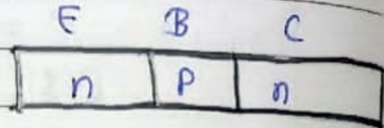
Transistor

- Transistor
  - Bipolar Junction (BJT)
    - npn
    - pnp
  - Unipolar Junc^n (UJT)
    - MOSFET (metal oxide shielded field effect transistor)
      - depletion type
        - ~~n channel~~ n type
        - ~~p channel~~ type
      - enhancement type
    - JFET (Junction field effect transistor)
      - n channel
      - p channel

Bipolar Junction Transistor (BJT)



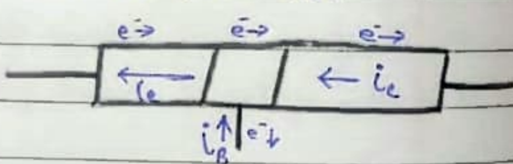
BJT has 3 components

1) Emitter :- Moderate size, highly doped, emits charge carriers,
2) Base :- Small size, ~~low doping~~ lightly doped.
3) Collector :- Large size, moderately doped. collects charge carrier

npn transistor

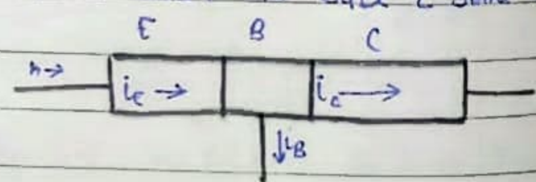
In npn, e^- goes from emitter to collector via base & direction of current is opposite to that of flow of e^-. Some e^- also leak from base

$I_E = I_B + I_C$



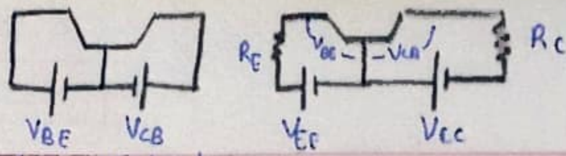
In pnp. holes travel from emitter to collector via base & some holes go out from base.

$I_E = I_B + I_C$



A transistor can be seen as a combination of two pn junc^n diodes. Therefore, it has 4 configurations (1 → emitter base, 2 → base collector)

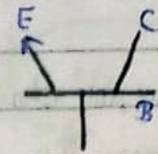
① ON - FF (aka saturation)
② OFF - RR (aka cutoff)
③ Active - FR - acts as amplifier
④ Reverse Active - RF



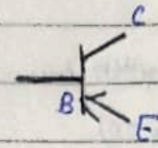
(without resistance)

Representation of BJT

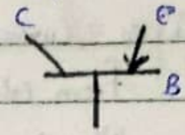
Bottom part = common terminal (base in this case)
Emitter = has an arrow
Arrow inwards = pnp, arrow outwards = npn



npn, common base



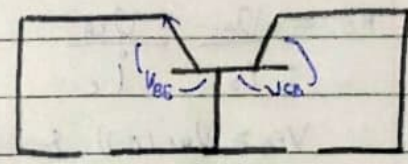
pnp Common emitter



~~npn~~ common base pnp

Common Base Configuration

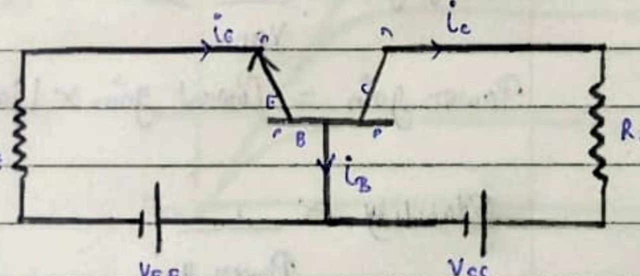
In this, base is connected to both emitter & collector.



\# V_{CB} = potential diff b/w collector & base (only in transistor)
V_{BE} = " " " base and emitter

V_{BB} = potential diff across base's branch.
V_{CC} = " " " collector's branch.
V_{EE} = " " " emitter's branch.
& CB doesn't have V_{BB}, CE doesn't have V_{EE}, CC doesn't have V_{CC}.

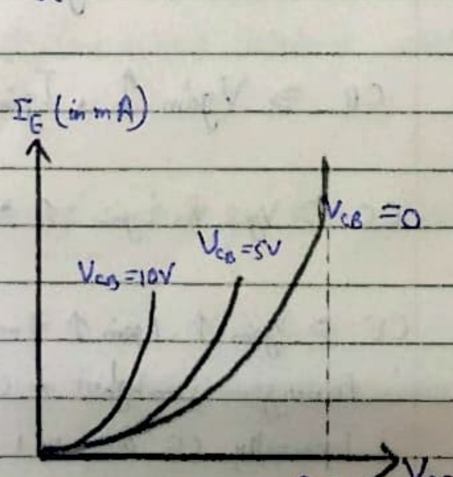
(Same for both npn & pnp)
CB configuration as an amplifier:



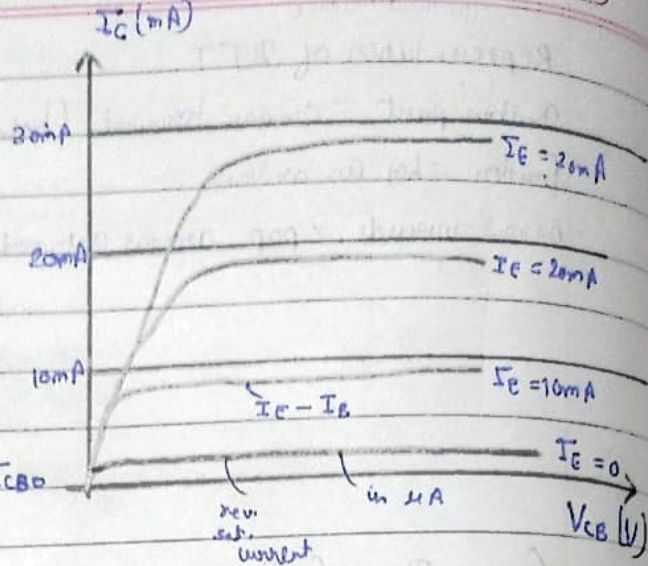
\# Generally, V_{EB} is inside transistor & is equal to junc^n potential
∴ $V_{BE} = 0.7V$ for Si diode
& $V_{BE} = 0.3V$ for Ge diode

Input Characteristics of Transistor (CB)
(Taking V_{CB} constant) ($V_{BE} \leq 0.7V$)
Input Resistance / Impedence

$$R_i = \frac{V_i}{I} = \frac{V_{BE}}{i_E}$$



Output Characteristics of CB
Keeping I_E constant



I_{CBO} = Current flowing from collector to emitter-base when ~~base~~ emitter is open ($I_E = 0$)

Output Resistance/ Impedence

$R_o = \frac{V_o}{i_o} = \frac{V_{CB}}{i_c}$

$\because$ $V_{CB} > V_{BE}(0.7)$ & $i_c < i_e$

$\therefore R_o > R_i$ for CB Transistor

Current gain $\alpha = \frac{i_c}{i_e} \approx 1$ but lesser than 1

Ideally, $\alpha = 1$ if $i_B = 0$.

Voltage gain $= \frac{V_{CB}}{V_{BE}} > 1$ $\because (V_{CB} > V_{BE})$

Power gain = Current gain × Voltage gain

Stability $\propto \frac{1}{\text{Power gain}}$

CB ⇒ Vgain ↑, Igain ↓ ⇒ less power gain, more stable, but hard to achieve stability

CC ⇒ Vgain ↓, igain ↑ ⇒

CE ⇒ Vgain ↑, igain ↑ ⇒ more power gain, less stability but easier to attain stability

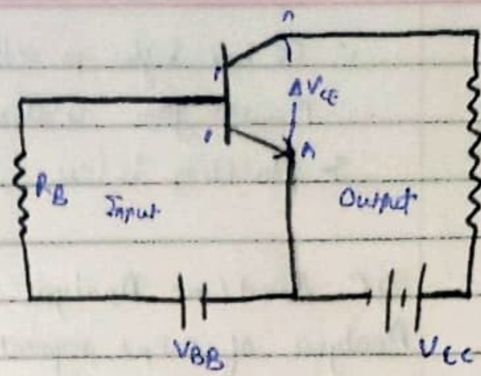
$\because$ Power gain is mostly highest in CE

$\therefore$ Generally CE are used to make amplifiers.

Common Emitter Configuration (CE):

Use as an Amplifier:

Input Characteristics:



#: In fig.

If $V_{BB} > V_{CC}$

Then EB & BC both will be forward bias

& If $V_{CC} > V_{BB}$

Then EB will be forward biased & BC will be reverse biased (used as an amplifier)

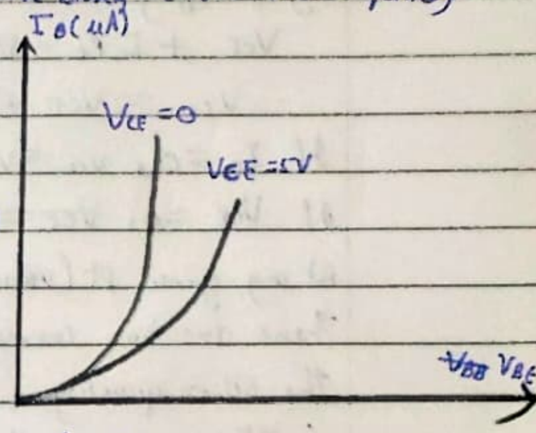
Input Characteristics keeping V_{CE} constant

Input Resistance

$R_i = \frac{V_{BE}}{i_B}$, $\because V_{BE} = 0.7V$ & i_B is in μA (very small)

R_i will be very large (in $M\Omega$)

$\therefore$ CE has high input impedence.



Output Characteristics keeping I_B constant

I_{CEO} = current from collector to emitter when base is open ($I_B = 0$) (rev. sat)

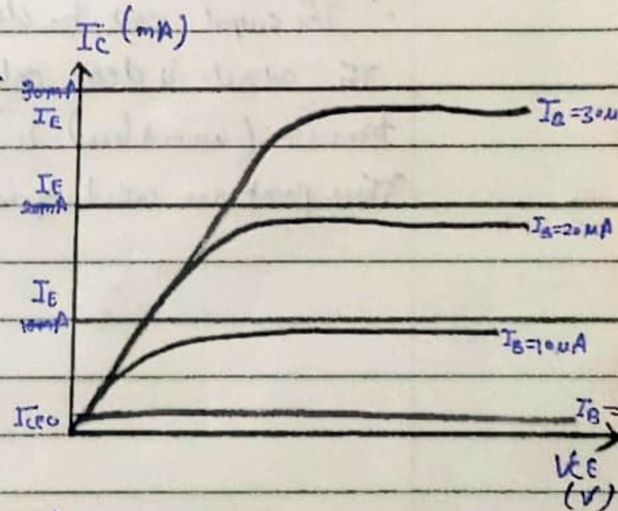
Output Impedence

$R_o = \frac{V_{CE}}{i_c}$

$i_c >>> i_B$

$\therefore R_o < R_i$

$\therefore$ CE config. has high input impedence & low output impedence which is good to use as amplifier



Current gain: $\beta = \frac{I_C}{I_B} >> 1$: very large current gain (300 - 500)

Voltage gain: $V_{gain} = \frac{V_{CE}}{V_{BE}} > 1$

$V_{CE} = V_{EB} + V_{BC}$

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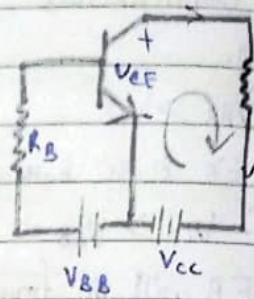
∴ CE has high i/p voltage & current gain
∴ Power gain is also high
& stability is less.



DC Load Line Analysis

Analysis of output segment (entire output circuit)

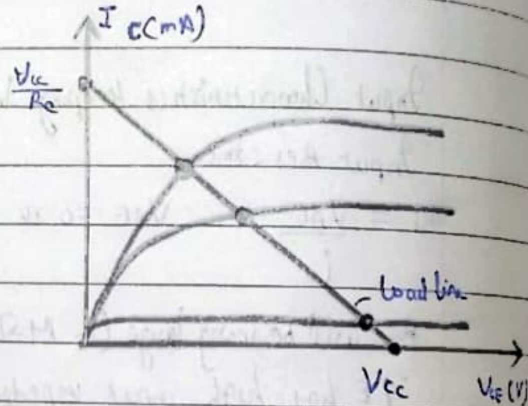
By applying KVL on output loop

$V_{CE} + I_C R_C - V_{CC} = 0$

$\therefore V_{CC} = V_{CE} + I_C R_C$

If $I_C = 0$, $V_{CC} = V_{CE}$

If $V_{CE} = 0$, ~~$V_{CC} = V$~~ $I = V_{CC}/R_C$



At any given pt (value of I_C or V_{CE}) there are two corresponding values of the other quantity

∴ The output won't be clear

The output is clear only at the pt. of int of output curves of both transistor (curved lines) & circuit (load line)

These points are called operating pts / Q pts / silent pts.

Varactor diode

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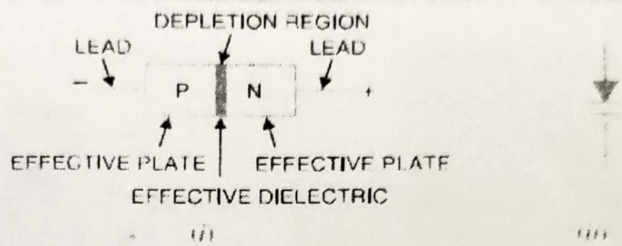
Introduction

Varactor diode is a special type of PN junction diode, in which PN junction capacitance is controlled using reverse bias voltage. When the diode is forward biased, current will flow through the diode. When the diode is reverse biased, charges in the P and N semiconductors are drawn away from the PN junction interface and hence forms the high resistance depletion zone.

Schematic Symbol



OTHER NAMES : • Variable capacitance (Varicap) diode • Voltage – Variable Capacitor (VCC) diode • Tuning diode
• Variable reactance diode

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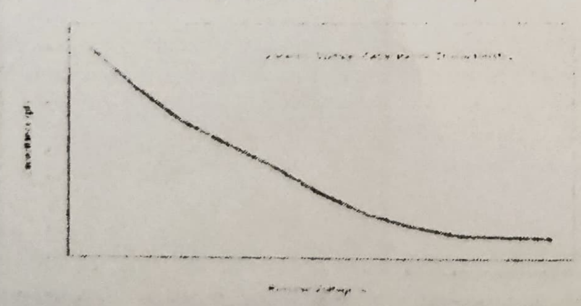
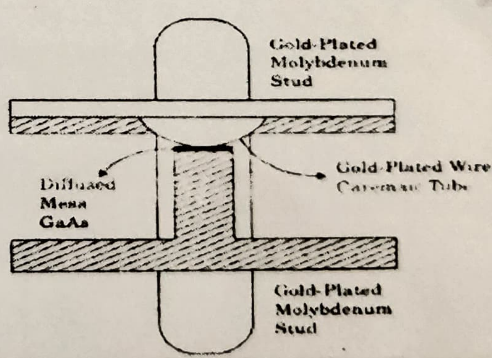
C – V CHARACTERISTICS

C – V CHARACTERISTICS



MATERIAL CONSTRUCTION



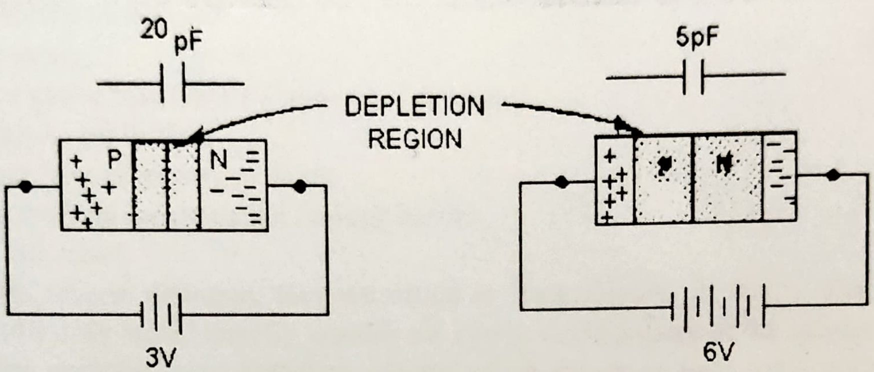
Varactor diodes are manufactured with gallium arsenide. GaAs has a higher operating frequency (up to nearly 1000 GHz)

APPLICATIONS

• Variable reactor in microwave circuits. • It is used in variable resonant tank LC circuit. Here C part is varied using varactor diode. • AFC (Automatic Frequency Control) where in varactor diode is used to set LO signal. • Varactor is used as frequency modulator in Radios and Television sets. • It is used as frequency multiplier in microwave receiver LO.
• It is used as RF phase shifter.

Basic Operation

- Operates in reverse bias and this gives rise to three regions. At either end of the diode are the P and N regions. However around the junction is the depletion region where no current carriers are available. As a result, current can be carried in the P and N regions, but the depletion region is an insulator.
- Same as capacitor construction. It has conductive plates separated by an insulating dielectric.
- The capacitance of a capacitor is dependent on a number of factors including the plate area, the dielectric constant of the insulator between the plates and the distance between the two plates. In the case of the varactor diode, it is possible to increase and decrease the width of the depletion region by changing the level of the reverse bias. This has the effect of changing the distance between the plates of the capacitor.



Tunnel Diode

It is heavily doped PN- junction. Doping density of about 1000 times greater than ordinary junction diode

History

- Tunnel diode was invented in 1958 by Leo Esaki.
- Also called Esaki diode.
- Leo Esaki observed that if a semiconductor diode is heavily doped with impurities, it will exhibit negative resistance.
- In 1973 Leo Esaki received the Nobel Prize in physics for discovering the electron tunneling effect used in these diodes.

Schematic Symbol

Materials commonly used to produce Tunnel doide

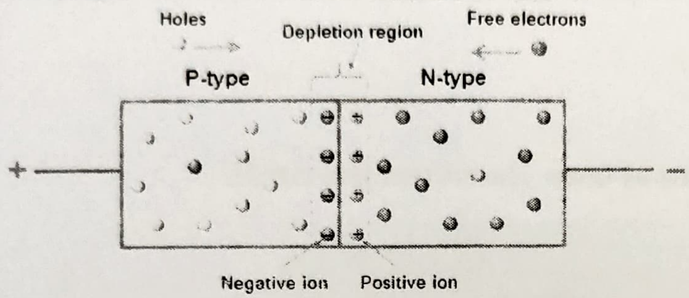
(GaSb), (GaAs), (GeAs)

Features of photodiode:

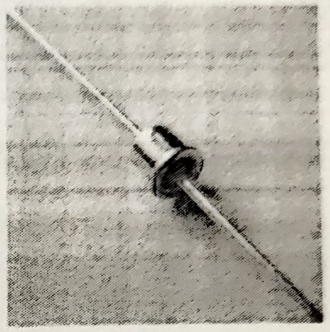
- Excellent linearity with respect to incident light
- Low noise
- Wide spectral response
- Mechanically rugged
- Compact and lightweight
- Long life

Basic principle of operation

O The operation depends upon quantum mechanics principle known as "tunneling".
O The movement of valence electrons from valence energy band to conduction band with no applied forward voltage is called "tunneling".
O Intrinsic voltage barrier (0.3V for Ge) is reduced which enhanced tunneling. O Enhanced tunneling causes effective conductivity.



Forward bias tunnel diode



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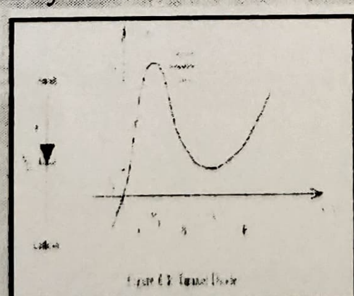
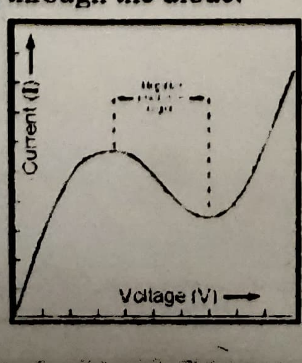
I/V Characteristics

As forward bias is applied, significant I is produced. After continuous increase of V, the current achieves its minimum value called as Valley Current. After further increase in V, current start increasing as ordinary diode.



•The Tunnel diode reverse I-V is similar to the Zener diode.
•The Zener diode has a region in its reverse bias characteristics of almost a constant voltage regardless of the current flowing through the diode.



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Working

- In a conventional diode, forward conduction occurs only if the forward bias is sufficient to give charge carriers the energy necessary to overcome the potential barrier.
- When the tunnel diode is slightly forward biased, many carriers are able to tunnel through narrow depletion region without acquiring that energy.
- The carriers are able to tunnel because the voltage barrier is reduced due to high doping.

Forward Bias operation:

At first voltage begin to increase:

- Electrons tunnel through pn junction.
- 2. Electron and holes states become aligned.

Voltage increases further:

- 1. States become misaligned.
- 2. Current drops.
- 3. Shows negative resistance (V increase, I decrease).

As voltage increase yet further:

- 1. The diode behave as normal diode.
- 2. The electrons no longer tunnel through barrier.

Reverse Bias Operation:

- When used in reverse direction, they are called as Back Diodes. In this, i. The electrons in valence band of p-side tunnel directly towards the empty states present in the conduction band of n-side. ii. Thus, creating large tunneling current which increases with application of reverse voltage.

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APPLICATIONS

- It is used as an ultra-high speed switch due to tunneling (which essentially takes place at speed of light). It has switching time of nanoseconds or picoseconds.
- Used as logic memory storage device.
- In satellite communication equipment, they are widely used.
- Due to its feature of –ive resistance, it is used in relaxation oscillator circuits.
- Tunnel diodes are resistant to the effects of magnetic fields, high temperature and radioactivity. That's why these can be used in modern military equipments, NMR machines.
- Due to low power requirement, they are used in FM receivers.

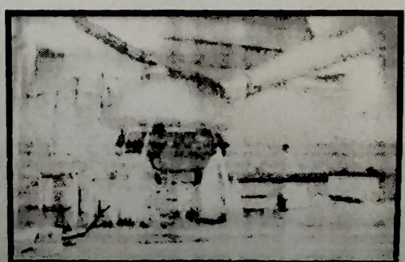

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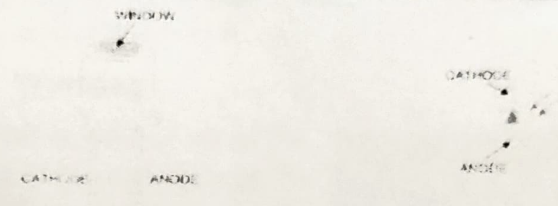
Photo diode

A **photo-diode** is a reverse-biased silicon or germanium p-n junction in which reverse current increases when the junction is exposed to light. The reverse current in a photo-diode is directly proportional to the intensity of light falling on its p-n junction. This means that greater the intensity of light falling on the p-n junction of photo-diode, the greater will be the reverse current.

Schematic Symbol



Materials commonly used to produce photodoide

MATERIALS	ELCTROMAGNETIC SPECTRUM WAVELENGTH RANGE (NM)
SILICON	190-1110
GERMANIUM	400-1700
INDIUM GALLIUM ARSENIDE	800-2600
LEAD SUFIDE	100-3500

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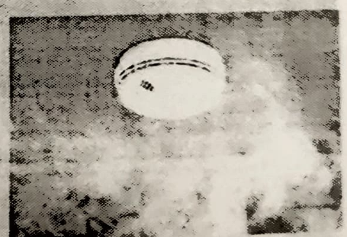
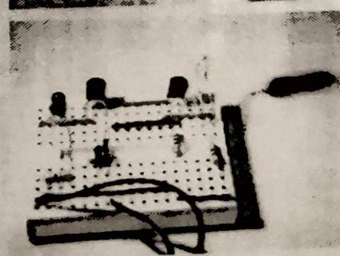
APPLICATIONS

- Photodiodes are used in consumer electronics devices such as CD players, smoke detectors, and the receivers for infrared remote control devices used to control equipment from televisions to air conditioners.
- Photodiodes are used as a light sensors
- Photodiodes are often used for accurate measurement of light intensity in science and industry.
- They are also widely used in various medical applications, such as detectors for computer tomography, instruments to analyze samples, and pulse oximeters.





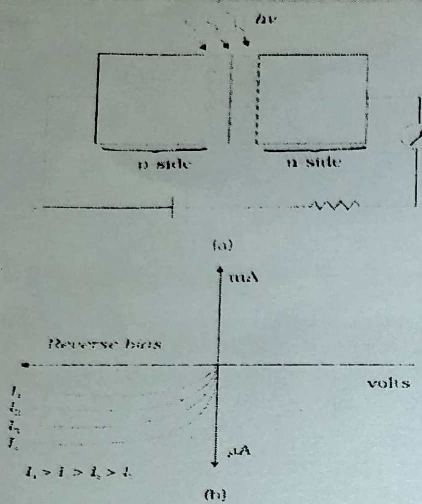
Computed Tomography Scan

factor

Principle of Photodoide

An illuminated (a) photodiode under reverse bias,
(b) *I-V* characteristics of a Photodiode for different illumination intensity $I_4 > I_3 > I_2 > I_1$.

Principle of Photodoide

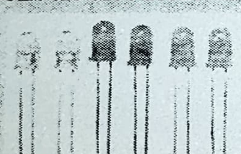


When a rectifier diode is reverse biased, it has a very small reverse leakage current. The same is true for a photo-diode. The reverse current is produced by thermally generated electron hole pairs which are swept across the junction by the electric field created by the reverse voltage. In a rectifier diode, the reverse current increases with temperature due to an increase in the number of electron-hole pairs. A photo-diode differs from a rectifier diode in that when its p-n junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa. This is explained as follows. When light (photons) falls on the p-n junction, the energy is imparted by the photons to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current. As the intensity of light incident on the p-n junction increases, the reverse current also increases. In other words, as the incident light intensity increases, the resistance of the device (photo-diode) decreases.

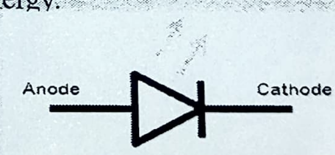
Light emitting diode

light emitting diode (LED) is essentially a PN junction opto- semiconductor that emits a monochromatic (single color) light when operated in a forward biased direction.

➢ LEDs convert electrical energy into light energy.



LED



LED symbol

➢LEDs are available in red, orange, amber, yellow, green, blue and white. LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color.

History

Paris. France 1962 - Nick Holonyack Jr. develops the red LED, the first LED of visible light.

1972 - Herbert Maruska and Jacques Pankove develop the violet LED using Mg-doped GaN films.

New Jersey 1976 - Thomas P. Pearsall develops special high brightness LEDs for fiber optic use.

Construction of LED

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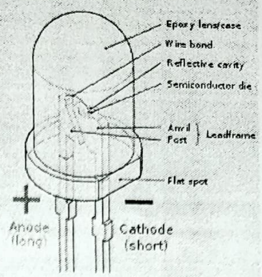


➢The LED consist of a chip of semiconductor material doped with impurities to create a *P N junction*.

➢ The chips are mounted in a reflecting tray order to increase the light output.

➢The contacts are made on the cathode side by means of conductive adhesive and on the anode side via gold wire to the lead frame.

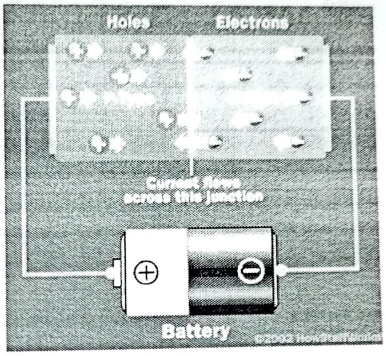
➢ The plastic case encloses the chip area of the lead frame

Working

•When the negative end of a circuit is hooked up to the N-type layer and the positive end is hooked up with P-type layer than electron and holes start moving.

• If we try to pass current the other way, with the P-type side connected to the negative end of the circuit and the N-type side connected to the positive end, current will not flow.

• No current flows across the junction because the holes and the electrons are each moving in the wrong direction.



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APPLICATIONS

• SENSOR APPLICATIONS: Medical Instrumentation, Bar Code Readers, Color & Money Sensors, Encoders, Optical Switches, Fiber Optic Communication

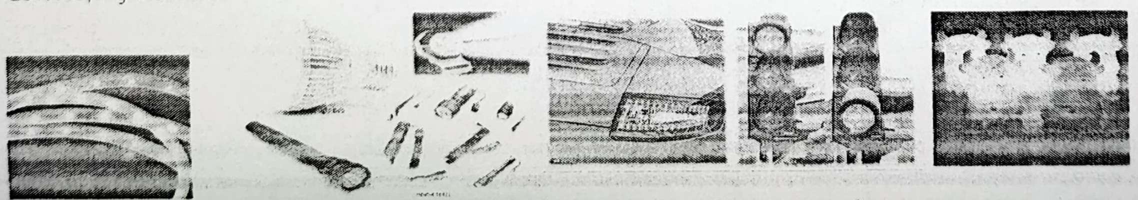
•MOBILE APPLICATIONS: Mobile Phone, PDA's, Digital Cameras,Lap Tops, General Backlighting

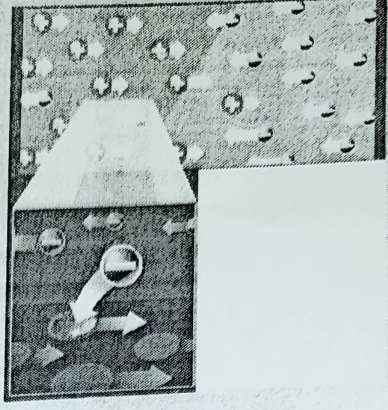
•AUTOMATIVE APPLICATIONS: Interior Lighting - Instrument Panels & Switches, Courtesy Lighting, Exterior Lighting - CHMSL, Rear Stop/Turn/Tail, Truck/Bus Lighting - Retrofits, New Turn/Tail/Marker Lights

•SIGNAL APPICATIONS: Traffic Rail Aviation, Tower Lights, Runway Lights, Emergency/Police Vehicle Lighting,LEDs offer enormous benefits over traditional incandescent lamps, including: Energy savings (up to 85% less power than incandescent), Reduction in maintenance costs, Increased visibility in daylight and adverse weather conditions

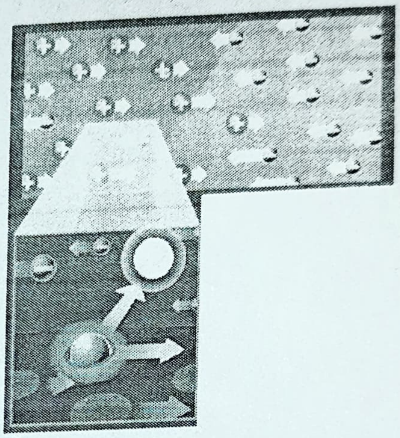
•ILLUMINATION: Architectural lightening, Machine Vision Retail Displays, Emergency Lighting (Exit Signs) Neon Replacement, Bulb Replacements, Flashlights,Outdoor Accent Lighting - Pathway, Marker Lights, Studies have shown that the use of LEDs in illumination applications can offer: Greater visual appeal, Reduced energy costs, Increased attention capture, Savings in maintenance and lighting replacements

•INDICATION: Household appliances, VCR/ DVD/ Stereo and other audio and video devices,Toys/Games





- ➤The holes exist at a lower energy level than the free electrons
- ➤Therefore when a free electrons falls it losses energy



- ➤This energy is emitted in a form of a photon, which causes light.
- ➤The color of the light is determined by the fall of the electron and hence energy level of the photon