SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

ALOE-POLYSACCHARIDES THIN FILM AS ALL-NATURAL AND FLEXIBLE RESISTIVE RANDOM ACCESS MEMORY

By

YEAP KEE LEONG

Supervisor: Prof. Ir. Dr. Cheong Kuan Yew

Dissertation submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering with Honours

(Materials Engineering)

UNIVERSITI SAINS MALAYSIA

JUNE 2018

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "**Aloe-Polysaccharides Thin Film as All-Natural and Flexible Resistive Random Access Memory**". I also declare that it has not been previously submitted for the award for any degree or diploma or other similar title of this for any other examining body or University.

Name of Student : YEAP KEE LEONG Signature:

Date :

Witnessed by

Supervisor : Prof. Ir. Dr. Cheong Kuan Yew Signature:

Date :

ACKNOWLEDGEMENTS

Here I would like to express my most sincere appreciation to those people who had helped me in this research work. Firstly, I would like to faithfully thank my supervisor, Prof. Dr. Ir. Cheong Kuan Yew for his advice and guidance in making success of this project. Prof Cheong is a competent supervisor who always gives me support and led me along this research work.

Secondly, I also want to express my sincere appreciation to School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia (USM) for providing me a safe and convenience environment, required equipment and chemical materials to perform my research work. Also, technical staffs of the School of Materials and Mineral Resources Engineering have given their help and technical support for along my final year project. I am indeed to thank them for their kindly help and support.

Other than that, I would also like to show my appreciation to Prof. Ir Dr Cheong Kuan Yew's research team member, Mr. Lim Zhe Xi who has given me useful suggestion while I have faced some problems in the project.

Last but not least, I would like to thank to all my course mates for their helpful and spirit support during my research work.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TGA	Thermogravimetric Analysis
DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infrared Spectroscopy
FESEM	Field Emission Scanning Electron Microscopy
ITO	Indium tin oxide
SPA	Semiconductor Parameter Analyzer
RAM	Random Access Memory
PCB	Polychlorinated Biphenyl
TBBA	Tetrabromobisphenol A
PBB	Polybrominated Biphenyl
PBDE	Polybrominated Diphenyl Ethers
PVC	Polyvinyl Chloride
CFC	Chlorofluorocarbon
etc	et cetera
Cu	Copper
Au	Gold

Ba	Barium
Li	Lithium
Pb	Lead
Cd	Cadmium
Hg	Mercury
Cr	Hexavalent Chromium
Be	Beryllium
As	Arsenic
BFR	Brominated flame retardants
S	Sulphur
CO	Carbon monoxide
CO_2	Carbon dioxide
SO_2	Sulphur dioxide
H_2	Hydrogen
ROM	Read only memory
RAM	Random access memory

LIST OF SYMBOLS

ΔJ	Change of Current Density
^{o}C	Degree Celsius
mg	Milligram
min	Minute
nm	Nanometer
s	Second
μm	Micrometer
J	Current Density
V	Voltage
cm	Centimeter

ALOE-POLYSACCHARIDES FILEM NIPIS SEBAGAI SEMULAJADI DAN FLEKSIBEL INGATAN CAPAIAN RAWAK (RAM)

ABSTRAK

Limbah elektronik adalah satu isu yang menimbulkan ancaman kepada persekitaran and kesihatan manusia. Ini disebabkan limbah elektronik adalah satu barang yang susah terurai dalam tempoh yang pendek and ia juga mengandugi bahan-bahan yang toksik seperti plumbum, merkuri, berilium dan polivinil klorida. Oleh itu, satu idea yang menggunakan ingatan capaian rawak (RAM) berdasarkan Aloe-polisakarida filem nipis telah dicadangkan dalam kerja penyelidikan ini. Dalam kajian ini, serbuk Acemannan mencampurkan dengan air deionized untuk membentukan Aloe-polisakarida filem nipis. Acemannan ialah komponen utama dalam sel parenchyma bagi lidah buaya. Ini merupakann polisakarida yang dibentukan oleh mannose. Seterusnya, kesan jumlah serbuk Acemannan (1 mg, 3 mg, 5 mg, 7 mg) dan kesan suhu pengeringan (40^{o}C, 80^{o}C, 120^{o}C, 140^{o}C) kepada ciri-ciri pemindahan ingatan capaian rawak telah diselidikan. Beberapa teknik pencirian telah dijalankan untuk memeriksa ciri-ciri filem nipis Acemannan dari segi kimia dan struktur. Sementara, ingatan capaian rawak yang berdasarkan filem nipis Aloe-polisakarida juga dibentukan daripada pencampuran serbuk Acemannan dengan air deionized, dan air Acemannan disalutkan spin atas Indium tin oksida (ITO)-bersalut cermin. Selepas itu, ITO-bersalut cermin telah dipanaskan dalam ketuhar bagi 1 jam untuk membentukan Aloe-polisakarida filem nipis. Terakhirnya, aluminium telah disalutkan atas filem nipis dan ciri-ciri pemindahan ingatan capaian rawak juga disiasatkan oleh Semikonduktor Parameter Penganalisis (SPA) bagi 1-12V voltan dalam positif dan negatif arah. Berdasarkan hasilnya, 3 mg dan 5 mg serbuk Acemannan menunjukkan pertukaran elecktrik ketumpatan (ΔJ)

yang paling tinggi bagi 3V, 5V dan 9V pada suhu pengeringan 80^{o}C dan 120^{o}C masing-masing. Bagi 3 mg serbuk Acemannan, ΔJ bagi 3V, 5V dan 9V dalam positif dan negatif arah ialah 2.040 x 10^{-4} J, 1.860 x 10^{-4} J, 1.727 x 10^{-4} J dan 2.361 x 10^{-4} J, 2.059 x 10^{-4} J, 2.011 x 10^{-4} J. Sementara, (ΔJ) untuk 5 mg serbuk Acemannan bagi 3V, 5V dan 9V dalam positif dan negatif arah ialah 1.850 x 10^{-4} J, 2.171 x 10^{-4} J, 2.216 x 10^{-4} J dan 2.011 x 10^{-4} J, 2.348 x 10^{-4} J, 2.406 x 10^{-4} J. Ini disebabkan 3 mg dan 5 mg serbuk Acemannan merupakan jumlah yang unggul untuk membentukan perangkap-perangkap yang banyak dalam Acemannan filem nipis pada suhu pengeringan 80^{o}C dan 120^{o}C. Ini membenarkan elektron untuk bergerak dari satu elektrod (Al) ke lagi satu elektrod (ITO) atau sebaliknya. Voltan yang sesuai seperti 3V, 5V dan 9V juga diperlukan bagi elektron memasukkan dalan perangkap-perangkap itu.

ALOE-POLYSACCHARIDES THIN FILM AS ALL-NATURAL AND FLEXIBLE RESISTIVE RANDOM ACCESS MEMORY

ABSTRACT

Electronic-waste (e-waste) is an issue that can pose a threat to the environment and human health. This is because e-waste is not easily to decompose within short term period and it often contains toxic materials such as lead, mercury, beryllium and polyvinyl chloride. Hence, an idea of using Aloe-polysaccharides thin film based resistive random access memory (RAM) is suggested in this research work. In this research, Acemannan powder was used to form Aloe-polysaccharides thin film by mixing with deionized water. Acemannan is the major component in the parenchyma cell of Aloe vera. It is the polysaccharide formed through the linking of mannose ($C_6H_{12}O_6$) by β-(1, 4)-glycosidic bonds. Then, the effect of Acemannan powder in the range of 1 mg, 3 mg, 5 mg, 7 mg and the effect of different drying temperatures (40^{o}C, 80^{o}C, 120^{o}C and 140^{o}C) on the memory-switching characteristics of Aloe-polysaccharide thin film based memory device was studied. There was several characterization techniques used to examine the characteristics of Acemannan thin film in term of its chemical, and structural properties. While, Aloe-polysaccharides thin film based memory device was fabricated by mixing Acemannan powder with deionized water to form precursor solution, then spin-coating the solution on top of the Indium tin oxide (ITO)-coated glass substrate with 1000 rpm for 30 seconds. After that, spin-coated sample was dried in oven for 1 hour to form Aloe-polysaccharides thin film. Finally, aluminium was thermally coated on top of the Aloe-polysaccharides thin film using thermal evaporator and characterized using Semicoductor Parameter Analyzer under 1-12 V for forward and reverse bias. Based on the results, 3 mg and 5 mg

Acemannan powders showed the most significant change of current density (ΔJ) at 3 V, 5 V and 9 V for 80^{o}C and 120^{o}C respectively. For 3 mg Acemannan powder, ΔJ at 3 V, 5 V and 9 V for forward and reverse bias were 2.040 x 10^{-4} J, 1.860 x 10^{-4} J, 1.727 x 10^{-4} J and 2.361 x 10^{-4} J, 2.059 x 10^{-4} J, 2.011 x 10^{-4} J. While, the ΔJ in 5 mg Acemannan powder at 3 V, 5 V and 9 V for forward and reverse bias were 1.850 x 10^{-4} J, 2.171 x 10^{-4} J, 2.216 x 10^{-4} J and 2.011 x 10^{-4} J, 2.348 x 10^{-4} J, 2.406 x 10^{-4} J. This is because 3 mg and 5 mg of Acemannan powder is the suitable amounts to form more trap centers at 80^{o}C and 120^{o}C in the interstitial space of Acemannan thin film which allow the injection electrons to move from top electrode (Al) to bottom electrode (ITO) or vice versa for completing the circuit. Hence, a significant current density can be obtained and set the memory device into ON-state. A suitable sweep voltage of 3V, 5V and 9V is also needed for the electrons to come across and able to be trapped in the trap centers of Acemannan thin film.

CHAPTER 1

INTRODUCTION

In this project, Acemannan powder which is the major component in the parenchyma cell of Aloe vera. It is the polysaccharide which is formed by the linking of mannose ($C_6H_{12}O_6$) via β-(1, 4)-glycosidic bonds and it was used to form Aloe-polysaccharides thin film which has been acted as an active layer for the development of nature material based memory devices. This chapter is included the background, problem statements, objectives, scopes of work and outline of the report.

1.1 Background

Nowadays consumer electronics have become a necessity in our daily life. Our personal life is highly dependent on those electronic products such as cell phones, laptops, television, iPad, e-Readers and audio equipment. Technology has advanced with years and revolutionized the way we communicate and we live (Sidelinger et al., 2008). Rapid development and growth in those advanced technologies to fulfill the customer's demands and life style are leading to the equally rapid abandonment of old electronic products which are no longer meet the satisfactions and requirement.

The pilling up of these abandonment consumer electronics has brought up the problem of so-called electrical and electronic waste or e-waste. E-waste is a description for electronic products which is nearing the end of their useful life span (Km, 2008). E-waste comprises of toxic heavy metals such as mercury, lead, arsenic, cadmium and polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and brominated flame retardants that can have an adverse impact on environment, human health and ecology if not handled properly. The below statistics illustrates that the generation volume of e-waste in worldwide has been climbing steadily from 2010 to 2018 (Figure 1.1). In 2018 (Figure 1.1), it is foreseen there are approximately 49.8 million metric tons of e-waste will be produced globally (Balde et al., 2017).

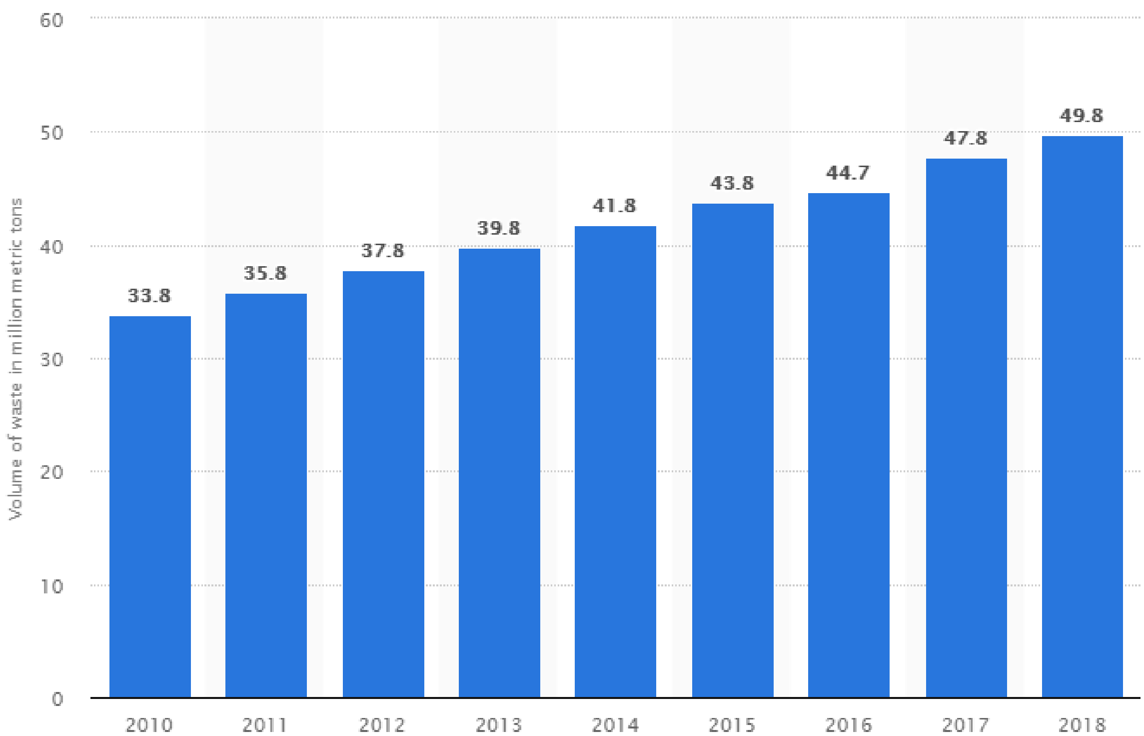

Figure 1.1: The statistics for the generation volume (in million metric tons) of e-waste from 2010 to 2018 (Balde et al., 2017).

Therefore, in order to make sure future generation can live in a beautiful, clean and free of e-waste world. A proper e-waste disposal management system is necessary to perform properly and orderly to dispose the hazardous and toxic components and meanwhile recover valuable components. However, e-waste disposal management system is now becoming a challengeable issue in the world. This is due to the technological advancements show not stopping, instead speed up to serve the growing demands for consumer electronics in marketing.

Hence, in order to solve the e-waste disposal issue without slow down the technological advancements and able to serve the growing consumer demands, an idea of using less-toxic, bio-degradable, less energy consumption and environmental-friendly natural materials based electronic devices have been proposed in this project. Among those natural materials based electronic products, natural material based resistive random access memory technologies have come up much attention. This is because nearly every electronic device such as computer server and mobile phone needs a storage memory technology to store and read enormous amount of data. In the last few years, there are several nature materials which shown the memory switching properties such as chitosan, apple, chicken egg albumen and Aloe vera. In this project, Aloe vera inner gel component, Acemannan was purchased in the form of powder which has been used to form Aloe-polysaccharide thin film, and then it has been acted as an active layer for the development of natural memory devices.

1.2 Natural Materials

Natural materials can be described as any materials or physical matter which basically derived from plant, animal or the ground and are either mined or farmed. Natural materials are often considered authentic, more traditional, and characterized by timeless beauty compared to synthetic or engineering materials. Natural materials are included timber, stone, chitosan, apple, chicken albumen, bamboo, cane, cork, Aloe vera, silver, gold, leather and so on. Most natural materials are complex composites which have outstanding properties in term of mechanical, chemical, physical and even electrical and their complex structures which have taken hundreds of million years to evolution. The basic building blocks for natural materials are normally twenty different types of amino acids which are then proceeding to polypeptides, polysaccharides, and polypeptides-saccharides (Marc et al., 2008). Meanwhile, they are used to compose the basic protein, which are the primary constituents of soft tissue in the most natural materials.

Natural materials are often biodegradable, less-toxic, and environmental-friendly which will not causes any pollution to environment or pose a threat to human health or ecology system. In the old era, they are the ingredients for making clothing and also the building raw material. However, natural materials have caught up great attention and played an important role in electronic device in the coming future due to their outstanding properties. There are natural materials which were used in the manufacturing of electronic devices such as apple, chitosan, chicken albumen and Aloe vera.

1.3 Aloe Vera as Natural Based Electronic Device

Natural materials as organic electronic devices have captured high interest in this new era. This is due to their excellent properties such as less energy consumption, less-toxic, environmental friendly, high availability, renewability and low-cost processing method, while they also possess comparative performance when compare to inorganic electronic devices such as silicon. Natural materials are now known to be utilized in electronic devices such as natural substrate, semiconductor layer, and random access memory technologies as well as dielectric layer. Among those natural materials, Aloe vera has come up a much attention due to its promising electrical properties in electronic devices.

Aloe vera (Aloe barbadensis Miller) is a perennial plant of the Xanthorrhoeaceae family. In the last century, Aloe vera plant is well known for its inner gel which provides the medical and cosmetic properties. The Aloe vera inner gel is basically colourless and tasteless, and it consists primarily of water (>98%) and polysaccharides such as cellulose, acemannan, pectin, glucomannan, hemicellulose and mannose derivate (Scala et al., 2013). However, based on the previous research, the finding showed that there is the emerge of electrical properties in Aloe vera which is possibility due to the present of some chemical properties (Calcium, Magnesium, Zinc, Chromium, Selenium) in Aloe vera leaf that result in generation of electricity (Teja et al., 2014). Hence, Aloe vera gel was proven and been used in any electrical applications.

1.4 Problem Statement

The rise of demand for electronic products has brought up the problem of disposing e-waste. E-waste is releases various toxic, carcinogenic gases and metals as it disassembled, and which are posing a threat to human health and also contaminate the environment and ecology. Hence, the use of natural based electronic products for reducing the pill up of large volume e-waste has caught much attention due to their outstanding features such as renewability, high availability, eco-friendly and bio-degradable. Of the natural material based electronic products; natural memory devices have demonstrated remarkable attention in recent years due to the use of memory storage in nearly every single piece of electronic products. To date, natural materials which showed the memory-switching effect in the bottom-up structure of conducting metal/natural materials/conducting metal are chitosan, DNA, apple, chicken egg albumen and Aloe vera plant. In this research work, Aloe vera inner gel component (Acemannan) is used to form Aloe-polysaccharide thin film and then it is act as an active layer for the development of natural memory device due to its comparative memory-switching characteristics.

The use of Aloe vera gel as an active layer for the development of nature material based memory devices has been proposed by Lim & Cheong (2015). Based on previous research (Lim & Cheong, 2015), Aloe vera gel has demonstrated comparative memory-switching characteristics which can become a potential candidate in replacing the semiconductor based memory devices due to its environmentally safe, renewability and less energy consumption. In this study, a fresh Aloe vera gel was extracted from Aloe vera leave, which was then centrifuged and vacuum filtered to obtain a high purity Aloe vera gel. After that, a memory device test structure was constructed in bottom-up structure of ITO/Aloe vera thin film/Al and the memory characteristics have been analyzed using Semiconductivity Parameter Analyzer (SPA).

Based on their research finding, a functional natural memory device consisting of a conducting metal-Aloe vera-conducting metal structure with Al and ITO as the top and bottom electrodes respectively has demonstrated bipolar memory-switching effects. The study showed that the memory-switching characteristics were mostly come from the main component of Aloe vera: pectin and acemannan in which the structural arrangement of polar functional groups (-OH) in these polysaccharides could form electron trap center that allow the electrons to trap in the interstitial spaces (Lim & Cheong, 2015). Hence, it was possible for the development as an active layer for natural-based memory device due to its electron trapping capability.

1.5 Objectives

The main objectives for this project are:

1) To investigate the effect of different amount of Acemannan powder (1 mg, 3 mg, 5 mg, 7 mg) on the memory-switching characteristics of Aloe-polysaccharides (Acemannan) thin film based memory device.
2) To study the effect of different drying temperatures (40 ^{o}C, 80 ^{o}C, 120 ^{o}C, 140 ^{o}C) on the memory-switching characteristics of Aloe-polysaccharides (Acemannan) thin film based memory device.

1.6 Scope of Work

This research work covered the investigation on the memory-switching characteristics of Aloe-polysaccharides thin film. The commercial Acemannan powder has been used as an active layer for the development of natural memory device. A little amount of Acemannan powder was mixed with deionized water to form a precursor solution. The precursor solution was then spin-coated on Indium tin oxide (ITO)-coated glass, and dried at four different temperatures: 40 ^{o}C, 80 ^{o}C, 120 ^{o}C and 140 ^{o}C. Fourier Transform Infrared Spectroscopy (FTIR) was used to identify the chemical properties of Acemannan powder, solution and thin film. Morphology characterization of the Acemannan thin film was determined by Field Emission Scanning Electron Microscopy (FESEM). Finally, the switching effect of a memory device with bottom-up structure as ITO/Acemannan thin film/Al was tested using Agilent 4156C Precision Semiconductor Parameter Analyzer (SPA).

1.7 Outline of Chapters

This thesis consists of five chapters. Chapter one covers the introduction, objectives, research motivation, problem statement and study scopes of the research work. Chapter two is discusses on the theory, concept and overview of the emerging memory technologies.

Then, experimental procedures and characterization methods are explained precisely in chapter three. While, chapter four is focuses on the analyzing of results and discussion of the project. Finally, a conclusion of this research project and recommendations for future use was stated in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This research work is mainly discusses on the fabrication and characterization of Aloe-polysaccharides thin film based memory device through a series of proper fabrication procedures for solving e-waste problem. In this chapter, there are several parts have been focused which are the rise of e-waste problem in the environment, the impact of e-waste towards environment and human health, remediation of e-waste issue, Aloe-polysaccharides thin film based memory device is chosen as a replacement for silicon based memory device to solve e-waste issue, chemical composition and structural of Aloe vera which give rise to the memory-switching phenomenon, and the study of conduction mechanism for charge trapping/detrapping in Insulator/Semiconductor system.

2.2 The Rise of Electrical or Electronic Waste (E-Waste)

In the last few years, there were enormous amounts of electrical or electronic wastes generated around global world, and this pose a threat to the environment and human health. There is an increasing acknowledgment that the reason of enormous e-waste piled up is due to our lifestyle in chasing a new technology which only to fulfill our satisfaction, desired and requirement in daily life. This lifestyle and habit have led to rapid development of technology and it is eventually end up with greatly increasing in e-waste volume.

E-waste is normally misinterpreted as related to old laptop, mobile phone, iPad, e-Reader or IT equipment in general, while Waste Electrical and Electronic Equipment

(WEEE) is also the synonymous term for e-waste used in the international literature. There are several e-waste definitions are summarized in Table 2.1 (Gaidajis et al., 2010).

Table 2.1: Summary of selected e-waste definitions (Gaidajis et al., 2010).

Reference	Term-definition
European Directive 2002/96/EC	"Waste electrical and electronic equipment, including all components, subassemblies and consumables which are part of the product at the time of discarding". The Directive 75/442/EEC, Article I (a), defines as "waste" "any substance or object which the holder discards or is required to discard in compliance with the national legislative provisions".
Basel Action Network (www.ban.org)	"E-waste includes a wide and developing range of electronic appliance ranging from large household appliances, such as refrigerators, air-conditioners, cell phones stereo systems and consumable electronic items to computers discarded by their users".
OECD (www.oecd.org)	"Any household appliance consuming electricity and reaching its life cycle end".

E-waste is not easily to decompose within short term and it often contains dangerous materials which requiring a series of proper treatment and recycling practices to avoid the adverse impact of e-waste towards the environment and human health. The different elements pollutants related to e-waste are illustrated in Table 2.2. Some of them, such as mercury, carbon black, beryllium and lead are utilized in the production of electronic devices, while other, such as Polycyclic Aromatic Hydrocarbons (PAHs) are produced by e-waste burning at low temperature (Gaidajis et al., 2010).

Table 2.2: Potential element pollutant related to e-waste (Gaidajis et al., 2010).

Substance	**Occurrence in e-waste**	**Typical concentration in e-waste (mg/kg) [a]**
Halogenated Compounds:		
PCB	Condensers, Transformers.	14
TBBA, PBB, PBDE	Fire retardants for plastics (thermoplastic components, cable insulation).	
CFC	Cooling unit, Insulation foam.	
PVC	Cable insulation.	
Heavy Metals and Other Metals:		
Antimony (Sb)	Fire retardant, plastics.	1,700
Arsenic (As)	Small quantities in the form of gallium arsenide within light emitting diodes.	
Barium (Ba)	Getters in CRT.	
Beryllium (Be)	Power supply boxes which contain silicon controlled rectifiers and x-ray lenses.	
Cadmium (Cd)	Rechargeable NiCd-batteries, fluorescent layer (CRT screens), printer inks and toners, photocopying machines (printer drums).	180
Chromium (Cr)	Data tapes, floppy-disks.	9,900
Copper (Cu)	Cabling.	41,000
Lead (Pb)	CRT screen, batteries, printed wiring boards.	2,900
Lithium (Li)	Li-batteries.	
Mercury (Hg)	Fluorescent lamps that provide backlighting in LCDs, in some alkaline batteries and mercury wetted switches.	0.68
Nickel (Ni)	Rechargeable NiCd-batteries or NiMH-batteries, electron gun in CRT.	10,300
Rare Earth Elements	Fluorescent layer (CRT screen).	
Selenium (Se)	Older photocopying machines (photo drums).	
Tin (Sn)	Solder metal glue, LCD.	2,400

2.3 The Effect of E-Waste towards Environment

There is a great advancement of technology in electronic industries, which is largely due to increasing market penetration of products in the world. However, the competition between those electronic industries in manufacturing and providing customers a better electronic device have caused e-waste problem. The higher product obsolescence rate has implied that the abandonment of old model electronic devices which are unable to fulfill the satisfaction of customer. Hence, the piled up of e-waste in landfill is potentially to cause environmental problem, if the disposal and e-waste management practices are not performing well. There are many heavy metals from e-waste have detrimental effect towards environment such as copper (Cu), gold (Au), barium (Ba), lithium (Li), lead (Pb), cadmium (Cd) (Singh & Ajay, 2011).

For instance, the open burning of computer wires which made up of Cu can cause the release of hydrocarbon such as methane and chlorofluorocarbons into air which may drastically increase the amount of carbon dioxide (CO_2), thus causing greenhouse effect and global warming. Also, the aromatic hydrocarbon such as benzene is able to deplete the red blood cells and cause cancer in mammals. Meanwhile, chemical stripping of gold-plated computer chips may cause the emission of brominated dioxins which can strongly adhere to soils and sediments, this result in soil contamination.

In addition, the abandonment of Ba from cathode ray tubes and Li from mobile phone and computer batteries in environment can leach through the soil and stream into the ground water which result in soil and water contamination. Then, Pb as the solder in printed circuit boards, glass panels and gaskets in computer monitors can decrease the soil's productivity and also inhibit some vital plant processes such as photosynthesis, mitosis and water absorption. Last but not least, Cd from the chip resistors and semiconductors can devastate effects on the ecological balance of aquatic environment and also the diversity of aquatic organisms if it is released into aquatic system.

2.4 The Effect of E-Waste towards Human Health

There were enormous amount of electrical and electronic wastes generated around the globe today which has posed a threat to human health if they are not disposed and managed in proper way. This is because they are considered dangerous, as certain components which are used in fabrication of electronic device are harmful and toxic, if the amounts of usage are huge enough to trigger the toxicity and dangerousness to human.

E-waste related health issues may result from either direct contact or indirect contact with the harmful materials in the abandonment electronic devices such as heavy metals: lead, mercury, arsenic as well as polyvinyl chloride (PVCs) and brominate flame retardants. Other than its hazardous components, e-wastes tend to release numbers of toxic by-products during disassembling and disposing which are also able to affect human health. Thus, residents living nearby the e-waste landfill are possible to intake the risk of e-waste causing health issues through different exposure pathways. Children and pregnant woman are especially vulnerable to the health risk as a result from e-waste exposure. The human health issues related to e-waste are explained below. There are many constituents from e-waste have detrimental effect towards human health such as Pb, Cd, mercury (Hg), hexavalent chromium (Cr) VI, beryllium (Be), Ba, arsenic (As), plastic including PVC, brominated flame retardants (BFR) and sulphur (S) (Singh et al., 2016).

For instance, Pb as the solder in printed circuit boards, glass panels and gasket in computer monitor can damage to central and peripheral nervous systems, blood systems and kidney. It can also affect the brain development in children. Then, Cd from chip resistors and semiconductors contains toxic which can accumulate in the kidney and liver, causes neural damage and even tetratogenic in people.

Moreover, Hg from the relays and switches can cause chronic damage to the brain and also the respiratory and skin disorder due to the bioaccumulation in fishes. Then, Cr from the galvanized steel plates, decorator or hardener for steel housings is able to cause asthmatic bronchitis and DNA damage.

In addition, Be from motherboard is considered as carcinogenic which can cause lung cancer and the inhalation of fumes and dust can cause chronic beryllium disease or beryllicosis. It also causes skin diseases such as warts. While, the short term exposure of Ba from the front panel of CRTs can cause muscle weakness and also damage to heart, liver and spleen.

As as the component in the cell phones and television sets is able to cause skin cancer, liver disorders, severe respiratory problems and the failure of the central nervous system. While, PVC from the cabling and computer housing can produce dioxide when burning which is able to cause reproductive and developmental problems, immune system damage and interfere with regulatory harmones.

Last but not least, BFR from the plastic housing of electronic equipment and circuit boards can disrupt endocrine system functions. Sulphur from the lead-acid batteries can damage to vital organs such as liver, kidney and heart.

2.5 Remediation of E-Waste Problem

There are number of e-waste disposal techniques have been utilized and carried out to reduce the amount of e-waste in the global world. The techniques included landfilling, incineration, acid baths (Sivaramanan, 2013) and the replacement of inorganic electronic device with natural based electronic device. Their operational process, advantages and disadvantages will be further explained in below subchapter.

2.5.1 Landfilling

Landfilling was a traditional waste handling method which to collect the e-wastes around all the electronic industries and then store in a designated landfills. According to the waste management hierarchy, although landfilling is considered the least preferable option in solving the e-waste issues, but it still worked to prevent, minimize and keep as far as possible the negative effects of e-waste away from the environment especially soil and ground water and human health through a stringent technical requirements for waste and landfills.

In the landfill, Landfill Directive has to define the categories of the wastes into four different types which are municipal waste, hazardous waste, non-hazardous waste and inert waste. This systematically step is useful to classify the wastes in landfills which still can be recycled or reused in other way. For instance, landfill gas-to-energy project is performed to convert the landfill gas to energy that reduces the reliance on fossil fuels such as coal, oil and natural gas. Table 2.3 shows three basic types of landfill gas-to-energy facilities (Brown et al., 2015). The advantages of landfilling in solving e-waste issue are it is an inexpensive method, the land used for landfill now can be reused for other community purposes later and the landfill gas can converted into energy sources. However, landfilling requires a high maintenance cost for whole landfill areas and it is also able to release toxic substances into the soil and ground water during waste disposal.

Table 2.3: The overview for landfill gas-to-energy facilities (Brown et al., 2015).

Landfill Gas-to-Energy Facilities	Overview
Electric	Landfill gas is used as a fuel to generate electricity at small power plant at the landfill, or at nearby industry, with the generated electricity delivered to a utility company. 20% of electricity can be generated.
Alternative fuel	Landfill gas is piped to an industrial or commercial facility, where it is used for heating in place of, or in combination with fossil fuels such as oil, coal or natural gas. 15% of energy can be generated.
Processed gas	Landfill gas is processed and cleaned to natural gas quality and delivered to transmission pipelines, to be used in normal applications for natural gas. 17% of energy can be generated.

2.5.2 Incineration

Incineration was also one of the traditional waste disposal methods which are used for reduction of landfilling requirement, recovering the energy in waste material and neutralization of harmful compounds of wastes. In the process of incineration, the waste materials is treated and converted into gases, ash particles and heat. These products are able to be used in the generation of electricity. Incineration is considered an effective wastes handling method than landfilling in reducing the mass of waste about 95-96 percent. The reduction of waste is depending on the recovery degree and composition of materials.

Basically there are three types of basic methods for thermal incineration of waste which are: combustion, pyrolysis and gasification (Georgieva & Keshav, 1999). The technologies, advantages and disadvantages for each method are described below.

First method is combustion, it involves the mass burning systems which is confiring of waste with huge amount of coal to produce the final product. The cost used for the waste incineration is cheaper, capacity for the waste incineration is huge and this is more efficient waste energy utilization. However, it causes the emission of pollutants during fossil fuels combustion such as CO_2, CO, SO_2 and dust. While, there is also considerable emission of harmful pollutants (heavy metals) such as PAH, PCDD/PCDFs and PCBs. Then, the fly ash from the waste burning plants is a also considered a dangerous pollutants.

Second method is pyrolysis, it involves the incineration of hazard wastes using the technology of DUOTHERM. The advantage of using pyrolysis is the better control and optimization of the process such as the condition of thermal decomposition (temperature and pressure), condition of pyrolysis product burning and the conditions of pyrolysis product conversion. However, it is an expensive process, more sophisticated and less efficient.

Third method is gasification, it involves the using of pyrolysis process to vaporize the volatile component, and then further break down the pyrolysis products with provision of addition heat energy and reversible water-gas shift reaction take places to change the concentration of CO, H_2O, CO_2 and H_2. This process is able to convert the valuable product from waste materials and possibilities to produce syngas such as H_2 and CO. However, it is an expensive process which only allows for small capacity of waste materials.

The advantages of using incineration method for solving e-waste is land of requirement is minimum can be operation in any weather and stable odor is produced. However, the requirement for high energy is needed in the process and the emission of cadmium and mercury is unpreventable.

2.5.3 Acid Bath

Acid bath was also one of the effective e-waste solving approaches which involve the soaking of the electronic circuits in a powerful acid such as sulfuric, hydrochloric acid or nitric acid solutions that dissolve and remove the metals from the electronic pathways. These removed metals such as copper, lead, gold and silver are able to be used in the later manufacturing process of other products (Sivaramanan, 2013).

In the process of acid bath, these dumped circuit boards are immersed into sulfuric acid up to 12 hours to dissolve and disintegrate the copper, and then the acid solution is boiled to obtain the precipitated copper sulfate. After that, scrapped particles are added into the remaining solution to extract the copper smudges. The advantage of acid bath in solving e-waste problem is cheapest cleaning method which only needs for low manpower and space requirement. However, the acid recovery systems are expensive process and the solvents used are flammable with greater handling risk. Figure 2.3 shows the schematic diagram of acid bath method.

2.5.4 Natural Based Electronic Device

In the high technology era, natural based electronic device have been proposed and it demonstrated tremendous versatility in a wide range of application including consumer electronics, photovoltaic, biotechnology and memory devices. This is because many natural based electronic devices have been shown to be biodegradable, safe, stable, non-toxic and meet comparative and satisfaction requirements (Mihai et al., 2012). Additionally, the unique features of natural materials also make them useful in biofunctional electronics, which give them functions that inorganic compounds could not be achieved such as natural based electronic devices will be more energy-efficient and resource-friendly than inorganic electronic devices which contributes to a more sustainable electronic world.

Several considerations such as cost, efficiency, ease of production and safety should be taken into account for choosing the most suitable method to solve the e-waste issue. Table 2.7 illustrates the summary of the advantages and disadvantages for all the remediations of e-waste. Based on the comparison of four different remediation techniques, an idea of using natural based electronic device was chosen due to its impressive and outstanding characteristics and perspective. Also, natural based electronic device is considered as a permanently e-waste solving method, due to its self-decompose ability within a short term period which can act as an alternative replacement for inorganic electronic devices which are unable to self-decompose and end up with e-waste problem. Although there are still some unknowns in natural based electronic devices, but it cannot deny that natural based electronic devices have provided the world to completely terminate the e-waste issue.

Table 2.4: Comparison of the four remediation techniques in solving e-waste issue (Rohit, 2016).

Remediating Techniques	Advantages	Disadvantages
Landfilling	-Inexpensive method. -Landfill gas can be converted into energy sources.	-Temporary action. It needs to perform constantly. E-waste amount is only can control, but not terminated. -E-waste disposes toxic substances released inside the soil and ground water. -High maintenance cost for whole landfill areas.
Incineration	-Requirement for land is low. -Recovering the energy in waste material. -Neutralization of harmful compound of waste.	-Expensive to build and operate. -High energy requirement. -Emission of cadmium and mercury. -Temporary action. It needs to perform constantly. E-waste amount is only can control, but not terminated.
Acid Bath	-Cheapest method. -Low manpower and space requirement.	-Temporary action. It needs to perform constantly. E-waste amount is only can control, but not terminated. -Acid recovery systems are expensive. -Solvents used are flammable with greater handling risk. -High maintenance cost.
Natural-Based Electronic Device (Mihai et al., 2012)	-Less toxic. -Biodegradable and biocompatible. -Less energy consumption. -Renewability and high availability. -Comparative properties as inorganic electronic devices. -Environmental-friendly.	-Permanently action which means e-waste issue can be terminated. -Electronic devices unable to last longer. -Easy affected by impurity problem during manufacturing process.

2.6 Natural Based Memory Device

Nowadays there are numbers of electronic devices were manufactured by natural materials such as natural substrates, natural smoothening layers, natural dielectrics, natural based memory device as well as unipolar and ambipolar natural semiconductors (Mihai et al., 2013). This is because the natural based electronic devices are biodegradable, biocompatible, less-toxic and less energy consumption which can prevent and reduce the e-waste issue from contaminating the environment and risking human life. The unique properties of natural materials have led the world to a better, beautiful and safety world. Of these electronic devices, natural based memory devices have caught the much attention from the world in last few years, due to memory technologies are extensively used in consumer electronics which is considered as the most crucial reason for increasing the amount of e-waste.

Therefore, the replacement of inorganic based memory devices with natural based memory devices throughout all the electronic industries in the world can considered as an ideal and effective method to reduce, minimize and even terminate the e-waste issue.

2.7 Memory Device

Memory device is just like a human brain which is used to read and store enormous amount of data, information and programs in every single piece of electronic device such as laptop, mobile phone and computer. Basically a memory device can be classified into two main types according to their characteristics which are permanent memory and temporary memory. The characteristics, advantage and disadvantage for 2 different types of memory device are explained below.

Permanent memory or read only memory (ROM) is a non-volatile memory in which the data is retained even power supplied is off and there is no editing of data is allowed once the data is stored except for special types of ROM that allow for reprogramming. The advantage of this kind of memory is it can store data for long term period and no tampering of data is allowed on the stored information. However, it is a slower type of memory and it can brick the memory if erasing the ROM content incorrectly. Examples for this memory are PROM, EPROM and EEPROM.

Another type of memory is temporary memory which is also called as random access memory (RAM). This is a volatile memory in which the data is unable to retain when the power supplied is off but it allows for numerous of writing-erasing cycle and retrieving. The advantage of this kind of memory is the information stored on it is able to recover; it is also a fastest type of memory which consumes less power compare to disk drives, hence increasing the batteries lifespan. However, it is not cost friendly since its pricing per bit is high and space is also limited. examples for this memory are DRAM, SRAM and DRDRAM.

2.8 Aloe-polysaccharides Thin Film as All-Natural and Flexible Resistive Random Access Memory (RAM)

Based on the previous research work, there are many natural materials which demonstrated impressive memory-switching effect in the bottom-up structure of conducting metal/natural materials/conducting metal such as apple, chicken egg albumen, lysozyme, DNA as well as Aloe vera (Lim & Cheong, 2015). Among these natural materials, Aloe vera has captured the great attention due to its outstanding and comparative memory-switching effect (Lim & Cheong, 2015). According to the research work done by Lim &

Cheong (2015), the main constituents in Aloe vera which provide the memory-switching characteristics are pectin and acemannan. The polar functional groups (-OH) from both of them play an important role in forming the electron trap center inside the Aloe vera layer that allow the electron to trap in the interstitial spaces, giving Aloe vera electron-trapping ability. Hence, a commercial Acemannan powder was used to fabricate a natural based memory device with structure of ITO/Acemannan thin film/Al. Table 2.5 shows the summary of the natural materials that have demonstrated memory switching effects in bottom-up structures of top electrode/natural materials/bottom electrode.

Table 2.5: Summary of the natural materials that have demonstrated memory switching effects in bottom-up structures of top electrode/natural materials/bottom electrode (Lim & Cheong, 2015).

Year	**Natural Material**	**Device Terminology**	**Substrate**	**Electrode**		**Responsible Compound**	**Purification**
				Top	**Bottom**		
2006	Tobacco mosaic virus (TMV)	Digital memory	Glass	Al	Al	TMV-Pt nanoparticle blend	
2011	Ferritin	Nonvolatile memory	Si/SiO_2	Ag, W, Pt	Pt	PAH/ferritin nanoparticle layers	
2012	Lysozyme (LYS)	Resistive switching memory	Si/SiO_2	Ag, Au, W	Pt	LYS/PSS, LYS/PSS/PAH/PSS	
2012	Silk fibroin	Bio-memristor	ITO-coated glass	Al	ITO	Silk fibroin extracted from cocoons of silkworms	√
2013	Sericin	ReRAM	Si/SiO_2, PET	Ag	Au	Sericin (M_w = 8000 g mol^{-1})	
2013	Silk fibroin	Bio-memristor	ITO-coated glass	Al	ITO	Silk fibroin-Au nanoparticle blend	√

Table 2.5**:** Summary of the natural materials that have demonstrated memory switching effects in bottom-up structures of top electrode/natural materials/bottom electrode (continue) (Lim & Cheong, 2015).

2014	Cellulose nanofiber paper (CNP)	Resistive memory	Si/SiO_2, Al foil	Ag	Pt	CNP-Ag	√
2015	Chitosan	ReRAM	Si/SiO_2, PES	Ag	Pt	Chitosan (deacetylation degree 75-85%), chitosan-Ag	
2015	DNA	Bio-memristor	Si/SiO_2	Au	Au	DNA of calf thymus	
2015	Chicken egg albumen	Bio-memristor	ITO-coated glass	Al	ITO	Ovotransferrin, Fe	

2.8.1 Aloe Vera Plant Cellular Structure and Composition

Aloe vera or Aloe barbadensis Miller, sometimes also called medicinal aloe, is a spiky, perennial and succulent plant which belongs to the member of the Asphodelaceae family (a former member of Liliaceae) (Christaki & Panagiota, 2010). It is native to western meridional Africa and belongs to the group of crassulacean acid metabolism plants (CAM plants) with nocturnal CO_2 assimilation, which prevent water loss in hours when there is less evaporative demand. The species is therefore adapted to arid and semi-arid regions such as northern Chile (from the II to IV Regions).

The plants has triangular, freshly leaves with serrated edges, yellow tubular flowers and fruits that contain numerous seeds. Each leaf is composed of three layers: the outer thick layer made of 15-20 cells called as rind which has protective function and synthesizes carbohydrates, fat and proteins. Inside the rind are vascular bundles that are composed of three types of tubular structures: the xylem, the phloem, and the pericyclic tubules which are responsible for transportation of substances such as water and starch. Then, the middle