

# Experiment-04

## 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) -  $\times 1$
2. Zener Diode (5 volt)  $\times 1$
3. Resistances (1k $\Omega$ )
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 a 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.

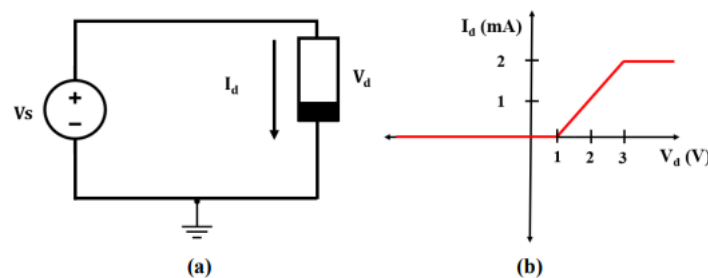


Figure 1: (a) A circuit with a voltage source, (b) I-V characteristic of the device

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 devices can be divided into two categories:

- (1) Linear Devices
- (2) Non-linear Devices

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

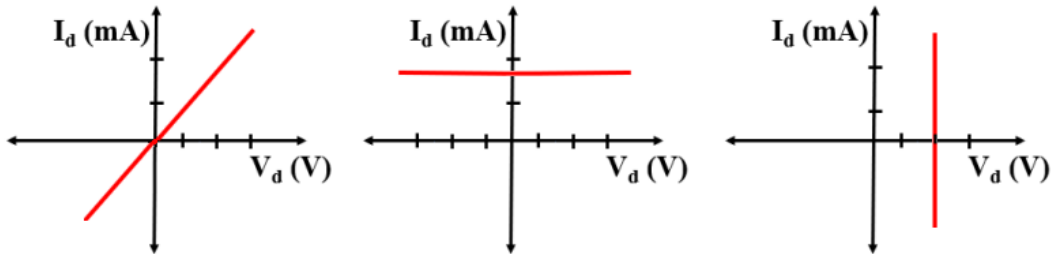


Figure 2: *I-V characteristics of some linear elements*

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

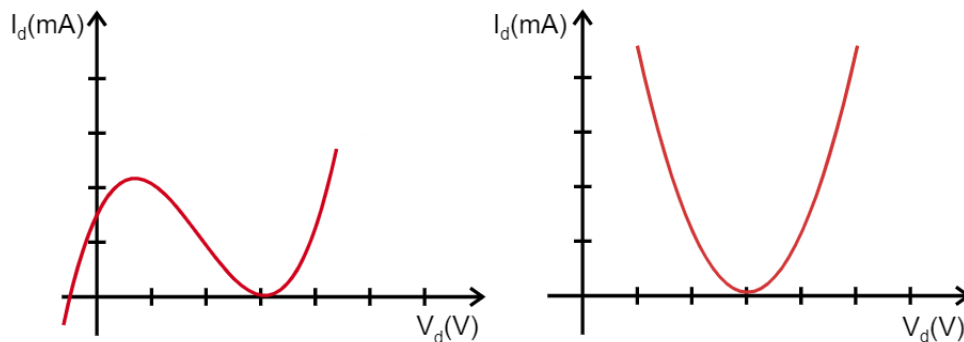


Figure 3: *I-V curves of some non-linear elements*

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

## Introduction to Diode

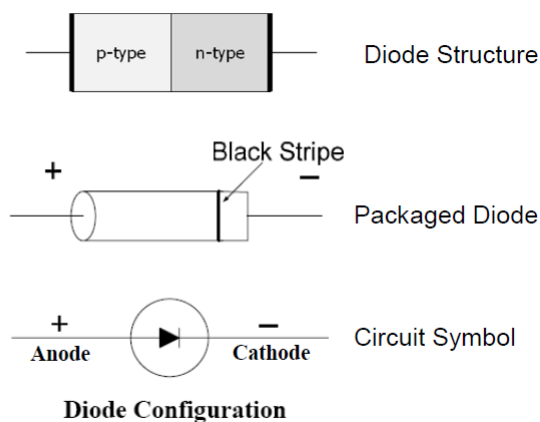


Figure 4: *Diode Structure, Packaged Diode and Circuit Symbol*

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 characterized 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.

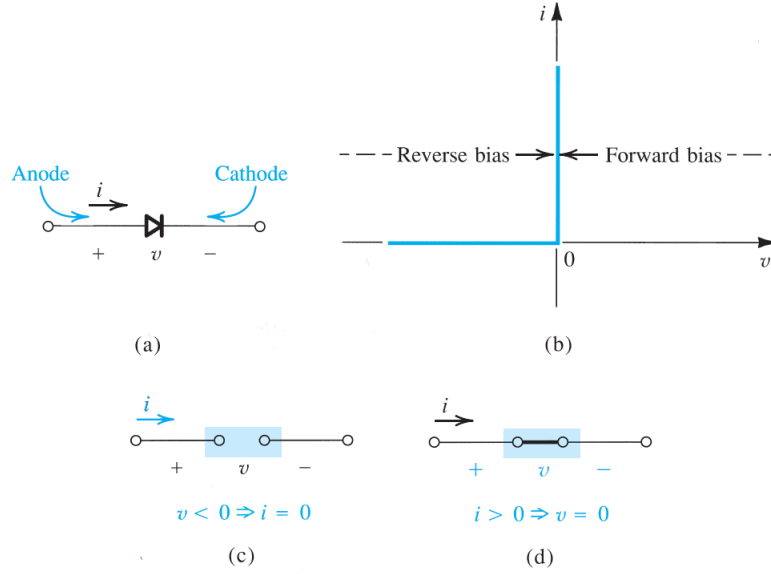


Figure 5: *I-V Characteristics of an ideal diode*

## 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.

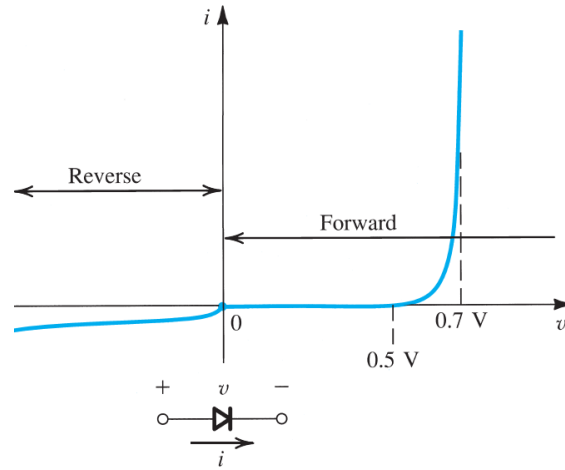


Figure 6: *I-V Characteristics of a Real Diode*

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  $V_D \gg nV_T$ : in this case,  $\exp(V_D/nV_T)$  will be much higher than 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  $\exp(V_D/nV_T)$  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,

$$r_d = \frac{d}{di}(v) \approx \frac{nV_T}{I_D}$$

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

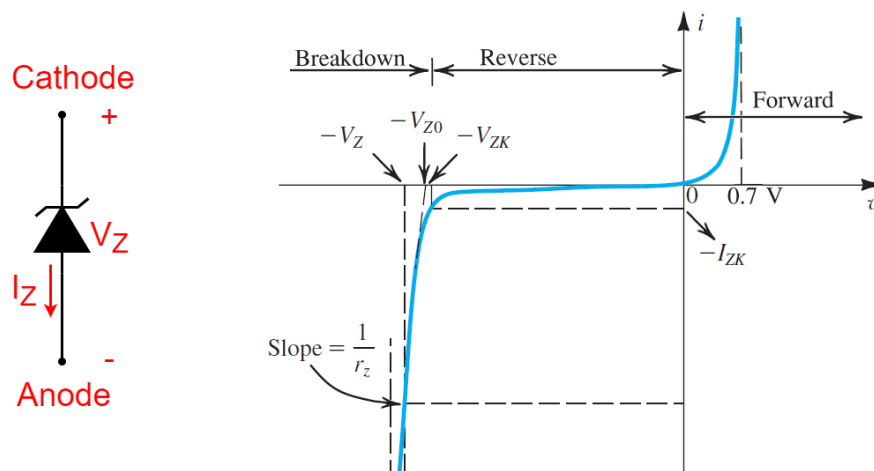


Figure 7: *Zener Diode Symbol and I-V Characteristics*

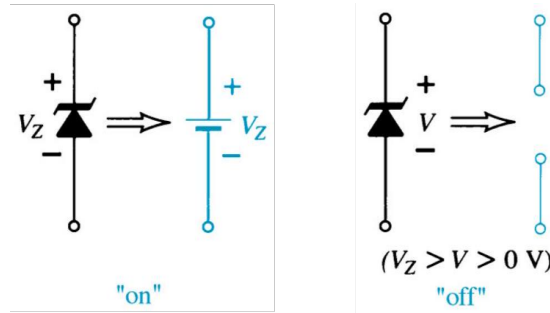
The diodes we have studied before do not operate in the breakdown region. But a Zener diode is different. It is a silicon diode that the manufacturer has optimized to operate in the breakdown region. It is used to build voltage regulator circuits that maintains almost constant voltage despite large change 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 bias region, reverse bias/leakage region and breakdown region.

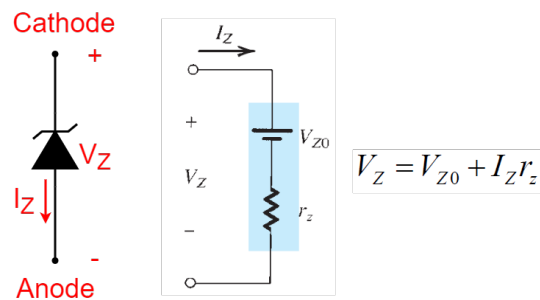
- In the forward bias region, it works as an ordinary diode.
- In the reverse bias/leakage region, it has only a small reverse saturation current.
- In the breakdown region, it has a sharp knee, followed by an almost vertical increase in current without changing the voltage.
- The voltage is almost constant,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

## Model Approximations

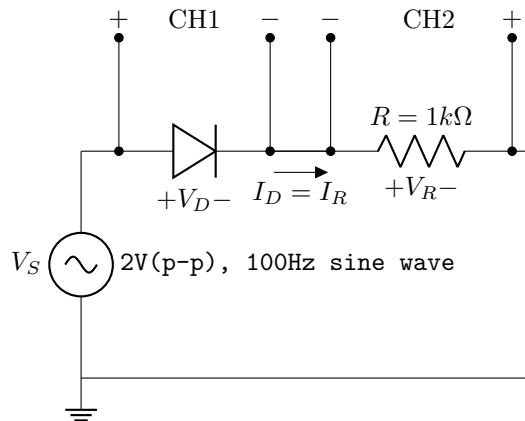
**First approximation:** When the voltage across the zener diode  $V \geq V_Z$ , the diode is ON, and it is represented by a battery with constant voltage of  $V_Z$ , otherwise the diode is OFF and it is represented by an open circuit.



**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  $I_Z$ .



## Task-01: Diode I-V Characteristics



### Procedure

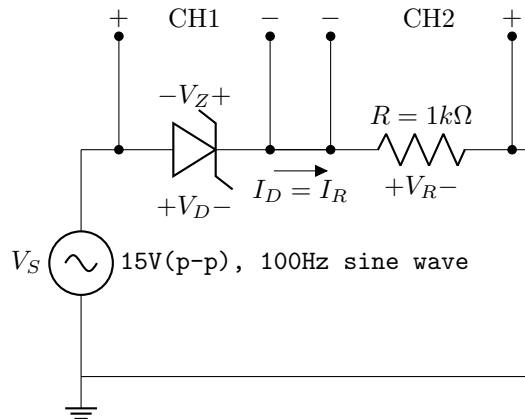
- Construct the circuit given above. Use the function generator to generate a 2V(p-p), 100Hz sine wave for the supply voltage  $V_S$ .
- Connect the CH1 and CH2 of the oscilloscope to the circuit as shown in the figure above.
- Observe the I-V characteristics of the diode in the XY mode of the oscilloscope and capture the image. To use the XY mode:
  - Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).
  - We need to invert the CH2 in the oscilloscope due to its 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**.

- (c) 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.
- (d) 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

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### Procedure

1. Construct the circuit given above. Use the function generator to generate a 15V(p-p), 100Hz sine wave for the supply voltage,  $V_S$ .
2. Connect the CH1 and CH2 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.

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Signature of the lab faculty

## Task-03: Report

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1. Add a cover page that includes course code, course title, name, student ID, group, semester, date of performance, date of submission.
2. Attach the captured photos of all the waveforms and measurements you have observed in the Oscilloscope. Each photo should contain necessary description.
3. Answer the questions in the “Test Your Understanding” section.
4. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
  - What did you learn from this experiment?
  - What challenges did you face and how did you overcome the challenges? (if any)
  - What mistakes did you make and how did you correct the mistakes? (if any)
  - How will this experiment help you in future experiments of this course?

## Test Your Understanding

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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. From the I-V characteristics of a diode that you obtained, which devices can be used to model the diode?

**Answer:**

3. Justify the usage of a voltage source with a higher peak-to-peak voltage with the zener diode over a regular diode in this experiment.

**Answer:**

4. Compare the I-V characteristics of a regular diode with that of a zener diode.

**Answer:**

5. What is voltage regulation? Which diode is more suitable for voltage regulation? Justify your choice with reference to the I-V characteristics of diode and zener diode that you obtained in the experiment.

**Answer:**