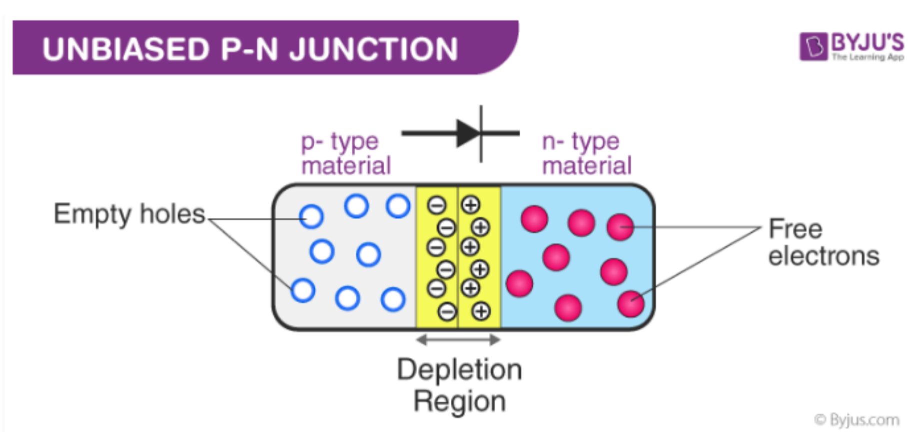
***Remember that the P-type and N-Type don't mean that the semiconductors are positively or negatively charged; in fact, they are both neutral. But it's describing the charges moving inside them.**



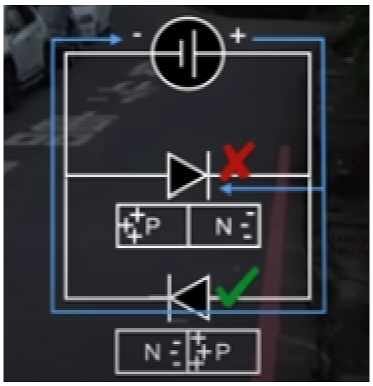


So referring back to transistors, both N-Type and P-Type semiconductors are used in transistors. Specifically, in BJT, bipolar junction transistors, there are PNP and NPN. Their names just imply the configuration in transistors. For instance, in a basic NPN transistor, there are N-type semiconductors in the ends and P-type in the middle. Just like a switch, a transistor has an electrical contact at each end, and these are called the “source” and the ”drain”. Source is a terminal where charge carriers enter the channel, and drain is a terminal where charge carriers leave the channel. Charge carriers are just a group of freely moving particles that carry charges; in this case, it’s “holes” and electrons. What makes transistors different from a conventional switch is that it has a “gate” in the middle to act as a switch, which is insulated from the semiconductor by an oxide layer.

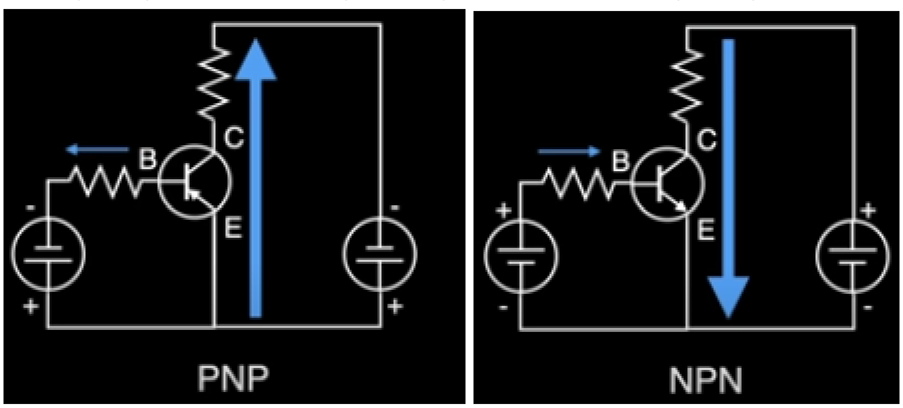
When a transistor is made, the electrons in the N-Type semiconductor actually diffuse to the P-Type semiconductor to fill the “holes” created by 3 valence electrons atoms, which creates a “depletion layer”.



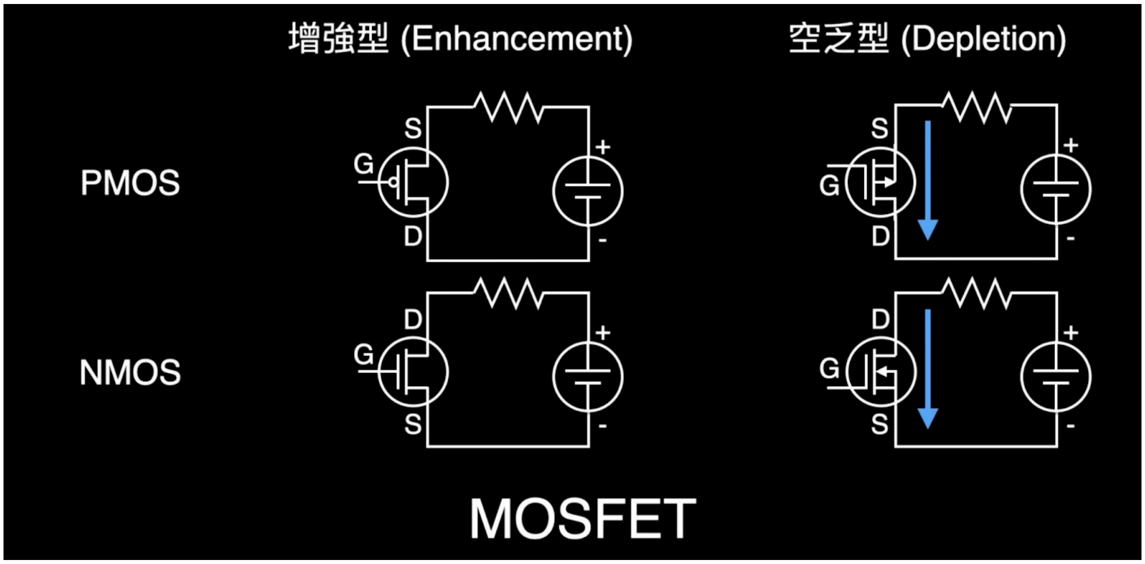
Depletion layer acts as a barrier, preventing the flow of electric current through the transistor. Therefore, the transistor is off, and to turn it on(Make the electrons flow again), we have to apply a small positive voltage to the gate to turn it back on, which overcomes the repulsion caused by the depletion layer. In addition to that, this concept can also be applied to the creation of diodes, only allowing current to flow through from one side.



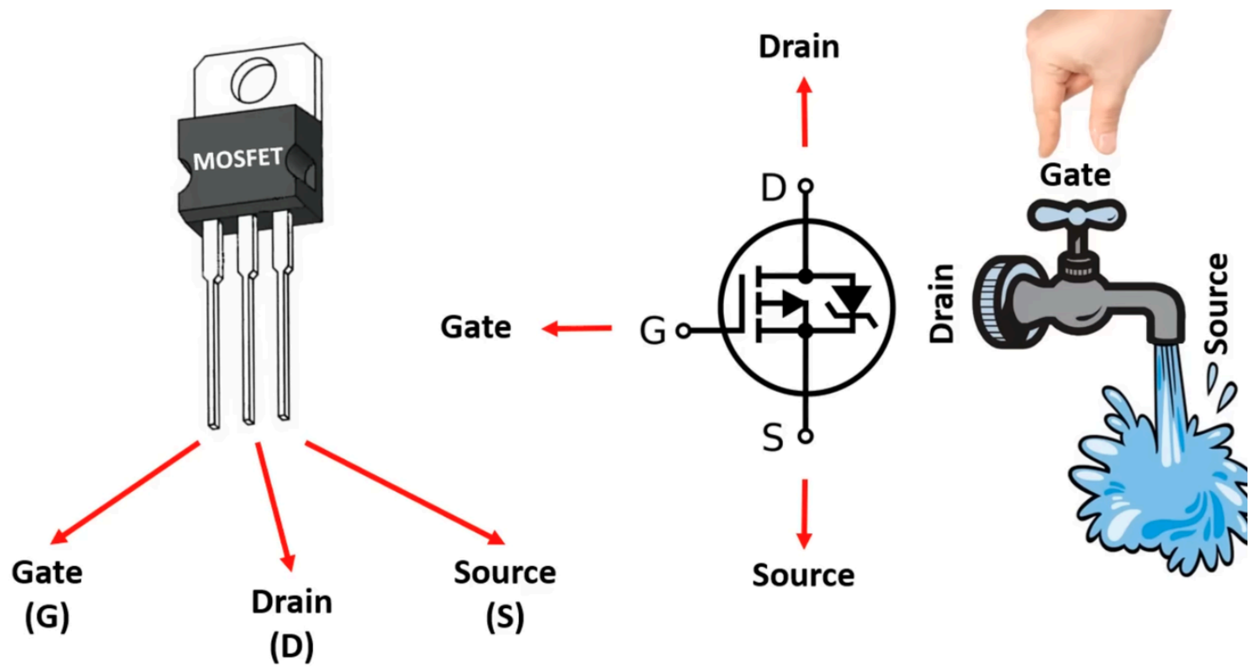
In summary, BJT transistors use the combination of N-Type and P-Type semiconductors to amplify the current and thus control the analog signal in circuits. In the picture below, B is the base (Gate), C is collector(Source), and E is emitter(Drain).



Equipped with basic understanding of transistors, we can now dig into the MOSFET transistor! Instead of using current flow to control the signal like BJT, MOSFET uses voltage to control the signal. In MOSFET, changes of voltage in the gate changes the resistance between the source and the drain.



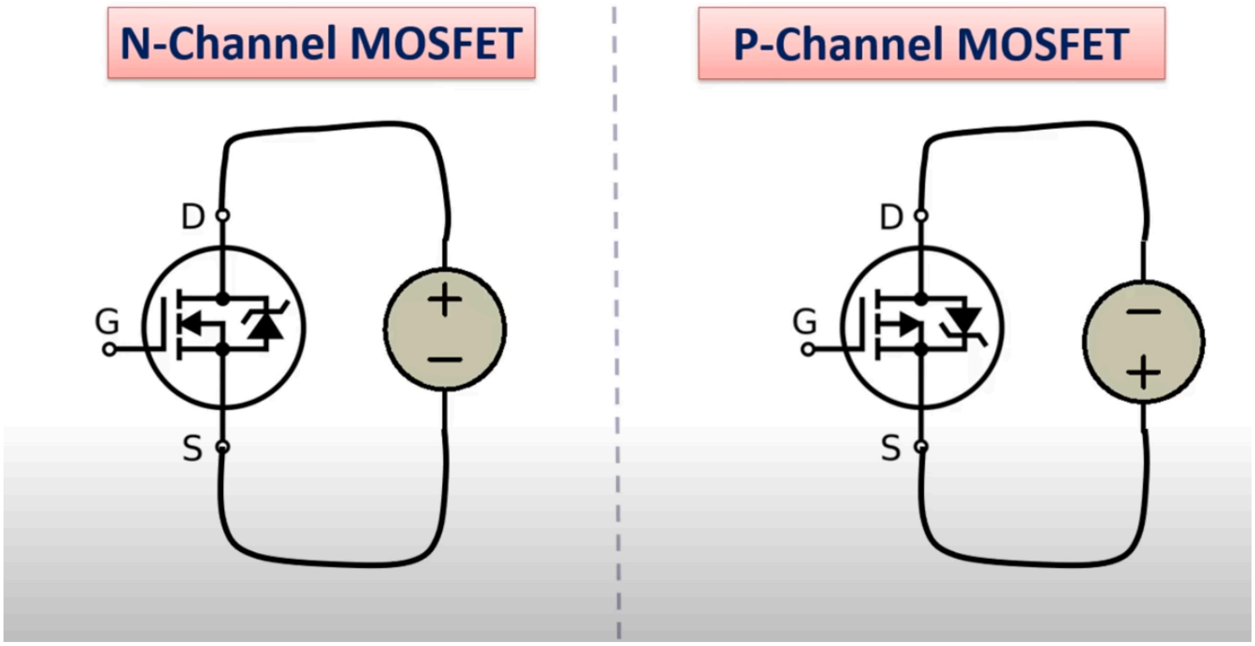
To further explore MOSFET, I found a useful video. And just like the hydraulic analogy for other components in circuit, MOSFET can also be explained in a similar way, a faucet.



Gate → Valve of a faucet (On and Off)
Between Drain and Source → Where the current passes through

Thus, when a trigger voltage is applied between gate and source, a current between drain and source is controlled.

MOSFET are divided into two types, depletion and enhancement types; further, each type can be divided into P-channel and N-channel. In P-channel, the current flows from source to drain; and it’s vice versa in N-channel.



And the difference between enhancement mode and depletion mode is whether the circuit is on or off when the gate-source voltage is at zero.

Enhancement Mode: Off at zero gate-source voltage
Depletion Mode: On at zero gate-source voltage, it’s naturally in a conducting state.

And here I’ll briefly break down each category and explain what’s happening.

-Enhancement:
In the enhancement mode MOSFET, we are enhancing the amount of free carriers so that it can conduct. The free carrier is electrons, so as we have a positive charge, it attracts electrons to the channel in order to conduct

-Depletion:
In the depletion mode MOSFET, we are depleting the number of free carriers, and thus it loses the ability to conduct.

And here is a more organizing table:

MOSFET type	$V_{GS} = +V_{th}$	$V_{GS} = 0$	$V_{GS} = -V_{th}$
NMOS Enhancement	ON	OFF	OFF
PMOS Enhancement	OFF	OFF	ON
NMOS Depletion	ON	ON	OFF
PMOS Depletion	OFF	ON	ON

In the preceding chart:
V(gs) is the voltage from gate to source.
V(th) is the threshold voltage at which MOSFET will turn on.

In practice, N-MOSFET is used when we want to control a high voltage load with a low voltage signal. And P-MOSFET is used when the controlled voltage is similar to the load voltage.

Transistors can take up many lectures to really understand the semantics behind it, and it’s extremely important not only in ASICs but basically in our everyday device. I tried to organize all the things I learned from different sources to give us a better overview because I found that oftentimes when we’re watching a tutorial, it introduces a new idea that I haven’t heard about before, which I have to watch another video to understand it. Thus, I think it’s helpful to gather these learnings from different sources as a blog. Hopefully it’ll help you guys, and if there’s something wrong or not clear, please correct me!