Group No:

Experiment-03

Study of I-V 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 characteristics 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

Equipment

1. p-n junction diode (1N4007) - ×1
2. Zener Diode (5 volt) ×1
3. Resistances (1kΩ)
4. Function Generator
5. Oscilloscope
6. Breadboard, Wires
7. Digital Multimeter

Background Theory

I-V Characteristics

I-V characteristic defines the relationship between the current flow and the voltage across two terminals of an electronic device or element. It is a tool for understanding the operation of the circuit. The 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 "voltage source" in another. A diode acts as an open circuit below a specific threshold voltage and acts differently beyond the it.

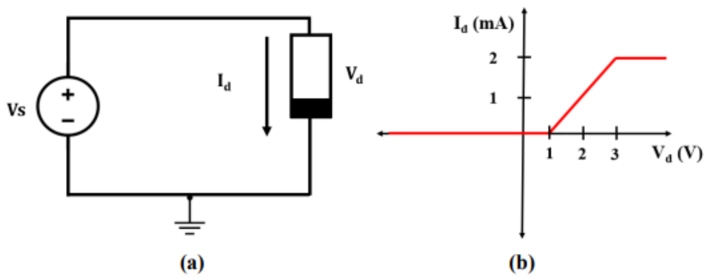


Figure 1: ***(a) A circuit with a voltage source, (b) I-V characteristic of the device***

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 illustrates the behaviour of a device which is enough to know the 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.

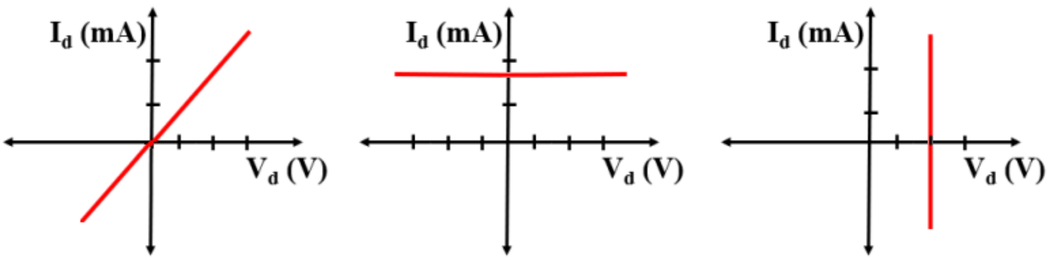


Figure 2: ***I-V characteristics of some linear elements***

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

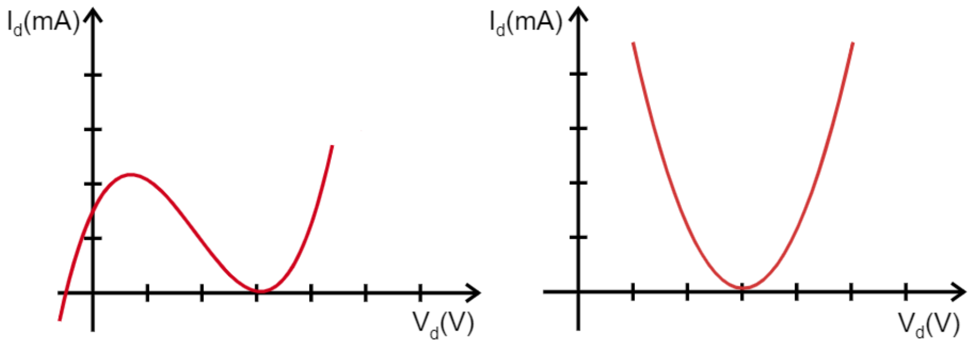


Figure 3: ***I-V curves of some non-linear elements***

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

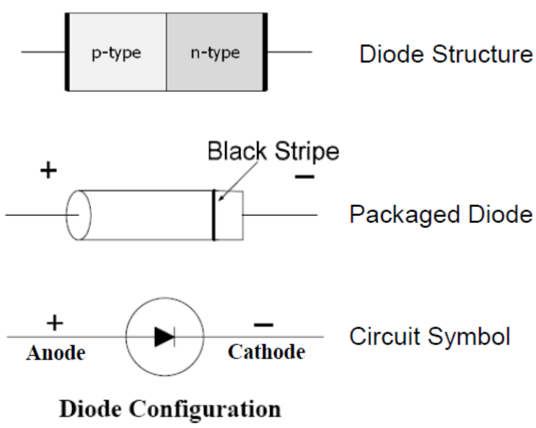


Figure 4: ***Diode Structure, Packaged Diode and Circuit Symbol***

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 the figure above. Diodes are usually marked with a dot or a bar appearing on the cathode side. This mark helps identify the diode terminals.

I-V Characteristics of an Ideal Diode

Ideally, we want a diode to behave like an electronic valve. It allows 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 I-V characteristics of the device.

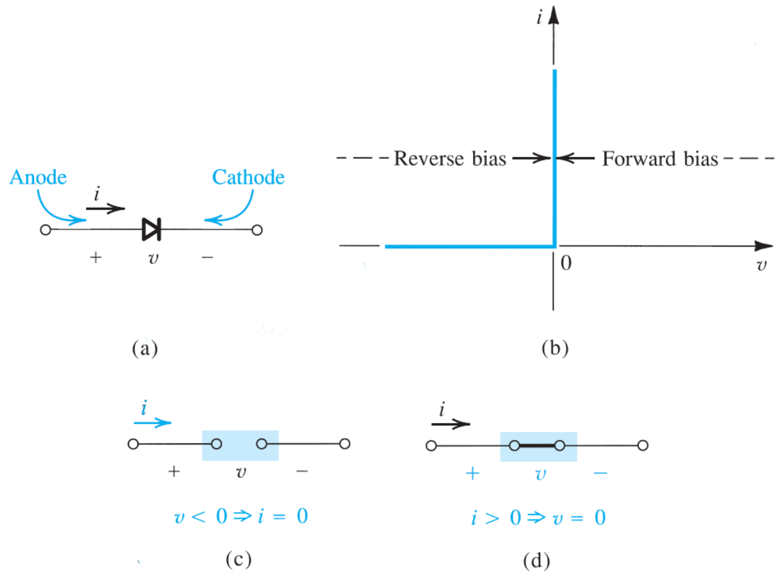


Figure 5: ***I-V Characteristics of an ideal diode***

I-V Characteristics of a Real Diode

Real diodes are made of semiconductor materials, which have highly non-linear I-V characteristics. However, under certain conditions and approximations, the real diode behaves like an ideal diode.

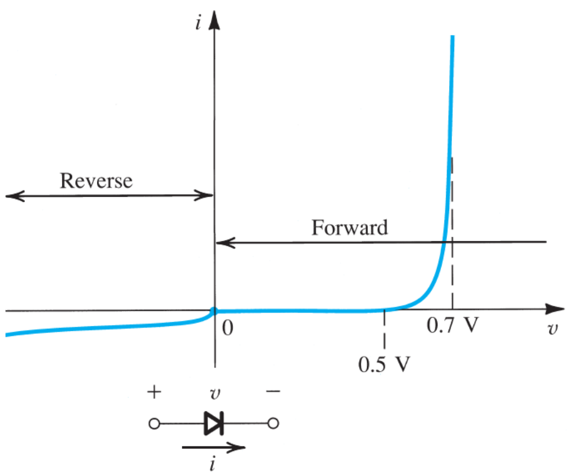


Figure 6: ***I-V Characteristics of a Real Diode***

For a real diode, the current I_D when a voltage V_D is applied across it is given by:

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

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. The equation becomes, $I_D \approx I_S \exp(V_D/nV_T)$
- When $V_D < 0$: in this case, $\exp(V_D/nV_T)$ will be negligible compared to 1, and hence we can ignore the exp() term and the equation becomes, $I_D \approx -I_S$

Diode Resistance

As the diode I-V 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.

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

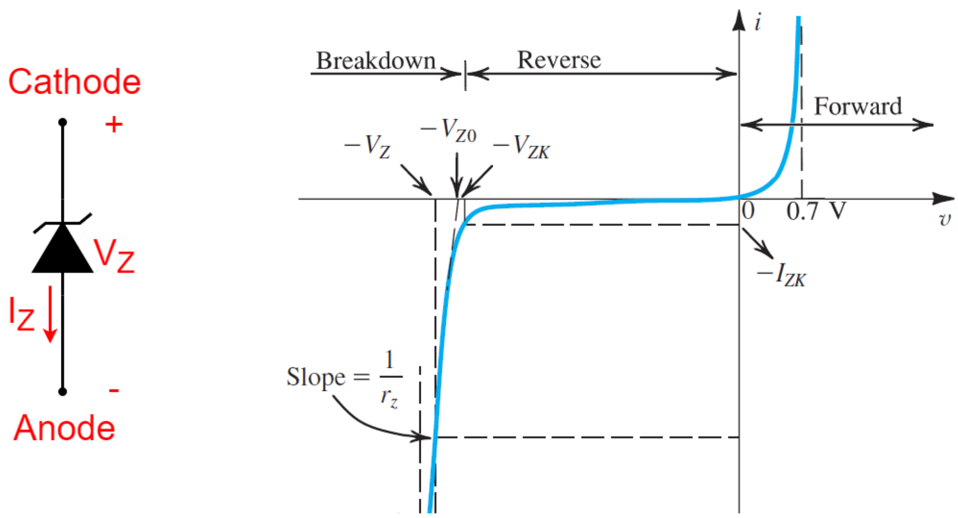


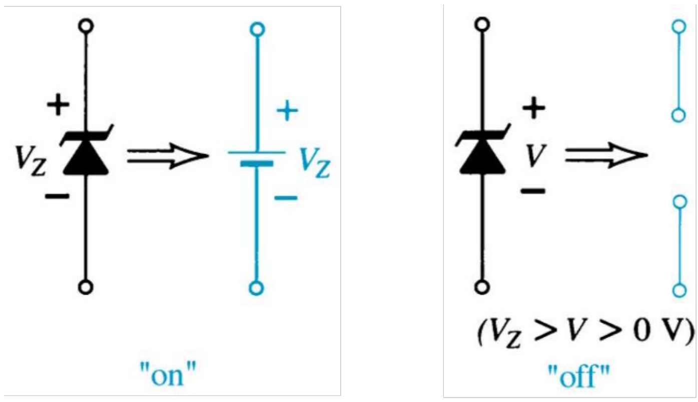
Figure 7: ***Zener Diode Symbol and I-V Characteristics***

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

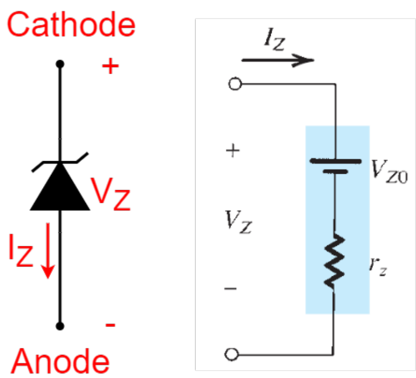
- In the forward region it works as an ordinary diode.
- In the leakage region (between zero and breakdown) it has only a small reverse saturation current.
- In the breakdown region it has a sharp knee, followed by an almost vertical increase in current without changing the voltage.
- The voltage is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

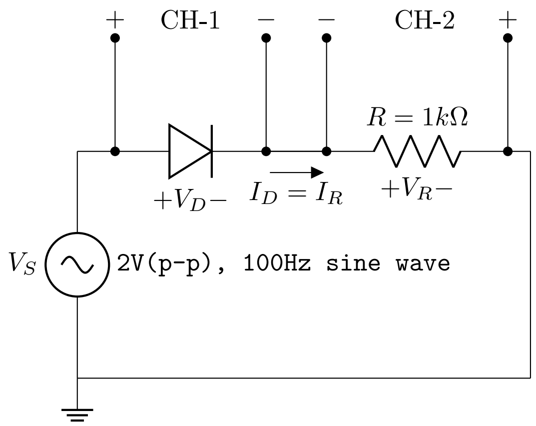


Second approximation: The Zener diode is modeled with a battery, V_{Z0} in series with a resistance r_Z, called the zener resistance, to account for the slight increase in the zener voltage V_Z with the zener current I_Z.



$$V_Z = V_{Z0} + I_Z r_z$$

Task-01: Diode I-V Characteristics



Procedure

1. Construct the circuit given above. Use the function generator to generate a 2V(p-p), 100Hz sine wave for the supply voltage V_S.
2. Connect the CH-1 and CH-2 of the oscilloscope to the circuit as shown in the figure above.

3. We need to invert the CH-2 in the oscilloscope due to it's inverted connection to the circuit.
   To do so: Press **CH2** button → Press the **Invert** button which can be found on the bottom of the display of the oscilloscope to select the option **On**.

4. Observe the I-V characteristics of the diode in the XY mode of the oscilloscope and capture the image. To use the XY mode:

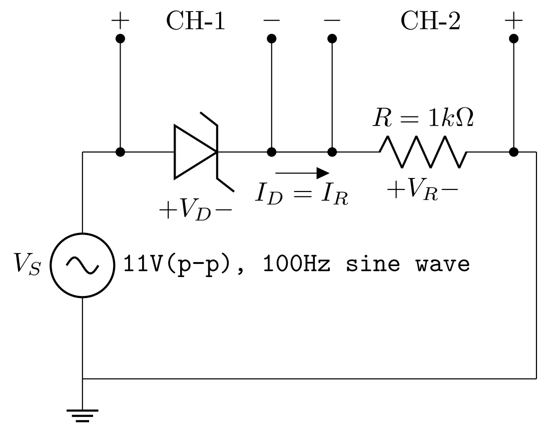
   (a) Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).

   (b) Press the **Acquire** button → Press the **XY** button which can be found below the display → Press the **Triggered XY** button which can be found on the right side of the display.

   (c) Change the scaling and position of the plot using the **Scale** knob and **Position** knob of both channels respectively if you need.

You will see a small screen showing the I-V characteristics graph using the XY mode of the oscilloscope. The XY mode plots the voltage data of CH1 and CH2 in the x-axis and y-axis respectively. So, the x-axis represents V_D. As, $I_D = I_R \propto V_R$, the y-axis represents I_D.

Task-02: Zener Diode I-V Characteristics



Procedure

1. Construct the circuit given above. Use the function generator to generate a 11V(p-p), 100Hz sine wave for the supply voltage V_S.

2. Connect the CH-1 and CH-2 of the oscilloscope to the circuit as shown in the figure above.

3. Observe the I-V characteristics of the zener diode in the XY mode of the oscilloscope like the previous task and capture the image.

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 captured images

3. Answer the questions in the "Test Your Understanding" section

4. Add a brief Discussion at the end of the report

Test Your Understanding

Answer the following questions:

1. $R = 1k\Omega$ was used in the experiment. If we use $R = 2.2k\Omega$, will there be any problem in observing the I-V characteristics plot? Explain briefly
   Answer:

2. Why do we need to invert the CH2 in the oscilloscope? What will happen if we don't invert the CH2 in the oscilloscope?
   Answer:

`Signature of the lab faculty`