GREEN COMPUTING: RERAM COMPUTER MEMORY BASED ON GELATIN NANOCOMPOSITE

BY

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DECLARATION

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I, Oladeji Olawumi Akinfenwa declare that the dissertation titled **Green Computing: ReRam Computer Memory Based On Gelatin Nanocomposite** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

23 FEBRUARY 2021

SIGNATURE DATE

DEDICATION

This study is dedicated to my late Father Oladeji Olatunde Areo and to my entire family. For their courage and support in ensuring I persevered with my studies.

Thank you for always telling me to reach for the stars.

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ABSTRACT

Global change and the rise in toxic waste produced by electronic devices are some of the problems presently being tackled using so-called 'green technologies. Although the approach to these significant issues does not rely on a single person, business, government or country, there are commitments that can be made to each person. Green computing is the most well-balanced and sustainable solution to creating a greener, healthier, and safer world without reducing the technical essentials of future generations. ReRAM built on biodegradable polymer nanocomposites is progressing rapidly in the direction of green computing for actualization. Biodegradable polymer nanocomposites have recently drawn tremendous research interest due to its unique potential for a vast spectrum of applications in environmental remediation and the resolution of various environmental challenges. The growing interest in nanocomposite material for use in various electronic devices and use of gelatin nanoparticles in organic non-volatile memory devices, remain rare. Investigate biomaterials, which reveal a potential method as materials for ReRAM devices due to the molecules are ecologically friendly, cheap, and flexible. Biocompatible and Gelatin has limited investigation on ReRAM applications regardless of its minimal effort, plenitude and great biodegradability, its impending for the application in unadulterated shape and furthermore as a composite with Nano crystalline CdTe as the dispersant, while production of biodegradable ReRAM is highly preferred prior to their natural abundance, disposability, and low cost. This study aims to model a ReRAM computer memory based on gelatin nanocomposite and in this context each type of particle was coated on ITO substrates and integrated into gelatin and micron thick films. Aluminum metal electrodes have been deposited using a home-made thermal evaporator under a vacuum of <10-5-mbar and gelatin nanocomposites-based ReRAM cells have been developed usingdifferent classes of nano particles and the current voltage (I-V) characteristics of the sandwich structure were recorded by scanning the voltage. This analysis compared and established the memory behavior in the mentioned ReRAM cells by measuring I-V characteristics and a new type of switching has emerged within the butterfly type of hysteresis and memory behavior. The use of inorganic nanoparticles in the polymer matrix can provide high-performance novel materials that find applications in many industrial fields, and a vast range of organic and inorganic nanoparticles have been add as essences or fillers for the preparation of nanocomposites with improved desired properties.

Keywords—Green Computing, ReRAM, Nanocomposite, Gelatin, Resistive Switching, Memory.

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LIST OF ACRONYMS

BIOS	Basic Input/output System
CC	Current compliance
CdTe	Nano Crystalline
CMOS	Complementary Metal Oxide Semiconductor
CSVT	Close space vapor transport
DRAM	Dynamic Random-Access Memory
ECM	Electrochemical metallization memory
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPEAT	Electronic Product Environmental Assessment Tool
EPROMs	Erasable Programmable Read-Only Memory
FeRAM	Ferroelectric Random-Access Memory
Gd2O3	Gadolium Oxide
IT	Information Technology
MERAM	Magnetic Memory
ML	Machine Learning
MMC	Multi Media Card
NN	Neutral Network
NPs	Nanoparticles
NRAM	Nano-Random-Access Memory
NVM	Non-Volatile Memory
NSPs	Nano-silver particles
PACA	Poly(alkylcyanoacrylate)
PCA	Poly(cyanoacrylate)
PCL	Poly(ÿ-caprolactone)
PCM	Phase Change Memory
PEA	Poly(ester-anhydride)
PLA	Polylactide
PLG	Polyglycolide

PLGA	Poly(D, L-lactide-co-glycolide)
PZT	Zirconate
RAM	Random-Access Memory
ReRAM	Resistive Random-Access Memory
ROM	Read-Only Memory
RSM	Resistive switching mechanisms
SAM	Serial access memory
SD	Secure Digital cards
SONO	Silicon-Oxide-Nitride-Oxide
SRAM	Static Random-Access Memory
SWCNTs	Single-Walled Nanotubes
STT-MRAM	Spin-Transfer Torque - Magnetic Random-Access Memory
TTRAM	Twin Transistor Random Access Memory
USB	Universal Serial Bus
VCM	Valence Change Memory
WORM	Write once read-many times
Z-RAM	Zero Capacitor Ram

THESIS OUTLINE

The dissertation is organized as follows:

Chapter One

This introductory chapter provides a general overview of the research subject and rationale. It covers the problem statement, research questions, research objectives, research design, research scope and limitations, research ethics and the contributions of the research.

Chapter Two

This chapter reviews relevant literature within the context of the research focus, situtates the research objectives in the framework of the wider academic community of organic memory, gelatin, nanocomposite, and gives credence to the research rationale by identifying the knowledge gaps that the research seeks to explore.

Chapter Three

Describes the research methodology and the proposed system models implemented in integrated and fabricating the new memory. It also describes how gelatin-based Nano composite was collected, prepared and incorporated for the experiments and model evaluation mechanisms.

Chapter Four

Presents experimental evaluations and results attained from the experiments conducted. It presents the fabrication mode generated in both gelatin and nanocomposite types. A show comparison of memory fabricated are presented.

Chapter Five

Gives the conclusion of the study. It also presents some professional implications and some areas for future work.

CHAPTER 1: INTRODUCTION

1. BACKGROUND TO THE STUDY

The world of electronics is broadly living a phase of reckless changes. Presently there is a development towards numerous and interconnected system. The industry is facing huge challenges which will stand the mounting of storage and memory. In order, to stun these challenge new methods and materials must be considered. Present computers assign separate space for the hard drive, Random-Access Memory (RAM), information processing and storage, respectively. The quality of computers is directly linked to the act of these elements. Recently, environmental and energy efficiency issues have been at the core of the global business landscape. The reality of rising energy charges and their effect on foreign relations, combined with various kinds of environmental concerns, has changed the social and economic perception of the business community. As a result, the corporate world is now searching for an eco-friendly business model.Owing to global warming, various environmental standards legislation and laws compel information technology (IT) kit manufacturers to acquire different energy supplies. Green computing is a harmonious and prosperous style to creating a greener, cleaner, and strong atmosphere without ignoring the scientific requests of modern and future generations.Everyone and expert are in nonstop contact with the computer and cell phones. A few divisions including broadcast communications, government, military, and aviation give steady interest to high trustworthiness, superior and low power devices. This interest intends to deliver both prevalent performing gadgets and better approaches putting away and preparing data. The developing conceivable outcomes regarding correspondence and calculation has made it conceivable by computers with data processing, data storage and data exchange. Presently diverse types of memory used in computers such asSerial access memory (SAM), Dynamic Random-Access Memory (DRAM), Static Random-Access and Memory (SRAM)[1]. Among all other emerging Nonvolatile memories, transparent Resistive Random-Access Memory (ReRAM) has shown a prospective potential for non-volatile memory applications due to its basic form and ease of processing [2]. ReRAM are irreplaceable method of non-volatile memory that is likely to show a crucial impact in prospect memory and computing solutions. The resistance condition of ReRAM devices has been shown and can also be modified by changing the properties of the switching signal, modulating switching voltages and limiting the peak current.

The following figure shown the basic principle of Resistive Random-Access Memory (ReRAM).

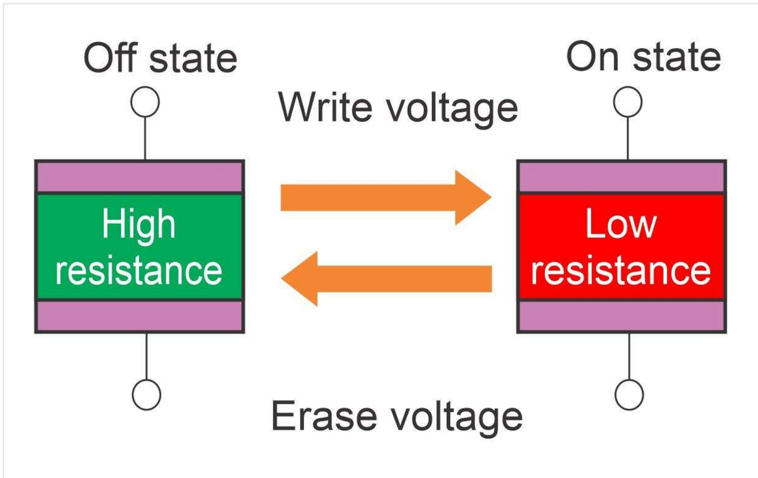


Figure 1—1: The basic principle of ReRAM. Adapted from [3]

ReRAM has possible uses in future information technology [3]and promising candidate for prospect memory architecture, with its high density, low leakage powerand fast read access [4]. It is reliable, high density, scalable, low power consumption, and fast switching; it can also generate immense amounts of semiconductor trash during processing, with adverse risks on health risks and costs in waste management[4]. The two noteworthy types of memory as of now applicable are flash and DRAM advancements. Streak is a versatile strong state type of memory, equipped for more than 10,000 composes. Moreover, the field of nanotechnology has become one of the key successful areas in material science research for the past few years. The fact that nanoparticles (NPs) display distinctive and interesting properties based on their specific features, such as distribution, size and morphology indicate itself to many applications [5], such as sensors, microelectronics, and catalysis [6]. These nanoparticles are filled with different types of hydrogels physically or covalently to relate with polymeric chains, and effect in revealing new properties of the nanocomposite matrix. In order, to describe filled polymers containing dispersed particles, nanocomposites were derived. Nanocomposites are heterogeneous materials whose structures are regulated by indistinguishable variables, i.e., section properties, synthesis, form, and interfacial partnerships, from traditional composites along these lines.Many materials, called biocompatible materials, comply with this acceptability, and can be used as components for implant devices. Biocompatible materials may be either inorganic or organic, such as silica gels, polymeric products, and magnesium alloys. Some of these products are biodegradable as well. Biodegradable materials in the human body can totally breakdown, allowing the body's circulatory system to remove or absorb non-toxic products. Biodegradability with no deadly by-products is one of the main statements a future matrix molecule will achieve in the development process of a nanoparticulate drug delivery system for in vivo use. For ages now, series of mechanisms mentioned in the literature have used manmade or natural basic products for the preparation of biodegradable nanoparticles.Rather than listing all possible solutions in detail, only a few of the most important biodegradable forms of nanoparticles will be analysed here. As for nanoparticles created on manmade polymers, poly(D, L-lactide-co-glycolide) (PLGA) polylactide (PLA) and polyglycolide (PLG) nanoparticles are the most broadly examined.Additional polymers discussed as feasible tactics are poly(ÿ-caprolactone) (PCL), poly(cyanoacrylate) (PCA), poly (alkylcyanoacrylate) (PACA) and poly(ester-anhydride) (PEA) [7]. Macromolecules such as sodium alginate, chitosan, collagen, albumin and natural biopolymers are more important to these polymers [8]. Biodegradable materials containing regular structures, which are appealing because of their repeatability and their self-repairing property. Wearable frameworks implantable demonstrative devices, e-paper and bio coordinated therapeutic hardware are the novel uses of Nano electronics[9, 10]. They are utilized to give an application inside the body and consequently debase over some time. To work as a reasonable biodegradable, embed, debasement ought to happen once the motivation behind the application has been accomplished. For genuine device applications, Nano- electronic devices must be synthetically steady and solid and implantable devices must work effectively and subsequently be resorb by the body. Possible uses of physically transient hardware incorporate implantable devices for restorative conclusions, environmentally well-disposed dispensable devices, safety device, biosensors, and protected information stockpiling for paramount mystery data.

Gelatin, a polymer that occurs naturally, is widely used in diverse applications including the manufacture of therapeutic products, production of photographic films and X-ray, and food processing[11].The mixture of protein and peptides formed by partial hydrolysis of natural occurring collagen is gelatin.Also, the fact that it is used among other items in medical products, cosmetics production, proves that it is completely non-toxic to humans. This describes the best use of gelatin in research as potential side effects of compounds derived from it, since signs can be considered low.Still, gelatin remainders produced in the various industrialized processes can be an environmental concern. Essentially, waste clearance from plastics based on both synthetic and semi-synthetic polymeric materials is growing ever more complicated due to their critical volume-to-weight ratio and the tremendously wide variation of the shape, form and composition of the polymeric materialswhich hinder the possibility of a simple and economically feasible management option.

Modelling the concern in unconventional methods such as neutral network (NN), processing-in-memory (PIM) and principally machine learning (ML) based quickening agents has developed fundamentally. ReRAM is a great innovation for well planning PIM-and NN-based quickening agents because of its skills to fill in as both: Low energy storage/ High-density and in-memory computation/internet searcher. The research seeks to investigate the theory behind the development of fabricating techniques for a ReRAM computer memory based on gelatin nanocomposite.

Several efforts to manufacture ReRAM have emerged in recent years with different nanoparticles[12, 13]. There is a limited information on using gelatin nanocomposite to fabricate a new computer memory and gelatin basednanocomposite is really an intriguing new field of research due to its unique properties that why this study is aiming to model a ReRAM computer memory based on gelatin nanocomposite. In this way, there is a requirement for a new form of memory.

1.2 Problem Statement

The concern is that there is a massive rise in electronic waste over the next decade. There are many negative effects to this climate, particularly to humans, which are gradually exposed. Owing to the rapid obsolescence of electronics, 70 per cent of all hazardous waste was bad. Significant amounts of energy are used to manufacture computer chips, and some of the most deadly gasses and chemicals are used by humans.The growing interest in green computing: Nano composite material for use in various electronic devices and use of gelatin nanoparticles in organic non-volatile memory devices, remain rare as proclaimed by[14]. Authors [15] investigate biomaterials, which reveal a potential method as materials for ReRAM devices due to the molecules are ecologically friendly, cheap and flexible. Biocompatible and Gelatin has limited investigation on ReRAM applications regardless of its minimal effort, plenitude and great biodegradability, its impending for the application in unadulterated shape and furthermore as a composite with Nano crystalline CdTe as the dispersant, while production of biodegradable ReRAM is highly preferred prior to their natural abundance, disposability, and low cost [16].

1.3 Research Aim and Objectives

1.3.1 Aim

The aim of the study is to produce ReRAM memory cells based on gelatin nanocomposites: to green computing.

1.3.2 Research Objectives

The following list are the objectives to actualize the aim of the study:

1. Identify and research a method to achieve ReRAM computer memory based on gelatin nanocomposite.
2. Investigate and develop a model for newly improved ReRAM using gelatin nanocomposite computer memory.
3. Develop a prototype of the new ReRAM using gelatin nanocomposite computer memory.

1.4 Research Question

This research question illustrated in this study are fixed prior to the main target of this research, which is to model and fabricate new computer memory structure. In a way, to fabricate a functional and unique gelatin Nano composites ReRAM structure, it is vital to fathom the used of gelatin Nano composites, current capabilities, challenges, and the new technologies with the technical design principles for new computer memory. The industry is as of now confronting barriers which will slow down the scaling of memory and storage. With the end goal to conquer these barriers, new materials and techniques must be considered. Current computers assign distinct space for data storage and data processing, Random-Access Memory, and hard drive individually. Diverse types of nanomaterial have been use for many applications[17, 18]. The properties of nanomaterials such asnanoparticles are altered as related to emerged materials thatmake the use of nanoparticles in public user applications. It hasalso led to various talk on security issue of nanotechnology. The risk to the environment is reduced by merging Nano composite into the gelatin.Computer quality is straightforwardly identified with the execution of these components.Therefore, the general thesis is centered on the subsequent principal questions and supports research questions.

Main research question: How can the performance of memory be improve with Gelatin nanocomposite?

To achieve the main research question carefully, secondary research questions are addressed and answer to the main research question effectively:

Secondary research questions 1:*How can one exploit gelatin nanocomposite to fabricate a special category of ReRAM computer memory?*

Secondary research question 2:*How can a prototype of this upgrade memory be implemented?*

Secondary research question 3:*What performance evaluation measures are best suited to benchmark the upgraded memory with the existing memory types?*

1.5 Research Contribution

This segment denotes the study's general research contributions to the scientific knowledge body, follow-on in both accredited and peer-reviewed publications.

1.5.1 Contributions to the scientific body of knowledge

The research study focuses on a efficient study of memory behavior in nano silver, CdTe and graphene oxide incorporated biodegradable gelatin nanocomposites, which pave way for conservation of energy in hardware stages of computing and it could be achieved by eliminating toxic chemicals and using biodegradable materials.Thus, the major contributions in the study are the following:

- Development of a new ReRAM memory using gelatin nanocomposites.
- The fabrication of the theory is compose of aluminum metal electrodes which areprocessed in a vacuum of <10-5 mbar by the means of home-made thermal evaporator.
- Detailed experimental evaluations conducted, and material used such as on publicly available nano silver, Cdteand graphene oxide nano particles and gelatin were commercially generated.

1.6 Research Ethical Consideration

In agreement with the process and procedures put in place by the UNISA Computing College Research Ethics Committee the scientific reliability of the study was secure by applying the following measures:

The results of the study were described based on the true test and results were not adjusted in order to back prejudice views.
No result was forged during the laboratory evaluations of the ReRAM Memory
The work was presented original and authentic because plagiarism was avoided
The dissertation has been run successfully through plagiarism software.

All sources used in this study were referenced accordingly.

1.7 Research Scope

This research primarily focuses on developing new computer memory using gelatin nanocomposites. By measuring I-V properties, we linked and defined the memory behavior in the described ReRAM cells. The critical topic in this study also discusses the concepts of gelatin, Nanocomposites, biodegradable materials, and machine memory.

1.8 Chapter Summary

Present world, computers and communication devices play an important part in life of human, and with the aid of these devices, the life of a common man becomes very pleasant and enjoyable. Yet these devices have several adverse effects on the human body and the environment over their lifespan, from manufacturing to use and destruction. With the end goal to conquer these barriers, new materials and techniques must be considered. Current computers assign distinct space for data storage and data processing, the Random-access memory and hard drive individually. Computer quality is straightforwardly identified with the execution of these components. Green computing has earned a lot of publicity owing to increasing environmental issues and rising energy consumption costs.

CHAPTER 2:LITERATURE REVIEW AND THEORETICAL BACKGROUND

2. INTRODUCTION

This section reveals the review of the literature relating to green computing IT, ReRAM and gelatin as well as the biomaterial, Polysaccharides based bio-ReRAMs and Proteins based bio-ReRAMs. A discussion on the gelatin-based bio-ReRAM modelling and nanocomposites are also provided in this chapter.

2.1 Green Computing

Green Computing is the process of implementing policies and procedures that increase the performance of computing resources in order to minimize energy use and the environmental effect of their use[19, 20]. Green computing goals are somewhat like green chemistry, which is intended to lessen the application of toxic constituents, improve energy proficiency over the lifetime of the commodity, and promote the reusability or biodegradability of non-operating goods and factory waste [21]. In recent years, green computing is not only under environmental group's attention, but also of trade sectors. Business in the computing firm have come to realize that a green business model is better suited to their needs, in summary, green computing is nothing but the effective use of machines and computer methods. The IT sector of most businesses are focusing on resources and time in green computing projects to lessen the environmental effect.

2.1.1 The Importance of Green Computing in Information Technology (IT)

According to [22, 23], green computing is a study of the design, manufacture, use and disposal of computers, servers and related subsystems, such as displays, printers, storage devices, and networking and communication systems that are effective and efficient with minimal or no environmental effects. It also aims to enhance the economic viability and efficiency of the system and use it to meet your social and ethical obligations.Green computing is an important concept for keeping our world clean and secure. When it's involved in the recycling of machines, it's hard to dispose of obsolete machines and some more to take up a lot of space in the landfills, widespread use of computers and related IT products has a very bad effect on the environment. Green computing can be achieved by reducing energy usage and pollution. We've got the availability of energy conservation and carbon monitoring tools. What IT imports from computing devices to paper has a big effect on how green IT is and how green the manufacturers are. If an IT company only consumes Electronic Product Environmental Assessment Tool(EPEAT), Energy Star and other power generation ratings, it can help to reduce energy usage and greenhouse gas impact and it is going to help drive technology suppliers to create goods that have a power generation value. Various environmental issues and problems due to the impact of ITon environment are discussed below:

2.1.1.1 Environmental Issues

As we all know, greenhouse gasses have negative and long-lasting detrimental impacts on our environment and the ecosystem. The growing accumulation of greenhouse gasses is disturbingly changing global warming and temperature patterns. The concentration of greenhouse gasses in the atmosphere is steadily rising global temperatures. World figures suggest that floods, droughts and other weather-related phenomena are becoming ever more frequent than ever before. Electricity is a big cause of climate change, as nuclear power plants that will generate electricity can emit huge quantities of carbon dioxide and many others.These emissions are responsible for major lung problems, smog, acid rain and global climate change. Reducing the use of electrical energy and producing power in a more environmentally friendly way is critical to reducing carbon dioxide emissions and their effect on our atmosphere and global warming[20]. More precisely, the weather activity was mostly sporadic.The sea level is now directly interacting, with Arctic glaciers declining as never before caused by global warming. Members across all countries are very excited to be able to avoid the build-up of greenhouse gasses in the atmosphere. They are of the opinion that global greenhouse gas emissions might have to avoid rising to lower the impact of a greenhouse effect.

2.1.1.2 Impact of IT on environment

Information Technology (IT) impacts our world in many ways, respective points of a computer's life, beginning with its development, usage and discarding, poses environmental problems. Computer industrialization and its diverse non-electronic and electronic gears consume energy, raw materials, unsafe chemicals, and water and manufacture hazardous waste. Any of these directly or indirectly rise carbon dioxide emissions and have an effect on the atmosphere. Gross electrical voltage usage of servers, computers, displays, data processing cooling and equipment systems for data centers is also rising at a very rapid pace.

This spike in electricity load usage increases the greenhouse gas emissions. Each personal computer (PC) in use emits around a ton of carbon dioxide each year. The elements of the Central Processing Unit (CPU) contain a lot of radioactive material. As more and more consumers use computers, a significant point of obsolete computers, TVs and other electrical equipment are increasingly being recycled by consumers a few years after procurement, and much of this ends up in landfills, polluting the soil and contaminating water due to the inclusion of various toxic constituents in electronic products. High usage of computers and their use, along with their occasional alternatives, make the environmental consequences of IT a big concern for all of us. As a result, all players in the IT industry, businesses and individuals are under-pressure to ensure that IT remains environmentally friendly throughout their lifetime, from birth to death to rebirth. It is our mutual responsibility to protect our ecosystem for future generations[23].

Green computing involves a green infrastructure that refers to the secure and efficient management of computers, servers, and equipment such as printers, displays, networking/communication gadgets and storage systems with minimal or zero environmental impacts by study and application of green computing. Global best practice in design, development, usage, and disposal[25].

2.1.2 Advantages of green I.T

1. Growing tools power density:
2. Growing cooling necessities:
3. Rapid growth of the internet:
4. Low server utilization rates:
5. Constraints on energy supply and access
6. Increasing energy costs:
7. Developing cognizance of IT's impact on the environment:

Green computing in general can dramatically ease energy usage by creating minor improvements to the way we operate computers. Mostly, desktop computers work even when they are not needed, so users needlessly leave them to waste electricity[26]. In addition, computers produce heat and need additional cooling, which contributes to overall energy usage and costs. Although the used in energy costs per PC might not be much, the combined savings for hundreds of computers in an entrepreneurship are considerable. More into PCs and computer memory will be discussed further herein.

2.2 Computer memory

In computing, memory is called machines used to access data on a disk. The term primary memory is used for high-speed (i.e. RAM) storage systems as a differentiation from secondary memory that includes program and data storage that is slow to access but offers higher memory space. The used of a memory storage method called "virtual memory," primary memory may be stored in secondary memory, where applicable. Digital memory is usually split into two, such as volatile and non-volatile memory.

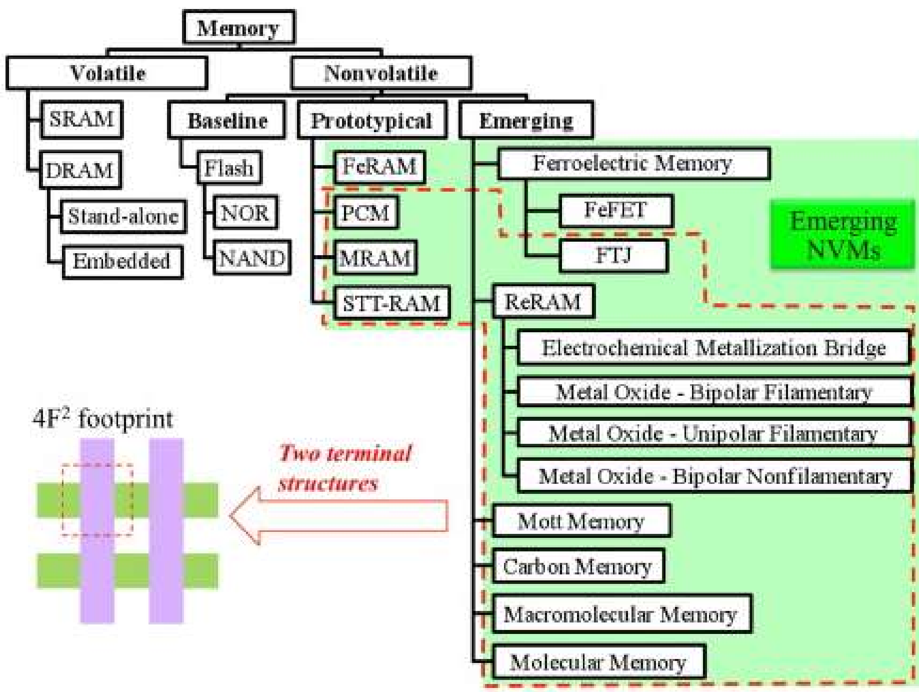


Figure 2—1:Showing the emerging volatile and nonvolatile structure. Adapted from [27]

2.2.1 Volatile Memory (VM)

Volatile memory requires a powered state in order to maintain data storage capabilities. The two components of volatile memory are DRAM and SRAM[28]. DRAM is a memory that store bits of information on individual's capacitors within an integrated circuit at high memory density while SRAM stores a single bit of information on multiple transistors simultaneously with a very fast reading and writing capabilities[29, 30]. Moreover, DRAM help to hit far higher densities, uses one transistor and one capacitor per bit and being much cheaper per bit with more bits on a memory chip. In desktop system memory, where DRAM governs, SRAM doesn't make sense, but is used in their cache memories.

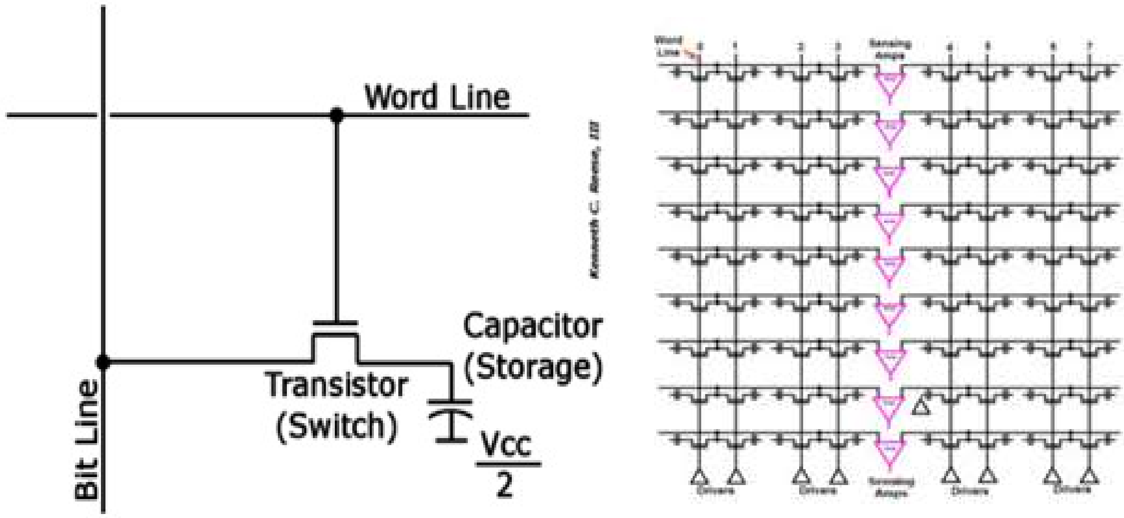


Figure 2—2: Deplete the typical diagram of DRAM. Adapted from [31]

Numerous of these mixed transistor-capacitor circuits creates a “word” of memory. DRAM must be provide with a voltage in other hold memory (and is thus volatile). SRAM is a typical place in small fixed systems which may require only less of tens kilobytes. Zero Capacitor Ram(Z-RAM), Twin Transistor Random Access Memory (TTRAM) include new volatile memory technologies that aim to interchange SRAM and DRAM or compete with them.

But SRAM still requirements regular power to sustain the charging state and is therefore volatile like DRAM. Because SRAM uses multiple transistors (Figure 2-3) per bit of memory versus DRAM, that further uses one transistor and one condenser per bit, DRAM is less costly. DRAM uses a method other than SRAM, so the discussion of size is in some ways an apple-to-orange analogy, depending on the objective of optimisation. DRAM is 10-fold slower than SRAM. SRAM is faster and is usually used in storage, DRAM is less costly and has a higher capacity and is mainly used as the main memory processor.

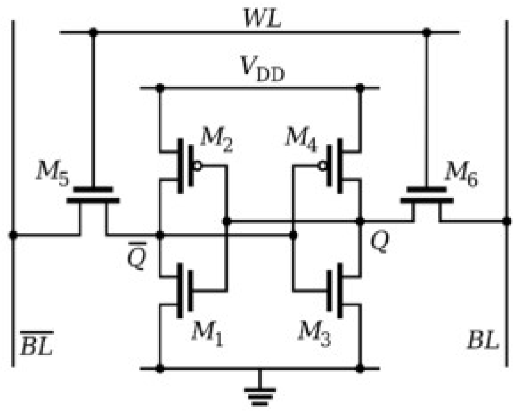


Figure 2—3: Representing SRAM cell with six transistors. Adapted from [31]

2.2.2 Non-volatile (NVM)

Non-volatile memory retains the deposited information also while power is not available. On the other hand, due to its capability it makes it a very desirable form of data storage for a broad variety of computer, automobile, business and communications technologies. The flare-up in these markets over the past decades, mostly in the portable electronics market, has motivate the success of a form of non-volatile memory which are called flash memory. Bestowing to Figure 2-1, the NVM can be categorized into two distinct parts to distinguish between technologies that have so far reached substantial intellect and those that are still emerging, namely; baseline and emerging memories.

2.2.2.1 Baseline memory

Baseline memory like flash memory is also witnessing new developments as two-dimensional (2D) materials are being used. Baseline refers to existing techniques which have already been used, this category includes read-only memory (ROM), and Flash memory. That term will be briefly addressed here.

2.2.2.1.1 Read-Only Memory (ROM)

A ROM can store data even when there is no electrical power, ROM is mainly used to load the computer operative system and is the long-lasting storage space for the basic input / output system and other hardware needed for computer system operations. ROMs are known as rewritetable programmable read-only memory (EPROMs) and write once read-many times (WORM), depending on their reprogrammable capacity. WORM is an NVM that reads data repetitively, and permanently stores data. Nevertheless, one can only write once, so the written material cannot be erased. WORM can store vast amounts of data, and access to information for a long time.

2.2.2.1.2 Flash memory

Flash memory was first introduced in 1980 by Dr. Fujio Masuoka, and it was named after its ability to remove a block of data “"in a flash”. Flash memory is a non-volatile memory that can stores one or more bits of information on a single floating-gate transistor and it permit an excellent concession between reliability, cost and performance capabilities such as detention, programming speed and data density[4, 5].Flash is popular because of localized load trapping, easy integration with complementary metal oxide semiconductor (CMOS) technology, lower load loss with low voltage programming and two-bit storage facing floating gate technologies [32]. Silicon-Oxide-Nitride-Oxide (SONO) devices such as NAND flash memory are regarded as mass storage devices of next generation due to integration with CMOS technologies [32]. SONOS flash memory has the advantages of better durability [33, 34, 35]. SONOS memory based on a high-K dielectric with gadolium oxide (Gd_2O_3) has been demonstrated by [36] as a trapping layer and the system has an elegant 11V memory window, strong 10-year retention and longevity characteristics [36].

Flash memory components work through the control of just a few electrons. Be that as it may, such a capacity component is vulnerable to warm disseminating and charge misfortune. Already, various examinations have been completed to create different of memory utilizing in computer in numerous pieces of the world [15, 16, 37]. Two versions of flash memories are NOR flash and NAND flash. NOR lash has a random and low-density access interface, while NAND flash has a sequential access interface and high density[38].

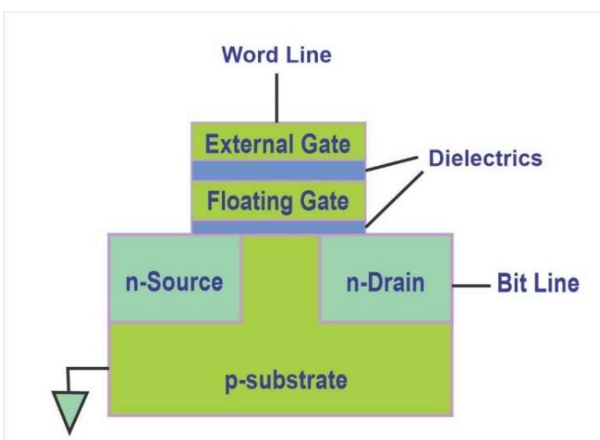


Figure 2—4: A typical Flash memory cell. Adapted from [39]

2.2.2.1.2.1 NOR and NAND Flash memory

NOR and NAND flash are popular in the memory market. NOR flash has lower density but a random-access interface while NAND flash has higher density and user access through a series of commands[40].The respective structures are shown in Figure 2-5. NOR and NAND Flash stem from the structure used for memory cell interconnections. Intel was the first company to introduce a commercial Flash chip (NOR type) in 1988; and in 1989 Toshiba published the first NAND Flash of the world [41]. Based on how the cells are placed in the matrix, it is possible to distinguish between NAND Flash memories and NOR Flash memories In NOR Flash, parallel to the bit lines, cells are linked which enables the cells to be read and programmed individually.In a CMOS NOR gate architecture, the parallel connection of NOR Flash cells parallels the parallel connection of transistors. On the other hand, the cells are connected within series in NAND Flash which resembles a NAND gate.The series connections use less space than the parallel links, minimizing NAND Flash costs. It does not, by itself, prohibit individual readings and programming of NAND cells. The distinction between these two systems is not so common to most engineers and scientists. We generally refer to the NOR architecture as ' Flash ' and are not aware of the NAND flash technology and its many advantages over NOR[42]. This may be due to the fact that most (usually small) flash devices are used to store and run codes for which NOR flash is the default choice, although we give some major differences between NOR and NAND through their architecture, flash technologies and the individual Flash's internal characteristic features. Compared with NAND flash[43], NOR flash is slower in erase and write operation.It means NAND flash will be able to erase and write times faster. In addition, NAND flash has smaller erase units, so it needs fewer erases. NOR flash will read data much quicker than NAND flash. NOR flash offers full address and data buses to access any of its memory locations randomly (addressable to each byte). This makes it an acceptable replacement for older ROM Basic Input/Output System(BIOS) / firmware chips, which rarely need upgrading. The lifespan is between 10,000 and 1,000,000 cycles in erase. NOR Flash is highly appropriate for the storage of codes in embedded systems. Most of today's microcontrollers come with Flash memory built in[44]. NAND Flash covers one smaller chip per cell. It allows NAND Flash visible at higher storage densities and at reduced cost per bit than NOR Flash. It even has up to ten-fold NOR Flash's durability.NAND is more suited for larger files including video and audio as storage media. Secure Digital (SD) cards, Universal Serial Bus (USB) thumb drives, and NAND-type Multimedia Card (MMC) cards [34]. The advantages of NAND are quick write (program) and erase operations, while the advantages of NOR are random access and byte write capability.The random-access feature of NOR facilitates the execution of on-site (XiP) functions, which is often a prerequisite for embedded applications.NAND is accessible slowly at random, while NOR is hampered by slow writing and performance erasure. NAND is best suited to application filing. More processors, however, include a direct NAND interface and can boot directly from NAND (no NOR). However, NAND cannot continuously perform read and write operations; it can perform these activities at system level using a technique called shadowing, which have been used on PCs for years by loading the BIOS from the slower ROM into the high-speed RAM.

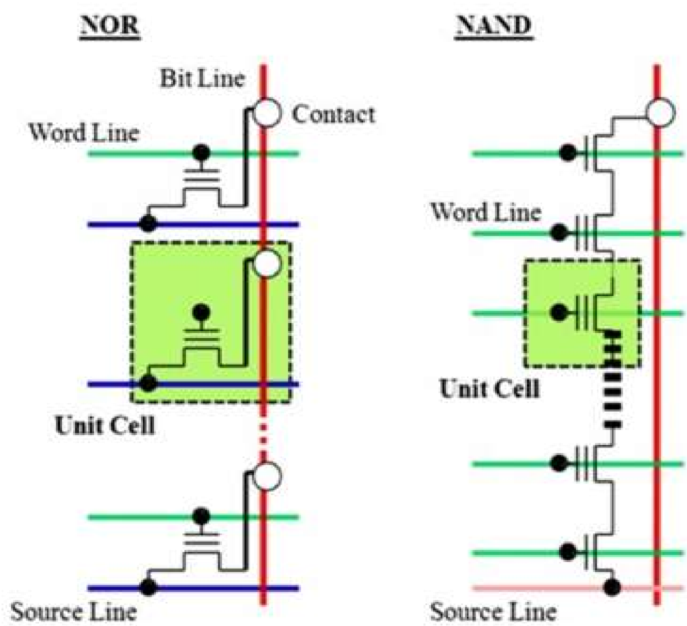


Figure 2—5: Showing the architectural structure of NOR and NAND flash memory cells. Adapted from [34]

Table 2-1: The characteristics of NOR and NAND flash memory listed summarized by [45].

	NOR	**NAND**
Write/Read/Erase	Slow/ Very fast/Very slow	Fast/Moderate/fast
Density	Low	High
Cost per bit	High	Low
Write/Read	Bitwise	Page-oriented
XIP	Yes	No

The flash memory's main operating source involves the ability to control the verge voltage of the flash memory (i.e., the minimum voltage gap between the gate and the source terminals needed to achieve conductivity between the sources and drain terminals) between different magnitudes that correspond to different cell logic states. Nevertheless, flash memory's storage capacity is approaching its scaling limit because it cannot further reduce the transistors used to make flash memory arrays. The power desired to write flash is also a constraint that has a greater effect on the battery life of portable devices. Flash is handicapped by high voltage write, low speed writes and poor endurance. According to [46] they demonstrated high-performance, high-resolution organic flash transistors made of reduced graphide oxide (rGO) and observed a 20V NVM window with a retention period of 10^5s from that report. Lately, Organic floating gate Flash memory with 2DMoS flakes as charging storage elements exhibited a -23V NVM window, a cycle of endurance exceeding 100, and a decade of data retention [47]. Flash memory with full endurance [48, 49] and a limited 2V memory range with solution stored molecular memory memories[49]. Thus, these technologies for Flash memory should be regarded as emerging technologies.

2.3 Emerging Technologies

There are many reviews for data storage, neuromorphic computation[50, 51, 52, 53, 54], functionalities and mechanisms [55] on fabrication optimization of emerging non-volatile memory at the physical, material, or system stage [56, 57, 58, 59, 60]. Recent researchhave shown that, despite scalability, there's a really similar connection between current and emerging memory technologies. The scaling pattern of memory transfer points to progressively smaller devices that have been observed regularly. To promote back this claim, alternative collection of current memory technology progress is described in terms of the extreme importance of memory to the interface of users and Emerging NVM innovations include resistive random-access memory (ReRAM), phase-change memory (PCM), ferroelectric random-access memory (FeRAM), magnetic memory (MRAM), motto memory, molecular memory, carbon memory (CBRAM) and macromolecular memory.There are several modern memory devices on the market that are seeking to replace current memory technologies. These modern memory chips, such as ReRAM, PCM, and STT-RAM, have different read/write/retention/endurance capabilities than the usual SRAM, DRAM, and Flash features [61]. But the ideal features of new emerging memory technologies must be meeting SRAM performance and NAND flash density in terms of switching speed, scalability and stability. Therefore, moving beyond conventional bistable memory, it is important to explore thepossibilities of market-appropriate, multilevel, high-performance memory devices. Any of these new emerging technologies are PCM, MRAM, STT-RAM, FeRAM, nano-random access memory (NRAM), ReRAM, memristor,racetrack memory and molecular memory[62, 63].The technologies will be illustrated briefly and discussed in the parts below PCM, FeRAM, and MRAM are currently in commercial production, but are still limited to niche applications compared to DRAM and NAND Flash, despite commercial production.There is a possibility that the most promising among the new memory technologies are MRAM, ReRAM and STT-RAM but they are still far from competing for market acceptance for many years [64].

2.3.1 Ferroelectric Random-Access Memory (FeRAM)

Ferroelectric random-access memory (FeRAM) is a non-volatile RAM that combines DRAM cells with quick read and write access, entailing a condenser and transistor structure as shown in Figure 2-6. The cell is then reached via the transistor, which allows the dielectric capacitor to be sensed in the ferroelectric state.FeRAM are free of iron, in spite of its name. The polarization properties of the ferroelectric material was used as a memory unit. Today, Feram uses zirconate lead titanate (PZT); other materials are considered. The major creator of Feram is Ramtron International. FeRAM is the most common form of personal computer memory capable of maintaining data while power is turned off, as are other non-volatile memory systems such as ROM and Flash memory [65]. In a DRAM cell, the data needs to be refreshed periodically due to condenser discharge, while FeRAM holds data without external power supply. This is achieved by using the ferroelectric layer between the condenser plates instead of the conventional dielectric material. When an electrical field is applied to dielectric or ferroelectric materials, it polarizes and depolarizes when the field is extracted.But in the polarization versus electrical field plot, the ferroelectric material exhibits hysteresis and retains its polarization. One downside to Feram is that the read duration is harmful. The method of reading involves writing a bit to each cell; if the state of the cell varies, a small current pulse is detected by signalling that the cell is in the state of OFF.Nonetheless, it is a quick memory that can withstand many cyclesat least10^{14} (100-trillion)[66]. The method of reading involves writing a bit to each cell; if the state of the cell varies, a small current pulse is detected by signalling that the cell is in the state of OFF.FeRAM is faster than memory in Flash. Replacing electrically erasable programmable read-only memory (EEPROM) and SRAM is also considered to be a central component of upcoming wireless devices for certain applications. And after Feram reached a degree of commercial success, the first machines were unveiled in 1993.[67, 68], the current FeRAM chips deliver enactment that is either equivalent to or greater than current Flash memories[66, 69], but still slower than DRAM.

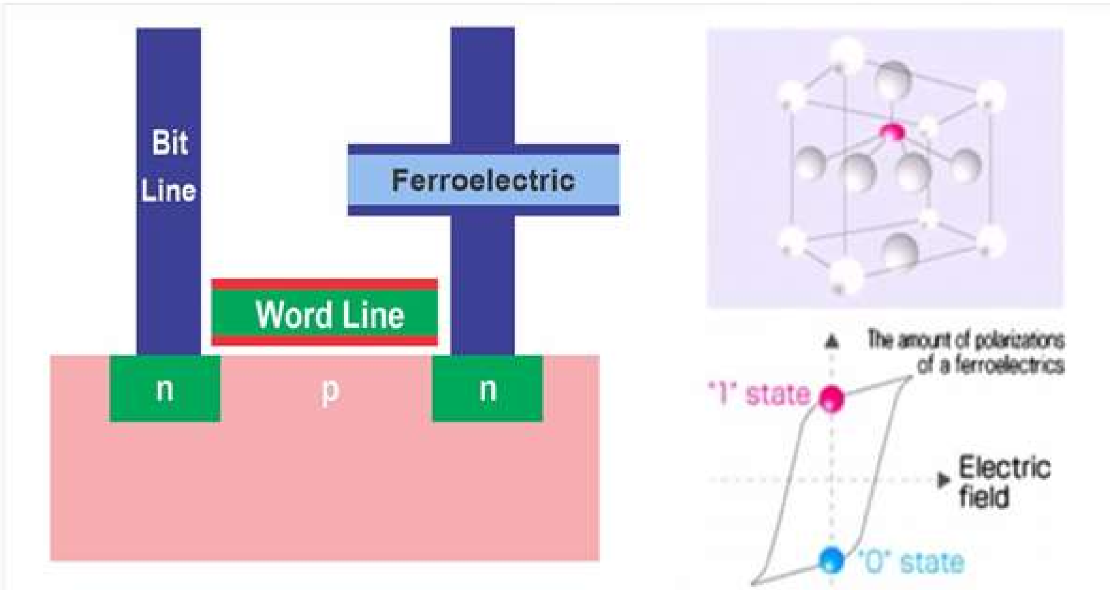


Figure 2—6: Typical structure of FeRAM. Adapted from [65]

2.3.2 Spin-Transfer Torque - magnetic random-access memory (STT-MRAM)

STT-MRAM is a magnetic memory technology that uses an existing memory platform named MRAM to allow a flexible, non-volatile memory solution for effective inventory nodes[70, 71].This is a modern method of magnetic RAM with the following points: easy read and write times, compact cell sizes, possibly much smaller, and compatible with current DRAM and SRAM.As mentioned earlier, MRAM holds data in the magnetization direction of each bit, and the bits are set by the nanoscopic magnetic fields of the traditional MRAM. STT-MRAM, on the other sides, uses spin-polarized currents, resulting in smaller bits and lower energy consumption. The structure of the base cell STTRAM is seen in Figure 2-7. STT-RAM writing is also a method for electrical current, polarized by connecting the direction of rotation of electrons moving through the portion of the magnetic tunnel junction (MTJ). Data writing is done by adjusting the magnetic alignment of the data storage layer in the MTJ portion by the use of polarized spin current.[72]. The subsequent difference in resistance of the MTJ component is used to read the content. For upcoming MRAMs developed using ultra-fine processes, STT-RAM is more suitable technology and can be easily implemented into future generations of semiconductor devices such as FPGAs, microprocessors, microcontrollers, etc. SoCs.The idea that the STT-RAM internal voltage needs just 1.2 V is a special benefit to built-in designers. The distinction between the STT-MRAM and the normal MRAM is restricted to the writing phase mechanism; the read device is the same. The STT-MRAM memory cell consists of a transistor, an MTJ, a bit line (BL),a word lineand a source line (SL)[73]. STT-RAM is currently being made by companies such as Everspin, Grandis, Hynix, IBM, Samsung, TDK, Toshiba and others. However, some key issues need to be resolved if STT-RAM is to be recognized as a universal standard semiconductor memory: low switching current and high thermal stability at the same time. It has to be dense (about 10 F2), fast (less than 10 ns of reading and writing) and work at low power[74].

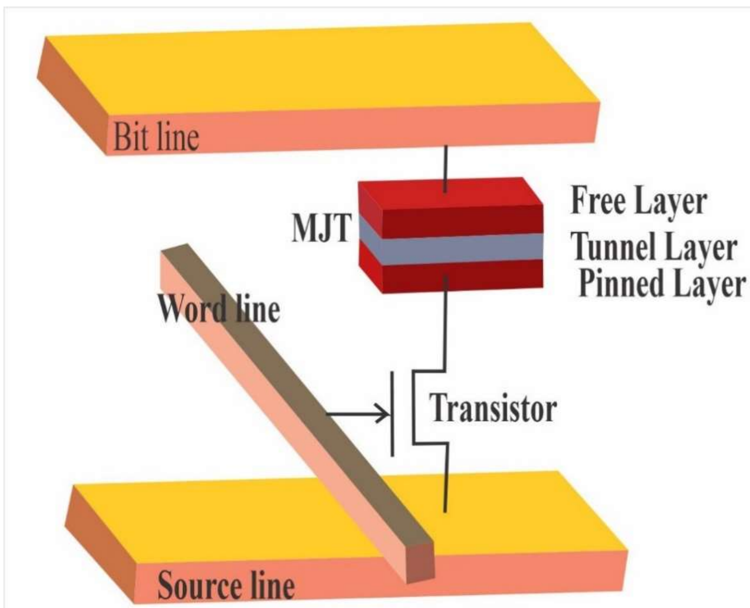


Figure 2—7: Represent the cell structure of STT-RAM. Adapted from[74]

2.3.3 Magnetic Memory (MRAM)

Magnetic Memory (MRAM) is a non-volatile RAM system, development since 1990s. RRAM data bit storage techniques use magnetic charges rather than electrical charges used with DRAM and SRAM systems. MRAM, was the first developed IBM in the 1970s [75], MRAM, was the first developed IBM in the 1970s [75], is designed to replace DRAM as an electronic memory standard. MRAM is fundamentally based on two magnetic storage elements in memory cells, both with a set magnetic polarity and a switchable polarity. As seen in the cell structure in Figure 2-8, these magnetic elements are placed on top of each other but isolated by a thin insulation tunnel barrier. In fact, when placed in a magnetic field, researchers define a metal as being magnet-resistant if it revealed a small improvement in electrical resistance through comparing the high speed of static RAM with the high density of DRAM, proponents claim that MRAM could be used to greatly boost electronic goods by storing greater volumes of data, enabling it to be processed more easily while using less battery power than existing electronic memories. Technically, it deals for the state of the cell, which is determined by electrical resistance when moving around the cell the magnetic tunnel effect [76], if all magnetic moments are similar to each other, the electrons will be tunneled, and the cell will be of low resistance in the 'ON' state. Nevertheless, if the magnetic minutes are antiparallel, the resistance of the cells is high. MRAM's writing and deleting memory characteristics are met by moving a current along the write line to create a magnetic field around the cell. MRAM eventually got off the ground but has now entered the industry and will become readily eligible for mass manufacturing over the next few years and beyond. Some level of market success in niche applications has now been reached [77]. Various firms, including Samsung, IBM, Hitachi, and Toshiba, and TSMC are aggressively designing the MRAM chip technology variant. With regard to power usage and tempo, MRAM competes well with an access time of a few nanoseconds [78, 79] than other current memories such as DRAM and Flash. While it has some drawback during the 'write' process, it could be possible to restrict the smaller size of the cells by expanding the magnetic field to neighboring cells and allowing the adjustment to serve as a generic memory. Although it has some disadvantage during the ' write ' process, by extending the magnetic field to adjacent cells and allowing an amendment to act as a universal memory, it may be possible to limit the smaller cell size. It is expected that in the future, MRAM will have the largest market of next generation memory technologies, followed by PCRAM, FeRAM and memristors.

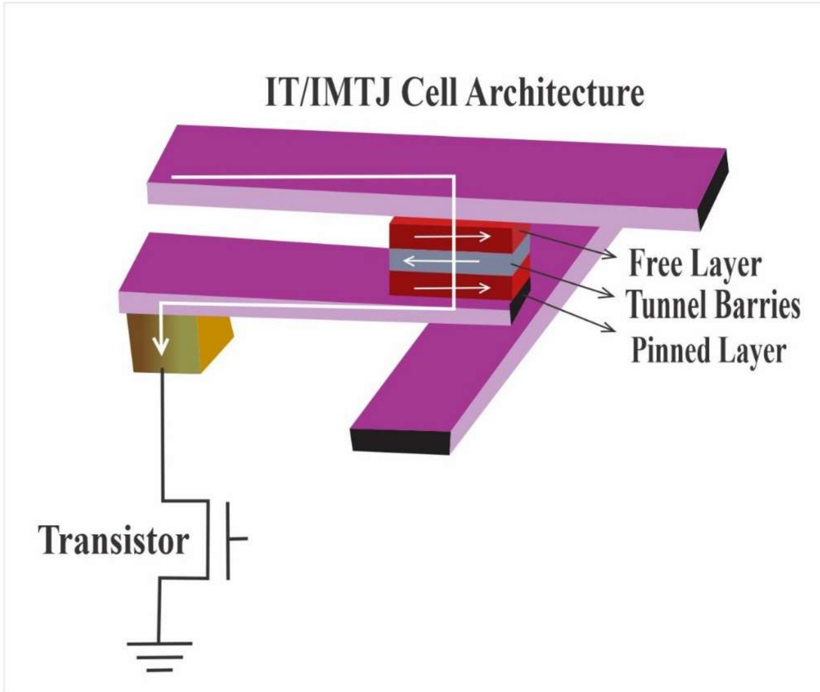


Figure 2—8*: Representing Basis MERAM Structure.*Adapted from[34]

2.3.4 Phase Change Memory (PCM)

Phase Change Memory (PCM), also be refer to as Perfect RAM (PRAM), OUM, PCM and Cralcogenide RAM (CRAM). PCM is an example of non -volatile RAM centered on a class of material called chalcogenide glass that can occur in two different phase states (e.g., crystalline and amorphous)[80, 81].The basic structure of cells in PCRAM is shown in Figure 2-9. Several phase-change materials hold at least one element from 6 members of the periodic table; and by doping these materials, the range of available materials may be further expanded[82, 83, 84].The most impressive are the GeSbTe alloys that adopt a pseudo binary composition (between GeTe and Sb2Te3),called GST. In reality, these materials are widely used in rewritable compact disks and digital portable disks (CD-RW and DVD-RW) as a virtual machine where variations in optical properties are used for storing informations.On a microscopic, the structure of the material will change rapidly between amorphous and crystalline.

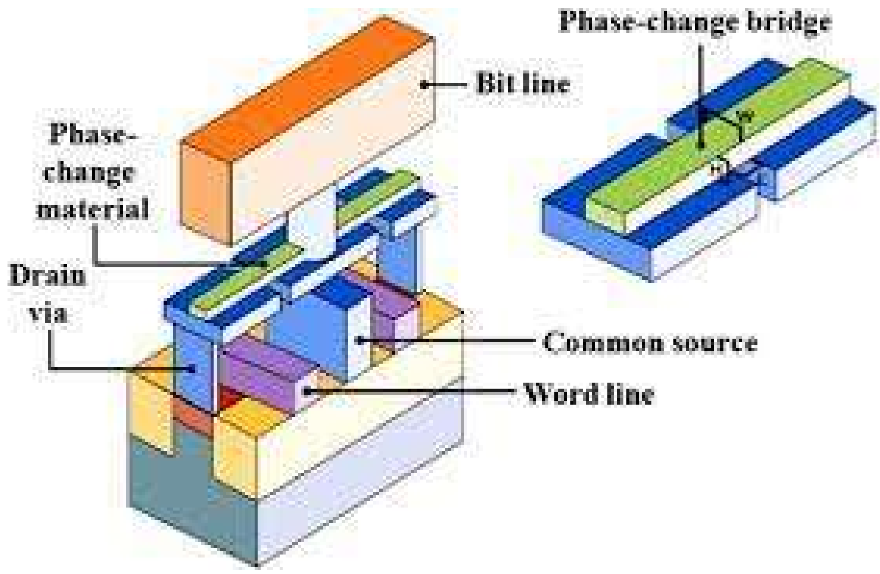


Figure 2—9: Diagram depicting Phase change material.Adapted from[34]

2.4 Organic Memory

Organic memory devices run a best solution, cheap, and at the same time it gives a favorable performance [37]. Presently Organic memories have currently attained more interest amid scientists, scholars in both academics and Industries. Because of their high adaptability, simple scaled down measurement, printing capacity and property that can be reasonably composed through compound union [47] which make natural material more suitable for minimal effort ReRAM use and it can defeat the limitations of regular silicon-based memory devices and enhance the upsides of Organic-based ReRAM [85, 86]. Normally, determined materials have the promising to be utilized in bio-enlivened electronic frameworks including restorative finding devices, natural hardware, brain– machine interfaces, careful bioelectronics, and skin biosensors. Various useful devices that utilization biomaterials as their urgent constituents have been created, including natural field-impact transistors, memory devices and optoelectronics. The utilization of biomaterials in non-unpredictable memory devices is favored for prospect bio-inspired data storage system. The fate of computing devices is one where memory (or, in other words significant piece of numerous devices) will increment considerably more as for rationale [87].

Conventional computer systems favor computation (CPUs) and information storage (memory) segments. While the volume of information that computer systems process has shoot up in the course of the most recent decade, information drive among CPUs and the memory is getting to be a standout amongst the most genuine acts and vitality burglaries in different computer systems changing from cloud servers to end-client devices. For instance, information exchange among CPUs and off-chip memory devours two requests of size more vitality than a gliding point task. Despite this developing enthusiasm for nanocomposite material for use in different electronic devices utilization of gelatin nanoparticles in natural non-unpredictable memory devices stay uncommon. As of present, different natural materials like polymers have been utilized in non-volatile memory components that includes resistive switching behavior[88, 89]. Among them, biomolecules reveal a potential use as materials for ReRAM devices on the grounds that the particles are cheap, ecologically kind, and adaptable and additionally biocompatible [15]. In this way, normal materials are being thought as a conceivable possibility for biocompatible hardware. Then again, creation of biodegradable ReRAM is profoundly wanted in perspective of their characteristic wealth, superfluity, and minimal effort. In this investigation, we utilized gelatin as a bio inspired SPE and linked to the resistive switching component in ReRAM.

2.5 Resistive Random-Access Memory (ReRAM)

Resistive Random-Access Memory is a kind of non-volatile random-access (RAM) computer memory that records information by sending electrical signal to safe materials, which occur as thin layers in the memory cell, and altering the substances' resistance. Even though it has not been marketed yet, the 3D cross point innovation is accepted to enhance the information get to speed by one thousand times contrasted with existing NAND flash memory chips. Since it straightforwardly tactics the location of every cell, it doesn’t have to write,read and erase cells of the pages and blocks, it can likewise enhance the strength of memory by one thousand times. NAND flash can write one thousand times in every cell except 3D cross point can support around One (1) million compose cycles [90].

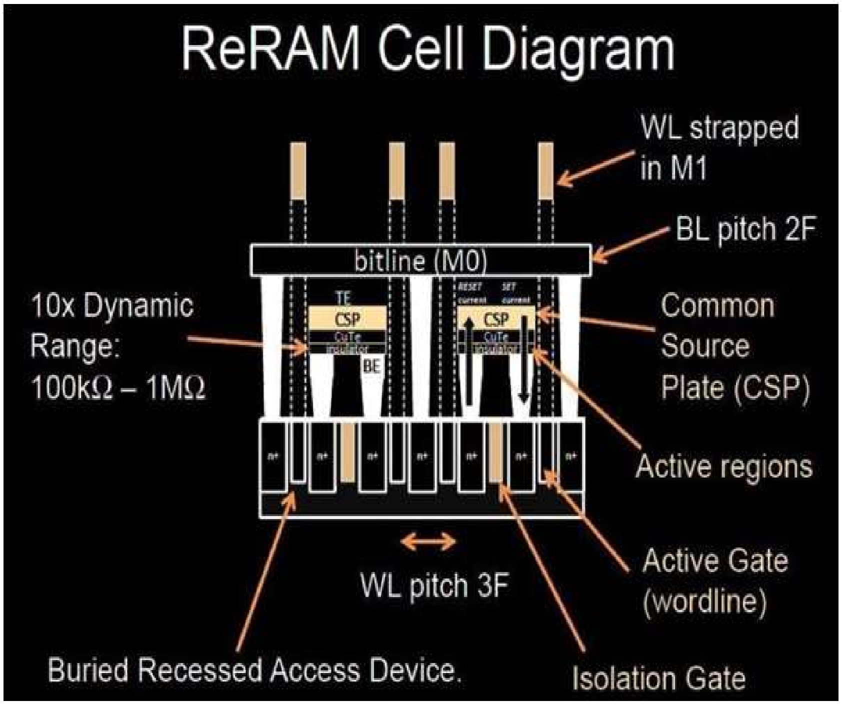


Figure 2—10: ReRAM 3D Cross Point.Source: [90]

In desktop computers and laptops, this is normally DRAM. "When the power disappears, the content of the memory is forgotten," report from University of Southampton's school of engineering sciences by Dr. Boardman Richard. “This procedure takes little time -in a couple of moments it is practically incomprehensible, even with refined devices. Also, the DRAM has to always keep powered, this builds reserve application for devices, alongside the danger that the application will vanish if the strength does. "ReRAM - or resistance memory - takes care of this issue by utilizing materials that change resistance in response of voltage. They then "recall" that level, notwithstanding when the power is off. As of late, memory manufacturer Elpida, Japanese reported it had created a model ReRAM memory with paces like DRAM. "Its most important component is that it can write and read information at high speeds using limited voltage," Elpida said in an official statement. "It has a compose speed of 10 nanoseconds, about the equivalent as DRAM"[91].

ReRAM has promising applications for future technology in data information. ReRAM or RRAM is a sort of non-volatile memory that stores information by adjusting the cell resistances. The all-inclusive definition does not stipulate the resistive exchanging innovation or material [92]. As an emerging non-volatile memory, ReRAM has been expressed as a promising contender for prospect in memory design, before its low spillage control, high thickness and quick read access. ReRAM has favorable circumstances with novel properties that are straightforward and adaptable, so it will be profitable for these devices. ReRAM is a two-terminal device involves a network of word and bit lines with metal/encasing/metal (MIM) structure. Data is composed in ReRAM by putting on a programming voltage that order the device from high-resistance state (HRS) to low-resistance state (LRS). After achieving LRS, the perusing procedure is actuated in a perfect non-volatile device, LRS ought to be held without utilization of outer inclination. Information are eradicated when a contrary voltage or higher voltage is connected to the device and alternate its state from LRS to HRS. In a reproducible ReRAM, this procedure ought to occur persistently for a few hundred cycles with no corruption. Biodegradable ReRAM is an option in contrast to semiconductor-based recollections and has developed as a practical answer for the waste administration worries of CMOS-good ReRAMs Semiconductor-based ReRAM has focal points with dependability, versatility, high thickness, quick exchanging and low power utilization. Nonetheless, when it is disposed of it doesn't separate promptly, so huge measures of semiconductor junk are created, with subsequent wellbeing dangers and waste administration costs.

2.5.1 Resistive switching mechanisms (RSM)

As it was earlier stated,diverse mechanisms ways have been proposed in other to describe the resistive switching effect detected in a large range of material. The main ideas of the switching mechanism are styled in this section see Table 2-2. The valence change memory cells have associated two different switching sources.

Table 2-2:Summary of the different memory cells together with the respective switching behavior and a brief description of the switching source.

Memory cell type	**Switching source**	**Switching behavior**
Electrochemical Metallization	Disband of Metallic filament contains one cell electrode / electrochemical formation cations Mz+	Bipolar
Valence change	Formation of an enriched oxygen vacancy zone propagates from cathode to anode difference in the composition of the metal / oxide interfaces with oxygen vacancies.	Bipolar
Thermochemical	Performing filament forming based on Variations in local stoichiometry and redoubled Local-temperature reactions Gradients which lead to electronic conductivity changes.	Unipolar

2.5.1.1 Electrochemical metallization memory (ECM)

The resistive switching operation in this memory cell lies on the breakdown of the metal filament amid the two electrodes and the electrochemical deposition. The electrochemical metallization (ECM) cell consists of an active electrode (AE) comprises of an electrochemically active metal (such as Cu, Ag etc.) and is regularly referred to as Conductive Bridging (CB) or Programmable Metallizing Cells (PMC) in literature. The cell is made up of an electrode composed of a metal electrochemically active electrode (AE), such as Ag or Cu, an inert balance, an electrode (CE), such as Pt, Ir or W, and a solid sandwiched electrolyte layer between CE and AE [93]. No electrondeposit of the AE metal on the CE is present in the cell 's initial high-resistance state (OFF).The switch to a low resistance state results from the formation of a metallic conductive filament through the insulating region, which can be characterized in three steps [37, 85].

1. Breaking at the active electrode by the reaction

$$Ag \rightarrow Ag^{+} + e^{-},$$

2. Migration of the Ag^{+}cations via the electrolyte below the impact of an applied electric field.

3. Decrease and electro crystallization of the metal ions at the inert electrode

$$Ag^{+} + e^{-} \rightarrow Ag;$$

The cations travel through the solid-electrolyte below the electric field, which act toward the inert cathode, where they are decrease and electro-crystallized as you can see in the figure 2-11 below. The electro-crystallisation process leads to the development of a metal filament in the active electrode route. The cell is modified to ON state as the metallic filament crosses the two electrodes. The RESET process is done by placing a suitable voltage of opposite polarity that affects the electrochemical dissolution of the metal filament.

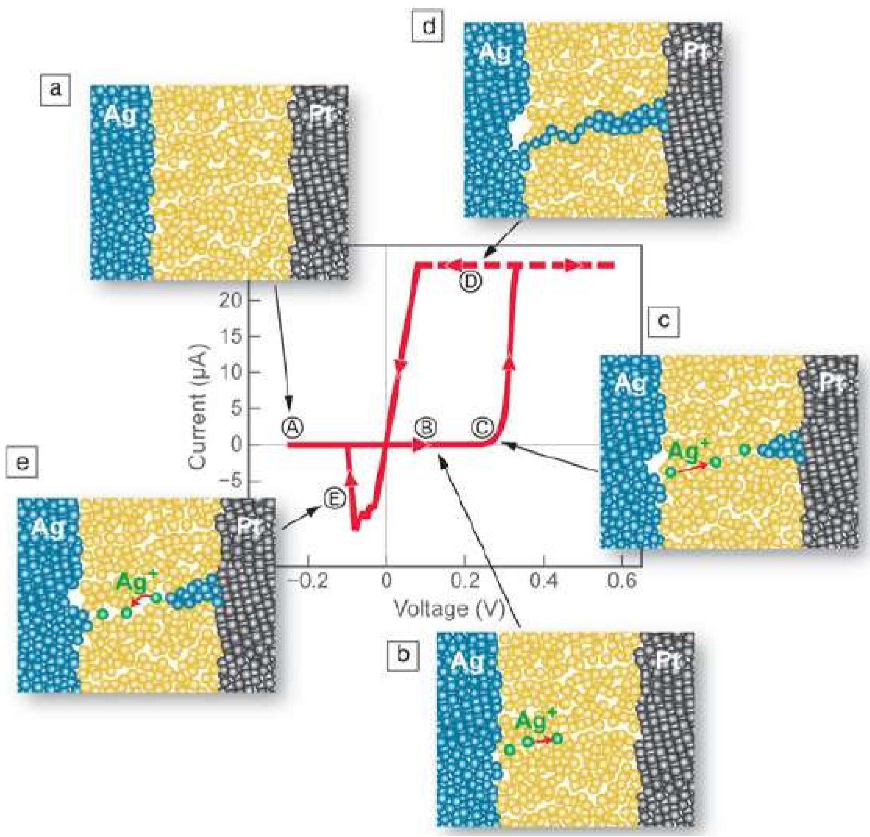


Figure 2—11:Diagram of the (A–D) SET and (E) RESET operations of an electro chemical metallization (ECM) cell. Adapted from [93]

2.5.1.2 Valence Change Memory (VCM)

The typical MIM cell of a valence change memory system consists of an active electrode (AE), an ohmic counter electrode (CE) and an insulating layer in between. It's also produced by field-assisted oxygen anions journey and valence change of the cation sub lattice [94]. The compact modelling consists of three inter-related modules

1. Evolution of CF
2. Temperature dynamic evolution
3. Conduction Mechanism

Evolution of CF is always enert with ion, electrical or thermal migration [94]. Among the mechanisms of conduction restricted by the electrodes are

(i) Schottky emission.
(ii) Direct tunneling
(iii) Fowler-Nordheim (F-N) tunneling and;

Bulk-limited conduction mechanism includes

(i) SCLC
(ii) Ohmic conduction
(iii) Hopping conduction
(iv) Poole-Frenkel (P-F) emission
(v) Trap - assisted tunneling (TAT) and;
(vi) Ionic conduction.

2.5.1.2.1 Thermionic Emission

The thermionic emission occurs as heat-initiated electrons infuse into the oxide conductive band over the energy barrier as appeared in Figure 2-12[95]. This kind of thermionic emission stands out among the regularly viewed oxide conductivity mechanisms , especially at relatively high temperatures [96].

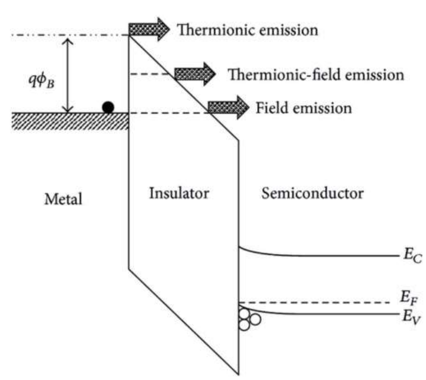


Figure 2—12: Diagram of Thermionic emission in metal-insulator-metal (MIM) structures.Source from [97]

The current density *JSE* can be allied to temperature (*T*) and electric field (*E*)by the thermionic equation as revealed in Equation (1).

$$J_{SE} = \frac{4\pi q m^*(kT)^2}{h^3} \exp\left[\frac{-q\left(\phi_B - \sqrt{qE/4\pi\varepsilon}\right)}{kT}\right]$$ **Equation 2-1**

Where

h - Planck's constant

k - Boltzmann's constant

m - Electron effective mass in the oxide*

T - Absolute Temperature

ε - Permittivity of the oxide

ΦB -denote the junction barrier height

E - Electric field across the oxide.

In scenario where the mean free path of the electrons is less than the width of the thermionic barrier, the revised thermionic equation of Simmons (Equation (2)) are apply[98, 99].

$$J_{SMSE} = \alpha T^{3/2} E \mu \left(\frac{m^*}{m_0}\right)^{3/2} \exp\left[\frac{-q\left(\phi_B - \sqrt{qE/4\pi\varepsilon}\right)}{kT}\right]$$ **Equation 2-2**

Where,

α is a constant,

m_0 is electron mass and;

μ is bulk mobility.

2.5.1.2.2 Poole-Frenkel (P-F) Emission

The Poole-Frenlel discharge occurs once caught electrons get energized through the transmission band of the oxide. The electric field diminishes the Coulombic possible obstruction of the electrons and consequently builds its chance for being thermally energized out from the trap's[100]. The exponential segment of P-F expression is fundamentally the same as Thermionic emission, aside from the intersection barrier height (ΦB) is supplanted with the profundity of trap's prospective well (ΦT) and the obstruction lowering the effect in

P-F is twofold of thermionic emission outflow because of the immobility of positive charge[101, 102]. The energy band outline of P-F outflow is portrayed in Figure 2-13.

The current density J_{PF}can be expressed as Equation (3) [100]:

$$J_{PF} = q\mu N_C E \exp\left[\frac{-q(\phi_T - \sqrt{qE/\pi\varepsilon})}{kT}\right]$$

Equation 2-3

Where,

E - Electric field applied,

k - Boltzmann's constant,

NC denote the states in conduction band density,

T - Absolute temperature,

μ - Electronic drift mobility, and

ΦT - Depth of traps potential well.

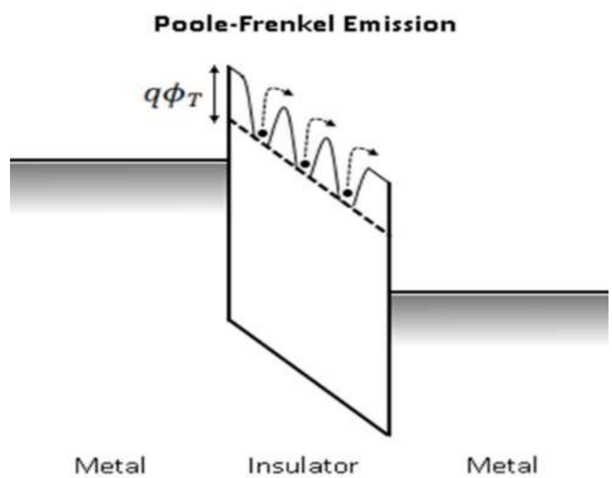


Figure 2—13: Energy band diagram of Poole-Frenkel emission in MIM structures. Source [97]

2.5.1.2.3 Ohmic Conduction

There is indeed few numbers of mobile electrons produced owing to thermal excitation, even though the oxide's energy band breach is expansive by description. Such electrons contribute to the Ohmic conduction in which the current density correlates to the electric field and in high resistance state (HRS) is reasonably evident. Equation (4) denote to the present thickness of the Ohmic conduction.

$$J_{ohmic} = \sigma E = q\mu N_C E \exp\left[\frac{-(E_C - E_F)}{kT}\right]$$ **Equation 2-4**

Where

μ denote electron mobility,

EF - Fermi energy level

Nc - Active density of states of the conduction band

σ - Electrical conductivity and

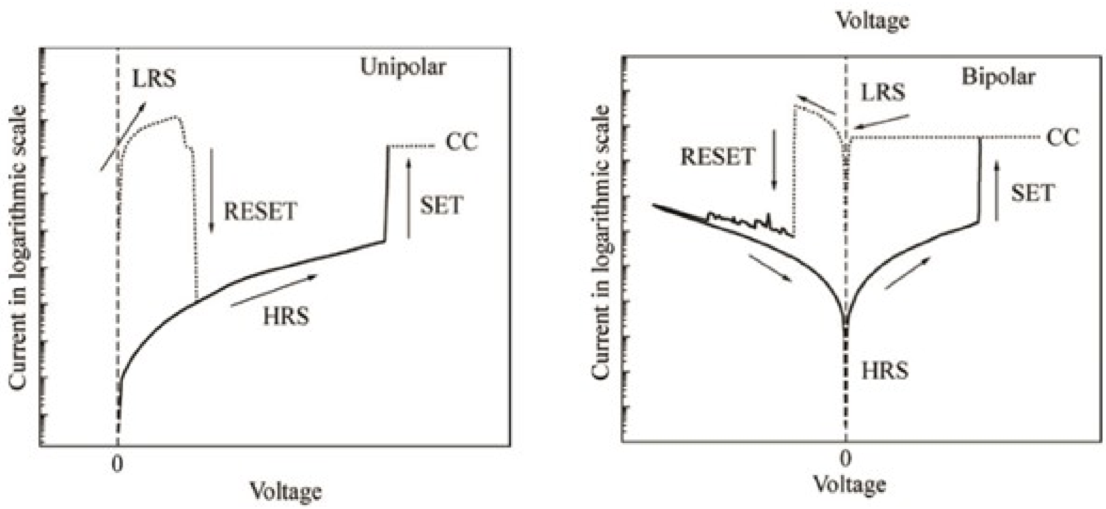
EC - Conduction band.

2.5.1.3 Thermochemical mechanism

The thermochemical resistance changes mechanism effects from local Joule heating which happen in the insulator owing to high current that occurs from a voltage used through the electrodes. A shift of a conductive state might occur if there is too much of electric field is applied across the insulator [87]. Until the film is recovered by subsequent voltage application, the resistance state of insulator after breakdown is low. It is vital to note that more than one of these mechanisms can add to the resistance change in a certain system, and isolation of one of the mechanisms as being the dominant one, where possible, will be governed on the state of the exact switching system. Moreover, analytical models for crucial values linked with switching incline to be particular to particular material systems, building generalization of the total mechanisms even more interesting [61, 103].The behavior of the resistive switching mechanism is discussed below.

2.5.1.3.1 Bipolar and unipolar resistive switching behaviors

ReRAM's main characteristic can be classify into two diverse resistance states, such as strong resistance state (HRS) and low resistance state (LRS), that could be operated by switching suitable electrical stimulus from one to the other. ReRAM's non-volatile nature in the precise resistance state (HRS or LRS) can still be maintained when there is no electrical stress. HRS and LRS resistances can be recorded when the voltage is low which has no impact on the resistance state. SET cycle usually adjusts the device's resistance from HRS to LRS when RESET works in the opposite direction. The resistive switching behaviors can be categorized into two classes owing to the relation of electrical polarity between the RESET and SET processes: bipolar and unipolar, which produced various current—voltage (I—V) appearances, as illustrated in Figure 2-14A and B, respectively.



A **B**

Figure 2—14: Unipolar I-V curves B and bipolar B in semilogarithmic scale and current compliance (CC).Adapted from [104]

The unipolar ReRAM switching mechanism is attributed to the conductive filament working beneath voltage stimulus placing the device into LRS and Joule heating effect affected the rupture of the filament, which turns it back to HRS. As the Joule heating effect does not rely on the polarity of the current, this type of device shows unipolar switching behavior. As it can be seen in Figure 2-14A, displays the unipolar resistive switching I-V curves in logarithmic scale, the device switches from HRS to LRS at a high voltage (VSET) and the switching path does not focus on the polarity of the useful voltage. The device proceeds to HRS at voltage (*VRESET*) greater than the (*VSET*). A current compliance (CC) is constantly used in the SET process to permanently resist breakdown, while the application of CC in

RESET process is not necessary. Devices that have the unipolar characteristic I — V usually have the symmetrical structure that indicates that the upper electrode (TE) uses the matching material as the bottom electrode (BE). Replicate of this resistive switching behavior has been detected in binary oxide system, such asPt/NiO/Pt[105, 106, 107, 108], Pt/TiO2/Pt [109, 110], Pt/ZnO/Pt [111]and Al/ZrO2/Al[112]. The switching characteristics of NiO films at diverse temperatures have also been scrutinized by [108] and the study indicates that the heating effect of the Joule system is determined and that the stability of the filament is regulated by the interaction between thermal dissipation and Joule heating impact.More so, the bipolar switching device structure is generally asymmetric. Diverse materials are used for example as TE and BE. The path of bipolar ReRAM switching influenced the polarity of the voltage used, as shown in Figure 2-14B. V_{RESET} polarity are vise-versa to each other $V_{SET'}$, and the electrical signal whose polarity is identical to V_{SET}(V_{RESET}) does not affect the LRS (HRS). The most perplexing thing about unipolar resistive switching is that VSET will intercept with VRESET due to the same polarity of V_{SET} and V_{RESET}. This does not necessarily occur in bipolar resistive switching, owing to the opposite voltage polarity of Fixed and RESET systems. Bipolar ReRAM has been extensively examined with the aim of preparing the non-volatile switches in a reconfigurable integrated large-scale circuits (LSIs)[113]. There are many pathways intricate in ReRAM bipolar swapping which contributes to different switching features. Switching guidelines in TiO_2 film were recorded against the clockwise and anticlockwise[114], which relies on the Al electrode deposition order and often an electroforming route is required to achieve the devices in the stoichiometric films[115] while some systems are electroforming-free [115]. Current compliance may be eluded in some cases, as reported by [116] in CeO_x films. All these reversed anomalies showed that the resistive switching system is prone to the materials' crystal nature, processing methods and the configuration of the components, and so on. To direct the optimization of the ReRAM system, disclosing the interaction between these variables and product properties is essential.

2.6 Nanocomposite

Nanocomposites is a leading material display unusual property, mixes and unique design potentials. With an expected yearly development rate of about 25% and quickest interest to be in building plastics and elastomers, their potential is striking to the point that they are valuable in a few regions extending from bundling to biomedical applications. Natural Nanocomposites, by scattering nanoparticles metal into natural mediums, have incredibly upgraded optical, mechanical and electrical properties. In any case, metal nanoparticle scattering in organic matrixes can hamper the consistency of the devices because of solid between molecule connections and powerless polymer nanoparticle interfacial collaboration (nanoparticle agglomeration). Furthermore, monitoring the extent of nanoparticles metal is challenging[47] cobalt-embedded gelatin (CoG) was utilized as a natural insulator layer, which is a one-component system that significantly shortens the device structure and fabrication process. In view of the CoG/Al/ITO device structure, 3Co.: gelatin mole proportions (0.5:1, 1:1 and 2:1) were incorporated in the tests. Device execution enhancements were brief and examined. Co.'s redox reaction can help structure the interfacial AlOx layer and mend the memory properties with the required concentration of Co. Compared to CoG 0.5M and 2M memory devices, CoG 1 M memory devices show huge, forming-free devices with a decent ON / OFF ratio (larger than 10^5), relatively long switching periods and extrapolated maintenance properties over 10 years. As stated by electrical stuffs and material analyzes, the adequate thickness of the AlOx interface layer and the polished dielectric thin film are described with a suitable concentration of Co. in the gelatin matrix, which promotes upgrades in the durability of the switching cycle and the holding capacity.

2.7 Biodegradation

Nanocomposite biodegradation properties dependent on biodegradable polymer are important in the production of new materials. Specific biodegradation circumstances may be measured: composting, hydrolytic, enzymatic depending on the ultimate uses and the post-use of the newly formed substance.The deterioration of a polymer is a dynamic process that includes diverse sections; precisely, we may observe four major phenomena in the situation of PLA compost degradation, viz. ester cleavage and the development of oligomer fragments,water absorption, oligomer fragment solubilization and as a final point bacterial dispersion of soluble oligomers[117]. The initial stage of PLA breakdown is the exterior hydrolysis; the polymer breaks down into low-molecular - weight particles. Molecular weight differences are a measure of the polymer degradation rate and provide details where there is a significant divergence in a polymer. At the onset, at the preliminary stage of the breakdown process, microorganisms strike the polymer amorphous phase, which contributes to a loss of transparency. In a biodegradable polymer matrix, the insertion of nanostructures has been found to disrupt all the properties of nanocomposites, specifically the rate of degradation, and this effect depends on the type of filler. It has also been found that clays can actually impact the bacterial degradation of the polymer, based on its chemical structure and the bacterial clay affinity. In composting, the application of Nano clays has been found to increase the rate of PLA degradation due to the incidence of hydroxyl groups related to the silicate layers of these clays[118, 119]. Due to the hydrophilic nature of Nano cellulose, cellulose Nano crystals (CNCs) also increased the dis-integrability rate of PLA [120]. In the situation of carbon nanostructures, the effect of CNT attachment on the stabilization of biopolymers has been limited to limited studies to date, most involving enzyme decomposition. Previous study investigates the in vitro degradation of PLGA and PLGA Nanocomposites films centered on Single-Walled Nanotubes (SWCNTs) and oxidized SWCNTs by analyzing the involvement of the content and functionality. The studies show that hydrolytic degradation degraded all PLGA films, and a separate process with respect to pristine content was observed for functionalized SWCNT[121].The application of SWCNTs rise the dimensional constancy of the polymeric materials but does not appear to change the kinetics and the hydrolytic erosion cycle in comparison to the tidy PLGA. The involvement of carboxylic groups in functionalized SWNTs-COOH has increased the hydrolytic degradation of the PLGA matrix and weight loss of the Nanocomposites.[122]Demonstrated that with Proteinase K, the enzymatic rate of PLA decomposition increased by 1% mass load of CNTs distributed in PLA.This prominent rate of decomposition was ascribed to a variety of likely reasons, comprising an improvement in amorphous areas additional liable to enzymatic hydrolysis owing to functionalization or possibly advanced enzyme required to CNTs in the polymer substratum Nanocomposites. In contrary, studies have revealed that MWCNTs diminish the rate of polymer biodegradation[123, 124]. The outcome of CNT loading and shape on PCL biodegradation has recently been investigated in the occurrence of *P. aeruginosa*, [125] the PCL matrix's biodegradation rate declined steadily as the CNT load increased from 0.1 per cent to 10 per cent w/w.

2.7.1 Biodegradable Materials

Biodegradable materials are desirable because of their self-fixing, properties and repeatability, including natural structures. Nano electronics ' innovative bids contain wearable systems, e-paper, bio-integrated medical electronics, and implantable diagnostic devices[126]. Nano electronic devices must be robust and chemically stable for actual device applications, but implantable devices must work at the desired output for a scheduled time, and then be resorbed by the body[127, 128]. Implantable medical diagnostic systems, environmentally sustainable disposable devices, biosensors, surveillance devices and protected data management for top-secret data are possible uses for physically transient electronics [127]. One important application of the bio-ReRAM is bio-restorable Nanoelectronics for medical treatment. These devices must fully dissolve into their components which are biocompatible. An emerging example is the use of nanoelectronics implants in medical cure circumstances.A bioresorbable electronic sensor has recently been suggested to allow the brain to gather wireless data in body cavities[129].The best advantage of biomedical applications is their ability to manufacture sustainable electronic circuits.[15].

2.7.2 Biomaterial ReRAM Device.

Biomaterials that have been utilized in ReRAM are characterized into two principles which are

1. Polysaccharides based bio-ReRAMs apologies
2. Proteins based bio-ReRAMs

The following diagram(Figure 2-15)depicting the biomaterial used in ReRAM characterization, each section will be subsequently review in this chapter.

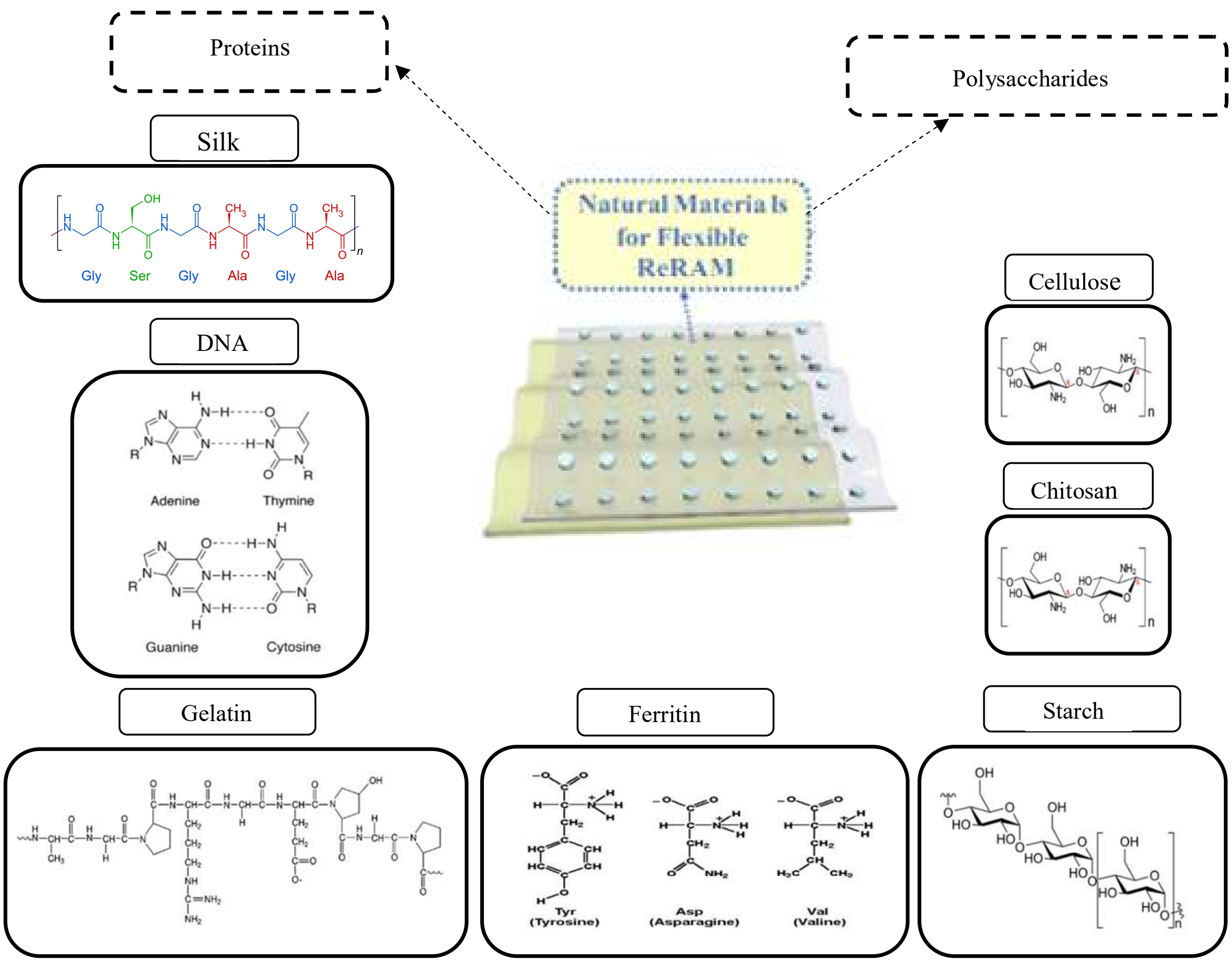


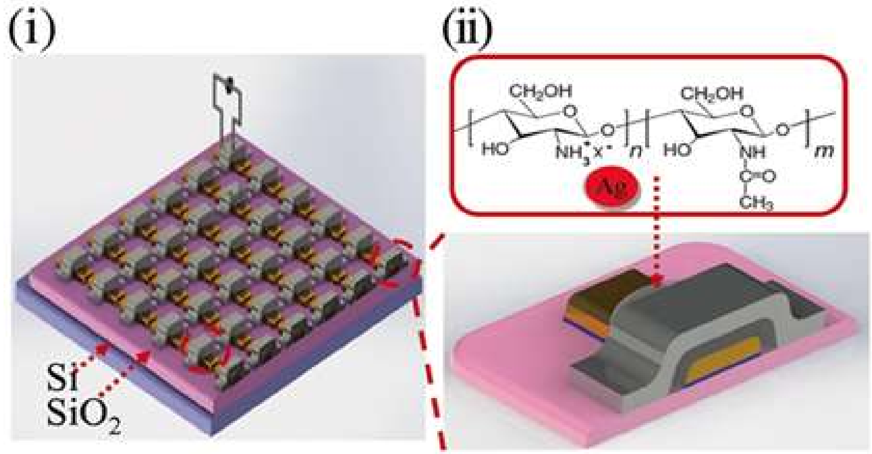
Figure 2—15: Depicting Natural materials for flexible ReRAM. Adapted from [128]

2.7.2.1 Polysaccharide-based bio-ReRAMs

Polysaccharide is a starch polymer which is includes long chains of monosaccharide items. It is a reasonable common proton conductor with different applications in sun-based cells, biosensors, power modules and actuators because of its synthetic OH^{-}gathering and is structures [130]. Polysaccharides like cellulose, chitin and chitosan have been measured in ReRAM, the two synaptic devices and transistors [128, 131]. Later in this part every class will be examined thoroughly.

2.7.2.1.1 Chitosan-based bio-ReRAM

Chitosan is a biocompatible polymer, indeed occurring in crustacean shells. It consists of recurring β (1,4)-linked 2-acetamide-2-deoxy-glucose N-deacetylated chitin units and is an auspicious biopolymer for ReRAM applications[3, 128]. It is a cationic biopolymer, formed in chitin to NH_2 groups by deacetylation of $HNCOCH_3$ groups [132]. Chitosan are comprises of two mains polar of hydroxyls and amides groups that easily react with metal ions through free duplicates of electrons [133]. Chitosan-based ReRAM was established prior to its non-toxicity, plenty in nature and biocompatibility. It can be placed consistently as opaque and as a film, and hence a popular material for electronic devices[3]. Ag fixed chitosan sandwiched between Pt as the bottom electrode and Ag as the top electrode was used to create a crossbar-structured memory unit (Figure 2-16Ai, Aii). Drop-casting has been used to implement chitosan solution, which is a process based on a cheap solution. A 10-V voltage was usedfor the uncontaminated chitosan-based device and the device was set at 6 V, when the resistance condition changed from HRS to LRS. Doping the chitosan solution with a enough quantity of $AgNO_3$ greatly improved the memory state of the device; forming-free switching behavior in this RERAM occurred at low voltage of ~0.5 V with high homogeneity during setting and reset phases (Figure 2-16B). The method of switching has been described as the defense and development of a conductive path to Ag that applies sufficiently positive voltage to the TE transfers Ag+ cations to the BE, while NO3 − anions migrate to TE. The electrode Ag has a significant role in a conductive track's oxidation reaction at the Ag interface with the insulator layer (Ag+ + e−). Ag+ cations crossed the thin paper, and under positive influence traveled downward. At the same time, at the interface between BE and the thin film, a cathodic reaction occurred; this reaction reduced Ag+ to Ag atoms to form the conductive bridge (Ag^{+}+ e^{-}Ag).Thermodynamically, the gathering of input Ag atoms into a TE filament is better suited, and thereby generating a conductive Ag path between TE and BE. After there is a change I the polarity of the voltage, Ag+ cations travel to the TE to reduce the voltage to Ag atoms and return the device to HRS (Ag^+ + $^+e-$).To stop the system's irreversible failure, a conformity current of 0.1 mA has been set at a positive bias in all electrical depths (Figure 2-16B). Generally, using acceptable electrical biases, chitosan-based devices demonstrated reproducible RS conduct.Following the formation and breakdown of the filaments, similar voltage sweeps performed repetitive cyclic operations. Data were held at ~10^4 sec with a high current OFF / ONF ratio of 10^5 (Figure 2-16C).



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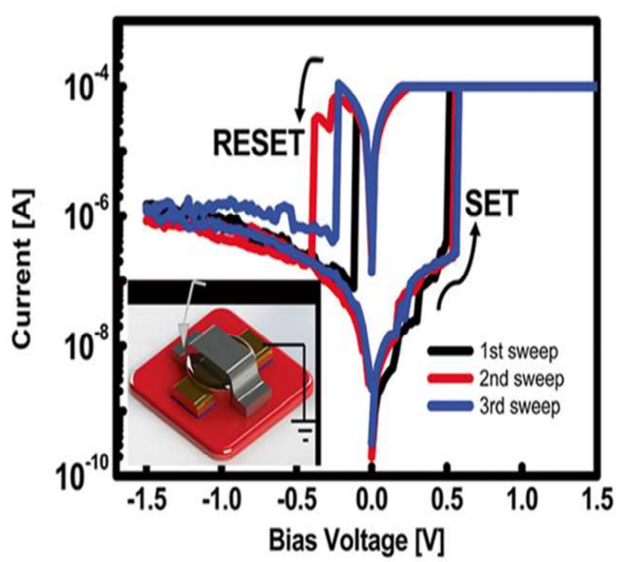
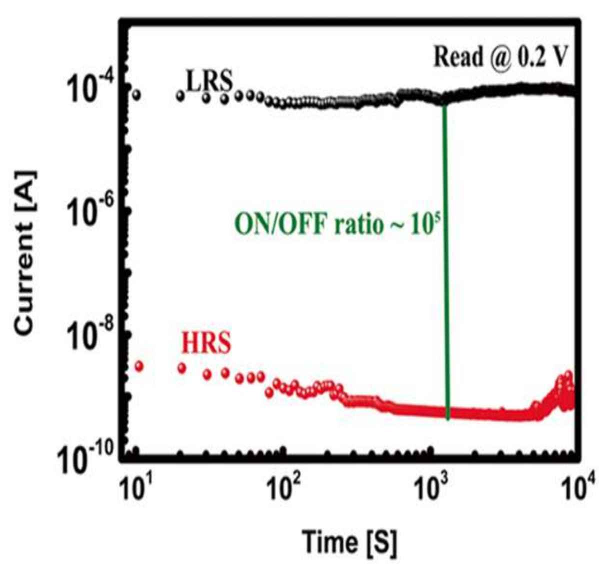




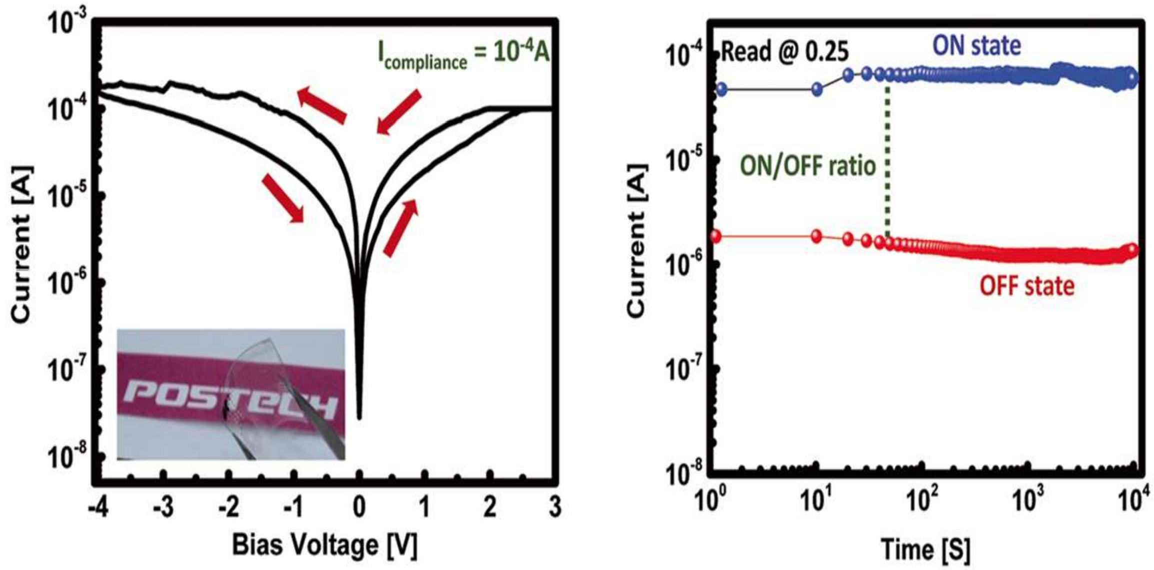
B C

Figure 2—16: Showing schematic representation of chitosan-based ReRAM, (A: ii) a unit cell configuration with Ag/Ag doped chitosan/Pt architecture, (B) I−V characteristics of the chitosan-based

bio-ReRAM in semilogarithmic scale; inset: a unit device with the measurement setup and (C) Data retention properties of chitosan-based bio-ReRAM for both states of the LRS and HRS. Adapted from [3]

2.7.2.1.2 Starch-chitosan-based bio-ReRAM (polysaccharide composites)

By combining starch and chitosan as an active substrate, a biodegradable memory unit with the same structure as the starch-based device has been achieved [134]. Chitosan integrated and changed its mechanical properties into the starch film[135, 136]. The mixed biomaterial is disposable, edible, and biodegradable. A natural Nano scale memory device was fabricated with the mixed active layer. An au / starch − chitosan / ITO bio-ReRAM was developed with the same structure as a starch dependent ReRAM. The unit was quantified under the same condition as the basic layer of ReRAM even though it displayed a distinct I-V activity from the specific layer of ReRAM.The processing power of the mixed biocompatible layer was considerably improved but the switching features remained gradual (Figure 2-17A). Slowly the resistance changed from LRS to HRS when an external tension was swept from 0 to a positive bias. Thanks to its bipolarity, the LRS was maintained until an overwhelming voltage of opposite polarity was smeared from which to transfer the device.The starch − chitosan-based bio-ReRAM gradually set and reset property is useful for the uses in analog-based synaptic devices. These switching features are the outcome of the starch and chitosan chemical structures. The OH^{-} starch groups are attracted by hydrogen bonds to NH^{3+} groups in the chitosan, resulting in a uniform, chitosan's forms, biocompatibleand thin film of starch [134]. For 10^4 s under 0.25-V reading bias (Figure 2-17B), the mixed bio-ReRAM realized unfailing switching without any noticeable degradation. Based on a monotonic system toggling between LRS and HRS, the I − V double-logarithmic curve of the unit was normal in both states; hence, the switching process is connected to the creation of rupture and CF. As the Au anode is inert it does not form filaments; rather, the filaments are mainly carbon-rich filaments (CRF). A local pyrolysis split was initiated at the SPE layer Joule Heating, so that voids formed [134]. Rising in the voltage triggered the void to swell and enlarge the local carbon- rich areas. Thus, as many CRFs were created, the area's conductivity increased, and the system was installed. The SPE and CRFs have diverse thermal conductivities, anytime high current passes through the CRF it breaks down and the device ensures reset state [134, 137, 138]. The cycles to be on and off are reproducible. One substantial success of this study is that by controlling its chemical composition, the starch's RS property can be tuned.



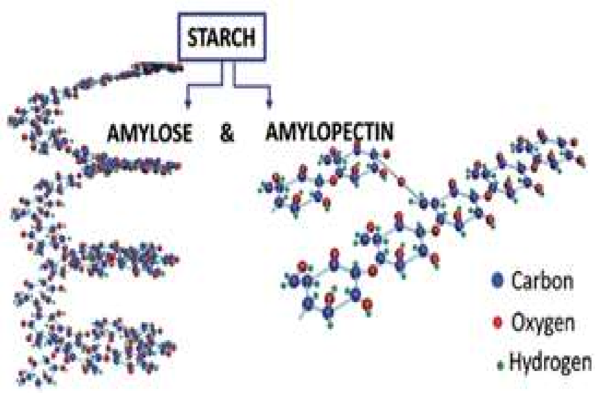
A B

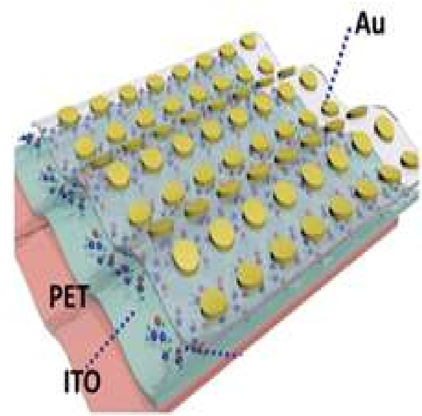
Figure 2—17: (A) Represent the I – V curves of the switching behaviors of starch-chitosan based bio-ReRAM and (B) Showing data retention characteristics of ON-state and OFF-state of Au/starch-chitosan/ITO device. Adapted from [134]

2.7.2.1.3 Starch-based bio-ReRAM

Starch is a natural polymer which is thermally stable and biocompatible and can be transformed into films. Used for electrochemical structures [139]. It is plenteous sustainable biopolymer which is naturally friendly and eco-friendly. It also has a wide range of bids in the agricultural, food, medicinal industries and used for electromagnetic shielding and energy storage[140]. This biomaterial is measured for application in electrochemistry owing to its natural abundance, biodegradability, solid polymer electrolyte (SPE), proton conductivity,low quality and biocompatibility due to its suitability as a polymer matrix[141, 142]. Starch consists of amylose as a linear polymer with (1,4)-connected anhydroglucose units, and amylopectinas as a cleft polysaccharide comprising amylose-like chains and (1,6)-connected polysaccharide branch points (Figure 2-18A)[142]. Starches can be acquired from many sources, but potato starch has an advantage because of its relatively high protocol conductivity [141].

The potato starch comprises two groups of water molecules; one closely bound, and one loosely bound. The ionic conduction of potato starch is caused by strongly bound molecules of water streaming through its crystallite network [143]. Glycerol is used as a plasticizer; it is a low molecular weight polymer used to mitigate starch fragility and rigidity to create a thin film that is smooth, flexible. Glycerol has large free OH groups and its molecular structure makes it harmonious with starch[144]. In a planar structure, memory resistance shifting devices that integrate glycerol-treated starch as Indium tin oxide (ITO) and switchable resistive material sandwiched between Au[134]. The RS layer made of water-soluble potato starch with amylopectin and amylose structure; the layer was thermally rinsed and treated with glycerol[140]. The dot-patterned memory unit Au / starch thin film / ITO structure had bipolar, non-volatile RS activity (Figure 2-18B). On Au electrode with an ITO electrode grounded, the device was characterized by a voltage sequence of $0 \rightarrow 3 \rightarrow 0 \rightarrow -4 \rightarrow 0$V. The V_{set}voltage set ~ 0.9Vand the V_{reset} ~ −2V reset voltage verified the change from HRS to LRS and backwards (Figure 2-18C). The SPE layer's chemical structure in starch dependent bio-ReRAMs and the existence of OH^- functional groups had vital functions in the devices ' switching behavior. For 10^4s [134], the produced devices had a reasonably high ON / OFF current ratio I_{ON} / I_{OFF}> 10^3(Figure 2-18D). Most bio-ReRAMs were worked centered on alterations in the conductivity of the isolator layer. Usage of an electric field changes the concentration of the carrier and charging mobility induces a change in conductivity[138]. Since their$I - V$ curves are semi-logarithmic, space-limited conduction (SCLC) has been attributed to the current conduction of starch-based ReRAM in the HRS rule, while the filamentary conduction form is the major source throughout the LRS. SCLC traps are associated with flaws in the starch structure of the amylopectin matrix connections to the linear amylose structure. Until reaching the set stage, the$I - V$ relationship is linear (Ohmic) at low voltage under positive bias and quadratic at high Voltage. The reason for low-voltage Ohmic conduction is because the electrical pitch nearby the unit is unproductive at low voltage [134]. As an outcome, the sum of carriers inserted is small related to the sum of free carriers thermally produced [104, 145, 146]. As voltage increases, the huge amount of charge carriers absorbs the trap centers and controls the SCLC system, so that the current is related to voltage quadratically[104, 147, 148, 149]. A perfect and reproductive RS system was used.





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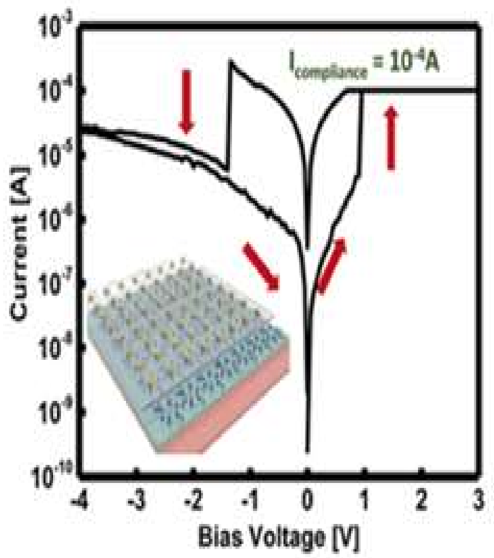
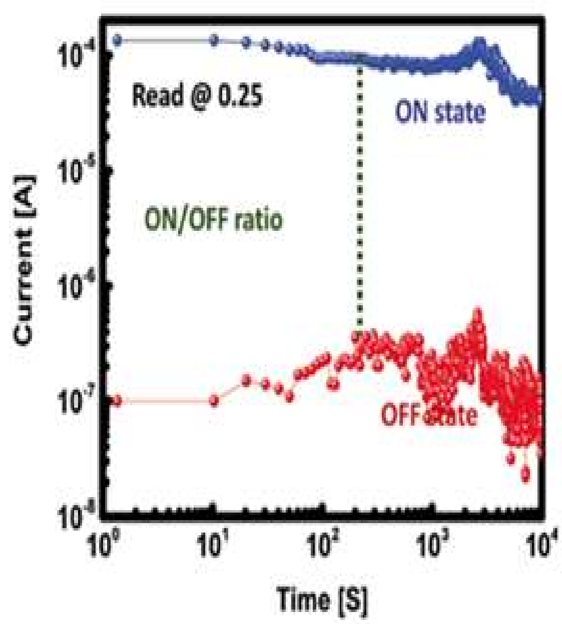




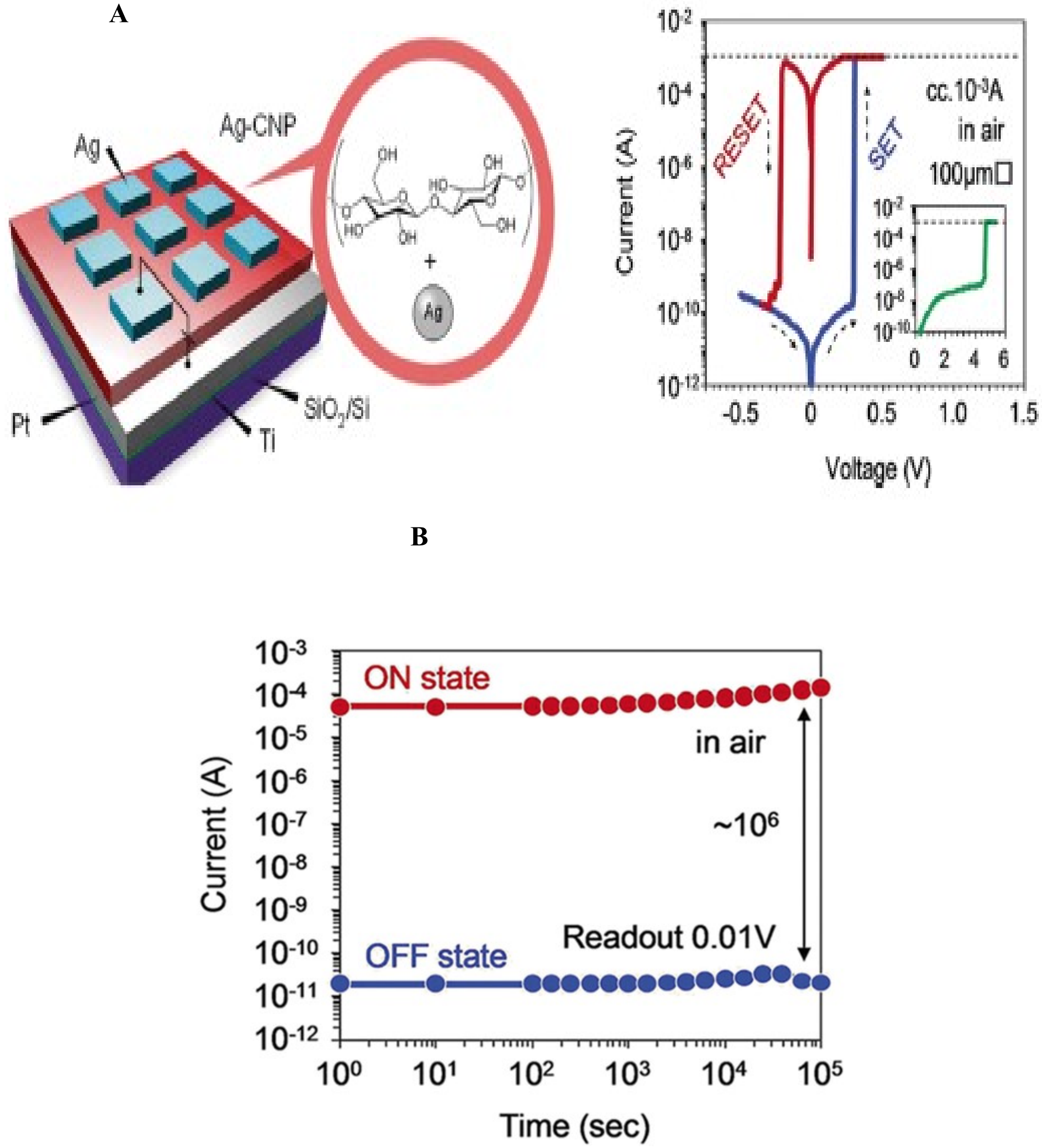
C D

Figure 2—18: (A)Schematic illustration of Chemical structure of starch including amylose and amylopectin chains, (B) device with Au/starch/ITO structure, (C) Typical I − V curves of the starch-based bio-ReRAM and (D) Retention test of the ON-state and OFF-state of Au/starch/ITO device. Adapted from [134]

2.7.2.1.4 Cellulose-based bio-ReRAM

Cellulose is a sustainable natural material with favorable nanoelectronic and optoelectronic properties. Nano fiber-shaped cellulose was used as a substrate in electronic devices[117, 150, 151] and switching layer[152]. Oxidized cellulose nanofibers (CNFs) with 2,2, 6,6-tetramethylpiperidine-1-oxyl base matrix have raised workable stress and poor thermal expansion coefficient. A thin sandwiched CNF film in amid the electrodes Ag and Pt will store electrical data in a memory which changes the resistance [152] (Figure 2-19A). Drop casting and drying of an Ag-decorated CNF solution on a Pt electrode on a rigid silicon substratum created the memory unit, then depositing Ag as a TE content into a pillar structure. The unit based on cellulose had I_{ON} / I_{OFF}> 10^6 which is ideal for non-volatile memory devices (Figure 2-19B). The original OFF state of the cellulose-based memory device was modified to ON status by implementing a forming voltage of 4.7 V.

The unit was then restored to its OFF state by applying a negative voltage; the set-reset cycle was achieved by altering the applied voltage polarity. The retention of data for durability of 10^5 s and 100-cycle switching demonstrated the stability of the memory device (Figure 2-19C). (Figure 2-19C). The system's ON and OFF size focus was interpreted as ensuring the switching cycle involved the creation and breaking of Ag CFs [152]. Ag+ cations breached the insulator layer based on the electro-metallization mechanism and transferred from the Ag electrode to the Pt electrode. Once the Pt electrode was reached, Ag^+ was concentrated to Ag atoms and the resulting metallization cycle resulted in an Ag-based CF[3, 152]. CNFs have proved capable of being used in bio-ReRAMs as powerful nanoelectronic data storage structures.



C

Figure 2—19*:* Representing the Schematic illustration of the fabricated bio-ReRAM (A) with an Ag/Ag-decorated cellulose/Pt configuration, (B) I – V characteristics of the Ag-decorated cellulose-based device with a current compliance of10−3 A; inset: required forming a voltage to trigger the device and (C) data retention of the cellulose-based resistive switching memory, where readout voltage was 0.01 V.Adapted from [134]

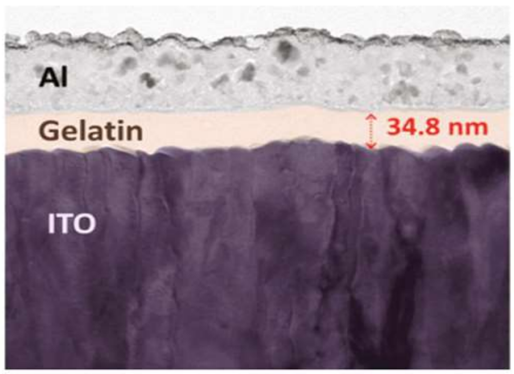
2.7.2.2 Protein –based bio-ReRAMs

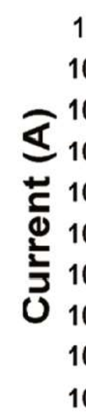
Protein is a conceivable contender for nanoelectronics because of its proficient electrical properties. Of late,protein-based ReRAMs have been comprehensively investigated in light of their cheerful properties because of power [153, 154]. In the recent time protein-based ReRAMs were thoroughly studied in response to electricity because of their promising properties[9, 92, 96, 128, 135, 10].Bio-ReRAMs based on protein are called silk-based, DNA-based, gelatin-based, and egg-based whites. Fundamentally, Deoxyribonucleic acid[126]isn't a protein; yet, in this section there will be more literature discuss on it. This research is based on bio ReRAM based on gelatin.

2.7.2.2.1 Gelatin-based bio-ReRAM

Gelatin are comprises of proline (Pro), glycine (Gly), alanine (Ala) and hydroxyproline (Hyp), in the repeating form of Ala-Gly-Pro-Arg-Gly-GlyGly-4Hyp-Gly-Pro [47, 155], however it can be cross-linked to produce a similar network in diverse way[155].Gelatin was used in bio-ReRAM as a solution-assisted layer of insulators with a planar MIM structure. A thin gelatin film was sandwiched as TE and BE between Al and ITO. Cross-sectional electron transmission microscopyconfirmed that the gelatin coating (~35 nm) was well prepared in the planar system (Figure 2-20A). The baked sample's I − V characteristics displayedforming-less RS and bipolar characteristics with three steps while the ReRAM was being rese (Figure 2-20B). The unit was in its pristine state at the voltage sweep of +4V 0V; by sweeping the voltage between −4V and 4V, it reached a corresponding setting and reset status.The three reset states were connected to ruptures in filaments at three distinctive reset voltages. The heating temperature has a significant effect on the thin film's equality and electrical properties due to the solubility of gelatin in water [47]. The HRS value was decreased by the highly elevated temperature; this effect suggests that the layer of the gelatin is semiconductor.

Nevertheless, as temperature increased, the value of LRS grew linearly; this pattern suggests insufficient metallic features. The resistance ratio in the tested sample are at high temperatures therefore declined by about one order of magnitude. Atomic-force microscopy (AFM) confirmed the filamentary origin of the switching process. An AFM analysis displayed the spreading of the current and found that interchanging was due to the creation and breakdown of CFs (Figure 2-20C). Analysis of energy dispersive X-ray (EDX) showed that CRF is the foremost mechanism for gelatin-based bio-ReRAM filament switching, although the TE is an active Al element. To sum up, the Al / gelatin / ITO-structured memory unit revealed high ION / IOFF with a bipolar RS property and appropriate data retention was acquired. Electrodes' position in the MIM structure and the edge between the gelatin thin film and the metallic electrode interfered with bio-ReRAM's RS behavior [47]. This work has demonstrated that gelatin as an active layer to develop bio-RAMs with stable bipolar RS properties.





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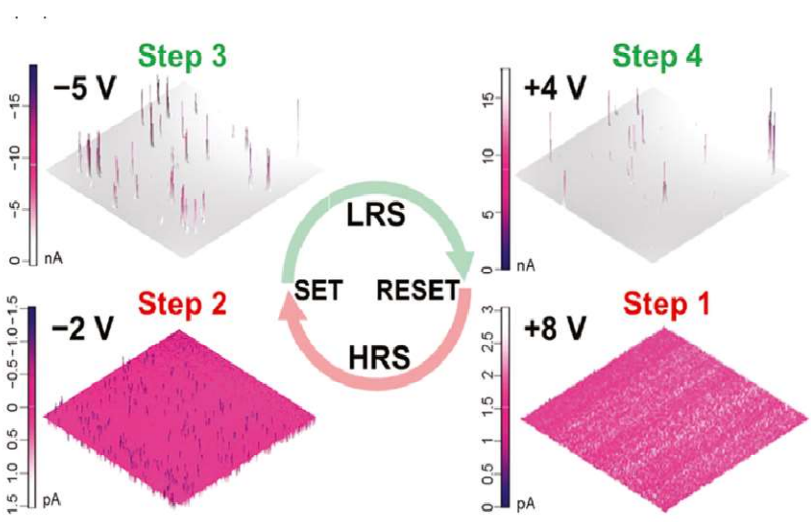
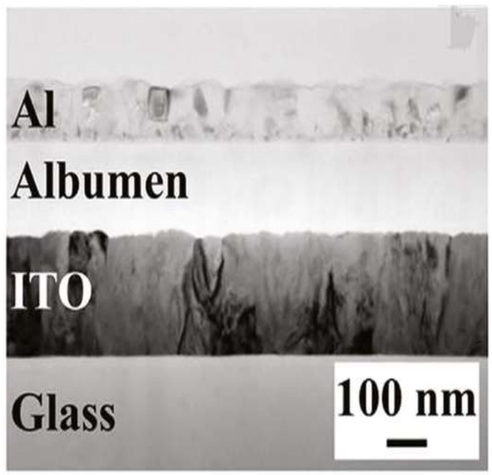


C

Figure 2—20: Depicting Protein-based bio-ReRAMs. (A) Cross-sectional TEM image of the device with Al/gelatin/ITO structure, (B) A semilogarithmic I − V curves of gelatin-based bio-ReRAM with three reset steps and (C) Conductive AFM images obtained from the gelatin thin film in LRS and HRS by voltage sweeps between set and reset. Adapted from [47]

2.7.2.2.2 Albumen-based bio-ReRAM

The whiteish in the egg are called the albumen. Almost 98.5% of egg white is water; the left over 1.5% involves of a family of ~40 proteins, known as albumens, with lysozyme (3%), ovomucoide (11%), ovalbumin (54%), globulins and mucoproteins. Albumen also contains minerals, such as sodium, fluoride, potassium, magnesium, and phosphorus[156]. More so, transistors also used albumen[157, 158] ReRAM and synaptic devices[48, 49, 131]. In (Figure 2-21A) bio-ReRAM based on albumen was manufactured in an Al/albumen/ITO MIM structure and $I_{ON}/I_{OFF} = 10^3$ RS was obtained by applying a bias between −3V and +4V (Figure 2-21B). The preparation and comparison of baked and dry-cured samples [48]. The dry-cured system was both LRS and HRS compatible with Ohmic conduction. The overheated device comply Ohmic conduction in SCLC model and LRS in HRS, the authors claimed that these variances in conductive mechanisms had arisen because the electrical alteration provided extra energy in the dry-curing device than in the overheated device[48]. The current dissemination features utilizing both states of conductive AFM showed that the electric field stress were induce by conductive filament. In the albumen-based device, interchanging happens when a negative voltage is used to the topmost electrode (Figure 2-21C); charging set-ups are then occupied in with the deposited electrons in the thin film of the insulator. Therefore, the electrons act as space charges, and the induced electric field tension decays the insulator's protein layer into amino acids [48].O and Fe ions are among the utmost prevalent of the numerous albumen ions; they offer a proper channel for transfer of electron between BE and TE. Once voltage outstrips V_{set}, the Fe ions decrease, and the O ions emitted and scatter into the thin film. In addition, the Fe ions procedure conductive paths via the active layer of the system, so it transits to LRS. When the polarity of the useful voltage is inverted, the reverse method occurs, so that the CFs disengage, and the system proceeds to its original state. Proteins denaturation in the albumen therefore changes O diffusion pathways and increases the opportunity of filament development and breakage[48]. This has shown that albumen eggs can be used to generate bio-RERAMs with stable bipolar RS properties as an active layer.



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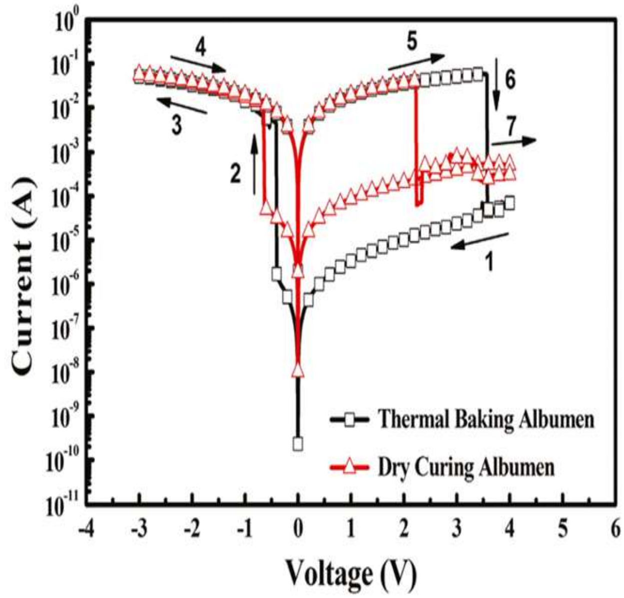

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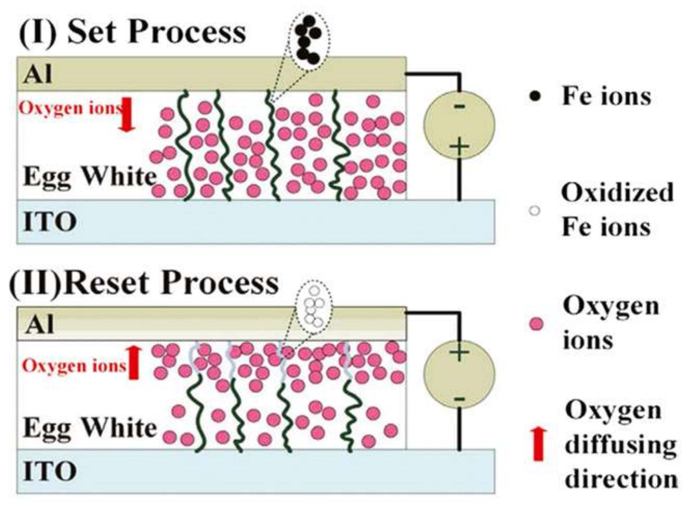

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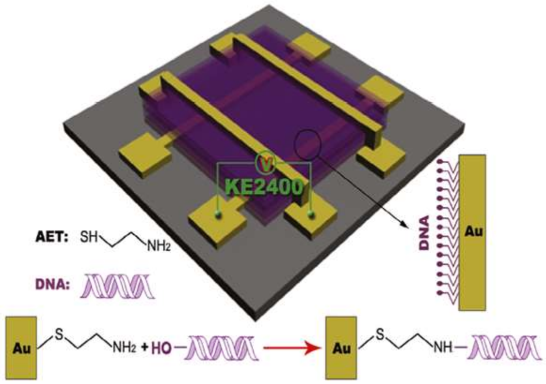
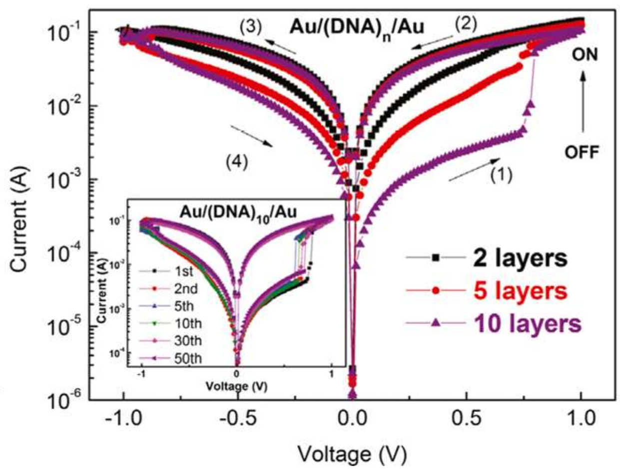
Figure 2—21: Showing Albumen bio ReRAM (A) Cross-sectional TEM image of the device withAl/Albumen/ITO structure, (B) I − V curves of the RS behaviors of baked- and dry-cured- albumen-based bio-ReRAMs, (C) RS mechanism of the albumen-based bio-ReRAM with formation and rupture of conductive filament. Adapted from [48]

2.7.2.2.3 DNA-based memory devices

Deoxyribonucleic acid (DNA) is a bio-macromolecule with an aromatic central structure and double helix[159]. DNA is mechanically solid,polymer compatible, chemically stable and thin film-processable. Nanoelectronics, precisely memory devices [46] and optoelectronics [160], a photo-induced writing once read-multiple times (WORM) with salmon DNA crammed between ITO and Ag electrodes has recently been introduced. In the WORM memory device, electrical bistability was enabled inside the DNA templates by creation of Ag NPs, and the RS was created on this occurrence [46]. A rewritable memory based on DNA with a bipolar RS property has been developed by altering the number of electrode materials and DNA layers [161]. WORM needs the ability to rewrite memories that is a fundamental function of ReRAM. In the technical approaches and types of materials closely similar to ReRAM, we describe DNA-based WORM as a kind of memristor[162]. In the bio-ReRAM based on DNA, the thin film has been inserted in a crossbar configuration like Au/ $(DNA)_n$ /Aubetween two Au electrodes (Figure 2-22A), where n signifies the number of layers of DNA. [161] The electrical test was carried out at room temperature, the Au BE was beached, and tension used to the Au TE. The voltage was swept amid $^{+}$1V and $^{-}$1V, and the various layers of DNA showed a bipolar RS behavior. The I_{ON} / I_{OFF} increased correspondingly if the number of layers improved from 2 to 10 (Figure 2-22B). The device's I − V characteristics beneath positive applied voltage indicate an unexpected rise of 0.73 V in current; this adjustment has given the device a steady LRS.Bio-ReRAM stayed at LRS till an opposite voltage was mandatory to reset the system at −0.85V (Figure 2-22C)[161].The conductive and switching mechanisms were Ohmic in the SCLC and LRS in the HRS due to faults in the DNA layers and load trapping at the sites beneath the conductive band. Since write – read – erase time test is a unique function of a non-volatile memory, this property was determined by the DNA-based method.It was inscribed by setting it to $^{+}$1V in ON and removed by resetting to $^{-}$1V; in both states read current was selected as 0.2V (Figure 2-22C)[161]. The rewritable properties of the DNA dependent bio-ReRAM have been verified by its I_{ON} / I_{OFF} behavior over many cycles without degradation. The tool demonstrated ReRAM flexibility with re-writability, WORM reproducibility and multi-state programmability.





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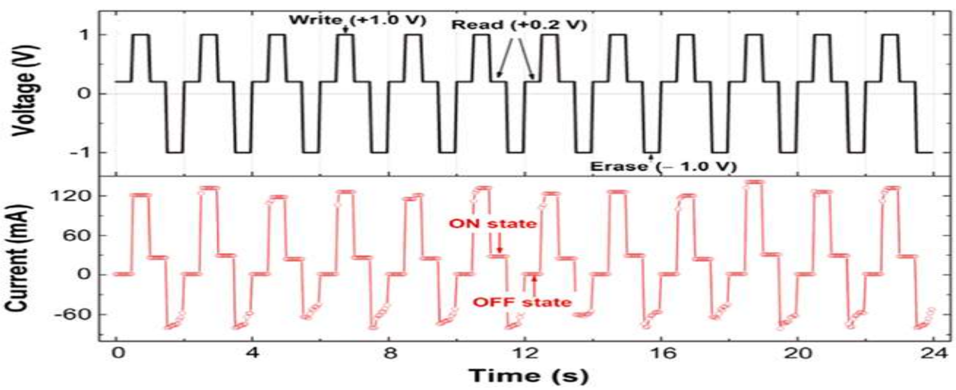

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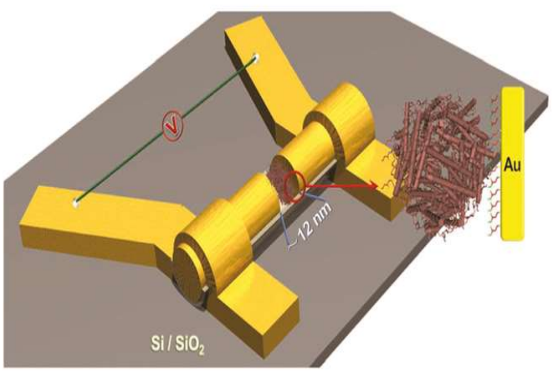
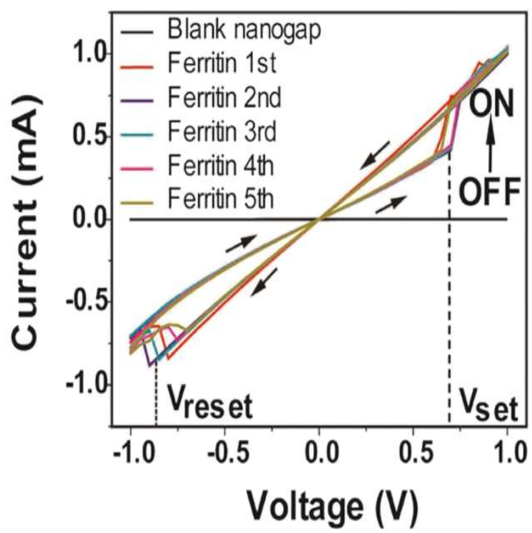
Figure 2—22: Showing (A) DNA based device with Au/(DNA)n/Au structure, (B) Semi-log scale I − V characteristics of DNA-based bio-ReRAM with different DNA layers; inset: I – V curve of the device with 10 layers of DNA and (C) Write-read-erase cycles of the memory device with 10 layers of DNA with 0.2 V reading voltage. Adapted from [161]

2.7.2.2.4 Ferritin-based bio-ReRAM

Some proteins are metalloproteins, which is why ferritin (Ftn) is an profuse silk protein containing iron in a spherical shell and a complex basic of hydrous ferric oxide (ferrihydrite)[163, 164].Ftn is cage-shaped with four triangular pores and distinctive properties[165, 166]. Ftn's ferrihydrite nuclei can be simply aloof by dialysis to produce apoferritin (AFtn),The shell and cavity of AFtn are connected through thin networks along the triple axis, which gives routes for the journey of Fe ions to the cavities[166]. AFtn encloses heavy-chain polypeptides and 24 unit's light-chain plus a nucleus of ferroxidase oxidizing Fe^{2+} to Fe^{3+}[167]. Ftn in diverse devices, such as, ReRAMs, floating gate memories and transistors [164]a typical Pt / Ftn / Pt MIM system had bipolar RS properties that coexisted with threshold and memory switching.The Ftn-based ReRAM had non-volatile / volatile RS behavior; changing the enforcement current could interconvert the two characteristics [168]. Another two-terminal tunable ferritin-based nanowire (NW) system was manufactured with on-wire lithography (OWL), where Ftn was mounted within a nanometer gap amid Au NWs [165] (Figure 2-23A). The RS effect was derived from the bio-ReRAM's I−V characteristics; by extending the voltage positively the unit was set to 0.7V, and by retrogressive the extending voltage it was changed to −0.8V (Figure 2-21B).AFtn didn't show any RS because of its empty core; nevertheless, implanting Fe active cores in the active triggered action of resistance-change. The amount of Fe put into the heart, and the essential parameter of bio-ReRAM dependent on ferritin was the Fe ion complex. The iron-filled basic switching mechanism was due to the strong redox action of Fe complex core[165]. The ferritin-based device's write-read-erase loop displayed programmable switching over many cycles (Figure 2-21C). This use of NW memristive device by introducing inorganic Fe ions to AFtn's core centers offers a innovative technique for memory system bioengineering.





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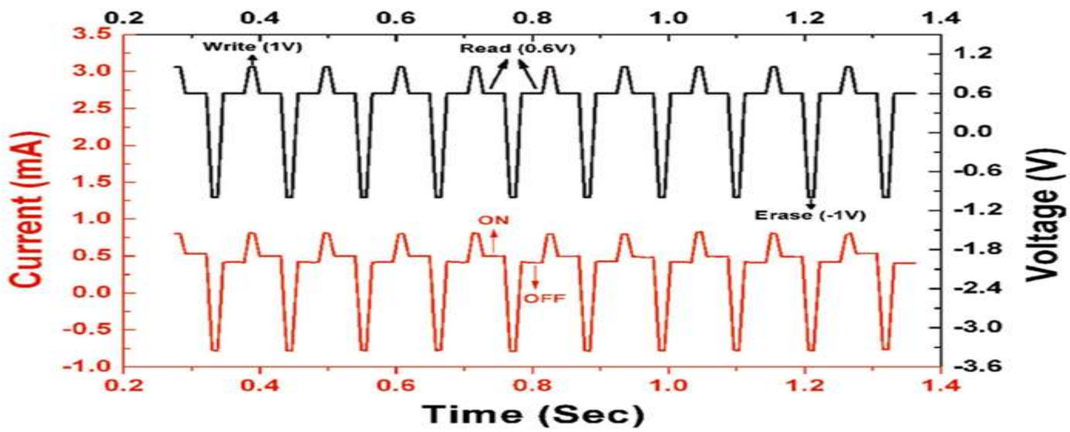

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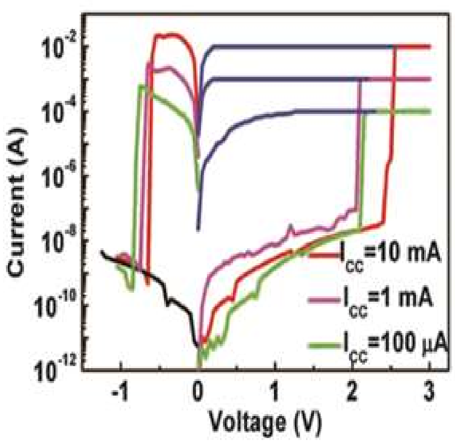
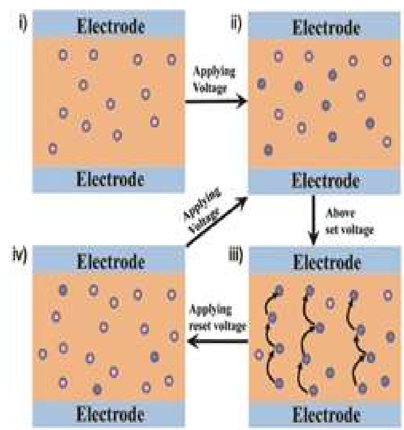
Figure 2—23*:* A typical diagram of Ferritin-based bio-ReRAM (A) The nanogap-filled ferritin memory device between Au nanowires, (B) I – V characteristics of ferritin-based bio-ReRAM with bipolar switching properties and (C) The write-read-erase cycle test of the ferritin-based device with a 0.6 V reading voltage. Adapted from [165]

2.7.2.2.5 Silk-based bio-ReRAM

Silk proteins have irreplaceable optoelectronic properties, flexible degradation, controllable water content, mechanical strength, and flexibility for ambient processes[169]. Many greatly well-organized, versatile devices and biocompatible, including memories, optoelectronics and transistors have used silk as their main components[169]. Sericin is a typical types of silk protein, made of amino acids with hydroxylnor carboxyl groups, making it water-soluble. Sericin's exceptional stability and mechanical strength make it a common candidate for optoelectronics and photonics[170]. Sericin has been evaluated with data storability at multilevel in bio-ReRAMs. In an Ag/sericin/Au MIM structure a thin layer of sericin was crammed between two metallic electrodes. The system moved from HRS to LRS with V_{SET}~2 V under positive voltage sweep, then twisted back to HRS under negative voltage sweep; I_{ON} / I_{OFF} was 10^6, which is appropriate (Figure 2-24A). The device's durability has been tested for 1000s by retention characteristic below 100-mV read voltage. Sericin-based system I_{ON} / I_{OFF} allowed the storability of multi-bit data in a single device. This property was reached by monitoring the current of enforcement at 10^{-2}A , 10^{-3} A or 10^{-4} A over the defined process; (Figure 2-24) [145]. This content will be used to increase the data space of the storage network.TheI−V curve was designed with the use of models to find the bio-ReRAM's regulating conduction mechanism. In HRS, the link between sqrt(V) and ln(I) was linear, meaning transport by carrier obeyed the Schottky emission rule; in LRS, convey was compatible with the SCLC rule. The RS mechanism was deduced to be the detrapping / trapping hopping conduction cycle (Figure 2-24B); sericin was an insulator when the system was off (Figure 2-24Bi). When applying a positive voltage several charges from the electrodes were inserted into the sericin layer.The charges inserted engaged the faults in the thin film and created a conductive course in the film under exact voltage V_{SET}, so it reformed from HRS to LRS (Figure 2-24Bi, iii). The present route was disrupted and brought about a change from LRS to HRS (Figure 2-24Biv) [145].Additional analysis found that RS influence was responsible for the trapping / detrapping of charging carriers by sericin layer impurities. Sericin-based devices met all Bio-ReRAM specifications. Realization of above 2bits for each ReRAM increased the data density. The high I_{ON} / I_{OFF} has been met as a basic necessity for continuous, multi-level operation. Because of its stability under ambient conditions, the sericin based device encouraged the development of the next generation of bio-ReRAMs. Silk fibroin (SF)is a biopolymer extracted from natural coconuts in the fiber. SF consists of Ala, Gly and Serine (Ser) in a reappearance of (−Gly-Ser-Gly-Ala-Gly-Ala-) which consists of hydrophobic crystalline and non-crystalline hydrophilic chains.SF chains are lined up and bound by hydrogen inter-chain bonds [171, 172].It is a candidate for biocompatible and bioelectronics implants, due to extraordinary SF properties such as mechanical strength programmability, resorbability,physical adjustability and implant ability.The SF's abundant bonding with hydrogen and hydrophobic reactions make it an important insulator content. Numerous studies have oppressed the non-volatile properties and characteristics of ReRAM based on fibroin; [164, 173]. An Al /SF /ITO fibroin-based device (Figure 2-24C; left inset) displayed classic bipolar forming-free I − V characteristics when the voltage was swept in four stages (0 → +14 → 0 → −14→ 0 V). Positive voltage use exchanged the bio-ReRAM to the ON state, where it stayed stable till a negative voltage sweep turned the device to the OFF state. The system had switched over several dc cycles between set and reset [153]. For the dimension setup the equivalent model was a rectifier parallel to the memristor (bio-ReRAM). Durability and durability characteristics have verified the device's reliability and stability. Several experiments were executed to scrutinize the physicochemical origins of the switching mechanism like cyclic voltammetry. The switching mechanism has been proposed as being a physical filament classic related to SF film's redox properties [153]. Oxidation (SF+) and reduction (SF0) condition of SF, respectively, were allocated to the LRS and HRS.The holes were inserted from the bottommost engaged molecular orbital into the thin film when putting in a positive bias to setting the device; hence, SF0 formed load trapping sites and were oxidized to SF^{+}. The trapped charges in SF0 resulted in a rise in space charges under continued constructive bias, producing excessive SF^{+}s that contributed to the creation of CFs. (Figure 2-24Di). In contrary, negative bias voltage pushed electrons from the peak engaged molecular orbital to the insulator layer, thereby reducing SF+ to SF0; as the outcome, the CF of SF^{+} disengaged and the bio-RAM returned to its initial state after ample CFs had been destroyed (Figure 2-24Di, ii) [153]. The proposed physical model explained the charging carrier detrapping / trapping phenomenon in the redox-based SF thin film, and the fibroin-based device displayed hopeful features for use in nano electronic memories.





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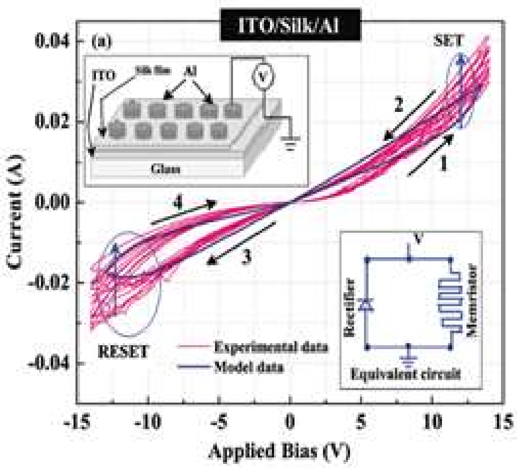

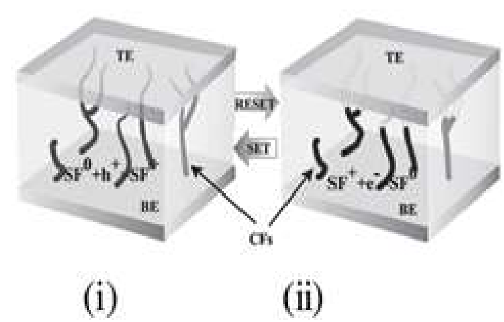

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Figure 2—24:Schematic diagram of Silk protein-based bio-ReRAMs Silk protein-based bio-ReRAMs. (A) I – V curves of the Ag/sericin/Au device with multi-level data storage property, (B: i-iv) Scheme of the resistance switching mechanism with hopping conduction mechanism, (C) Bipolar I – V characteristics of Al/fibroin/ITO device; left inset schematic illustration of fibroin-based bio-ReRAM; right inset: The

equivalent circuit model for the device measurement setup and (D) The switching mechanism of the Al/fibroin/ITO device. Adapted from [145, 153]

2.8 Chapter Summary:

In brief, green computing and nanotechnology are working together to create systems and products that are more environmentally sustainable. The use of green technologies in the planning and design stage will become more widespread in the industry as the environment becomes more ecologically sensitive.Emerging Resistive Memory (ReRAM) is a credible tool as a substitute for DRAM due to its low power consumption, high density and high durability. ReRAM can be built with a very high density due to its special crossbar construction, it demonstrates predominant switching speeds, requires limited power, displays high perseverance, and is good with current CMOS fabricating forms. This proposition is a method for the fabrication of ReRAM cells for utilize Gelatin nano-composite and handling components. By exploiting inconclusive maintenance times, ReRAM can be utilized to store data.

CHAPTER 3: RESEARCH DESIGN, METHODOLOGY AND MATERIALS

3. INTRODUCTION

In this chapter, the design and fabrication process of the ReRAM will be discussed. More information on the connected processing overviews for designs will be provided, as well as descriptions of the important design and challenges faces during processing will be discussed and how these tasks were addressed in order to fabricate ReRAM memory cell based on gelatin nanocomposite.

A significant design challenge associated with ReRAM as a viable NVM application is related to uniformity of the switching behaviors[88]. This necessitates strict control over formations of the CF, due to the strong connection between size of the CF and the magnitudes of all the fundamental performance metrics of the ReRAM cell. As mentioned in the previous chapter, there is a strong connection between compliance current and the CF. Additionally, strict control of the forming current is necessary in order to achieve stable multi-level switching, which could greatly increase data density through controlling the size or number of CF's [88].

A variety of design solutions have been researched to address the issue of strict control of CF size, many of which involve the inclusion of current limiters such as transistors or diodes in the design of a memory device cell in order to limit current overshoot during the forming operation[37, 88]. While integration of these devices into the memory cell design can effectively offer more precise control over the current through the MIM stack, new problems with scaling limits and parasitic electrical effects due to the presence of the current limiting elements then arise, greatly magnifying the already significant challenge of achieving all of the benchmarks for viable NVM applications mentioned in chapter 1.

A possible alternative to the inclusion of a current limiting device in a memory cell is the arrangement of the ReRAM cells in a cross-point array. If the memristive system being employed has a significantly high degree of non-linearity in the switching behaviors, the resulting OFF/ON ratio for an individual cell can be high enough to exhibit desirable resistance read-out characteristics while simultaneously preventing unwanted leakage currents from the cell during read-out or programming of itself or of neighboring cells. This effect then also eliminates the space and power requirements associated with the inclusion of a current limiting device on a per-cell basis. The simple cross-point structure also shows great potential for stacking of memory cell arrays in three dimensions, thereby making significantly increased data density possible by increasing overall device density [16, 37, 47, 88]. For these reasons, a cross-point design was chosen as the primary design of the gelatin ReRAM described in this work.

3.1 Material

Nano silver, CdTe, gelatin and Graphene Oxide nano particles were acquired commercially. Type A gelatin was obtained from Goodrich Pvt Ltd, Chennai, India and chemicals and has a bloom power of 300 and a purity of 99.5 percent. Silver nanoparticles were bought from Sigma Aldrich and they have a typical particle size of 10 nm.

3.1.1 Nano Silver

Nano-silver particles (NSPs) typically exist in at least one dimension at a scale of 1 to 100 nm [174, 175, 176]. When particle size decreases, the NSPs surface-to-volume ratio significantly increases, leading to major enhancements in their physical, chemical, and biological stuffs. For hundreds of years, NSPs have been among the nanomaterials most widely used in our healthcare system. Recently, due to their unusual properties, NSPs have been of considerable interest and have been used for many applications.

3.1.2 Graphene Oxide

Graphene has recently achieved substantial prominence and it has grown to be one of the most highly researched materials due to its superior mechanical properties. Graphene, a monolayer of graphite, is well known as ultra-thin, complete two-dimensional (2D) barriers against gas diffusion[177]. Ideally, single-crystalline, defect-free, monolayer graphene not only has outstanding mechanical properties[177] and high transparency[178]but is also impervious to gases. But large-scale, single-crystalline, defect-free, monolayer graphene synthesis remains tremendously perplexing[179, 180, 181].One technique for using grapheme's gas barrier properties in mass processing is the use of graphene oxide (GO) and its reduced form (reduced graphene oxide (rGO) (Figure 3-1). Graphene oxide (GO) is a versatile and promising substratum in mechanical, electronic, chemical, energy storage and biological applications. GO was just an easy and cheap step at the beginning of graphene history to prepare single- and multilayer graphene films and bulk structures by reduction. Namely, thin layers of GO can be coated for barrier applications on suitable polymer substrates. GO consists of functional groups containing oxygen on the basal plane [182] and can be easily dispersed in polar aqueous solvents such as water, resulting in mass manufacturing becoming flexible [183, 184]. However, GO has some shortcomings on its basal plane; thus, multilayer, heavily interlocked folding is much preferred [185, 186]. Alas, owing to its hydrophilic nature, GO is highly influenced by relative humidity and is also hampered by thermal shock due to its inherent metastability, often at low temperatures. As such, to prevent the passage of water vapor or water sorption into the soil, coated thin film GO layers should be chemically or thermally decreased.

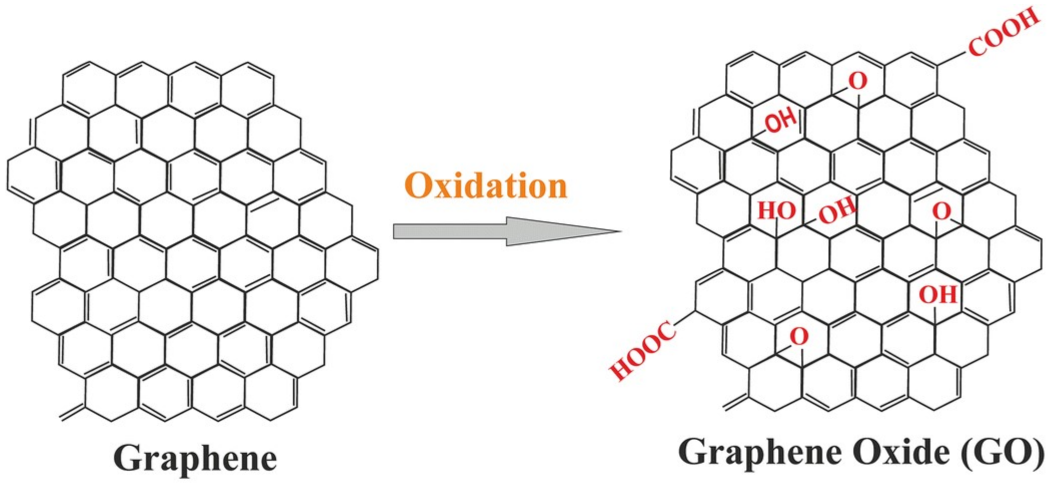


Figure 3—1: Showing the Conversion of Graphene to Graphene Oxide

3.1.3 Cadmium Telluride (CdTe)

The semiconductor of cadmium telluride (CdTe) belonging to the family II-VI has been studied for ages. The ancient works on the production and applications of CdTe date from 1890–1920. CdTe has been researched in the last 10 years primarily as a polycrystalline thin film and as a quantum dot. It was prepared by means of close space vapor transport (CSVT)[187], laser ablation as a thin film[188], electrodeposition [189] and spray pyrolysis, and sputtering [190], the absorbent substrate of thin film solar cells was mainly used. CdTe's more recent deposition strategies concentrate on taking scattered CdTe nanocrystals in water or organic solvents[190]and transforming them into thin CdTe films using very simple and inexpensive dip-coating or spin-coating methods and annealing methods[191].

3.1.4 Gelatin Nanocomposite

Gelatin a polymeric biomaterial product made of amino acid protein has revealed a great ability for application of ReRAM[92, 103]. Author[9] Atype A Gelatin electrochemical analyzes have been carried out extensively to develop its electronic applications. The heteroatomic, nitrogen-containing gelatin structure responds with metal ions to cause electrical run when used as an energetic layer of ReRAM modules [192].

3.2 Development of the Proposed Methods

3.2.1 Experimental Technique

Type A gelatin was obtained from Goodrich Pvt Ltd, Chennai, India ingredients and chemicals and has an energetic power of 300 and a purity of 99.5 percent. Sigma Aldrich got the graphene oxide powder. Glass biker was cleaned thoroughly with water and was left to dry for some time, and one gram (1g) gelatin Type A thin film was weighed with Analytical weighing scale (Figure 3-2) and dissolved in 100ml of distilled water inside a glass biker by heating and stirring at 60°C for 30 minutes using a magnetic stirrer with a hotplate and magnetic stirrer (Figure 3-3), until the gelatin was completely dissolved and a gel solution was formed.

Figure 3—2: Showing of Analytical weighing scale.

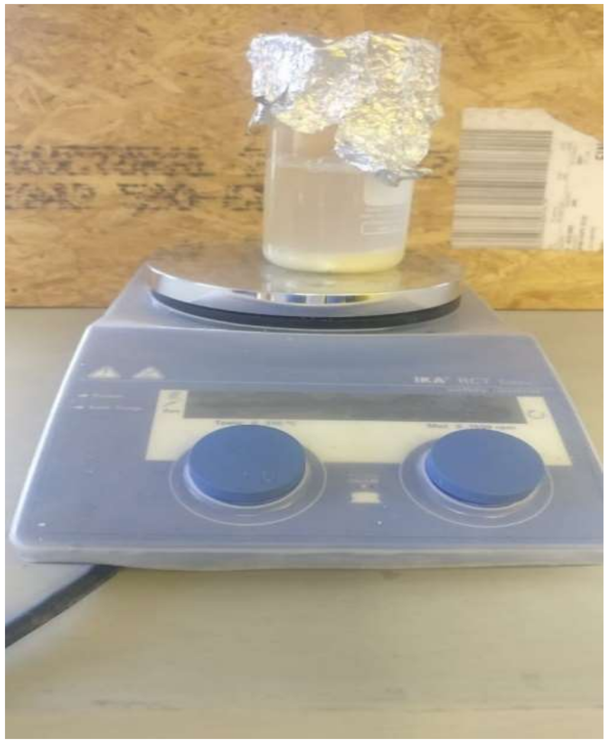


Figure 3—3: Showing the Magnetic Stirrer hot plate

3.2.2 Device Fabrication

Silver nanoparticles were bought from Sigma Aldrich and they have a typical particle size of 10 nm. The Silver nanoparticles was pre-cleaned with acetone for 5 minutes, followed by isopropyl alcohol for 5 minutes and lastly by distilled water for 5 minutes with a sonicate. At start a nominal 0.5wt percent of these particles were integrated into the gelatin matrix and mixed perfectly with an ultrasonicator (Figure 3-4) for about 15mins for uniform particle distribution in gelatin. On ITO substrates micron thick films were then smeared using a spin coater. A two-pronged mechanism has been implemented here. First a rotation of 500rpm for 15sec preceded by a rotation of 2500rpm for 30sec to produce a homogeneous layer of gelatin combination over the ITO. At room temperature, those films were dried.

Figure 3—4: Showing the heated Ultrasonic cleaner

Figure 3—5: Diagram of the spin coating.

Spin coating(Figure 3-5)is a systematic skill to produce thin, uniform organic films over large areas. Throughout the microelectronics industry, in certain, spin coating is often used to cover silicon wafers thru a photoresist at the outset of the lithographic patterning process[193, 194]. It takes a smooth, uniform photographic film of expected and reproducible thickness to achieve high fidelity lithography[195]. The spin coating cycle can be divided into four stages. The processes of spin-up, absorption, evaporation and spin off. Both three stages take place consecutively, while the final phase, i.e. evaporation, takes place during the whole process, demonstrating the major modes of near-end thinning.

The Spin Coating system involves four different stages, as seen in Figure 3-6. Throughout the first step, the coating solution is stored on the wafer or flat substrate by testing the required substrate location. The substratum flew up to its actual required spinningvelocity in stage 2. In the 3rd level, the substratum spins at a steady rate and fluid viscous forces influence the properties of fluid thinning. This period is also known as the period of regulated wind. The substratum rotates at a steady rate in the last step, and solvent evaporation controls the thinning properties of the soil. A solid film is formed after all the solvent has been evaporated. This era is also known as the time of controlled evaporation.

A theoretical study on spin coating technique

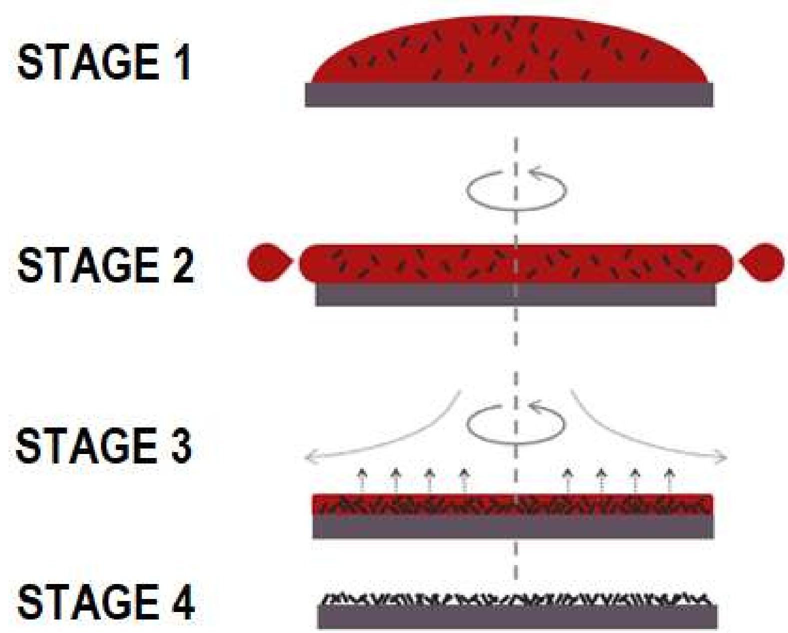


Figure 3—6: Four distinct stages to spin coating. (1) Dispensation (not modeled): first the substrate is coated in the containing the molecules dissolved in a solvent. (2) Acceleration (not modeled): Then the substrate is rotated at high speed and the majority of the solvent is flung off the side. (3) Flow dominated: Airflow then dries the majority of the solvent, leaving a plasticised film. (4) Evaporation dominated: Before the film fully dries to just leave the molecules on the surface. Adapted from [196]

(1) 500 rpm for 15 sec

(2) 2500 rpm for 30 sec

Figure 3—7: Thin films for different speed and time.

The figure 3-7 Showseach type of particles incorporated into the gelatin matrix and thoroughly mixed for uniform distribution of particles in gelatin using an ultrasonicator for about 15 min. Then micron thick films were coated on ITO substrates using a spin coater. (1) A rotation of 500 rpm for 15 sec followed by (2) 2500 rpm rotation for 30 sec was done so that a uniform layer of the gelatin composite was formed over the ITO. These films were dried at room temperature.

3.2.3 Electrical measurements.

The aluminum metal electrodes were deposited under a vacuum of < 10-5- mbar using a home-made thermal evaporator. A semiconductor parameter analyser (Keysight) was used to conduct electrical measurements. In a typical procedure, the sandwich structure's current voltage (I-V) characteristics were restrained by scanning the voltage from -8V to +8V (forward sweep), monitored by a reverse sweep (+8V to -8V).Figure 3-8 showing the Keysight I-V measurement used in this study.

Figure 3—8: Keysight I-V measurement.

3.2.4 Sample characterization.

A Scanning Electron Microscope (SEM) is an electron microscope that captures a sample by scanning it using a high energy beam of electrons in a raster scan configuration. The electrons interact with the atoms that make up the sample producing signals providing information on the topography, structure and other surface properties of the sample, such as electrical conductivity. Using a piece of equipment called the scanning electron microscope, scanning electron microscopy is used to examine topographies of specimens at exceptionally high magnifications. SEM magnifications can reach more than 300,000 X but most semiconductor production applications do need magnifications of less than 3,000 X. SEM diagram is shown in Figure 3-9. SEM magnifications can reach over 300,000 X, but most applications for semiconductor production need magnifications of less than 3,000 X. The SEM representation appears in Figure 3-9.

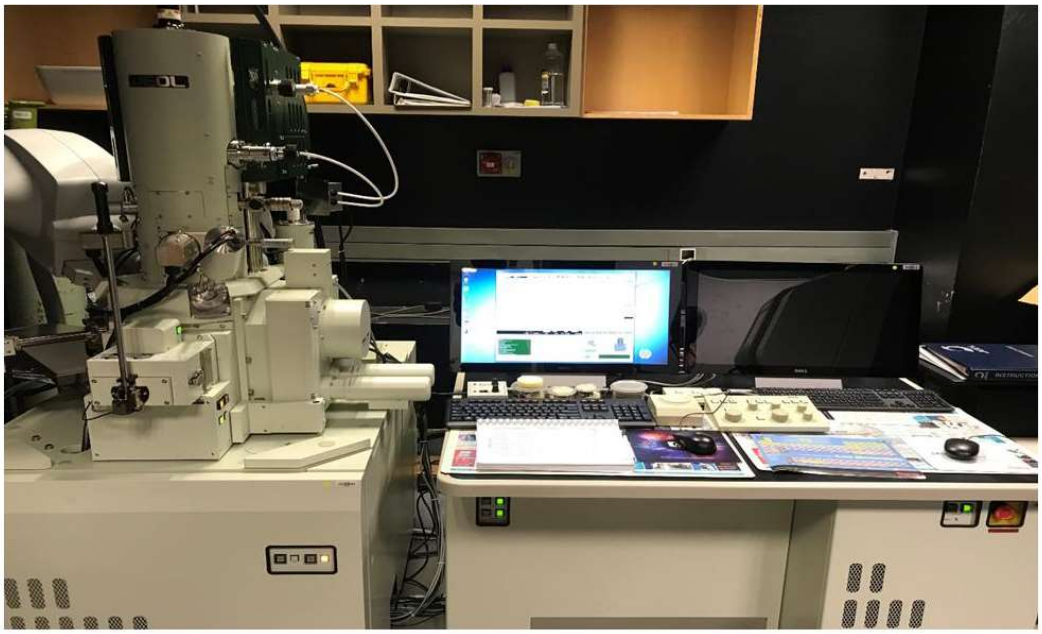


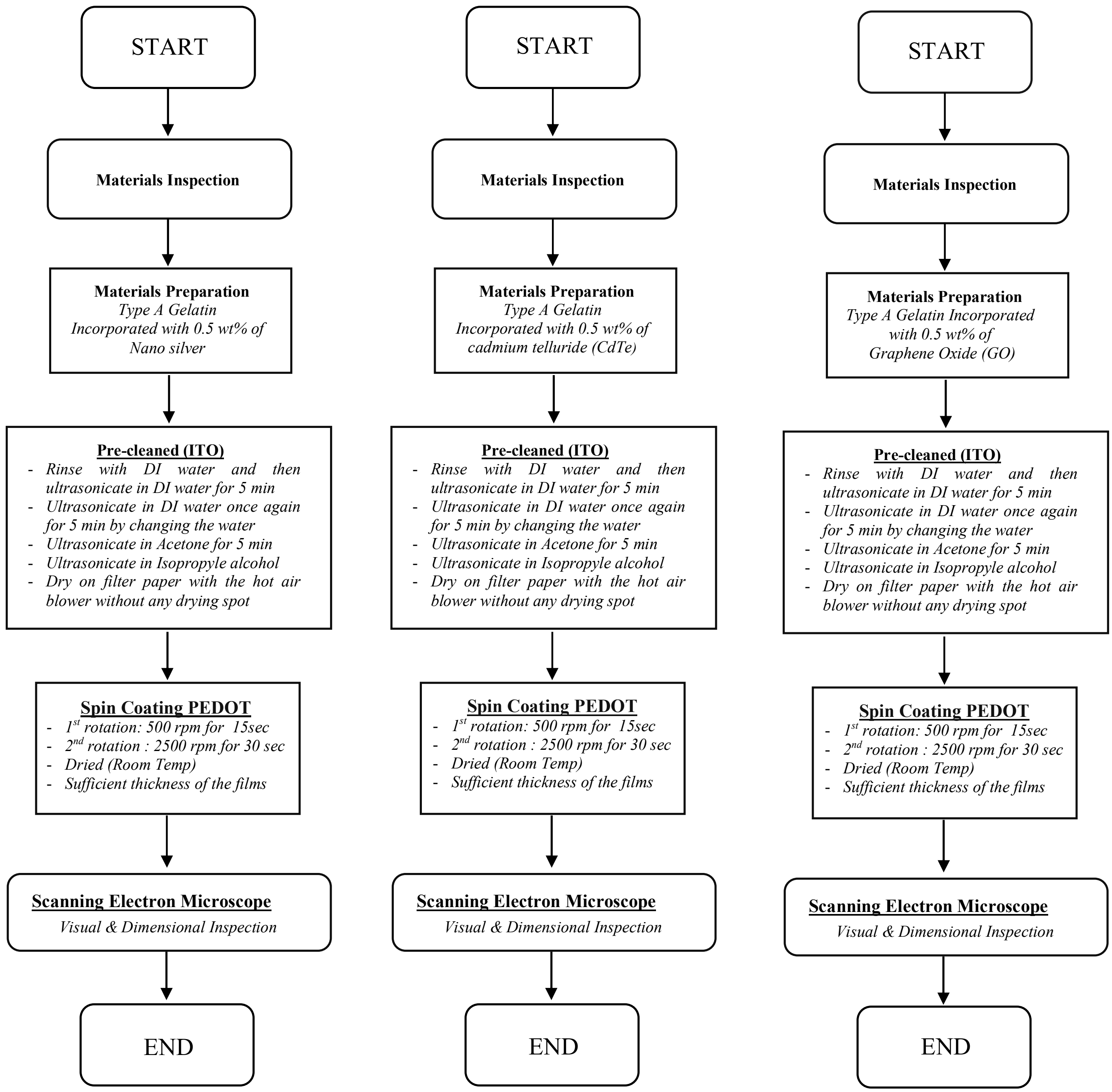
Figure 3—9: Showing full Diagram of Scanning Electron Microscope (SEM)

The SEM consists of the electron gun which discharges between 1-40 keV of magnitude energy from the electron beam. The basic principle is that an electron beam, typically a tungsten filament or a field-emission unit, is generated by an appropriate source. The electron beam is directed by a high voltage and passes to create a thin electron beam through an aperture and electromagnetic lens system. The beam then scans the sample, the electrons are released from the sample by the action of the scanning beam and captured by the detector in an appropriate location.A scanning electron microscope (SEM, Joel, JSM 6360 A) was used to analyze thin-film layer surface morphology and to confirm the films 'homogeneity during this study.

3.3 Research Design and Framework

The aim of this study is to model and fabricate a new computer memory that could be precise and stored huge amount of memory using gelatin-based nanocomposites. The main idea is that when starting from the problem state, there is need to be a multi-level analysis towards the source of the problem, and then the real measure should be motivated on eradicating this problem rather than any artificial cause. In this study a mixture of research techniques was used to achieve this purpose. These include review of the literature, construction of arguments, proposals, prototyping, contextual assessments, experimentation and testing.The following flow chart represent the fabrication process of gelatin and nano silver ReRAM, gelatin and cadium telluride ReRAM, and gerlatin and graphene oxide ReRAM used for the purpose of the study.

3.3.1 Flowchart for the Fabrications ReRAM devices



A **B** **C**

Figure 3—10:(A) Flowchart for fabrication of gelatin and silver ReRAM. (B) Flowchart for fabrication of gelatin and cadmium telluride ReRAM. (C) Flowchart for fabrication of gelatin and graphene oxide ReRAM.

3.4 Research Summary

Instead of the actual realization of a fully-fledged ReRAM memory team performing specific memory tasks, the ReRAM memory created for this dissertation is intended to demonstrate the proof of concept implementation. In addition, ReRAM cells based on gelatin nanocomposites were produced in this context, using various classes of nano particles, namely nano silver, CdTe and graphene oxide, but they may also be studied in other environments.

CHAPTER 4: EXPERIMENTAL EVALUATIONS AND RESULTS

4. EXPERIMENT I: EVALUATION AND VALIDATION MECHANISM

Figure 4-1 shows the I-V characteristics of pristine gelatin type A. The I-V characteristics shows a flat response, indicating no memory behavior. This is in contrast with a report by [197] on type B gelatin, where a memory behavior was observed.

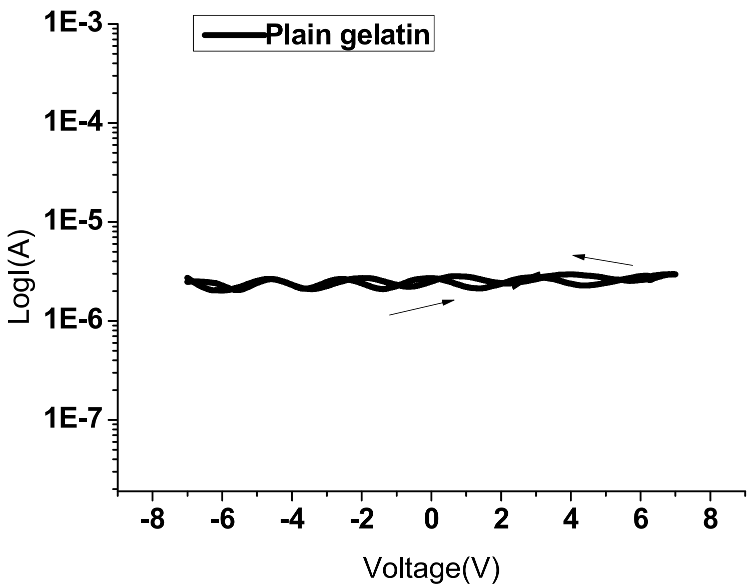


Figure 4—1: **I-V characteristics for pure type A gelatin, showing no memory behavior.**

It should be noted that the bloom strength of type A and type B gelatin are different. Figure (4-2 to 4-4) shows what happens when certain nano particles are added into the type A gelatin.

4.1 Experiment II: Fabrication of gelatin and silver ReRAM device

The I-V characteristics measured for 0.5wt% nano silver added gelatin is shown in Figure 4-.2. Here we see appreciable hysteresis and therefore the memory behavior. An O-shaped I-V response but with a butterfly shaped hysteresis behavior is observed[37]. Earlier such a hysteresis in O-shaped I-V response was reported in the Pt/MoOx/ITO system by [198]. No abrupt increase of current is usually seen at a specific voltage in this type of resistive switching behavior. Here, the write voltage either increases or decreases the conductivity. This is definitely different from the S-shaped behavior reported in the pristine gelatin B[47, 199] memory cell, in which an abrupt increase or jump in current (resistive switching) at a particular voltage was observed.

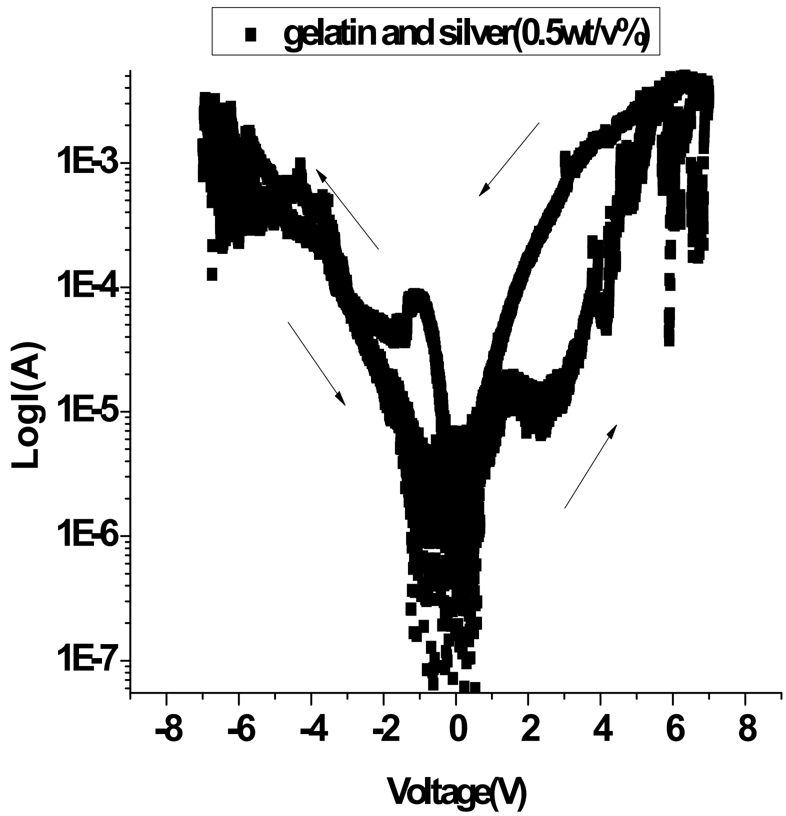


Figure 4—2: **I-V characteristics for pure type A gelatin incorporated with 0.5 wt% of nano silver, showing appreciable memory behavior.**

4.2 Experiment III: Fabrication of gelatin and cadmium telluride ReRAM device

Similar O-shaped I-V characteristics with a butterfly type of hysteresis memory behavior is observed again in 0.5wt% CdTe nano particle added type A gelatin. The data is shown in Figure 4-3. Figure 4-.3 I-V characteristics for pure type A gelatin incorporated with 0.5wt% of nano CdTe, showing appreciable memory behavior. The characteristics are O-type but with small kinks observed both in forward and reverse sweep. These kinks could be due to the formation of conduction filaments and certain percolation.

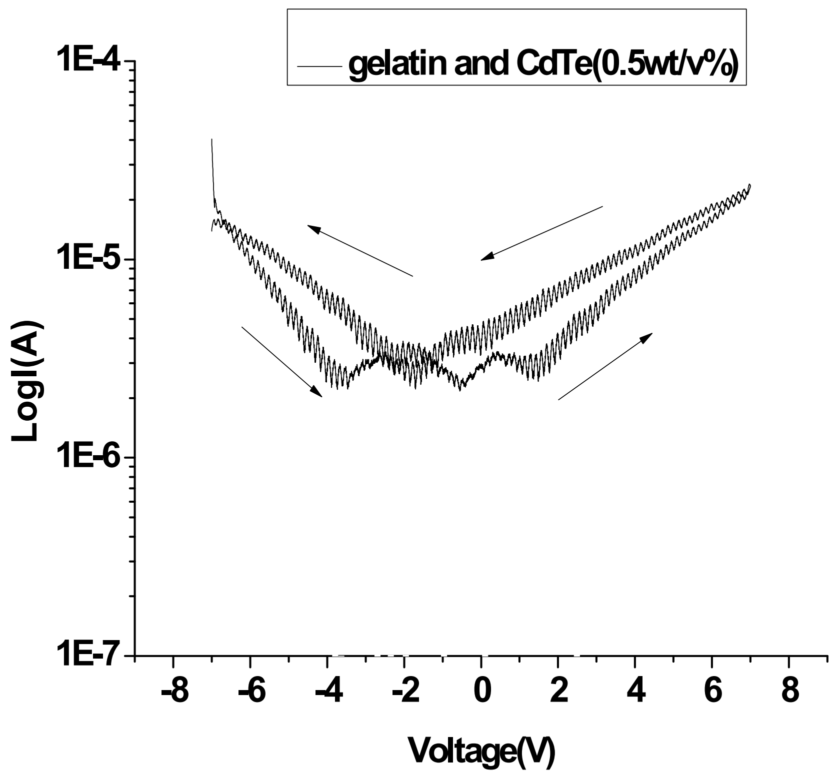


Figure 4—3: **I-V characteristics for pure type A gelatin incorporated with 0.5 wt% of nano Cadmium Telluride (CdTe), showing appreciable memory behavior.**

4.3 Experiment IV: Fabrication of gelatin and Graphene oxide ReRAM device

Similar kink in the negative branch I-V characteristics is observed for the 0.5wt% graphene oxide (GO) added gelatin, as shown in Figure 4-4. As this is suspicious, and to confirm this, we changed the GO wt% to 1wt% in gelatin and the I-V characteristics are shown in Figure 4-5.

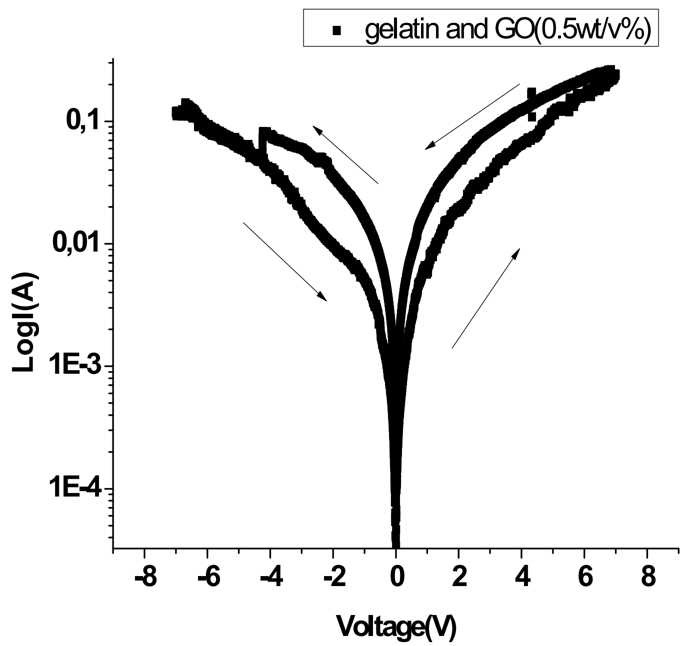


Figure 4—4: I-V characteristics for pure type A gelatin incorporated with 0.5 wt% of nano Graphene Oxide, showing appreciable memory behavior.

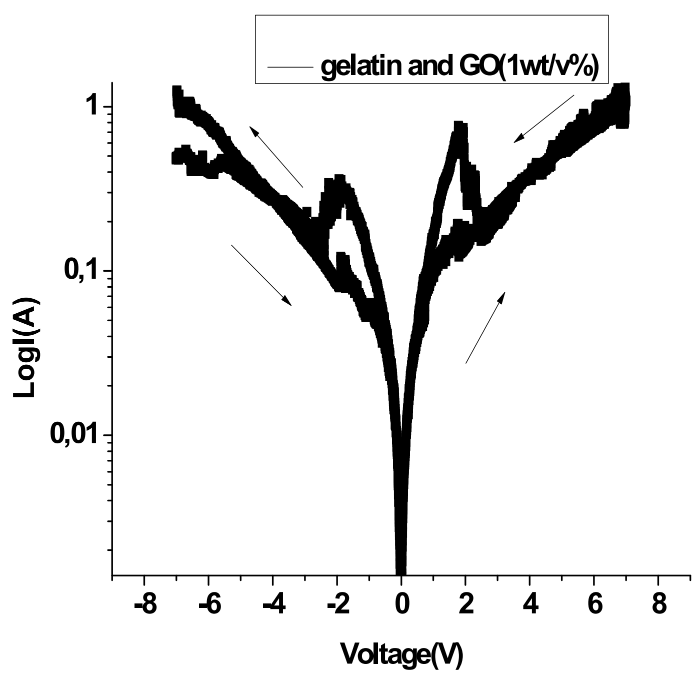


Figure 4—5: I-V characteristics for pure type A gelatin incorporated with 1 wt% of nano Graphene Oxide, showing appreciable memory behavior

One can see the reproducibility of the kink on the negative branch but also the appearance of the kink on the positive branch as well. Not only this, there are smaller kinks on both negative and positive branches for the reverse sweeps, with a new kind of hysteresis. This kink formation is a new feature which was not reported earlier in the literature. These kink formations could be due to the conduction filament and percolation of such clusters. Such cluster formation also can lead to the observed hysteresis around the kinks. These kinds of kinks can also be observed in the I-V characteristics of nano silver added gelatin, as shown in Figure 4-2. This means, filament formation, percolation and cluster formation that leads to kinks and hysteresis around kinks is a kind of universal behavior in all gelatin nano composite-based ReRAM memory cells.

Resistive switching random access memory (ReRAM) is one of the memories that is showing promise in comparison with traditional computer memories like flash[200], and as a best candidate [200] among the emerging memories like Phase change memory (PCM), Ferroelectric RAM (FeRAM), Mott Memory, Carbon, Molecular and millipede memories etc. [34, 201, 202, 203, 204, 205]. Nano particle induced resistive switching, is a technical principle of ReRAM as a result of swept voltage. ReRAM is also considered a threat for potential NAND Flash There are several types of ReRAMs reported in the literature such as semiconductor based [206] and polymer nano composite based[89, 207, 208]. Among these, biodegradable Gelatin nano composite-based ReRAM is a recent trend [47, 197] towards green computing. This is simply because gelatin is a biodegradable material. While pure Gelatin and several types of nano particles incorporated gelatin nano composites have been reported to be good candidates for ReRAM memory cells, a complete understanding of the memory behavior in these cells is not available. Personal Computers are leading to e-waste and are not biodegradable[199]. This can give rise to environmental pollution due to manufacturing defects of computers and its components [199]. Energy conservation in Hardware levels of computing can be done by reducing hazardous materials and using biodegradable materials [209]. Therefore, in this context we have done a systematic study of memory behavior in nano silver, CdTe and Graphene Oxide incorporated biodegradable gelatin nanocomposites.

4.4 Benchmarking the Proposed Method with Common Approaches

Recent data in the field of resistive random-access memory (RAM) technology, that is recognized to be one of the extremely outstanding emerging memory technologies due to its high speed, low cost, increased storage density, prospective unique properties, and excellent scalability, has been systematically reviewed.Resistive Random Access Memory, termed to be one of the most impressive next-generation non-volatile memory (NVM) devices and reflective of memristor technologies, has shown great capability to reinforce as an artificial synapse in the neuromorphic and artificial intelligence (AI) industry due to its advantages such as rapid operating speed, low power consumption. Graphene and related materials (GRMs), in a common graphene oxide (GO), serving as active materials for RRAM applications, are recognized as a favorable substitute to other materials, including metal oxides and perovskite materials.Assessment between main synthesis technologies and applications for graphene and its derivatives are presented in the following Table 4-1[155, 156, 157, 158, 159, 160].

Table 4-.1: Assessment between main synthesis technologies and applications for graphene and its derivatives.

Synthesis Methods	Materials	Devices
Chemical Vapor	Graphene h-BN TMD	FeRAM MRAM TRAM RRAM STT-RAM
Electrochemical Exfoliation	GO TMD	FeRAM MRAM RRAM STT-RAM
Nucleation and Growth	Graphene h-BN TMD	FeRAM PCM MRAM RRAM STT-RAM
Atomic Layer Deposition	Graphene h-BN TMD	FeRAM MRAM ReRAM
Liquid Phase Exfoliation	GO TMD	FeRAM RRAM Flash
Solution Deposition	GO h-BN	FeRAM ReRAM

In the present studies, the major contribution, and the main prospects of this work to the knowledge in the field is the following:

- ❖ Resistive switching in diodes which use metal nanoparticles is alike to bulk oxide MIMstructures.

- ❖ An imperative significance of this conclusion is that non-oxidized metal nanoparticles such asgold nanoparticles cannot be used to make reliable ReRAMs.
- ❖ Only through the migration of metal species and the formation/breaking of metal filaments can they lead to resistive switching devices.
- ❖ Resistive switching necessitates the use of an oxide in a bilayer structure.
- ❖ The electronic process of resistive switching in silver oxide nanoparticles.
- ❖ The system must be electroformed.

Table 4--2: Comparison of emerging memories and existing memories devices: [216]

		Cell Area	Endurance	Retention	Read Time	Write Time	Multi -bit	Voltage
Emerging Memories	**ReRAM**	$<4F^2$ if 3D	$>10^{15}$	>10y	<10ns	<10ns	2	<3V
	STT-MRAM	$6\sim20F^2$	$>10^{15}$	>10y	<10ns	<5ns	1	<2V
	PCRAM	$4\sim20F^2$	$>10^4$	>10y	<10ns	~50ns	2	<3V
Mainstream Memories	**DRAM**	$6F^2$	$>10^3$	~64ms	~10ns	~10ns	1	<1V
	SRAM	$>100F^2$	$>10^{14}$	N/A	~1ns	~1ns	1	<1V
	NOR FLASH	$10F^2$	$>10^8$	>10y	~50ns	10µs-1ms	2	>10V
	NAND FLASH	$<4F^2$(3D)	$>10^{15}$	>10y	~10µs	100µs -1ms	3	>10V

F: the lithography's feature size,and the energy estimation is on the cell-level (not the array-level)

4.5 Research Summary

ReRAM, a resistive random-access memory that is based on resistive switching, will find its way into the memory of the device. This is because ReRAM is intended to have contrasting output characteristics and Flash memory quality. ReRAM memory cells based on gelatin nanocomposite thin film have been developed in the study. In these ReRAMs, the memory behaviour was measured, evaluated and calculated. We found that in general O-shaped butterfly type hysteresis behavior in all these memory cells, modeling and controlling hysteresis is a field of keen importance to the control community. For the first time, we report on the production of kinks with I-V characteristics due to conduction filament and percolation effects that lead to cluster forming. Our tests and measurements clearly show that biodegradable gelatin nanocomposite films are highly suitable for ReRAM memory, for green computers.

CHAPTER 5: CONCLUSIONS AND FUTURE WORK

5. CONCLUSIONS

5.1 Research Summary

The analysis of various aspects linked to gelatin showed the superiority of this biodegradable polymer for the use of different proteins and peptides. Since it is very consistent with the human system which is confirmed by the analysis of their development, it can be used as a section for different formulations, the use of gelatin nanoparticles indicates and the other characteristics can be easily analyzed by means of similar formulations Consequently, gelatin as a tool reveals its clear dominance over other usable polymers to meet the potential nano-biotechnology challenges that arise in the development of ReRAM memory devices.

5.2 Resolutions of Research questions

ReRAM memory cells mounted on gelatin nanocomposite thin film have been formed in this research. Memory activity in these ReRAM cells has been measured, analyzed and assessed. I reviewed various models that describe switching mechanisms. Then the developed ReRAMs and their memory behavior and the experimental I-V curves along with the switching mechanisms have been analyzed and explained in terms of different models.

5.3 Summary of Contributions

A ReRAM memory was fabricated, experiments and tests specifically demonstrate that biodegradable gelatin nanocomposite films are extremely ideal for ReRAM memory, for green computers. A well-constructed researched article was also generated and published as a result of the scientific research conducted for this dissertation.

5.4 Limitations and Future Work

Research in new memory technology has grown significantly over the decades, and several ReRAM display programs have been designed to show the ability for high-speed and low-power internal memory applications. One of the most important things that needs to be extensively investigated is the reliability of ReRAM, ReRAM becomes one of the most optimistic memory technologies due to the advantages of simple structure, compatible with existing CMOS technology, fast switching speed and ability to fit to the smallest dimension.These problems need to be resolved successfully before ReRAM is introduced in future memory applications.Although ReRAM is highly desirable for use in neuromorphic computation, the biggest challenge to industrialization of ReRAM lies with the need to address heterogeneity problems, not even under realistic system parameters but also at high temperatures, before it can be used in a wide variety of applications. As a matter of fact, green computing ReRAM is becoming a potential replacement particularly for fast operation and medium-sized storage density memory applications. The ReRAM has a switching speed that is fast enough to replace the DRAM and the materials used in the manufacture of ReRAM are very close to the DRAM, making it a vital task to enhance the endurance characteristics of the ReRAM. It is necessary to control the flow of oxygen between the electrode and the oxide layer at the interface so as to improve the durability features.

5.5 Scope for Future work

I intend to continue with this research/studies green computing IT in future because such optimal technologies would be unified memory, removing the need for dynamic hierarchies of the memory subsystem.Since green computing nanotechnologies can rapidly and efficiently affect the design of nanomaterials and goods by removing or attenuating pollution from nanomaterial manufacturing, take a life-cycle concept to nan products to predict and mitigate where environmental effects will occur in the product chain, assess the toxicity of nanomaterial, and use nanomaterial to handle or remediate current enviable materials.

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