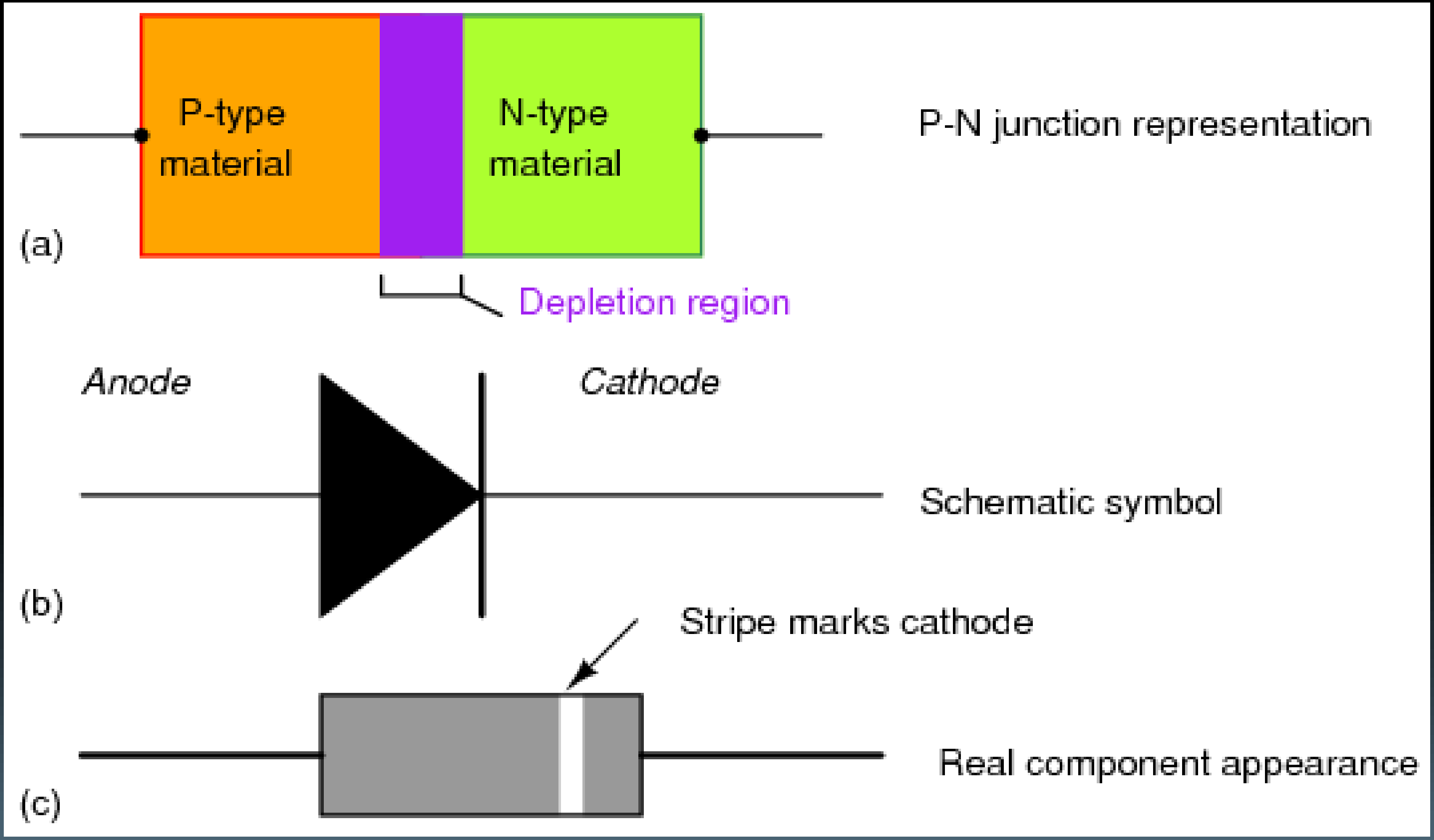
Semiconductor Diode

An electronic device that results from the fusion of P-type material and an N-type material

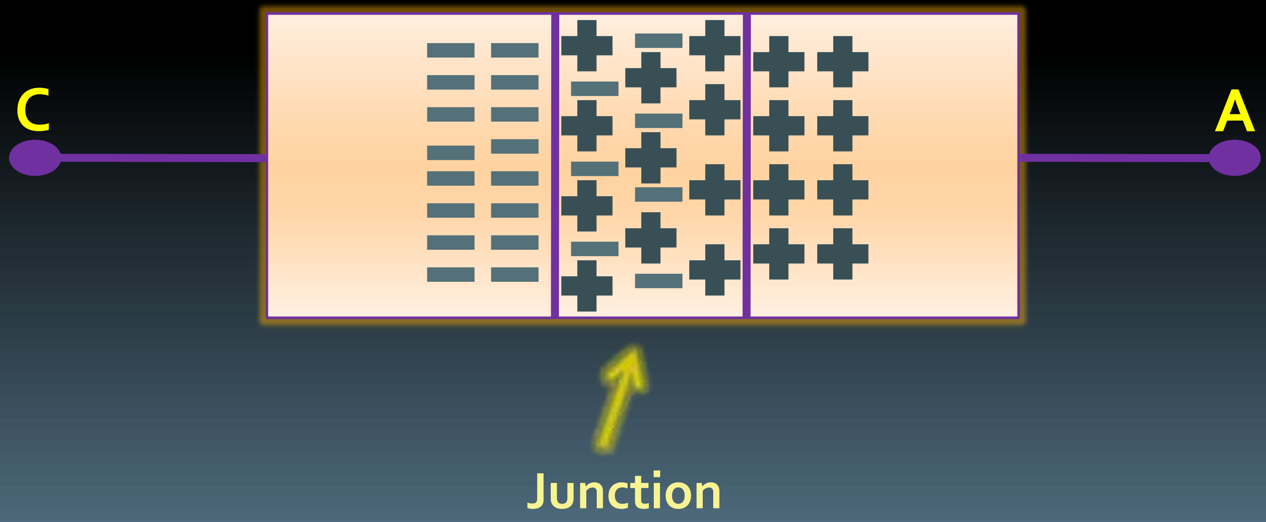


Formation of the Depletion Region

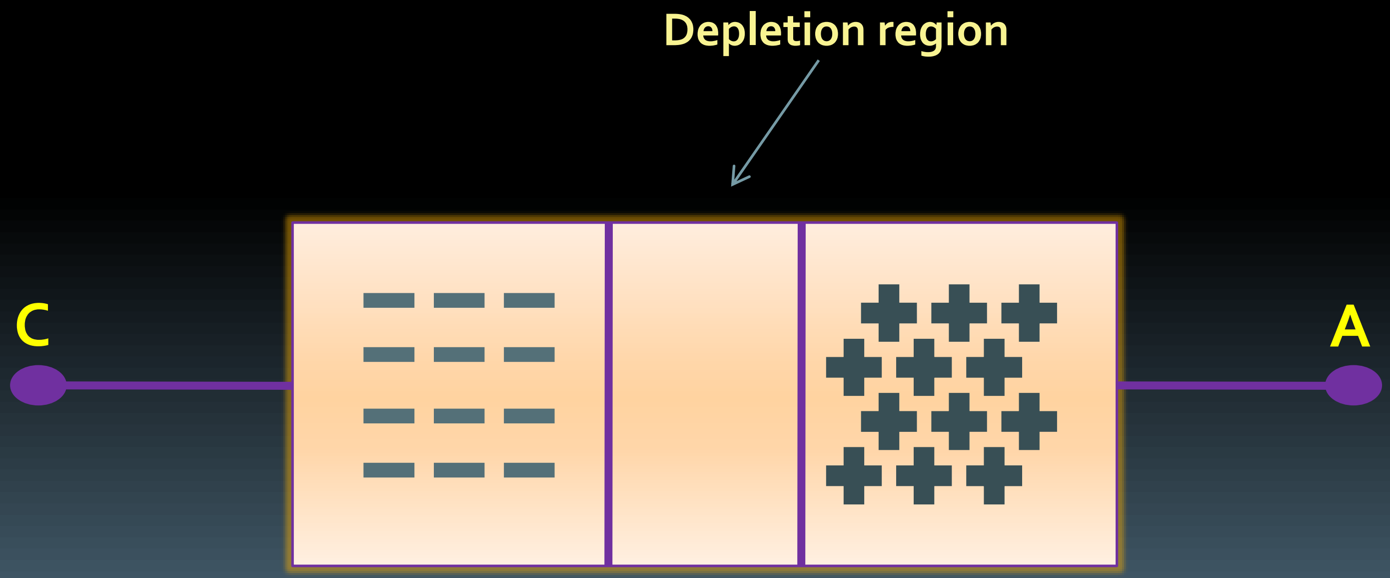
a. Diffusion

- movement of electrons from a region of high concentration to lower concentration

b. At the junction, the electrons from the n-type and holes from the p-type attract each other, combine and cancel their net charges

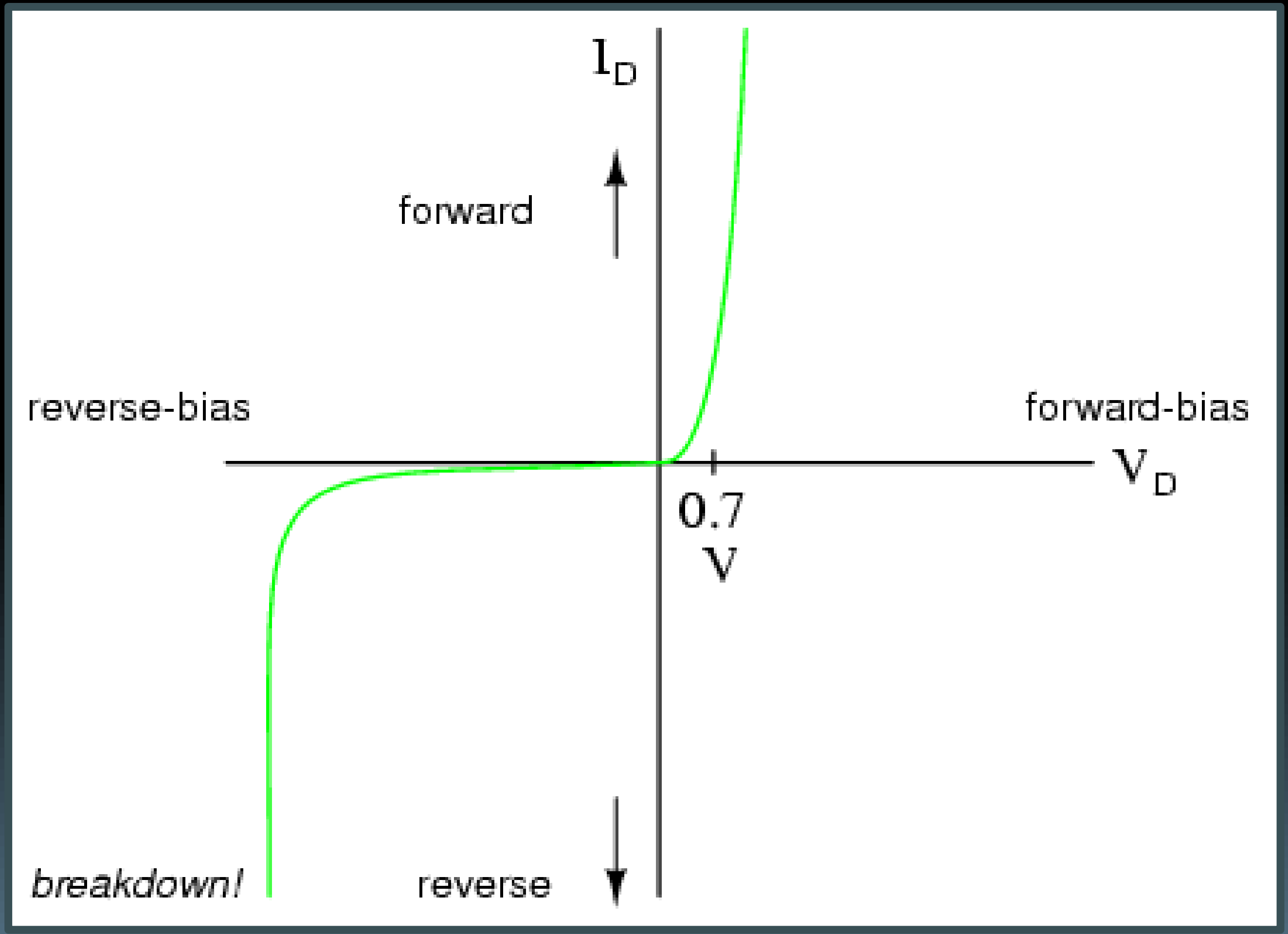


c. Due to the cancellation of electrons and holes at the junction, the junction will have no more carriers so it is called a **depleted region** or **depletion region.**



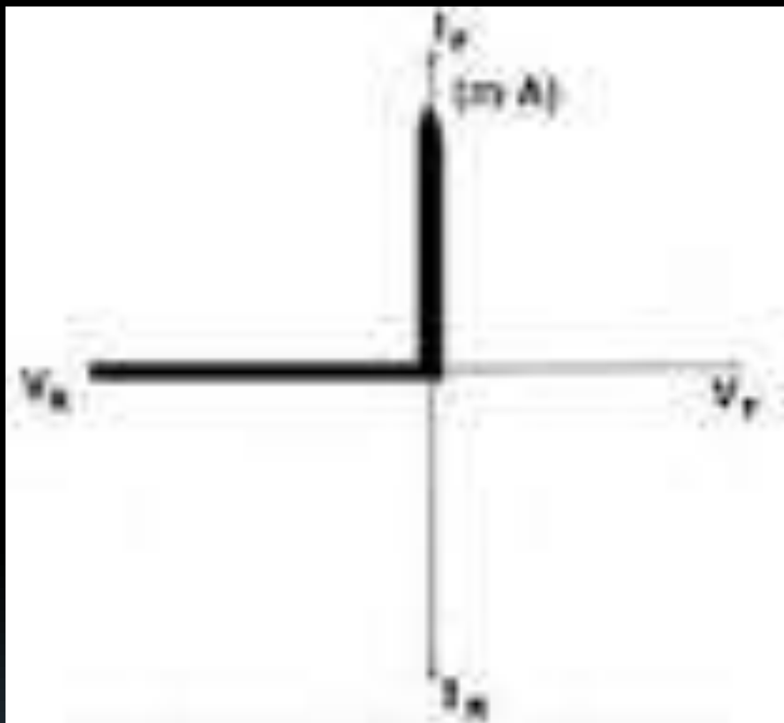
Practical diode is a nonlinear device with a current versus voltage

Barrier potential (0.7 for Si and 0.3 for Ge)

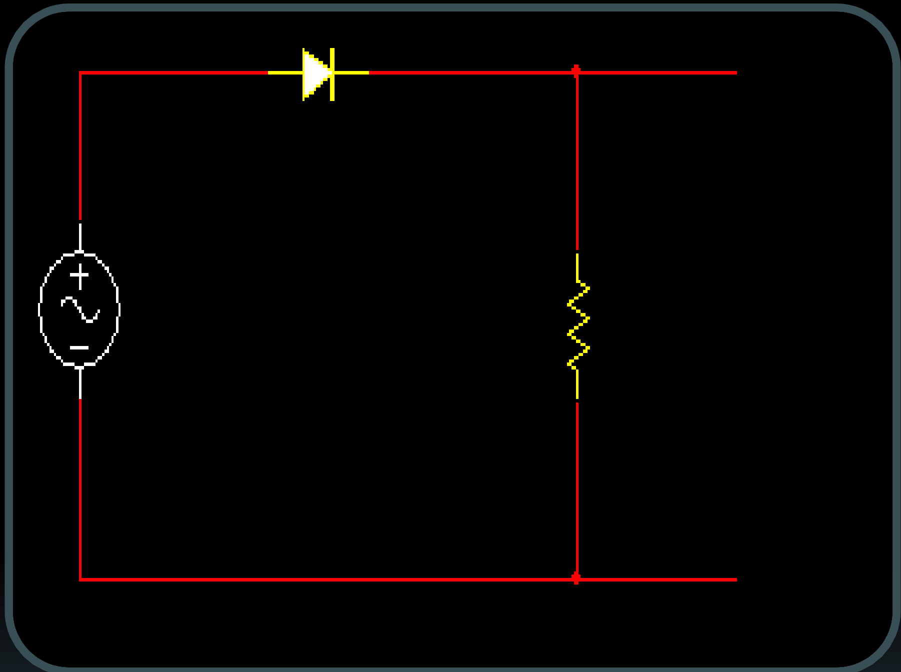


To simplify the analysis of diode circuits,

Diodes are assumed to be Ideal.



V-I characteristics of an ideal diode



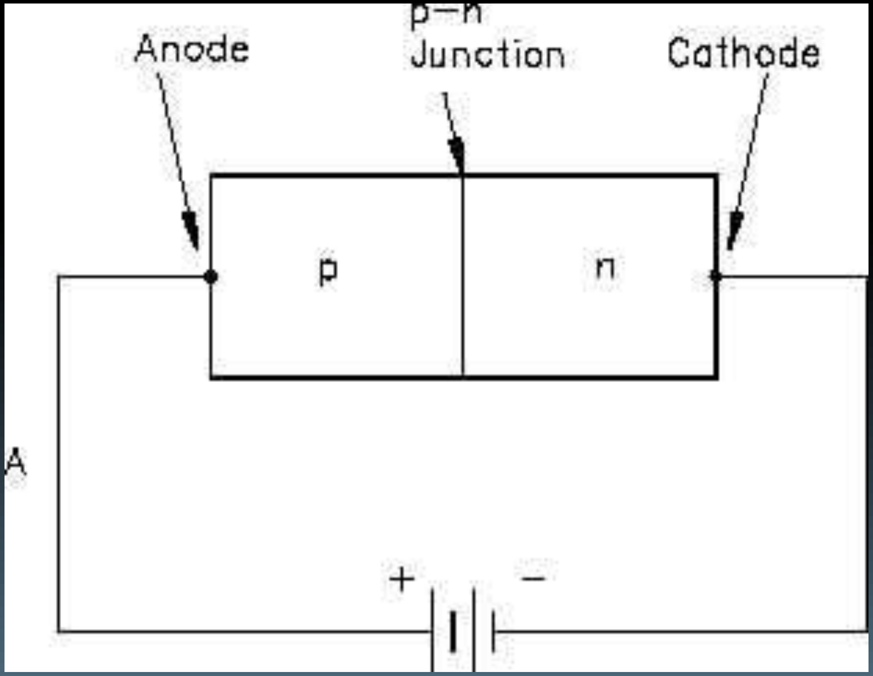
Short circuit when forward biased

Open circuit when reverse biased

Biasing the PN Junction

a. Forward Biased

- P-type is more positive than the N-type
- A condition that allows current to flow through the pn junction
- The pn junction narrows



Forward Biases Conditions

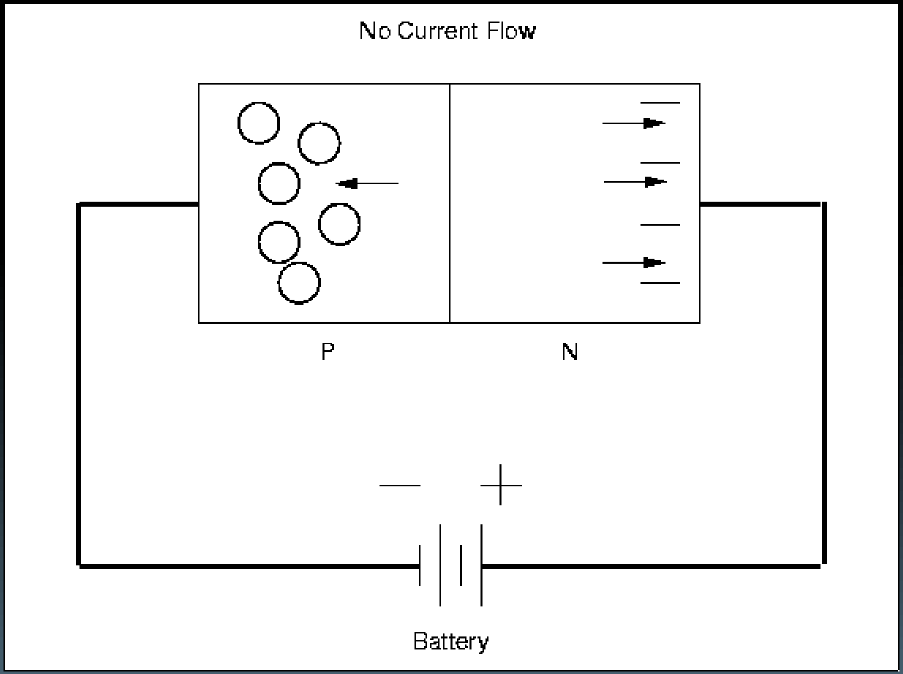
1. Anode must be positive with respect to cathode
2. The potential difference (Vd) should be greater than the diode threshold voltage (Vth)

Threshold Voltage

- Required voltage across the junction of the diode before forward current can flow significantly

b. Reverse Biased

- P-type is more negative than the N-type
- A condition that prevents current to flow through the pn junction
- The pn junction widens



Reverse Biased Conditions

1. Cathode must be positive with respect to anode
2. The potential difference should not be greater than the diode's breakdown voltage

Breakdown Voltage:

- Maximum voltage the junction diode can handle when reverse biased
- Also called Peak Reverse Voltage & Peak Inverse Voltage

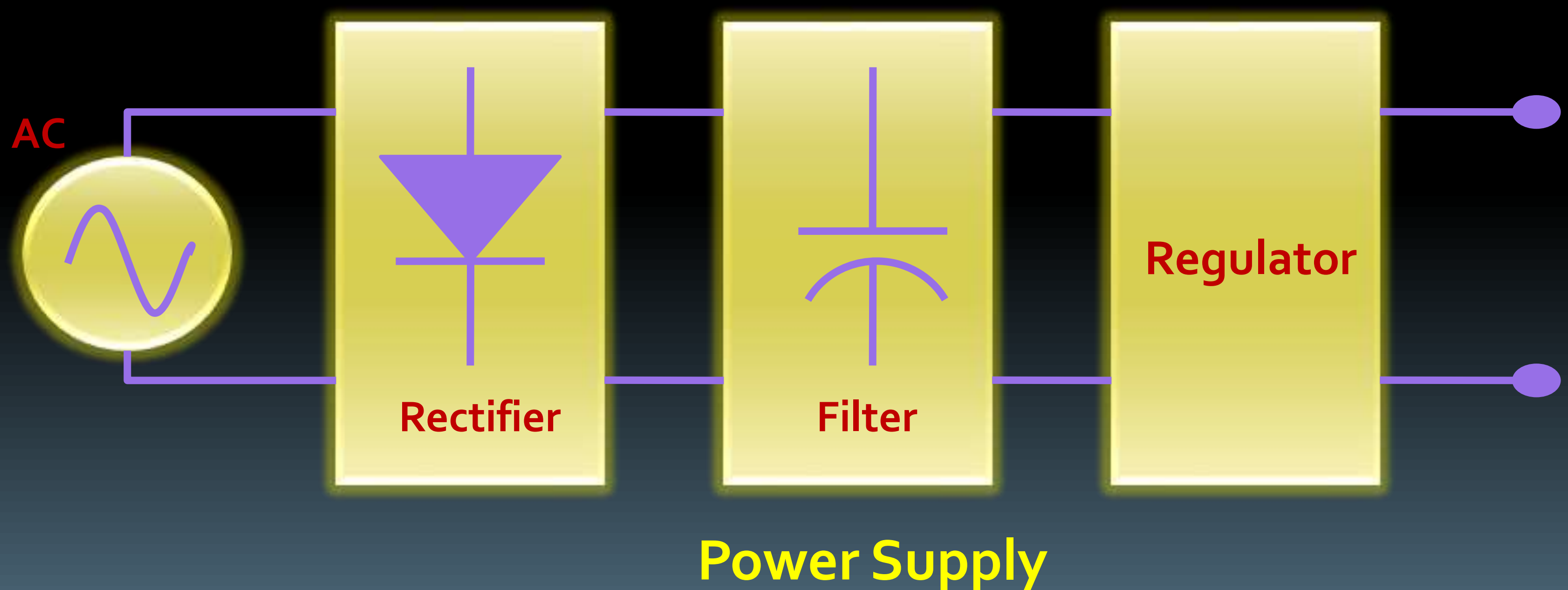
Note:

Silicon has relatively higher breakdown voltage than Germanium

I. Applications

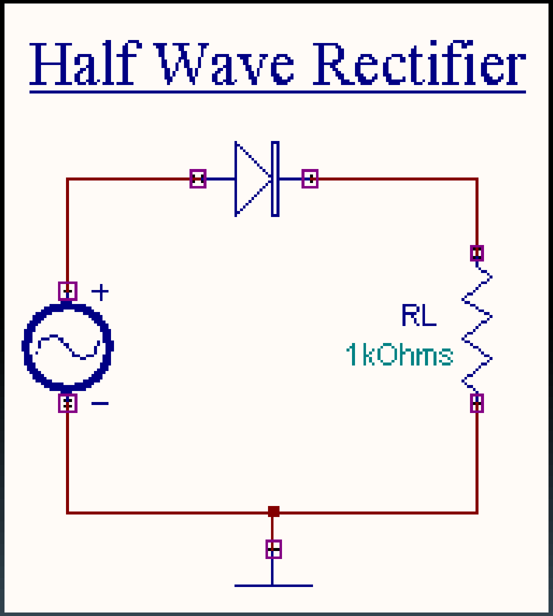
1. Diode Rectifier

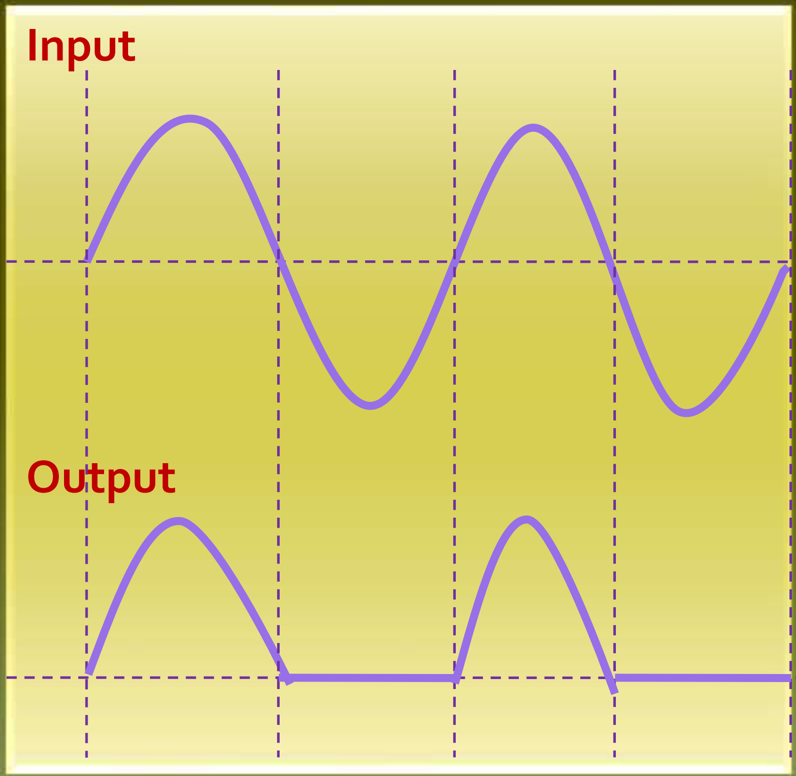
- Type of diode that converts alternating current into unidirectional current (**DC**)
- Typically seen in power supplies



Half – Wave Rectifier

- A rectifier circuit with a single diode that conducts current during positive or negative half cycles of input AC signal at a rate determined by the input frequency.





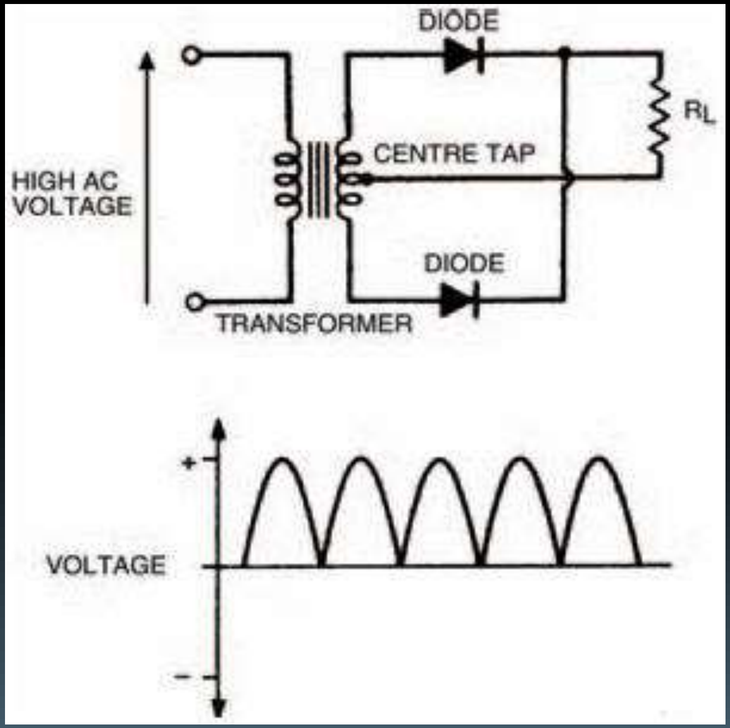
Conversion factor = **40.6%**

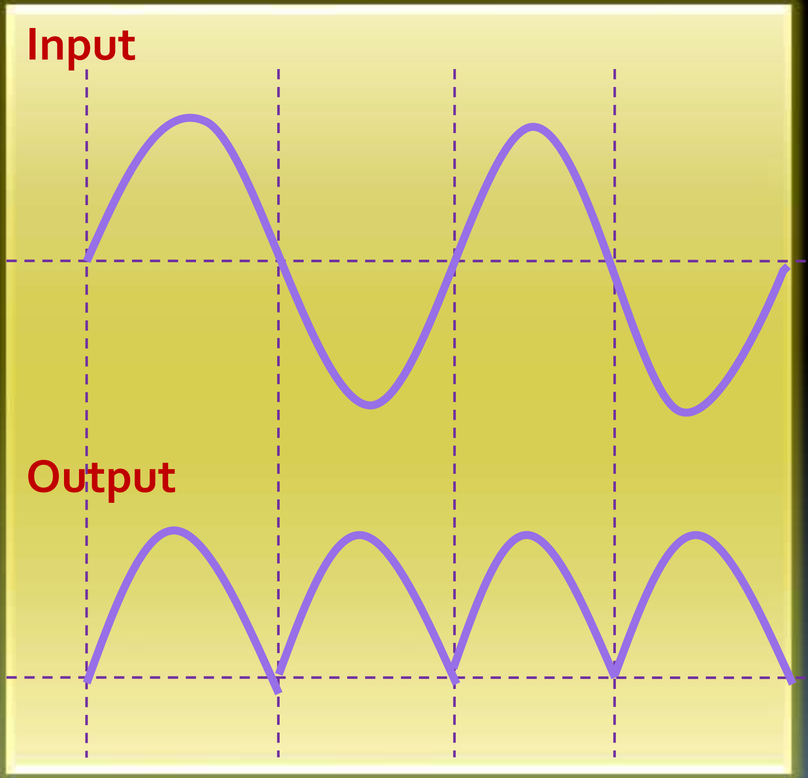
Freq$_{output}$ = Freq$_{input}$

Full – Wave Rectifier

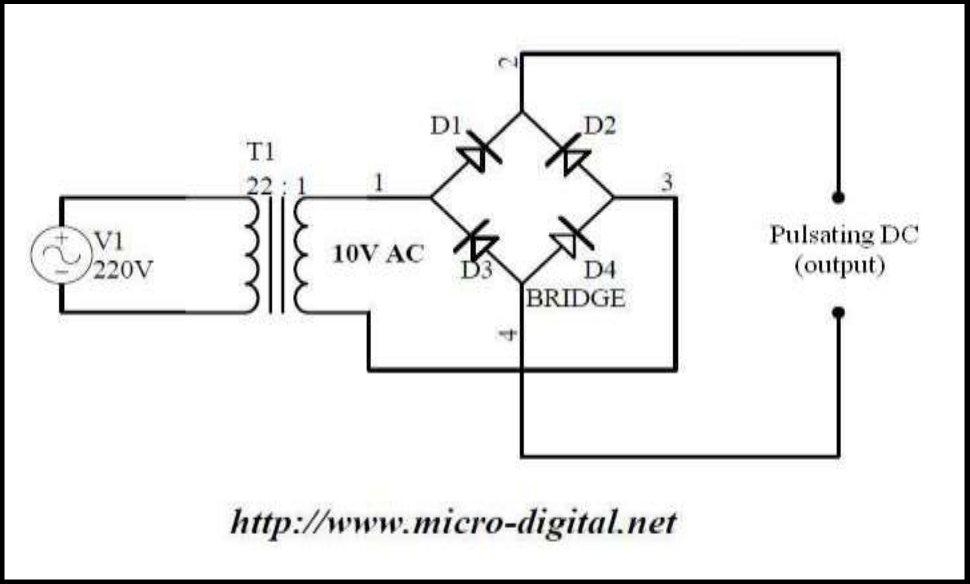
- A rectifier circuit that conducts current during positive and negative half cycles of input AC signal.

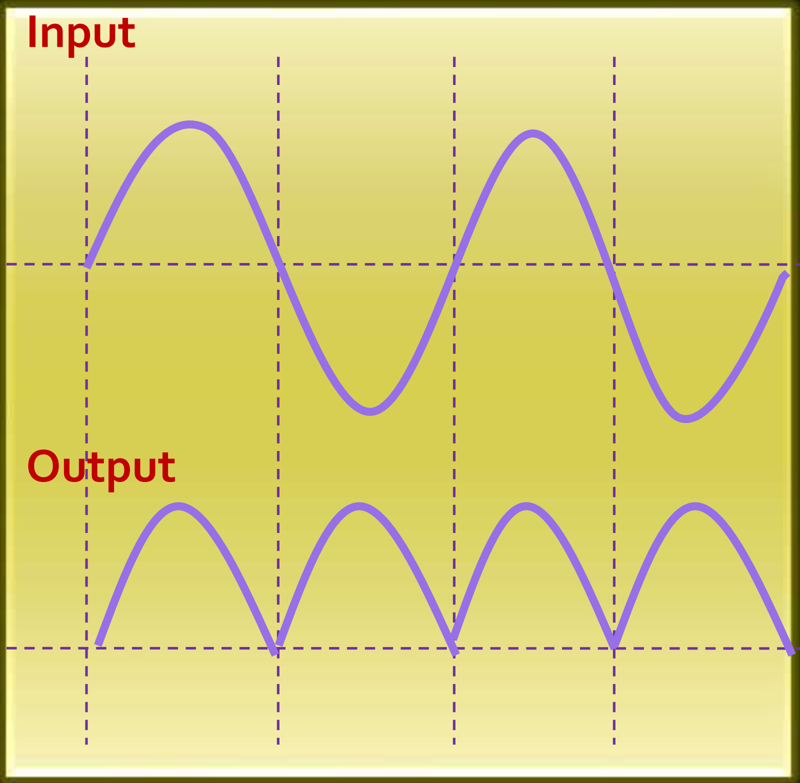
Center – Tapped





Bridge Type





Conversion factor = **81.2%**

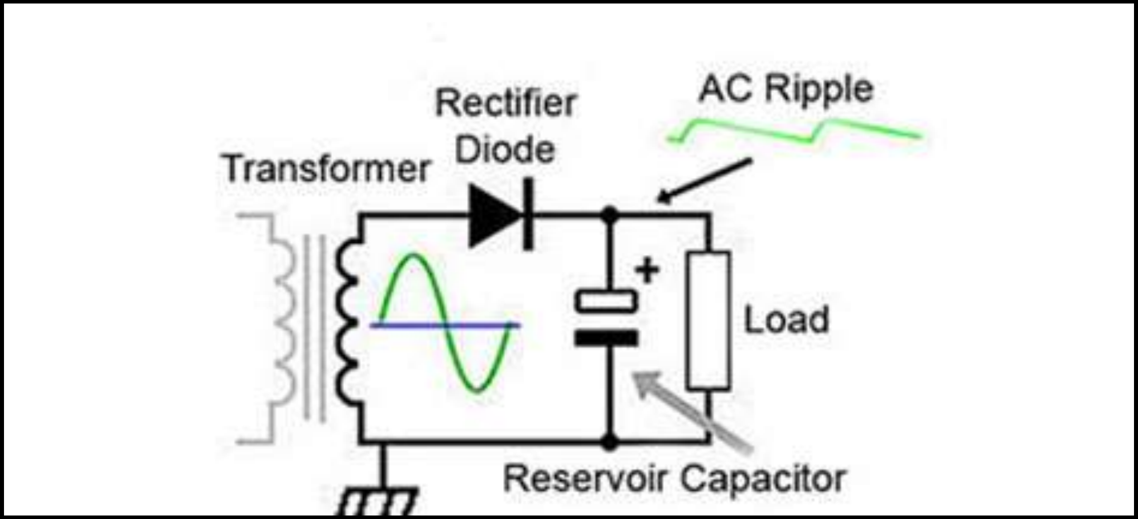
$Freq_{output}$ = 2 x $Freq_{input}$

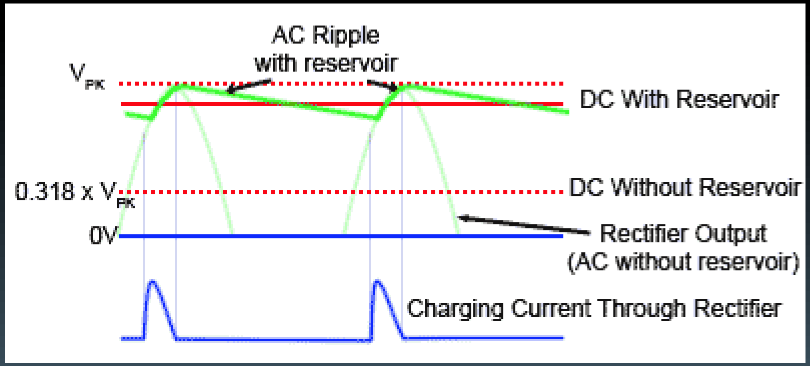
Comparison of Rectifiers

	Half – Wave	Center –tapped	Bridge Type
V_{rms}	$V_{pk} / 2$	$V_{pk} / \sqrt{2}$	$V_{pk} / \sqrt{2}$
V_{ave}	V_{pk} / π	$2V_{pk} / \pi$	$2V_{pk} / \pi$
I_{rms}	$I_{pk} / 2$	$I_{pk} / \sqrt{2}$	$I_{pk} / \sqrt{2}$
I_{ave}	I_{pk} / π	$2I_{pk} / \pi$	$2I_{pk} / \pi$
PIV	V_{pk}	$2V_{pk}$	V_{pk}

Filter

- Smoothens the output waveform





Ripple Factor of a Rectifier

- Ratio of the rms value of the AC component of the signal to the average value of the signal

$$r = \frac{V_{r(rms)}}{V_{dc}}$$

$$V_{r(rms)} = \frac{1}{2}\left((Vrms)^2 - (Vdc)^2\right)$$

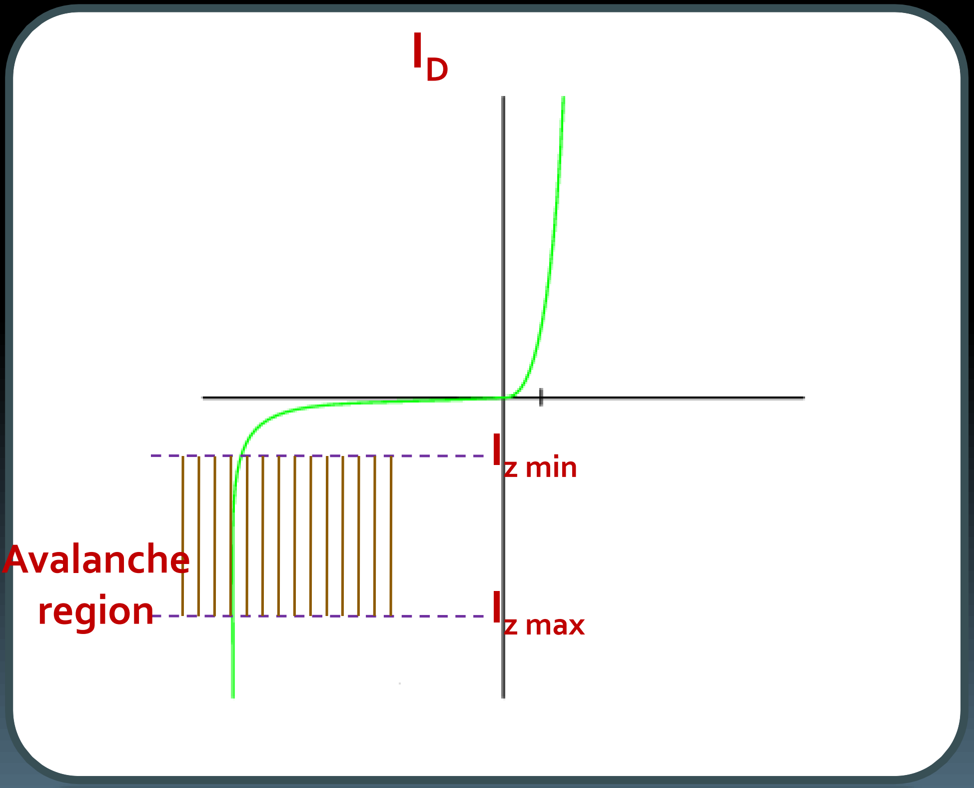
Vr(rms) = 0.385 (Vpeak for Half wave Rectifier)

Vr(rms) = 0.308 (Vpeak for Full Rectifier)

Voltage Regulation

- Means maintaining the output voltage at any load
- The type of diode used for regulation is **Zener diode**

Zener Regulation



Voltage Regulation

$$VR = \frac{Vnoload\ - Vfullload}{Vfullload}\ x\ 100\%$$

Current Regulation

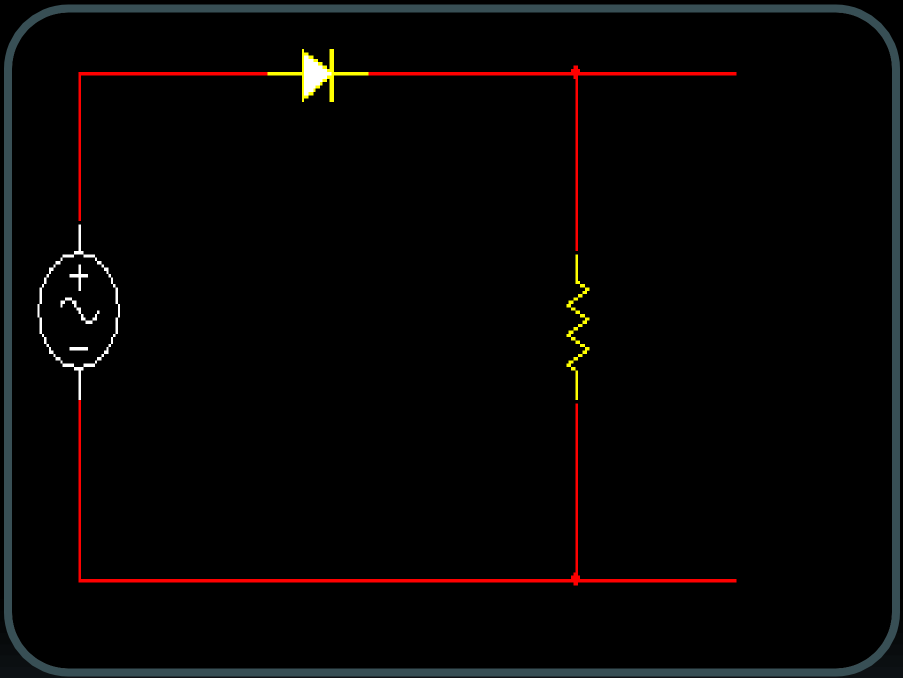
$$CR = \frac{Inoload\ - Ifullload}{Ifullload}\ x\ 100\%$$

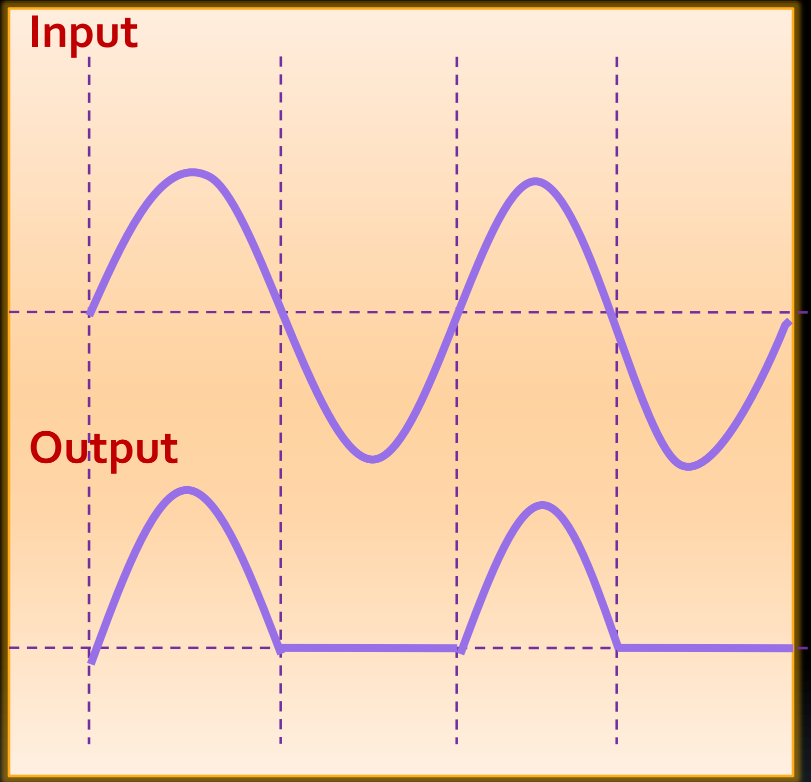
2. Clippers

- Electronic circuits that have the ability to clip – off a portion of the input signal without distorting the remaining part of the alternating waveform

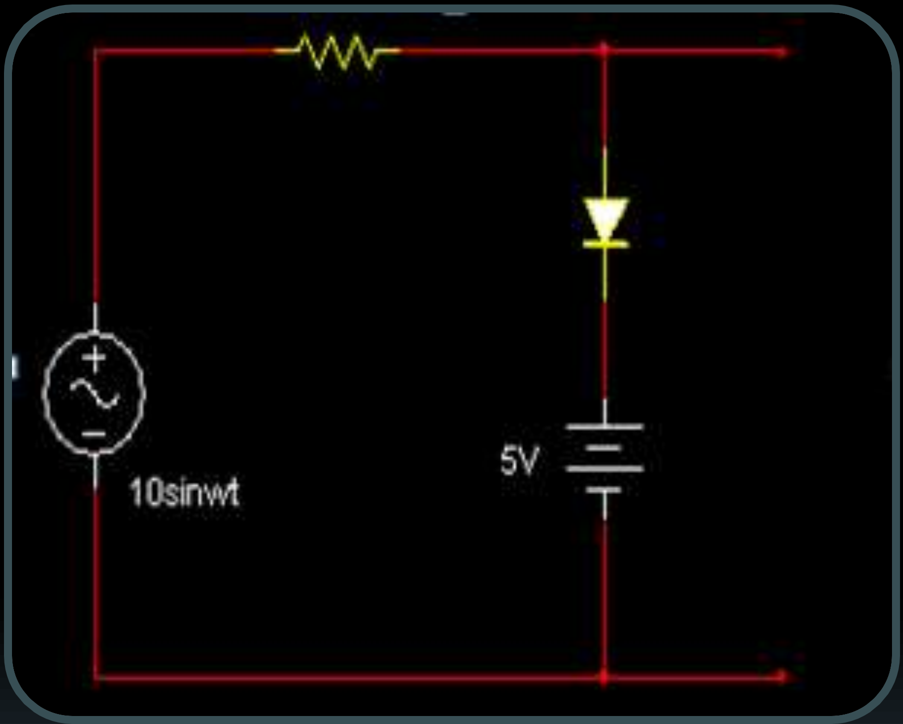
- Other names are **limiters**, **amplitude selectors** and **slicers**

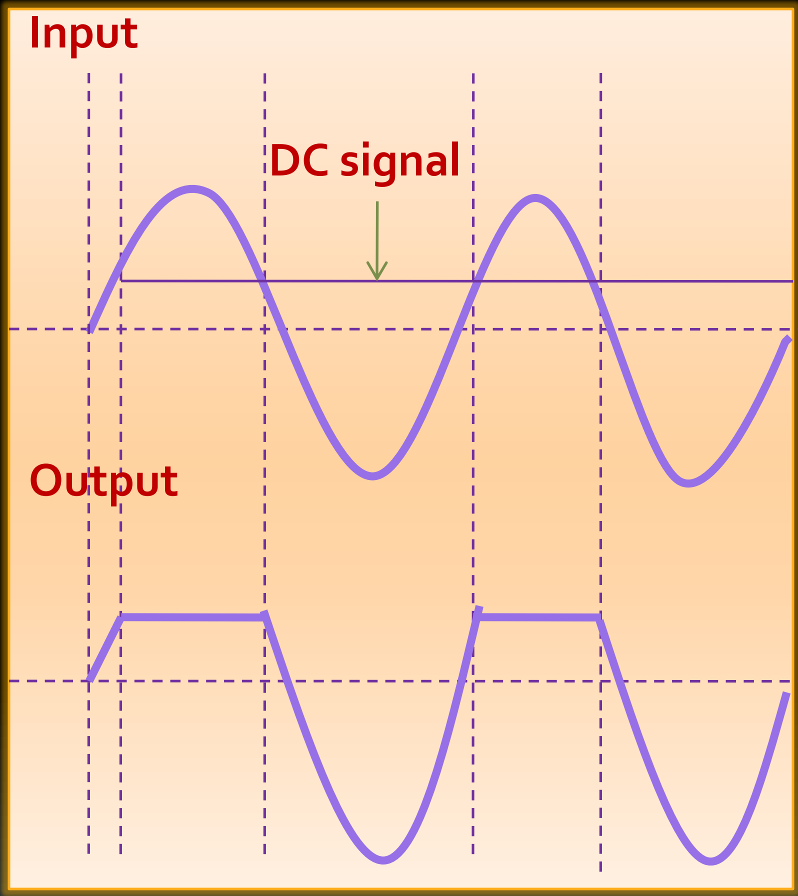
Example of Clipper Circuit





Example of Clipper Circuit





Analysis of Clippers - Short Cut Method

1. Determine the output waveform without the effect of the diode by
   a. shorting the diode for series limiter
   b. opening the diode for parallel limiter.

2. Determine the Clipping Line
   a. For Series Limiter, the clipping line is at the abscissa.
   b. For Parallel Limiter, the clipping line is the output reflection of the voltage source; if there is no voltage source present, the clipping line is at the abscissa.

Analysis of Clippers - Short Cut Method

3. Inspect the position of the diode

a. For series limiters, if the arrowhead of the diode is

i. pointing to the right, the output waveform is above the clipping line.

ii. Pointing to the left, the output waveform is below the clipping line

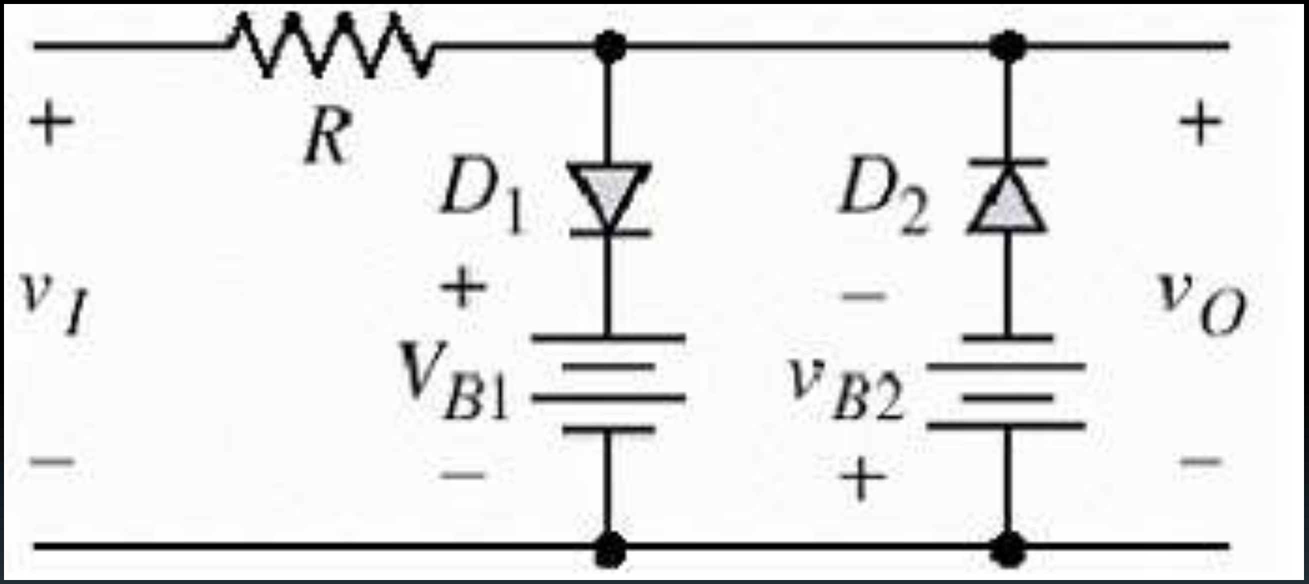
b. For parallel limiters, if the arrowhead of the diode is

i. pointing upward, the output waveform is above the clipping line.

ii. Pointing downward, the output waveform is below the clipping line.

Analysis of Clippers - Short Cut Method

4. For Double Diode Clippers, same procedure for 1 and 2. The resulting waveforem is between the 2 clipping lines.

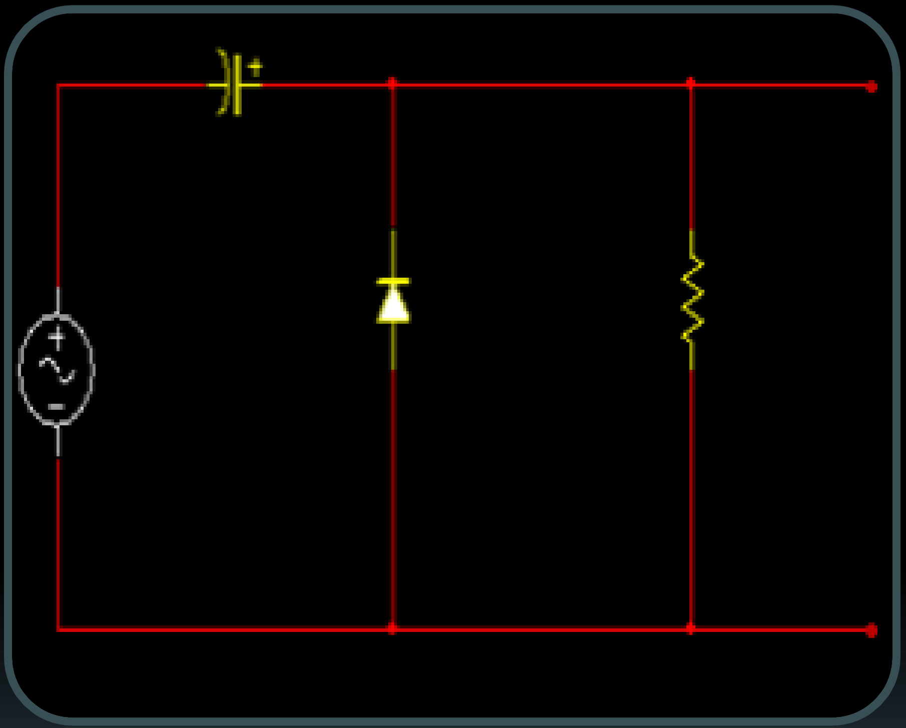


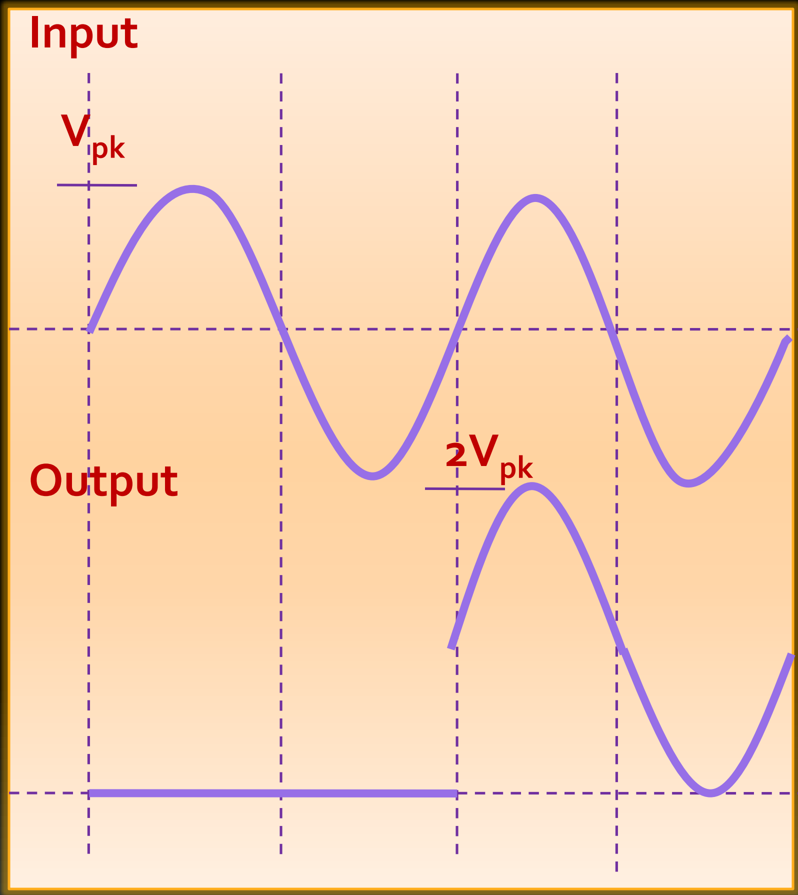
3. Clampers

- Circuits that shift the waveform of the input signal either all above or below the reference voltage
- Add or restore a DC level to an electrical signal
- Also known as **DC restorer**

- **Clamping circuit** is often used in television receivers as dc restorer. Incoming composite video signal is normally processed through capacitively coupled amplifiers that eliminate the dc component losing the reference levels which must be restored using clamping circuits before applying to the picture tube.

Example of Clamper Circuit





Positive Clamper

Analysis of Clampers - Short Cut Method

1. Determine the Clamping Line as given by the output reflection of the voltage source. If there is no voltage source present, the clamping line is at the abscissa.

Note: There should be no part of the waveform to be either above or below the clamping line.

2. Determine where the arrowhead of the diode is pointing

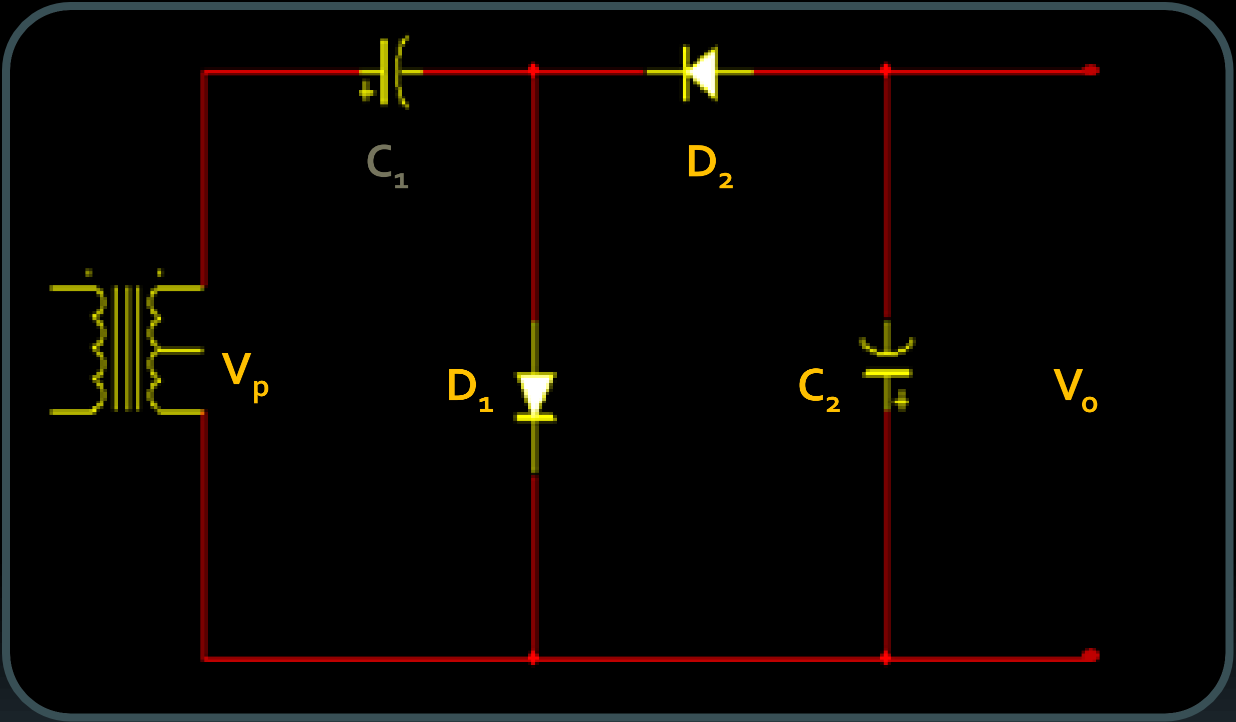
   a. upward, the waveform is above the clamping line.
   b. downward, the waveform is below the clamping line.

4. Voltage Multiplier

- Circuit which produces a greater DC output voltage than AC input voltage to the rectifiers
- Uses clamping action to increase peak rectified voltages without the necessity of increasing the input's transformers voltage rating
- Used in high – voltage, low current applications such as TV receivers

Voltage Doubler

- A voltage multiplier with a multiplication factor of 2



At the first negative half cylcle

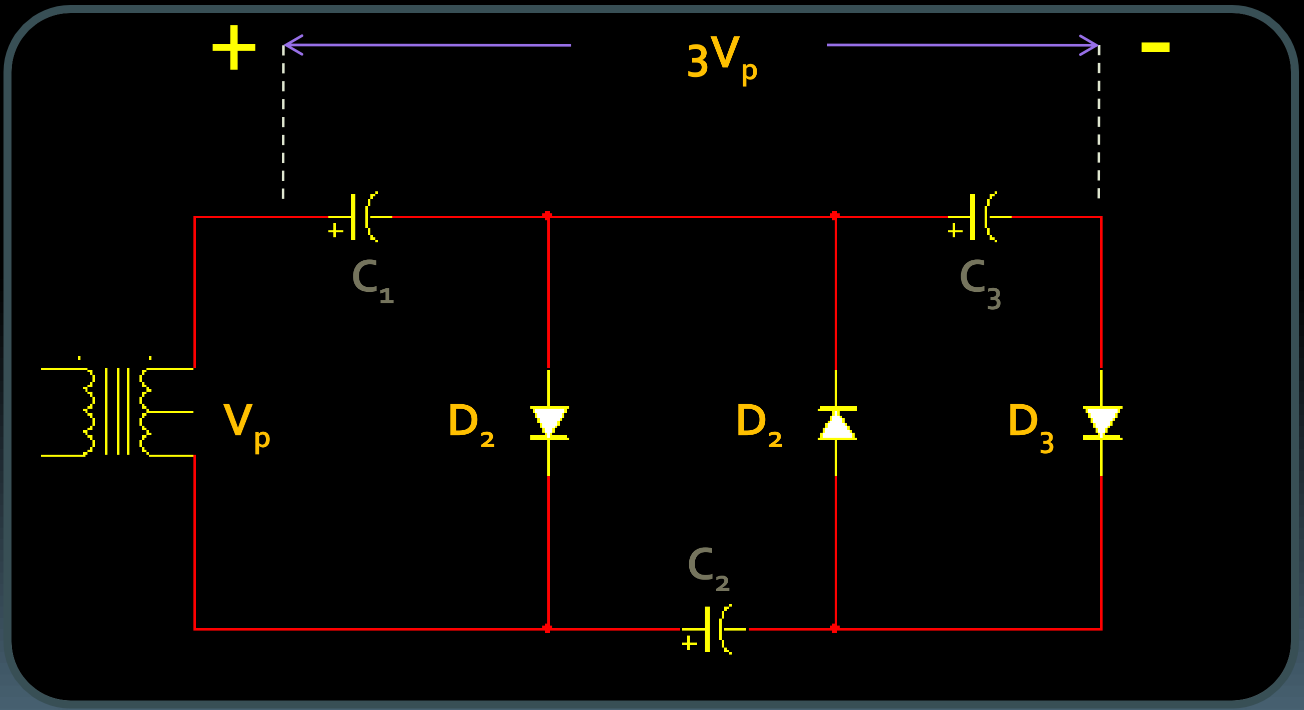
D_1 = forward bias
D_2 = reverse bias
$VC_1 = V_p$
$VC_2 = 2V_p$

At the first positivehalf cylcle

D_1 = reverse bias
D_2 = forward bias
$VC_1 = V_p$
$V_o = VC_2 = 2V_p$

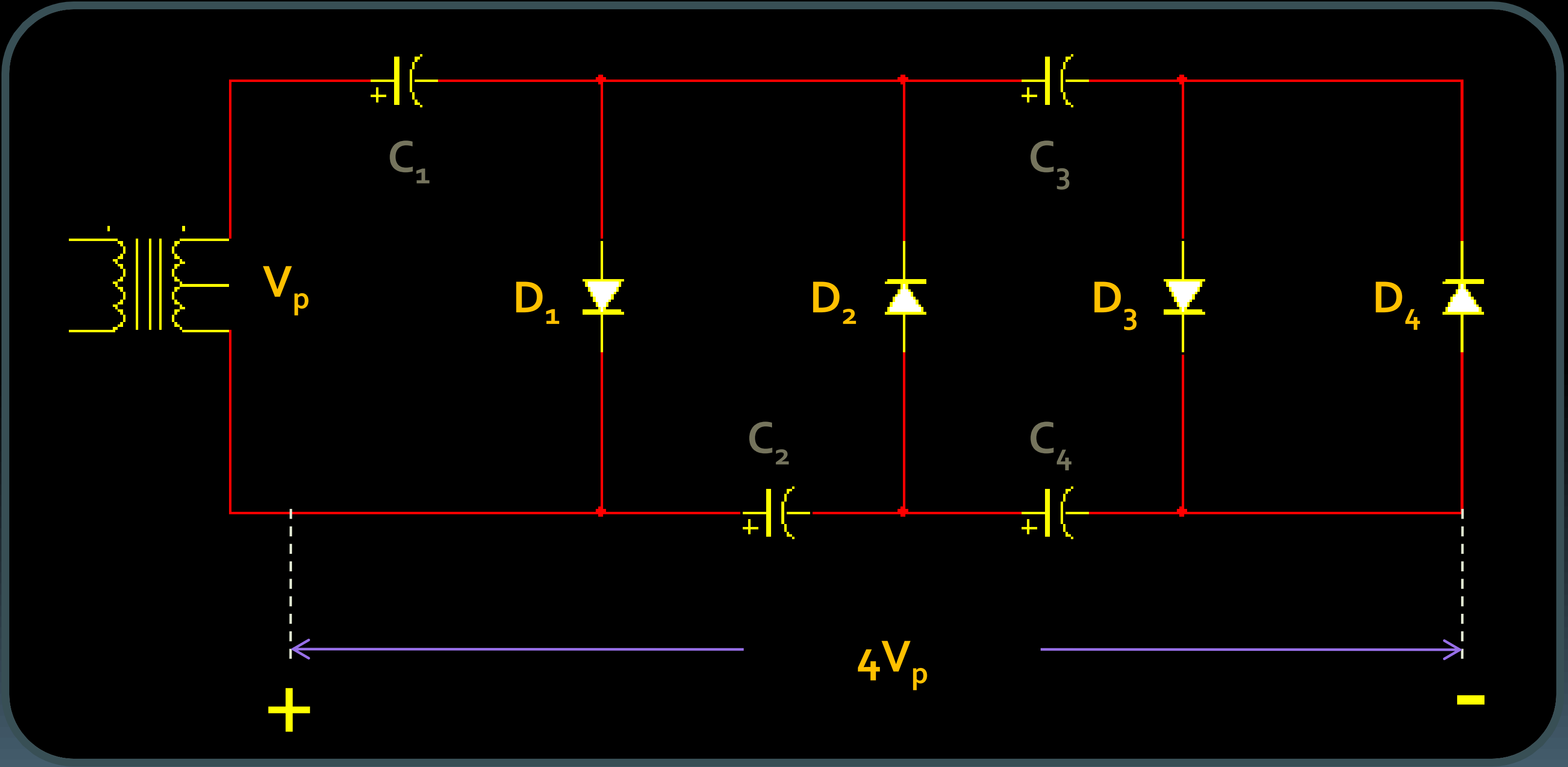
Voltage Tripler

- Addition of another diode – capacitor section to the half wave voltage doubler creates voltage tripler
- The PIV of each diode is **$2V_p$**



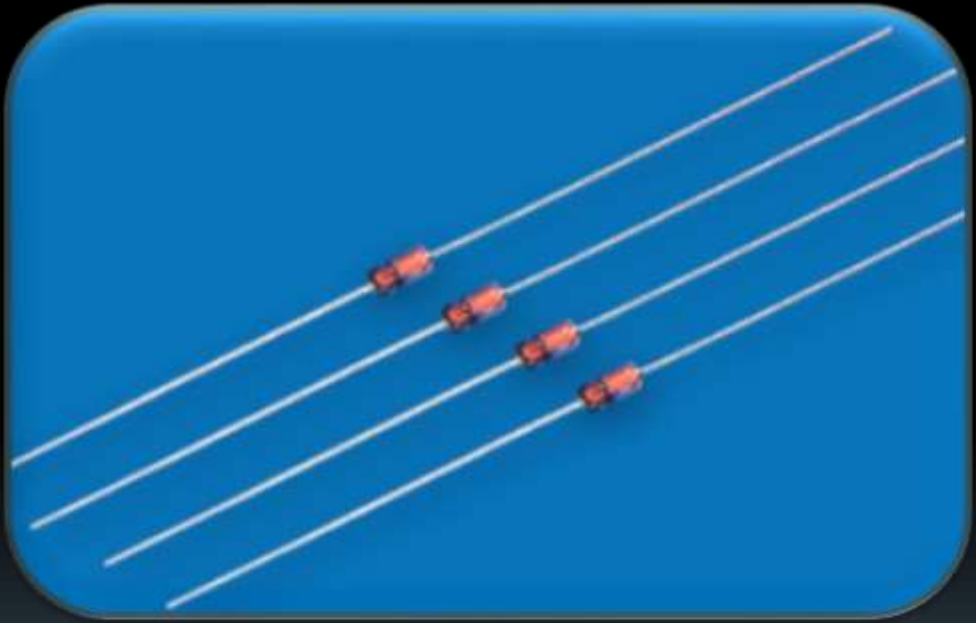
Voltage Quadrupler

- The addition of still another diode – capacitor section in a voltage tripler circuit
- The PIV of each diode is **$2V_p$**



II. Special Purpose Diodes

1. Zener Diode



Symbol

2. Zener Diode

- Diode designed to operate in the **reverse breakdown region**

a. Zener breakdown
   - When the breakdown voltage is **below 5V**

b. Avalanche breakdown
   - When the breakdown voltage is **above 5V**

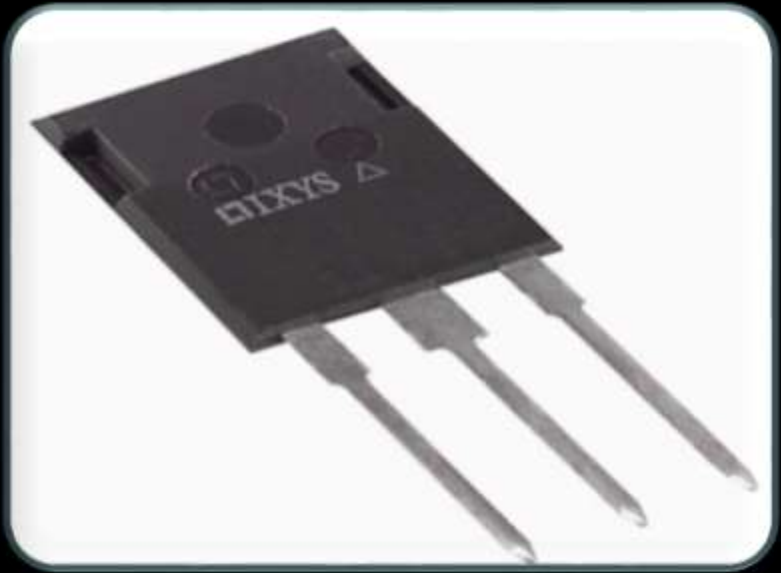
- Typical breakdown voltages of **1.8V to 200V** with specified tolerances from **1% to 20%**
- With very stable voltage drop
- Useful as voltage regulator

2. Point Contact Diode

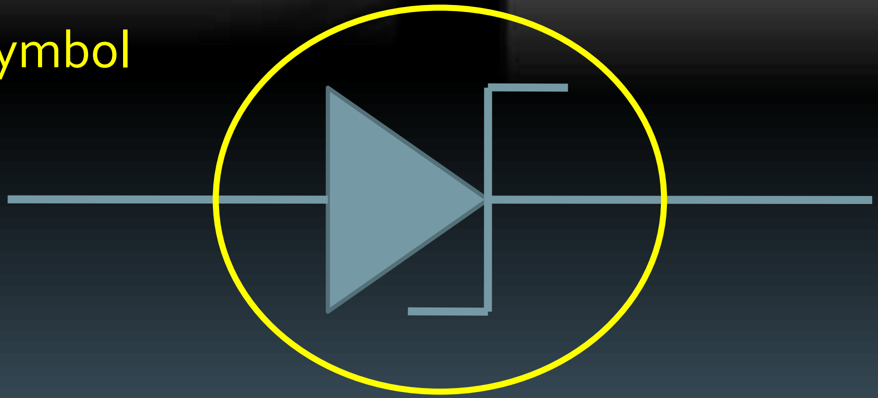
2. Point Contact Diode

- Semiconductor diode having fine wire whose point is permanent contact with the surface of a wafer of a semiconductor material such as silicon, germanium or gallium arsenide
- The fine wire is called **cat - whisker**
- For signal mixing and detection

3. Schottky Diode



Symbol

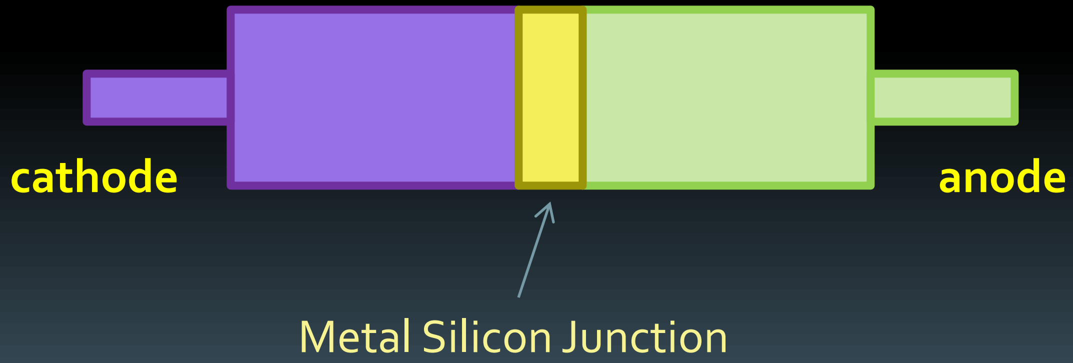


3. Schottky Diode

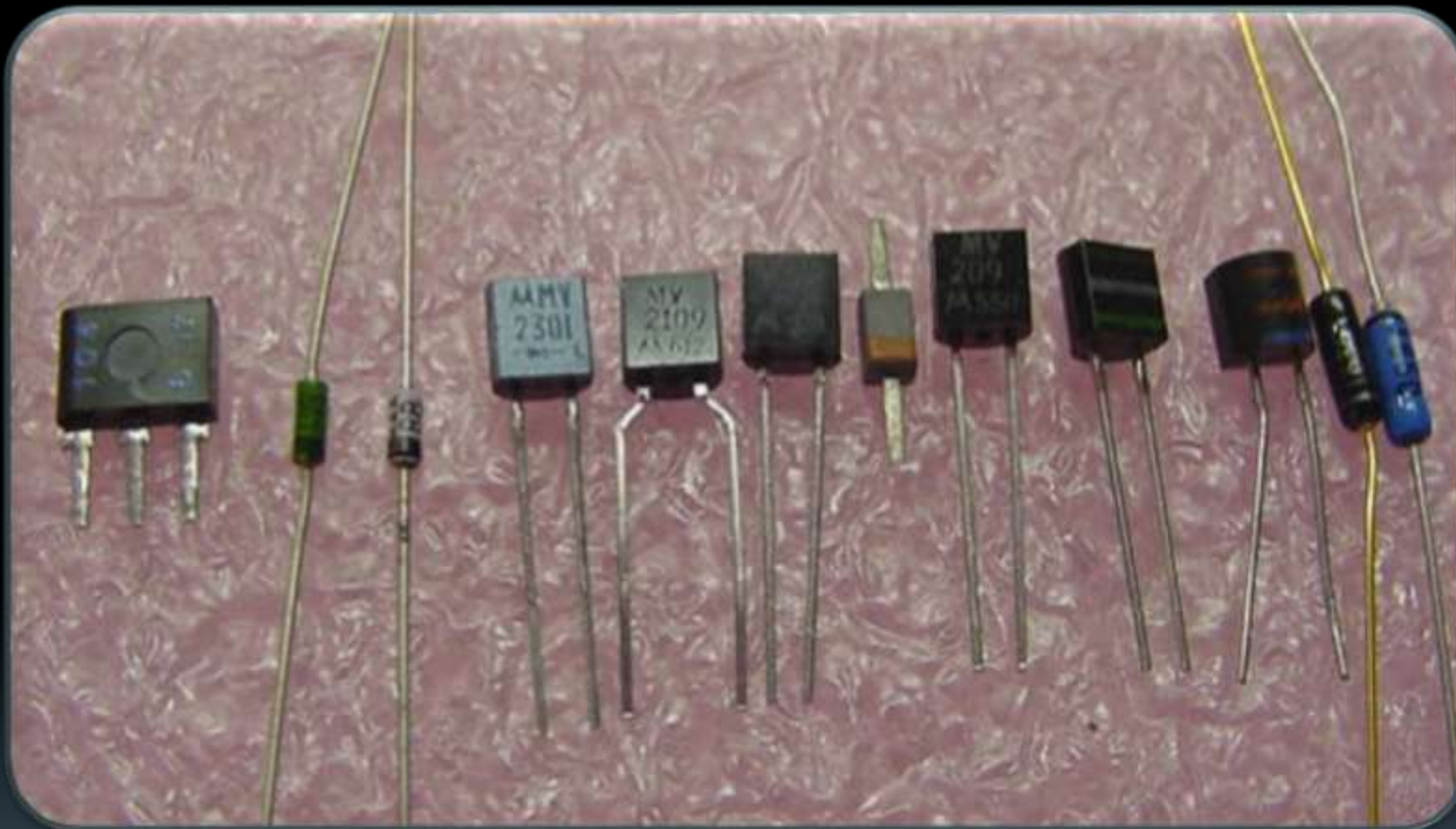
- Also known as **Surface Barrier Diode**
- Also known as **Hot - Carrier Diode**
- This type of diode has no depletion layer which eliminates the stored charges in the junction
- A rectifying metal semiconductor junction such as gold, silver and platinum

- Typical forward voltage drop is typically around **0.25V to 0.3V**
- Can rectify frequencies up to **300 MHz**
- ESBAR (**Epitaxial Schottky Barrier**)

Construction of Schottky Diode



4. Varactor (varicap)

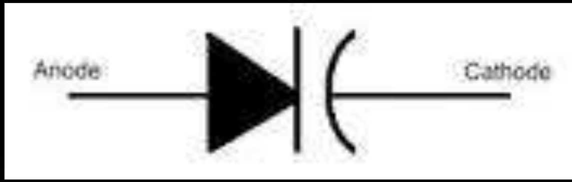


- **Voltage-variable capacitor**

- When this diode is reverse bias, the width of the depletion layer increases with the reverse voltage

- Used for electronic tuning, harmonic generator and parametric amplifier

Symbol



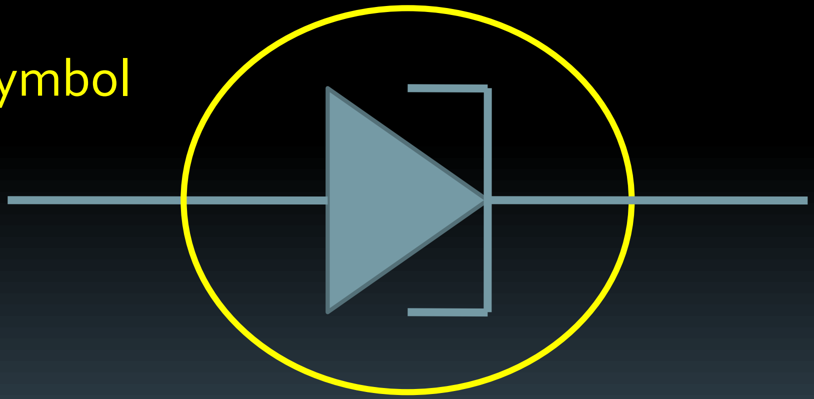
$$\text{Figure of Merit} = \frac{0.159}{fR_sC_t}$$

where

f = frequency
R_s = series resistance
C_t = total diode capacitance

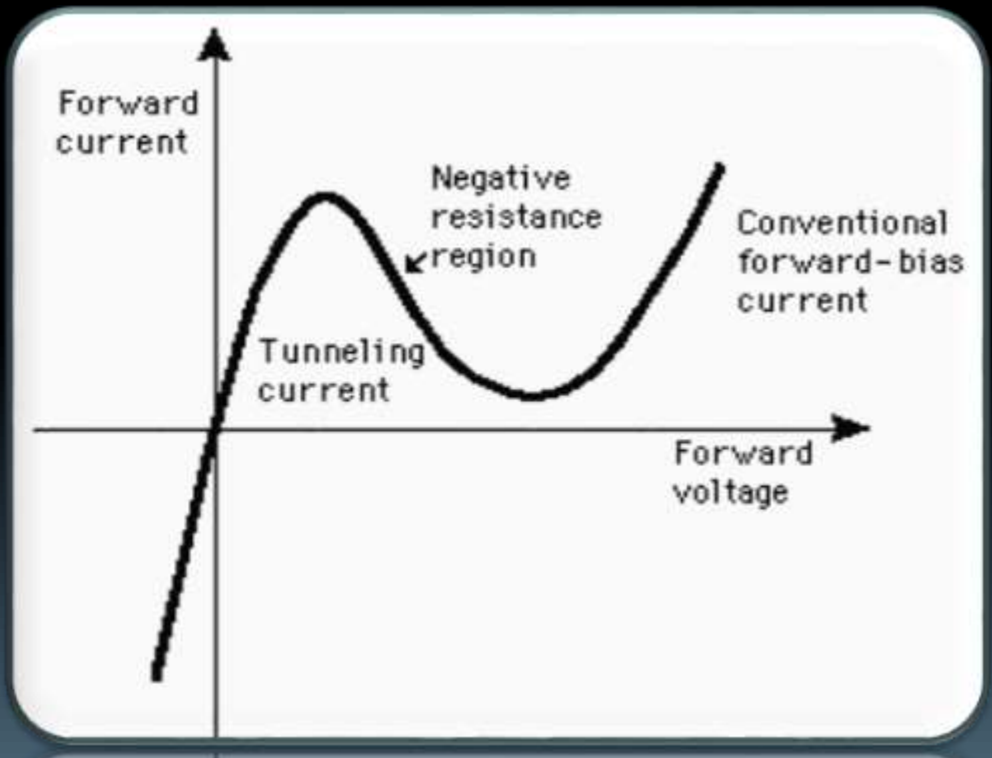
5. Tunnel Diode

Symbol



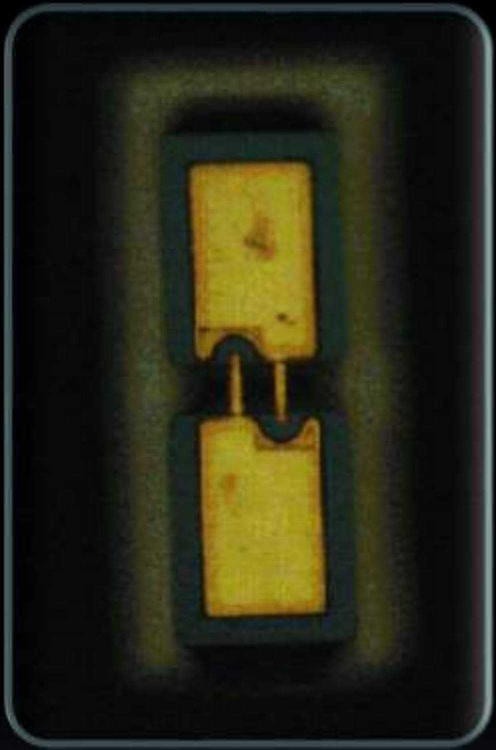
5. Tunnel Diode

- Also known as **Esaki diode**
- Type of diode that exhibits the phenomenon known as **negative resistance**



- **Negative resistance** implies that an increase in forward voltage produces a decrease in forward current for a certain part
- Utilizes a heavily doped material and therefore have so many electrons
- Has a very thin depletion layer
- The extremely narrow depletion region emits electrons to “tunnel” through the pn junction at very low forward bias voltage
- Used for oscillators and amplifiers

6. Backward Diode

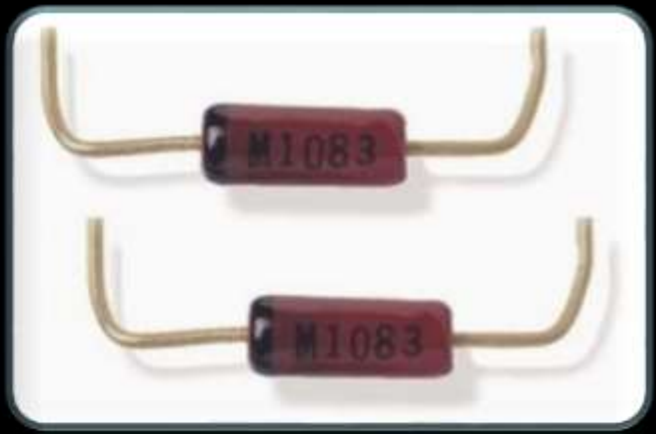


Symbol

6. Backward Diode

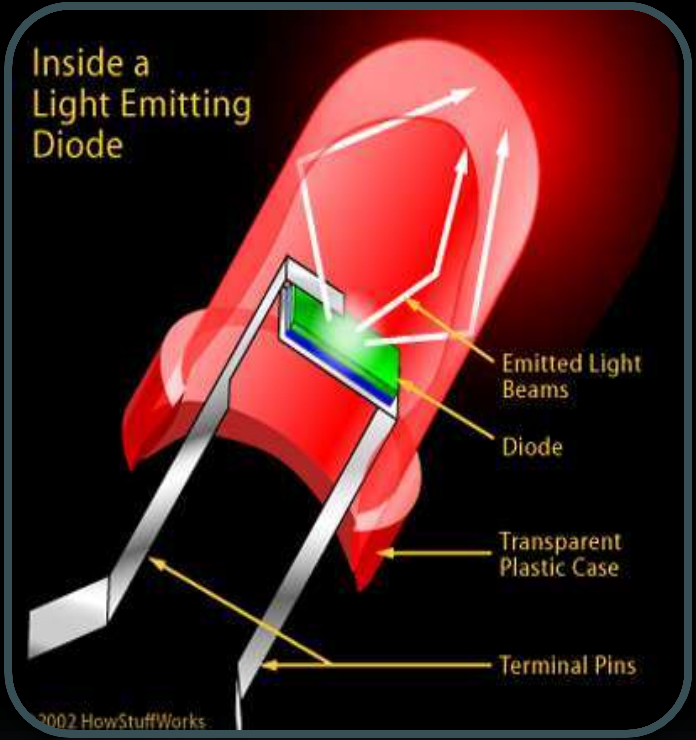
- Conducts better in the reverse (**-0.1V**) than in the forward (**+0.7V**) direction
- Designed such that its high current flow takes place when the junction is reverse bias

7. PIN Diode

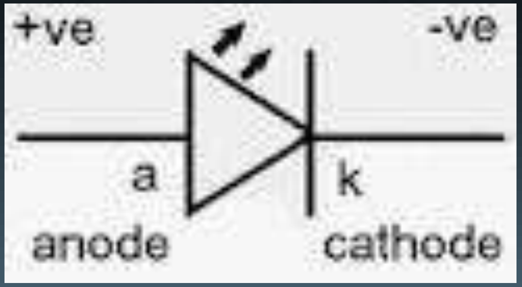


- **Positive – intrinsic Negative Diode**
- The intrinsic material between the P and N layer offers impedance at microwave frequencies being controlled by low frequency signals
- Used in microwave switches

8. Light Emitting Diode (LED)

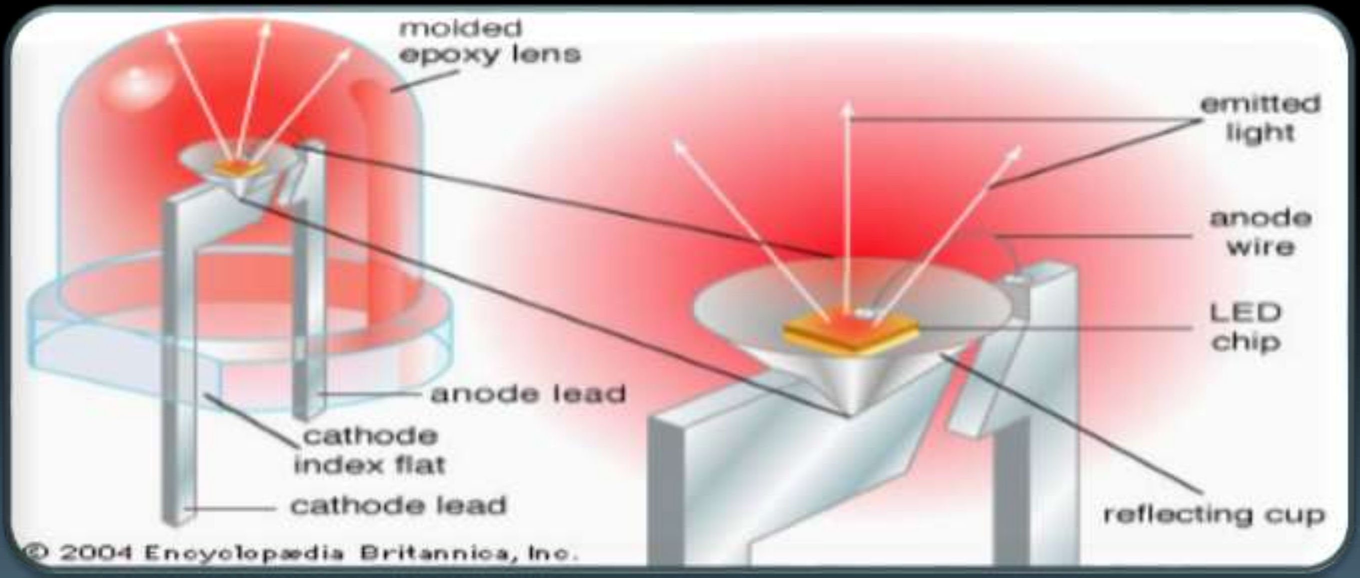


Symbol



8. Light Emitting Diode (LED)

- In a forward biased LED, free electrons cross the junction and fall into holes. As these electrons fall from higher to a lower energy level, they radiate energy which goes off in the form of heat. But in an LED, the energy is being radiated as light.

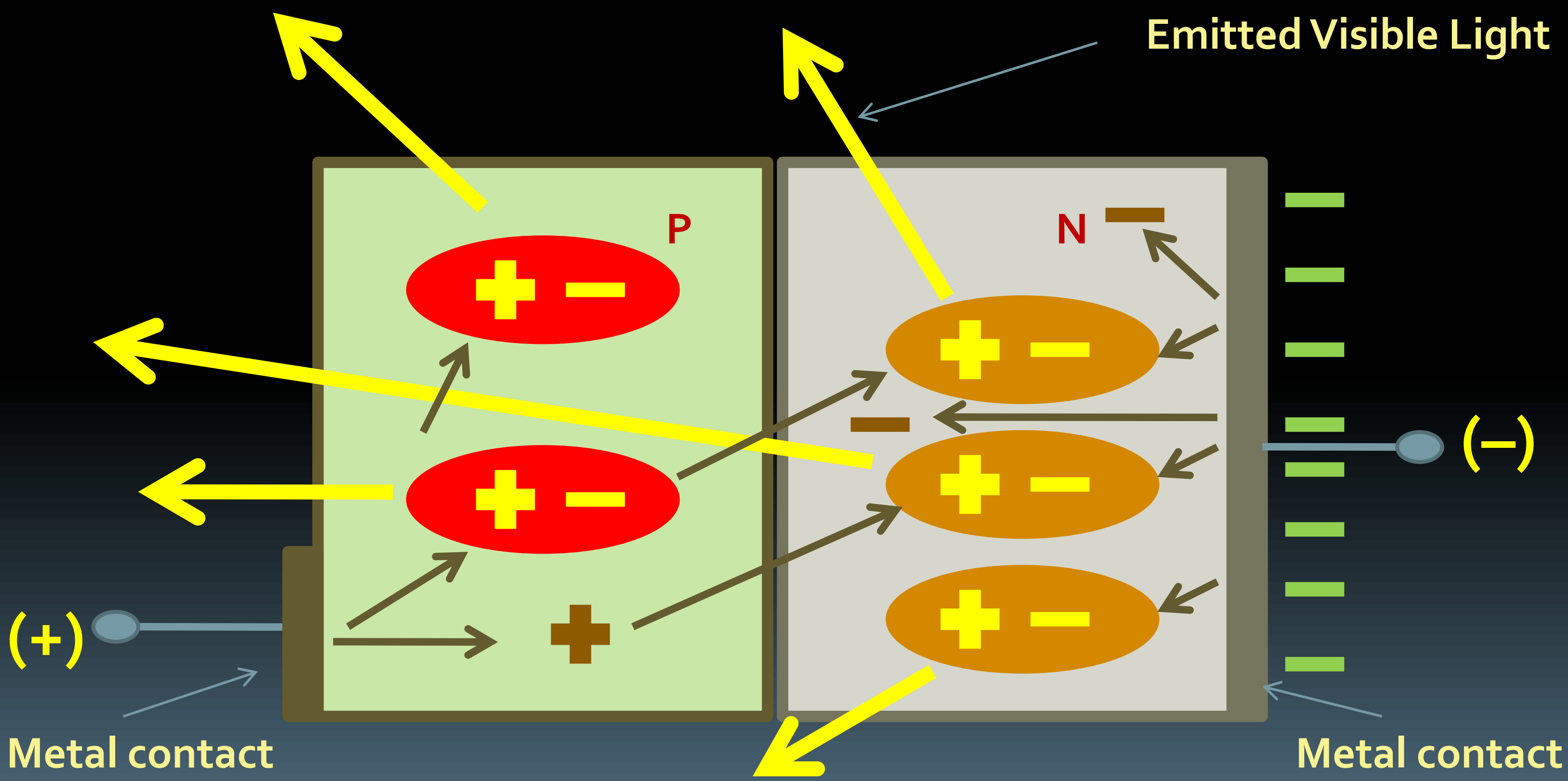


- Commonly used **Gallium Arsenide**, **Gallium Arsenide Phosphide**, and **Gallium Phosphide**

- **GaAs** LEDs emit infrared (IR) radiation which is non visible, **GaAsP** produces either red or yellow visible light and **GaP** emits red or green visible light

- **Red** is the most common color of LEDs

- **Electroluminescence** is the process involved when large surface area on one layer of one semiconductive material permits the photons to be emitted as visible light



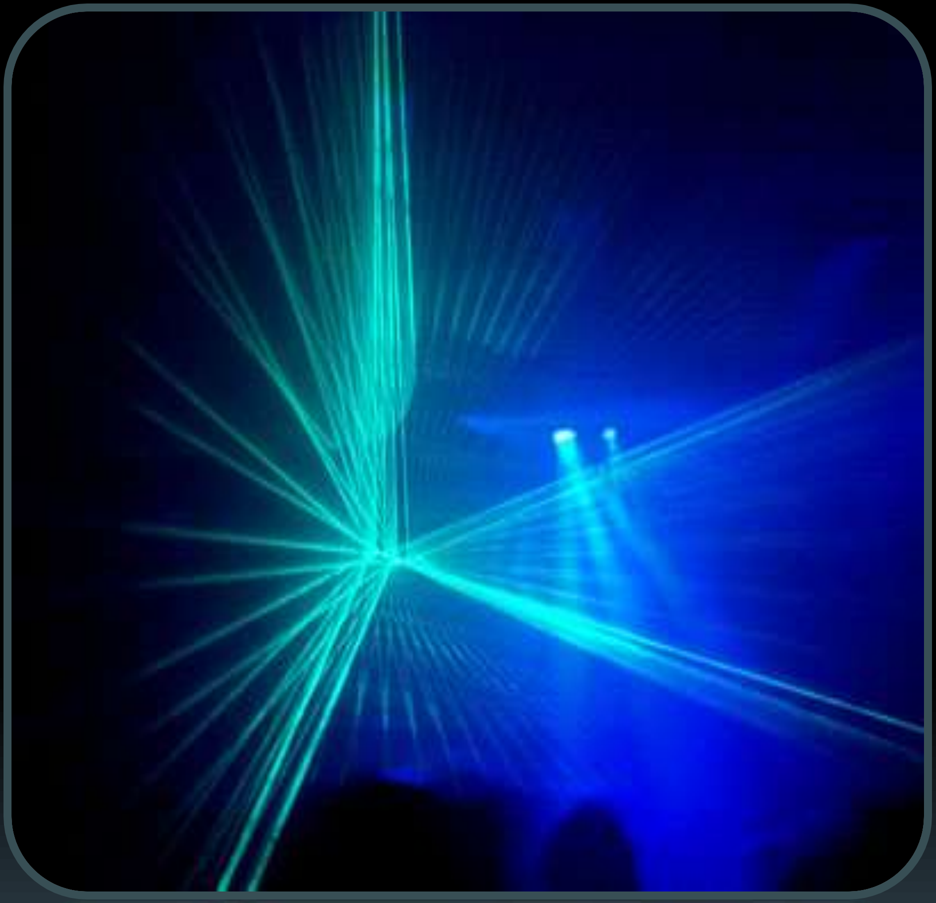
- **Irradiance** is the power per unit area at a given distance from an LED source expressed in **mW/cm^2**.
- **Typical voltage drop: 1.5V to 2.5V** for currents between **10mA and 50mA**
- **Nominal Voltage drop: 2V**
- **Reverse Breakdown: 3V – 10V**

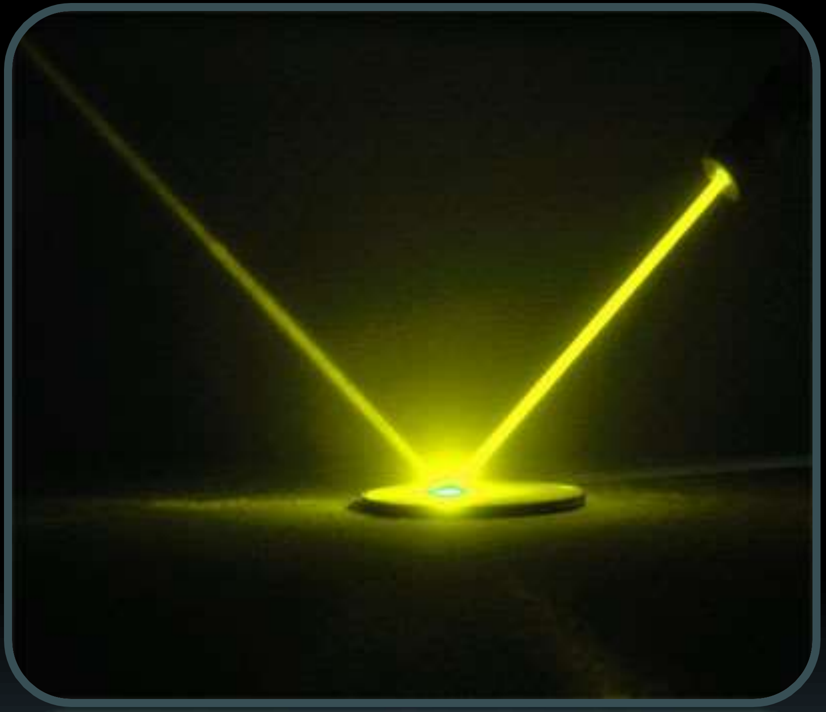
9. LASER Diode

9. LASER Diode

- The term **LASER** stands for **Light Amplification by Stimulated Emission of Radiation**
- LASER light is **monochromatic** meaning it consists of a single color and not a mixture of colors
- LASER light is also a **coherent light** meaning a single wavelength

LASER Light (coherent and monochromatic)

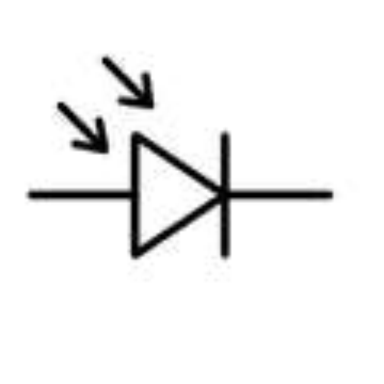




- LASER diode pn junction is formed by two layers of doped **gallium arsenide**
- It is **forward biased**
- LASER diodes and photodiodes are used in the pick – up system of compact disk (CD) layers. Audio information is digitally recorded in stereo on the surface of a compact disk in the microscopic “pits and flats”

10. Photodiode

Symbol



10. Photodiode

- Operated in **reverse bias** condition
- Is one that is optimized for its sensitivity to light
- A window let light to pass through the package of the junction. The incoming light produces free electrons and holes producing larger reverse current.
- **Dark current** is the reverse current flowing through the photodiode when there is no incident light.