Group No:

Experiment-03

Study of IV Characteristics of Diode and Zener Diode

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To become familiar with a silicon p-n junction diode and understand its operation
2. To study the current-voltage i.e. I-V characteristics of silicon p-n junction diodes
3. To study the I-V characteristics of a zener diode and its application as a voltage regulator

Equipments

1. p-n junction diode (1N4007) - ×1
2. Zener Diode (5 volt) ×1
3. Resistances $(220\Omega, 470\Omega, 1k\Omega, 10k\Omega)$
4. POT $10k\Omega$
5. DC power suply
6. Breadboard, Wires
7. Digital multimeter

Background Theory

IV Characteristics

I-V characteristic defines the relationship between the current flow, I and the voltage across two terminals, V of an electronic device or element. It is a tool for understanding the operation of the circuit. The Current-Voltage (I-V) characteristics are found by evaluating the response of a device/element under different conditions. The behavior of a device depends on the applied excitation and can change if the excitation changes. For example, a device may act as an "open circuit" under certain input conditions and as "current source" in another. A diode acts as an open circuit below a specific threshold voltage and acts differently after that.

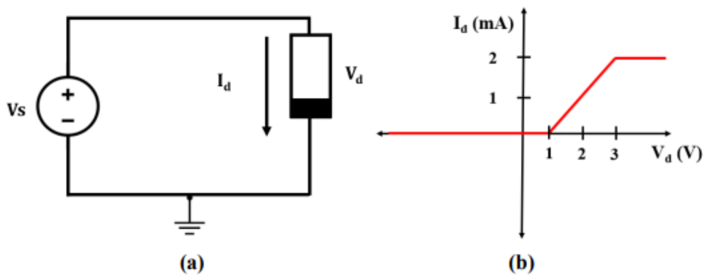


Figure 1: (a) A circuit with a voltage source, (b) I-V characteristic of the device

A simple circuit with a voltage source and an electronic device is shown in the figure above. The voltage source acts as an excitation medium for the device. Varying the voltage source would result in change in the current flow, I_d across the device. By plotting this current with respect to the voltage across the device, V_d, the I-V

characteristics of this device can be determined.
I-V characteristics gives us the idea of the behaviour of a device which is enough information for us to know about a device. Depending on the I-V characteristics, the electronic devices can be divided into two categories:

(1) Linear (2) Non-linear

If the current through an element is a linear function of the applied voltage across it, it is a linear device.

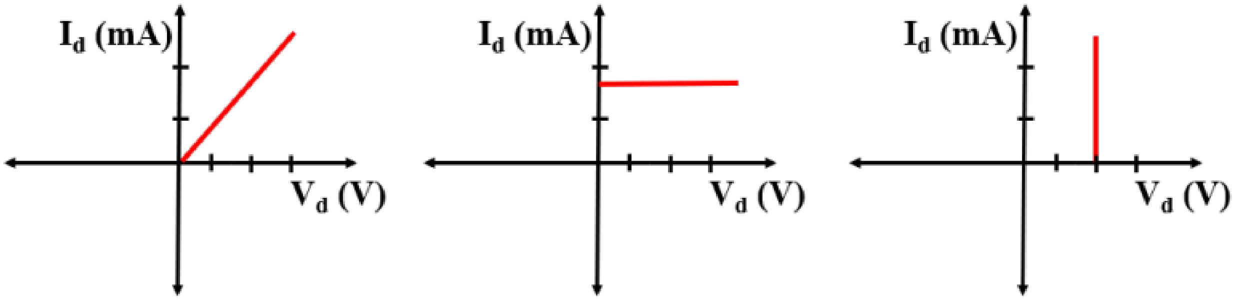


Figure 2: I-V curves of some linear elements

If the current through an element is a nonlinear function of the applied voltage across it, it is a non-linear device.

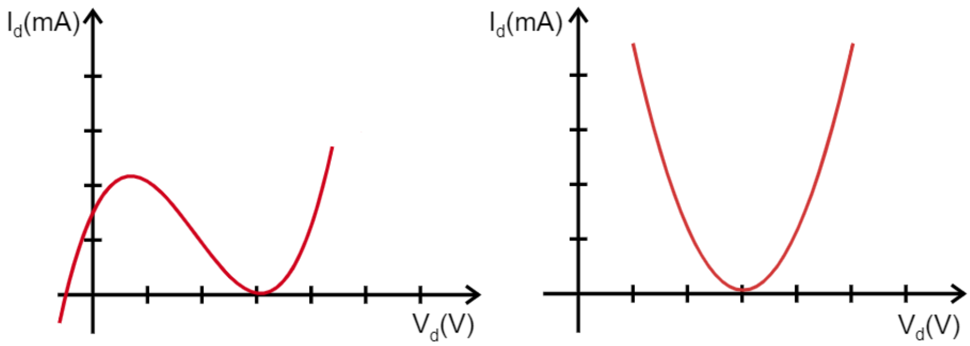


Figure 3: I-V curves of some non-linear elements

In this experiment, we will study the I-V characteristics of diodes. We will observe that, diodes exhibit non-linear I-V characteristics.

Introduction to Diode

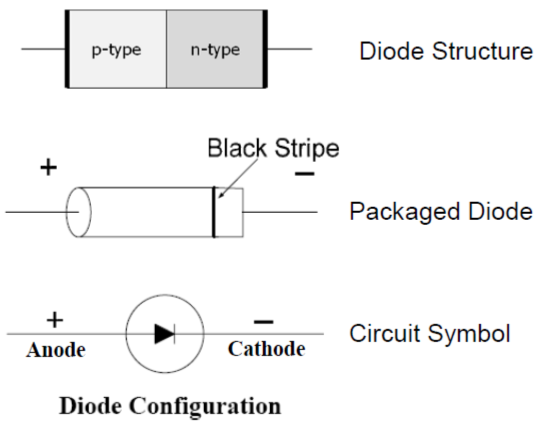


Figure 4: Diode structure and circuit symbol

Diode is a semiconductor device that allows current flow only in one direction, from p to n or anode to cathode. The schematic diagram, diode notation and circuit symbol are shown in Figure-1. Diodes are usually marked with a dot or a bar appearing on the cathode side. This mark helps identify the diode terminals.

Ideal Diode Characteristics

Ideally, we want a diode to behave like an electronic valve. That is, it should allow any amount of current in one direction, while blocking all the currents in the opposite direction. This behavior can be characterize using the current and voltage relation between the diode (or for any electronic device) – which is also known as the IV characteristics of the device.

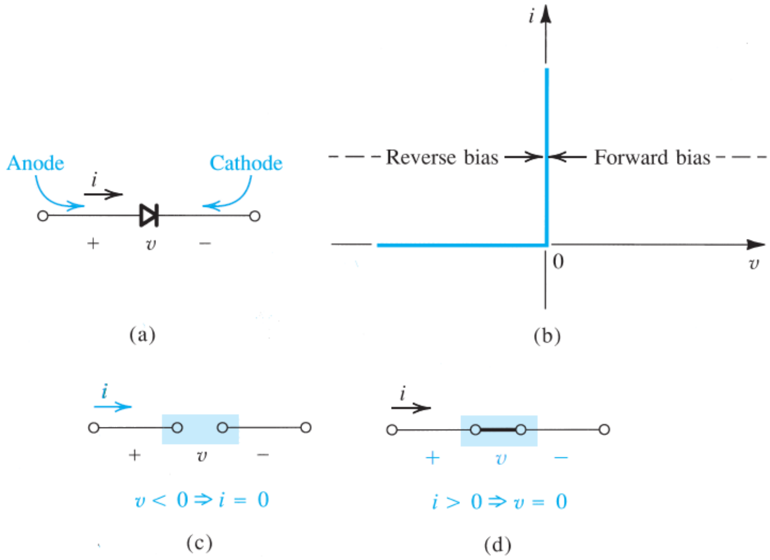


Figure 5: IV Characteristics of an ideal diode

Real Diode Characteristics

Real diodes are made of semiconductor materials, which have highly non-linear IV characteristics. However, under certain conditions and approximations, the real diode behaves like an ideal diode. For a real diode, the current I_D when a voltage V_D is applied across it is given by:

$$I_D = I_S \left(\exp\left(\frac{V_D}{nV_T} \right) - 1 \right)$$

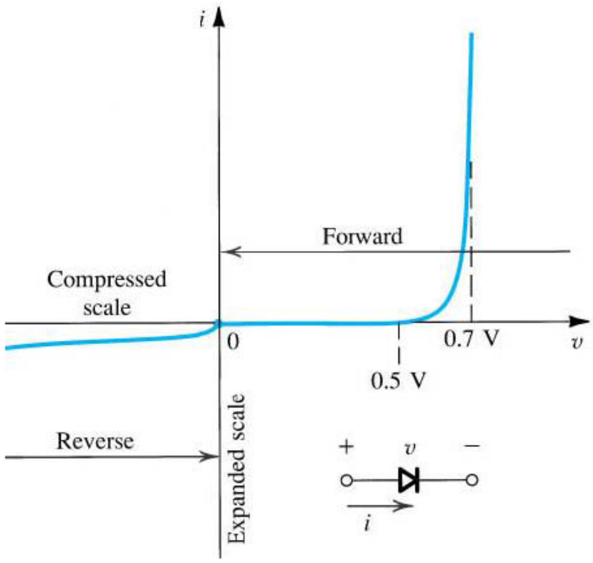


Figure 6: IV Characteristics of a Real Diode

Here,

- I_S is called the reverse saturation current
- n is called the diode ideality factor, and it has a value between 1 and 2

- V_T is called the thermal voltage, which has a value of 25 mV at 27°C

However, there are 2 special cases:

- When $V_D >> nV_T$: in this case, e^{V_D/nV_T} will be much higher that 1, and hence we can ignore 1. Therefore, $I_D \approx I_S\ exp(V_D/nV_T)$
- When $V_D < 0$: in this case, e^{V_D/nV_T} will be negligible compared to 1, and hence we can ignore the exp() term. Therefore, $I_D \approx -I_S$

Diode Resistance

As the diode IV characteristic is not linear, it will have different resistances at different points on the curve. A dynamic or AC resistance for the diode is defined as,

$$r_d = \frac{dv}{di} \approx \frac{nV_T}{I_D}$$

The static or DC resistance at any point is defined as, $R_D = V_D/I_D$

Diode Specification

There are many specifications for each type of diode, the most important two are:

1. Peak inverse Voltage (PIV): maximum voltages the diode can tolerate in reverse direction.
2. Maximum Forward Current (I_F) the maximum current the diode can conduct in forward biased condition without exceeding the safe limit.

Look at the data sheet of a diode provided at the last page to get familiar with some of the diode specifications.

Diodes are widely used in applications such as mixers, detectors, protection circuits. In this experiment you will investigate its I-V characteristics.

Introduction to Zener Diode

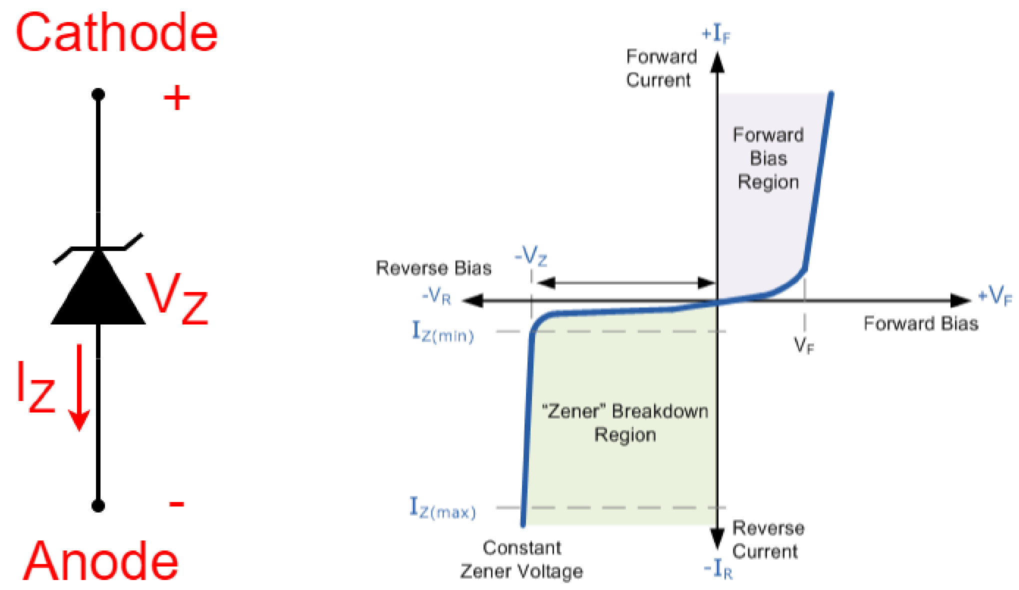


Figure 7: Zener Diode Symbol and IV-characteristics

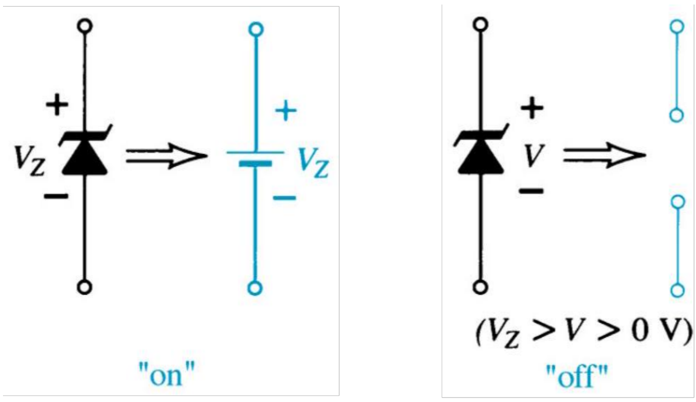
The diodes we have studied before do not operate in the breakdown region because this may damage them. A Zener diode is different. It is a silicon diode that the manufacturer has optimized for operation in the breakdown region. It is used to build voltage regulator circuits that hold the load voltage almost constant despite large change in line voltage and load resistance. Figures above show the symbol of Zener diode and its operating

region.
The Zener diode may have a breakdown voltage from about 2 to 200 V. These diodes can operate in any of the three regions: forward, leakage and breakdown.

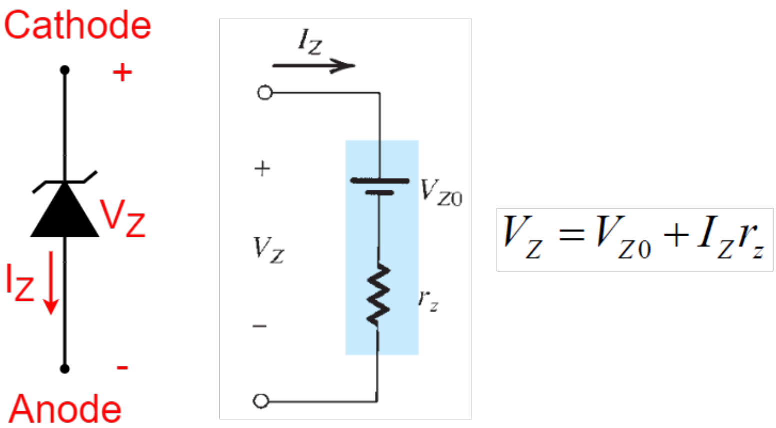
- In the forward region it works as an ordinary diode.
- In the leakage region (between zero and breakdown) it has only a small reverse saturation current.
- In the breakdown region it has a sharp knee, followed by an almost vertical increase in current without changing the voltage.
- The voltage is almost constant, approximately equal to Vz over most of the breakdown region.

Model Approximations

First approximation: When the voltage across the zener diode $V \geq V_Z$, the diode is ON, and it is represented by a battery with constant voltage of V_Z, otherwise the diode is OFF and it is represented by an open circuit.



Second approximation: The Zener diode is modeled with a battery of voltage V_{Z0} in series with resistance r_Z, called the zener resistance, to account for the slight increase in the zener voltage V_Z with the zener current I_Z.



Task-01: Diode IV Characteristics

In this task, we will build a circuit that will enable us to collect required data to observe the characteristics of a diode. We will vary the source voltage of the circuit which will eventually change the voltage and current across the diode. This data of voltage and current will be used to plot the IV graph of the diode.

Experimental Design

The following figure shows the circuit required for this experiment.

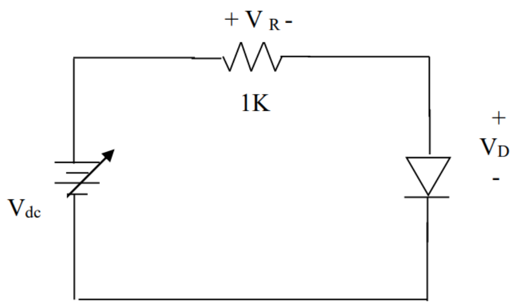
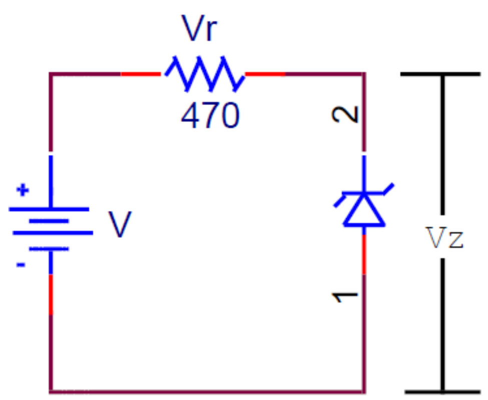


Figure 8: Circuit diagram for finding out the diode IV Characteristics

Procedure

1. Measure resistance accurately using a digital multimeter.
2. Construct the circuit as shown in the figure above. Vary input voltage V_{dc} from 0v to 14v and measure V_R and V_D. Increase V_{dc} in 0.1v steps for 0v to 1v, and then in 1v steps for 1v to 14v.
3. For each value of V_{dc}, also calculate the diode current using $I_R = V_R$.
4. Plot diode IV characteristics of the diode for different readings obtained.
5. Calculate the diode ideality factor n and the reverse saturation current I_S, using the diode equation assuming $V_D >> V_T$.
6. Calculate the static and dynamic resistances for $I_D = 4$, 8 and 12 mA.
7. Complete the Data Sheet. Use google sheets to plot the IV characteristics.

Task-02: Zener Diode IV Characteristics



Procedure

1. Build the circuit as shown in the figure.
2. Vary the supply voltage from 0 to 10 volt, in steps of $1v$ and complete the data sheet. Try to take more readings with smaller voltage increments ($0.1v$ or $0.2v$) near the breakdown region in order to accurately capture the transition.
3. Complete the Data Sheet. Use google sheets to plot the IV characteristics.

Task-03: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Attach the signed Data Sheet.
3. Attach the graphs plotted using google sheets. Go to **'https://cutt.ly/l3QaTBf'** to know how to plot in google sheet.
4. Add a brief Discussion at the end of the report.

Data Sheet

Diode IV Characteristics

$R = 1k\Omega$ (measure the accurate resistance using the digital multi-meter)

Supply Voltage, V_{DC} (v)	Diode Voltage, V_D (v)	Voltage across the Resistor, V_R (v)	Diode Current, $I_D = I_R = V_R/R$ (mA)
0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1			
2			
4			
6			
8			
10			
12			
13			
14			

Calculation

Determining Ideality Factor, n

Let, $\alpha = \frac{1}{nV_T}$

Take any two data from the table: $I_{D1} = I_S \exp(\alpha V_{D1})$ and $I_{D2} = I_S \exp(\alpha V_{D2})$

Taking ratio of I_{D1} and I_{D2},

$$\Rightarrow \frac{I_{D1}}{I_{D2}} = \exp(\alpha(V_{D1} - V_{D2}))$$

$$\Rightarrow \alpha = \frac{\ln\left(\frac{I_{D1}}{I_{D2}}\right)}{V_{D1}-V_{D2}} = \frac{1}{nV_T} \qquad \Rightarrow n = \frac{1}{\alpha V_T} =$$

Determining Static (R_D) and Dynamic (r_D) Resistance

$$R_D = V_D / I_D$$

$$r_D \approx \frac{nV_T}{I_D} =$$

Zener Diode IV Characteristics

$R = 470\ \Omega$ (measure the accurate resistance using the digital multi-meter)

V (volt)	V_R (volt)	V_Z (volt)	$I_Z = V_R/R$ (mA)
0			
1			
2			
3			
4			
4.9			
5			
5.1			
5.2			
5.3			
5.4			
5.5			
6			
7			
8			
9			
10			