Zener diode

In a reverse biased p-n junction a small amount of reverse saturation current flows which is almost independent of the reverse-bias voltage. However, if the reverse voltage exceeds certain critical value the current suddenly rises to a very large value. This is referred to as breakdown in diodes. Unless the diode is specially designed it may damage the diode. Diodes which have adequate power dissipation capabilities to operate in the breakdown region are called breakdown diodes or Zener diodes. The breakdown of a p-n junction may occur due to the effects of a strong electric field in the depletion region or the heat generated by the reverse current. The breakdown phenomenon is reversible. The following two mechanism can be cause breakdown in a junction diode.

Avalanche breakdown:

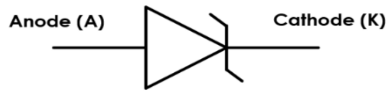
In a reverse biased p-n junction thermally generated minority carriers flowing down the junction barrier acquire energy from the applied potential. The carriers are always undergoing collision with crystal ions. When the applied voltage is high carriers acquire sufficient energy from the field and some of the collisions may become so violent that electrons are knocked out of the covalent bonds of the crystal atoms thereby producing new electron-hole pairs in addition to the original carriers. As these carriers are generated in the midst of high field, they rapidly separate out and cause further pair generation through further collision. This cumulative process is known as avalanche multiplication. It results in a large reverse current and the diode is then said to be operating in the avalanche breakdown region. **Avalanche breakdown take place in a junction having wide depletion region.**

With a rise of temperature, the crystal ions vibrate with a greater amplitude, increasing the possibility of collisions of the carriers and the crystal ions. So, the avalanche breakdown voltage increases with a rise of temperature. **Thus temperature coefficient of the avalanche breakdown voltage is positive.**

Zener breakdown:

When both sides of a p-n junction are heavily doped the **width of the depletion region becomes very small** and electric field at the junction may become very high with relatively small reverse bias. In this case carriers get very few chances to generate new carriers through collision. But in the simple covalent bonding model it is possible to initiate the breakdown by the direct rupture of covalent bonds. The strong electric field existing at the junction may exert sufficiently strong force on a bound electron and tear it out of the covalent bond. The new electron-hole pairs thus created increase the reverse current. The phenomenon was theoretically explained by Zener to result from quantum mechanical tunnelling of carriers through the barrier at the junction. In tunnelling phenomenon an electron confined by a potential barrier, higher than its energy, is shown to have a finite probability to pass through the barrier. The probability of tuntielling increases with the decrease in the width of the depletion region i.e., with the increase in doping concentration. Break down by the above process is known as Zener breakdown. It does not involve collisions of carriers with the crystal ions. The field strength starting the process is about 2×10^7 V/m. This value can be reached **at or below 6 V for heavily doped diodes**. **For lightly doped diodes the breakdown occurs at voltages greater than 6 V and avalanche multiplication is then the predominant breakdown mechanism.**

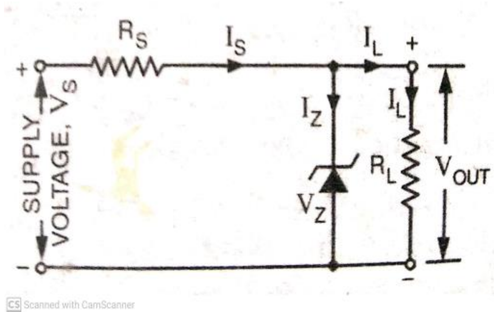
With a rise of temperature, the energy of the valance electron increases so that a lower applied voltage can pull these electrons out of their covalent bond. So, the zener breakdown voltage decreases with increasing temperature. That is **the temperature coefficient of the zener breakdown is negative.**



Zener Diode

Zener diode application: Zener Diode Shunt Regulator (or Voltage Regulation):

Voltage regulation is a measure of a circuit's ability to maintain a constant output voltage even when either input voltage or load current varies. Figure 1 shows how a zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary appreciably. A resistor Rs is necessary to limit the reverse current through the diode to safer value. The voltage source Vs and resistor Rs are so selected that the diode operates in breakdown region. The diode voltage in this region, which is also the voltage across the load R_L, is called zener voltage Vz and the diode current is called the zener current Iz. The series resistor Rs absorbs the output voltage fluctuations so as to maintain voltage across the load constant. Zener diode is reverse connected across the input voltage whose variations are to be regulated.



As long as voltage across the load resistor R_L , is less than the breakdown voltage Vz, the zener diode does not conduct, the resistors R_S and R_L constitute a potential divider across Vs. At an increased supply voltage Vs, the voltage drop across load resistor (or zener diode) becomes greater than the zener breakdown voltage. It then operates in its breakdown region. The series resistor Rs limits the zener current from exceeding its rated maximum Iz max Current through resistor Rs is given as

$$I_S = \frac{V_S - V_Z}{R_S}$$

The current from the power supply splits at the junction of zener diode and the load resistor R_L

So $I_S = I_Z + I_L$ ………eq (1)

When the zener diode operates in its breakdown region, the voltage across it, Vz remains fairly constant even though the current I flowing through it may vary considerably. When the supply voltage V_S increases, the current through both the zener diode and load resistance R_L increases. At the same time, however, the zener diode resistance decreases and the current through the diode increases more than proportionately. As a result, a greater voltage drop will occur across the series resistor Rs and the output voltage Vout (voltage across the diode or load resistance R_L) will become very close to the original value. The reverse is also true. Thus a zener diode can maintain the output voltage Vout within a fraction of a volt when the supply or input voltage Vs may vary over a range of several volts. The zener diode will maintain a constant voltage across the load as long as the supply voltage is more than the zener voltage.

Let us examine the other cause of the output voltage variation. When the load resistance R_L decreases for constant input voltage Vs, load current I_L increases. This additional current is not supplied from the source of supply but the demand of additional load current is met by decrease in zener current Iz. This keeps the voltage drop across series resistance Rs constant and so the output voltage Vout. The worst case occurs for minimum source voltage and maximum load current because the zener current reduces to a minimum. In such a case,

$$I_{S\,min} = \frac{V_{S\,min} - V_Z}{R_{S\,max}}$$

$$or, R_{S\,max} = \frac{V_{S\,min} - V_Z}{I_{S\,min}} \quad ....(2)$$

From Eq. (1) Iz= Is – $I_{L,}$ In worst case, this may be written as $I_{Zmin} = I_{\ Smin} - I_{Lmax}$ .The critical point occurs when $I_{Lmax} = I_{S\,min}$. At this point, the zener current, Iz reduces to zero, and regulation is lost. By substituting I_{Lmax} for I_{Smin} in Eq. (2), we have

$$R_{Smax} = \frac{V_{Smin} - V_Z}{I_{Lmax}}$$

where R_{Smax} is the critical value of series resistance, Vs min is the minimum source voltage, Vz is zener voltage and I max is maximum load current.

The critical resistance, Rs max is the maximum allowable series resistance. The series resistance R_S must always be less than the critical value, otherwise; breakdown operation is lost, and the regular stops its operation.

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