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Jacobs University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2021

Lab Experiment 4 – Single PN - Junction

Author of the report
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Experiment conducted by : Ramin Udash, Dhespina Pepa Pecini
Place of execution : Teaching Lab EE Room 1, Bench 1 and 2
Date of execution : Sept 30, 2021

1. Introduction

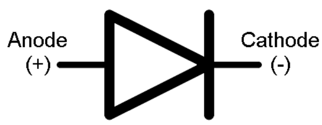
The main objectives of this experiment are to:

- Examine the behavior of a diode built by a PN junction of two semi-conductors,
- Understand the characteristics of a Zener diode,
- Demonstrate practical application of diodes.

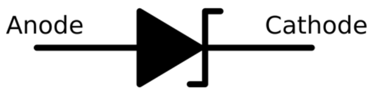
A diode is an electronic component made of semi-conductors that conducts primarily in one direction i.e., when it is in forward bias. Diodes are made up of semi-conductors such as Silicon and Selenium. As the name suggests, semi-conductors conduct partially.

When the diode is in forward bias, it has 0 resistance allowing the current to flow in. When in reverse bias, its resistance becomes extremely high (infinite for an ideal diode) disallowing the flow of current through it. In the first part of this experiment, we use a PN diode, a type of two-terminal semiconductor based on a PN junction that conducts only in one direction.

A diode is diagrammatically represented in a circuit in the following way:



In our experiment, we are going to use a Zener diode. It is a special type of diode that conducts normally when it is connected in forward bias but when connected in reverse bias, does not let current flow until a specific voltage called "Breakdown voltage" is attained. The diagrammatical representation for Zener diode in a circuit is shown below:



2. Execution

Instruments used in this experiment:

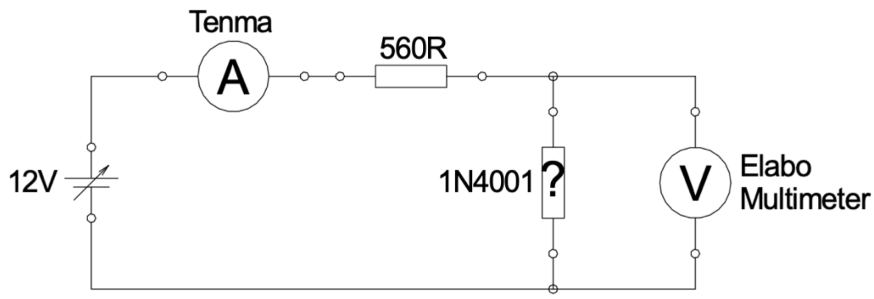
- Diode
- Zener Diode
- Resistor Decade
- 560 Ohm resistor
- 470 Ohm resistor
- Power Supply
- Connecting Wires
- ELABO multimeter
- TENMA multimeter

Part 1: Determine Anode and Cathode:

The SETUP

In this part of the experiment, we're supposed to determine the polarity i.e., the cathode and the anode of the semi-conductor diode. Cathode is related to the p-type of the semi-conductor diode and anode is linked to the n-type of the semi-conductor diode. The ring of the diode is used as the reference point in this experiment.

The following circuit was setup:



Execution and results:

Using the ring of the diode was used as a point of reference, we measured the voltage and current values. The measured values when the ring of the diode is connected to the negative of the power supply are tabulated below:

Voltage drop/ V	Current (uA)	Range (Voltage)
0.7165	20563.00	2

After that, we reversed the orientation of the diode in a way that the ring of the diode is connected to the positive end of the power supply. The measured values when the ring of the diode is connected to the negative of the power supply are tabulated below:

Voltage drop/ V	Current (UA)	Range (Voltage)
12.09100	1.11000000	20

For the next part, we used a different approach to determine the polarity of the diode. The diode was clamped in both directions to the TENMA multimeter with one end connected to the COM and the other end to the V Ω plug since we know that the V Ω plug has a positive polarity compared to the COM plug. We again use the ring of the diode as the point of reference. We measured the resistance with the diodes placed on both directions. When the ring of the diode was connected to the positive end of the multimeter i.e., the V Ω plug, we recorded:

Resistance = 4.35E+09 Ω

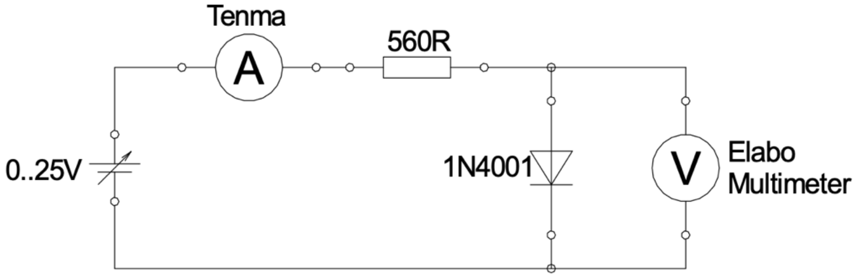
Reversing the orientation of the diode i.e., connecting the ring of the diode to the negative end of the multimeter i.e., the V Ω plug, we recorded:

Resistance = 0 Ω

Part 2: Forward V-I curve of a general purpose diode:

The SETUP

The objective of this experiment is to understand the behavior (V-I curve) of a normal diode with current values from 0-40 mA. We vary the voltage values in the power supply until we get desired current values. We recorded the voltage value at ELABO and the current value at TENMA. The following circuit was set up:



Execution and results:

Observing the range of the values of current to be altered, we used the lowest range for the TENMA multimeter i.e., the range with the plug at mAuA and the switch to uA. To create the V-I curve, we altered the power supply to get the following current values for TENMA multimeter as per stated in the Lab manual:

0uA, 50uA, 100uA, 200uA, 500uA, 1000uA
2mA, 3mA, 4mA, 5mA, 10mA, 20mA, 40mA

The voltage and current values recorded are tabulated below:

I manual/ A	Voltage(ELABO)/ V	Current(TENMA)/A
0.00000	0.241	0.00000000
0.00005	0.4376	0.00005026
0.00010	0.4657	0.00009846
0.00020	0.4976	0.00020243
0.00050	0.5401	0.00049920
0.00100	0.5742	0.00100010
0.00200	0.6085	0.00200000
0.00300	0.6295	0.00306500
0.00400	0.6423	0.00400200
0.00500	0.653	0.00500200
0.01000	0.6856	0.01008200
0.02000	0.7167	0.02002700
0.04000	0.74443	0.04009000

Part 3: Reverse and Forward Characteristic of a Z-Diode:

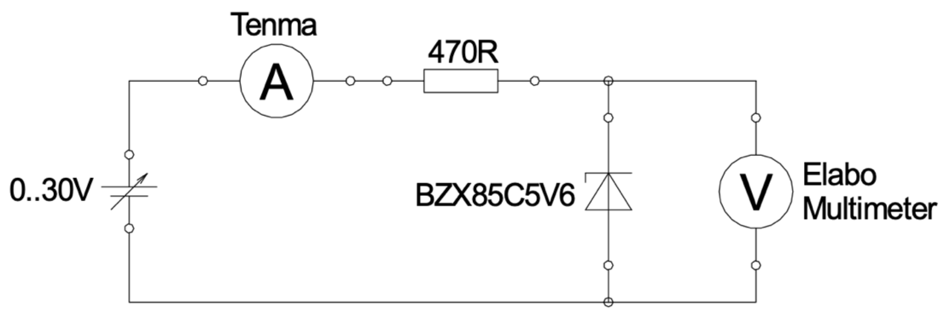
The SETUP

In part 3 of this experiment, we used a Zener diode (BZX85C5V6). We recorded the reverse V-I curve of the Zener diode varying the current from 0-45mA. After that, we reversed the orientation of the diode and measured the values again.

Again, observing the range of the values of current to be altered, we used the lowest range for the TENMA multimeter i.e., the range with the plug at mAuA and the switch to uA. To create the V-I curve, we altered the power supply to get the following current values for TENMA multimeter as per stated in the Lab manual:

0uA, 100uA, 200uA, 500uA, 700uA, 1000uA, 1100uA,
1.5 mA, 2mA, 5mA, 10mA, 20mA, 40mA, 45mA

This experiment was based on the circuit shown below:



Execution and results:

The current and voltage values when the Zener diode is in reverse is tabulated below:

I manual/ A	Current(TENMA)/A	Voltage(ELABO)/ V
0.00000	0.00000	0.02070
0.00010	0.00011	4.8760
0.00020	0.00020	5.0530
0.00050	0.00050	5.2650
0.00070	0.00070	5.3250
0.00100	0.00101	5.3780
0.00110	0.00110	5.3900
0.00002	0.00150	5.4260
0.00200	0.00201	5.4550
0.00500	0.00505	5.5140
0.01000	0.01009	5.5460
0.02000	0.02009	5.5840
0.04000	0.03999	5.6470
0.04500	0.04545	5.6650

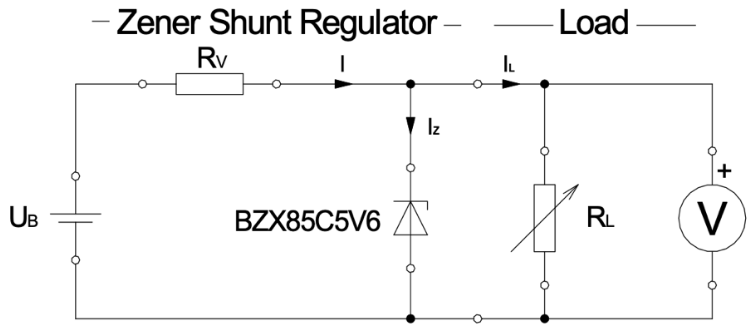
The current and voltage values when the Zener diode is in forward is tabulated below:

I manual/ A	Current(TENMA)/A	Voltage(ELABO)/ V
0.00000	0.00000	0.02430
0.00010	0.00010	0.66200
0.00020	0.00020	0.68000
0.00050	0.00050	0.70500
0.00070	0.00072	0.71500
0.00100	0.00100	0.72300
0.00110	0.00111	0.72600
0.00002	0.00154	0.73500
0.00200	0.00203	0.74300
0.00500	0.00508	0.76800
0.01000	0.01008	0.78800
0.02000	0.02002	0.80900
0.04000	0.03999	0.83200
0.04500	0.04532	0.83600

Part 4: A Zener Shunt Regulator:

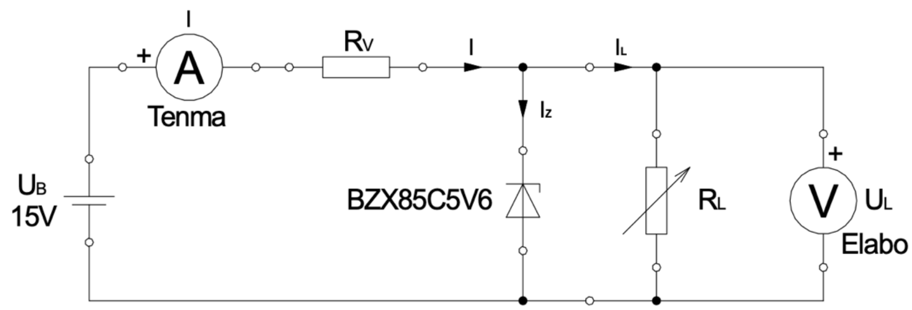
The SETUP

In part 4 of this experiment, we demonstrate the use of Zener Shunt Regulator in the circuit below. Unlike normal diodes, this type of diode is used in reverse and is also used to stabilize and limit voltages. Below is shown a Zener Shunt Regulator:



This circuit acts as a current divider. The current through Rv is supplied to RL and the diode.

In this experiment, we needed to supply a constant voltage and current over the load. The voltage over the load was set to 5.6 V and the current over the load was set to 10 mA. We set up the circuit as below:



Execution and results:

Rv should be calculated for two cases: when Iz = 1mA and Iz = 10mA. To calculate Rv, we assume that the load is 10mA at 5.6 V. The calculated values of Rv are show below:

When Iz= 1mA, ***Rv= 854 Ohms.***

When Iz= 10mA, ***Rv= 470 Ohms.***

Then, we need to record Current (I) and Voltage (UL) from the multimeters, for load resistors being 56R, 560R, 5K60 and with an open circuit i.e., without RL. The readings recorded are tabulated below:

When Rv= 470 Ohms:

RL/Ohm	Current(A)	Voltage(UL)
56.00	0.02826	1.58600
560.00	0.02000	5.54700
5600.00	0.01991	5.58700
Open	0.01990	5.59100

When Rv= 854 Ohms:

RL/Ohm	Current(A)	Voltage(UL)
56.00	0.01636	0.91900
560.00	0.01115	5.42800
5600.00	0.01101	5.54700
Open	0.01100	5.55300

3. Evaluation

3.1 Part 1: Determine Anode and Cathode

Question:1 Use the measurements to explain which terminal of the diode is the anode, and which one is the cathode? In general the lead with the ring has the same polarity for every diode!

Solution:

We used the ring as reference to determine the polarity of the diode. When the ring of the diode was connected to the negative of the power supply, we received a voltage drop of 0.7165V across the diode and the current reading of 20563.0 uA.

When the ring of the diode was connected to the positive of the power supply, we received a voltage drop of 12.0910 V across the diode and the current reading of 1.110 uA.

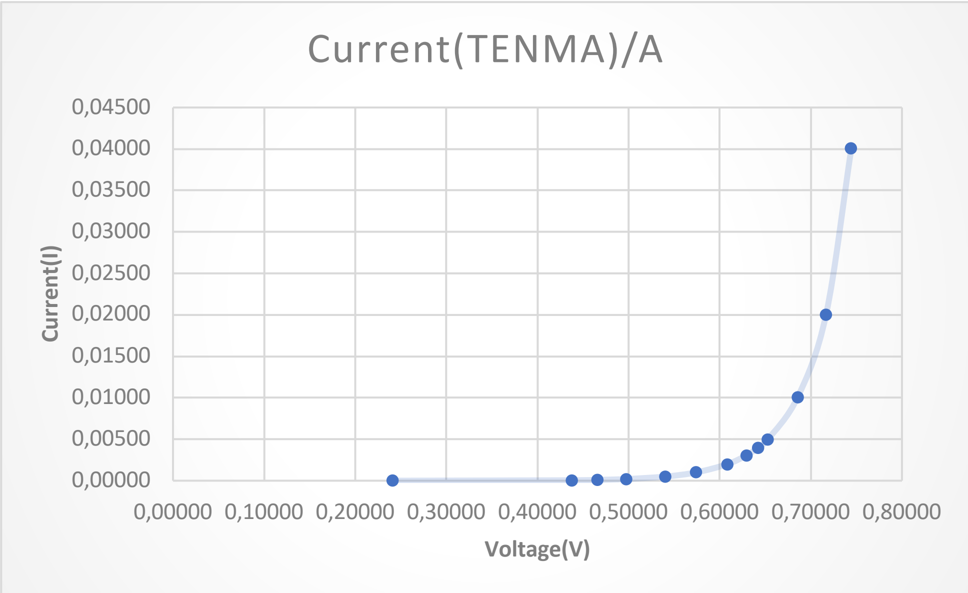
This means that the diode conducts when the ring is connected to the negative of power supply and does not conduct when the ring is connected to the positive of the power supply. From this it can be well inferred that the ring of the diode is the cathode and the side without the ring is the anode. Therefore, the diode is connected in forward bias if the cathode faces the negative side of the power supply and in reverse bias if the cathode faces the positive side of the power supply.

3.2 Part 2: Forward I-V curve of general-purpose diode.

Question:1 Plot the diagram $I_F = f(U_F)$.

Solution:

The following graph is creating based on the values we recorded in the part 2 of this experiment:



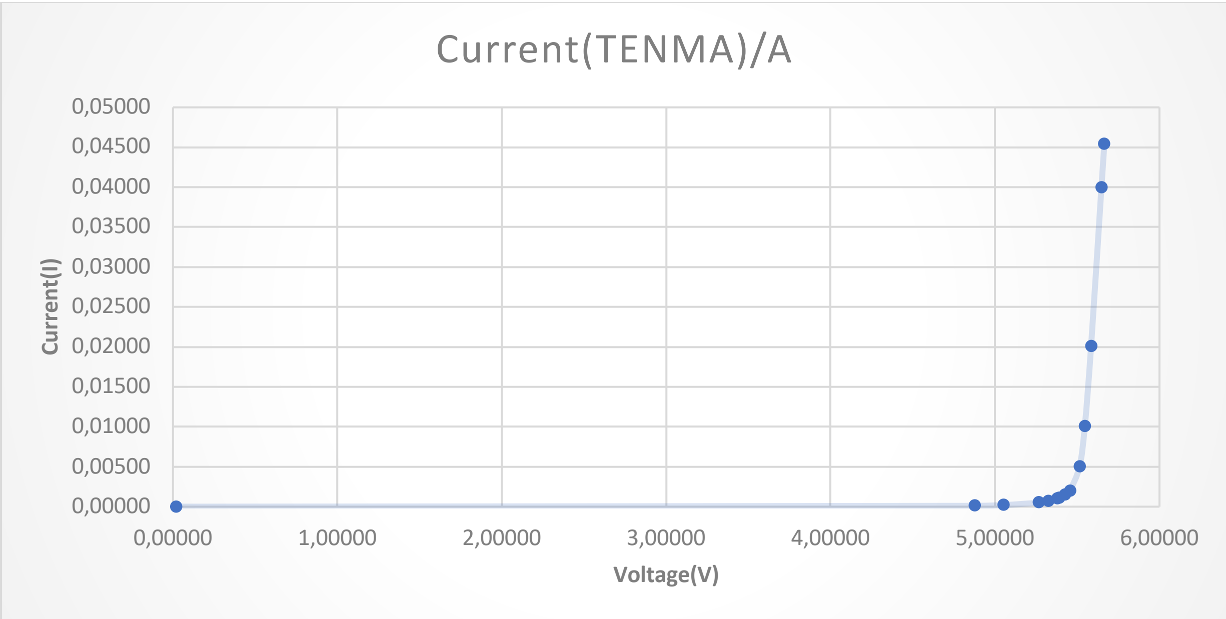
From the graph, it can be noticed that the current starts escalating at around 0.6V. The exponential nature of the curve reflects the typical behavior of diodes.

3.3 Part 3: Reverse and Forward characteristic of a Z-diode.

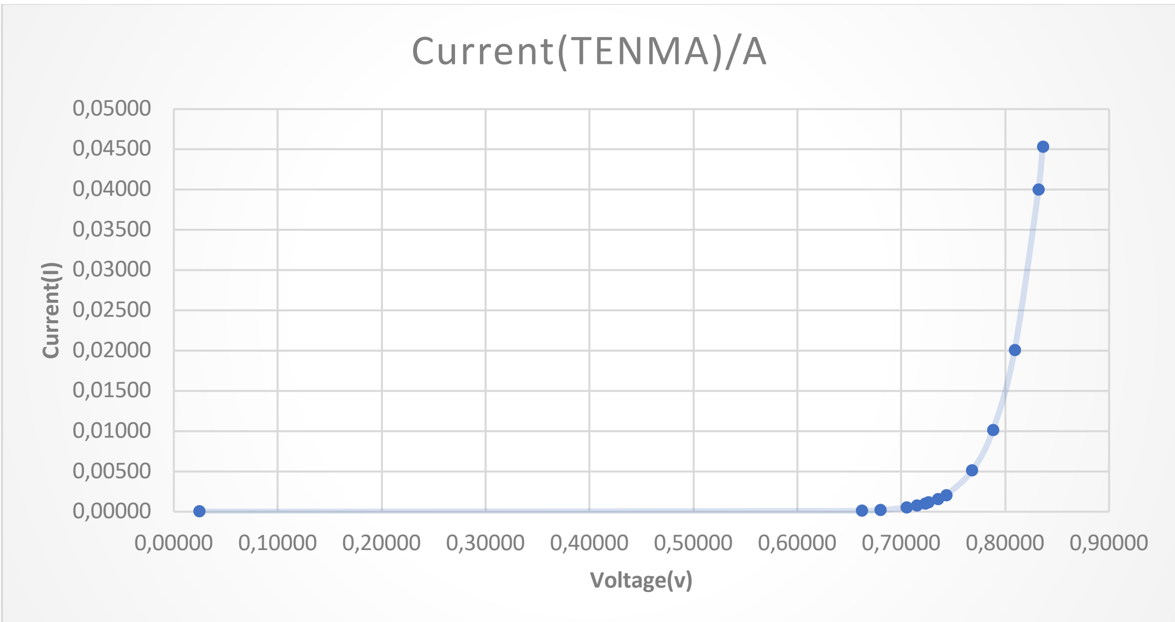
Question:1 Plot I = f(U) for both directions.

Solution:

In reverse direction (when the ring is connected to the positive side of the supply):



In forward direction (when the ring is connected to the negative side of the supply):



Question:2 Determine the differential resistance of the diode at Z_{ZT}@I_{ZT} = 45 mA and Z_{ZK} @I_{ZK} = 1 mA in reverse direction from your experimental data? Compare with the data sheet. What information do you get from the differential resistance?

Solution:

At Z_{ZT} @I_{ZT} = 45mA in reverse direction,

Differential Resistance= (V(at 45 mA)- V(at 40mA))/ (I(at 45 mA)- I(at 40mA))

= (5.66500-5.64700)/ (0.04545-0.03999)

= 3.29670 Ohms

At Z_{ZT} @I_{ZT} = 1mA in reverse direction,

Differential Resistance= (V(at 11 mA)- V(at 10mA))/ (I(at 11 mA)- I(at 10mA))

= (5,39000- 5,37800)/ (0,00110 - 0,00101)

= 126.98 Ohms

Differential Resistance for Z_{ZT} @I_{ZT} = 45 mA/ Ohms	**Differential Resistance for** Z_{ZK} @I_{ZK} = 1 mA/ Ohms
3.29670	126.98413

According to the data sheet, for Zener Diode BZX85C 5V6, the differential resistances for Z_{ZK}@I_{ZK} is 400 Ohms, and for Z_{ZT} @I_{ZT} is 7 Ohms. From our calculations, we get the values of Z_{ZK}@I_{ZK} as 126.98 ohms and *of* Z_{ZT} @I_{ZT} as 3.29 ohms. The data in data sheet accounts for the maximum possible value of differential resistance so it would be safe to say that the values we calculated are well within the bounds with unsignificant errors.

3.4 Part 4: A Zener Shunt Regulator

Question:1 Show the full calculation for R_V.

Solution:

Over Rv, the voltage drop is:

$$V \text{ at } Rv= (15-5.6)\ V= 9.4V$$

When Iz= 1mA,

Using Kirchhoff's current law:

$$Total\ Current(I) = Iz + IL= 1mA + 10mA= 11mA$$

$$Resistance = V/I= 9.4/ (11*10\text{^}(-3))= 854.4\ \Omega$$

When Iz= 10mA,

Using Kirchhoff's current law:

$$Total\ Current(I) = Iz + IL= 10mA + 10mA= 20mA$$

$$Resistance = V/I= 9.4/ (20*10\text{^}(-3))= 470\ \Omega$$

Question:2 Compile a table with the measured values.

Solution:

When Resistance(R)= 854.4 Ω,

RL/Ohm	Current(A)	Voltage(UL)
56.00000	0.01636	0.91900
560.00000	0.01115	5.42800
5600.00000	0.01101	5.54700
Open	0.01100	5.55300

When Resistance(R)= 470 Ω,

RL/Ohm	Current(A)	Voltage(UL)
56.00000	0.02826	1.58600
560.00000	0.02000	5.54700
5600.00000	0.01991	5.58700
Open	0.01990	5.59100

Question:3 Describe the function of the circuit.

Solution:

The function of this circuit is to maintain a constant voltage between the loads. It limits and does not let the voltage go over 5.6 V. If the load resistance is big, most of the current flows through the Zener diode leaving a constant voltage over the load resistance. It can be noticed that for Resistance of load equal to 56 Ohms, voltage drop is very small and current flow is high.

Question:4 Why is it not advisable to use loads with a too low resistance?

Solution:

When we use loads with low resistance, the current flow through the load will be high which leads to low current flow through the Zener diode. Because of this, the diode does not reach the break point required affecting the voltage regulation for the load. To attain a constant voltage supply, we need a load resistance that is big enough that it won't cause the voltage over the diode lower than the breakdown voltage. As a result, we do not get a constant voltage supply of 5.6V.

Conclusion

In part 1 of this experiment, we evaluated the basic workings of a semi-conductor diode. We measured the voltage drop through the diode and current to determine the polarity of the diode. Using the ring of the diode as the point of reference, we were able to conclude that when the ring i.e., the cathode was connected to the negative of the power supply, the diode is forward biased i.e., the diode lets current pass through it. However, if the ring is connected to the positive of the supply, it is reverse biased, and the diode will have infinite resistance blocking the flow of current.

On part 2, we observe the V-I characteristics of a diode when in forward bias. After we graphed the data we collected, it was observed that after the voltage supply reaches around 0.6V, the current flow increases significantly for small changes in voltage value. This value is also referred to as the knee value of a diode. After the knee value is reached, the diode starts acting like a short circuit.

On part 3, we observed the properties of a Zener diode. A Zener diode is a type of diode which allows the flow of current even when it is in reverse direction but only when a specific voltage called the voltage breakdown is achieved. If this value is not achieved, the diode acts as a big resistor just like a normal diode when in reverse bias. When connected in forward bias, the Zener diode functions as a normal diode.

For part 4 of this experiment, we understood the usage of the Zener diode in a Zener Shunt Regulator. With this type of circuit, we ensure that the voltage over the load is constant when few conditions are met. Analyzing our results, we can say that the resistance of the load should be substantial enough so that the diode can pass the breakdown voltage. This is because when the load resistance is low, the current flow through the load will be high resulting in the current through the diode being less.

We have done errors in this experiment as well. Types of errors that might have been done in this experiment might include the diode heating up altering the characteristics of the elements, relative errors due to the instruments, and random errors.

4 References

I. Lab Manual

Jacobs University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2021

Lab Experiment 5 –

Transistor Characteristics

Author of the report
Ramin Udash

Experiment conducted by : Ramin Udash, Dhespina Pepa Pecini
Place of execution : Teaching Lab EE Room 1, Bench 1 and 2
Date of execution : October 1, 2021

Part 1: Input Characteristic

Power Source/V	Ube	Ibe(A)	Voltmeter Range	Ammeter Range	I
0.4	0.0055	0	2	uA	0
0.6	0.6234	5.67E-06	2	uA	5.00E-06
0.7	0.6484	1.02E-05	2	uA	1.00E-05
0.8	0.6681	2.09E-05	2	uA	2.00E-05
1	0.6863	4.01E-05	2	uA	4.00E-05
1.2	0.698	5.06E-05	2	uA	6.00E-05
1.5	0.7071	8.16E-05	2	uA	8.00E-05
1.7	0.7136	1.01E-04	2	uA	1.00E-04
2.8	0.7371	2.01E-04	2	uA	2.00E-04
4.9	0.7633	4.00E-04	2	uA	4.00E-04
7	0.772	6.06E-04	2	uA	6.00E-04
9.2	0.7886	8.10E-04	2	uA	8.00E-04
11.3	0.8124	1.01E-03	2	uA	1.00E-03

Readings after the polarity of the source was interchanged and the second supply was removed:

Power Source/V	Voltmeter Range	Ammeter Range	Ibr(uA)	Ube
0	20	uA	0	-0.0088
8	20	uA	-5.11E-06	-8.063
8.1	20	uA	-1.04E-05	-8.064
8.2	20	uA	-2.05E-05	-8.065
8.4	20	uA	-4.07E-05	-8.064
8.6	20	uA	-6.16E-05	-8.064
8.8	20	uA	-8.09E-05	-8.067
9	20	uA	-1.01E-04	-8.068
10.1	20	uA	-2.02E-04	-8.071
12.2	20	uA	-4.03E-04	-8.079
14.3	20	uA	-6.04E-04	-8.085
16.4	20	uA	-8.04E-04	-8.092
18.6	20	uA	-1.01E-03	-8.099

Part 2: Output Characteristic

When Ib= 20uA,

For IB=20uA			
Collector Supply	Uce(V)	Ice/A	Power(W)
0	0.03100	1.70E-05	5.27E-07
0.2	0.20500	2.82E-03	5.77E-04
0.4	0.40600	2.84E-03	1.15E-03
0.6	0.60000	2.85E-03	1.71E-03
0.8	0.81900	2.85E-03	2.34E-03
1	1.03000	2.86E-03	2.94E-03
2.5	2.51400	2.90E-03	7.29E-03
5	5.07400	2.96E-03	1.50E-02
10	10.08200	3.08E-03	3.10E-02
15	15.14400	3.19E-03	4.82E-02
20	20.06000	3.35E-03	6.71E-02

When Ib= 40uA,

For IB=40uA			
Collector Supply	Uce(V)	Ice/A	Power(W)
0	0,03100	1,70E-05	5,27E-07
0,2	0,20380	5,77E-03	1,18E-03
0,4	0,40740	5,85E-03	2,38E-03
0,6	0,60850	5,87E-03	3,57E-03
0,8	0,80160	5,89E-03	4,72E-03
1	1,00370	5,91E-03	5,93E-03
2,5	2,50100	6,01E-03	1,50E-02
5	5,02800	6,17E-03	3,10E-02
10	10,03600	6,55E-03	6,58E-02
15	15,05000	7,04E-03	1,06E-01
20	20,08000	7,54E-03	1,51E-01

When Ib= 60uA,

For IB=60uA			
Collector Supply	Uce(V)	Ice/A	Power(W)
0	0.001	4.60E-05	4.60E-08
0.2	0.2032	9.13E-03	1.85E-03
0.4	0.4065	9.20E-03	3.74E-03
0.6	0.6146	9.15E-03	5.63E-03
0.8	0.8053	9.12E-03	7.34E-03
1	1.009	9.11E-03	9.19E-03
2.5	2.513	9.29E-03	2.34E-02
5	5.092	9.76E-03	4.97E-02
10	10.019	1.05E-02	1.05E-01
15	15.05	1.15E-02	1.73E-01
20	20.66	1.27E-02	2.62E-01

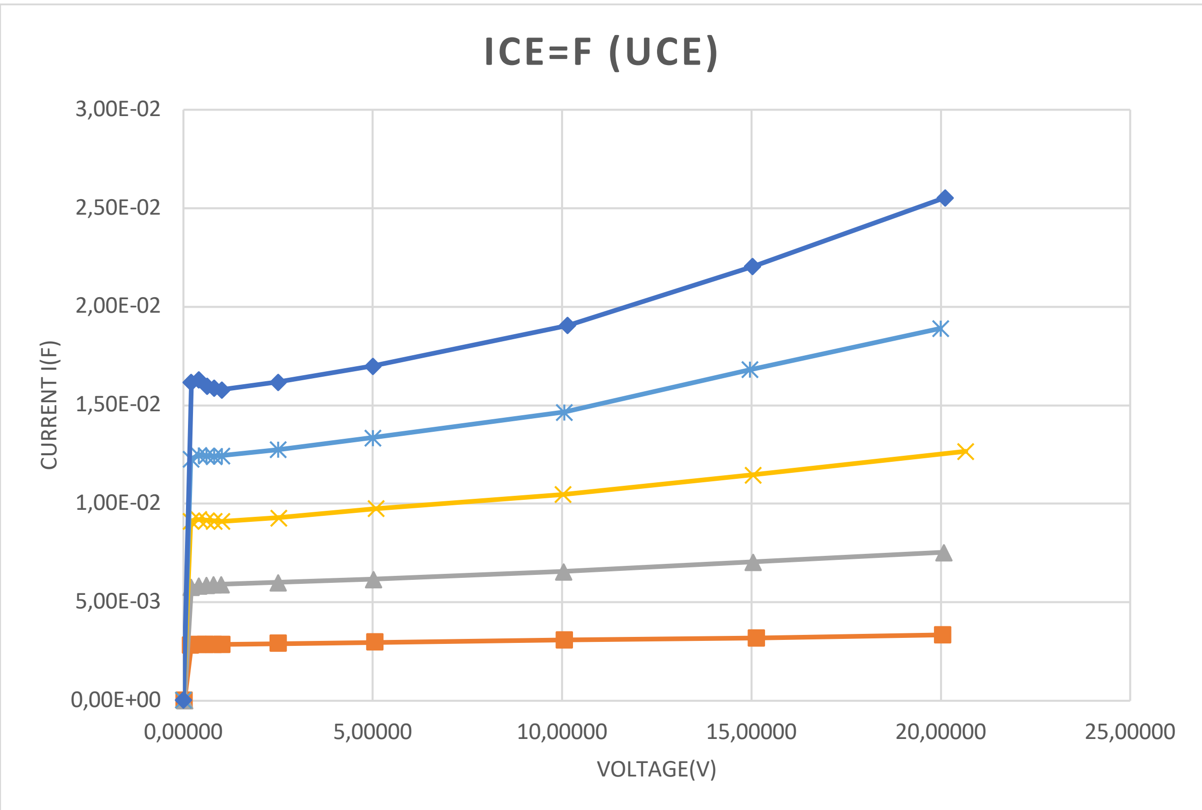
When Ib= 80uA,

For IB=80uA			
Collector Supply	Uce(V)	Ice/A	Power(mW)
0	0.0001	5.10E-05	5.10E-09
0.2	0.201	1.23E-02	2.47E-03
0.4	0.4106	1.25E-02	5.11E-03
0.6	0.6028	1.24E-02	7.50E-03
0.8	0.8042	1.24E-02	9.99E-03
1	1.0209	1.24E-02	1.27E-02
2.5	2.5	1.27E-02	3.19E-02
5	4.999	1.33E-02	6.67E-02
10	10.06	1.46E-02	1.47E-01
15	14.963	1.68E-02	2.52E-01
20	19.99	1.89E-02	3.78E-01

When Ib= 100uA,

For IB=100uA			
Collector Supply	Uce(V)	Ice/A	Power(W)
0	0.0028	5.10E-05	1.43E-07
0.2	0.2097	1.62E-02	3.39E-03
0.4	0.4125	1.63E-02	6.72E-03
0.6	0.6216	1.60E-02	9.93E-03
0.8	0.8096	1.59E-02	1.29E-02
1	1.0159	1.58E-02	1.60E-02
2.5	2.508	1.62E-02	4.06E-02
5	5.005	1.70E-02	8.51E-02
10	10.148	1.91E-02	1.93E-01
15	15.032	2.20E-02	3.31E-01
20	20.11	2.55E-02	5.14E-01

Combined graph for all five values of Ib:



After we finished with that part we recorded Ice for values of Ib = 100 µA; 200 µA; 300 µA; 400 µA, and 500 µA with Uce set to 1 V . The Uce was adjusted every time after we altered the Ib.

Recorded data is tabulated below:

Ib/ A	Ice/ A	Uce/ V
1.00E-04	0.01485	1
2.00E-04	0.03192	1
3.00E-04	0.04536	1
4.00E-04	0.06176	1
5.00E-04	0.00008	1