1.5 FULL WAVE BRIDGE RECTIFIER.

A Full wave rectifier is a circuit arrangement which makes use of both half cycles of input alternating current (AC) and convert them to direct current (DC). In our tutorial on **half wave rectifiers**, we have seen that a half wave rectifier makes use of only onehalf cycle of the input alternating current. Thus a full wave rectifier is much more efficient (double+) than a half wave rectifier. This process of converting both half cycles of the input supply (alternating current) to direct current (DC) is termed full wave rectification. Full wave rectifier can be constructed in 2 ways. The first method makes use of a center tapped transformer and 2 diodes. This arrangement is known as **Center Tapped Full Wave**

Rectifier. The second method uses a normal transformer with 4 diodes arranged as a bridge. This arrangement is known as a Bridge Rectifier.

Full Wave Rectifier Theory

To understand full wave bridge rectifier theory perfectly, you need to learn half wave rectifier first. In the tutorial of half wave rectifier we have clearly explained the basic working of a rectifier. In addition we have also explained the theory behind a p n junction and the characteristics of a p n junction diode.

Full Wave Rectifier Working & Operation

The working & operation of a full wave bridge rectifier is pretty simple. The circuit diagrams and wave forms we have given below will help you understand the operation of a bridge rectifier perfectly. In the circuit diagram, 4 diodes are arranged in the form of a bridge. The transformer secondary is connected to two diametrically opposite points of the bridge at points A & C. The load resistance R_L is connected to bridge through points B and D.

During the first half cycle

During first half cycle of the input voltage, the upper end of the transformer secondary winding is positive with respect to the lower end. Thus during the first half cycle diodes D1 and D3 are forward biased and current flows through arm AB, enters the load resistance RL, and returns back flowing through arm DC.

During this half of each input cycle, the diodes D2 and D4 are reverse biased and current is not allowed to flow in arms AD and BC. The flow of current is indicated by solid arrows in the figure above. We have developed another diagram below to help you understand the current flow quickly. See the diagram below – the green arrows indicate beginning of current flow from source (transformer secondary) to the load resistance. The red arrows indicate return path of current from load resistance to the source, thus completing the circuit.

Full Wave Bridge Rectifier – Circuit Diagram with Input and Output Wave Forms

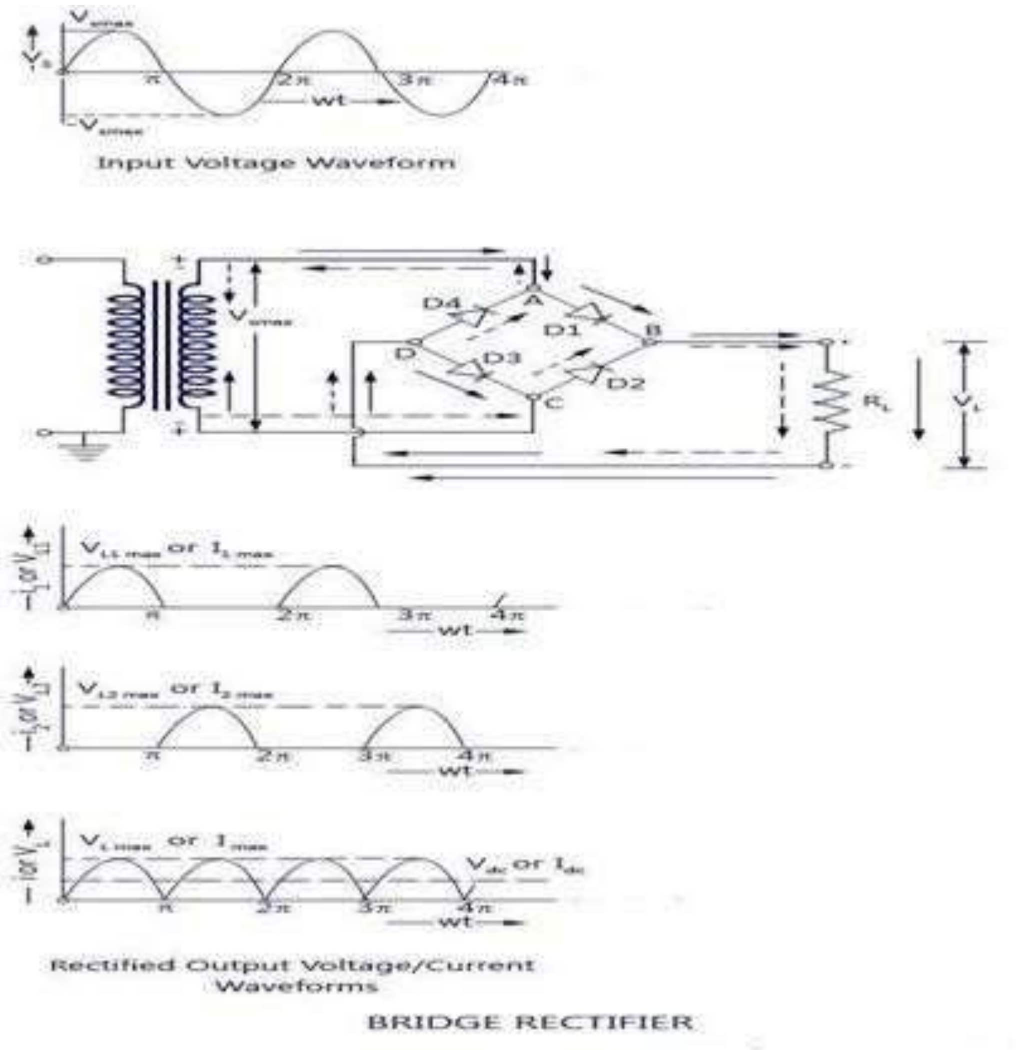


Figure: 1.5.1 Flow of current in Bridge Rectifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 271]

During the second half cycle

During second half cycle of the input voltage, the lower end of the transformer secondary winding is positive with respect to the upper end. Thus diodes D_2 and D_4 become forward biased and current flows through arm CB, enters the load resistance R_L, and returns back to the source flowing through arm DA. Flow of current has been shown by dotted arrows in the figure. Thus the direction of flow of current through the load resistance R_L remains the same during both half cycles of the input supply voltage. See the diagram below – the green arrows indicate beginning of current flow from source (transformer secondary) to the load resistance. The red arrows indicate return path of current from load resistance to the source, thus completing the circuit.

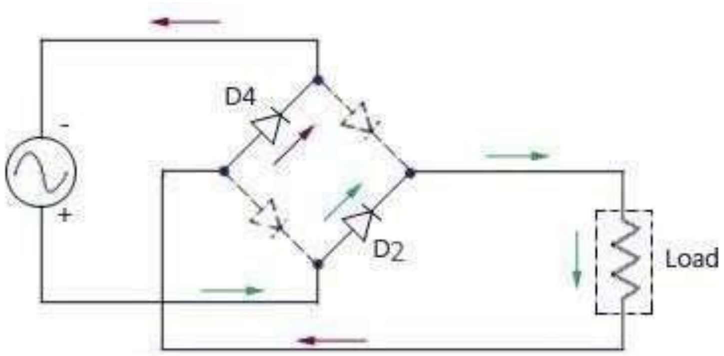


Figure: 1.5.2 Full Wave Bridge Rectifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 271]

1.4 FULL WAVE RECTIFIER

Full wave rectifier rectifies the full cycle in the waveform i.e. it rectifies both the positive and negative cycles in the waveform. We have already seen the characteristics and working of Half Wave Rectifier. This Full wave rectifier has an advantage over the half wave i.e. it has average output higher than that of half wave rectifier. The number of AC components in the output is less than that of the input.

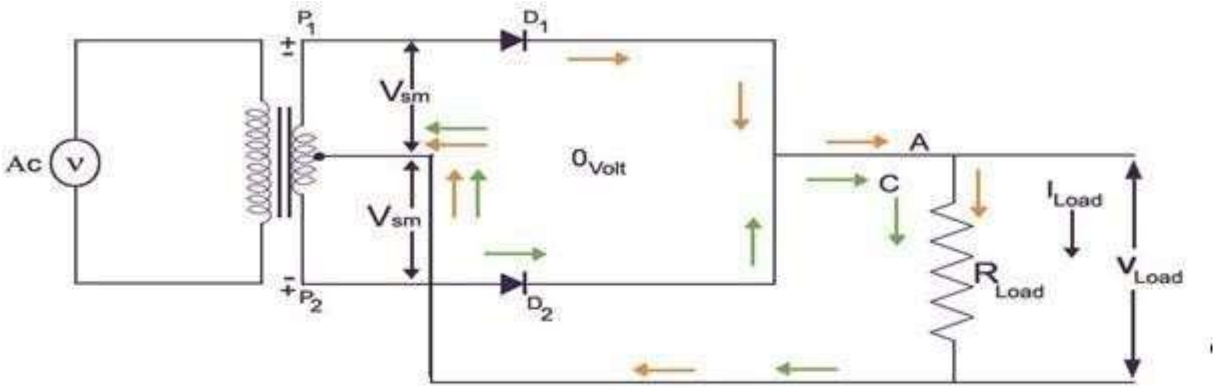
The full wave rectifier can be further divided mainly into following types.

- Center Tapped Full Wave Rectifier
- Full Wave Bridge Rectifier

Centre-Tap Full Wave Rectifier

We have already discussed the Full Wave Bridge Rectifier, which uses four diodes, arranged as a bridge, to convert the input alternating current (AC) in both half cycles to direct current (DC).

In the case of centre-tap full wave rectifier, only two diodes are used, and are connected to the opposite ends of a centre-tapped secondary transformer as shown in the figure below. The centre-tap is usually considered as the ground point or the zero voltage reference point.



CENTRE - TAP FULL- WAVE RECTIFIER CIRCUIT

Figure: 1.4.1 Centre Tap Full Wave Rectifier Circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 268]

Working of Centre-Tap Full Wave Rectifier

As shown in the figure, an ac input is applied to the primary coils of the transformer. This input makes the secondary ends P1 and P2 become positive and negative alternately.

For the positive half of the ac signal, the secondary point D1 is positive, GND point will have zero volt and P2 will be negative.

At this instant diode D1 will be forward biased and diode D2 will be reverse biased.

As explained in the Theory behind P-N Junction and Characteristics of P-N JunctionDiode, the diode D1 will conduct and D2 will not conduct during the positive half cycle. Thus the current flow will be in the direction P1-D1-C-A-B-GND. Thus, the positive half cycle appears across the load resistance RLOAD.

During the negative half cycle, the secondary ends P1 becomes negative and P2 becomes positive. At this instant, the diode D1 will be negative and D2 will be positive with the zero reference point being the ground, GND. Thus, the diode D2 will be forward biased and D1 will be reverse biased. The diode D2 will conduct and D1 will not conduct during the negative half cycle. The current flow will be in the directionP2-D2-C-A-B-GND.

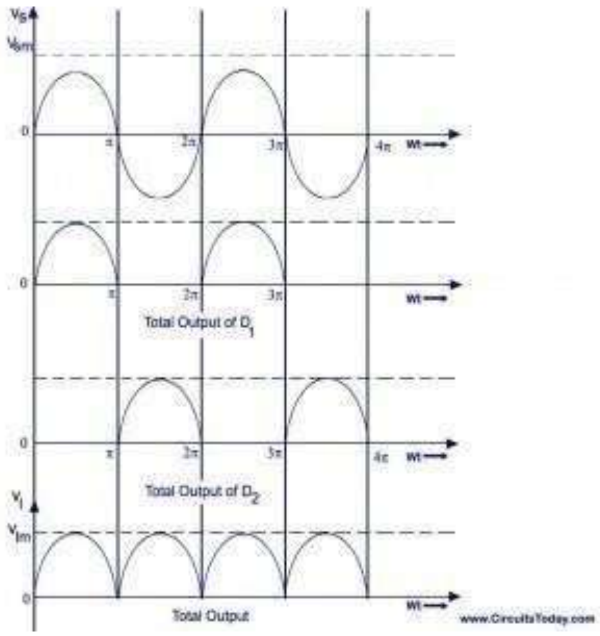


Figure: 1.4.2 Centre-tap Full-wave Rectifier-Waveform

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 268]

When comparing the current flow in the positive and negative half cycles, we can conclude that the direction of the current flow is the same (through load resistance RLOAD). When compared to the Half-Wave Rectifier, both the half cycles are used to produce the corresponding output.

The frequency of the rectified output voltage is twice the input frequency. The output that is rectified, consists of a dc component and a lot of ac components of minute amplitudes.

Peak Inverse Voltage (PIV) of Centre-Tap Full Wave Rectifier

PIV is the maximum possible voltage across a diode during its reverse biased period. Let us analyze the PIV of the Centre-tapped rectifier from the circuit diagram. During the first half or the positive half of the input ac supply, the diode D1 is positive and thus conducts and provided no resistance at all. Thus, the whole of voltage Vs developed in the upper-half of the ac supply is provided to the load resistance RLOAD. Similar is the case of diode D2 for the lower half of the transformer secondary.

Therefore,

PIV of D2 = Vm +Vm =

2VmPIV of D1 = 2Vm

- **Peak Current**

The instantaneous value of the voltage applied to the rectifier can be written as

Vs = Vsm Sinwt

Assuming that the diode has a forward resistance of RFWD ohms and a reverse resistance equal to infinity, the current flowing through the load resistance RLOAD isgiven as

Im = Vsm / (RF + RLoad)

- **Output Current**

Since the current is the same through the load resistance RL in the two halves of the ac cycle, magnitude of dc current Idc, which is equal to the average value of ac current, can be obtained by integrating the current i1 between 0 and pi or current i2 between pi

$$Idc = 1/\pi \int_0^\pi i1\, d(wt) = 1/\pi \int_0^\pi Imax \sin wt\, d(wt) = 2I\, m/\pi$$

Output current of Centre Tap rectifier

- **DC Output Voltage**

Average or dc value of voltage across the load is given as

$$Idc = 1/\pi \int_0^\pi i1\, d(wt) = 1/\pi \int_0^\pi Imax \,\mathrm{wt}\, \mathrm{d}(wt) = 2I\, m/\pi$$

DC Output Voltage of center Tap Rectifier

- **Root Mean Square (RMS) Value of Current**

RMS or effective value of current flowing through the load resistance R_L is given as

$$I^2 rms = 1/\pi \int_0^\pi i\, d(wt) = I^2\, m/2 \; or \; I_{rms} = I_m/\sqrt{2}$$

1.6 LIGHT EMITTING DIODE (LED)

A light emitting diode (LED) is known to be one of the best optoelectronic devices out of the lot. The device is capable of emitting a fairly narrow bandwidth of visible or invisible light when its internal diode junction attains a forward electric current or voltage.

The visible lights that an LED emits are usually orange, red, yellow, or green. The invisible light includes the infrared light. The biggest advantage of this device is its high power to light conversion efficiency. That is, the efficiency is almost 50 times greater than a simple tungsten lamp.

The response time of the LED is also known to be very fast in the range of 0.1 microseconds when compared with 100 milliseconds for a tungsten lamp. Due to these advantages, the device wide applications as visual indicators and as dancing light displays.

We know that a P-N junction can connect the absorbed light energy into its proportional electric current. The same process is reversed here. That is, the P-N junction emits light when energy is applied on it. This phenomenon is generally called electro luminance, which can be defined as the emission of light from a semi-conductorunder the influence of an electric field.

The charge carriers recombine in a forward P-N junction as the electrons cross from the N- region and recombine with the holes existing in the P-region. Free electronsare in the conduction band of energy levels, while holes are in the valence energy band.

Thus the energy level of the holes will be lesser than the energy levels of the electrons. Some part of the energy must be dissipated in order to recombine the electrons and the holes. This energy is emitted in the form of heat and light.

The electrons dissipate energy in the form of heat for silicon and germanium diodes. But in Gallium- Arsenide-phosphorous (GaP) and Gallium-phosphorous (GaP) semiconductors, the electrons dissipate energy by emitting photons. If the semiconductor is translucent, the junction becomes the source of light as it is emitted, thus becoming a light emitting diode (LED). But when the junction is reverse biased no light will be produced by the LED, and, on the contrary the device may also get damaged.

All the semiconductors listed above can be used. An N-type epitaxial layer is grown up on a substrate, and the P-region is produced by diffusion. The P-region that includes the recombination of charge carriers is shown is the top. Thus the P-region becomes the device surface. In order to allow more surface area for the light to be emitted the metal anode connections are made at the outer edges of the P-layer.

For the light to be reflected as much as possible towards the surface of the device, a gold film is applied to the surface bottom. This setting also enables to provide a cathode connection. The re-absorption problem is fixed by including domed lenses forthe device. All the wires in the electronic circuits of the device is protected by encasingthe device.

The light emitted by athe device depends on the type of semiconductor material used. Infrared light is produced by using Gallium Arsenide (GaAs) as semiconductor. Red or yellowlight is produced by using Gallium -Arsenide-Phosphorus (GaAsP) as semiconductor.

LED Circuit Symbol

The circuit symbol of LED consists of two arrow marks which indicate the radiation emitted by the diode.

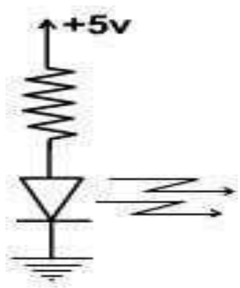


Figure: 1.6.1 Symbol of LED

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 145]

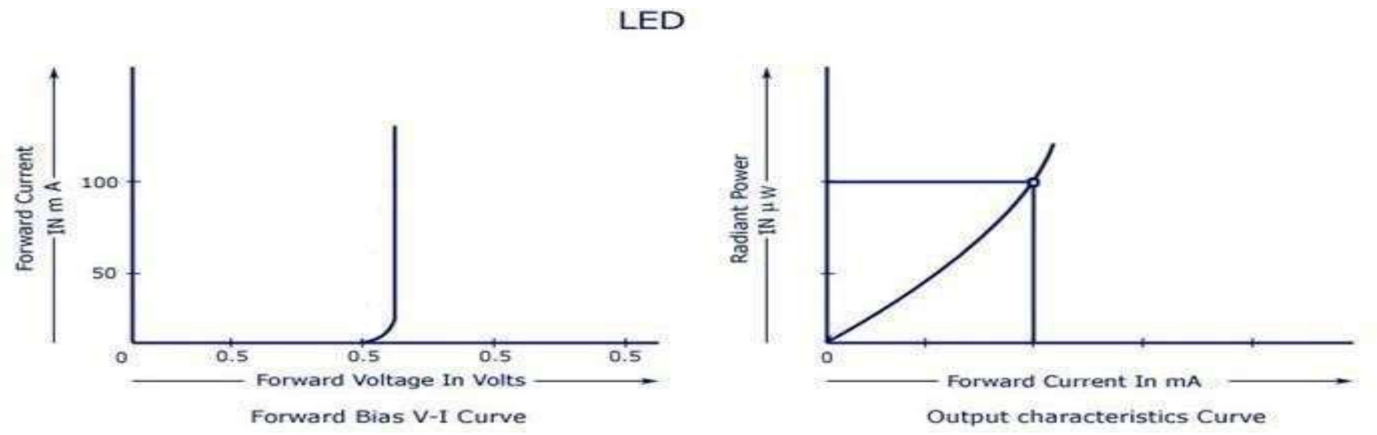


Figure: 1.6.2 LED characteristics curve

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 145]

The forward bias Voltage-Current (V-I) curve and the output characteristics curve is shown in the figure above. The V-I curve is practically applicable in burglar alarms. Forward bias of approximately 1 volt is needed to give significant forward current. The second figure is used to represent a radiant power-forward current curve. The output power produced is very small and thus the efficiency in electrical-to-radiant energy conversion is very less.

The commercially used LED's have a typical voltage drop between 1.5 Volt to

2.5 Volt or current between 10 to 50 milli amperes. The exact voltage drop depends onthe LED current, colour, tolerance, and so on.

LED as an Indicator

The circuit shown below is one of the main applications of LED. The circuit is designed by wiring it in inverse parallel with a normal diode, to prevent the device from being reverse biased. The value of the series resistance should be half, relative to that o f a DC circuit.

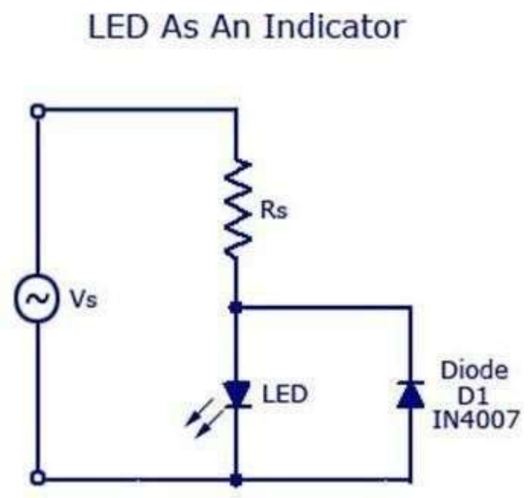


Figure: 1.6.3 LED as an indicator

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 147]

LEDS displays are made to display numbers from segments. One such design is the seven- segment display as shown below. Any desired numerals from 0-9 can be displayed by passing current through the correct segments. To connect such segment a common anode or common cathode cathode configuration can be used. Both the connections are shown below. The LED's are switched ON and OFF by using transistors.

➢ **Advantages of LED's**

- Very low voltage and current are enough to drive the LED.
- Voltage range – 1 to 2 volts.
- Current – 5 to 20 mill amperes.
- Total power output will be less than 150 mill watts.
- The response time is very less – only about 10 nanoseconds.
- The device does not need any heating and warm up time.
- Miniature in size and hence light weight.
- Have a rugged construction and hence can withstand shock and vibrations.
- An LED has a life span of more than 20 years.

- **Disadvantages of LED**

  - A slight excess in voltage or current can damage the device.
  - The device is known to have a much wider bandwidth compared to the laser.
  - The temperature depends on the radiant output power and wavelength

Laser diode

A laser diode, or LD, is an electrically pumped semiconductor laser in which the active laser medium is formed by a p-n junction of a semiconductor diode similar to that found in a light-emitting diode.

The laser diode is the most common type of laser produced with a wide range ofuses that include, but are not limited to, fiber optic communications, barcode readers, laser pointers, CD/DVD/Blu-ray Disc reading and recording, laser printing, laser scanning and increasingly directional lighting sources.

A laser diode is electrically a P-i-n diode. The active region of the laser diode is in the intrinsic (I) region, and the carriers, electrons and holes, are pumped into it fromthe N and P regions respectively.

While initial diode laser research was conducted on simple P-N diodes, all modern lasers use the double-hetero structure implementation, where the carriers and the photons are confined in order to maximize their chances for recombination and light generation. The laser diode epitaxial structure is grown using one of the crystal growth techniques, usually starting from an N doped substrate, and growing the .I doped active layer, followed by the P doped cladding, and a contact layer. The active layer most often consists of quantum wells,

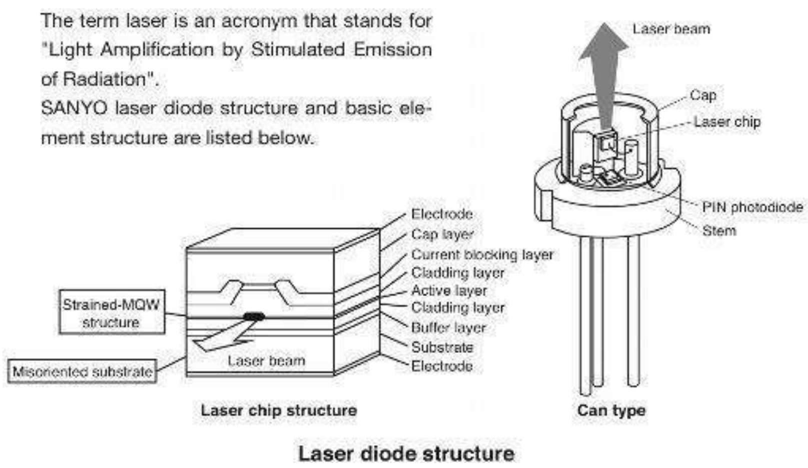


Figure: 1.6.4 Laser Diode

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 151]

Laser diode L/I characteristic

One of the most commonly used and important laser diode specifications or characteristics is the L/I curve. It plots the drive current supplied against the light output. This laser diode specification is used to determine the current required to obtain a particular level of light output at a given current. It can also be seen that the light output is also very dependent upon the temperature.

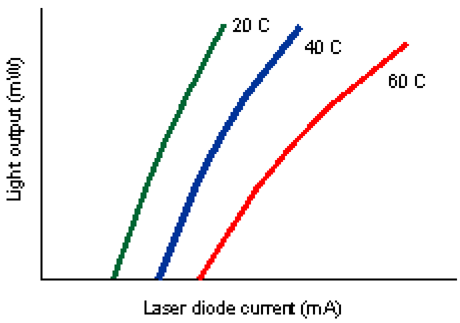


Figure: 1.6.5 Laser diode L/I Characteristic

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 146]

From this characteristic, it can be seen that there is a threshold current below which the laser action does not take place. The laser diode should be operated clear of this point to ensure reliable operation over the full operating temperature range as the threshold current rises with increasing temperature. It is typically found that the laser threshold current rises exponentially with temperature.

Laser Diode Specifications & Characteristics

A summary or overview of laser diode specifications, parameters and characteristics used in defining laser diode performance for datasheets.

In this section

- Laser diode technology
- Laser diode types
- Structure & materials
- Theory & operation
- Specs & characteristics
- Lifetime, failure & reliability

- Other diodes

When using a laser diode it is essential to know its performance characteristics. Accordingly laser diode specifications are required when designing equipment using laser diodes or for maintenance using near equivalents.

Like any electronics components, many of the specifications are relatively generic, but other parameters will tend to be more focused on the particular component. This is true for laser diode specifications and characteristics.

There are a number of laser diode specifications, or laser diode characteristics thatare key to the overall performance and these are outlined.

1.3 RECTIFIERS

Rectifiers are classified according to the period ofconduction. They are

- Half Wave Rectifier
- Full Wave Rectifier

Half Wave Rectifier:

The half wave rectifier is a type of rectifier that rectifies only half cycle of the waveform. This describes the half wave rectifier circuit working. The half rectifier consist a step down transformer, a diode connected to the transformer and a load resistance connected to the cathode end of the diode. The circuit diagram of half wave transformer is shown below:

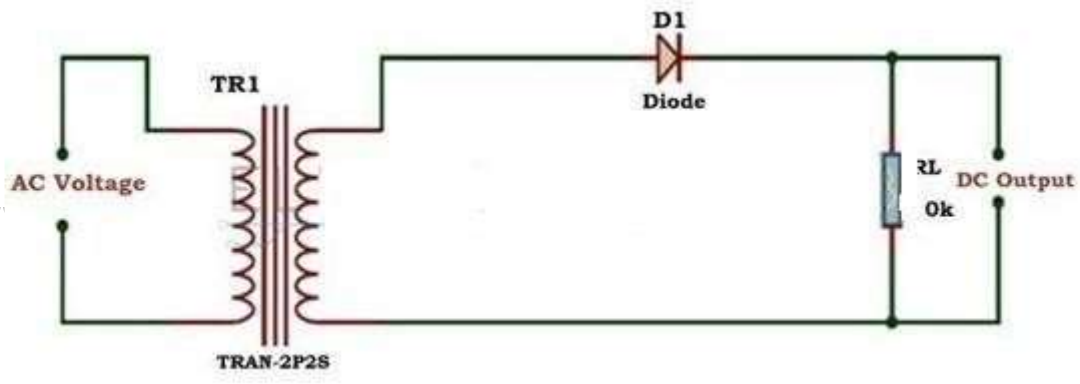


Figure: 1.3.1 Half wave Rectifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 252]

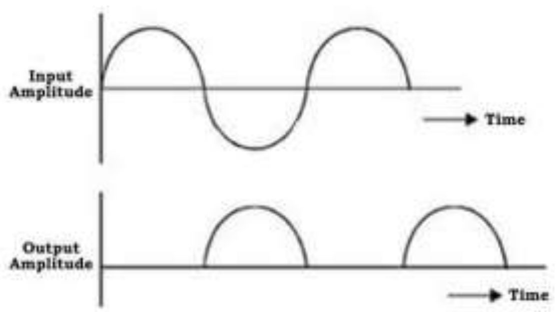


Figure: 1.3.2 Half wave Rectifier Wave Form

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 253]

The main supply voltage is given to the transformer which will increase or decrease the voltage and give to the diode. In most of the cases we will decrease the supply voltage by using the step down transformer here also the output of the step down transformer will be in AC. This decreased AC voltage is given to the diode which is connected serial to the secondary winding of the transformer, diode is electronic component which will allow only the forward bias current and will not allow the reverse bias current. From the diode we will get the pulsating DC and give to the load resistance RL.

Working of Half Wave Rectifier:

The input given to the rectifier will have both positive and negative cycles. The half rectifier will allow only the positive half cycles and omit the negative half cycles. So first we will see how half wave rectifier works in the positive half cycles.

Positive Half Cycle:

- In the positive half cycles when the input AC power is given to the primary winding of the step down transformer, we will get the decreased voltage at thesecondary winding which is given to the diode.
- The diode will allow current flowing in clock wise direction from anode to cathode in the forward bias (diode conduction will take place in forward bias)which will generate only the positive half cycle of the AC.
- The diode will eliminate the variations in the supply and give the pulsating DCvoltage to the load resistance RL. We can get the pulsating DC at the Load resistance.

Negative Half Cycle:

- In the negative half cycle the current will flow in the anti-clockwise directionand the diode will go in to the reverse bias. In the reverse bias the diode will not conduct so, no current in flown from anode to cathode, and we cannot getany power at the load resistance.
- Only small amount of reverse current is flown from the diode but this current is almost negligible. And voltage across the load resistance is also zero.

Characteristics of Half Wave Rectifier:

There are some characteristics to the half wave rectifier they are

- **Efficiency:** The efficiency is defined as the ratio of input AC to the output DC.Efficiency, Ƞ = P dc / Pac
- DC power delivered to the load, $P_{dc} = I^2_{dc} R_L = (I_{max/pi})^2 R_L$

AC power input to the transformer, P_{ac} = Power dissipated in junction of diode + Power

Dissipated in load resistance RL= $I^2_{rms} R_F + I^2_{rms} R_L = \{I^2_{MAX}/4\} [R_F + R_L]$

Rectification Efficiency, $Ƞ = P_{dc} / P_{ac} = \{4/ ^2\} [RL/ (R_F + R_L)] = 0.406/\{1+ R_{F/RL} \}$

If RF is neglected, the efficiency of half wave rectifier is 40.6%.

- **Ripple factor:** It is defined as the amount of AC content in the output DC. It nothingbut amount of AC noise in the output DC. Less the ripple factor, performance of the rectifier is more. The ripple factor of half wave rectifier is about 1.21 (full wave rectifier has about0.48). It can be calculated as follows:
- The effective value of the load current I is given as sum of the rms values of harmonic currents I1, I2, I3, I4 and DC current Idc.
- $I^2 = I^2dc + I^2 1 + I^2 2 + I^2 4 = I^2dc + I^2ac$
- Ripple factor, is given as $\gamma = I_{ac} / I_{dc} = (I^2 – I^2_{dc}) / I_{dc} = \{(I_{rms}$ / I_{dc} $^2)-1\} = K_f^2 – 1)$ Where Kf is the form factor of the input voltage. Form factor is given as

  $K_f = I_{rms} / I_{avg} = (I_{max}/2) / (I_{max}/pi) = pi/2 = 1.57$

  So, ripple factor, $\gamma = (1.57^2 – 1) = 1.21$
- **Peak Inverse Voltage:** It is defined as the maximum voltage that a diode can with standin reverse bias. During the reverse bias as the diode do not conduct total voltage drops across the diode. Thus peak inverse voltage is equal to the input voltage Vs.

- **Transformer Utilization Factor (TUF):** The TUF is defined as the ratio of DC poweris delivered to the load and the AC rating of the transformer secondary. Half wave rectifier has around 0.287 and full wave rectifier has around 0.693.
- Half wave rectifier is mainly used in the low power circuits. It has very low performance when it is compared with the other rectifiers.

1.1 SEMICONDUCTOR

A semiconductor is a material which has electrical conductivity to a degree between that of a metal (such as copper) and that of an insulator (such as glass). Semiconductors are the foundation of modern electronics, including transistors, solar cells, light -emitting diodes (LEDs), quantum dots and digital and analog integrated circuits.

DIODE

Diode – Di + ode

Di means two and ode means electrode. So physical contact of two electrodes is known asdiode and its important function is alternative current to direct current.

REVIEW OF INTRINSIC AND EXTRINSIC SEMICONDUCTORS

INTRINSIC SEMICONDUCTOR

An intrinsic semiconductor is one, which is pure enough that impurities do not appreciably affect its electrical behaviour. In this case, all carriers are created due to thermally or optically excited electrons from the full valence band into the empty conduction band. Thus equal numbers of electrons and holes are present in an intrinsic semiconductor. Electrons and holes flow in opposite directions in an electric field, though they contribute to current in the same direction since they are oppositely charged. Whole current and electron current are not necessarily equal in an intrinsic semiconductor, however, because electrons and holes have different effective masses (crystalline analogues to free inertial masses).

The concentration of carriers is strongly dependent on the temperature. At low temperatures, the valence band is completely full making the material an insulator. Increasing the temperature leads to an increase in the number of carriers and a corresponding increase in conductivity. This characteristic shown by intrinsic semiconductor is different from the behaviour of most metals, which tend to become less conductive at higher temperatures due to increased phonon scattering.

Both silicon and germanium are tetravalent, i.e. each has four electrons (valence electrons) in their outermost shell. Both elements crystallize with a diamond- like structure, i.e. in such a way that each atom in the crystal is inside a tetrahedron formed by the four atoms which are closest to it. Each atom shares its four valence electrons with its four immediate neighbours, so that each atom is involved in four covalent bonds.

EXTRINSIC SEMICONDUCTOR

An extrinsic semiconductor is one that has been doped with impurities to modifythe number and type of free charge carriers. An extrinsic semiconductor is a semiconductor that has been doped, that is, into which a doping agent has been introduced, giving it different electrical properties than the intrinsic (pure) semiconductor.

Doping involves adding doping atoms to an intrinsic semiconductor, which changes the electron and hole carrier concentrations of the semiconductor at thermal equilibrium. Dominant carrier concentrations in an extrinsic semiconductor classify it as either an n-type or p-type semiconductor.

A pure or intrinsic conductor has thermally generated holes and electrons. However these are relatively few in number. An enormous increase in the number of charge carriers can be achieved by introducing impurities into the semiconductor ina controlled manner. The result is the formation of an extrinsic semiconductor. This process is referred to as doping. There are basically two types of impurities: donor impurities and acceptor impurities. Donor impurities are made up of atoms (arsenic for example) which have five valence electrons. Acceptor impurities are made up of atoms (gallium for example) which have three valence electrons.

The two types of extrinsic semiconductor are

N-TYPE SEMICONDUCTORS

Extrinsic semiconductors with a larger electron concentration than hole concentration are known as n-type semiconductors. The phrase 'n-type' comes from the negative charge of the electron. In n-type semiconductors, electrons are the majority carriers and holes are the minority carriers. N-type semiconductors are created by doping an intrinsic semiconductor with donor impurities.

In an n-type semiconductor, the Fermi energy level is greater than that of the intrinsic semiconductor and lies closer to the conduction band than the valence band. Arsenic has 5 valence electrons, however, only 4 of them form part of covalent bonds.The 5th electron is then free to take part in conduction. The electrons are said to be themajority carriers and the holes are said to be the minority carriers.

P-TYPE SEMICONDUCTORS

As opposed to n-type semiconductors, p-type semiconductors have a larger hole concentration than electron concentration. The phrase 'p-type' refers to the positive charge of the hole. In p-type semiconductors, holes are the majority carriers and electrons are the minority carriers. P-type semiconductors are created by doping an intrinsic semiconductor with acceptor impurities. P-type semiconductors have Fermi energy levels below the intrinsic Fermi energy level.

The Fermi energy level lies closer to the valence band than the conduction band in a p- type semiconductor. Gallium has 3 valence electrons, however, there are 4 covalent bonds to fill. The 4^{th} bond therefore remains vacant producing a hole. The holes are said to be the majority carriers and the electrons are said to be the minority carriers.

PN JUNCTION DIODE

When the N and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the junction so some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P- type material producing negative ions.

FORWARD BIAS CONDITION

When positive terminal of the battery is connected to the P-type and negative terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The applied potential in external battery acts in opposition to the internal potential barrier which disturbs the equilibrium.

As soon as equilibrium is disturbed by the application of an external voltage, the Fermi level is no longer continuous across the junction. Under the forward bias condition the applied positive potential repels the holes in P typeregion so that the holes move towards the junction and the applied positive potential repels the electrons in N type region so that the electrons move towards the junction.

When the applied potential is more than the internal barrier potential the depletionregion and internal potential barrier disappear.

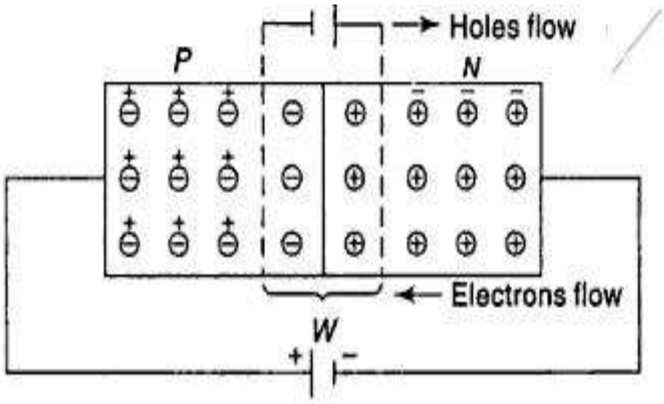


Figure: 1.1.1 PN Junctions under forward bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 110]

V-I Characteristics

As the forward voltage increased for $V_F < V_o$, the forward current I_F almost zero because the potential barrier prevents the holes from P region and electrons from N region to flow across the depletion region in opposite direction.

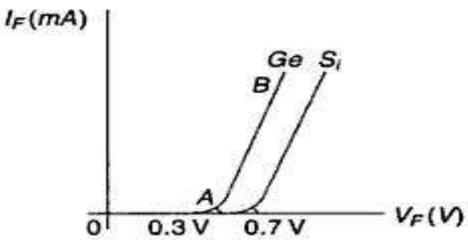


Figure: 1.1.2 V-I characteristics of a diode under forward bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 111]

For $V_F > V_o$, the potential barrier at the junction completely disappears and hence, the holes cross the junction from P to N type and electrons cross the junction to opposite direction, resulting large current flow in external circuit.

A feature noted here is the cut in voltage or threshold voltage V_F below which the current is very small. At this voltage the potential barrier is overcome and the current through the junction starts to increase rapidly.

- Cut in voltage is 0.3V for germanium and 0.7 for silicon.

UNDER REVERSE BIAS CONDITION

When the negative terminal of the battery is connected to the P-type and positive terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The holes from the majority carriers of the P side move towards the negative terminal of the battery and electrons which from the majority carrier of the N side are attracted towards the positive terminal of the battery.

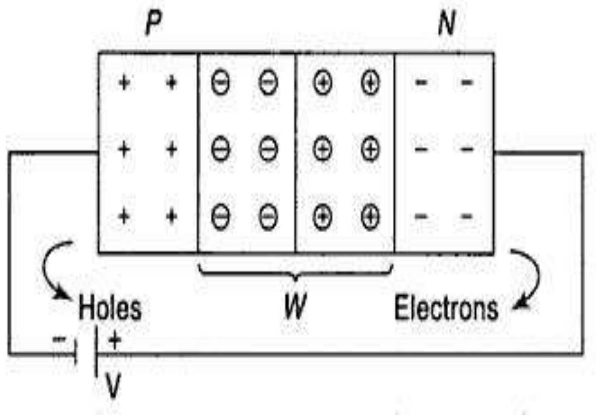


Figure: 1.1.3 PN junctions under reverse bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 111]

Hence, the width of the depletion region which is depleted of mobile charge carriers increases. Thus, the electric field produced by applied reverse bias, is in the same direction as the electric field of the potential barrier. Hence the resultant potential barrier is increased which prevents the flow of majority carriers in both directions. The depletion width W is proportional to under reverse bias.

V-I characteristics

Theoretically no current flow in the external circuit. But in practice a very small amount of current of the order of few microamperes flows under reverse bias.

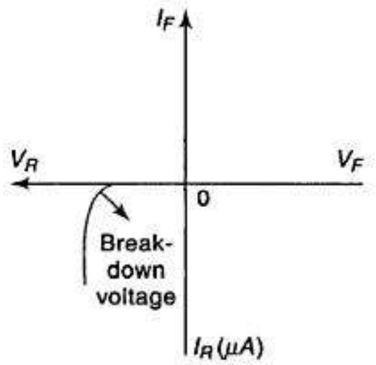


Figure: 1.1.4 V-I characteristics under reverse bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 112]

Electrons forming covalent bonds of semiconductor atoms in the P and N type regions may absorb sufficient energy from heat and light to cause breaking covalent bonds. So electron hole pairs continuously produced.

Consequently the minority carriers electrons in the P region and holes in the N region, wander over to the junction and flow towards their majority carrier side giving rise a small reverse current. This current is known as reverse saturation current Io.

The magnitude of this current is depends on the temperature because minority carrier is thermally broken covalent bonds.

1.2 TRANSITION CAPACITANES

- When P-N junction is reverse biased the depletion region act as an insulator or as a dielectric mediumand the p-type an N-type region have low resistance and act as the plates.
- Thus this P-N junction can be considered as a parallel plate capacitor.
- This junction capacitance is called as space charge capacitance or transition capacitance and isdenoted as CT.
- Since reverse bias causes the majority charge carriers to move away from the junction, so the thickness of the depletion region denoted as W increases with the increase in reverse bias voltage.
- This incremental capacitance CT may be defined as CT= d Q / d V,

  Where d Q is the increase in charge and d V is the change or increase in voltage.
- The depletion region increases with the increase in reverse bias potential the resulting transitioncapacitance decreases.
- The formula for transition capacitance is given as CT = A ε / W, where A is the cross sectional area of the region, and W is the width.

DIFFUSION CAPACITANCE

- When the junction is forward biased, a capacitance comes into play that is known as diffusioncapacitance denoted as CD. It is much greater than the transition capacitance.
- During forward biased the potential barrier is reduced. The charge carriers moves away from thejunction and recombine.
- The density of the charge carriers is high near the junction and reduces or decays as the distanceincreases.
- Thus in this case charge is stored on both side of the junction and varies with the applied potential. Soas per definition change in charge with respect to applied voltage results in capacitance which here is called as diffusion capacitance.

- The formula for diffusion capacitance is $C_D = \tau I_D / \eta V_T$, where τ is the mean life time of the chargecarrier, I_D is the diode current and V_T is the applied forward voltage, and η is generation recombinationfactor.
- The diffusion capacitance is directly proportional to the diode current.
- In forward biased $C_D >> C_T$. And thus C_T can be neglected.

1.7 ZENER DIODE

A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Zener, who discovered this electrical property.

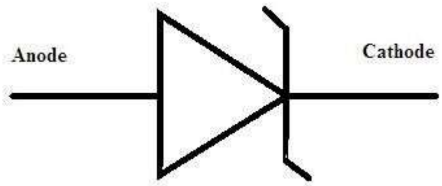


Figure: 1.7.1 Zener Diode Symbol

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

- However, the Zener Diode or "Breakdown Diode" as they are sometimes called, are basically the same as the standard PN junction diode but are specially designed to have a low pre- determined Reverse Breakdown Voltage that takes advantage of this high reverse voltage.
- The point at which a zener diode breaks down or conducts is called the "Zener Voltage" (Vz).The Zener diode is like a general-purpose signal diode consisting of a silicon PN junction.
- When biased in the forward direction it behaves just like a normal signal diode passing the rated current, but when a reverse voltage is applied to it the reverse saturation Current remains fairly constant over a wide range of voltages.
- The reverse voltage increases until the diodes breakdown voltage VB is reached at Which point a process called Avalanche Breakdown occurs in the depletion layer and the current flowing through the zener diode increases dramatically to the maximum circuit value (which is usually limited by a series resistor).
- This breakdown voltage point is called the "zener voltage" for zener diodes.

Avalanche Breakdown: There is a limit for the reverse voltage. Reverse voltage can increase until the diode breakdown voltage reaches. This point is called Avalanche Break down region. At this stage maximum current will flow through the zener diode. This breakdown point is referred as –Zener voltage‖.

The point at which current flows can be very accurately controlled (to less than 1%tolerance) in the doping stage of the diodes construction giving the diode a specific zener breakdown voltage, (Vz) ranging from a few volts up to a few hundred volts. This zener breakdown voltage on the I-V curve is almost a vertical straight line.

Zener diode characteristics

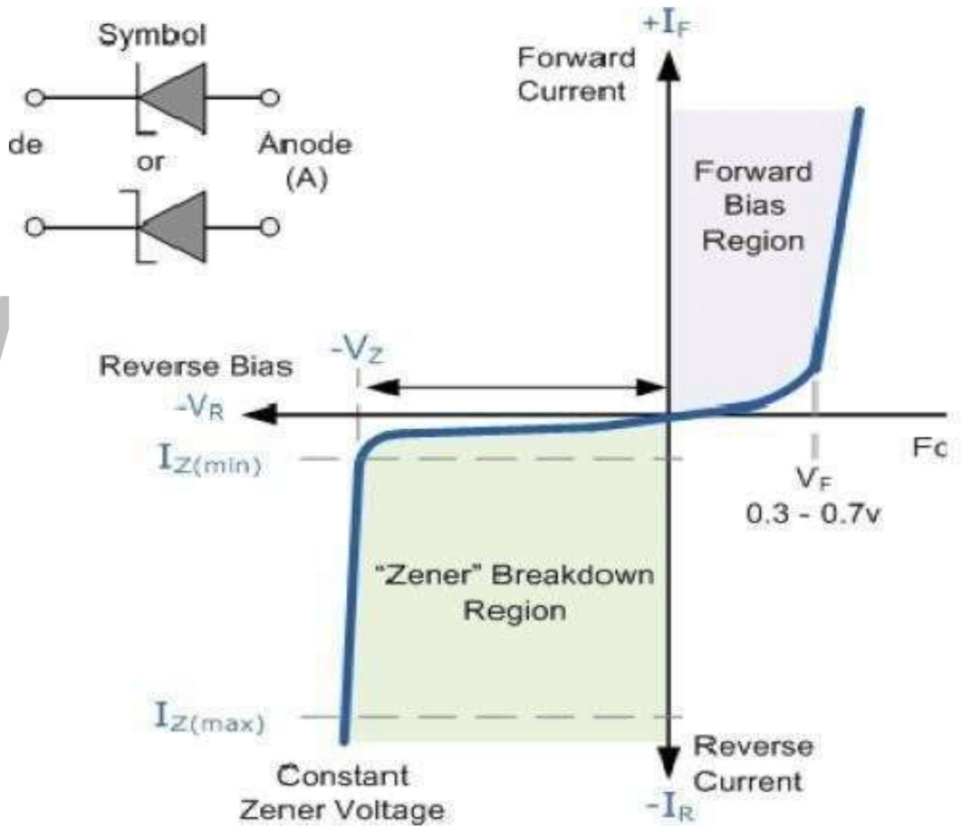


Figure: 1.7.2 Zener diode V I Characteristics

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 137]