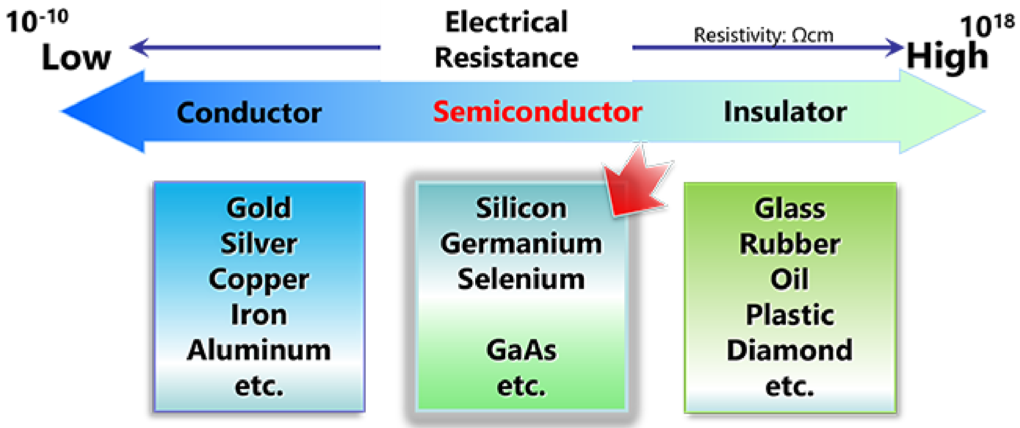
Semiconductors

YORK COLLEGE & UNIVERSITY CENTRE

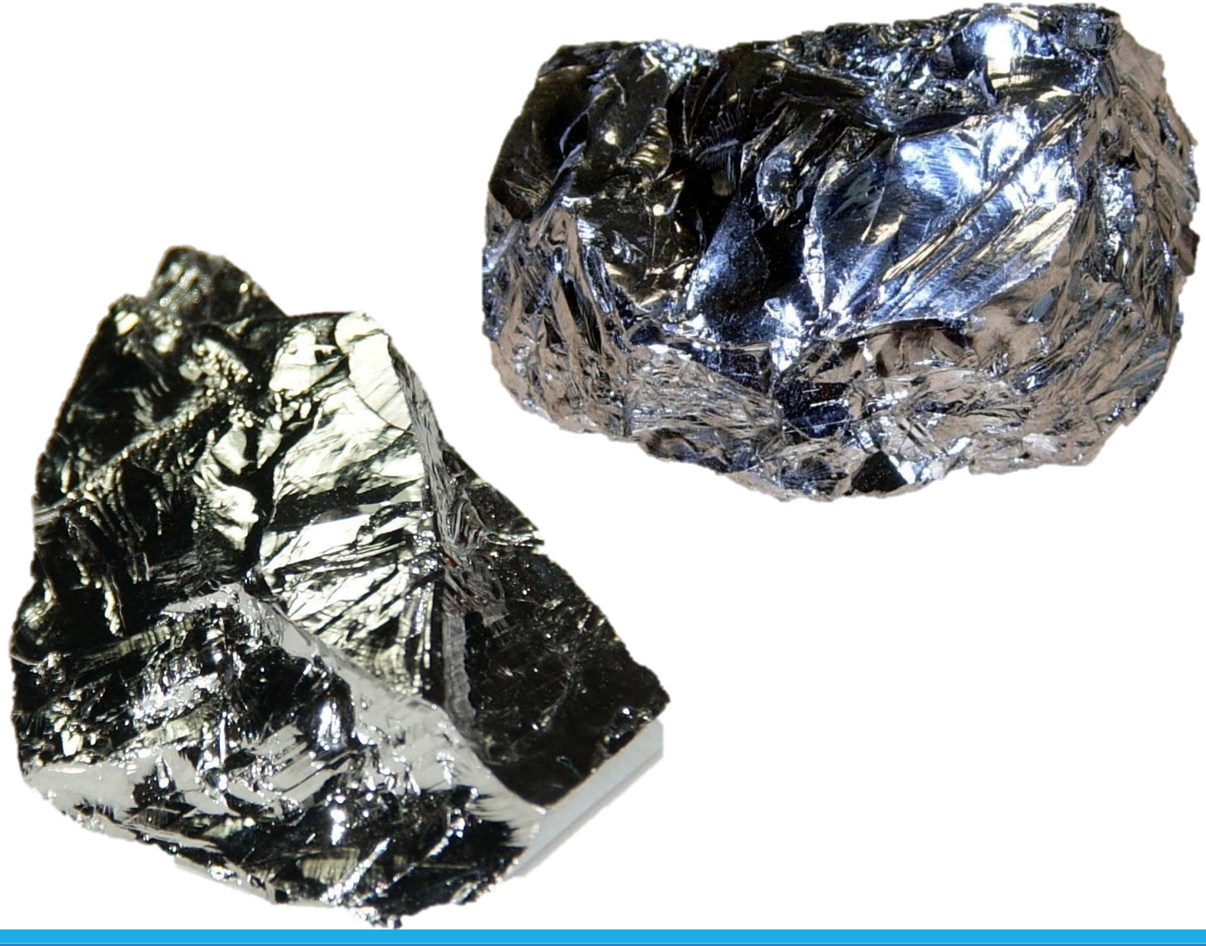
What are semiconductor materials

- Semi conductor is a term used for a material that has a resistivity somewhere between a conductor and an insulator
- This means it can play the role of both
- Typically, we can control its resistivity using an external source such as heat or external voltage
- This ability to control them makes them essential for everyday electronics



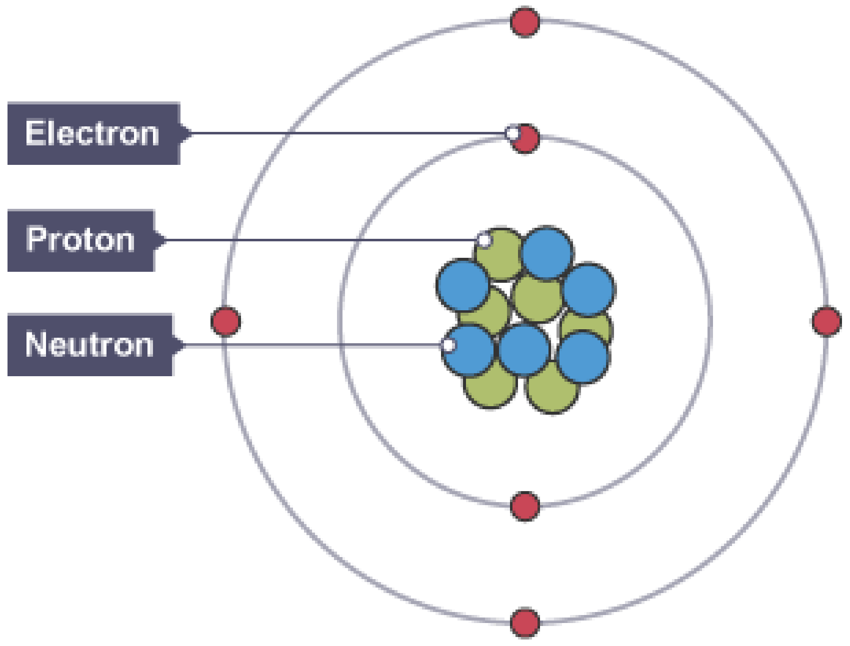
Typical semiconductor materials

- Typically, devices will use either silicon (Si) or germanium (Ge)
- Both silicon and germanium are most common due to their low ‘band gap’
- A low band gap means less power is required to swap it to and from conductive and non conductive states
- They are also used as they are very abundant and found everywhere meaning they are cheap



Atomic makeup

- Atoms are made up of bands of electrons
- The outermost band is loosely attached to the atom
- They freely detach and reattach to different atoms
- This is how electricity flows in a wire
- We can refer to the atoms the electron has jumped to as a “hole”



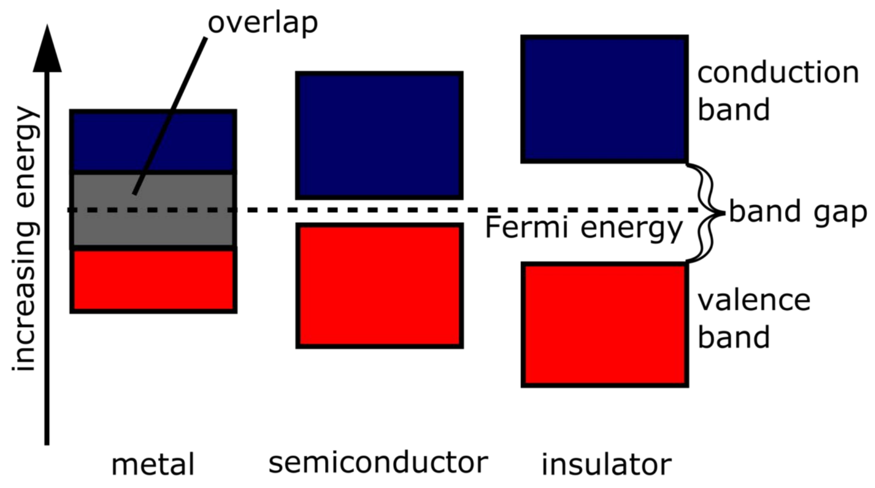
Band Gap

- A band gap is the energy gap (energy required) for an electron to swap from being attached to an atom to jump to a conduction band, where it can move freely and participate in electrical conduction.

- If electrons can easily jump the gap, then it is likely a metal

- If electrons can't jump the gap easily then it is an insulator

- And if the gap is medium but jumpable with some extra power then it is a semiconductor



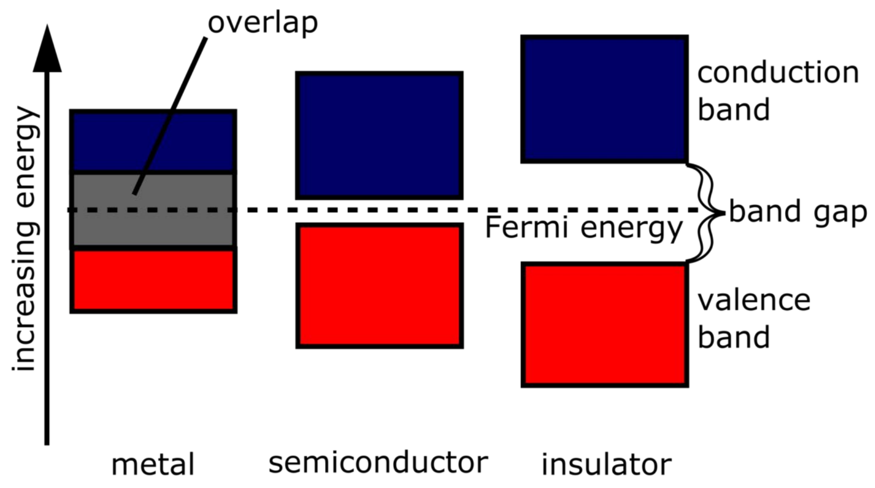
Band Gap

- We measure band gap in electron volts (eV)

- Typical values of band gaps are:

  - **Silicon (Si):** 1.12 eV
  - **Germanium (Ge):** 0.66 eV
  - **Gallium Arsenide (GaAs):** 1.43 eV

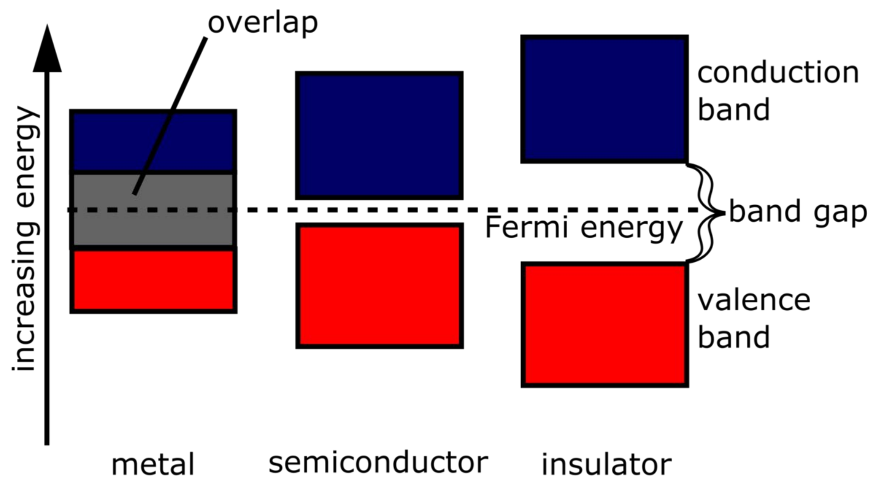
- Increasing the temperature of a material reduces the band gap making it easier for the electrons to bridge the gap



Band Gap

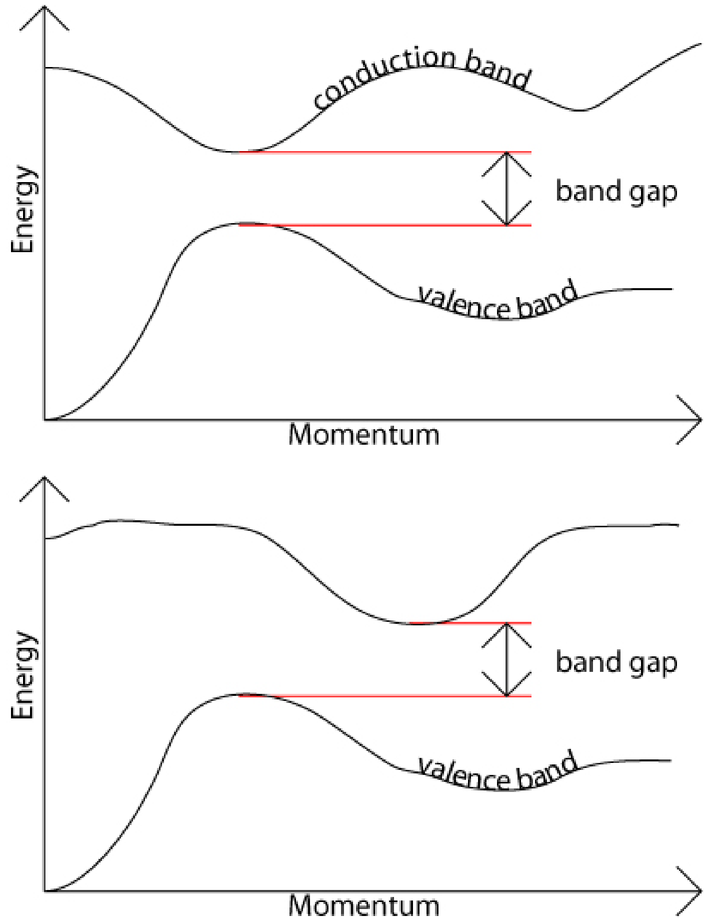
- The lower the band gap the more appropriate it is for high-speed electronics due to the speed in which it switches on and off

- However, you have the trade off that it reduces robustness meaning its not ideal for high voltage and high temperature applications



Band Gap

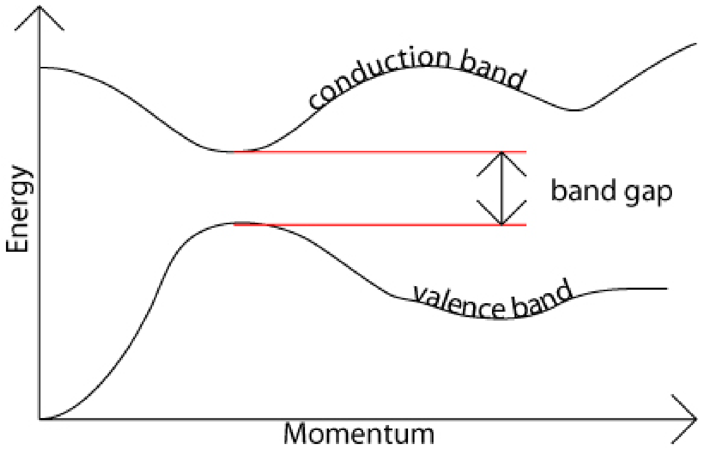
- Semi conductor materials come in two main forms;
- Direct Band Gap materials are where the lowest conduction band and the highest valence band are aligned in momentum space
- Indirect Band Gap materials are where the lowest conduction band and highest valence band are misaligned and thus something else is needed to change that momentum

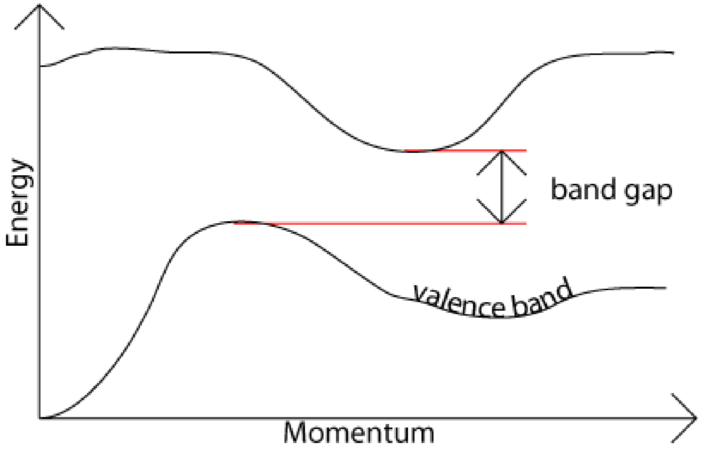


Band Gap

- A Direct Band Gap just interacts with a photon (light) either releasing one or absorbing one when an electron jumps, this makes them ideal for LEDs and lasers

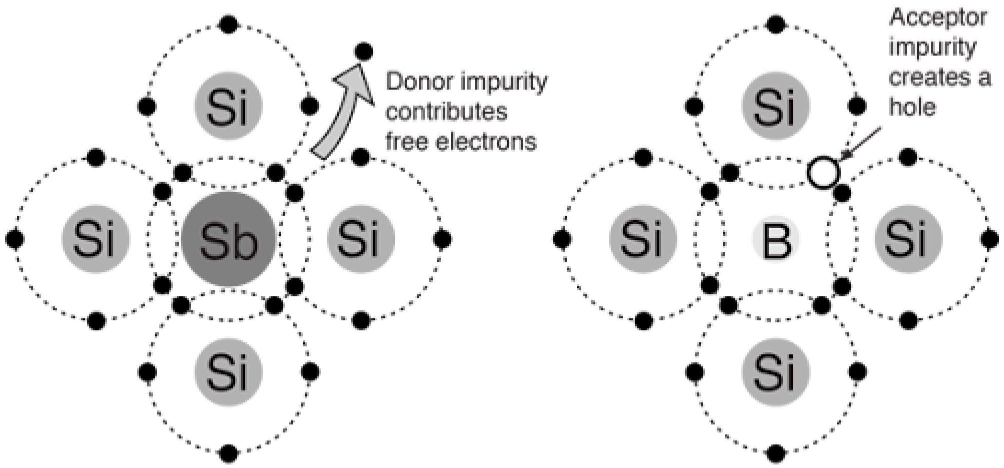
- For an Indirect Band Gap, the electron interacts with a photon and a phonon to compensate for the momentum difference, this makes them ideal for other components as it doesn’t produce much light instead it produces heat





Doping

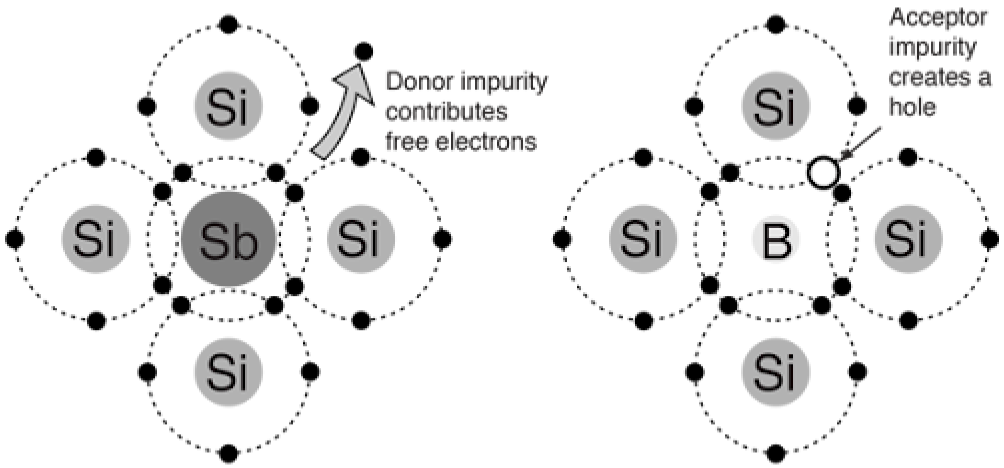
- The process of doping involves adding impurities to a semiconductor materials, this mostly involves adding conductors to the semiconductor
- This gives the semiconductor electrical properties and improves conductivity
- 100% semiconductors are bad at carrying charge as they have few electrons and free holes
- The addition of the impurities adds more electrons and holes making a better electric component



P vs N

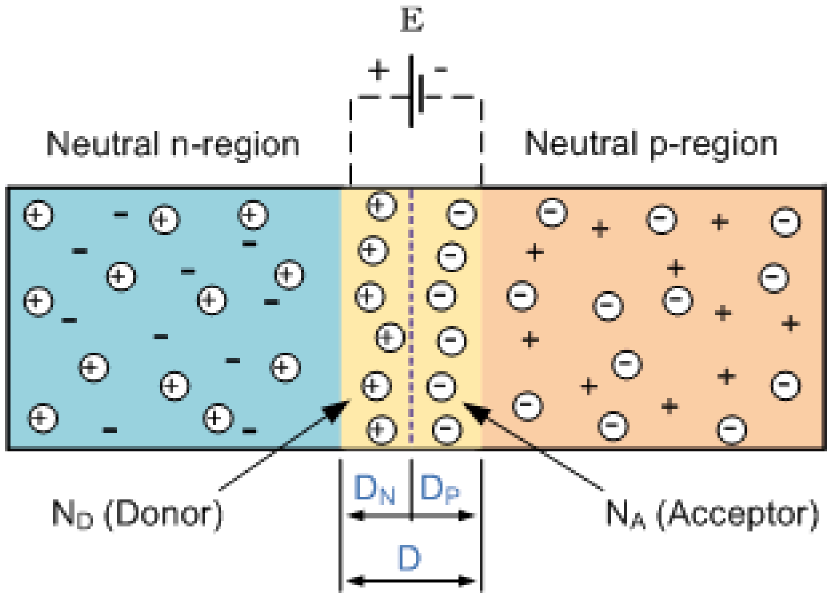
- **P-Type (Positive-Type) Doping** adds more holes to the material (more atoms with free electron spots).

- **N-Type (Negative-Type) Doping** adds more electrons to the material.



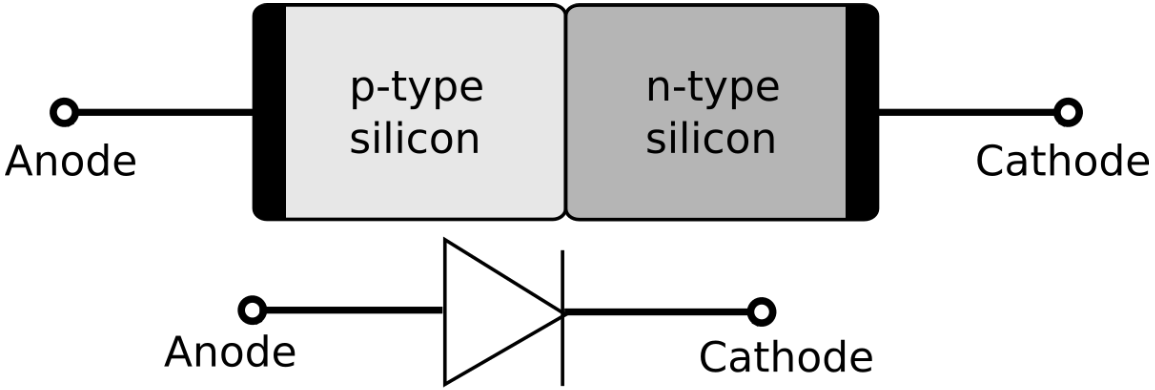
Forming a PN junction

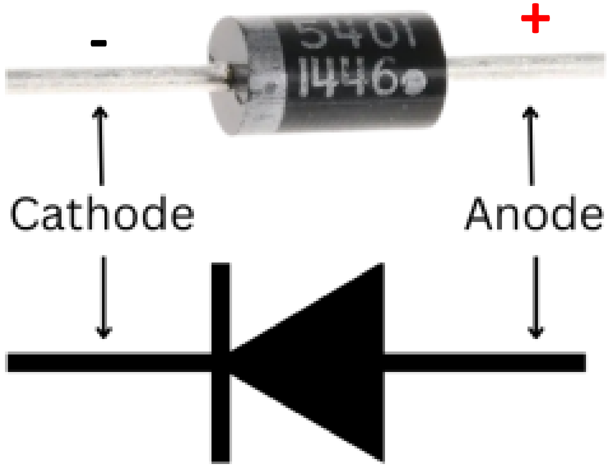
- When we make a PN junction we stick two materials together, a P doped semiconductor and an N doped semiconductor
- The two doped regions mix in the middle and cancel each other out making a “depleted region”
- In the depleted region there are no free charge carriers meaning this region acts like an insulator
- We can push through this region with an external voltage which grabs the electrons and carries them through the region, however as 1 side is positive, and the other is negative we can only go one way



Junction Diode

- A junction diode is just a basic PN junction
- This means its one way and blocks flow in the opposite direction
- In forward bias it allows current to flow normally
- In reverse bias it blocks current flow until a breakdown voltage is reached at which point current flows, but it permanently damages the diode





Zener Diode

- A Zener diode is just a PN junction which is specially doped to make it able to work in reverse
- Current can usually only flow one way unless a breakdown voltage is applied to in reverse
- In forward bias it allows current to flow normally
- In reverse bias it blocks current flow until a breakdown voltage is reached at which point current flows without damaging the diode
- Zener diodes output a constant voltage when plugged in in reverse.

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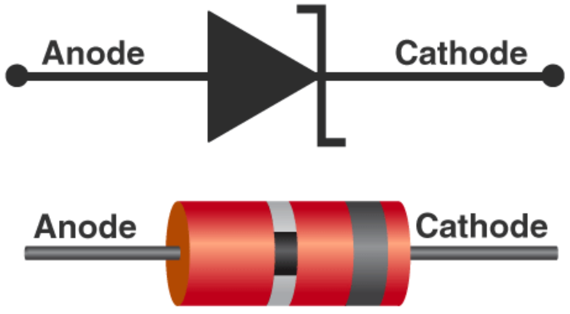
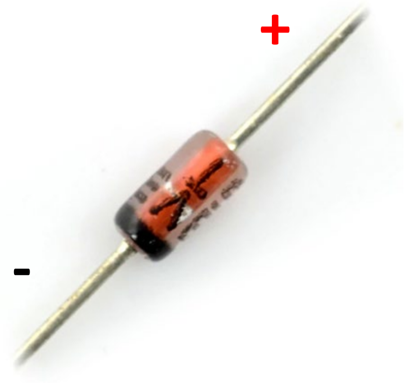
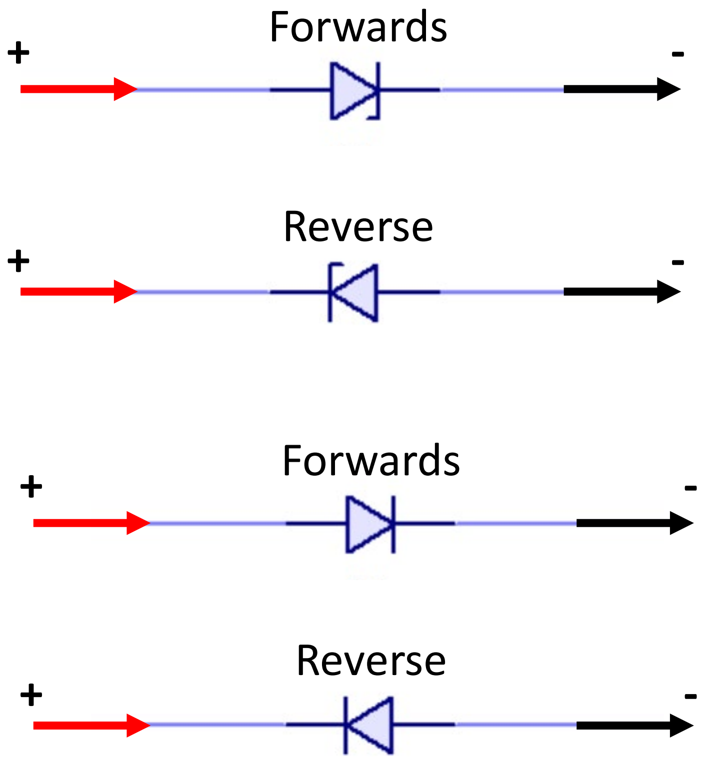


(Zener diode)

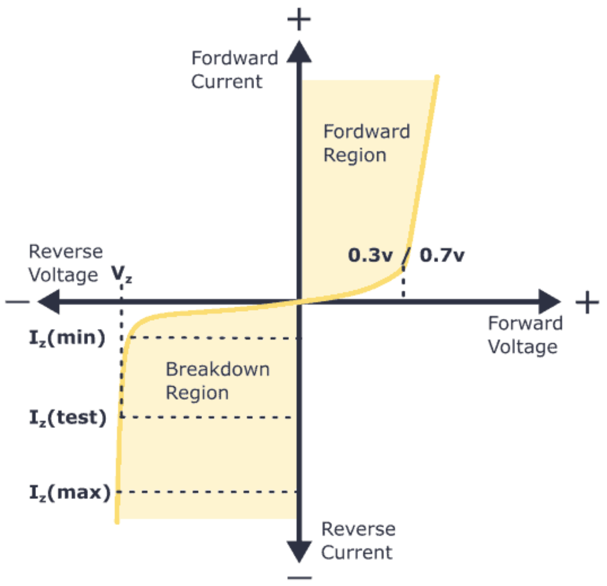


Reverse vs Forwards Bias

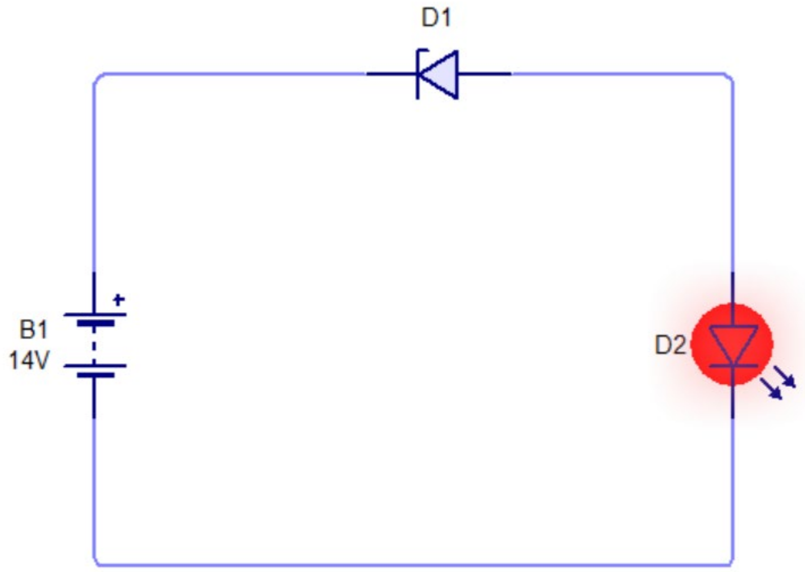
- The bias of a diode depends on how it's connected in the circuit.
- If the diode is forward biased, it's connected in the direction of current flow, allowing current to pass once the forward voltage is reached.
- If the diode is reverse biased, it's connected opposite to current flow, so it blocks current (except for a tiny leakage current).



Voltage Regulator

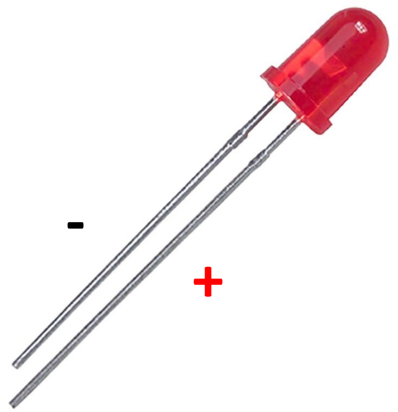


- We can use a Zener diode in reverse as a voltage regulator
- This clamps the voltage to a certain value and stops it rapidly increasing
- Often used as protection to ensure circuits continue to function properly



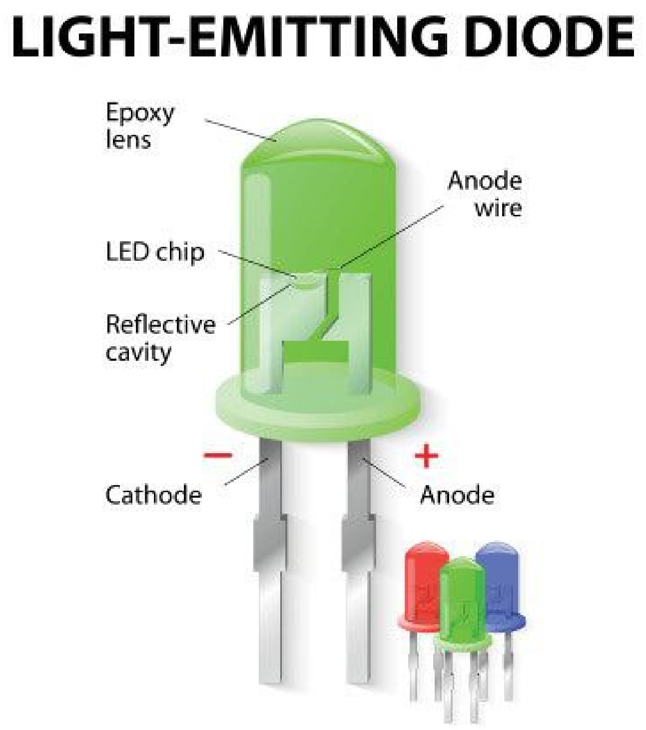
Light Emitting Diode (LED)

- An LED is a diode made of a compound of semiconductors which emits light
- Light is only emitted when current is flowing the right way, if reversed no light is emitted
- We can tell which is the anode and cathode of the LED based on the length of the leg, the longer leg is the anode and the shorter is the cathode



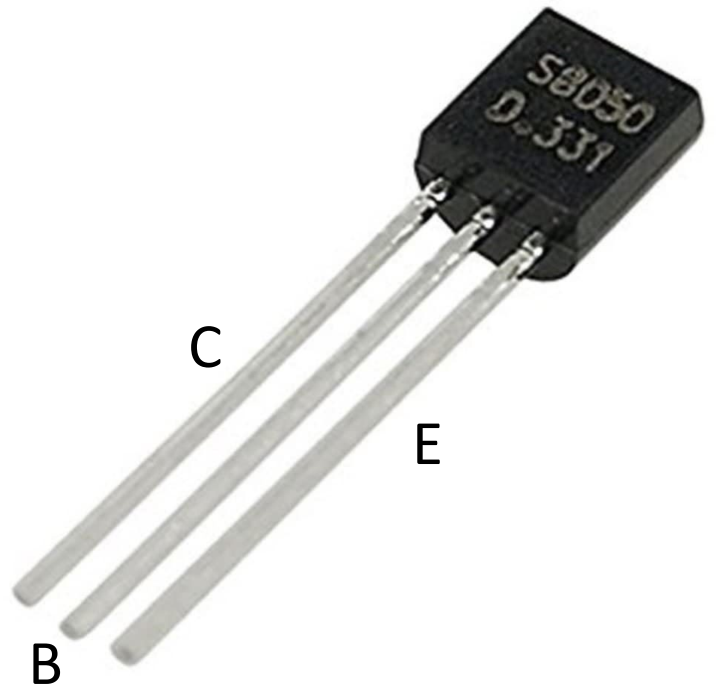
LED Construction

- The diode in an LED is tiny, its located right at the top of the cathode
- The anode and Cathode are constructed out of metal plates allowing them to carry charge easily
- As the LED chip is very small, we need a reflective shield around it to amplify and redirect the light coming off it
- The anode and the LED chip are connected by a tiny wire
- When an LED stops functioning its often because this tiny wire has just melted



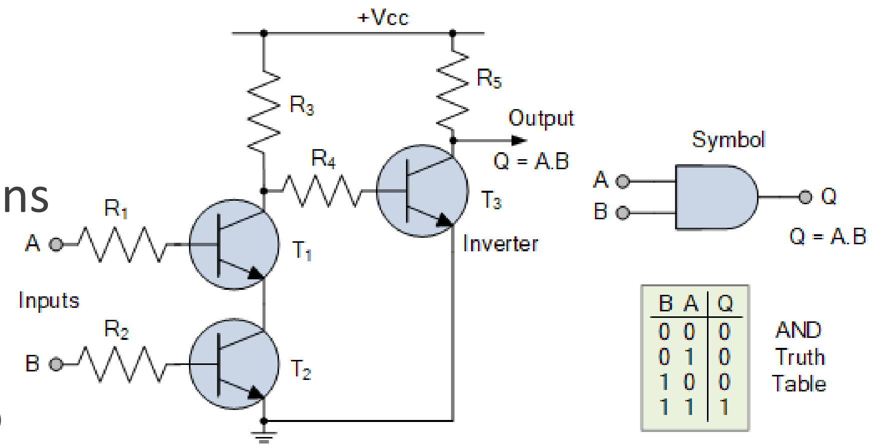
Transistors

- Transistors are another major use of semiconductors. Unlike diodes, they have three terminals instead of two.
- These terminals are the Emitter (E), Collector (C), and Base (B) for BJTs. Or Drain (D), Source (S), Gate (G) for FETs.
- The Emitter is the terminal that releases charge carriers, while the Collector receives them. Their roles depend on the transistor's operation.
- The Base acts as the control input, allowing us to regulate the current flowing between the Collector and Emitter.
- Transistors allow us to control current flow in a circuit using either current (in BJTs) or voltage (in FETs).



Transistors in modern engineering

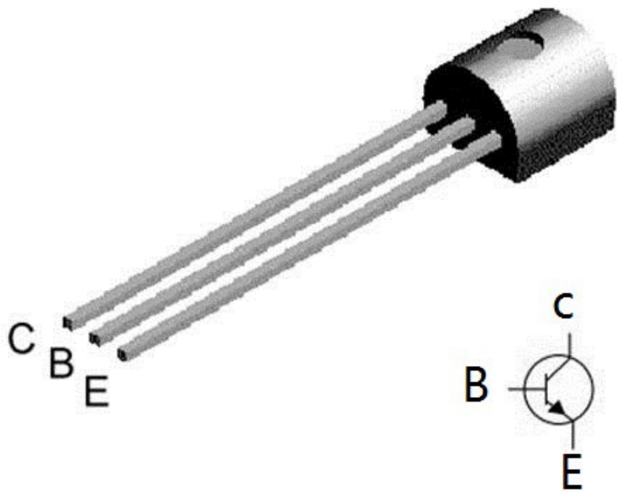
- Transistors have 2 main roles in modern engineering
- Transistors can be used to make logic gates
  - These logic gates are used in computing devices allowing us to perform maths and logic operations
- Transistors can be used to control electrical machines
  - As transistors allow a small current or voltage to control a large current or voltage, they are perfect for controlling modern electric machines
  - They actuate much faster than relays making them ideal for high-speed BLDC motors



B	A	Q
0	0	0
0	1	0
1	0	0
1	1	1

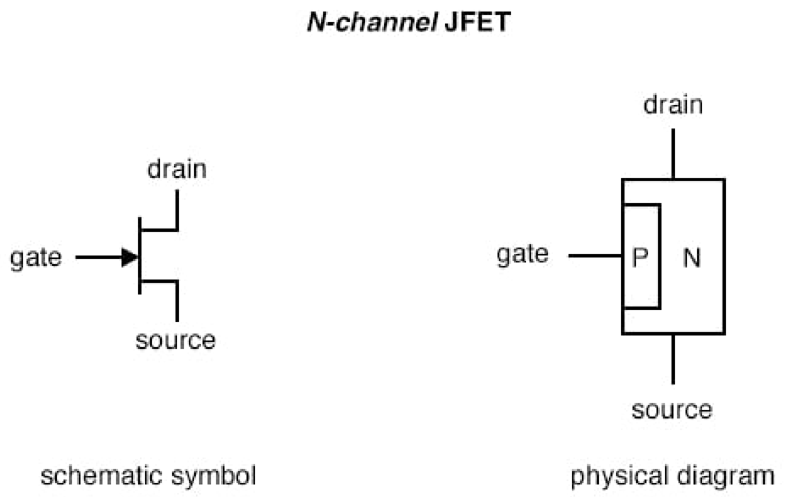
Bipolar Junction Transistor (BJT)

- BJTs are a type of transistor that allow us to control a large current flow with a small current flow
- As BJTs are current controlled they have a higher power usage than other transistors
- They are also much slower than other types of transistors
- However, as they allow a small current to control a large current, they are perfect for amplifiers where you want a very small current to become a much larger current
- They came before FETs due to being easier to build with older machines (1940s vs 1960s)



JFETs

- JFETs allow a voltage at the gate to control a current flow through the transistor
- When we put no voltage into the gate on the JFET it allows current to flow normally
- When we put a small voltage (below the threshold/pinch-off) into the gate on the JFET it reduces the current through the JFET
- When we put a large voltage (above the threshold/pinch-off) into the gate on the JFET it blocks current from flowing through the JFET



MOSFETs

- MOSFETs are very similar to JFETs in operation and construction
- They differ to JFETs as they have a small oxide layer on the gate which acts like a good insulator
- This insulator means the power consumption of the MOSFET is very small when compared to all other transistors