Faculty of Electronics and Computer Technology and Engineering

DEVELOPMENT OF CARBON NANOTUBE-BASED NANOELECTRONIC BIOSENSORS FOR GLUCOSE DETECTION

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

2024

DEVELOPMENT OF CARBON NANOTUBE-BASED NANOELECTRONIC BIOSENSORS FOR GLUCOSE DETECTION

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A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI KEJUTERAAN ELEKTRIK DAN ELEKTRONIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Development of Carbon Nanotube-Based Nanoelectronic Biosensors For Glucose Detection

Sesi Pengajian : 2023/2024

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DEDICATION

To my beloved father, Ismail bin Jusoh, and my late mother, Siti Zaliha binti Ali, they are my inspiration and motivation
Thank you for always giving me endless love and support for me.

To my siblings, Mohd Faizal bin Ismail,
Intan Zurina binti Ismail,
Intan Zuraidah binti Ismail,
Intan Zuraini binti Ismail,
Mohd Firdaus bin Ismail,
Thank you for taking care of me, giving emotional support for me to continue my education journey, and being my motivation for completing this project.

To my supervisor, Madam Najmiah Radiah binti Mohamad,
Thank you for your dedication, organization, enthusiasm, and hard work.
Thank you for giving me this opportunity to meet such an amazing lecturer.
You are an inspiring lecturer.

Last but not least, thank you to yourself for your hard work in completing this project.

ABSTRACT

In the development of nanoelectronic biosensors for glucose detection, a common approach involves the utilization of nanomaterials such as carbon nanotubes or graphene as the sensing elements. These nanomaterials are often functionalized with biomolecules, such as enzymes, to enhance selectivity by forming specific bonds with glucose molecules. The interaction between glucose and the biomolecule induces changes in the electrical characteristics of the nanomaterial, which can be assessed through techniques like electrochemical impedance spectroscopy or cyclic voltammetry. However, biosensor development faces challenges related to detection limits, detection time, and specificity. Addressing the need for efficient biosensor systems with high sensitivity and specificity, this research focuses on fabricating a Polypyrrole (PPY)/Multiwalled Carbon Nanotube (MWCNT) nanofilm through the chronoamperometry method. The electrodeposition and cyclic voltammetry of the fabricated nanofilm are conducted using an AutoLAB potentiostat with NOVA 2.0 AutoLAB software. Characterization of the nanofilm is carried out through Fourier transform infrared spectroscopy (FTiR), and Field emission scanning electron microscopy (FE-SEM) to analyze morphology and material properties. During chronoamperometry for 3 minutes using PPY/MWCNT 1.5 hours sonication, the carbon electrode exhibits the highest current at 1.326 mA. However, longer chronoamperometry processes yield different results. After 5 minutes, the carbon electrode registers the highest current at 0.929 mA, followed by stainless steel at 0.721 mA and the indium tin oxide electrode at 0.350 mA. Further, chronoamperometry for 3 minutes using PPY/MWCNT 3 hours sonication, the carbon electrode exhibits the highest current at 0.972 mA, followed by stainless steel at 0.954 mA and 0.496 mA. After 5 minutes, the carbon electrode registers the highest current at 0.898 mA, followed by stainless steel at 0.836 mA and the indium tin oxide electrode at 0.437 mA. Cyclic voltammetry, conducted between -0.8V and +0.4V in a PBS solution, reveals that the current for the carbon electrode in PBS solution is 1.562 mA, while in glucose solution, it is 2.099 mA. For the indium tin oxide electrode, the current in the PBS solution is 0.700 mA, and in the glucose solution, it is 0.144 mA. For the stainless steel electrode, the current in the PBS solution is 0.942 mA, and in the glucose solution, it is 0.499 mA. These results collectively indicate the successful detection of glucose, affirming the efficacy of the developed nano biosensor.

ABSTRAK

Dalam pembangunan biosensor nanoelektronik untuk pengesanan glukosa, pendekatan umum melibatkan penggunaan nanomaterial seperti nanotub karbon atau grafen sebagai unsur sensor.. Interaksi antara glukosa dan biomolekul menghasilkan perubahan dalam ciri-ciri elektrik nanomaterial, yang boleh dinilai melalui teknik seperti spektroskopi impedans elektrokimia atau voltametri sikel. Walau bagaimanapun, pembangunan biosensor menghadapi cabaran berkaitan dengan had pengesanan, masa pengesanan, dan spesifisiti. Menanggapi keperluan sistem biosensor yang efisyen dengan sensitiviti dan spesifisiti yang tinggi, penyelidikan ini tertumpu pada pembuatan nanofilm Polipirrol (PPY)/Nanotub Karbon Berbilang Lapisan (MWCNT) melalui kaedah krontoamperometri. Elektrodeposit dan voltametri sikel nanofilm yang difabrikasi dilakukan menggunakan potensiostat AutoLAB dengan perisian NOVA 2.0 AutoLAB. Pencirian nanofilm dilakukan melalui spektroskopi inframerah transformasi Fourier (FTIR), dan mikroskopi elektron pengimbasan medan (FE-SEM) untuk menganalisis morfologi dan sifat material. Semasa krontoamperometri selama 3 minit menggunakan PPY/MWCNT sonikasi 1.5 jam, elektrod karbon menunjukkan arus tertinggi pada 1.326 mA. Walau bagaimanapun, proses krontoamperometri yang lebih lama memberikan hasil yang berbeza. Selepas 5 minit, elektrod karbon mendaftar arus tertinggi pada 0.929 mA, diikuti oleh keluli tahan karat pada 0.721 mA dan elektrod indium tin oksida pada 0.350 mA. Selanjutnya, krontoamperometri selama 3 minit menggunakan PPY/MWCNT sonikasi 3 jam, elektrod karbon menunjukkan arus tertinggi pada 0.972 mA, diikuti oleh keluli tahan karat pada 0.954 mA dan 0.496 mA. Selepas 5 minit, elektrod karbon mendaftar arus tertinggi pada 0.898 mA, diikuti oleh keluli tahan karat pada 0.836 mA dan elektrod indium tin oksida pada 0.437 mA. Voltametri sikel, dilakukan di antara -0.8V dan +0.4V dalam larutan PBS, mendedahkan bahawa arus untuk elektrod karbon dalam larutan PBS adalah 1.562 mA, manakala dalam larutan glukosa, ia adalah 2.099 mA. Untuk elektrod indium tin oksida, arus dalam larutan PBS adalah 0.700 mA, dan dalam larutan glukosa, ia adalah 0.144 mA. Untuk elektrod keluli tahan karat, arus dalam larutan PBS adalah 0.942 mA, dan dalam larutan glukosa, ia adalah 0.499 mA. Hasil ini secara kolektif menunjukkan pengesanan berjaya glukosa, mengesahkan keberkesanan biosensor nano yang dibangunkan.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisor, Puan. Najmiah Radiah binti Mohamad, and co-supervisor, Dr. Jeefferie bin Abd Razak for their precious guidance, words of wisdom, and patient throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) for the financial support which enables me to accomplish the project. Not forgetting my fellow colleagues, for their willingness to share their thoughts and ideas regarding the project.

My highest appreciation goes to my parents, and family members for their love and prayer during the period of my study.

Finally, I would like to thank all the staff at the Universiti Teknikal Malaysia Melaka (UTeM), fellow colleagues and classmates, the Faculty members, and other individuals not listed here for being cooperative and helpful.

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μM	-	Micrometre
mM	-	Milimetre

LIST OF ABBREVIATIONS

V	-	Voltage
SPR	-	Surface Plasmon Resonanse
FET	-	Field-Effect Biosensor
AuNPs	-	Gold nanoparticles
MOH	-	Oxidative Adsorbed Hydroxide
QCM	-	Quartz Crystal Microbalance
MHz	-	Megahertz
ng/ml	-	Nanograms per Milliliter
fg/ml	-	Femtogram per Molliliter
pH	-	Potential of Hydrogen
MoS_2	-	Molybdenum Disulphide
EGFET	-	Extended Gate Field Effect Transistor
PPy	-	Polypyrrole
MBs	-	Magnetic Beads
GO	-	Graphene Oxide
NiO	-	Nickel Oxide
LED	-	Light-Emitting Diode
MTM	-	Multi-mode Thincore Multi-mode
Ag NPs	-	Silver nanoparticle
RuO2	-	Ruthenium(IV) oxide
T	-	Time
mV	-	Millivolt
M	-	Reductive Metal Adsorption
FDTD	-	Finite-difference time-domain
CO2	-	Carbon dioxide
SEM	-	Scanning Electron Microscope
XRD	-	X-ray diffraction
FTIR	-	Fourier-transform infrared spectroscopy
Cm	-	Centimeter
XRD	-	X-ray diffraction
GOx	-	Glucose Oxidation

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CHAPTER 1

INTRODUCTION

1.1 Background

A biosensor is an analytical device that detects biological or chemical reactions and generates reliable data for several fields such as gene analysis, disease monitoring, drug discovery, and detection of pollutants [1]. The biosensor typically consists of a bio-receptor such as enzyme, antibody, cell, nucleic acid, aptamer, transducer component (semi-conducting material/nanomaterial), and electronic system which includes a signal amplifier, processor & display [2]. Carbon nanotube-based biosensors have great potential for glucose detection due to the unique properties of carbon nanotubes [3]. These biosensors can be functionalized with enzymes or antibodies that recognize glucose or integrated into field-effect transistor (FET) based biosensors [4]. The biosensors can detect glucose concentrations as low as 1 μM and can be used to detect glucose in complex biological fluids such as blood serum and saliva [4]. However, the reproducibility of the sensing performance is a challenge that needs to be addressed [4]. Despite this challenge, the development of CNT-based biosensors holds great promise

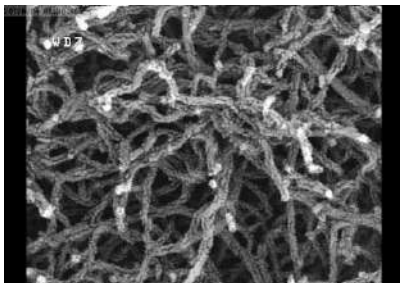

Figure 1.1 Image of Carbon Nanotube

for the development of low-cost, portable, and highly sensitive glucose detection devices [4].

1.2 Driving Sustainable Development Through Carbon Nanotube-Based Nanoelectronic Biosensors

Carbon nanotube-based nanoelectronic biosensors have emerged as a promising technology with the potential to contribute significantly to sustainable development [5]. By offering enhanced accuracy, sensitivity, and selectivity in monitoring glucose levels and other environmental parameters, these biosensors have a positive impact on environmental conservation, economic growth, and social well-being [6]. These biosensors offer enhanced accuracy, sensitivity, and selectivity in detecting glucose levels and other environmental parameters [7]. This increased precision allows for more effective monitoring and management of environmental resources, leading to better conservation practices. Furthermore, the resource efficiency of carbon nanotube-based biosensors sets them apart from traditional technologies. With their lightweight design and reduced material requirements, these biosensors minimize resource consumption and waste generation during manufacturing [5]. This can contribute to sustainable development by reducing the strain on natural resources and minimizing negative environmental impacts. Additionally, the real-time monitoring capabilities of carbon nanotube-based biosensors enable early intervention in environmental issues such as air and water pollution [8]. This early intervention allows for more effective pollution prevention and reduced environmental degradation.

The development and implementation of carbon nanotube-based nanoelectronic biosensors have the potential to drive sustainable development across various domains

[5]. Their resource efficiency and pollution prevention capabilities contribute to environmental conservation. Economically, these biosensors offer cost efficiencies and improved healthcare outcomes [9]. By providing more accurate and timely data, carbon nanotube-based biosensors can help in the early detection and prevention of diseases, leading to reduced healthcare costs and improved health outcomes [10]. Socially, the use of carbon nanotube-based biosensors enhances public health by providing individuals with better access to real-time health monitoring. This can lead to early detection of health issues and prompt medical interventions, ultimately improving overall well-being. This technology can be particularly beneficial for remote or underserved communities, where access to healthcare resources may be limited. Continued research and development efforts are essential to address scalability, cost-effectiveness, and regulatory challenges to enable the widespread adoption of these biosensors [9]. By embracing carbon nanotube-based biosensors, we can pave the way for a sustainable future marked by environmental preservation, economic prosperity, and societal well [11].

1.3 Problem Statement

Diabetes is a chronic disease that affects millions of individuals worldwide, leading to numerous complications and significantly impacting their quality of life. One of the main challenges in managing diabetes is monitoring blood glucose levels regularly and accurately. Current methods for glucose monitoring include handheld devices that use enzyme-based electrochemical sensors. While these devices have been successful in the market and are widely used, they still pose certain limitations [12]. These limitations include the need for frequent finger pricks to obtain blood samples, resulting in discomfort and inconvenience for patients. Furthermore, the enzyme-based electrochemical sensors used in these devices can be affected by interfering substances present in the blood, leading to inaccurate glucose measurements [12]. A diabetes biosensor is a device that can accurately and continuously monitor glucose levels in individuals with diabetes. Traditional glucose biosensors have limitations in terms of sensitivity, accuracy, and specificity, and to address these limitations, there is need to develop of a more efficient and reliable diabetes biosensor

1.4 Project Objective

The aim of this project is to create a nanoelectronic biosensor for detecting glucose. The specific objectives are as follows:

a) To fabricate of PPY/MWCNT nanofilm through chronoamperometry.

b) To examine the correlation between voltage and current for carbon, indium tin oxide and stainless steel as a substrate.

c) To characterize the Polypyrrole/MWCNT nanofilm using techniques such as Fourier Transform Infrared Spectroscopy (FTiR), Field Scanning Electron Microscope (FE-SEM).

1.5 Scope of Project

The scope of this project are as follows:

a) Investigate the relationship between the voltage , current, and the surface area by using cyclic voltammetry method for Indium Tin Oxide, Stainless Steel, and Carbon.

b) Design and simulate the experiment using Comsol software for simulation electrochemistry to show the cyclic voltammetry graph .

c) Comparing the electrodes of Indium Tin Oxide, Stainless Steel and Carbon on which are is better at sensitivity for detecting glucose based on sensogram results.

d) Electrodeposition and cyclic voltammetry is experimented by using AutoLAB

e) Potentiostat with NOVA 2.0 AutoLAB software for Indium Tin Oxide Stainless Steel and Carbon.

f) Using PBS and glucose solution for cyclic voltammetry process for Indium Tin Oxide, Stainless Steel and Carbon.

CHAPTER 2

LITERATURE REVIEW

2.1 Potential of Carbon Nanotubes for Advancing Glucose Biosensors

Carbon nanotubes (CNTs) have emerged as pivotal materials in the development of glucose biosensors, capitalizing on their exceptional physical and chemical properties. The incorporation of CNTs in biosensor design is driven by their outstanding electrical conductivity, large specific surface area, and superior electron transport capability, making them ideal candidates for applications in glucose sensing [4].

The excellent electrical conductivity of CNTs is a key attribute that enhances the performance of glucose biosensors. In the context of electrocatalysis for glucose detection, CNTs play a crucial role in facilitating efficient electron transfer reactions. This property is particularly advantageous when applied to glucose enzymatic sensors, where precise electron tunneling into the enzyme is essential for accurate and sensitive glucose detection [4]. The ability of CNTs to act as efficient conduits for electron transport ensures that the biosensors exhibit heightened sensitivity and reliability.

Furthermore, the large specific surface area of CNTs contributes to their effectiveness in glucose biosensors [4]. This property provides ample space for the immobilization of enzymes, such as glucose oxidase, enhancing the sensor's overall performance. The immobilization of enzymes on CNT surfaces ensures stable and functional biosensor configurations, enabling selective and specific glucose detection.

CNT-based glucose sensors have demonstrated remarkable sensitivity to glucose in bodily fluids, positioning them as valuable tools for point-of-care applications. The ability of these sensors to accurately detect glucose levels in complex physiological environments underscores their potential in real-time monitoring and diagnostic applications. The integration of CNTs in biosensor platforms facilitates rapid and reliable glucose detection, addressing the critical need for point-of-care solutions in healthcare [4].

In addition to enzymatic sensors, CNTs have been employed in the construction of amperometric glucose biosensors [13]. By immobilizing glucose oxidase on CNT surfaces, these biosensors showcase the potential of CNTs in enhancing the efficiency of glucose detection. The synergy between CNTs and enzyme immobilization contributes to the development of robust biosensor configurations with improved selectivity and sensitivity, making them promising candidates for glucose monitoring in various settings [13].

Moreover, CNT-based non-enzymatic glucose sensors have been investigated for their electrocatalytic activity and broad linear range for glucose detection. These sensors offer an alternative approach to glucose sensing by leveraging the inherent electrocatalytic properties of CNTs without relying on enzyme-based reactions [14]. The broad linear range of CNT-based non-enzymatic sensors enhances their versatility, allowing for the detection of a wide range of glucose concentrations with high precision.

2.2 Diverse Materials Beyong CNT in Glucose Biosensors

In the realm of glucose biosensor development, the exploration of materials beyond carbon nanotubes (CNTs) has led to exciting advancements, bringing forth a diverse array of options with unique properties. Among these materials, chitosan stands out for its versatile applications [Choi]. When modified with CNTs, chitosan has proven instrumental in biosensing analytes such as alcohols and 2,2_-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt. This synergistic combination enhances the sensitivity and selectivity of the biosensor, showcasing the potential of chitosan-modified CNTs in various sensing applications [15].

Another compelling material combination involves molybdenum disulfide (MoS2) and nickel nanoparticles (NiNPs) [14]. The integration of these components into a CNT/MoS2/NiNPs composite has resulted in highly efficient non-enzymatic electrochemical glucose sensors [14]. This composite exhibits excellent electrocatalytic activity and a broad linear range for glucose detection. The versatility and performance of this composite make it a promising candidate for glucose biosensing, hinting at its potential impact in the field of medical diagnostics and monitoring.

Gold nanoparticles, renowned for their unique properties, have also found a place in the evolution of glucose biosensor technology [13]. A noteworthy example is the construction of a carbon nanotube/chitosan/gold nanoparticles-based amperometric glucose biosensor. This innovative design harnesses the synergies among these materials, offering a platform that shows great promise for glucose detection [13]. The incorporation of gold nanoparticles not only contributes to the sensor's sensitivity but

also imparts a level of specificity that is crucial for accurate glucose monitoring in diverse contexts.

These materials, alongside CNTs, collectively contribute to the rich tapestry of glucose biosensor development. The distinct properties of each material bring about unique advantages and potential applications. Chitosan-modified CNTs extend the biosensor's applicability to various analytes, showcasing adaptability in different sensing scenarios. The CNT/MoS2/NiNPs composite, on the other hand, exhibits outstanding electrocatalytic activity, offering a robust solution for non-enzymatic electrochemical glucose sensing with an expansive linear range [14].

Furthermore, the carbon nanotube/chitosan/gold nanoparticles-based amperometric glucose biosensor represents a sophisticated integration of materials, combining the mechanical strength of carbon nanotubes, the versatility of chitosan, and the unique properties of gold nanoparticles [13]. This amalgamation results in a biosensor with the potential for high sensitivity and specificity in glucose detection.

In conclusion, the exploration of materials beyond carbon nanotubes has propelled the development of glucose biosensors into a realm of versatility and efficiency. Chitosan, molybdenum disulfide, nickel nanoparticles, and gold nanoparticles, when combined with CNTs, offer a spectrum of options, each with its distinct advantages and potential applications. These advancements not only enhance our ability to monitor glucose levels accurately but also pave the way for innovative biosensing technologies with broader implications in healthcare and other fields.

2.3 Glucose Monitoring Technique

Glucose monitoring techniques play a crucial role in the management of diabetes, a condition characterized by high blood sugar levels. These techniques allow individuals with diabetes to monitor their glucose levels and make informed decisions about their treatment, diet, and lifestyle [16]. By regularly tracking their glucose levels, individuals can optimize their diabetes management, reduce the risk of complications, and maintain better overall health.

Glucose monitoring techniques provide invaluable tools for individuals with diabetes to track their glucose levels, make informed decisions, and effectively manage their condition [17]. From traditional self-monitoring blood glucose to continuous and flash glucose monitoring, these techniques empower individuals to take control of their health and maintain optimal glucose control, thereby reducing the risk of complications and promoting overall well-being [17].

2.3.1 Self Monitoring Blood Glucose (SMBG)

Self-Monitoring Blood Glucose (SMBG) is a widely used technique for measuring blood glucose levels at home. It is primarily used by individuals with diabetes to monitor and manage their condition effectively. Clinical guidelines recommend regular individualized SMBG as a tool for self-management in type 1 diabetes mellitus [17]. SMBG involves the use of a glucose meter, lancet device, and test strips. The process begins with pricking a fingertip using the lancet device to obtain a small drop of blood. The blood sample is then applied to a test strip inserted into the glucose meter. Within seconds, the meter analyzes the sample and displays the blood glucose reading on its screen. This technique

allows individuals to track their glucose levels regularly, make informed decisions about their diet, medication, and lifestyle choices, and take necessary actions to maintain optimal glucose control. By recording and monitoring their blood glucose readings, individuals with diabetes can actively manage their condition and reduce the risk of complications. Some challenges associated with SMBG include the inconvenience of finger pricking, the cost of test strips, and the emotional impact of high or low blood glucose readings[17]. However, these challenges were outweighed by the benefits of SMBG in terms of improved glucose control, increased confidence in managing diabetes, and better communication with healthcare professionals [17].

Figure 2.1 Self Monitoring Blood Glucose (SMBG)

2.3.2 Continuous Glucose Monitoring (CGM)

Continuous Glucose Monitoring (CGM) is a technique that provides real-time measurement and monitoring of glucose levels in individuals with diabetes. CGM systems utilize a small sensor inserted under the skin, typically in the abdomen or arm, to measure glucose levels in the interstitial fluid. The sensor continuously records glucose readings throughout the day and night, allowing users to track their glucose levels and trends over time. CGM provides information unattainable by intermittent capillary blood glucose, including instantaneous real-time display of glucose levels, trends, patterns, and alarms for hypo- and hyperglycemia [18]. CGM systems collect and store glucose data in an effort to

provide a more complete picture of glycemic control and to identify patterns and trends in glucose levels that may not be apparent with intermittent glucose monitoring [19]. Furthermore, the challenges associated with CGM implementation are addressed. These challenges include issues related to accuracy and calibration, sensor insertion, data interpretation, and user adherence [18].

Figure 2.2 Type of Continuous Glucose Monitoring

2.3.3 Flash Glucose Monitoring

Flash Glucose Monitoring (FGM) is a type of glucose monitoring system used by individuals with diabetes to monitor their blood sugar levels. FGM provides a continuous and real-time display of glucose levels without the need for traditional fingerstick blood testing. The FGM system consists of a small sensor, usually worn on the back of the upper arm, that measures glucose levels in the interstitial fluid. The sensor is inserted subcutaneously using a small applicator device and remains in place for a specified period, typically 10 to 14 days. Unlike traditional blood glucose monitoring, FGM does not require fingerstick testing. Instead, users can obtain their glucose readings by scanning the sensor with a reader device or a smartphone app. The reader/app provides a graphical representation of glucose levels over time, showing trends, patterns, and historical data. Several studies have demonstrated the efficacy of FGM in improving glucose control and reducing

hypoglycemia in individuals with type 1 diabetes and type 2 diabetes [20] [21]. A randomized pilot study evaluated the efficacy of FGM on glucose control in women with pregestational diabetes and found that FGM was effective in improving glucose control [22]. Another study found that FGM was accepted in daily life of children and adolescents with type 1 diabetes and reduced severe hypoglycemia in real-life uses [20]. It is advisable to consult with healthcare professionals and review the specific devices and technologies available in your region to determine the most suitable glucose monitoring system for your individual needs [16].

Figure 2.3 Flash Glucose Monitoring

2.3.4 Non-Invasive Glucose Monitoring

Non-Invasive Glucose Monitoring (NIGM) refers to the detection of human blood glucose without causing damage to human tissues. NIGM has become an international research topic and a new method that could relieve many patients [23]. There are several methods for non-invasive blood glucose detection, which can be generally divided into optical methods, microwave methods, and electrochemistry and optics in non-invasives [23]. NIGM has several advantages over invasive glucose monitoring, including reduced pain and infections caused by the invasive nature of mainstream commercial glucose meters [23]. However, the accuracy and reliability of NIGM devices are still being evaluated, and it is

important to note that they may not be suitable for all individuals with diabetes, particularly those who require more frequent glucose monitoring or those who have skin sensitivities or allergies to the adhesive used in the sensor [23]. It is advisable to consult with healthcare professionals and review the specific devices and technologies available in your region to determine the most suitable glucose monitoring system for your individual needs [23].

Figure 2.4 Non-Invasive Glucose Monitorin

2.4 Carbon Nanotube-Based Biosensors

Carbon nanotube-based biosensors are advanced devices that utilize the unique properties of carbon nanotubes (CNTs) for the detection and analysis of various biomolecules [24]. Carbon nanotubes are cylindrical structures composed of carbon atoms arranged in a hexagonal lattice. These nanotubes possess exceptional electrical, mechanical, and chemical properties, making them ideal for biosensing applications. The sensing mechanism of carbon nanotube-based biosensors relies on the interaction between the nanotubes and biomolecules such as proteins, DNA, and enzymes [24]. At the nanoscale level, carbon nanotubes can be functionalized with specific receptors or biomolecules, enabling them to selectively bind to target analytes. When the target analyte binds to the nanotubes, it induces changes in their electrical conductivity, optical properties, or

mechanical characteristics [24]. These changes can be measured and quantified, providing a means for detecting and analyzing the target biomolecule.

One common approach in carbon nanotube-based biosensors is the utilization of field-effect transistor (FET) structures. [25]. Carbon nanotubes are integrated into the FET structure, and the binding of target analytes modulates the conductivity of the nanotubes, thereby altering the electrical characteristics of the transistor. This change in conductivity can be correlated with the concentration of the target biomolecule, allowing for sensitive detection [25]. In addition to electrical biosensors, carbon nanotubes also exhibit unique optical properties. They possess strong absorption and emission capabilities, particularly in the near-infrared region. By functionalizing the nanotubes with specific biomolecules, they can be used as fluorescence-based sensors [25]. Binding events between the nanotubes and target analytes cause changes in fluorescence intensity or wavelength, enabling the detection and quantification of the analyte. One of the key advantages of carbon nanotube-based biosensors is their high sensitivity and selectivity. The large surface-to-volume ratio of carbon nanotubes and the ability to functionalize their surfaces with specific recognition elements allow for the detection of biomolecules at very low concentrations. This makes them highly promising tools for medical diagnostics, environmental monitoring, and drug discovery.

Furthermore, carbon nanotube-based biosensors can be integrated into miniaturized devices, offering portability and the potential for point-of-care applications [25]. They can be combined with microfluidics and other technologies to develop lab-on-a-chip systems, enabling rapid and automated analysis of biological samples. This integration and miniaturization enhance the practicality and accessibility of carbon nanotube-based

biosensors for various applications. Ongoing research in the field of carbon nanotube-based biosensors aims to improve their performance, stability, and reproducibility [25]. Researchers are exploring methods to enhance the functionalization of carbon nanotubes, develop novel transduction mechanisms, and integrate multiple sensing modalities into a single device.

Overall, carbon nanotube-based biosensors hold great promise in numerous fields, including disease diagnostics, drug discovery, environmental monitoring, and personalized medicine. Their high sensitivity, selectivity, and versatility make them valuable tools for the detection and analysis of biomolecules, paving the way for advancements in healthcare, biotechnology, and environmental science [25].

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2.5 Thin Film Detectors

Carbon nanotube-based biosensors utilize thin film detectors to enhance their sensing capabilities. These biosensors typically consist of a thin film of carbon nanotubes deposited onto a substrate, such as silicon or glass. The thin film serves as the sensing layer for detecting biological analytes [25].

One common configuration is the field-effect transistor (FET) setup. In this design, the thin film of carbon nanotubes is patterned into source, drain, and gate electrodes on the substrate [25]. The gate electrode is functionalized with specific biomolecules that can selectively bind to the target analyte. When the analyte interacts with the functionalized gate surface, it induces changes in the electrical properties of the carbon nanotubes. These changes result in a measurable electrical signal, which can be detected as a shift in the current

or voltage between the source and drain electrodes. This enables the biosensor to detect and quantify the analyte.

Another approach is the use of thin film detectors for optical sensing. In this configuration, the carbon nanotube thin film acts as a sensing layer for optical detection. By functionalizing the carbon nanotubes with specific biomolecules, they can selectively interact with the target analyte. When the analyte binds to the carbon nanotubes, it induces changes in their optical properties, such as absorbance or fluorescence [25]. These changes can be measured using optical techniques such as spectrophotometry or fluorescence spectroscopy, allowing for the detection and quantification of the analyte [25].

Additionally, thin film detectors can be employed in electrochemical biosensing [3]. Thin films of carbon nanotubes serve as electrodes with high surface area and excellent electrical conductivity. The thin film electrodes can be functionalized with biomolecules that facilitate selective binding to the target analyte. When the analyte binds to the carbon nanotubes, it causes changes in the electrochemical properties, such as current or potential [3]. These changes can be measured using techniques like cyclic voltammetry or amperometry, enabling the detection and quantification of the analyte.

The use of thin film detectors in carbon nanotube-based biosensors offers several advantages. The thin film format provides a large surface area of carbon nanotubes, enhancing the sensitivity of the biosensor [26]. This increased surface area allows for more binding sites, increasing the probability of binding events and improving the detection limit [26].

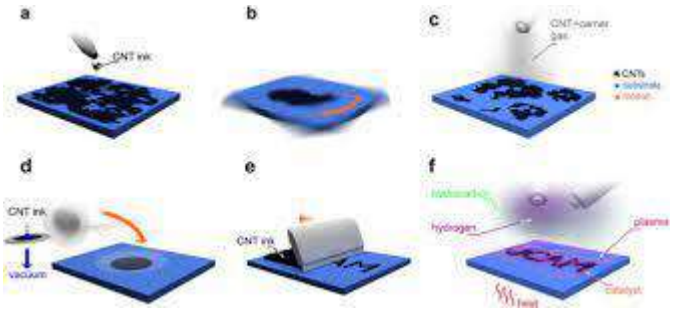

Figure 2.5 Process of Thin Film

Furthermore, the thin film design enables integration with microfluidic systems. By combining the thin film biosensor with microfluidic channels, the sample solution can be precisely directed over the functionalized surface of the carbon nanotubes [26]. This integration enhances the interaction between the analyte and the carbon nanotubes, improving the sensitivity and specificity of the biosensor.

Moreover, the thin film detectors enable miniaturization and portability of the biosensors. The compact size and low weight of the biosensors make them suitable for point-of-care diagnostics and on-site detection applications. They can be easily integrated into portable devices or lab-on-a-chip systems, allowing for real-time monitoring or rapid analysis.

In summary, thin film detectors play a crucial role in carbon nanotube-based biosensors, allowing for the detection and quantification of biological analytes. These detectors can be based on electrical, optical, or electrochemical principles [6]. The thin film format offers advantages such as increased sensitivity, integration with microfluidic systems, and portability, making them highly promising for applications in biomedical diagnostics, environmental monitoring, and food safety [26].

2.6 Immobilization of Glucose on Carboxyl (COOH) Functionalized Carbon Nanotubes (CNTs)

Immobilization is the process of attaching a molecule or a biological compound to a solid surface. In the case of glucose and COOH-CNTs, the immobilization process involves attaching the glucose molecules to the carboxyl groups on the surface of the CNTs. This process allows for the conjugation or bonding of glucose molecules to the CNTs, enabling their interaction and potential utilization in various applications. The COOH functionalization of carbon nanotubes plays a crucial role in immobilizing glucose on carbon nanotubes. The COOH functional groups on the surface of carbon nanotubes provide reactive sites for the immobilization of glucose oxidase (GOx) and other enzymes that recognize glucose. The COOH functionalization can be achieved by treating the carbon nanotubes with strong acids or oxidizing agents, which introduce the COOH groups on the surface of the carbon nanotubes [27]. The COOH functionalized carbon nanotubes can then be used as scaffolds for the immobilization of GOx and other enzymes that recognize glucose [28]. The immobilization of GOx on COOH functionalized carbon nanotubes can improve the sensitivity and selectivity of glucose biosensors based on carbon nanotubes.[29].

Table 2.1 Type of Method Immobilize Glucose on COOH Carbon Nanotube

No.	Type of method immobilize glucose on cooh carbon nanotube	Steps	Advantages	Applications
1.	Coating Glucose Oxidase (GOx) on Carbon Nanotube (CNT) [22]	1. Dispersion of CNTs in a suitable solvent 2. Addition of GOx to form a homogeneous mixture 3. Incubation for enzyme adsorption onto CNT surface 4. Deposition of GOx/CNT composite on an electrode	1. High sensitivity and selectivity 2. Stable and conductive platform for the enzyme 3. Fast response time and efficient electron transfer 4. Prolonged sensor lifetime and enhanced stability	1. Glucose monitoring 2. Diabetes management

2.	Adsorption of Enzymes on CNTs at the Electrode Surfaces [27]	1. Functionalization of CNTs to introduce desired surface chemistry 2. Deposition of functionalized CNTs onto electrode surface 3. Application of enzyme solution onto the modified electrode 4. Adsorption of enzyme on CNTs via non-covalent interactions	1. Enhanced sensitivity and response time 2. Efficient electron transfer between enzyme and electrode 3. 3. Preserves enzyme activity and stability	1. Gene analysis 2. disease monitoring 3. drug discovery
3.	Covalent Immobilization of GOx on CNT Nanoelectrode Ensembles via Carbodiimide Chemistry [29]	1. Functionalization of CNTs with carboxyl groups 2. Mixing of COOH-functionalized CNTs with GOx in a solvent 3. Reaction between carboxyl groups and amine groups of GOx	1. Stable and long-term enzyme attachment 2. Direct electron transfer and improved biosensor performance	1. Glucose Biosensing 2. Diabetes Management

			3. Strong attachment preventing enzyme leaching or detachment	
4.	Covalently Linking of a CNT-Chitosan Nanocomposite with Ferrocene-Grafted Dendrimer [30]	1. Preparation of CNT-chitosan nanocomposite 2. Covalent linkage of ferrocene-grafted dendrimer to nanocomposite 3. Electron mediation between immobilized GOx and electrode	1. Enhanced sensitivity and stability 2. Efficient electron transfer and improved response 3. Durable connection for repeated and prolonged use	1. Glucose Biosensors
5.	Covalent Immobilization of Glucose on COOH CNTs using Glutaraldehyd [31]	1. Functionalization of CNTs with carboxyl groups 2. Mixing of COOH-functionalized CNTs with glucose solution	1. Stable and long-term immobilization of glucos	1. Glucose biosensors 2. Biomedical research

		3. Addition of glutaraldehyde to cross-link glucose and CNTs	2. Covalent bonding between glucose and CNT via glutaraldeheyde 3. Enhanced stability and prevention of glucose leaching	
6.	COOH-terminated CNTs immobilized with Glucose using EDC/NHS [32]	1. Carboxylation of CNTs with acid 2. Reacting carboxylated CNTs with EDC and NHS in the presence of glucose	1. Reliable and efficient immobilization method 2. High yields of immobilized glucose 3. Short reaction time 4. Enhanced stability of immobilized glucose 5. Specific detection of glucose	1. Glucose sensing and monitoring 2. Biomedical diagnostics 3. Point of care tenting 4. Biosensing applications

2.6.1 Coating Glucose Oxidase (GOx) on Carbon Nanotube (CNT)

Coating glucose oxidase (GOx) on carbon nanotubes (CNTs) offers a promising approach for the development of highly sensitive and selective glucose biosensors [22]. Glucose oxidase is an enzyme that specifically catalyzes the oxidation of glucose, producing hydrogen peroxide (H2O2) as a by product [22]. By immobilizing GOx on the surface of CNTs, the CNTs act as a supporting matrix, providing a stable and conductive platform for the enzyme.

The process of coating GOx on CNTs involves the dispersion of CNTs in a suitable solvent, followed by the addition of GOx to form a homogeneous mixture. The CNTs can be functionalized with carboxyl (-COOH) groups to enhance the interaction with the enzyme [22]. The mixture is typically incubated under controlled conditions, allowing the enzyme to adsorb or attach onto the CNT surface through non-covalent interactions, such as electrostatic forces and π-π stacking [22].

Once immobilized, the GOx/CNT composite can be integrated into a biosensor configuration. The biosensor usually consists of an electrode, such as a glassy carbon electrode or a screen-printed electrode, onto which the GOx/CNT composite is deposited [22]. The immobilized GOx catalyzes the oxidation of glucose, producing gluconic acid and generating H_2O_2 as a byproduct. The H_2O_2 can be electrochemically detected at the electrode surface [22].

In the presence of glucose, the enzymatic reaction occurs, resulting in the production of H_2O_2 in direct proportion to the glucose concentration. The generated H_2O_2 can be

detected electrochemically using various methods, such as amperometry or voltammetry. The resulting current or signal is then measured, providing a quantitative representation of the glucose concentration in the sample [22].

The coating of GOx on CNTs enhances the biosensor's performance in several ways. The CNTs not only provide a high surface area for enzyme immobilization but also offer excellent electrical conductivity, facilitating efficient electron transfer between the enzyme and the electrode. This direct electron transfer pathway improves the sensitivity and response time of the biosensor [22].

Additionally, the CNTs can protect the immobilized enzyme from denaturation and provide a stable environment for its activity, leading to prolonged sensor lifetime and enhanced stability. The unique properties of CNTs, such as their mechanical strength and biocompatibility, further contribute to the overall robustness of the biosensor.

In summary, the coating of glucose oxidase on carbon nanotubes provides a highly sensitive and selective platform for glucose detection. The immobilized enzyme catalyzes the oxidation of glucose, generating a measurable current or signal that is proportional to the glucose concentration. This approach combines the unique properties of CNTs with the specificity of the enzyme, enabling the development of advanced glucose biosensors for various applications, including diabetes management.

2.6.2 Adsorption of Enzymes on CNTs at the Electrode Surfaces

Adsorption of enzymes, such as glucose oxidase (GOx), on carbon nanotubes (CNTs) at the electrode surfaces offers a highly effective method for immobilizing the enzyme and developing glucose biosensors with enhanced sensitivity. The process involves the utilization of CNT-modified electrodes, which provide a large surface area and excellent electrical conductivity, facilitating the adsorption of the enzyme [27].

To begin, CNTs are typically functionalized to introduce desired surface chemistry, such as carboxyl (-COOH) groups, which enhance the interaction between the CNTs and the enzyme. The functionalized CNTs are then deposited onto the electrode surface, creating a CNT-modified electrode [27].

Next, the enzyme solution, in this case, GOx, is applied to the modified electrode. The adsorption process occurs as the enzyme molecules attach to the surface of the CNTs via non-covalent interactions, including electrostatic forces, hydrogen bonding, and π-π stacking interactions [27]. The CNTs serve as an anchoring matrix, providing a stable environment for the immobilized enzyme.

Once the enzyme is adsorbed onto the CNT-modified electrode, it remains in close proximity to the electrode surface, allowing for direct electron transfer between the enzyme and the electrode [27]. This direct electron transfer pathway enhances the sensor's sensitivity, as it eliminates the need for additional mediators or redox agents to facilitate electron transfer.

In the presence of glucose, the adsorbed GOx catalyzes the oxidation of glucose, leading to the production of hydrogen peroxide (H_2O_2) as a byproduct [27]. The H_2O_2 can be electrochemically detected at the electrode surface [27]. Depending on the biosensor configuration, different electrochemical techniques, such as amperometry or voltammetry, can be employed to measure the resulting electrical signal.

The adsorption of GOx on CNTs at the electrode surfaces provides several advantages for glucose biosensing. The high surface area of the CNTs allows for a larger number of enzyme molecules to be immobilized, increasing the sensitivity of the biosensor [27]. The good electrical conductivity of the CNTs ensures efficient electron transfer between the enzyme and the electrode, improving the response time and overall performance of the biosensor.

Moreover, the adsorption method preserves the enzyme's activity and stability, as the immobilized enzyme retains its native conformation and functionality. The proximity of the enzyme to the electrode surface enables rapid electron transfer, leading to a fast and accurate glucose detection.

In summary, the adsorption of enzymes, such as GOx, on CNT-modified electrodes provides an effective approach for the immobilization of enzymes and the development of glucose biosensors with enhanced sensitivity [27]. The CNTs' high surface area and excellent electrical conductivity facilitate enzyme adsorption and direct electron transfer, resulting in a measurable electrical signal proportional to the glucose concentration. This method offers a versatile and reliable platform for glucose monitoring applications in various fields, including diabetes management.

2.6.3 Covalent Immobilization of GOx on CNT Nanoelectrode Ensembles via Carbodiimide Chemistry

Covalent immobilization of glucose oxidase (GOx) on carbon nanotube (CNT) nanoelectrode ensembles through carbodiimide chemistry is a robust method for creating glucose biosensors with stable and long-term enzyme attachment [29]. Carbodiimide chemistry involves the use of a coupling agent, such as N, N'-dicyclohexylcarbodiimide (DCC), to facilitate the covalent binding between the enzyme and the CNTs [29].

To initiate the process, CNTs are functionalized with carboxyl (-COOH) groups on their surfaces, which provide reactive sites for subsequent covalent bonding. This functionalization can be achieved by various methods, including oxidation or acid treatment. The resulting COOH-functionalized CNTs are then mixed with GOx in a suitable solvent [29].

In the presence of the coupling agent, such as DCC, the carboxyl groups of the CNTs react with the amine groups present on the GOx enzyme. The DCC acts as a mediator, facilitating the formation of stable amide bonds between the carboxyl groups on the CNTs and the amine groups of the enzyme. This covalent bonding ensures a strong and durable attachment of GOx to the CNTs, preventing enzyme leaching or detachment during biosensor use [29].

The carbodiimide chemistry-based covalent immobilization method offers several advantages [29]. Firstly, it provides a reliable and long-lasting binding between the enzyme and the CNTs, enabling repeated and extended use of the biosensor without a significant loss

of enzyme activity. The stable attachment also enhances the biosensor's overall robustness and sensitivity.

Furthermore, this covalent immobilization approach facilitates direct electron transfer between the immobilized enzyme and the CNT nanoelectrode ensembles, leading to enhanced electrochemical signal transduction [29]. The high electrical conductivity of CNTs and the close proximity between GOx and the electrode surface promote efficient electron transfer, resulting in improved biosensor performance and sensitivity.

Covalent immobilization of GOx on CNT nanoelectrode ensembles via carbodiimide chemistry provides a versatile platform for the development of glucose biosensors [29]. The strong attachment of the enzyme to the CNTs ensures stability and longevity, while the direct electron transfer enables rapid and accurate glucose detection. This method finds applications in glucose monitoring for diabetes management, as well as in other fields where precise glucose measurements are necessary.

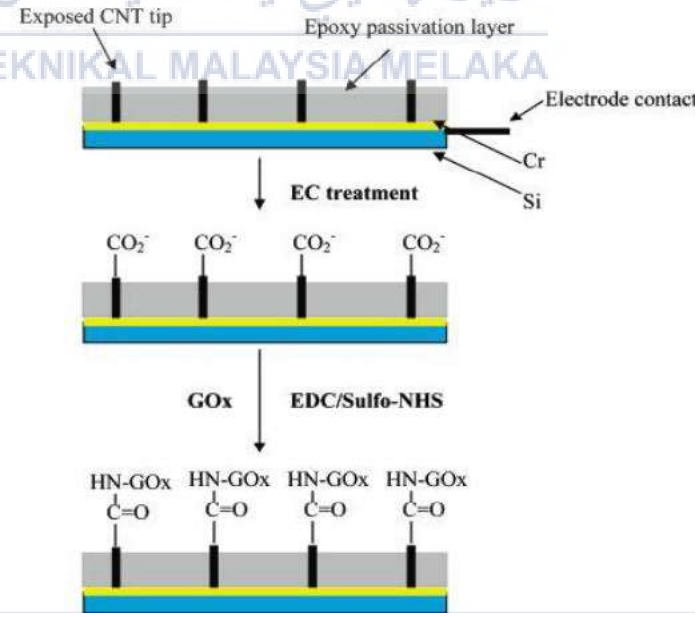

Figure 2.6 Coupling of the enzyme (GOx) to the functional CNT NEEs

2.6.4 Covalently Linking of A Carbon Nanotube (CNTs)-Chitosan (CS) Nanocomposite

Covalently linking a ferrocene-grafted dendrimer to the surface of a carbon nanotube (CNT)-chitosan (CS) nanocomposite modified electrode is a strategy that enhances the sensitivity and stability of glucose biosensors [30]. The method involves the utilization of a dendrimer molecule that has been functionalized with ferrocene, a redox-active compound capable of facilitating direct electron transfer [30].

To begin, a CNT-chitosan nanocomposite is prepared, providing a supporting matrix for the immobilization of the dendrimer and subsequent enzyme attachment. The CNTs offer a high surface area and excellent electrical conductivity, while chitosan provides biocompatibility and stability [30].

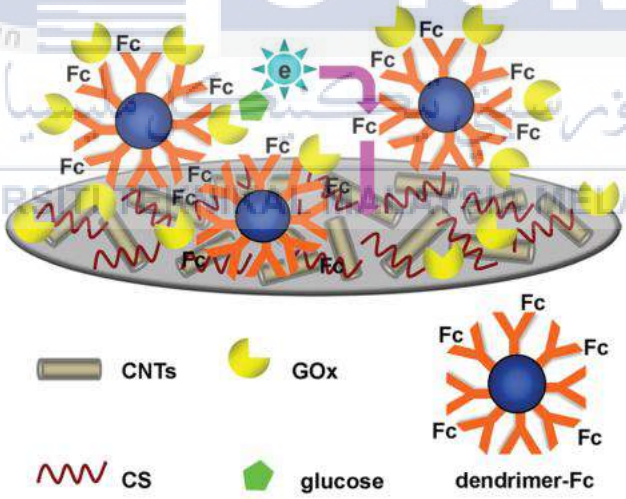

Figure 2.7 The detection strategy of the glucose biosensor

Next, the ferrocene-grafted dendrimer is covalently linked to the surface of the nanocomposite-modified electrode [30]. The covalent linkage is typically achieved using

suitable coupling chemistries, such as amide or ester formation, to form stable bonds between the dendrimer and the nanocomposite.

Once the ferrocene-grafted dendrimer is attached to the nanocomposite-modified electrode, it acts as an electron mediator between the immobilized glucose oxidase (GOx) enzyme and the electrode surface [30]. The redox-active nature of ferrocene allows for efficient and direct electron transfer between the enzyme and the electrode, enhancing the sensitivity and response of the biosensor.

In the presence of glucose, the immobilized GOx catalyzes the oxidation of glucose, leading to the production of hydrogen peroxide (H_2O_2) [30]. The generated H_2O_2 can be electrochemically detected by the electrode, with the ferrocene in the dendrimer serving as the redox-active species [30]. This direct electron transfer pathway enables rapid and sensitive detection of glucose concentrations.

The covalent linking of ferrocene-grafted dendrimers to the CNT-chitosan nanocomposite modified electrode offers several advantages. Firstly, the presence of ferrocene improves the electron transfer kinetics between the enzyme and the electrode, resulting in enhanced biosensor performance [30]. This allows for a more accurate and rapid detection of glucose levels.

Additionally, the covalent attachment provides stability to the biosensor by ensuring a durable connection between the dendrimer, nanocomposite, and enzyme. This stability allows for repeated and prolonged use of the biosensor without significant loss of enzyme activity or detachment of components.

In summary, the covalent linking of ferrocene-grafted dendrimers to the CNT-chitosan nanocomposite modified electrode is a method that enhances the sensitivity and stability of glucose biosensors. The direct electron transfer facilitated by the presence of ferrocene improves the biosensor's performance, while the covalent attachment ensures long-term functionality. This approach holds promise for the development of highly efficient and reliable biosensors for glucose monitoring in various applications, including diabetes management.

2.6.5 Covalent Immobilization of Glucose on COOH CNTs immobilized Using Glutaraldehyde

Glutaraldehyde (GA) is a dialdehyde that can be used to covalently immobilize biomolecules on the surface of carbon nanotubes (CNTs) [31]. The reaction between GA and a carboxylic acid group on the CNT is a two-step process. In the first step, GA reacts with the carboxylic acid group to form a Schiff base. In the second step, the Schiff base is reduced to form a stable imine bond [31]. This method can be used to immobilize glucose on COOH-terminated CNTs. The first step is to functionalize the CNTs with carboxyl groups. This can be done by treating the CNTs with an acid, such as nitric acid or sulfuric acid. Once the CNTs are carboxylated, they can be reacted with GA in the presence of glucose [31].

The reaction between GA and carboxylic acid groups is relatively mild and can be carried out at room temperature. The reaction time is typically short, on the order of minutes. The reaction is also very efficient, with high yields of immobilized biomolecules. The method of immobilizing glucose on COOH-terminated CNTs using GA is a well-established

technique that has been used in a number of studies [31]. It is a reliable and efficient method for immobilizing biomolecules on the surface of CNTs.

2.6.6 COOH-terminated CNTs immobilized with Glucose using EDC/NHS

COOH-terminated carbon nanotubes have emerged as promising materials for various applications, including bio-sensing, drug delivery, and catalysis. One specific area where COOH-terminated CNTs have shown great potential is in the immobilization of glucose using EDC/NHS chemistry [32]. COOH-terminated CNTs possess several desirable properties that make them suitable for immobilization of glucose. Firstly, COOH-terminated CNTs have significant mechanical strength, allowing them to withstand various processing steps and provide a stable platform for immobilization of biomolecules [32].

Secondly, COOH-terminated CNTs have a high surface area, which provides ample opportunities for glucose molecules to interact with the CNT surface and be effectively immobilized. Furthermore, COOH-terminated CNTs exhibit excellent electrical conductivity, which can facilitate efficient electron transfer between immobilized glucose and the electrode surface [33]. In the immobilization of glucose using EDC/NHS chemistry, EDC (1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride) and NHS are commonly used as coupling agents to covalently link the COOH-terminated CNTs with glucose [34].

This covalent immobilization strategy involves activating the carboxyl groups on the COOH-terminated CNTs using EDC, which reacts with the carboxyl groups to form an O-acylisourea intermediate. Next, NHS is added to the reaction mixture to stabilize the

intermediate and enhance the efficiency of coupling between the COOH-terminated CNTs and glucose. The resulting O-acylisourea intermediate undergoes a nucleophilic attack by the amino group present in glucose, leading to the formation of an amide bond between the COOH-terminated CNTs and glucose. The covalent immobilization of glucose onto COOH-terminated CNTs using EDC/NHS chemistry offers several advantages over other methods, such such as physical adsorption or cross-linking with glutaraldehyde [35].

2.7 Oxidation in Carbon Nanotubes for Glucose Detection

Carbon nanotubes (CNTs) are a promising material for the development of highly sensitive and selective biosensors for glucose detection. CNTs have a large surface area and high electrical conductivity, which makes them ideal for electrochemical sensing applications [36]. Glucose can be oxidized by CNTs to produce electrons, which can be detected using electrochemical methods.

The oxidation of glucose on CNTs is a complex process that involves several steps. First, glucose molecules must adsorb onto the surface of the CNTs. Once adsorbed, the glucose molecules are oxidized by the CNTs, producing electrons and hydrogen peroxide. The electrons can be detected using electrochemical methods, such as amperometry or cyclic voltammetry. The hydrogen peroxide can be detected using methods such as fluorescence or chemiluminescence [37].

The oxidation of glucose on CNTs is a sensitive process, and the sensitivity can be further improved by functionalizing the CNTs with other molecules, such as enzymes or nanoparticles. For example, CNTs can be functionalized with glucose oxidase (GOx), which is an enzyme that catalyzes the oxidation of glucose. The GOx-functionalized CNTs can

then be used to develop biosensors that can detect glucose concentrations in the nanomolar range [38].

Glucose detection using oxidation in carbon nanotubes offers several advantages. It enables highly sensitive detection of glucose at nanomolar concentrations, while the selective functionalization of carbon nanotubes ensures reduced risk of false positives. These nanotubes exhibit stability in diverse environments, making them suitable for long-term monitoring applications. Moreover, carbon nanotubes are cost-effective due to their relative affordability. However, challenges lie in improving stability, reducing costs, and enhancing reproducibility [39]. Overcoming these obstacles holds the potential for widespread adoption of carbon nanotube-based glucose detection, ultimately benefiting medical diagnostics and monitoring.

Oxidation in carbon nanotubes for glucose detection is a promising technology with the potential to revolutionize the way glucose is monitored in people with diabetes. However, there are still some challenges that need to be addressed before this technology can be widely adopted. With continued research and development, oxidation in carbon nanotubes for glucose detection has the potential to become a standard method for glucose monitoring in the future [40].

2.8 Reduction in Carbon Nanotubes for Glucose Detection

Reduction in carbon nanotubes (CNTs) for glucose detection is a promising method for developing highly sensitive and selective biosensors. CNTs have a large surface area and high electrical conductivity, which makes them ideal for electrochemical sensing applications [41]. Glucose can be reduced by CNTs to produce electrons, which can be detected using electrochemical methods [41].

The reduction of glucose on CNTs is a complex process that involves several steps. The first step is the adsorption of glucose molecules onto the surface of the CNTs. The glucose molecules are then reduced by the CNTs, producing electrons and hydrogen gas [41]. The electrons can be detected using electrochemical methods, such as amperometry or cyclic voltammetry. The hydrogen gas can be detected using methods such as thermal conductivity or mass spectrometry [41].

The reduction of glucose on CNTs is a sensitive process, and the sensitivity can be further improved by functionalizing the CNTs with other molecules, such as enzymes or nanoparticles. For example, CNTs can be functionalized with glucose dehydrogenase (GDH), which is an enzyme that catalyzes the reduction of glucose. The GDH-functionalized CNTs can then be used to develop biosensors that can detect glucose concentrations in the nanomolar range [41].

Reduction in carbon nanotubes for glucose detection presents several advantages, including high sensitivity, selectivity, stability, and cost-effectiveness. The utilization of carbon nanotubes allows for the detection of glucose at nanomolar concentrations

with remarkable sensitivity, while their selective functionalization reduces the likelihood of false positives [41].

Reduction in carbon nanotubes for glucose detection is a promising technology with the potential to revolutionize the way glucose is monitored in people with diabetes. However, there are still some challenges that need to be addressed before this technology can be widely adopted. With continued research and development, reduction in carbon nanotubes for glucose detection has the potential to become a standard method for glucose monitoring in the future.

2.9 Challenges and Limitations

CNTs represent a highly fascinating area within the field of materials sciences, with significant implications for bioengineering and biomedical applications, particularly in the realm of biomolecule detection. This review aims to shed light on the recent advancements in CNT-based biosensors, which have been rapidly evolving. Despite the remarkable progress made in this domain, several challenges persist, which can be categorized into five key aspects.

The first challenge revolves around cost-effectiveness. The high costs associated with CNT materials and CNT-based enzymatic biosensors pose significant obstacles that hinder their widespread adoption and development [42]. Addressing this challenge necessitates a comprehensive approach that combines materials research and nanotechnology. Some research groups have begun exploring non-enzymatic sensors based on CNTs as a potential alternative, while novel nanotechnologies like nanoimprint lithography and soft lithography offer additional avenues for progress [43].

The second challenge pertains to the thermal stability and lifespan of CNT-based biosensors under various ambient conditions, such as temperature and pH. Prolonging the durability and stability of these sensors represents a primary concern for researchers. One potential solution lies in the use of nanocomposite materials, which can replace costly and fragile enzymes in target molecule detection. Nanocomposites demonstrate improved properties, including thermal tolerance, long-term stability, and cost effectiveness. Moreover, studies have shown that combining nanocomposite materials with CNTs and metals (such as Au and Pt) significantly enhances sensitivity and detection limits in biosensors.

As the sustainable development of new nanomaterials in conjunction with CNTs progresses, characterizing these materials at the molecular level becomes crucial and poses a key scientific challenge. Alongside experimental studies, molecular modeling must be further developed as a predictive tool to evaluate the performance of new materials in relation to biomolecules. Computational methods facilitate rapid material assessment, ultimately leading to a comprehensive understanding of structure-function relationships, thereby supporting and guiding experimental efforts toward the most promising structures with enhanced biosensing capabilities.

Furthermore, CNT-based optical biosensors have displayed unique characteristics and have been widely investigated. Similarly, CNT fibers possess higher specific modulus strength and offer simplified fabrication processes [44]. These fibers can be employed as DNA probes for the detection of DNA molecules and their incorporation into gene vector therapy. Consequently, the fabrication of novel CNT-based optical

biosensors and the synthesis of new CNT fibers remain focal points for future research in the field of biosensing.

Undoubtedly, the development of CNT-based biosensors represents a multifaceted and challenging endeavor that necessitates fruitful collaboration between materials scientists, focused on developing novel materials, and engineers dedicated to fabricating micro/nanodevices, including bionanosensors. Consequently, the ultimate challenge lies in establishing a collaborative platform that facilitates efficient discussions, learning, and cooperation among physicists, chemists, and electrical/mechanical engineers.

2.10 Prevoius Recent Projects.

In order to enhance and address the limitations of the new project, various previous projects were selected that employed different techniques, software, technologies, and equipment. Table 2.1 provides an overview of recent studies in the field of biosensors for glucose detection, which will be discussed in this section. These technologies and their applications will be elaborated upon to generate a conceptual framework for improving and overcoming the drawbacks associated with the new project.

Table 2.2 Comparison between glucose biosensors from previous research

No	Author	Title	Year	Descriptions	Findings
1.	[45]	Glucose biosensor prepared by glucose oxidase encapsulated sol-gel and carbon-nanotube-modified basal plane pyrolytic graphite electrode.	2004	The development of a highly sensitive and stable glucose biosensor using sol-gel encapsulation and carbon nanotube modification techniques. The study demonstrates improved glucose detection capabilities and highlights the potential for advanced biosensors in biomedical and clinical applications.	The present carbon nanotube sol-gel biocomposite glucose oxidase sensor showed excellent properties for the sensitive determination of glucose with good reproducibility, remarkable stability, and rapid response and in comparison to bulk modified composite biosensors the amounts of enzyme and carbon nanotube needed for electrode fabrication are dramatically decreased.
2.	[46]	Hierarchical Co(OH)2 nanotube	2017	The development of Co(OH)2 nanotube arrays on carbon cloth as a means of non-enzymatic glucose	Benefiting from the hierarchical structure of nanotube arrays and 3D self-supported construction,

		arrays grown on carbon cloth for use in non-enzymatic glucose sensing		sensing. The study explores the electrochemical properties of these nanotube arrays and their potential application in glucose detection without the use of enzymes. The findings contribute to the advancement of glucose sensing technologies, offering a promising alternative for accurate and enzyme-free glucose monitoring..	Co(OH)2 NTAs/CC shows high performance for non-enzymatic glucose sensing with a wide linear range from 1 μM to 0.6 mM, a remarkable sensitivity of 2.77 mA mM−1 cm−2, a low detection limit of 0.5 μM (S/N = 3), a good selectivity against common interferents, and a reliability for glucose detection in human serum samples.
3.	[47]	Facile Preparation of Nickel Nanoparticle-Modified Carbon Nanotubes with Application as a Nonenzymatic	2016	The development of a nonenzymatic electrochemical glucose sensor using nickel nanoparticle-modified carbon nanotubes. The study presents a straightforward method for preparing the sensor and evaluates its effectiveness in detecting glucose without the use of enzymes. The findings contribute to the advancement of	Consequently, the modified carbon nanotubes were shown to be a suitable enzyme-free glucose electrochemical sensor when attached to a glassy carbon electrode, with excellent long term stability, a short response time, a low limit of detection, a long linear dynamic range, high sensitivity, and good precision

		Electrochemical Glucose Sensor		glucose sensing technologies and have potential implications in various fields such as healthcare and diagnostics.	
4.	[29]	An ECL biosensor for glucose based on carbon-nanotube/Nafion film modified glass carbon electrode	2008	The research focuses on modifying a glass carbon electrode with a film consisting of carbon nanotubes and Nafion. The biosensor's performance and its ability to detect glucose through ECL signals are investigated. The findings contribute to the advancement of glucose biosensing technology and highlight the potential of carbon nanotube-based films in enhancing sensor capabilities.	The present carbon-nanotube/Nafion biocomposite glucose oxidase ECL biosensor showed excellent properties for sensitive determination for glucose with good reproducibility and stability, and it has been used to determine the glucose concentrations in real serum samples with the satisfactory results
5.	[48]	Adsorption of Glucose Molecule onto Platinum-	2015	Nanotubes and Carbon Nanostructures investigates the adsorption behavior of glucose molecules on platinum-decorated single-walled carbon	Pt-decorated carbon nanotube is expected to be a novel material for enhancing the fabrication of glucose biosensors.

		Decorated Single-Walled Carbon Nanotubes: A Dispersion-Corrected DFT Simulation		nanotubes. The study employs dispersion-corrected density functional theory (DFT) simulations to understand the interaction between glucose and the nanotube surface. The findings provide valuable insights into the molecular-level adsorption mechanism and its implications for glucose sensing and related applications	
6	[49]	Functional carbon nanotube material-based enzyme biosensors for glucose sensing	2005	Preliminary results show purified carbon nanotubes electrodes exhibit better electrochemical performance for glucose detection, compared with other nanotube based electrodes.	The journal investigates he use of carbon nanotube materials in the development of enzyme biosensors for glucose detection. The study explores the integration of carbon nanotubes with enzymes to create highly sensitive and selective biosensors. The findings emphasize the potential of carbon nanotube-based materials in advancing glucose sensing

					technology and contribute to the development of innovative biosensor applications.
7.	[50]	Soluble functionalized carbon nanotube/poly(vinyl alcohol) nanocomposite as the electrode for glucose sensing	2006	The journal investigates the use of a soluble functionalized carbon nanotube/poly(vinyl alcohol) nanocomposite as an electrode for glucose sensing. The study aims to enhance the performance of glucose sensors by developing an innovative nanocomposite material.	The potential of this nanocomposite electrode in advancing glucose sensing technology and contribute to the field of smart materials and structures.
8.	[51]	Electrochemical Glucose Biosensor of Platinum Nanospheres Connected by	2010	The study introduces a novel approach using platinum nanospheres connected by carbon nanotubes to enhance glucose detection. The findings emphasize the potential of this biosensor in improving glucose monitoring for diabetes	The GOX-CNT/Pt nanosphere biosensor outperforms similar CNT, metallic nanoparticle, and more conventional carbon-based biosensors in terms of glucose sensitivity and detection limit.

		Carbon Nanotubes. Journal of Diabetes Science and Technology.		management. The research contributes to the field of diabetes science and technology, offering promising advancements in glucose sensing technologies.	
9.	[52]	A High-Resolution Amperometric Acetylcholine Sensor Based on Nano-Assembled Carbon Nanotube and Acetylcholinesterase Thin Films	2007	The journal presents a study on the development of a high-resolution amperometric acetylcholine sensor. The sensor utilizes nano-assembled carbon nanotube and acetylcholinesterase thin films to achieve enhanced detection capabilities. The findings highlight the potential of this sensor in achieving accurate and sensitive measurements of acetylcholine. The research contributes to the field of nano research, offering advancements in the development of biosensors for neurotransmitter detection.	Due to its high resolution, fast response, small size, and low cost, the carbon nanotube biosensor has tremendous potential for applications in medical research and clinical diagnosis.

10.	[53]	Study of carbon nanotube modified biosensor for monitoring total cholesterol in blood.	2005	The journal investigates the application of carbon nanotube modified biosensors for monitoring total cholesterol in blood. The study focuses on the development and evaluation of a biosensor that utilizes carbon nanotubes to enhance the detection of cholesterol levels. This research contributes to the field of biosensors and bioelectronics, offering advancements in the detection and monitoring of cholesterol-related conditions.	Experimental results show that the carbon nanotube modified biosensor offers a reliable calibration profile and stable electrochemical properties.
11.	[54]	Electrochemical Biosensing Platform Using Carbon Nanotube Activated Glassy Carbon Electrode	2007	The journal presents a study on the development of an electrochemical biosensing platform. The study focuses on utilizing a carbon nanotube activated glassy carbon electrode to enhance the performance of biosensors. This research contributes to the field of electroanalysis, offering advancements in the	These observations suggest that the carbon nanotube activated glassy carbon electrode could be utilized as a very sensitive and stable biosensor for some specific biological process

				development of biosensing technologies for various applications.	
12.	[55]	Size-controlled synthesis of Cu2O nanoparticles on reduced graphene oxide sheets and their application as non-enzymatic glucose sensor materials	2015	The journal presents a study on the synthesis of Cu2O nanoparticles on reduced graphene oxide sheets. The research focuses on controlling the size of the nanoparticles and exploring their potential as non-enzymatic glucose sensor materials. This study contributes to the field of solid-state electrochemistry, providing insights into the development of advanced glucose sensor materials for biomedical applications.	The proposed biosensor can be applied to the quantification of glucose with a high sensitivity and durability, wide linear range, a low detection limit of 0.1 μM, and ease of construction, thus is promising for the future development of non-enzymatic glucose sensors.
13.	[56]	Immobilization of Glucose Oxidase on a	2017	The article oxidase on a carbon nanotubes/dendrimer-ferrocene modified electrode for reagentless glucose biosensing. The authors used a ferrocene-grafted dendrimer that was	The results showed that the biosensor performed well in detecting glucose without the need for additional reagents. The modification of the electrode using carbon nanotubes and dendrimer-

		Carbon Nanotubes/Dendrimer-Ferrocene Modified Electrode for Reagentless Glucose Biosensing		covalently linked to the surface of a carbon nanotubes (CNTs)-chitosan (CS) nanocomposite modified electrode for immobilizing glucose oxidase. The resulting biosensor showed good sensitivity and selectivity for glucose detection. The article suggests that this method could be useful for developing glucose biosensors for clinical applications.	ferrocene significantly enhanced the stability and electrochemical properties of the electrode. Furthermore, the immobilized enzyme retained its catalytic activity and exhibited good sensitivity for glucose detection. Overall, the successful immobilization of glucose oxidase on a carbon nanotubes/dendrimer-ferrocene modified electrode demonstrated the potential for reagentless glucose biosensing. This development holds promise for applications such as continuous glucose monitoring and other biomedical sensing applications.
14.	[57]	Non-enzymatic glucose sensor based on ZnO–CeO2 whiskers	2020	The research focuses on utilizing ZnO-CeO2 whiskers as the sensing material for glucose detection. The findings highlight the potential of this sensor in achieving accurate and sensitive	These results indicate that such non-enzymatic sensor based on nanocomposites could be an ideal method for detection of glucose.

				measurements of glucose without the need for enzymes. This study contributes to the field of materials chemistry and physics, offering advancements in the development of non-enzymatic sensors for glucose monitoring and other biomedical applications.	
15.	[24]	Platinum nanoparticles functionalized nitrogen doped graphene platform for sensitive electrochemical glucose biosensing	2015	The research described in the paper focuses on the development of a sensitive electrochemical biosensor for glucose detection. The biosensor utilizes a platform composed of nitrogen-doped graphene functionalized with platinum nanoparticles. The combination of these materials aims to enhance the sensitivity and performance of the biosensor.	The proposed glucose biosensor also demonstrated excellent selectivity, good reproducibility, acceptable stability, and could be successfully applied in the detection of glucose in serum samples at the applied potential of -0.33 V. This research provided a promising biosensing platform for the development of excellent electrochemical biosensors

16.	[17]	Self-monitoring of blood glucose in insulin-treated diabetes: a multicase study	2018	The multicase study involved interviewing and analyzing the data from 16 individuals with type 1 or type 2 diabetes who were using insulin therapy and regularly performing SMBG. The participants were from different age groups and had varying experiences with diabetes management.The study found that self-monitoring of blood glucose was perceived by the participants as an essential tool for diabetes self-management. It provided them with immediate feedback on their blood glucose levels and allowed them to make timely adjustments to their insulin doses, diet, and physical activity. SMBG helped the participants gain a better understanding of how their bodies responded to	The study concluded that self-monitoring of blood glucose played a significant role in the daily lives of individuals with insulin-treated diabetes. It facilitated personalized diabetes management, empowered individuals to make informed decisions, and improved their overall well-being. The findings highlighted the importance of ongoing support, education, and access to appropriate resources to optimize the use of SMBG and enhance diabetes self-management.

				different factors and empowered them to take control of their diabetes management.	
17.	[18]	Continuous Glucose Monitoring: A Review of Successes, Challenges, and Opportunities	2016	The author discusses the benefits of CGM in providing real-time glucose measurements, enabling individuals with diabetes to make informed decisions about their treatment, diet, and lifestyle choices. The article emphasizes the potential of CGM to improve glycemic control, reduce hypoglycemia, and enhance overall diabetes management	The article also explores the opportunities for further advancements in CGM technology. It discusses the potential for improved accuracy, longer sensor wear, better user experience, and integration of CGM with insulin delivery systems. The author emphasizes the need for ongoing research and development to enhance CGM capabilities and expand its application in various populations and clinical settings
18.	[19]	Continuous Glucose Monitoring: A Review for Behavioral Researchers	2012	This article discusses continuous glucose monitoring (CGM), a method used to monitor blood glucose levels continuously in individuals with diabetes. It provides an overview of CGM technology, its benefits and limitations, and its	The finding from the article is that while the use of continuous glucose monitoring (CGM) in behavioral research is increasing, only a small number of behavioral researchers are currently utilizing CGM. CGM is primarily being used to investigate basic

				potential impact on diabetes management and psychosocial well-being. The study likely explores the psychological and emotional aspects of living with diabetes and using CGM as a tool for self-management.	biobehavioral processes, assess the effects of behavioral interventions on diabetes control, and utilize CGM itself as a behavior modification and teaching tool in diabetes self-management interventions.
19.	[20]	Flash Glucose Monitoring Accepted in Daily Life of Children and Adolescents with Type 1 Diabetes and Reduction of Severe Hypoglycemia in Real-Life Use	2019	The benefits of FGM is its ability to provide real-time glucose data and trend analysis. This allows individuals and their healthcare providers to have a better understanding of their glucose patterns and make informed decisions regarding diabetes management. By identifying trends and fluctuations, FGM can help optimize insulin dosing, adjust diet and exercise, and prevent hypoglycemic or hyperglycemic episodes.	FGM has been shown to have several advantages in the daily lives of children and adolescents with type 1 diabetes. It provides continuous glucose monitoring without the need for frequent fingerstick testing, which can improve convenience and reduce the discomfort associated with traditional monitoring methods.

20.	[21]	Efficacy of flash glucose monitoring in pregnant women with poorly controlled pregestational diabetes (FlashMom): A randomized pilot study	2021	The study titled "Efficacy of flash glucose monitoring in pregnant women with poorly controlled pregestational diabetes (FlashMom): A randomized pilot study" by Tumminia et al. (2021) likely aimed to investigate the effectiveness of FGM in pregnant women with pregestational diabetes who had poor glycemic control. The study design was randomized, meaning participants were assigned randomly to different groups to compare the outcomes. In general, FGM can offer several benefits during pregnancy for women with diabetes. Continuous glucose monitoring provided by FGM systems allows for real-time monitoring of glucose levels,	Managing blood glucose levels during pregnancy is crucial for the health of both the mother and the developing fetus. Traditional glucose monitoring methods, such as fingerstick testing, can be burdensome and may not provide a comprehensive view of glucose patterns throughout the day and night.FGM offers continuous glucose monitoring without the need for frequent fingerstick testing, which can provide valuable insights into glucose fluctuations and trends in pregnant women with diabetes. It allows for real-time glucose monitoring, enabling timely adjustments to insulin dosing, diet, and physical activity.

				which can help optimize glycemic control. This information can aid healthcare providers in making necessary adjustments to insulin therapy and other interventions, leading to improved glycemic management	
21.	[16]	Continuous Glucose Monitoring (CGM) or Blood Glucose Monitoring (BGM): Interactions and Implications	2018	The article titled "Continuous Glucose Monitoring (CGM) or Blood Glucose Monitoring (BGM): Interactions and Implications" by Heinemann (2018) likely discusses the interactions and implications of using continuous glucose monitoring (CGM) versus traditional blood glucose monitoring (BGM) methods. Continuous Glucose Monitoring (CGM) and Blood Glucose Monitoring (BGM) are two approaches used to measure and monitor blood glucose levels in individuals with	CGM involves using a small sensor placed under the skin to measure glucose levels in the interstitial fluid continuously. The sensor sends glucose readings to a receiver device or a smartphone app, providing real-time glucose data and trend information throughout the day and night. CGM allows for more comprehensive glucose monitoring and provides insights into glucose patterns, trends, and fluctuations. On the other hand, BGM involves obtaining glucose readings by performing fingerstick

				diabetes. Each method has its advantages and considerations, and the choice between CGM and BGM depends on individual needs and preferences.	tests using a blood glucose meter. This method requires individuals to manually prick their finger, obtain a blood sample, and use a test strip and meter to measure their glucose level at a specific point in time. BGM provides discrete glucose values at the time of testing and requires repeated fingerstick tests for monitoring throughout the day.
22.	[23]	Non-Invasive Blood Glucose Monitoring Technology: A Review	2020	However, despite the promising results, there are currently no commercially successful non-invasive glucose monitors on the market. Many researchers and people with diabetes alike seem to have mixed emotions about the prospect of a non-invasive glucose monitor – a device that can measure glucose levels in the body without	The Journal highlighted the current research achievements and limitations of non-invasive electrochemical glucose sensing systems in continuous monitoring, point-of-care, and clinical settings to discuss the development tendency in future research. The authors concluded that non-invasive blood glucose monitoring technology has become an international research topic and a new

				puncturing the skin, drawing blood or causing any pain	method which could bring relief to a vast number of patients
23.	[25]	Carbon Nanotube (CNT)-Based Biosensors	2021	An overview of recent advances in the application of carbon nanotubes (CNTs) for the development of sensors and biosensors. Carbon nanotubes (CNTs) possess unique properties that make them ideal for biosensing applications, including high surface area, high electrical conductivity, and the ability to be functionalized with specific biomolecules. CNT-based biosensors can be developed using different transduction mechanisms, such as field-effect transistor (FET) structures, fluorescence-based sensors, and electrochemical sensors. Ongoing research in the field of CNT-based	The potential of CNT-based biosensors for various applications, including disease diagnostics, drug discovery, environmental monitoring, and personalized medicine. The article provides a comprehensive overview of the recent advances in the field and the challenges that need to be addressed to improve the performance and practicality of CNT-based biosensors. CNT-based biosensors have high sensitivity and selectivity, making them valuable tools for the detection and analysis of biomolecules at very low concentrations.CNT-based biosensors can be integrated into miniaturized devices, offering

				biosensors aims to improve their performance, stability, and reproducibility	portability and the potential for point-of-care applications.
24.	[3]	Carbon nanotube biosensors	2015	This review article provides an overview of the historical developments in the field of biosensors and describes the different types of biosensors that have been developed over time, with a focus on carbon nanotube-based biosensors. The article discusses the unique physical, chemical, electrical, and optical properties of carbon nanotubes that make them well-suited for biosensing applications. The review covers various configurations of carbon nanotube-based biosensors, including electrochemical, optical, and field-effect transistor (FET) biosensors. The article also discusses the	A research article on carbon nanotube-based biosensors for glucose detection describes the use of a thin film of carbon nanotubes as the sensing layer for electrochemical detection. The thin film was deposited onto a glassy carbon electrode and functionalized with glucose oxidase to enable selective detection of glucose

				challenges and future directions in the development of carbon nanotube-based biosensors.	
25.	[26]	Nano-carbons in biosensor applications: an overview of carbon nanotubes (CNTs) and fullerenes (C60)	2020	The review article provides an overview of the use of carbon nanotubes (CNTs) and fullerenes (C60) in biosensor applications. The article discusses the unique physical, chemical, and electrical properties of CNTs and fullerenes that make them well-suited for biosensing applications. The review covers various configurations of CNT-based biosensors, including electrochemical, optical, and field-effect transistor (FET) biosensors. The article also discusses the challenges and future directions in the development of CNT-based biosensors. The review concludes that CNTs and fullerenes have great potential for use in biosensor applications due to	The findings of the article highlight several key points regarding the use of carbon nanotubes (CNTs) and fullerenes (C60) in biosensor applications. First, both nano-carbons exhibit exceptional properties, including unique electrical, mechanical, and chemical characteristics, which make them highly suitable for biosensing. Their ability to interact with biomolecules positions them as promising materials for the development of biosensors.Within the realm of biosensing, carbon nanotubes have garnered significant attention. They have emerged as transducers capable of converting binding events between biomolecules and nanotubes into

				their unique properties, and that further research is needed to fully realize their potential.	measurable signals. This enables the detection and quantification of various analytes with remarkable sensitivity and selectivity, making carbon nanotubes an attractive choice for biosensor design and implementation.The article also touches upon the utilization of fullerenes, particularly C60, in biosensing. Fullerenes have been explored for their electrochemical properties and their potential applications in biosensing. However, further research is required to comprehensively understand and optimize their performance within biosensor systems.
26.	[42]	Advances in Carbon-Nanotube Assembly	2007	The research article provides an overview of the advances in carbon-nanotube (CNT) assembly techniques and their applications. The article	The article highlights key findings regarding carbon nanotube (CNT) assembly. It explores solution-based assembly methods involving surfactants,

				discusses various methods for CNT assembly, including chemical vapor deposition, solution-phase assembly, and template-assisted assembly. The article also describes the properties of CNTs that make them attractive for assembly, such as their high aspect ratio, mechanical strength, and electrical conductivity. The review covers various applications of CNT assembly, including biosensors, electronics, and energy storage. The article concludes that advances in CNT assembly techniques have enabled the development of new applications for CNTs, and that further research is needed to fully realize their potential.	polymers, and solvents, emphasizing the importance of understanding CNT interactions with the surrounding medium. Template-guided assembly techniques, employing microchannels and nanopores, offer precise control over CNT alignment. Chemical functionalization is shown to be significant in modifying CNT surface properties and promoting assembly with other materials. Mechanical assembly methods, including dielectrophoresis and direct manipulation, leverage electric fields and mechanical forces. The article also showcases hybrid structures and devices, such as CNT-polymer composites, sensors, and electronic devices, highlighting their enhanced properties. Finally, the authors discuss challenges and future

					directions, emphasizing the need for improved techniques, characterization methods, and theoretical understanding to fully exploit CNTs' potential in diverse applications
27.	[43]	A Critical Review of Glucose Biosensors Based on Carbon Nanomaterials: Carbon Nanotubes and Graphene	2012	The critical review article provides an overview of glucose biosensors based on carbon nanomaterials, specifically carbon nanotubes and graphene. The article discusses the history of glucose biosensors and the advantages of using carbon nanomaterials in their construction. The review covers various synthesis methods for carbon nanotubes and graphene, as well as sensing approaches and non-enzymatic hybrid sensors. The article also discusses the challenges and future directions in the development of glucose biosensors based on	It highlights the advantages of CNTs, such as high sensitivity and fast response, while discussing challenges like purification and biocompatibility. The use of graphene in biosensors is explored, emphasizing its exceptional properties and various integration strategies. The comparison of CNT-based and graphene-based biosensors examines factors like sensitivity and selectivity. The article also addresses challenges including device reproducibility and biocompatibility, emphasizing the need for further research. Overall, the findings

				carbon nanomaterials. The review concludes that carbon nanomaterial-based sensors generally have higher sensitivities and lower detection limits than conventional ones, and that further research is needed to fully realize their potential.	contribute to understanding the potential of CNTs and graphene in glucose biosensing and highlight areas for future development.
28.	[44]	State of the Art of Carbon Nanotube Fibers: Opportunities and Challenges	2012	The research article provides an overview of the state of the art of carbon nanotube (CNT) fibers, including their fabrication methods, properties, and potential applications. The article discusses the superb mechanical and physical properties of individual CNTs that have led to the development of high-performance continuous fibers based on CNTs. The review covers various fabrication methods for CNT fibers, including spinning, chemical vapor deposition, and solution	It discusses different fabrication methods and emphasizes the importance of achieving high fiber strength and alignment. The exceptional mechanical properties of CNT fibers, including high tensile strength and flexibility, are highlighted for potential structural applications. The article explores the electrical and thermal conductivity of CNT fibers, noting challenges but also showcasing their potential in electronics and thermal management. Various applications are discussed, including lightweight

				processing. The article also describes the properties of CNT fibers, such as high specific strength, specific stiffness, and electrical conductivity, that demonstrate their potential for wide application in many fields. The review concludes that CNT fibers have great potential for use in various applications, but that further research is needed to fully realize their potential and overcome the challenges associated with their fabrication and processing.	materials, composites, textiles, energy storage, and biomedical applications. Challenges such as scalability and cost-effectiveness are identified, emphasizing the need for further research and development to unlock the full potential of CNT fibers.
29.	[58]	Carbon Nanotubes Based Thin Films: Fabrication, Characterization And Applications	2014	This journal article provides an overview of the fabrication, characterization, and applications of carbon nanotube-based thin films. The article discusses various fabrication techniques for carbon nanotube-based thin films, including chemical vapor deposition, solution processing, transfer	The main findings of the article highlight several key aspects regarding carbon nanotube-based thin films. The study examines various fabrication techniques employed in creating these films, such as chemical vapor deposition, solution processing, transfer printing, Langmuir-Blodgett technique, spin coating,

				printing, Langmuir-Blodgett technique, spin coating, and layer-by-layer assembly. The article also describes the properties of carbon nanotube-based thin films, such as high electrical conductivity, mechanical strength, and flexibility, that make them attractive for various applications. The review covers various applications of carbon nanotube-based thin films, including sensors, energy storage, and electronic devices. The article concludes that carbon nanotube-based thin films have great potential for use in various applications, but that further research is needed to fully realize their potential and overcome the challenges associated with their fabrication and processing.	and layer-by-layer assembly. These techniques offer different approaches to producing carbon nanotube-based thin films, each with its own advantages and limitations. The article also discusses the properties exhibited by carbon nanotube-based thin films, which include high electrical conductivity, mechanical strength, and flexibility. These properties make them highly attractive for numerous applications, such as sensors, energy storage, and electronic devices. The films' high electrical conductivity enables efficient charge transport, while their mechanical strength and flexibility make them suitable for use in various environments and applications.

30.	[59]	Fabrication and Characterization of Thin Films of Single-Walled Carbon Nanotube Bundles on Flexible Plastic Substrates	2004	The purpose of this study was to investigate the fabrication and characterization of thin films composed of bundles of single-walled carbon nanotubes (SWCNTs) on flexible plastic substrates. The researchers employed a fabrication technique known as Langmuir-Blodgett (LB) deposition to deposit the SWCNT bundles onto the plastic substrates. The LB technique involves spreading a monolayer of SWCNTs on a water surface, compressing them to form a densely packed film, and transferring the film onto the substrate using a controlled vertical dipping process. The resulting SWCNT thin films were then characterized using	The main findings of the article highlight several key aspects regarding the fabrication and characterization of thin films using single-walled carbon nanotube (SWCNT) bundles on flexible plastic substrates. The study explores the use of a surfactant to disperse the SWCNT bundles in water, followed by their deposition onto the flexible plastic substrate. This method allows for the creation of the thin films. The thin films were characterized using scanning electron microscopy (SEM), atomic force microscopy (AFM), and Raman spectroscopy. SEM and AFM analysis revealed a high degree of alignment and uniformity in the thin films, indicating

				various techniques. Scanning electron microscopy (SEM) was utilized to examine the morphology and structure of the films, revealing the presence of aligned SWCNT bundles. Raman spectroscopy was employed to analyze the vibrational properties of the films, confirming the presence of SWCNTs and providing information about their structural integrity.The study demonstrated that the LB deposition technique could successfully produce SWCNT thin films on flexible plastic substrates. The resulting films exhibited good adhesion to the substrate and demonstrated electrical conductivity, mechanical strength, and flexibility. These properties make them suitable for applications in	the successful deposition of SWCNT bundles onto the substrate. Raman spectroscopy provided valuable information about the structural properties of the thin films. Based on the observations, the article highlights the potential of these thin films for use in flexible electronic devices and other applications. The uniformity and alignment of the SWCNT bundles in the films suggest that they can contribute to the development of flexible electronics, where conformability and lightweight materials are crucial.

				flexible electronics, sensors, and other areas that require conformable and lightweight materials.	
31.	[60]	Carbon Nanotube Thin Films: Fabrication, Properties, and Applications	2010	This comprehensive review provides an in-depth examination of carbon nanotube (CNT) thin films, covering various aspects including fabrication techniques, properties, and applications.The authors discuss several fabrication methods used to create CNT thin films, such as solution processing, chemical vapor deposition, and vacuum filtration. These techniques enable the formation of films with different structural arrangements, such as random networks or aligned arrays, depending on the desired application.The review also highlights the unique properties exhibited by CNT thin films. These properties include high electrical	The main findings of the article are the study explores various fabrication techniques for carbon nanotube (CNT) thin films, including chemical vapor deposition, solution processing, transfer printing, Langmuir-Blodgett technique, spin coating, and layer-by-layer assembly. Additionally, the use of surfactants and polymers to disperse and align CNTs in the thin films is discussed.The article also highlights the unique mechanical, electrical, and optical properties of CNTs that make them highly attractive for thin film applications. The influence of CNT diameter, chirality, and length on the properties of the thin films is investigated. The characterization

				conductivity, excellent mechanical strength, and flexibility, making them suitable for a wide range of applications. The authors explore the use of CNT thin films in various fields, including electronics, energy storage, sensors, and transparent conductive coatings.	of CNT thin films is examined through scanning electron microscopy, atomic force microscopy, and Raman spectroscopy. In terms of applications, the article identifies various uses for CNT thin films, including transparent conductive films, sensors, energy storage, and electronic devices. The potential of CNT thin films in flexible and stretchable electronics is also highlighted.
32.	[61]	Immobilization Techniques in the Fabrication of Nanomaterial-Based Electrochemical Biosensors: A Review	2013	This review paper focuses on discussing various immobilization techniques employed in the fabrication of electrochemical biosensors using nanomaterials. The authors provide a comprehensive overview of different immobilization methods utilized to attach biomolecules, such as enzymes or antibodies, onto	The main findings of the article highlight several key aspects regarding the use of nanomaterials in the fabrication of electrochemical biosensors. The study discusses the evolution of electrochemical biosensors from 1st to 3rd generation, emphasizing the simplification and enhancement of the transduction pathway. One of the main findings is

				nanomaterial surfaces for biosensor applications. These techniques include physical adsorption, covalent binding, entrapment within polymers, layer-by-layer assembly, and self-assembled monolayers. The advantages, limitations, and specific considerations associated with each immobilization method are thoroughly discussed.The article emphasizes the importance of effective immobilization techniques in achieving stable and sensitive electrochemical biosensors. Proper immobilization ensures the retention of biomolecular activity and enhances the selectivity and sensitivity of the biosensor for target analytes. The review highlights the use of nanomaterials, such as carbon nanotubes, nanoparticles, and	the significant improvement in the sensitivity and overall performance of enzymatic biosensors through the incorporation of nanomaterials. The review focuses on various nanomaterials, including gold nanoparticles, carbon nanotubes, and graphene, used to modify enzymatic biosensors. These nanomaterial modifications offer advantages such as enhanced electron transfer, increased surface area, and improved stability, leading to improved sensor performance. The article specifically examines the challenges associated with electrochemical biosensors, including non-specific binding, electrode fouling, and poor selectivity in complex sample matrice

				graphene, in combination with immobilization techniques to enhance the performance of electrochemical biosensors. The authors provide examples of applications where these immobilization techniques and nanomaterials have been successfully employed, including the detection of biomarkers, toxins, and environmental pollutants. They also discuss emerging trends and future prospects in the field, such as the integration of nanomaterials and immobilization techniques with microfluidic systems and the development of point-of-care biosensors.	
33.	[22]	Glucose oxidase immobilized amine	2019	The researchers designed and fabricated a modified screen-printed carbon electrode using a	The article describes the fabrication of a novel glucose biosensor based on a screen-printed carbon

		terminated multiwall carbon nanotubes/reduced graphene oxide/polyaniline/gold nanoparticles modified screen-printed carbon electrode for highly sensitive amperometric glucose detection		combination of amine-terminated multiwall carbon nanotubes (MWCNTs), reduced graphene oxide (rGO), polyaniline (PANI), and gold nanoparticles (AuNPs). Glucose oxidase (GOx) was immobilized on the electrode surface to facilitate the specific detection of glucose.The performance of the sensor was evaluated using amperometric measurements, and the results demonstrated a high sensitivity and a low limit of detection for glucose detection. The presence of the MWCNTs, rGO, PANI, and AuNPs in the electrode modification enhanced the electrocatalytic activity and electron transfer kinetics, resulting in improved glucose detection performance.	electrode (SPCE) modified with amine terminated multiwall carbon nanotubes, polyaniline, reduced graphene oxide, and gold nanoparticles. The biosensor exhibited high sensitivity and selectivity for glucose detection, with a linear response to glucose concentrations ranging from 0.1 to 10 mM and a detection limit of 0.03 mM. The biosensor also exhibited good stability and reproducibility. The article demonstrates the potential of carbon nanotubes and graphene for biosensing applications. The article highlights the potential of the developed sensor for various applications in glucose monitoring, such as in clinical diagnostics and diabetes management. The highly sensitive amperometric detection of glucose provided by the

					modified electrode offers promising prospects for the development of accurate and reliable glucose sensing devices
34.	[62]	A novel glucose biosensor based on immobilization of glucose oxidase in chitosan on a glassy carbon electrode modified with gold–platinum alloy nanoparticles/multiwall carbon nanotubes	2007	The study focuses on the development of a sensor for highly sensitive amperometric glucose detection. The researchers designed and fabricated a modified screen-printed carbon electrode using a combination of amine-terminated multiwall carbon nanotubes (MWCNTs), reduced graphene oxide (rGO), polyaniline (PANI), and gold nanoparticles (AuNPs). Glucose oxidase (GOx) was immobilized on the electrode surface to facilitate the specific detection of glucose. The performance of the sensor was evaluated using amperometric measurements, and the results	The article describes the fabrication of a novel glucose biosensor based on the immobilization of glucose oxidase (GOx) with cross-linking in the matrix of biopolymer chitosan (CS) on a glassy carbon electrode modified with gold-platinum alloy nanoparticles/multiwall carbon nanotubes. The biosensor exhibited high sensitivity and selectivity for glucose detection, with a linear response to glucose concentrations ranging from 0.1 to 10 mM and a detection limit of 0.05 mM. The article demonstrates the potential of carbon nanotubes and gold-platinum alloy nanoparticles for biosensing

				demonstrated a high sensitivity and a low limit of detection for glucose detection. The presence of the MWCNTs, rGO, PANI, and AuNPs in the electrode modification enhanced the electrocatalytic activity and electron transfer kinetics, resulting in improved glucose detection performance.	applications. The article highlights the potential of the developed sensor for various applications in glucose monitoring, such as in clinical diagnostics and diabetes management. The highly sensitive amperometric detection of glucose provided by the modified electrode offers promising prospects for the development of accurate and reliable glucose sensing devices.
35.	[29]	Glucose Biosensors Based on Carbon Nanotube Nanoelectrode Ensembles	2004	The article focuses on the development of glucose biosensors utilizing carbon nanotube (CNT) nanoelectrode ensembles.The researchers in this study aimed to design and develop a highly sensitive and selective glucose biosensor using carbon nanotubes. Glucose biosensors are widely	The article "Glucose Biosensors Based on Carbon Nanotube Nanoelectrode Ensembles" by Lin et al. (2004) describes the development of glucose biosensors based on carbon nanotube (CNT) nanoelectrode ensembles (NEEs) for the selective detection of glucose. The biosensor was fabricated

				used for monitoring blood glucose levels in medical diagnostics, particularly for diabetic patients. Carbon nanotubes have unique electrical and mechanical properties that make them suitable for various applications, including biosensing. In this study, the researchers fabricated nanoelectrode ensembles using carbon nanotubes as the sensing elements. These ensembles were designed to enhance the sensitivity and selectivity of the biosensor. The researchers utilized a functionalization process to modify the carbon nanotubes' surfaces, which improved their performance as glucose sensing elements. The functionalization process involved	by immobilizing glucose oxidase (GOx) on the surface of CNTs, which were grown on a glassy carbon electrode (GCE) using chemical vapor deposition (CVD). The biosensor exhibited high sensitivity and selectivity for glucose detection, with a linear response to glucose concentrations ranging from 0.1 to 5 mM and a detection limit of 0.05 mM. The article demonstrates the potential of carbon nanotubes for biosensing applications. The fabricated biosensor demonstrated excellent sensitivity and selectivity towards glucose. The carbon nanotube nanoelectrode ensembles exhibited a significantly enhanced electrochemical response to glucose compared to traditional biosensors. The researchers attributed this improvement to the unique

				attaching glucose oxidase (GOx) to the nanotubes, which allows for the specific detection of glucose molecules.	properties of carbon nanotubes, such as their high surface-to-volume ratio and excellent electrical conductivity.

CHAPTER 3

METHODOLOGY

3.1 Material and Reagents

This segment will provide an overview of the equipment and materials employed. The electrodes will undergo an electrodeposition process facilitated by a potentiostat.

Table 3.1 List of Material

Equipment	Quantities
Carbon Nanotube	1 pack
Carbon plate	20 pcs (1cm x 2cm)
Indium Tin Oxide plate	20 pcs (1cm x 2cm)
Stainless steel plate	20 pcs (1cm x 2cm)
Sodium Dodecylbenzesulfonate (SDBS)	1
Polypyrrole (PPY)	1
Distilled Water (DI)	1
Ethanol	1
Methanol	1
Ethyl-3-(3-dimethlaminopropyl) carbodiimide hydrochloride (EDC)	4 mg

N-hydroxysuccinimide (NHS)	6 mg
Glucose Oxidase	1 mg

Table 3.2 List of Equipments

Equipment	Quantities
Potentiostat	1
NOVA 2.0 Advance Electrochemistry software	1
Field Emission Scanning Electron Microscope	1
Fourier Transform Infrared Spectroscopy	1

3.1.1 Carbon Nanotube

Carbon nanotubes (CNTs) are cylindrical structures made up of carbon atoms arranged in a hexagonal lattice. These structures can be thought of as rolled-up sheets of graphene, which is a single layer of carbon atoms arranged in a hexagonal pattern. Carbon nanotubes exhibit unique and remarkable properties due to their nanoscale dimensions and the strong carbon-carbon bonds in their structure

Figure 3.1 Carbon Nanotube

3.1.2 Carbon Plate

Carbon plates are flat, solid components made predominantly from carbon fibers or carbon composites. They possess exceptional mechanical properties and high strength-to-weight ratios, making them ideal for a range of applications. In the aerospace industry, carbon plates are used to construct lightweight aircraft components like wings, fuselages, and structural panels, enhancing fuel efficiency and performance. Automotive and motorsports industries utilize carbon plates to manufacture high-performance vehicles, improving speed, handling, and overall capabilities. Additionally, carbon plates find use in

sporting goods production, providing strength and durability to items like bicycles, tennis rackets, and hockey sticks. Their mechanical properties also make them valuable in industrial applications such as robotics, offering rigidity and vibration damping. With their combination of lightweight find use in sporting goods production, providing strength and durability to items like bicycles, tennis rackets, and hockey sticks. Their mechanical properties also make them valuable in industrial applications such as robotics, offering rigidity and vibration damping. With their combination of lightweight construction, strength, and versatility, carbon plates play a crucial role in industries that prioritize performance, efficiency, and durability.

Figure 3.2 Carbon plate

3.1.3 Indium Tin Oxide Plate

Indium tin oxide (ITO) is a transparent and conductive material that consists of a mixture of indium oxide (In2O3) and tin oxide (SnO2). It is commonly used as a transparent electrode in various electronic devices and optoelectronic applications. The primary reason for its widespread use is its combination of transparency and electrical conductivity.

Figure 3.3 Indium Tin Oxide

3.1.4 Stainless Steel

A stainless steel plate refers to a flat, solid sheet or panel made primarily of stainless steel, an alloy composed of iron, chromium, and other elements. Stainless steel plates are widely used in numerous industries due to their exceptional properties. In the construction sector, they find applications in structural components, building facades, and roofing due to their durability, corrosion resistance, and aesthetic appeal. The food and beverage industry utilizes stainless steel plates for equipment, storage tanks, and sanitary surfaces due to their hygienic properties and resistance to corrosion and contamination. In the manufacturing sector, stainless steel plates are favored for their strength, heat resistance, and ease of fabrication, making them suitable for machinery components, automotive parts, and kitchen appliances. Moreover, stainless steel plates

find uses in the medical field for surgical instruments, implants, and medical equipment due to their biocompatibility and corrosion resistance. With their versatility, durability, and corrosion resistance, stainless steel plates are widely regarded as a reliable and high-performance material in various industries.

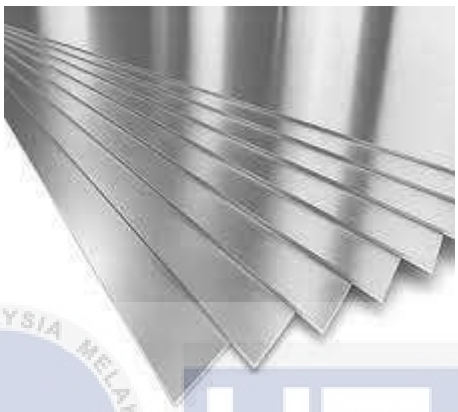

Figure 3.4 Stainless Steel Plate

3.1.5 Sodium Dodecylbenzesulfonate (SDBS)

Sodium dodecylbenzenesulfonate (SDBS) is a synthetic detergent and surfactant. It belongs to the class of anionic surfactants and is commonly used in various applications due to its ability to reduce the surface tension of liquids and enhance the dispersion of particles

Figure 3.5 SDBS

3.1.6 Polypyrrole (PPY)

A polypyrrole solution typically refers to a solution containing polypyrrole, which is a conducting polymer. Polypyrrole is often synthesized through chemical oxidative polymerization, and the resulting polymer can be dispersed or dissolved in certain solvents to create a solution.

Figure 3.6 Polypyrro

3.1.7 Disstiled water

Distilled water is water that has undergone a process called distillation to remove impurities and contaminants. Distillation is a method of separating components of a liquid mixture based on differences in their boiling points. In the case of water, the process involves boiling water to produce steam, then condensing the steam back into liquid water. This effectively removes most impurities, minerals, and other substances, leaving behind a purified form of water.

Figure 3.7 Disstilled Water

3.1.8 Ethanol

Ethanol, also known as ethyl alcohol, is a type of alcohol that is commonly used in various applications. It is a simple organic compound with the chemical formula C_2H_5OH. Ethanol is a clear, colorless liquid with a characteristic odor, and it is a psychoactive substance, meaning it has the ability to affect the central nervous system when consumed.

Figure 3.8 Ethanol

3.1.9 Methanol

Methanol, also known as methyl alcohol or wood alcohol, is a simple alcohol with the chemical formula CH_3OH. It is a colorless, volatile liquid with a slightly sweet odor. Methanol is used in various industrial applications, but it is important to note that it is highly toxic and should not be consumed.

Figure 3.9 Methanol

3.1.10 Ethyl-3-(3-dimethlaminopropyl) carbodiimide hydrochloride (EDC)

Ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride, commonly known as EDC or EDC•HCl, is a chemical compound used in biochemistry and molecular biology for protein crosslinking and peptide coupling reactions. It is an important reagent in bioconjugation and immobilization techniques.

3.1.11 N-hydroxysuccinimide (NHS)

N-Hydroxysuccinimide (NHS) is a chemical compound that is commonly used in biochemistry and molecular biology for amine coupling reactions, particularly in the formation of amide bonds between carboxyl groups and amino groups. It is often employed in conjunction with other reagents like carbodiimides, such as EDC (ethyl-3-(3-dimethylaminopropyl) carbodiimide), to enhance the efficiency of these reactions.

Figure 3.10 NHS

3.1.12 Glucose Oxidase

Glucose oxidase (GOx) is an enzyme that catalyzes the oxidation of glucose to produce gluconic acid and hydrogen peroxide. This enzyme is widely used in various applications, particularly in the food and beverage industry, clinical diagnostics, and biosensors.

Figure 3.11 Glucose Oxidase

3.1.13 Potentiostat

A potentiostat is a scientific instrument used in electrochemistry to control and measure the potential (voltage) difference between an electrode and a reference electrode. It consists of three main components: a working electrode where the electrochemical reaction occurs, a reference electrode with a known potential used as a reference point, and a counter electrode that completes the electrical circuit. The potentiostat applies a controlled voltage or current to the electrochemical cell and measures the resulting current or potential. By adjusting the applied voltage, it maintains a constant potential difference and measures the current flowing through the cell. This data is crucial for analyzing the electrochemical behavior in corrosion studies, battery research, fuel cell development, sensor development, and materials characterization. Potentiostats provide insights into the kinetics, mechanisms, and thermodynamics of electrochemical processes, contributing to advancements in various scientific and industrial fields.

Figure 3.12 BiPotential

3.1.14 NOVA 2.0 – Advance Electrochemistry Software

Autolab, from Metrohm, introduces its advanced electrochemistry software known as NOVA 2.0. This powerful program serves as a comprehensive control system for Autolab equipment and compatible accessories. Developed by electrochemists for electrochemists, NOVA 2.0 incorporates more than two decades of user experience and utilizes cutting-edge.NET software technology. By integrating the capabilities and flexibility of previous versions, NOVA 2.0 presents a user-friendly interface that is both simple and modern. The software features intuitive graphical representations of common instrument activities, allowing users to easily navigate and perform tasks. Whether new to electrochemistry or seasoned in the field, both novice and experienced users will find NOVA 2.0 to provide a comfortable and efficient software experience.

Figure 3.13 Autolab Machine

3.1.15 Field Emmision Scanning Electron Microscope (FE-SEM) Machine

The scanning electron microscope (FE-SEM) is an instrument that produces highly magnified images using electrons instead of light. At the top of the microscope, an electron cannon generates an electron beam. This beam travels vertically through the vacuum-sealed microscope and is directed towards the sample by electromagnetic fields and lenses, resulting in focused imaging. When the electron beam interacts with the sample, it causes the emission of electrons and X-rays. Figure 3.15 illustrates the FE-SEM machine employed in this project.

Figure 3.14 SEM Machine

3.1.16 Fourier Transform Infared Spectroscopy Machine

Fourier Transform Infrared Spectroscopy (FTIR) is a technique used to generate an infrared absorption spectrum, enabling the identification of chemical bonds within a molecule. The resulting spectra offer a sample profile, essentially a distinct chemical fingerprint that can be utilized for screening and analyzing various components in samples. FTIR is a valuable analytical tool for detecting functional groups and analyzing data related to covalent bonding.

Figure 3.15 XRD Machine

3.2 Fabrication Techniques for Carbon Nanotube-Based Thin Film Detectors

Fabrication techniques play a crucial role in developing carbon nanotube-based thin film detectors for glucose sensing. This chapter outlines the various fabrication methods used to create the thin film structures incorporating carbon nanotubes.

3.2.1 Deposition Technique

Deposition techniques are fundamental in the fabrication of carbon nanotube-based thin film detectors for glucose sensing. Two prominent methods for depositing carbon nanotubes are Chemical Vapor Deposition (CVD) and Solution-Based Deposition.

Chemical Vapor Deposition (CVD) is widely employed for the synthesis of carbon nanotubes [58] In this technique, carbon-containing precursors are decomposed at elevated temperatures, typically in the presence of metal catalysts. The process initiates the growth of carbon nanotubes directly on substrates, resulting in a dense and well-aligned network that is well-suited for thin film deposition [58]. CVD offers control over the nanotube diameter, length, and alignment, enabling precise customization of the thin film properties [58].

Solution-Based Deposition methods utilize liquid mediums, such as solvents or polymers, to disperse carbon nanotubes and create stable inks or suspensions [58]. This approach facilitates the deposition of nanotubes onto substrates using techniques like spin coating, drop casting, inkjet printing, or spray coating [58]. Spin coating involves applying the carbon nanotube solution onto the substrate and then spinning it at high speeds to achieve a uniform thin film as the solvent evaporates [58]. Drop casting entails depositing droplets of the nanotube solution onto the substrate, which then spreads and

forms a film through self-assembly [58]. Inkjet printing and spray coating enable precise and controlled deposition of carbon nanotubes onto desired areas, offering versatility in creating patterns and complex structures.

These solution-based techniques provide simplicity, scalability, and control over the film's thickness and morphology. The concentration of nanotubes in the solution can be adjusted to achieve the desired film density, and the film properties can be further tailored by manipulating factors like drying time, solvent composition, and substrate temperature. Moreover, these methods offer compatibility with a variety of substrate materials, including silicon wafers, glass, flexible polymers, or specialized biosensor substrates with surface properties optimized for biomolecule immobilization.

3.2.2 Substare Preparation

Substrate preparation is a critical step in the fabrication of carbon nanotube-based thin film detectors for glucose sensing [63]. It involves thorough cleaning and surface treatment of the substrates to ensure optimal film quality and performance. Additionally, the choice of substrate is crucial and depends on the desired application and compatibility with the deposition technique.

Prior to deposition, substrates undergo a cleaning process to remove any contaminants that could adversely affect the quality of the thin film. Various techniques are employed for substrate cleaning, including ultrasonication in solvents, plasma cleaning, or chemical treatments. Ultrasonication involves immersing the substrates in a solvent and subjecting them to high-frequency sound waves, which create cavitation bubbles that effectively dislodge and remove contaminants from the substrate surface

[64]. Plasma cleaning utilizes low-pressure plasma to remove organic and inorganic residues from the substrate, creating a clean surface ready for deposition. Chemical treatments involve immersing the substrates in specific cleaning solutions or employing chemical agents to dissolve or remove contaminants. These cleaning processes ensure a pristine substrate surface, which is crucial for achieving uniform and reliable thin film deposition.

The choice of substrate is determined by the intended application and compatibility with the deposition technique. Commonly used substrates include silicon wafers, glass, flexible polymers, and specialized biosensor substrates with surface properties optimized for biomolecule immobilization. Silicon wafers offer excellent thermal stability, chemical resistance, and compatibility with cleanroom fabrication processes. Glass substrates are transparent, which is advantageous for certain optical detection methods. Flexible polymer substrates, such as polyethylene terephthalate (PET) or polydimethylsiloxane (PDMS), provide flexibility and conformability, enabling the fabrication of wearable or flexible biosensors [65]. Specialized biosensor substrates may have surface coatings or functionalization that facilitate the immobilization of biomolecules, such as enzymes or antibodies, for enhanced specificity and sensitivity in glucose detection.

The choice of substrate material is influenced by factors such as the desired film properties, device integration requirements, and the specific techniques used for deposition and subsequent processing. Compatibility between the substrate and deposition technique ensures good adhesion and uniformity of the carbon nanotube-based thin film, leading to improved device performance and reliability [66].

By carefully preparing the substrates and selecting appropriate materials, the fabrication process can optimize the adhesion, uniformity, and overall quality of the carbon nanotube-based thin film detectors. These steps contribute to the development of glucose biosensors with enhanced sensitivity, selectivity, and stability, enabling accurate and reliable glucose detection for various applications in healthcare, biotechnology, and food industry settings.

3.2.3 Thin Film Formation

Thin film formation is a crucial step in the fabrication of carbon nanotube-based biosensors for glucose detection [67]. Several techniques are commonly employed to deposit carbon nanotubes onto substrates, including drop-casting, spin-coating, layer-by-layer assembly, and vacuum deposition.

Drop-casting and spin-coating are solution-based techniques used to deposit carbon nanotube solutions or dispersions onto the substrate [68]. In drop-casting, small droplets of the solution are placed onto the substrate using droppers or pipettes. The solution is then spread evenly across the surface by spinning or tilting the substrate, allowing the solvent to evaporate and leaving behind a thin and uniform carbon nanotube film. Spin-coating involves a similar process, but the substrate is placed on a spin coater, and the solution is dispensed onto the substrate while it is spinning at high speeds [68]. The centrifugal force spreads the solution, resulting in a thin and homogeneous film as the solvent evaporates.

Layer-by-layer assembly is another technique used for thin film formation. In this method, carbon nanotubes are alternately deposited with other materials, such as polymers or nanoparticles, to create multilayer thin films [56]. The deposition can be achieved through various mechanisms, including electrostatic interactions, chemical reactions, or van der Waals forces. By controlling the number and sequence of deposition steps, precise control over film thickness and composition can be achieved, allowing for the customization of film properties [59].

Vacuum deposition techniques, such as thermal evaporation or sputtering, can also be employed to deposit carbon nanotubes in a controlled environment. Thermal evaporation involves heating a carbon nanotube source, which then evaporates and condenses onto the substrate, forming a thin film [69]. Sputtering involves bombarding a carbon nanotube target with high-energy ions, causing the release of carbon nanotubes that then deposit onto the substrate. Vacuum deposition methods offer precise control over film thickness and uniformity, but they often require specialized equipment and a controlled vacuum environment.

The choice of thin film deposition technique depends on several factors, including the desired film properties, the compatibility with the carbon nanotube solution, the substrate material, and the specific application requirements [70]. Each technique offers advantages and considerations in terms of simplicity, scalability, control over film thickness and uniformity, and compatibility with different substrate materials. By carefully selecting and optimizing the thin film deposition technique, researchers can

achieve high-quality carbon nanotube-based films for enhanced sensitivity and selectivity in glucose biosensors

3.2.4 Post-Treatment

Post-treatment steps play a crucial role in optimizing the performance of carbon nanotube-based thin film detectors for glucose sensing [71]. These steps involve various techniques aimed at improving the film's properties, such as crystallinity, conductivity, stability, and selectivity. Two commonly used post-treatment methods are thermal annealing and surface functionalization.

Thermal annealing is a widely employed technique to enhance the crystallinity and remove residual impurities in carbon nanotube thin films. By subjecting the film to controlled heating at elevated temperatures, the annealing process promotes the rearrangement and alignment of carbon nanotubes, resulting in improved structural integrity and electrical conductivity [72]. This treatment helps to reduce defects and enhances charge transport within the film, thereby enhancing the overall performance of the glucose biosensor.

Surface functionalization treatments are applied to modify the surface properties of carbon nanotube thin films, leading to improved performance, stability, and selectivity for glucose detection. Plasma treatment is one method used to modify the film's surface by exposing it to a low-pressure plasma environment [73]. The plasma initiates chemical reactions on the surface, introducing functional groups or creating reactive sites that can facilitate the immobilization of biomolecules or enhance the film's interaction with glucose molecules.

Chemical modification involves treating the carbon nanotube film with specific chemical agents or solutions to introduce desired functional groups onto the film's surface. These functional groups can enhance the film's affinity towards glucose molecules or enable the attachment of specific biomolecules, such as enzymes or antibodies, for glucose sensing [46]. Additionally, coating the carbon nanotube film with functional molecules, such as polymers or specific receptors, can enhance the film's selectivity and sensitivity towards glucose molecules while minimizing interference from other analytes.

By employing these post-treatment techniques, the properties of carbon nanotube-based thin film detectors can be tailored to meet the specific requirements of glucose sensing applications. Thermal annealing enhances the film's structural and electrical properties, while surface functionalization treatments modify the film's surface chemistry, improving its stability, selectivity, and interaction with glucose molecules [74]. These post-treatment steps contribute to the development of high-performance glucose biosensors, enabling accurate and reliable glucose detection for a range of applications in healthcare, biotechnology, and food industry settings.

3.3 Glucose Biosensor Fabrication Process

The initial step of this project involves the electrodeposition of carbon, indium tin oxide and stainless steel electrodes by coating them with solutions containing PPY (polypyrrole) and MWCNT (multi-walled carbon nanotube). Electrodeposition is a technique used to create solid materials from a solution containing molecules, ions, or complexes. To achieve optimal results, it is recommended to allow the electrodeposition process to proceed for a minimum of 5 to 10 seconds after coating the electrodes. Subsequently, the coated electrodes are immersed in methanol solutions.

To examine the morphology of the deposited film, field emission scanning electron microscopy (FE-SEM) is employed. Fourier-transform infrared spectroscopy (FTIR) is employed to analyze the composition and functional groups present in the coated electrodes.

The relationship between voltage, current, and the electrode's surface area is analyzed to understand their interdependence. Efficient and straightforward biosensors are then developed through the immobilization process. Glucose solutions with specific molarities are dropped onto the electrodes, and the sensitivity of the biosensor is measured using NOVA 2.0 software. The sensogram results obtained through the software aid in determining the targeted redox reactions. Figure 3.13 illustrates the flowchart depicting the fabrication process of the glucose biosensor.

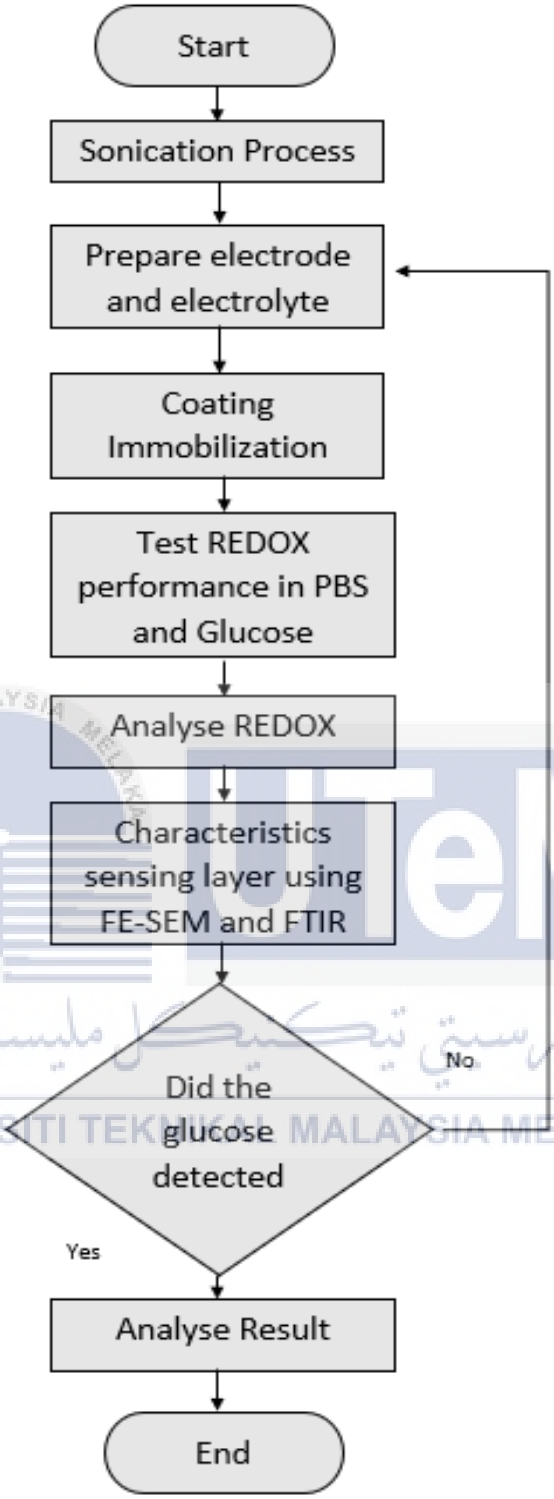

Figure 3.16 Flowchart of Glucose Biosensor Fabrication

The procedure for functionalizing carbon nanotubes (CNTs) involves several detailed steps to attach specific molecules or functional groups onto the surface of the nanotubes. Firstly, purification of the CNTs is crucial to remove any impurities or residual catalysts. This purification step can be accomplished through various techniques such as acid treatment or thermal oxidation [75]. Acid treatment involves treating the CNTs with strong acids, such as nitric acid or a mixture of sulfuric and nitric acid, to remove amorphous carbon and metallic impurities. Thermal oxidation involves subjecting the CNTs to high temperatures in the presence of oxygen, which helps to remove organic contaminants.

Once the CNTs are purified, the next step is to select an appropriate functionalization method based on the desired molecules or functional groups to be attached. There are several methods available, including covalent functionalization, non-covalent functionalization, and polymer wrapping [75]. Covalent functionalization involves the formation of covalent bonds between the CNT surface and the desired functional groups. One common approach is to treat the CNTs with strong acids or oxidizing agents to generate carboxyl groups on the nanotube surface [76]. These carboxyl groups can then react with specific molecules or coupling agents to attach desired functional groups. Other methods for covalent functionalization include diazonium chemistry or organic reactions to introduce functional groups onto the CNT surface.

Non-covalent functionalization, on the other hand, involves the adsorption or wrapping of molecules or polymers onto the CNT surface through non-covalent interactions. This can be achieved through mechanisms such as π-π stacking interactions, van der Waals forces, or electrostatic interactions. Common examples include using surfactants, polymers, or biomolecules to coat the CNTs and modify their properties.

The actual functionalization process starts with dispersing the CNTs in a suitable solvent to create a stable suspension or solution. The functionalizing agents, such as molecules or polymers, are then added to the suspension and allowed to react or interact with the nanotubes. The process may require specific reaction conditions, such as temperature, time, or stirring, to facilitate the attachment of functional groups onto the CNT surface [77].

After functionalization, the functionalized CNTs undergo purification to remove any unreacted or loosely attached molecules. This purification step typically involves techniques such as filtration, centrifugation, or dialysis. The aim is to obtain pure, functionalized CNTs with the desired properties [78].

In summary, the procedure for functionalizing carbon nanotubes involves the detailed steps of purification, selection of a functionalization method, attachment of desired molecules or functional groups, purification of functionalized CNTs, and characterization to verify the functionalization process. These steps are crucial for tailoring the properties of CNTs to meet specific requirements in various applications, including glucose detection.

3.3.1 Process for Electrode

The cutting plate process involves various steps for different types of plates. Firstly, for carbon, prior to the cutting process, we mark the plate with dimensions of 1 cm in width and 2 cm in length, followed by using scissors to make the necessary cuts. Moving on to the indium tin oxide plate, employ a glass cutter t-shaped to achieve a width of 1 cm and a length of 2 cm. Subsequently, any rusty the indium tin oxide plate are eliminated through the application of a methanol for thorough cleaning. As for stainless steel plates, prior to the cutting process, we mark the plate with dimensions of 1 cm in width and 2 cm in length, followed by using scissors to make the necessary cuts.

3.3.2 Process for Electrode Coating into PPY/MWCNT

For MWCNT Solution Process, the materials used for preparing the Ppy/MWCNT solution are described below. The accompanying figures illustrate the step-by-step process. Figure 3.23 displays a beaker containing 50ml of deionized water. Moving on, Figure 3.24 showcases the MWCNT (multi-walled carbon nanotubes) powder. Figure 3.25 exhibits the of SDBS (sodium dodecylbenzenesulfonate) then need to measure using a Weighing Digital Scale. Figure 3.26 shown 0.025g MWCNT being measured and figure 3.27 shown 0.250 g SDBS being measured. After measure part, the MWCNT and SDBS put into Deiozined Water.

Figure 3.17 Deionized Water

Figure 3.18 Multi-Walled Carbon Nanotube

Figure 3.19 SDBS

Figure 3.20 0.0250 g CNT

Figure 3.21 0.2504 g SDBS

3.3.3 Sonication Process

After making the SDBS and MWCNT solution, the proceed to sonicate the solution by using Ultrasonic Cleaner for 4 hours. Figure 3.17 shows the sonication process. During this period, samples are systematically extracted at 30-minute intervals. Each extracted sample is meticulously transferred into a microcentrifuge tube as shown in figure 3.29 using a precise pipetting technique. Subsequently, the tube is placed in a mini centrifuge to ensure the proper settling of Carbon Nanotubes (CNT) at the base, facilitating the subsequent removal of excess material as shown in figure 3.30. This removal process is carried out over an 8-minute duration, followed by a thorough washing procedure involving ethanol and disttilled water.

Figure 3.22 Sonicating the MWCNT Solution

Figure 3.23 Sample in Mini Centrifuge

Figure 3.24 CNT in Microcentrifuge Tube

3.3.4 Drying Process

Subsequent to the centrifugation and washing steps, a pivotal phase in the experimental procedure involves the drying process. The extracted samples are meticulously arranged in an oven as shown in figure 3.31 and figure 3.32, ensuring a comprehensive drying duration of 8 hours at a controlled temperature of 60 degrees Celsius. This meticulous drying protocol is imperative to guarantee the complete desiccation of Carbon Nanotubes (CNT) within each sample as shown in figure 3.34 and store in closed container as shown in figure 3.33.

Figure 3.25 Oven

Figure 3.26 Sample in the Oven

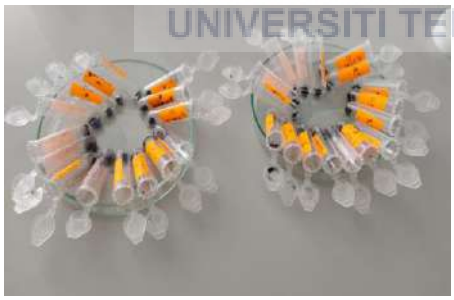

Figure 3.28 Drying Sample

Figure 3.27 Sample in Container

3.3.5 Process of Stirring and Electrodeposition Ppy/MWCNT

After subjecting the SDBS/MWCNT solution to sonication for a duration of 4 hours, Plypyrrole (Ppy) is introduced into the solution. Figure 3.35 and depict the addition of Polypyrrole (Ppy) to the SDBS/MWCNT solution in figure 3.36. Subsequently, the resulting solution, now known as PPY/MWCNT, is stirred using a Magnetic Stirrer for a period of 5 minutes in figure 3.37. Next, the process electrodeposition using PPY/MWCNT solution and using Carbon, Indium Tin Oxide and Stainless Steel as a electrodes as shown in figure 3.34.

Figure 3.29 Polypyrrole

Figure 3.30 Putting Polypyrole into MWCNT solution

Figure 3.31 The PPY/MWCNT solution stirred using Magnetic Stirrer

Figure 3.32 Electrodeposition process PPY/MWCNT solution on electrode

Figure 3.33 Coated Electrode

3.3.6 Process of Immobilization Layer

To enable glucose detection, a detailed procedure can be followed to create an immobilization layer on carbon nanotubes (CNTs). To enhance the stability of the immobilization layer, cross-linking agents or appropriate treatments are applied. Cross-linking agents like glutaraldehyde are utilized to establish covalent linkages between glucose and the functionalized CNTs, providing additional stability. Washing and drying steps are also employed to remove unbound glucose molecules and stabilize the immobilization layer. In this process, an EDC-NHS solution is prepared using EDC and NHS. In the initial step, 4 mg of EDC is measured, as depicted in the accompanying figure. Subsequently, 5 ml of diluted water is added to the measured EDC, as illustrated in the corresponding figure. To ensure thorough mixing of the solution, the EDC solution is then placed on a Vertex Mixer. This step is crucial to guarantee the effective integration of the components.

Figure 3.34 4 mg EDC

Figure 3.35 EDC mix with diluted water

Figure 3.36 EDC on Vortex Mixer

Following the previous step, the next stage involves measuring 6 mg of NHS, as shown in the figure. Similar to the EDC procedure, 5 ml of diluted water is added to the measured NHS, and thorough mixing is ensured. Subsequently, the 5 ml EDC solution and the 5 ml NHS solution as shown in figure 3.39 are combined in a 10 ml bottle in figure 3.38. This mixture is then carefully blended using a Vortex Mixer as shown in figure 3.40, ensuring comprehensive integration of the EDC and NHS components. This step is crucial for the successful preparation of the EDC-NHS solution.

Figure 3.38 5 ml EDC and 5ml NHS

Figure 3.37 10 ml EDC-NHS solution

Figure 3.39 EDC-NHS on Vortex Mixer

In the subsequent step, the prepared EDC-NHS solution is divided into two separate bottles. Following this, six electrodes, specifically ITO, Stainless Steel, and Carbon, previously coated for 5 minutes using the sample, are immersed in the solution. The electrodes are left in contact with the solution for a duration of 4 hours as shown in figure 3.41. This step is crucial to facilitate the desired reactions and coatings on the electrode surfaces for the intended experimental or application purposes.

Figure 3.40 Soaked electrodes in EDC-NHS solution

Continuing the procedure, the next step involves measuring 1 mg of GOX as shown in figure 3.43. This measured quantity is then mixed with 1 ml of diluted water as shown in figure 3.42. Utilizing a Vortex Mixer, the solution undergoes thorough mixing to ensure a homogeneous blend as shown in figure 3.44. This step is essential to prepare the GOX solution, contributing to the subsequent stages of the experimental process as shown in figure 3.45.

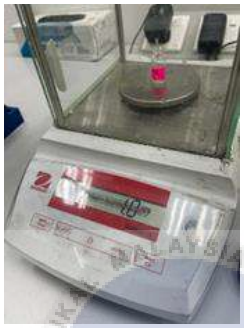

Figure 3.42 1mg GOx

Figure 3.41 1mg GOx mix with 1 ml distilled water

Figure 3.44 GOx solution

Figure 3.43 GOx on Vortex Mixer

Following the preparation of the GOX solution, the next step involves applying this solution onto the three electrodes that have been immersed in the EDC-NHS solution for the previous 4-hour duration. The remaining three electrodes, which have also undergone the EDC-NHS soaking process, are sent to FTIR (Fourier Transform Infrared Spectroscopy) for characterization.Carefully dropping the GOX+DI solution onto each electrode as shown in figure 3.48 and in figure 3.47, a uniform coating is achieved. Subsequently, the entire sample is placed in a freezer as shown in figure 3.46 and allowed to incubate for a duration of 12 hours. This step is crucial for promoting the desired interactions and reactions between the coated electrodes and the GOX solution, ultimately contributing to the experimental objectives.

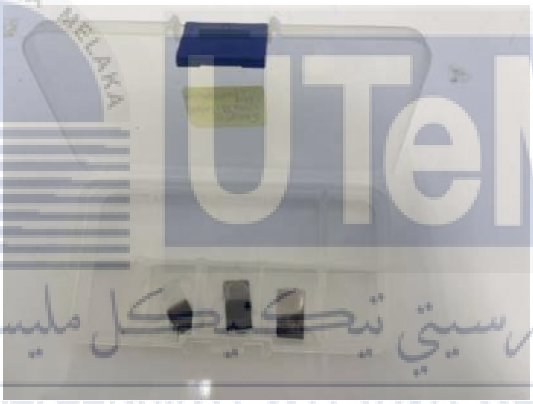

Figure 3.47 The GOx solution drop on electrodes

Figure 3.46 Electrodes soaked in GOx solution

Figure 3.45 Electrodes put in chiller

3.3.7 Process of Cyclic Voltammetry on PBS (Phosphate Buffered Saline)

In this process, we put the Phosphate Buffered Saline (PBS) on Deionized Water. In figure 3.49, the addition of Phosphate Buffered Saline (PBS) as shown in figure 3.50 into Deionized Water as shown in figure 3.51. The ratio of PBS to Deionized Water is shown to be 1:100ml in Figure 3.52.

Figure 3.48 PBS (Phospate Buffered Saline) and Deionized water

Figure 3.49 PBS (Phosphate Buffered Saline**)**

Figure 3.50 Deionized Water

Figure 3.51 Inserting PBS into 100 ml Deionized Water

3.3.8 Electrodeposition of PBS

After a 12-hour incubation period, the electrodeposition process commences, utilizing the electrodes that were previously stored in the freezer. The electrodeposition procedure involves the use of a 35 ml PBS (Phosphate Buffered Saline) solution. Once the PBS solution is meticulously prepared, the electrodeposition process is initiated. Figure 3.53 visually illustrates the electrodeposition procedure of PBS onto the different electrodes, marking a critical stage in the experimental protocol.

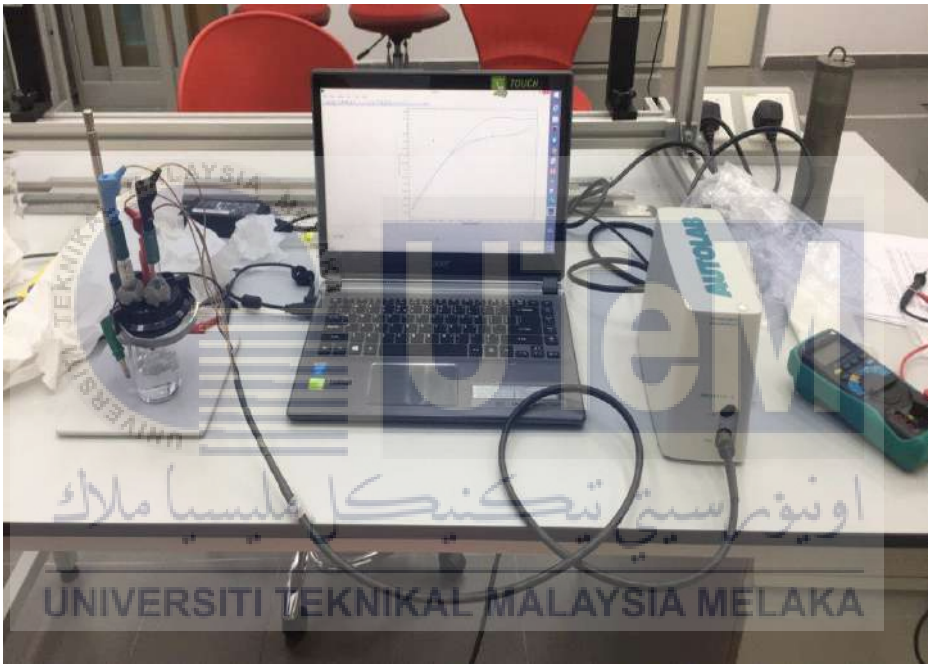

Figure 3.52 Eletrodeposition process PBS on electrode

3.3.9 Mixing Phosphate Buffered Saline (PBS) with Glucose

To achieve the project's objectives, it is necessary to incorporate glucose into the PBS solution. Figure 3.54 illustrates the glucose component. For the preparation of a 0.3 mM glucose solution, 3 mg of glucose, as depicted in figures 3.55 and 3.57, is combined with 35 ml of distilled water. This distilled water has previously been mixed with PBS, as illustrated in figure 3.56. This meticulous process ensures the proper integration of glucose into the PBS solution, a crucial step in the experimental methodology.

Figure 3.54 Glucose

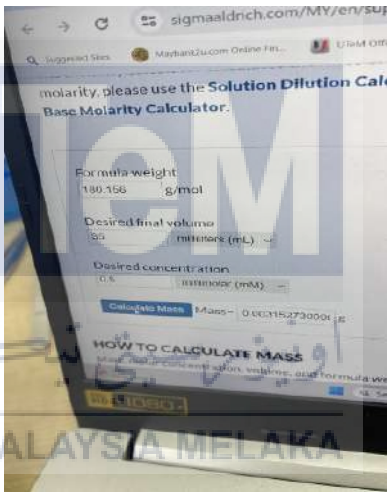

Figure 3.53 Formula

Figure 3.56 Glucose mix with disttilled water

Figure 3.55 Measured Glucose

3.3.10 Electrodeposition of 0.5 mM glucose solution and PBS

Continuing with the experimental procedure, the electrodeposition process is advanced by utilizing a solution comprising 0.5 mM glucose mixed with PBS. This solution is applied to carbon, indium tin oxide (ITO), and stainless steel electrodes. These electrodes have undergone a prior soaking in glucose oxidase (GOX) while stored in the freezer. This step builds on the preparation process, ensuring the incorporation of glucose into the electrodeposited material on carbon, indium tin oxide, and stainless steel surfaces.

Figure 3.57 Electrodeposition process with glucose solution

3.3.11 Analyse REDOX result

The analysis of redox results in carbon nanotubes for glucose detection can be done using a variety of methods, such as amperometry, cyclic voltammetry, and electrochemical impedance spectroscopy [83].

The factors that can affect the redox results in carbon nanotubes for glucose detection. Firstly, the type of carbon nanotubes used in the sensor plays a role. Single-walled carbon nanotubes (SWCNTs) are generally more conductive than multi-walled carbon nanotubes (MWCNTs), which can result in a larger current when glucose is reduced on their surface [84].

Additionally, the functionalization of the carbon nanotubes can impact the redox results. If the carbon nanotubes are functionalized with a molecule that acts as a catalyst for the reduction of glucose, it can enhance the redox process and lead to a higher current response compared to non-functionalized carbon nanotubes [84].

The concentration of glucose in the sample being tested is another significant factor [84]. As the glucose concentration increases, more glucose molecules are available for the redox reaction, resulting in an increased current response. Therefore, the redox results are directly influenced by the concentration of glucose present in the sample.

Furthermore, the temperature of the sample can affect the redox results. Higher temperatures generally accelerate the rate of the glucose reduction reaction, leading to an increased current response. The temperature dependence of the redox process should be considered to ensure accurate measurements and interpretation of the results [85].

Overall, understanding these factors and their influence on the redox results is crucial for optimizing glucose detection using carbon nanotubes [84]. By controlling and considering these variables, researchers can improve the sensitivity, selectivity, and reliability of the redox analysis in carbon nanotube-based glucose detection systems.

3.3.12 Characteristics sensing layer using FESEM and FTIR

The sensing layer in carbon nanotubes (CNTs) for glucose detection can be characterized using several analytical techniques, including field-emission scanning electron microscopy (FESEM) and Fourier-transform infrared spectroscopy (FTIR) [86].

FESEM allows for high-resolution imaging of the sensing layer's surface morphology [87]. It enables researchers to observe the size, shape, and distribution of the carbon nanotubes, as well as their interaction with the immobilized glucose. FESEM images provide insights into the presence of aggregates, the formation of a uniform layer, and any surface modifications that may impact glucose sensing performance [87].

FTIR analysis is employed to investigate the chemical bonds and functional groups in the sensing layer. It helps identify the presence of specific functional groups, such as carboxyl (-COOH) groups, involved in the functionalization of the CNTs [88]. FTIR spectra also reveal interactions between the immobilized glucose and the CNT surface, allowing for the identification of characteristic chemical bonds or shifts in peak positions [88].

Through the combined use of FE-SEM, and FTIR, researchers gain a comprehensive understanding of the structural, morphological, chemical, and optical properties of the sensing layer in CNT-based glucose detection [89]. This knowledge

contributes to the optimization of the sensing layer, leading to improved accuracy and sensitivity in glucose detection using carbon nanotubes.

3.3.13 Optimize Sensor Parameter

There are a number of sensor parameters that can be optimized in carbon nanotubes for glucose detection. The type of carbon nanotubes used significantly impacts sensor performance. Single-walled carbon nanotubes (SWCNTs), due to their enhanced conductivity compared to multi-walled carbon nanotubes (MWCNTs), can produce larger currents when glucose is reduced [84].

Another crucial aspect is the functionalization of carbon nanotubes. By introducing molecules that catalyze the reduction of glucose, the functionalized carbon nanotubes can generate larger currents, thus improving the sensor's sensitivity [90]. The concentration of glucose in the sample is an essential parameter to consider. As the glucose concentration increases, the current resulting from glucose reduction also increases. This correlation allows for more accurate and reliable glucose detection [91].

Temperature plays a vital role in sensor performance. As the sample temperature rises, the rate of glucose reduction accelerates, leading to an increase in the produced current. Controlling and optimizing the temperature can enhance the sensor's responsiveness and accuracy.

The choice of electrode material impacts the sensor's overall performance. For instance, gold electrodes exhibit higher conductivity than platinum electrodes, enabling them

to produce larger currents during glucose reduction [91]. Selecting the appropriate electrode material contributes to improved sensitivity and efficiency.

The electrolyte used in the sensor system also affects its performance. Electrolytes with a high concentration of ions facilitate more significant current generation during glucose reduction [91]. By carefully selecting the electrolyte composition, the sensor's sensitivity and response can be optimized.

Through the optimization of these sensor parameters, carbon nanotubes can be tailored for glucose detection, resulting in improved performance, enhanced sensitivity, and increased reliability. These advancements can pave the way for more accurate and efficient glucose monitoring technologies.

3.3.14 Test Enhanced Sensor Performance

The tests that can be used to test enhanced sensor performance in carbon nanotubes for glucose detection [92]. Sensitivity testing involves measuring the current generated by glucose reduction at various concentrations. A highly sensitive sensor will produce a larger current even at lower glucose concentrations, indicating superior detection capabilities.

Selectivity testing assesses the sensor's ability to differentiate glucose from other interfering molecules. By measuring the current produced in the presence of interfering substances, a more selective sensor will exhibit a larger current response to glucose and a smaller response to the interfering molecules [93].

Reproducibility testing involves measuring the current produced by glucose reduction multiple times at the same concentration [94]. A sensor with excellent reproducibility will consistently yield the same current measurement, indicating its reliability and precision.

Stability testing examines the sensor's performance over time [95]. By monitoring the current produced by glucose reduction at regular intervals, a stable sensor will demonstrate minimal fluctuations, ensuring consistent and reliable measurements throughout its lifespan.

Accuracy testing involves comparing the sensor's results with those obtained from a reference method such as high-performance liquid chromatography (HPLC). A highly accurate sensor will produce measurements that closely align with the reference method, indicating its reliability in quantifying glucose levels [95].

By conducting these comprehensive tests, the performance of carbon nanotube-based sensors for glucose detection can be thoroughly assessed. This evaluation enables the identification of areas for improvement, leading to advancements in sensitivity, selectivity, reproducibility, stability, and accuracy, ultimately enhancing the overall reliability and effectiveness of the sensor technology.

3.4 Process of Oxidation in Carbon Nanotube for Glucose Detection

The procedure of oxidation in carbon nanotubes (CNTs) for glucose detection involves several detailed steps [36]. To begin, carbon nanotubes are obtained or synthesized using methods such as chemical vapor deposition or arc discharge [37]. The CNTs are then purified to remove impurities and catalyst residues that could interfere with the oxidation process.

The next step is the functionalization of the CNT surface. In the case of oxidation, the goal is to introduce oxygen-containing functional groups onto the CNT surface. This can be achieved by treating the CNTs with strong oxidizing agents such as nitric acid (HNO3), sulfuric acid (H2SO4), or a mixture of acids like a mixture of concentrated H2SO4 and HNO3, also known as the "Piranha solution" [38]. These oxidizing agents react with the CNTs, leading to the incorporation of functional groups such as carboxyl (-COOH), hydroxyl (-OH), or carbonyl (-C=O) groups onto the CNT surface.

Once the CNTs are functionalized, the oxidation process can be initiated. This typically involves subjecting the functionalized CNTs to mild heating in the presence of an oxidizing gas, such as air or oxygen. The heating and exposure to oxygen promote the reaction between the oxygen-containing functional groups and the CNTs, resulting in the formation of additional functional groups and the removal of carbon atoms from the CNT structure. This oxidation process alters the surface chemistry and structure of the CNTs, making them more amenable to glucose detection.

After oxidation, the oxidized CNTs can be used to fabricate an electrochemical sensor for glucose detection [40]. The oxidized CNTs are typically deposited onto a

suitable substrate, such as a glassy carbon electrode or a gold electrode, using techniques like drop-casting, spin-coating, or electrodeposition.

To further enhance the selectivity and sensitivity of the sensor towards glucose, the sensor surface can be further modified. This can be achieved by immobilizing specific enzymes, such as glucose oxidase, or other glucose recognition elements onto the oxidized CNT surface. These recognition elements facilitate the specific binding and detection of glucose molecules.

Once the sensor is prepared, it can be used for glucose detection. The sensor is immersed in an electrolyte solution containing the glucose sample, and electrochemical measurements are performed [35]. Glucose molecules present in the sample undergo specific reactions on the sensor surface, resulting in measurable changes in current or potential. These changes can be correlated to the concentration of glucose in the sample, providing a means of glucose detection.

Overall, the procedure of oxidation in carbon nanotubes for glucose detection involves obtaining and purifying the CNTs, functionalizing the CNT surface, initiating the oxidation process, fabricating an electrochemical sensor, modifying the sensor surface, and performing electrochemical measurements for glucose detection [36]. These steps, when carried out carefully, contribute to the development of highly sensitive and selective glucose detection platforms based on carbon nanotubes.

3.5 Process of Reduction in Carbon Nanotube for Glucose Detection

The procedure for reducing carbon nanotubes (CNTs) for glucose detection involves several detailed steps. Firstly, carbon nanotubes are obtained or synthesized using methods such as chemical vapor deposition or arc discharge [41]. These CNTs are then subjected to a purification process to remove any impurities or catalyst residues that might affect their performance.

The next step is the functionalization of the CNT surface to enhance its electrochemical properties. One common approach is the treatment of CNTs with strong acids like nitric acid or sulfuric acid [41]. This treatment introduces functional groups, such as carboxyl (-COOH) or hydroxyl (-OH) groups, onto the CNT surface. The functionalization step improves the solubility and reactivity of the CNTs.

Following functionalization, the CNTs can be further reduced to enhance their electrochemical activity. Chemical reduction and electrochemical reduction are two commonly employed methods. In chemical reduction, a reducing agent like hydrazine or sodium borohydride is used to chemically reduce the CNTs [41]. Electrochemical reduction involves subjecting the CNTs to a potential cycling process in an electrolyte solution to induce reduction.

Once the CNTs are reduced, they can be utilized to fabricate an electrochemical sensor for glucose detection. This involves depositing the reduced CNTs onto a suitable substrate, such as a glassy carbon electrode or a gold electrode. Techniques like drop-casting, spin-coating, or electrodeposition can be employed for the deposition process.

To improve the selectivity and sensitivity of the sensor towards glucose, the sensor surface is further modified. This can be achieved by immobilizing specific glucose oxidase enzymes or other glucose recognition elements onto the CNT surface [63]. These recognition elements facilitate the specific binding and detection of glucose molecules.

With the sensor prepared, electrochemical measurements can be conducted for glucose detection. The sensor is immersed in an electrolyte solution containing the glucose sample. The glucose molecules in the sample undergo specific reactions on the sensor surface, leading to measurable changes in current or potential. These changes can be correlated to the concentration of glucose in the sample, providing a means of glucose detection.

Overall, the procedure of reducing carbon nanotubes for glucose detection involves steps such as obtaining and purifying CNTs, functionalizing the CNT surface, reducing the CNTs, fabricating an electrochemical sensor, modifying the sensor surface, and performing electrochemical measurements for glucose detection [41]. These steps, when followed meticulously, contribute to the development of highly sensitive and selective glucose detection platforms based on carbon nanotubes.

3.6 Simulation in Comsol

The simulation framework was constructed using COMSOL software, incorporating relevant physics modules, such as electrochemistry and mass transport, to accurately capture the behavior of the CNT-based glucose sensor. The geometry and material properties of the sensor were defined based on experimental data and literature references. The governing equations for the electrochemical reactions and diffusion of glucose were implemented within COMSOL, allowing for a comprehensive analysis of the sensor's performance.

Figure 3.58 COMSOL Software

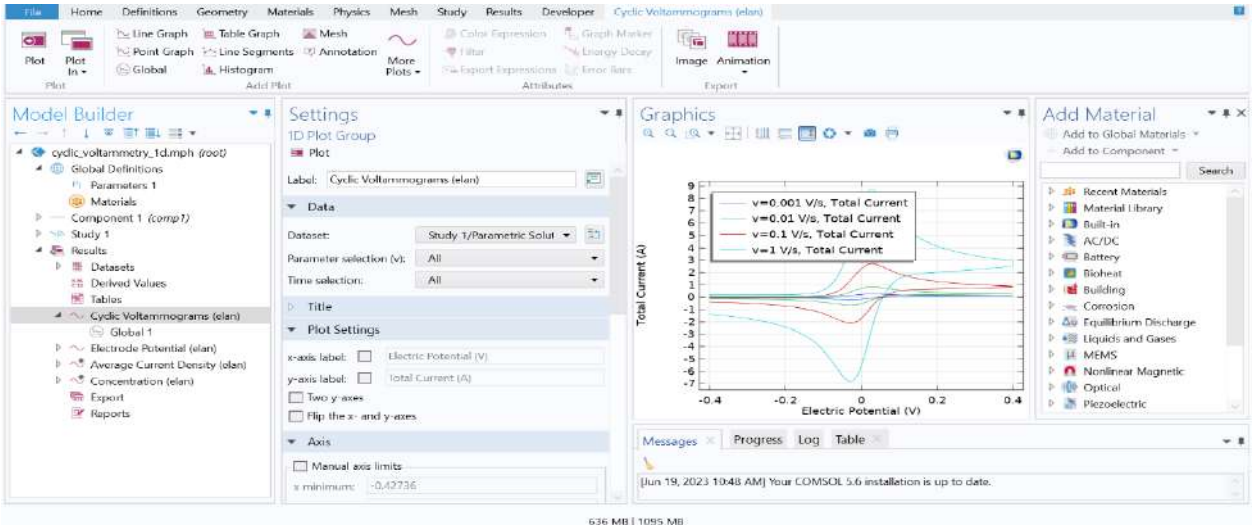

Figure 3.59 Simulation in COMSOL Software

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the initial and preliminary results of a carbon-based biosensor for glucose detection.

4.2 Results and Analysis

Figure 4.1 shows the cyclic voltammetry input parameters that has been put for 50 mV and the cyclic voltammetry output readings. Figure 4.2 shows the present the cyclic voltammetry graphs obtained at a voltage of 50 mV. Figures 4.3 shows the cyclic voltammetry input parameters that has been put for 100 mV and the cyclic voltammetry output readings. Figures 4.4 display the cyclic voltammetry graphs and output readings at a voltage of 100 mV. These graphs illustrate the relationship between electrical potential (V) and current density (A/m^2).

From the cyclic voltammetry graphs, it is evident that the flow of current and movement of electrons differ depending on the applied voltage. Analyzing the cyclic voltammetry output readings, we observe that the current measurement at 100 mV is higher compared to the output reading at 50 mV. This indicates that increasing the scan rate of the voltammetric experiment accelerates the experimental process and leads to higher current output readings.

Input and Results

Input

Electrolyte properties and kinetics

Bulk concentration of reactant:	1.0	mmol/L
Bulk concentration of product:	0	mmol/L
Temperature:	298.15	K
Diffusion coefficient of reactant:	1.0e-9	m^2/s
Diffusion coefficient of product:	1.0e-9	m^2/s
Exchange current density:	10	A/m^2
Anodic transfer coefficient (α):	0.5	
Cathodic transfer coefficient (α):	0.5	
Double layer interfacial capacitance:	0.2	F/m^2

Cyclic voltammetry parameters

Start potential:	-0.5	V
Switching potential:	0.5	V
Voltammetric scan rate:	0.05	V/s
Number of scans for sample preparation:	3	

Results

Peak anodic current:	1.667	A/m^2
Electrode potential at peak anodic current:	0.03765	V
Peak cathodic current:	-1.523	A/m^2
Electrode potential at peak cathodic current:	-0.03587	V
Potential difference, cathodic vs anodic peak:	0.07352	V

Figure 4.1 Setting parameter input for scan rate 50 mV and results

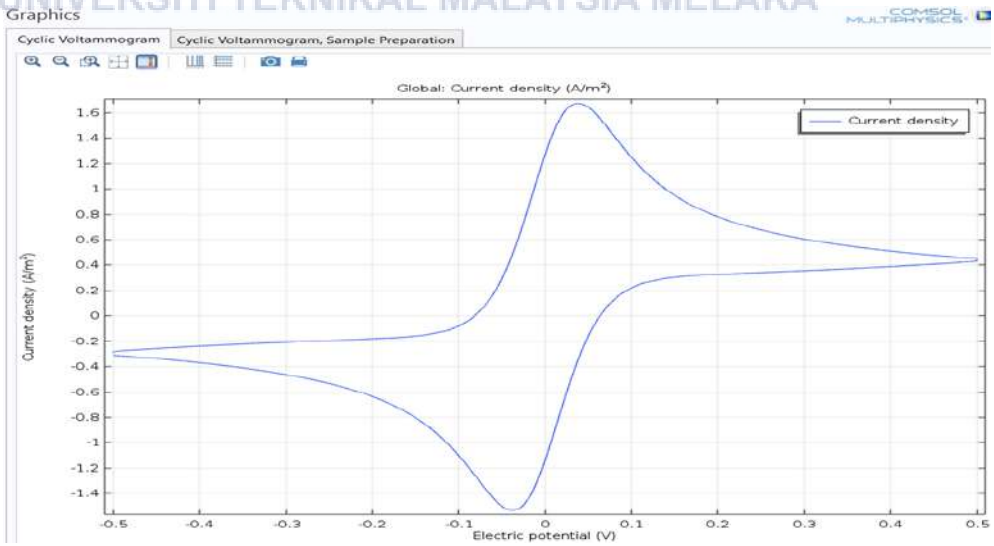

Figure 4.2 Cyclic Voltammetry Output Graph for 50mV

Input and Results

Input

Electrolyte properties and kinetics

Bulk concentration of reactant:	1.0	mmol/L
Bulk concentration of product:	0	mmol/L
Temperature:	298.15	K
Diffusion coefficient of reactant:	1.0e-9	m^2/s
Diffusion coefficient of product:	1.0e-9	m^2/s
Exchange current density:	10	A/m^2
Anodic transfer coefficient (α):	0.5	
Cathodic transfer coefficient (α):	0.5	
Double layer interfacial capacitance:	0.2	F/m^2

Cyclic voltammetry parameters

Start potential:	-0.5	V
Switching potential:	0.5	V
Voltammetric scan rate:	0.1	V/s
Number of scans for sample preparation:	3	

Results

Peak anodic current:	2.316	A/m^2
Electrode potential at peak anodic current:	0.04091	V
Peak cathodic current:	-2.113	A/m^2
Electrode potential at peak cathodic current:	-0.03939	V
Potential difference, cathodic vs anodic peak:	0.0803	V

Figure 4.3 Setting Parameter input for scan rate 100mV and results.

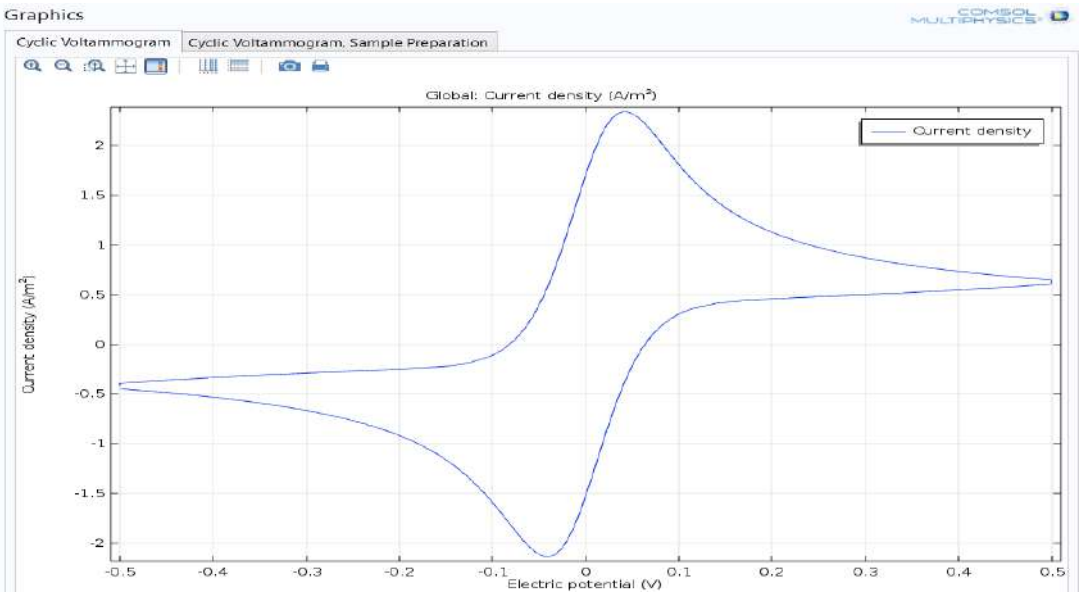

Figure 4.4 Cyclic Voltmmetry Output Graph for 100 Mv

4.2.1 Field Emission Scanning Electron Microscopy Result

In the sonication process, Multi-Walled Carbon Nanotubes (MWCNT) and Sodium Dodecyl Benzene Sulfonate (SDBS) are sonicated for a total duration of 4 hours, with samples extracted every 30 minutes into microcentrifuge tubes. The selected samples for characterization through Field Emission Scanning Electron Microscopy (FESEM) are those subjected to sonication for 2 hours and 3 hours.

Figure 4.5 provides an overview of the original CNT. Figure 4.6 showcases CNT after a 2-hour sonication process, while Figure 4.7 displays CNT after a 4-hour sonication process. This characterization is crucial to observe size variations in CNT, highlighting differences after 2 and 4 hours of sonication. This analysis informs the decision to truncate the sonication duration from the initial 4 hours to a more optimal range of 2 to 3 hours.

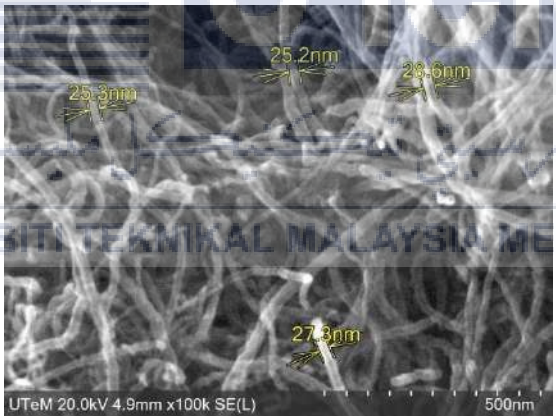

Figure 4.5 Original CNT without undergo sonification process

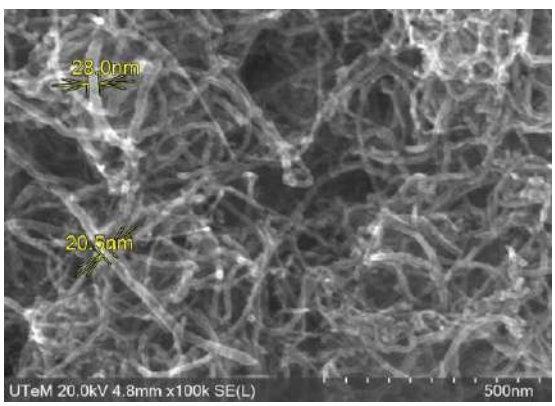

Figure 4.6 CNT undergo 2 hours sonication process

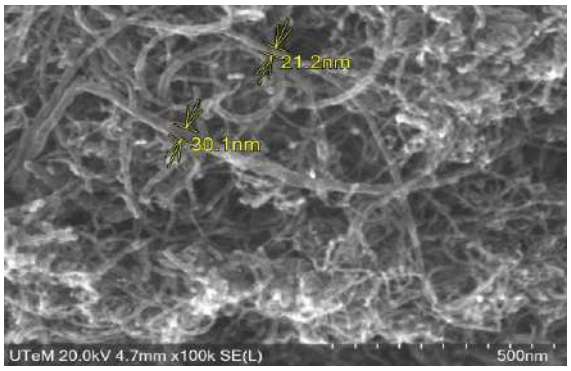

Figure 4.7 CNT undergo 4 hours sonication process

4.3 FTIR After Sonication Process Result

In the sonication process, Multi-Walled Carbon Nanotubes (MWCNT) and Sodium Dodecyl Benzene Sulfonate (SDBS) undergo a 4-hour sonication period, with samples extracted every 30 minutes into microcentrifuge tubes. Two samples are collected for further analysis. In the subsequent cleaning process, two methods, denoted as A and B, are employed. For Method A, the sample is initially washed with distilled water, followed by centrifugation to ensure the settling of carbon nanotubes (CNT) at the tube's base. Subsequently, a wash with ethanol is performed. In Method B, the sample is washed with distilled water, subjected to the mini centrifuge for CNT settling, and then cleaned once again with distilled water.

The samples chosen for FESEM characterization include those subjected to 3 hours of sonication using different cleaning methods (A and B), along with the original CNT without sonication. Figure 4.8 visually presents the original CNT without undergoing the sonication process for black line which is label as MWCNT-COOH (raw). For red line shown, CNT after 3 hours of sonication with cleaning method A which label as MWCNT-COOH. After Sonicate A, while blue line displays CNT after 3 hours of sonication with cleaning method B is label as MWCNT-COOH After Sonicate B. This characterization aims to assess the effectiveness of cleaning methods (A and B) in removing Sodium Dodecyl Benzene Sulfonate (SDBS) after sonication. Additionally, the study seeks to analyze the elemental composition of Carbon Nanotubes (CNT) after the sonication process and compare it to the original CNT before undergoing sonication.

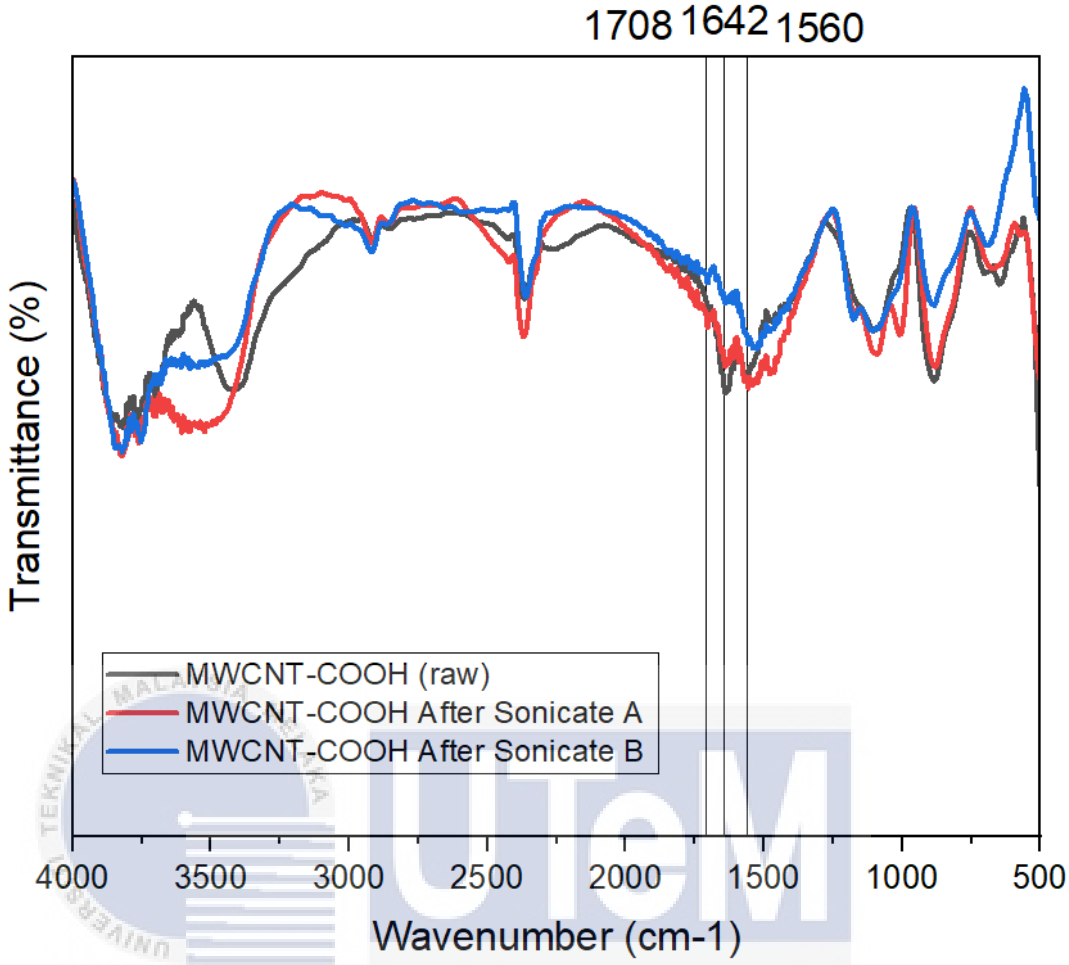

Figure 4.8 Graph of FTIR for MWCNT after sonication process

Based on the graph, the method A is the best cleaning method because the line shown that MWCNT-COOH is followed the black colour line which is the MWCN-COOH (raw) before sonication. The investigation of modified carbon nanotubes (CNT) initially utilized FTIR spectroscopy. The presence of carboxyl functional groups on the surface of MWCNT-COOH is indicated by characteristic C–O bands observed at 1708, 1642, and 1560 cm^{-1}. The peak at 1560 cm^{-1} is specifically associated with the stretch mode of the carboxylate anion [96].

4.4 Electrode Coating Result

4.4.1 Electrode Coating Result in PPY/MWCNT

Each of the electrode is being coated in Ppy-MWCNT at 3 minutes and 5 minutes respectively. As shown at the figure below, there are carbon, indium tin oxide and stainless steel that have been coated to Ppy-MWCNT solution that have been sonicate 1.5 hours and 3 hours for 3minutes as in figure 4.9 and 5 minutes as in figure 4.10.

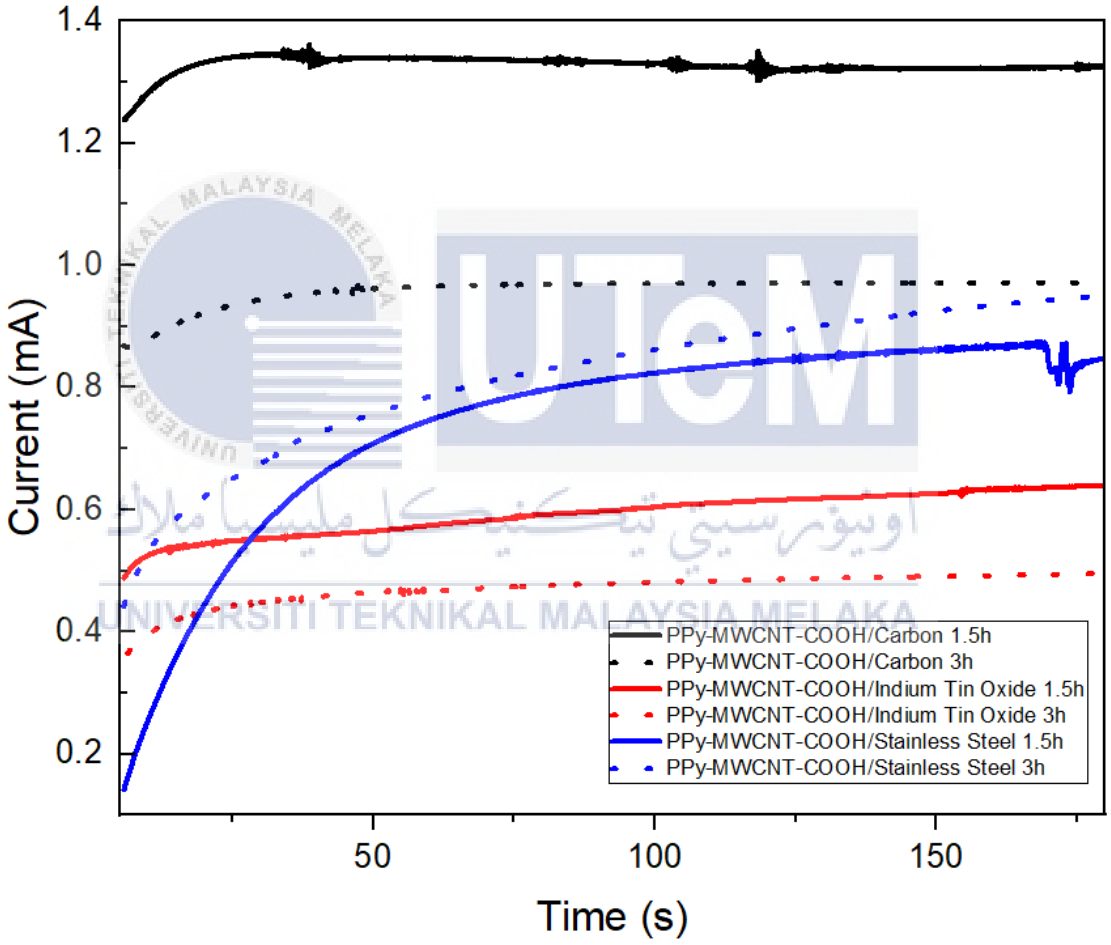

Figure 4.9 Chronoamperometry for 3 minutes

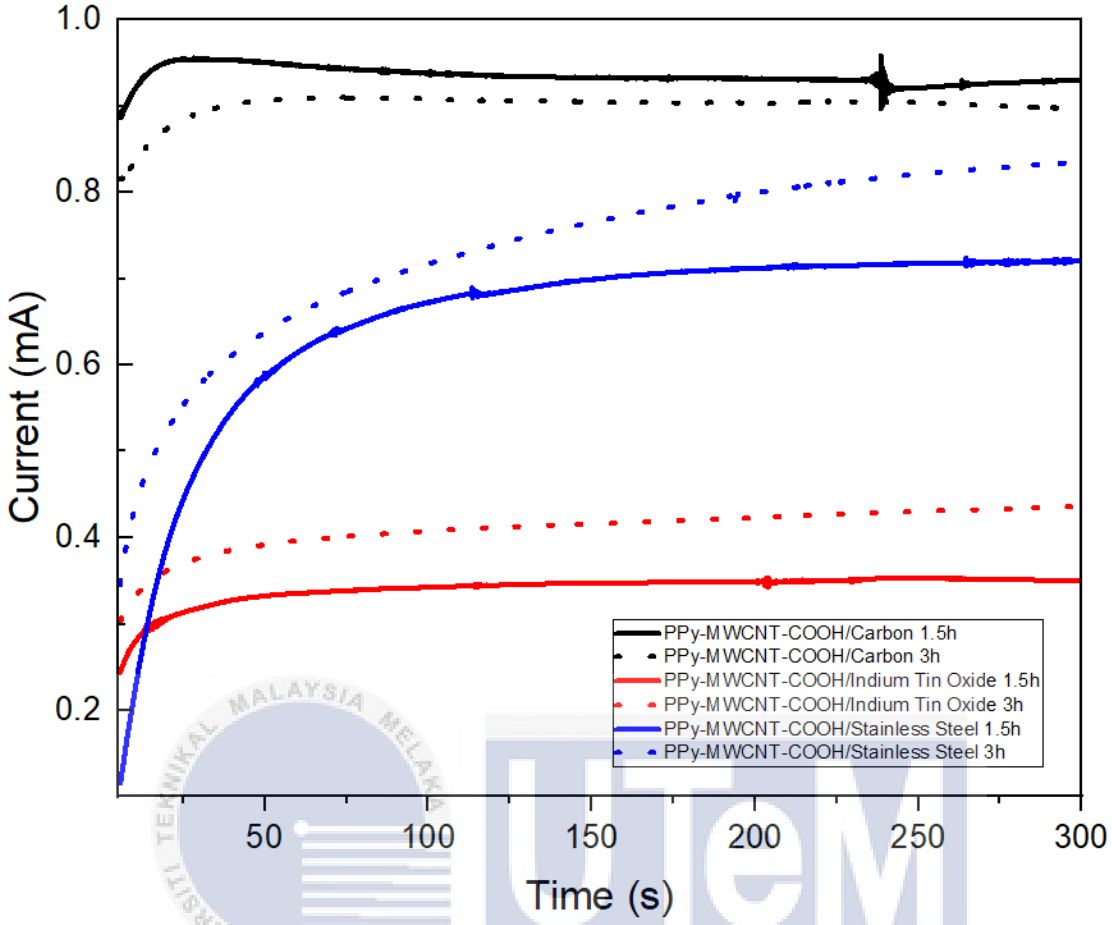

Figure 4.10 Chronoamperometry for 5 minutes

4.5 Electrode Coating Result FTIR

This process involves the examination of elemental composition after coating electrodes for varying durations specifically, 3 minutes and 5 minutes utilizing a Multi-Walled Carbon Nanotube (MWCNT) solution subjected to sonication for 1.5 hours and 3 hours using diferrent electrodes. This systematic approach aims to analyze the FTIR spectra to understand the effects of sonication duration and coating time on the elemental composition of the coated electrodes. Figure 4.11 shown graph of ftir for 3 minutes using 1.5 hours and figure 4.12 using 3 hours sonication solution. Figure 4.13 shown graph of ftir for 5 minutes using 1.5 hours sonication solution and figure 4.15 using 3 hours sonication solution

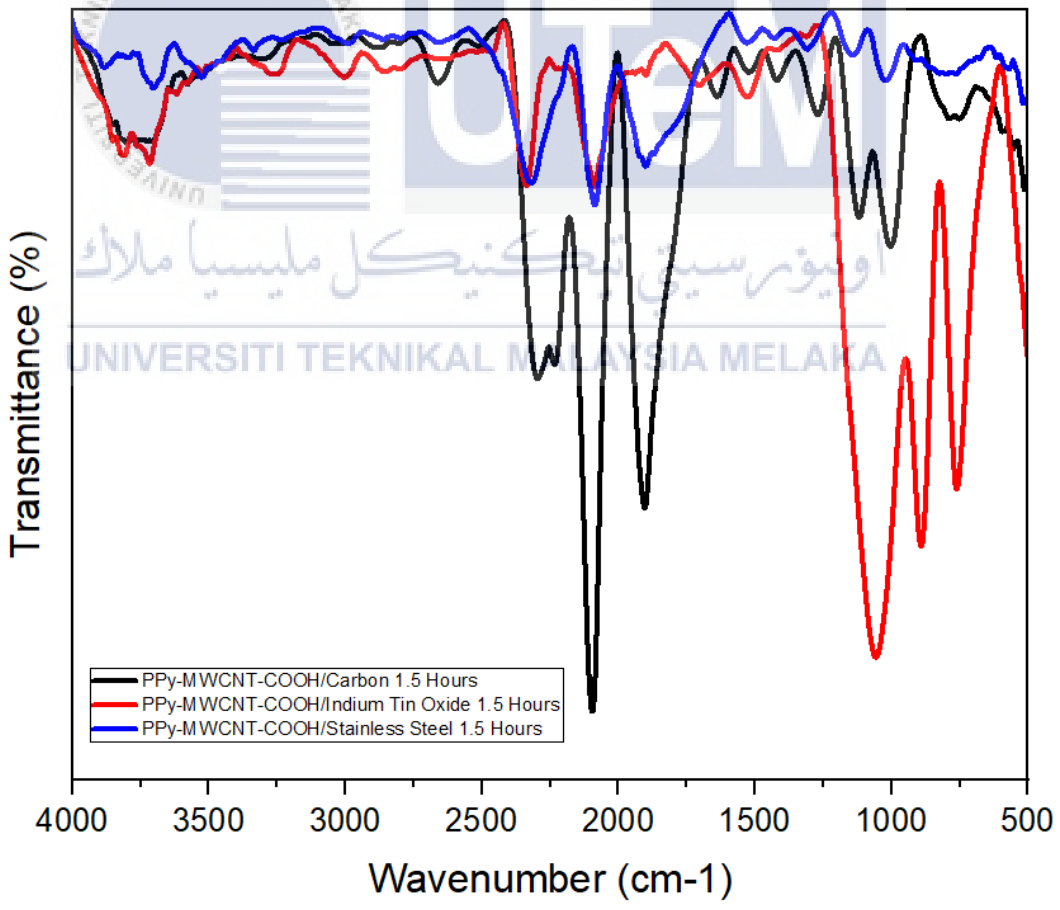

Figure 4.11 Graph of FTIR for 3 minutes using 1.5 hours sonication solutin

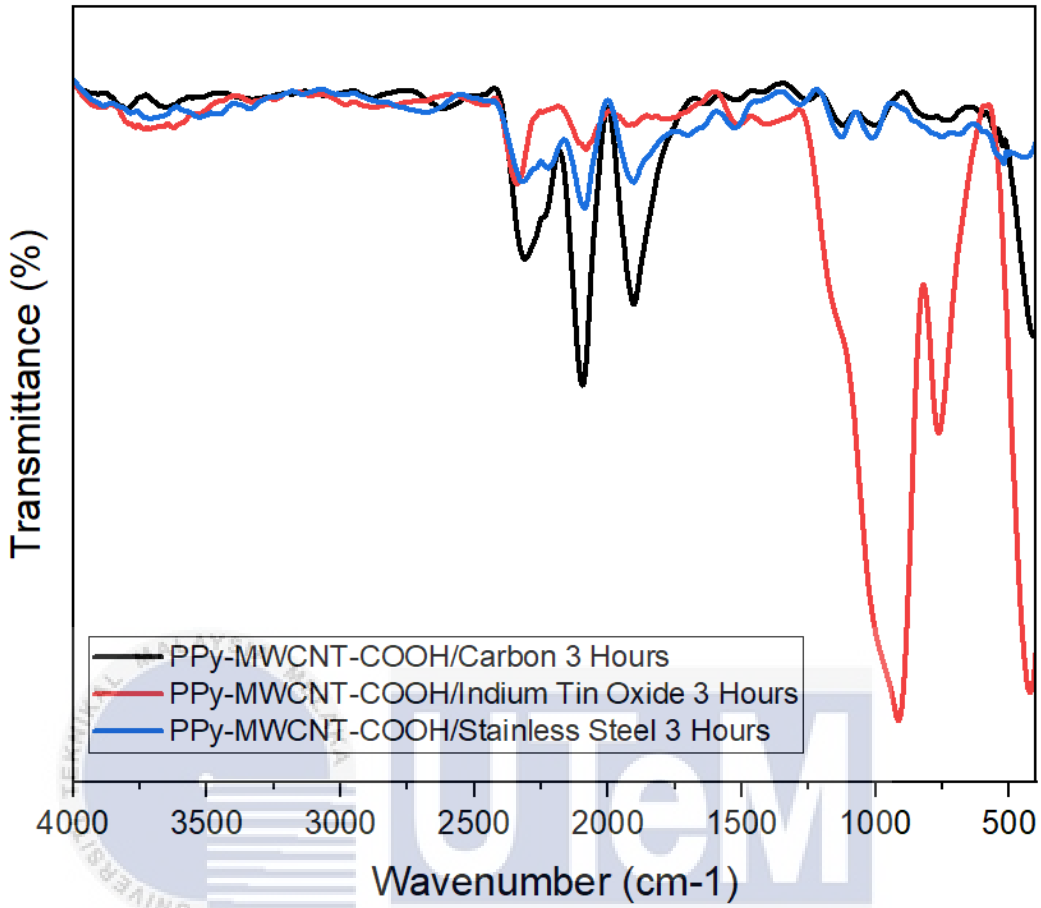

Figure 4.12 Graph of FTIR for 3 minutes using 3 hours sonication solution

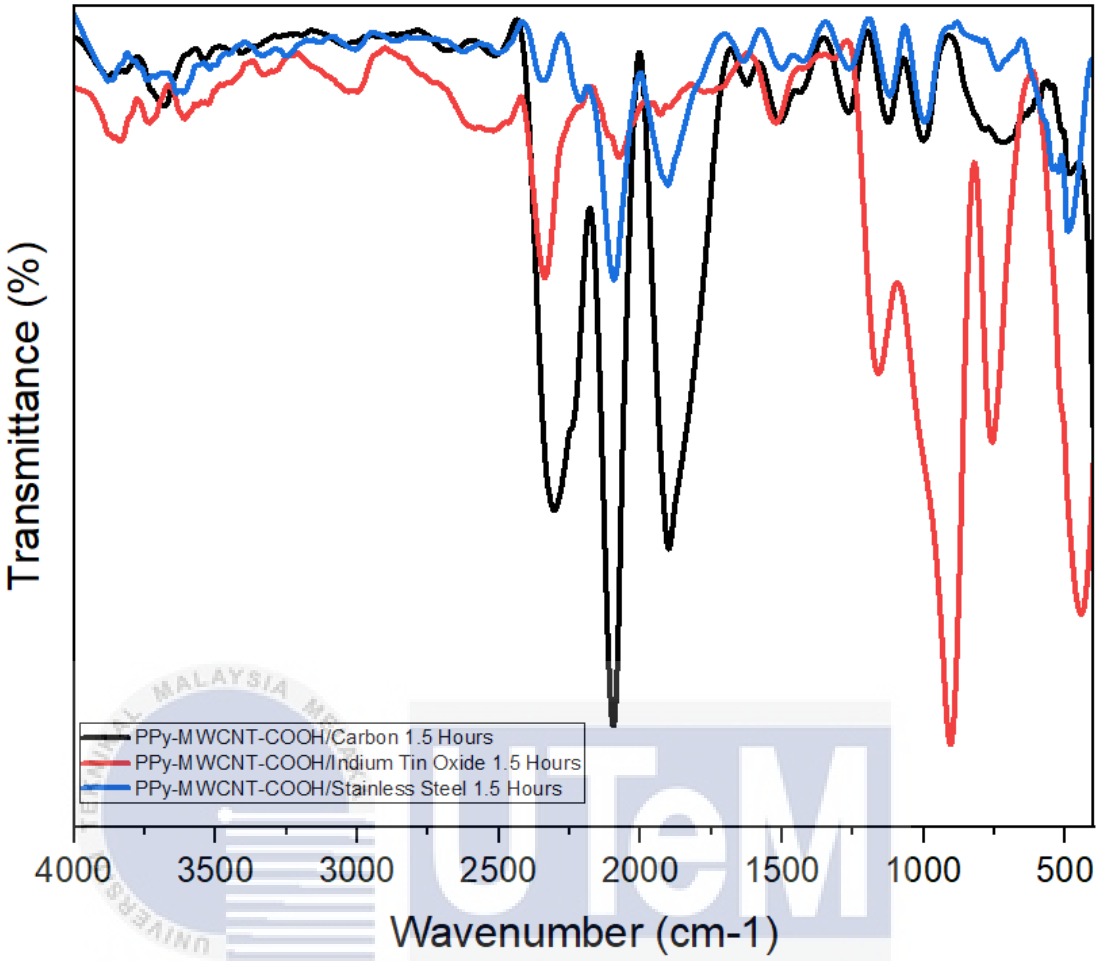

Figure 4.13 Graph of FTIR for 5 minutes using 1.5 hours sonication solution

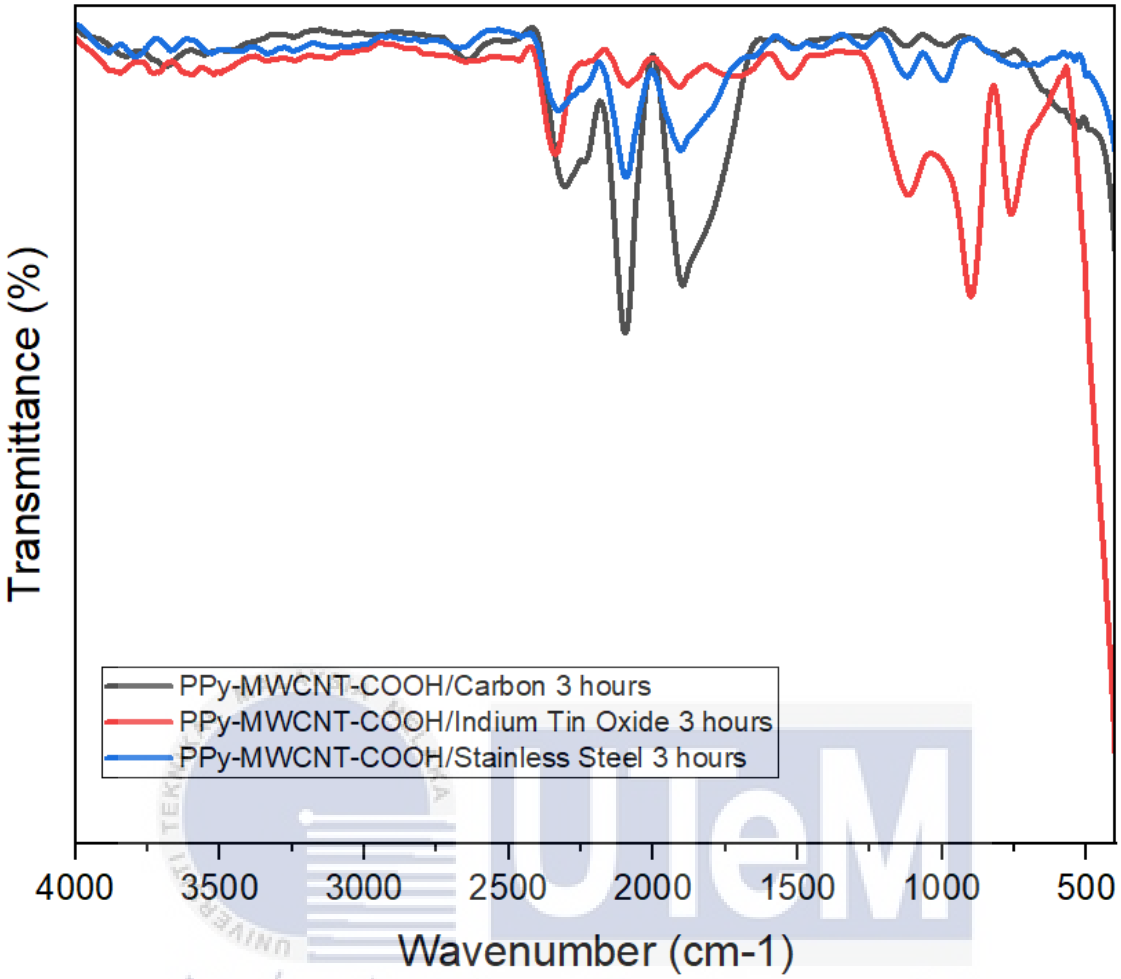

Figure 4.14 Graph of FTIR for 5 minutes using 1.5 hours sonication solution

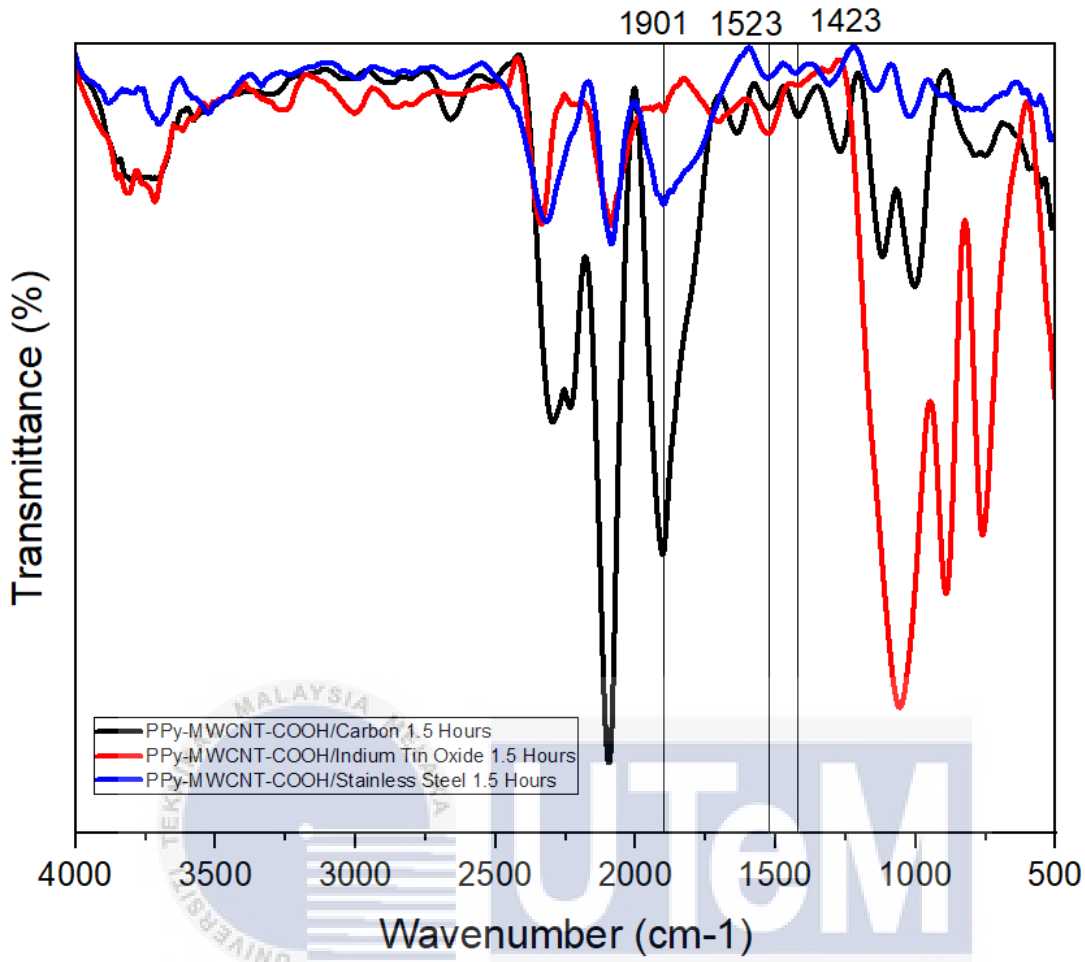

Figure 4.15 Graph of FTIR with label

In figure 4.15, using the graph of ftir 3 minutes for 1.5 hours sonication solution, The distinctive absorption peaks of the C–OH bond are evident on the surface of MWCNTs. Significantly, the characteristic absorption peaks observed at 1523 cm^{-1} and 1423 cm^{-1} in MWCNTs−COOH correspond to the stretching vibration of C–C and C–O within MWCNTs. A noteworthy change is observed when comparing FTIR spectrum curves a and b, where a new absorption peak emerges in curve b at 1901 cm^{-1}.

4.6 Electrode Result after Immobilization

As shown at the figures below, figure 4.16 are using carbon electrodes for cyclic voltammetry process. Then, figure 4.17 are using indium tin oxide electrodes for cyclic voltammetry process. Lastly, Figure 4.18 are using stainless steel electrodse for cyclic voltammetry process.

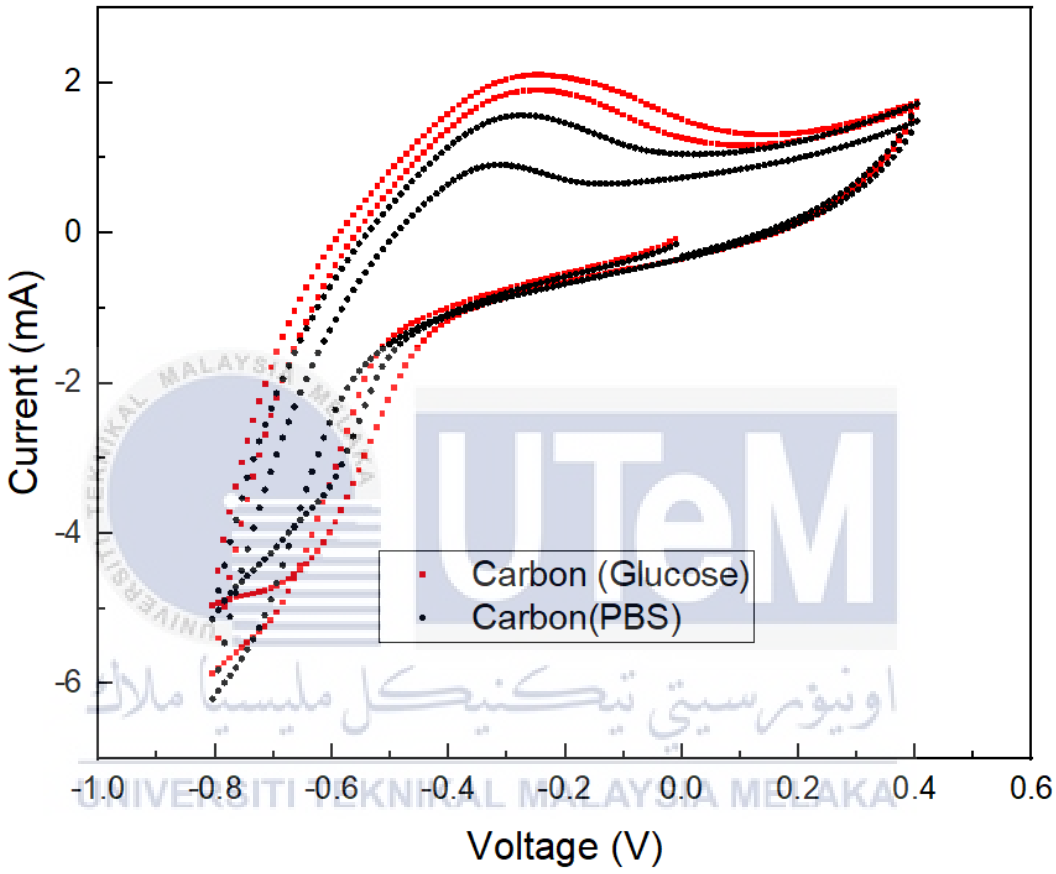

Figure 4.16 Cyclic Voltammetry of Carbon

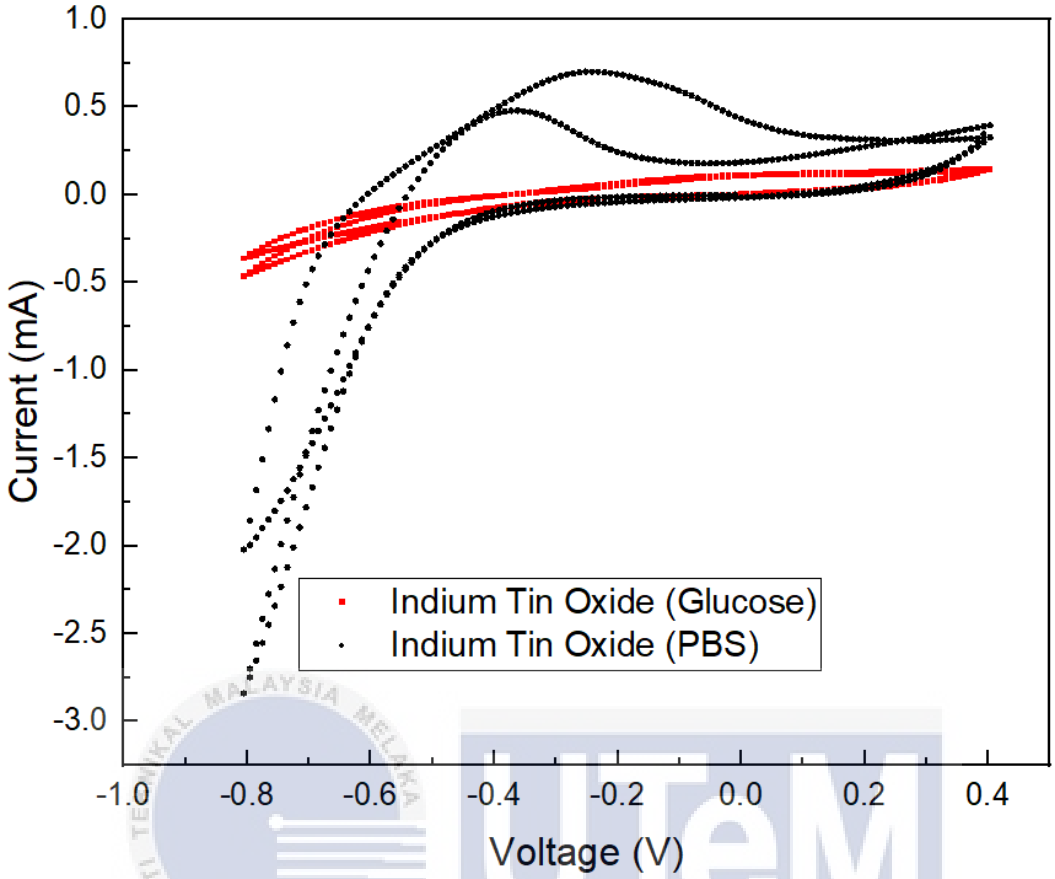

Figure 4.17 Cyclic Voltammetry of Indium Tin Oxidde

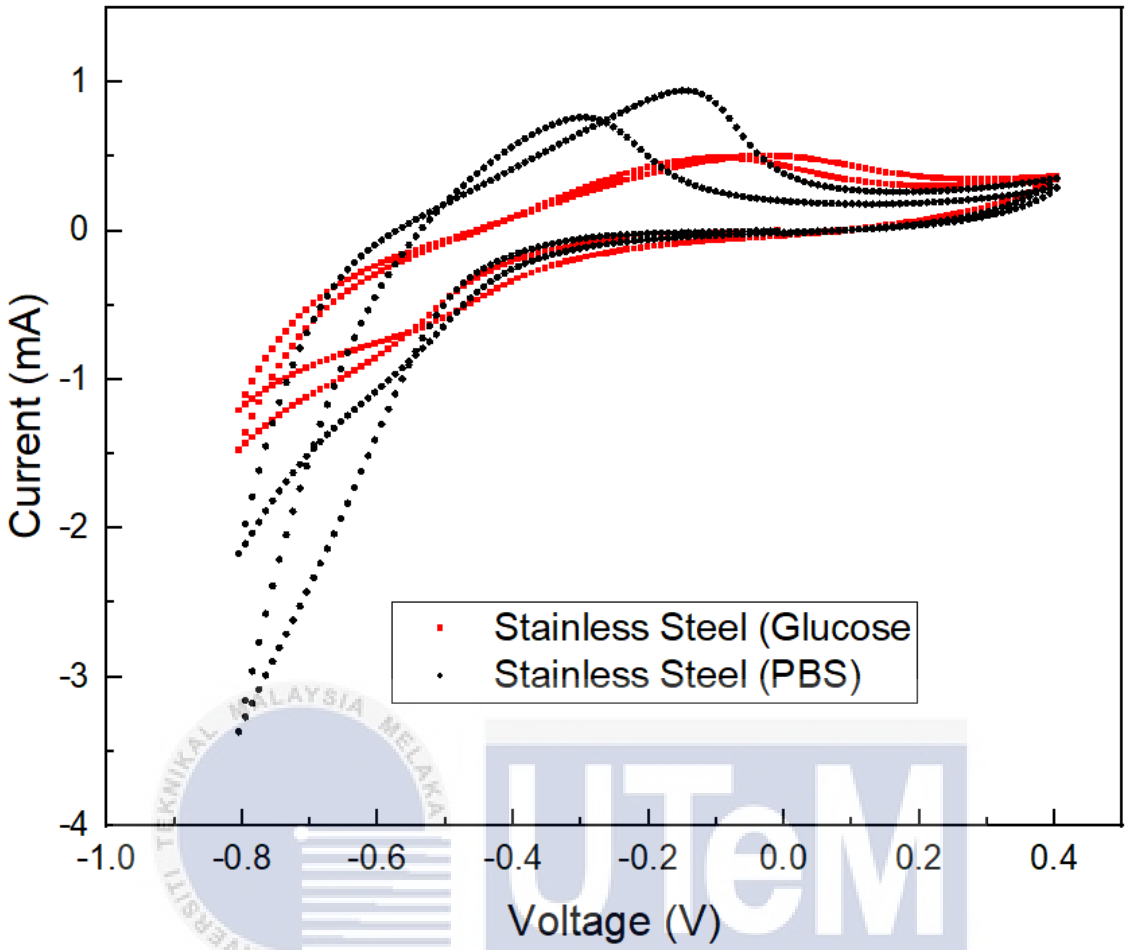

Figure 4.18 Cycliv Voltammetry of Stainless Steel

Based on this graph of cyclic voltammetry for the realm of electrochemical studies, the selection of an appropriate substrate plays a pivotal role in influencing the performance and efficiency of electroactive materials. The cyclic voltammetry (CV) graph obtained for indium tin oxide (ITO), stainless steel, and carbon substrates reveals distinctive electrochemical characteristics that warrant attention in the context of substrate suitability. ITO, known for its high conductivity and transparency, exhibits a noteworthy response in the cyclic voltammogram, suggesting its efficacy as a promising substrate. Stainless steel, recognized for its durability and corrosion resistance, demonstrates a comparable performance, showcasing its potential utility in electrochemical applications. Meanwhile, carbon, with its diverse forms and excellent conductivity, exhibits a robust electrochemical

behavior, further substantiating its candidacy as a favorable substrate. This analysis underscores the importance of substrate selection in electrochemical investigations, emphasizing the unique attributes of ITO, stainless steel, and carbon as substrates that merit careful consideration for enhancing electrochemical performance. Future studies may delve deeper into the specific electrochemical mechanisms at play on these substrates to unravel the nuanced intricacies of their interactions with electroactive materialsElectrode Result Immobalizition FTIR.

4.7 FTIR in Immobilization Process

As shown at the figures below, figure 4.19 are graph of FTIR for electrodes after coating and the electrodes that have being soak in EDC-NHS solution. So the straight line refer to electrode after coating which is PPy-MWCNT-COOH while the dot line for electrodes that have being soak in EDC-NHS solution which is PPy-MWCNT-COOH-NH. The occurrence of stretching vibration at 1886 cm^{-1} indicates the attachment of enzyme molecules on the nanotubes through the (–COOH) functional group. Additionally, the presence of peaks at 3346 and 3327 cm^{-1} suggests the existence of N-H, highlighting the bonding of phytase on the surface of modified multi-walled carbon nanotubes (MWNTs) [97].

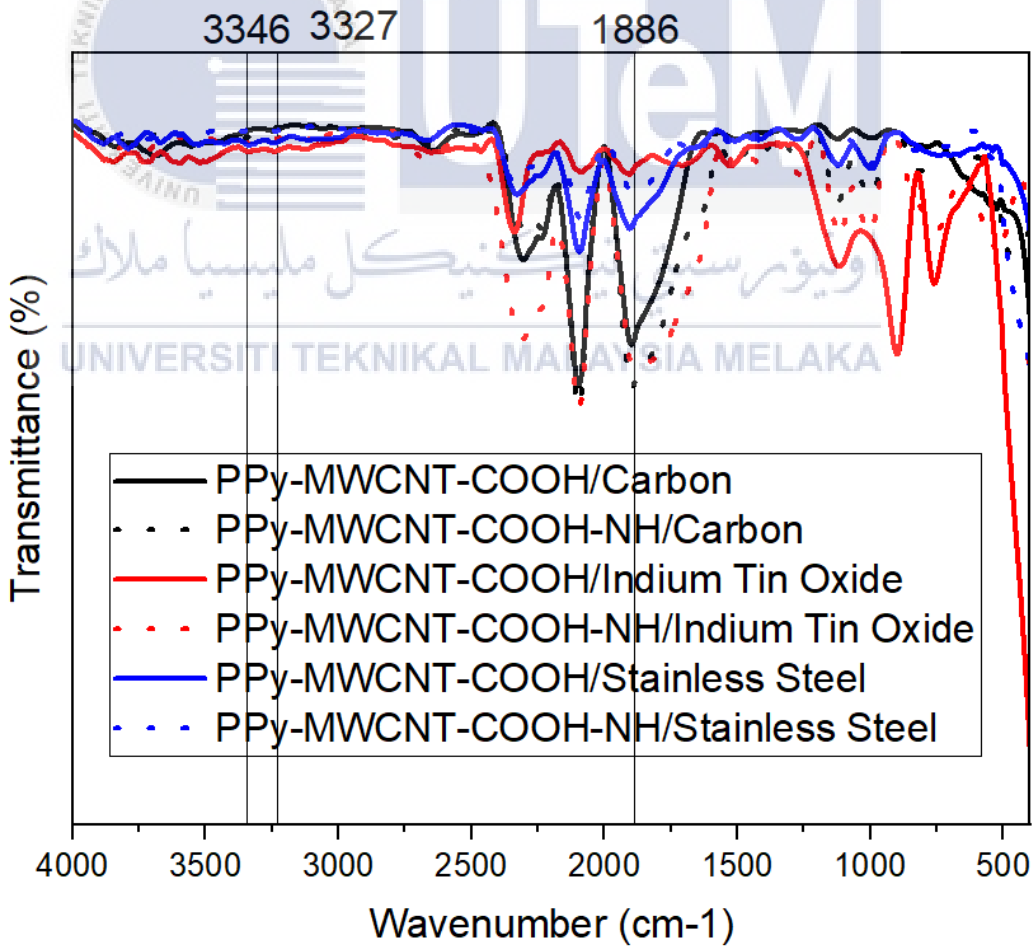

Figure 4.19 Graph of FTIIR for Immobilization Process

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Glucose biosensors have emerged as highly effective tools, benefiting communities and serving as a preventive measure against potential fatalities and diseases. Among these biosensors, nanoelectronic glucose biosensors have gained recognition for their ability to complement early detection methods for harmful chemical or biological agents within the human body. Notably, these biosensors possess the capability to convert biological signals into electrical or electronic signals, facilitating easy measurement, quantification, and amplification. This significant advancement holds promise for the future development of glucose biosensors.

A key advantage of biosensor technology lies in its cost-effectiveness and high specificity for detecting target analytes. The project's objectives were successfully achieved, with the simulation functioning flawlessly. Consequently, the analysis of data pertaining to redox reactions and reductions was feasible. This accomplishment also fulfilled the intended goals outlined in the bachelor's degree project.

To conclude a research or report on cyclic voltammetry, it is crucial to outline the major findings and insights derived from the conducted experiments and data analysis. This includes elucidating the reduction and oxidation potentials of materials such as carbon, aluminum, copper, and stainless steel electrodes.

5.2 Potential for Commercialization

The commercialization of nanoelectronic biosensors involves the entire lifecycle of developing, manufacturing, and marketing these sensors for diverse applications, including medical diagnostics, environmental monitoring, and food safety. This process typically encompasses research and development efforts aimed at enhancing sensor performance, reliability, and cost-effectiveness, while also minimizing their size. Once the biosensors are designed and thoroughly tested, they can be produced on a large scale and made available to various industries and end-users.

5.3 Future Works

Ongoing research efforts are focused on the development of nanoelectronic biosensors specifically designed for glucose detection. One promising approach involves utilizing nanoparticles, such as gold or silicon, as the sensing element within the biosensor. These nanoparticles can be functionalized with glucose-specific enzymes or antibodies, enabling them to selectively bind to glucose molecules and generate an easily measurable electrical signal. Another approach involves employing carbon nanotubes or graphene as the sensing element, which can also be functionalized with glucose-specific enzymes or antibodies. These nanoelectronic biosensors hold great promise in terms of their anticipated high sensitivity, specificity, and stability, enabling continuous glucose monitoring for individuals with diabetes. However, it is important to note that these biosensors are currently in the research and development phase, and further efforts are necessary before they can be extensively utilized in clinical applications.

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APPENDICES

PROJECT ACTIVITIES	STATUS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16
BDP Briefing	E									M							S
	A																
Meeting with Supervisor	E									I							T
	A																
Finding equipment and Paper research	E									D							U
	A																
PSM 1 Rubrics Explanation	E									B							D
	A																
Project planning	E									R							Y
	A																
Chapter 1 Preparation	E									E							
	A																
Chapter 2 Preparation	E									A							W
	A																
Chapter 3 Preparation	E									K							E
	A																
Construct the simulation	E																E
	A																
Preparation for present	E									M							
	A																
Report draft submission	E																
	A																
PSM 2 Present	E																
	A																