# STUDY OF MEMRISTOR MODEL IN CIRCUIT INTERCONNECT

By

NURAINA AKMAL BINTI MISMAN

15039

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering

In Partial Fullfilmen of the Requirements

For the Degree

Bachelor of Engineering (Hons)

(Electrical & Electronic Engineering)

JAN 2015

Universiti Teknologi PETRONAS

32610 Bandar Seri Iskandar

Perak Darul Ridzuan

**CERTIFICATION OF APPROVAL**

**STUDY OF MEMRISTOR MODEL IN CIRCUIT INTERCONNECT**

By

Nuraina Akmal binti Misman

A project dissertation submitted to the

Department of Electrical & Electronic Engineering

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical & Electronic Engineering)

Approved:

_________________________

Nooraini binti Zainuddin

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

Jan 2015

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained here in have not been undertakn or done by unspecified sources or persons.

________________________________

NURAINA AKMAL BINTI MISMAN

# ABSTRACT

Memristor is another fundamental circuit element in electrical after resistor, capacitor and inductor. Found in year 2008 after only being a theory for almost 40 years, the application of memristor in communication field is widely used. The special ability of memristor is storing a data or memory. For the time being, there are only two device that identified as a memristor. The device are Titanium Dioxide and Iron Coherer. Titanium Dioxide is a device fabricated by HP while Iron Coherer used the be important device in radio technology. Both device have the same characteristics, which is also the fingerprint of memristor, pinched hysteresis loop of current voltage characteristics. However, the other characteristics of both device is different as the device different in size and type. The objective of this research is mainly to study the behaviour of iron coherer as a memristor and applied in selected circuit interconnect, thus analyse the effect. Preliminary research is done to collect the necessary information to achieve the objective. Few experiments were conducted towards the iron coherer. Further discussion is made to come out with a conclusion of the proect and recommended steps a listed for future study. The results shows that the unrelevancy of using experimental approach towards the study of iron coherer as a memristor and effect of iron coherer to the LED circuits.

## ACKNOWLEDGEMENTS

There were many people involved throughout the process of completing this Final Year Project. Many advice, guidance, assistance, motivation and support were given. It was a very valuable experience and many lessons obtained to complete the project. I would like to express my highest gratitude to all individuals that have givenn their precious time to assist me in completing the project. Without the cooperation given from these people, I would have to face many difficulties.

Special thanks to my supervisor, Ms. Nooraini binti Zainuddin for her guidance, assistance and support during my period of completing the project. Thanks also to my co-supervisor, Dr Ho Tatt Wei for the sharing and questions to help me strengthen my fundamental knowledge and motivate me as well. Thanks to the Fina Year Coordinator, Dr Nasreen Badruddin and the Final Year Project Committees for their information and guidance given for the project.

Thanks to the technicians and coursemate who provided many valuable advices and hept throughout the project. To both my parents, thank you for the motivation and support given during the hardships in completing the project.

Finally, I would like to apologize if any party was inadvertently excluded from being mentioned above.

**TABLE OF CONTENTS**

**LIST OF FIGURES**



.

# LIST OF TABLES

# CHAPTER 1: INTRODUCTION

## 1.1 Background

In 1971, Chua has discovered new circuit elements named as memristor [1]. 37 years after that, in year 2008, the memristor theory is proved when it was invented by the Hewlett Packard (HP) lab researchers [2]. Since then, there are too many applications of memristor in many devices and memristor is not only have the capability to store data or memory, but it also has many special functions [1,8]. Memristor not only can be built from Titanium Dioxide (Ti$O_2$) [2] but also other material.

In this project, the behaviour of iron coherer as a memristor will be studied. The implementation of the memristor in circuit interconnect will be analyzed.

## 1.2 Problem Statement

Memristor is only a theory when it was first discovered. After the HP lab researchers successfully producing one physical memristor, many people are following their step by producing their own memristor or applying the memristor in any devices. Many effect and function of the memristor can be seen in their research [6,8,9,10].

In this Final Year Project, the memristor will be implemented in the circuit interconnect and thus study its effect towards the circuit.

## 1.3 Objectives

The objectives for this FYP are as follows:

1. To study the behaviour of iron coherer as a memristor.
2. To implement the iron coherer in the circuit interconnect.
3. To study the influence of the iron coherer on the circuit interconnects.

### 1.4 Scope of study

The scope of this study are as follows:

1. Understanding the theory and properties of memristor.
2. Understanding the properties of iron coherer as a memristor.
3. Applying iron coherer in circuit interconnect.
4. Study the effect of iron coherer to circuit interconnect.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 Memristor

In the world of electrical, there is three fundamental circuit elements – resistor *R*, inductor *L*, and capacitor *C*. However, in year 1971, [1] Chua, had proposed that there is fourth elements electrical that is memristor which simplified name of memory resistor. During this time, memristor was only a theory, which is derived from the fundamental circuit variables – current *i*, voltage *v*, charge *q* and the flux-linkage *φ*. The circuit elements are defined from the relationship of these fundamental circuit variables which are the resistor is defined from the relationship between *v* and *i* – ($dv = R\, di$), the inductor is defined from the relationship between *φ* and *i* – ($d\varphi = L\, di$) and the capacitor is defined from the relationship of *q* and *v* – ($dq = C\, dv$). Chua claimed that memristor was the missing link in the pairwise mathematical equation that relate the circuit variables and defined from the relationship of *φ* and *q* which is represented as [3, 19]

$$M(q) = d\varphi / dq$$

Memristor have the same unit as resistance, (Ohm) and it is a charge controlled resistance.

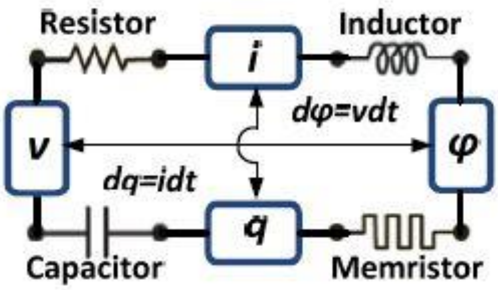


Figure 1. Four fundamental circuit elements including memristor which Chua argued**.**

In 1976, Chua and Kang had presented the broad generalization of memristor to a class of device system called memristive system[4].

As per stated by Chua, if an object is pinched, it is a memristor, which make the properties of pinched hysteresis loop as the fingerprint of memristor [ ]. The special criteria of the memristor is it can store the memory or data. The electrical resistance is not constant but depend on the history of the current that has flow through it [6]. As an addition, the memory storing can be done without the power supply. Ions are used by the memristor to store the data. When charge is applied to the memristor, the ions will move in a tiny distance which cause the change in resistance in power lost condition [7].

### 2.2 Memristance

Memristance is a property of the memristor [ ]. In a circuit, when the charge flows in one direction through it, the resistance of memristor will increase. If the charge flow in opposite direction, the resistance decreases. When a voltage is applied to a memristor, charge will flow, and when it is turned off, the charge flow will stop and the memristor “remembers” the last resistance that it had. When the flow of the charge is start again, the resistance of the circuit will be what it was when it last active.

### 2.3 The Function and Effect of Memristor

After the existence of memristor in year 2008, many people have done the research about the memristor. The memristor not only can store data, but throughout the research, many function of resistance are recorded [6,8,9,10].

Chua has again make some improvement in his memristor research combine with other research with Itoh from Fukuoka Institute of Technology, Japan [6]. They concluded that memristor is useful to design nonlinear oscillator. With a control scheme, memristor can provide a simple realization of digital potentiometer. Few memristor-based programmable analog circuit had been built using a memristor emulator [8].

Memristor also can be applied for programmable interconnect circuit. The input for the memristor, which is in the waveforms is controlled precisely by programming it to be unbalanced or not. Memristor is useful and have broad-range of application in electronics [8].

In addition, binary massage can be stored in memristor, no matter the memristance value is high or low. This condition lead to the development of memristor-based amplitude-shift-keying, frequency-shift-keying and binary-phase-shift-keying modulator [9]. More advance application were done by the researchers from China, when they manage to apply the memristor in the microwave devices. They explored the memristor to be used in some other planar radio frequency devices. In this study, memristor also found to be effective in reducing power dissipation in the future [10].

## 2.4 Titanium Dioxide as Memristor by Hewlett Package (HP)

The memristor and memristive system was just a theory for almost 40 years [5], until in year 2008, after doing research for six years, the researchers at Hewlett Packard (HP) presented the physical model of two-terminal electrical device that have the characteristics of the memristor perfectly for a certain range of state variable [2]. The memristor designed by the researcher is made from Titanium Dioxide ($TiO_2$) thin films [2]. It is consisted of two sets of 21 parallel 40-nm-wide wires crossingn over each other to form a crossbar array that were fabricated using nano imprint lithography. 20-nm-thick layer of the semiconductor $TiO_2$ was sandwiched between the horizontal and vertical nanowires, forming a memristor at the intersection of each pair of wire. Technology may enable functional scaling of logic and memory circuits beyond the limits of complementary metal-oxide-semiconductors with the characteristics of electrical switching in the thin-film devices. They proposed that the atomic arrangements modulates the electronic current cause the hysteresis [2].

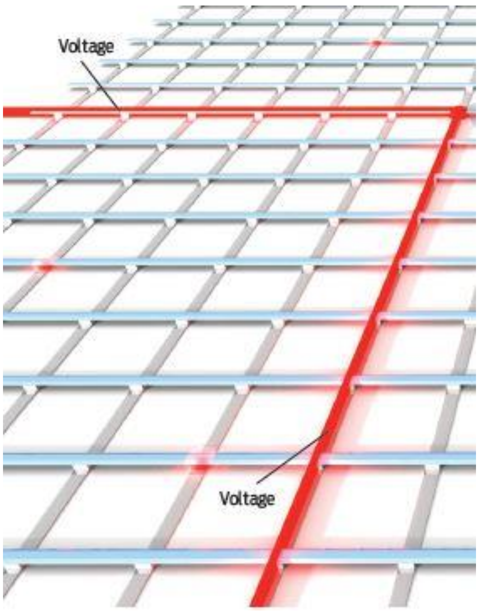


Figure 2 .The crossbar architecture of $TiO_2$ consists of fully connected mesh of wires.

The dopants in $TiO_2$ don't stay stationary in a high electric field so that they tend to drift in the direction of the current. The oxygen atoms are negatively charged ions and have huge electrical field. The size of the electrical field allows oxygen ions move and change the material's conductivity which is a requirement for a memristor. Two thin $TiO_2$ is then sandwiched between 5 nm thick electrodes. A small electrical current was applied causes the atoms to move around and changing quickly from conductive to resistive, which enable memristor functionality [2].

The oxygen vacancies drift changing the boundary between the high resistance and low resistance layers when an electric field is applied. The whole resistance of the film will be dependent on how much charge has been passed through it particular direction, which can be reverse by changing current direction. HP device displays fast ion conduction at nanoscale, so it is considered as a nanoionic device.  When the device is shut down, oxygen atoms stay put, maintaining their state and data they represent [2].

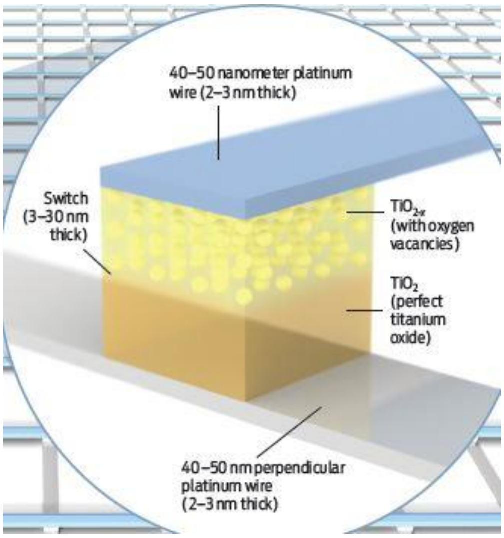


Figure 3. Close up view of Ti$O_2$ that sandwiched between horizontal and vertical wires with oxygen vacancies.

### 2.5 Iron Coherer as a Memristor

A study by Gandhi and Aggarwal have concluded that iron coherer is an elusive memristor [12]. Their discovery provides a simple memristor to physicist and engineers for widespread experimentation.

Figure 4. An iron coherer.

Coherer previously used as signal radio detector consists of ball bearings, metallic fillings in a tube or a point-contact shows an initial high resistance state and coheres to a low-resistance state on the arrival of radio waves. After being tapped mechanically, it attains its original resistance. The study discovered that coherers which was considered as one-way electrical fuses, exhibits bipolar electrical switching formed by the simple point-contact or granular arrangement formed of metal pieces. Furthermore the study found that the state variable controlling the resistance state and the device can be programmed to switch between multiple stable resistance states.

Further research were done by Gandhi and Aggarwal together with Kwarta and Chadha, which is analog circuits implementation using coherer based memristor [13]. From the observations, the device exhibit maximum current resistance behavior (Imax), the resistance changes as the maximum current passing through the device changes that demonstrates that the device at certain level has some kind of memory which makes it remember the amount of current that pass through it.

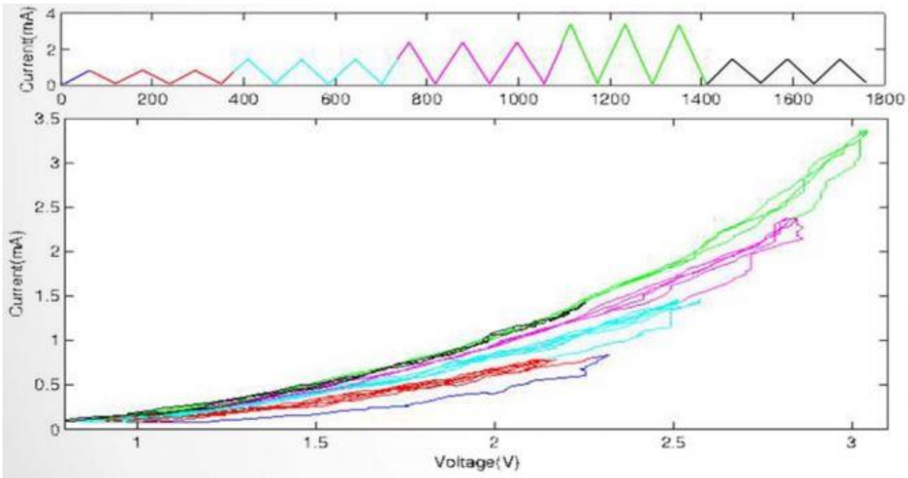


Figure 5. Resistance change as maximum current changing.

They also found that the device has bistable memristive behavior. Under suitable bipolar input, the device exhibits pinched hysteresis.

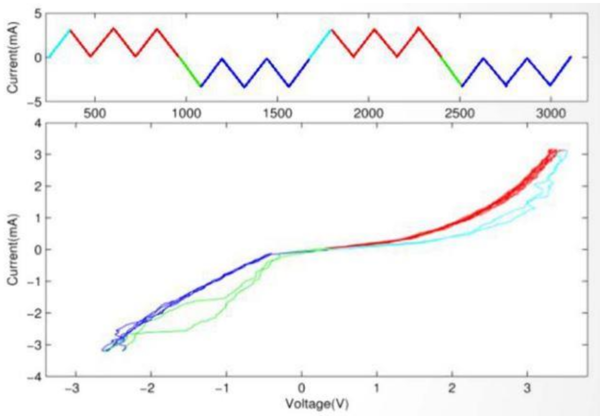


Figure 6. Device exhibits pinched hysteresis give bipolar input.

The iron coherer built by the team, have nonlinear characteristics in graph of voltage across memristor vs input voltage which is proportional to the memristor's current voltage characteristic

# CHAPTER 3: METHODOLOGY

## 3.1 Research Methodology

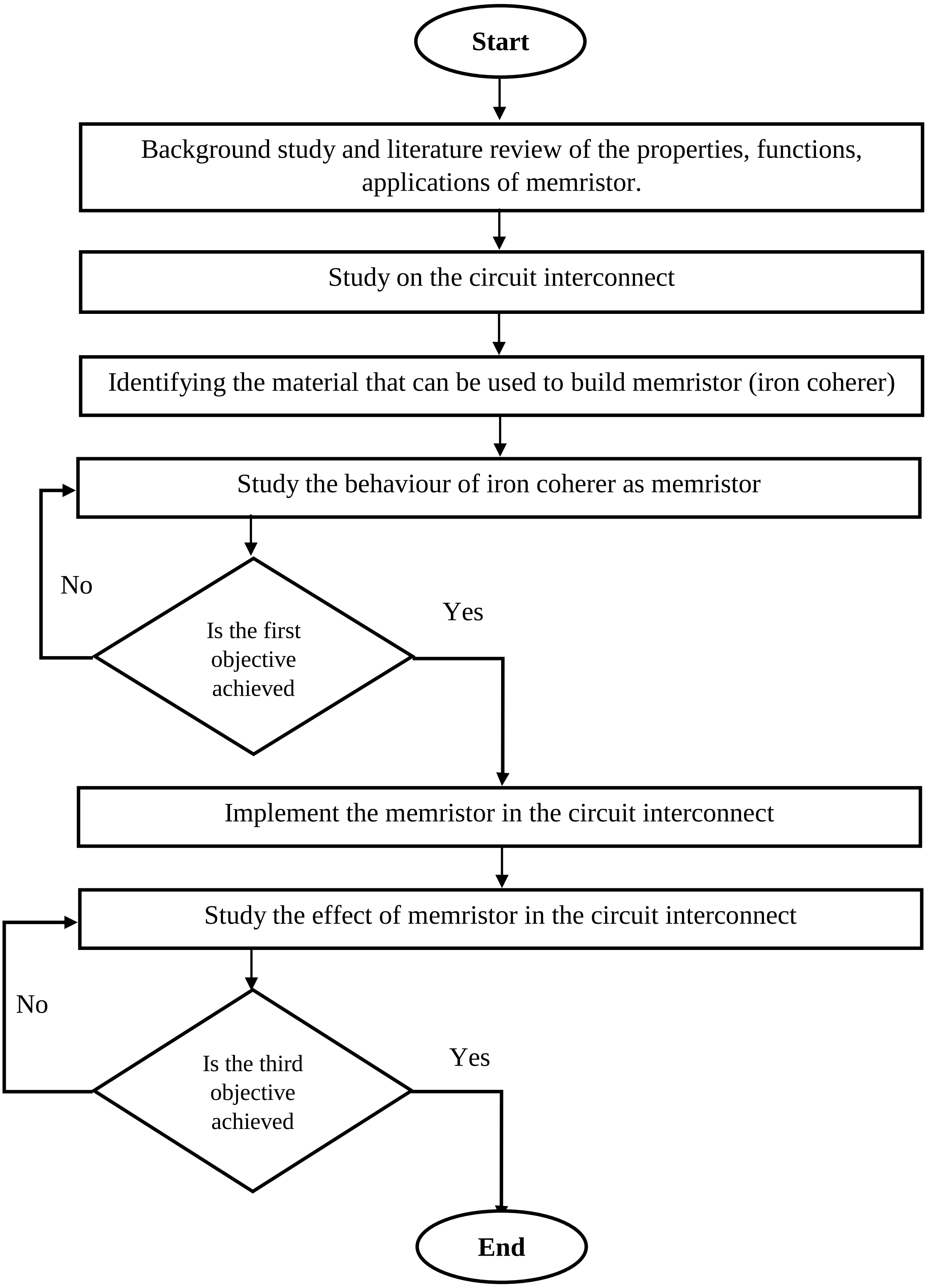


Figure 7. Research Methodology and Project Activities

### 3.1.1 Preliminary Research Work

This stage focuses on data collection related to the project. All information existed from journals, articles, technical papers and books that are related to the project are gathered and compiled to have a better understanding to the project.

A meeting with the supervisor and co-supervisor also were done in order to get some idea to continue this project.

### 3.1.2 Lab Experiment

As explained in the literature review, iron coherer is the simplest memristor. So, in this project, an iron coherer was made in order to study the behaviour of memristor.

<u>Fabrication of iron coherer</u>

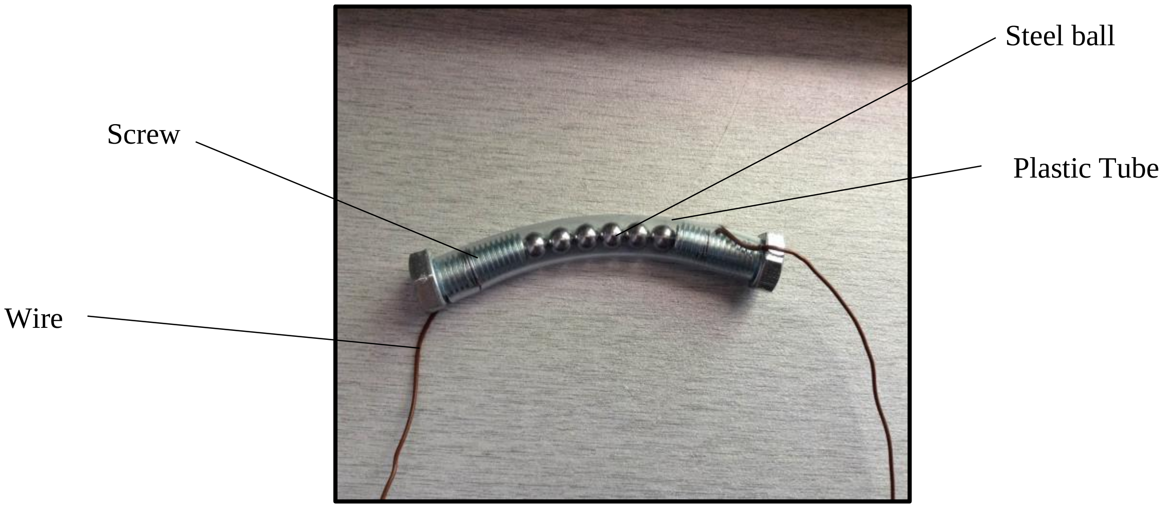


Figure 8. Iron Coherer Fabricated.

Iron coherer is replicated from the study of G.Gandhi and V.Aggarwal in [12]. Six steel balls were put in the plastic tube and closed by two screws. There must be no space between each steel ball, to make sure each steel have contact between them to enable switching between resistance state as stated in [13].

**Experiment 1**

**Objective** : To prove the iron coherer fabricated is a memristor.

**Equipment :** Resistor, Iron Coherer, Voltage Supply, Oscilloscope, Wire

**Method** : Experiment in [12] is replicated. In this circuit, iron coherer is put series with a 2 kΩ resistor, with one terminal is connected to the ground. The voltage across the memristor and the voltage input is connected to the oscilloscope to measure the relationship graph.

The circuit is represented as below :

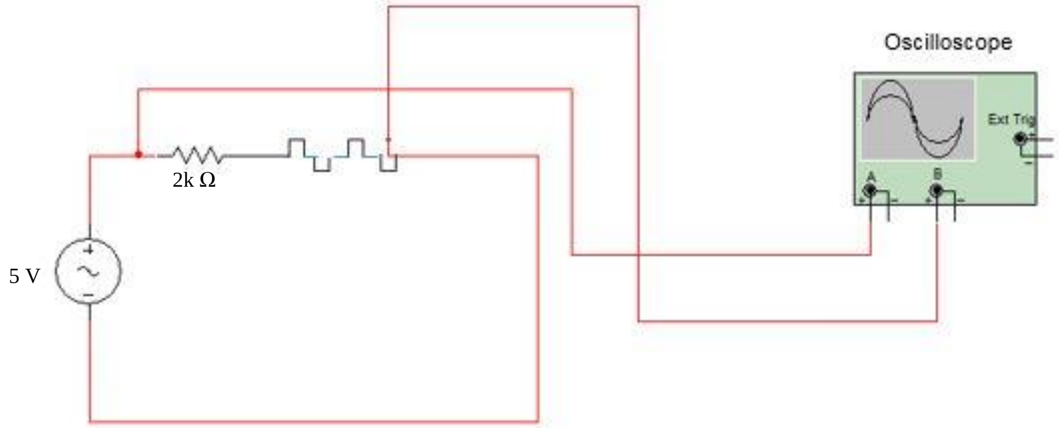


Figure 9. Circuit of Experiment 1.

**Expected Output** :

The graph in oscilloscope is expected to give the result as below :

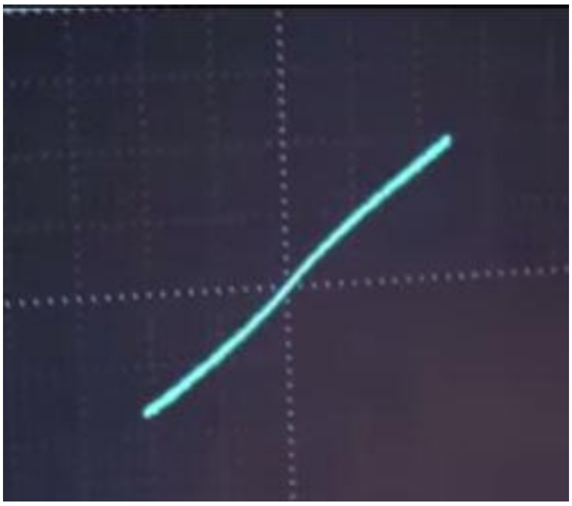

Figure 10. Oscilloscope Reading in Experiment by G.Gandhi and V.Aggarwal

The graph is the relation of voltage across iron coherer vs voltage input. It represented all voltage current relationship of iron coherer. It should give non linear reading which is the characteristics of the memristor.

**Experiment 2**

**Objective** : To implement iron coherer in LED circuit and analyse the effect.

**Equipment :** Resistor, Iron Coherer, Voltage Supply, Wire, Red LED.

**Method** : LED circuit is first connected without iron coherer. Next, iron coherer is put series with a 2 kΩ resistor, and then series with the LED.

The circuit is represented as below :


Figure 11. LED Circuit without Iron Coherer

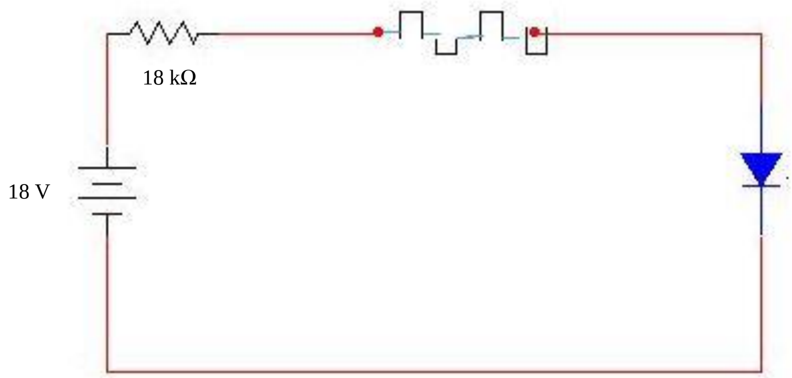


Figure 12. LED Circuit connected with Iron Coherer

In this experiment, the effect to the LED is observe and also the resistance reading of the iron coherer is compared with the LED circuit without iron coherer.

**Expected Output** :

The LED reading should be giving different output when it is connected with the iron coherer, compared to without iron coherer.

# CHAPTER 4: RESULTS AND DISCUSSIONS

**Experiment 1**

The graph represented in the oscilloscope is as below :

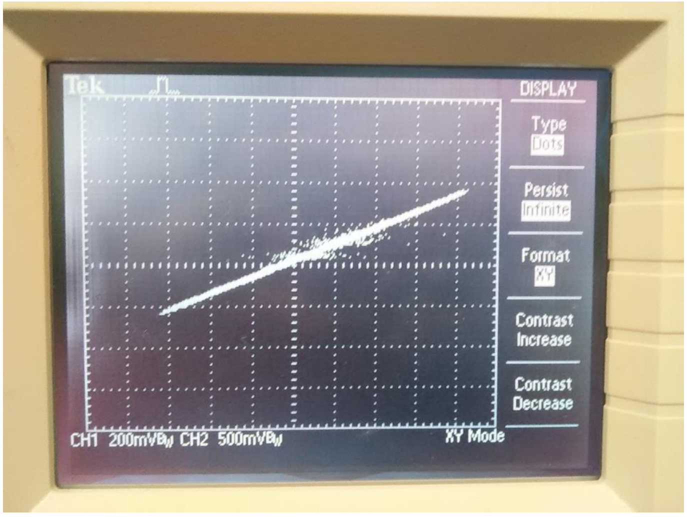


Figure 13. Graph of Voltage Across Memristor vs Voltage Input.

The graph of the voltage across memristor vs voltage input showing a linear relationship. As per stated in [12], the non linearity of the graph represented is influenced by the pressure given to the iron coherer. Higher pressure should give more non linear graph.

In this experiment, a few trial were done to get the non linear graph. A lot of pressure is given but still a linear graph is obtained. As mentioned in [12], coherer is very elusive, which the characteristics is not all the time can be seen.

The expected reason of the graph are not giving non linear are because of the pressure given to the iron coherer is not enough and the material might be giving the problem.

**Experiment 2**

| | LED Circuit without Iron Coherer | LED Circuit with Iron Coherer |
|---|---|---|
| LED Brightness | Bright | Dim |
| Current (A) | 0.015 | 0.001 |
| Voltage Supply (V) | 5 | 18 |
| Resistance (Ω) | 18k | 2k |

Table 1. Comparison of LED Circuit with Iron Coherer.

During the experiment, the resistance in the iron coherer was measured and gave the reading 25 MΩ.

The resistance value in the iron coherer was identified as the reason of the current giving the reading 0.001 and LED become very dim.

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

As for the conclusion, iron coherer characteristics as a memristor cannot be proved using the experiment by G.Gandhi and V.Aggarwal in [12]. Iron coherer is an elusive memristor [12] is another reason which it cannot be proved in this experiment which the characteristics cannot be proved by doing only few experiment.

Iron coherer gave the effect to the brightness of LED because of the high resistivity of the iron coherer. It have the ability to switch between multiple stable resistance states. The voltage was given in the direction which cause the iron coherer having a high resistance state. High resistance will reduce the current value flow, as stated in Ohm's Law,

$$V = IR$$

high resistance with fixed voltage gave small current.

For the recommendation, the experiment in proving the iron coherer by G.Gandhi and V.Aggarwal should not be follow as it does not give the detail instruction of the experiment. A good research using experiment should give a very detail information for it to be replicated.

As there is still no fix physical device of memristor, the study of the memristor is better to be done by simulation rather than having experimental.

**REFERENCES**


[1] L. O. Chua, "Memristor: The missing circuit elements," *IEEE Trans. Circuit Theory,* vol. CT-18, no. 5, pp. 507-519, 1971.

[2] D. B. Strukov, G. S. Snider, D. R. Stewart, and R. S. Williams, "The missing memristor found," *Nature 453,* pp. 80-83, 2008.

[3] H. Yenpo, L. Peng, M. H. Garng, "Memristor System Properties and Its Design Applications to Circuits Such as Nonvolatile Memristor Memories," *Communications, Circuits and Systems (ICCCAS), 2010 International Conference,* p. 6, 2010

[4] L. O. Chua and S. M. Kang, "Memristive Devices and System," *Proc. IEEE,* vol. 64, no. 2, pp. 209-223, 1976.

[5] K. Kyungmin, S. Sangho, Sung-Mo (Steve) Kang, "Memristor Application for Programmable Analog Ics," IEEE Transaction On Nanotechnology, vol. 10, p. 9, 2011.

[6] L. O. Chua, M. Ito, "Memristor Oscillator," *International Journal of Bifurcation and Chaos,* vol. 18, p. 24, 2008.

[7] M. Fink (2014, August 14). *Beyond DRAM and Flash, Part 2: New Memory Technology for the Data Deluge Available*. Retrieved from http://www8.hp.com

[8] M. D. Ventra, Y. V. Pershin, "Practical Approach to Programmable Analog Circuits with Memristors," *IEEE Transaction On Circuit and Systems-I,* vol. 57, p. 8, August 2010.

[9] F. Oncul, I. C. Coknar, E. Minayi, "New Memristor Applications: AM, ASK, FSK, and BPSK Modulators," *IEEE Antennas and Propagations Magazine,* vol. 55, p. 10, 2013.

[10] K. D. Xu, L. Wang, M. Q. Yuan Q. H. Liu, W. T. Joines, Y. Fan, Y. H. Zhang , "Two Memristor SPICE Models and Their Applications in Microwave Devices," *IEEE Transaction On Nanotechnology,* vol. 13, p. 10, 2014

[11] K. Kerur, "A Study of The Memristor, The Fourth Circuit Element, "Master of Science, Department of Electrical and Computer Engineering, College of Engineering, Kansas State University, Manhattan, Kansas, 2010

[12] G. Gandhi (2013, June 16). *Coherer is the Elusive Memristor*, Retrieved from https://www.youtube.com

[13] G. Gandhi, P. Chadha, S. Kwatra,V. Aggarwal (2015, March 1), *Analog Circuits Implementation using Coherer based Memristor,* retrieved from http://www.ce.ewi.tudelft.nl/

[14] ] G. Gandhi, V. Aggarwal, "Bipolar Electrical Switching in Metal-Metal Contacts," Cornell University Library, 2013.