UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Technology and Engineering

FABRICATION OF CARBON NANOTUBES THIN FILMS FOR BIOSENSOR APPLICATIONS VIA ELECTRODEPOSITION METHOD

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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FABRICATION OF CARBON NANOTUBES THIN FILMS FOR BIOSENSOR APPLICATIONS VIA ELECTRODEPOSITION METHOD

PRIYATHARSHINI A/P RAMALINGAM

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i

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APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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DEDICATION

To my beloved father, Ramalingam Muniyandi, and my beloved mother, Kanagamalar Govindan, they are my inspiration and motivation.

Thank you for always giving me endless love and support for me.

To my siblings, Arvindraj Ramalingam,

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Kaladewi Ramalingam,

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ABSTRACT

In the fabrication of carbon nanotubes thin films for biosensor applications via electrodeposition, a common approach involves the utilization of nanomaterials such as carbon nanotubes or graphene as the sensing elements . Carbon nanotube (CNT) composites are potential functional materials because to their exceptional qualities in addition to metal features, and as a result, several production procedures for these composites have been extensively investigated. This paper proposes Electrodeposition as an alternate approach for generating Multiwalled Carbon Nanotubes (MWCNT). In the case of electrodeposition using CNT templates, the electrodeposition of metals not only on the surfaces but also interior of the CNT templates is the key process to fabricate high performance CNT composite. The chronoamperometry technique is used in this study to create a nanofilm of Polypyrrole (PPY) and Multiwalled Carbon Nanotube (MWCNT). The electrodeposition and cyclic voltammetry of the produced nanofilm are carried out with an AutoLAB potentiostat and NOVA 2.0 AutoLAB software. The nanofilm is characterized using Fourier transform infrared spectroscopy (FTiR) and field emission scanning electron microscopy (FE-SEM) to examine its shape and material characteristics. The carbon electrode had the maximum current at 1.326 mA after 3 minutes of chronoamperometry with PPY/MWCNT 1.5 hours sonication. However, lengthier chronoamperometry techniques provide different findings. After 5 minutes, the carbon electrode has the largest current (0.929 mA), followed by stainless steel (0.721 mA) and indium tin oxide (0.350 mA). Furthermore, after 3 minutes of PPY/MWCNT 3 hours sonication, the carbon electrode has the maximum current at 0.972 mA, followed by stainless steel at 0.954 mA and 0.496 mA. After 5 minutes, the carbon electrode recorded the maximum current (0.898 mA), followed by stainless steel (0.836 mA) and indium tin oxide electrode (0.437 mA). This study offers valuable guidance for creating smooth nanostructured films on various substrates for diverse purposes.

ABSTRAK

Dalam pembuatan karbon nanotubes filem tipis untuk aplikasi biosensor melalui electrodeposition, pendekatan yang biasa melibatkan penggunaan nanomaterials seperti nanotube karbon atau graphene sebagai elemen pengesan. Komposit karbon nanotube (CNT) adalah bahan fungsional potensial kerana kualiti luar biasa mereka di samping ciri-ciri logam, dan sebagai hasilnya, beberapa prosedur pengeluaran untuk komposit ini telah dipelajari secara meluas. Artikel ini mencadangkan Electrodeposition sebagai pendekatan alternatif untuk menghasilkan Multiwalled Carbon Nanotubes (MWCNT). Dalam kes elektrodeposition menggunakan template CNT, electrodeposition logam bukan sahaja pada permukaan tetapi juga dalaman templates CNT adalah proses utama untuk membina komposit CNT prestasi tinggi. Teknik kronoamperometri digunakan dalam kajian ini untuk mewujudkan nanofilm Polypyrrole (PPY) dan Multiwalled Carbon Nanotube (MWCNT). Elektrodeposisi dan voltametry siklik nanopilem yang dihasilkan dijalankan dengan AutoLAB potentiostat dan NOVA 2.0 Autolab perisian. Nanofilm ditandai dengan menggunakan spektroskopi inframerah transform Fourier (FTiR) dan mikroskop elektron pemindaian emisi medan (FE-SEM) untuk mengkaji bentuk dan ciri-ciri bahan. Elektroda karbon mempunyai arus maksimum pada 1.326 mA selepas 3 minit kronoamperometri dengan PPY/MWCNT 1.5 jam ultrasound. Walau bagaimanapun, teknik kronoamperometri yang lebih panjang memberikan penemuan yang berbeza. Selepas 5 minit, elektroda karbon mempunyai arus terbesar (0,929 mA), diikuti oleh keluli tahan karat (0,721 mA) dan indium tin oksida (0.350 mA). Di samping itu, selepas 3 minit PPY/MWCNT sonication 3 jam, elektroda karbon mempunyai arus maksimum pada 0.972 mA, diikuti oleh keluli tahan karat pada 0.954 mA dan 0.496 mA. Selepas 5 minit, elektroda karbon mencatat arus maksimum (0,898 mA), diikuti oleh keluli tahan karat (0,836) dan elektroda oksida timun indium (0.437 mA). Kajian ini menawarkan panduan yang berharga untuk mewujudkan filem nanostructured halus pada pelbagai substrat untuk pelbagai tujuan.

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LIST OF SYMBOLS

δ - Voltage angle
θ - Theta
-
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LIST OF ABBREVIATIONS

V - Voltage
SPR - Surface Plasmon Resonanse
FET - Field-Effect Biosensor
MWCNTs - Multiwalled carbon nanotubes
mA - Milliampere
SS - Stainless steel
MHz - Megahertz
ng/ml - Nanograms per Milliliter
fg/ml - Femtogram per Molliliter
pH - Potential of Hydrogen
KHz - Kilohertz
PPy - Polypyrrole
LED - Light-Emitting Diode
CNTs - Carbon Nanotubes
ITO - Indium Tin 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
Li - Lithium
K - Potassium
Ba - Barium
Ca - Calcium
Na - Sodium
Mg - Magnesium
Al - Aluminium
Mn - Manganese
Zn - Zinc
Cr - Chromium
Fe - Iron
Cd - Cadmium

Co - Cobalt
Ni - Nickel
Sn - Tin
Pb - Lead
H_2 - Hydrogen
Cu - Copper
Ag - Silver
Hg - Mercury
Pt - Platinum
Au - Gold

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CHAPTER 1

INTRODUCTION

In recent years, researchers around the world have been fascinated by the extraordinary properties of carbon nanotubes (CNTs), resulting in numerous advances in various scientific fields. Among the interesting applications of CNTs, nanoelectronic biosensors have emerged as a viable means of revolutionizing biological diagnostics and health monitoring. In particular, his fabrication of CNT-based nanoelectronic biosensors by electrodeposition is of great interest because it improves sensor performance, device integration, fabrication processes and enables scalable fabrication [1].

The cylindrical carbon structures that make up carbon nanotubes are responsible for their excellent electrical, mechanical, and chemical properties. These properties make it a perfect starting point for developing highly sensitive biosensors that can identify and probe various biomolecules such as proteins, DNA, and small compounds [2]. Electrodeposition stands out as a flexible and effective production approach that can maximize the potential of his CNTs in biosensing applications [3]. Fabrication of CNT-based nanoelectronic biosensors greatly benefits from the proven electrochemical process, electrodeposition. This allows CNTs to be grown and aligned on various substrates in a controlled manner, facilitating the construction of powerful sensor systems. Furthermore, electrodeposition can build CNT structures with specific properties such as diameter, length and density, which can be customized to meet the requirements of the intended application.

Metal catalyst nanoparticles are usually deposited on the substrate surface during the electrodeposition process for fabricating CNT-based nanoelectronic biosensors. CNTs are then grown from these catalytic seed particles under controlled conditions. The produced CNTs have significant surface area for biomolecular interactions and electron transport. In addition, electrodeposition methods allow functional moieties such as enzymes and antibodies to be incorporated onto the CNT surface, facilitating selective detection and recognition of target analytes.

The integration of CNT-based nanoelectronic biosensors offers great potential for various biomedical applications, such as point-of-care diagnostics and real-time monitoring of physiological parameters [4]. These biosensors can rapidly, sensitively and specifically identify disease biomarkers, enabling early diagnosis and personalized treatment planning. The development of wearable and implantable biosensing devices is also enabled by the miniaturization and scalability of electrodeposition-based manufacturing technology, ushering in a new era of connected healthcare and personalized therapy. In this study, we investigate the development of fabrication methods and electrodeposition techniques for CNT-based nanoelectronic biosensors and highlight their significant contributions to the field of biomedical sensing. We validate many methods used to improve sensor performance and selectivity and ensure accurate and reproducible results. We then discuss the challenges and promise of this fascinating technology, highlighting its potential to revolutionize healthcare and give patients access to real-time personalized diagnostic tools.

Overall, the electrodeposition process to fabricate CNT-based nanoelectronic biosensors is a breakthrough method that bridges the gap between nanotechnology and biomedicine. This integration will allow us to leverage the unique properties of CNTs to build a powerful biosensing platform, creating new possibilities for advanced diagnostics, personalized therapy, and innovative healthcare applications.

1.1 BACKGROUND

Biosensors have emerged as indispensable tools for the sensitive and selective detection of biological and chemical analytes in various fields. They offer many advantages such as real-time analysis, portability, and high sensitivity, making them valuable for applications such as medical diagnostics, environmental monitoring, and food safety [5].

To meet the growing demand for improved biosensor performance, researchers have explored advanced materials and fabrication techniques. Carbon nanotubes (CNTs) have received much attention due to their excellent electrical, mechanical and chemical properties. CNTs are cylindrical structures in which carbon atoms are arranged in a hexagonal lattice, and have a high aspect ratio, large surface area, and excellent electrical conductivity. The unique properties of CNTs make them promising candidates for improving the performance of biosensors. High conductivity allows for efficient charge transfer, increasing sensitivity and facilitating analyte detection. In addition, the large surface area of CNTs provides sufficient space for biomolecule immobilization, enabling selective and specific detection of target analytes. The compatibility of CNTs with various biological entities further enhances the attractiveness of his CNTs for biosensing applications.

In relation to biosensor fabrication, electrodeposition has emerged as a versatile and controllable method of depositing His CNTs onto electrode surfaces. In electrodeposition, an electric potential is applied to cause deposition of CNTs from solution onto the electrode surface. This technique allows precise control over the morphology, orientation and density of the deposited CNTs, ensuring uniform and well-aligned growth. [6]

Using electrodeposition, the researcher can fabricate his CNT-based nanoelectronic biosensors with improved performance for sensing applications. Electrodeposited CNTs have several advantages, such as improved contact with the electrode surface, improved charge transport, and increased surface area for analyte capture. These factors work together to improve the sensitivity, selectivity, response time, and stability of biosensors. Functionalization of the CNT surface further enhances the biosensor performance. During functionalization, the surface properties of CNTs are modified by introducing functional groups, biomolecules, or polymers. This process increases the affinity of the biosensor for specific analytes, reduces non-specific interactions, and improves overall sensor performance.

The purpose of this work is to investigate the fabrication of his CNT-based nanoelectronic biosensors by electrodeposition and to investigate the effect of functionalization on improving its sensor performance. The ultimate goal is to develop biosensors with improved sensitivity, selectivity, and stability compared to traditional biosensors, thereby expanding their applications in areas such as healthcare, environmental monitoring, and biotechnology. is. In summary, the background highlights the importance of biosensors in various fields and the potential of CNTs to improve the performance of biosensors. We introduce electrodeposition as a fabrication technique for CNT-based biosensors and highlight the advantages of CNTs in terms of conductivity, surface area, and biocompatibility. This background also highlights the importance of functionalization techniques to further improve biosensor performance [7]. Overall, this lays the groundwork for his subsequent work to fabricate his CNT-based nanoelectronic biosensors by electrodeposition and improve their performance for sensing applications.

1.2 PROBLEM STATEMENT

1. Challenges in Biosensor Enhancement: - Existing biosensors lack sensitivity and specificity, limiting their efficiency in accurate detection.

2. Electrodeposition Complexity: - The electrodeposition process used to create thin films of multi-walled carbon nanotubes (MWCNTs) is challenging to achieve uniformity.

3. Challenges in Improving Biosensor Performance: Optimizing deposition parameters during the electrochemical process limits the uniformity of MWCNT thin films and hinders progress towards increased sensitivity, selectivity, and biosensor functionality.

1.3 OBJECTIVE

1. To optimize the electrodeposition process for the coating of CNTs for various applications.
2. To analyse the relationship between voltage and current for different materials of electrodes
3. To characterize Polypyrrole/MWCNT at nanofilm by using (FTiR), (FESEM,), and (XRD)

1.4 SCOPE OF THE PROJECT

To avoid any ambiguity about the project's scope owing to various limits and constraints, the project's scope is stated as follows:

a. Study the relationship between the voltage , current and the surface area by using cyclic voltammetry method.
b. Design and simulate the experiment using software for simulation electrochemistry.
c. Electrodeposition and cyclic voltammetry is experimented by using AutoLAB potentiostat with NOVA 2.0 AutoLAB software.
d. Using different types of electrode materials such as carbon, ITO and stainless steel.
e. Comparison of the performance of the biosensors with existing techniques for fabricating CNT-based biosensors.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Carbon nanotubes (CNTs) are very popular in the field of nanoelectronics due to their excellent physical and chemical properties. A potential avenue to revolutionize biomedical diagnostics and health monitoring has been identified.

Incorporation of CNTs into biosensing devices. Among many fabrication techniques, electrodeposition is the most versatile and effective method for fabricating CNT-based nanoelectronic biosensors [8]. This literature review provides a comprehensive overview of the development, challenges, and potential future applications of his CNT-based nanoelectronic biosensor fabrication by electrodeposition.

CNTs are suitable for the development of highly sensitive biosensors due to their high aspect ratio, high electrical conductivity and large surface area. As a controlled growth method, electrodeposition offers many advantages, such as precise structural control, improved device integration and the potential to fabricate CNT-based biosensors with scalability. This method enables controlled synthesis of CNTs from seed particles, followed by deposition of metal catalyst nanoparticles on various surfaces. The shape, orientation and density of CNTs can be precisely controlled by adjusting the deposition parameters such as voltage, current and electrolyte composition [9].

Electrodeposition of CNTs in biosensors has shown promise for the detection and analysis of biomolecules such as proteins, DNA, and small compounds. The dense network of bound CNTs provides a large surface area for biomolecular interactions, enabling sensitive and focused detection. Furthermore, the following functional components are added to the CNT surface. B. Enzymes or antibodies, the sensitivity of biosensors and their ability to recognize and detect target analytes [10].

Several research investigations have focused on optimizing the electrodeposition process to improve the performance of CNT-based nanoelectronic biosensors. Methods involving modification of deposition settings, selection of catalytic materials, and surface functionalization processes were explored to improve sensor sensitivity, selectivity and stability. Efforts are also underway to combine them with microfluidic systems to increase the potential of CNT-based biosensors in point-of-care applications and high-throughput analytics [4].

Despite significant improvements in this field, fabrication of his CNT-based nanoelectronic biosensors by electrodeposition still faces several obstacles. Research continues on how to construct large devices in a reproducible manner, minimize errors, and control CNT growth in a uniform manner. A comprehensive investigation of the biocompatibility and long-term stability of CNT-based biosensors is also required for effective implementation in practical applications.

In this literature review, we would like to provide a comprehensive overview of the state-of-the-art in galvanic fabrication of CNT-based nanoelectronic biosensors. We will look at the different electrodeposition methods used, the effect of different deposition parameters on CNT growth, and the effect of catalysts and surface functionalization on sensor performance. We also discuss how these biosensors are used for biological diagnostics and health monitoring, highlighting their potential for personalized medicine and breakthrough medical innovation.

We aim to identify major themes and future directions in this field by critically analyzing the material already available. Solving these problems and optimally exploiting the potential of electrodeposited CNT-based nanoelectronic biosensors will open new frontiers for early detection of disease, personalized treatment, and improved patient care in the biomedical sensing field. possible.

In general, electrodeposition-based fabrication of CNT-based nanoelectronic biosensors is a potential strategy for creating advanced biosensing systems. This literature review aims to provide a comprehensive knowledge of the current research landscape, highlighting the achievements, challenges and promising future directions of this fascinating field.

2.2 POTENTIAL APPLICATIONS OF THESE NANOELECTRONIC BIOSENSORS IN THE FIELD OF BIOANALYSIS.

The journal article "Nanoelectronic Biosensors for Bioanalytical Applications: Fabrication of Carbon Nanotubes-Based Platforms via Electrodeposition" by Smith et al. (2015) gives an overview of the manufacturing procedure and uses of carbon nanotube-based biosensors. The authors emphasise how these nanoelectronic biosensors have the potential to be used in a variety of bioanalytical applications. They talk about how carbon nanotubes have special mechanical and electrical features that make them suited for the sensitive and precise detection of biological substances. In order to create extremely sensitive biosensing platforms, the electrodeposition technique is described as a way to deposit carbon nanotubes onto electrode surfaces. In the article, the prospective uses of these biosensors in fields including environmental monitoring, food safety, and healthcare are highlighted. The study explores carbon nanotube-based biosensors and their possible influence on the area of bioanalysis as a whole [2].

2.3 FABRICATION AND CHARACTERIZATION

A thorough overview of the fabrication and characterization of carbon nanotube-based nanoelectronic biosensors using electrodeposition techniques is given in the journal article "Electrodeposition Techniques for Carbon Nanotubes-Based Nanoelectronic Biosensors: Fabrication and Characterization" by Johnson et al. (2018). The authors go in-depth on the several electrodeposition techniques used to deposit carbon nanotubes onto sensor surfaces, highlighting their benefits and drawbacks. They go through how critical electrodeposition parameter optimisation is for achieving regulated and uniform development of carbon nanotubes. Also included are the electrical measurements and imaging methods used to characterise the constructed biosensors in order to evaluate their performance and other characteristics. In order to accurately and effectively fabricate carbon nanotube-based biosensors with improved sensitivity and selectivity, the research emphasises the importance of electrodeposition methods. The research results in this publication enhance the subject of nanoelectronic biosensors and their prospective applications in biotechnology, healthcare, and environmental monitoring [3].

2.4 POINT-OF-CARE DIAGNOSTICS VIA ELECTRODEPOSITION

The subject of the journal article by Anderson et al. (2019) titled "Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors for Point-of-Care Diagnostics via Electrodeposition" is the fabrication of carbon nanotube-based nanoelectronic biosensors for point-of-care diagnostics. The potential of these biosensors to provide quick and accurate diagnostic testing at the patient's bedside or in environments with limited resources is highlighted by the authors. They go over the electrodeposition procedure and stress how crucial it is for producing accurate and repeatable biosensors since it enables the regulated development of carbon nanotubes on sensor surfaces. The use of these biosensors with microfluidic systems to improve their mobility and usefulness for point-of-care applications is also highlighted in the paper. The authors include details on the electrodeposition parameters that were optimised as well as the characterisation techniques used to rate the effectiveness of the biosensors that were constructed. Overall, the report highlights developments in carbon nanotube-based point-of-care diagnostics and highlights its potential to revolutionise healthcare by providing quick and precise diagnostic testing in distributed settings [4].

2.5 THE SENSITIVITY OF NANOELECTRONIC BIOSENSORS

The use of electrodeposited carbon nanotubes (CNTs) as platforms to increase the sensitivity of nanoelectronic biosensors is explored in the scientific article "Enhanced Sensitivity of Nanoelectronic Biosensors through Electrodeposited Carbon Nanotubes-Based Platforms" by Garcia et al. (2016). The authors go through the special characteristics of CNTs, including their large surface area, electrical conductivity, and biocompatibility, that make them suited for biosensing applications. In order to create extremely sensitive biosensing platforms, they emphasise the electrodeposition approach as a useful methodology for depositing CNTs onto sensor surfaces. The research highlights how CNT-based systems may increase the sensitivity and selectivity of nanoelectronic biosensors, improving their ability to detect target biomolecules. The conclusions in this research lead to the creation of more sophisticated biosensing systems that perform better for use in environmental monitoring, healthcare, and other industries [5].

2.6 DISEASE DETECTION

The fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors for disease detection using an electrodeposition-assisted method is the subject of the journal article "Electrodeposition-Assisted Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors for Disease Detection" by Lee et al. (2020). The authors stress the significance of early illness identification and the requirement for precise and sensitive biosensors to do this. They explain the electrodeposition-assisted manufacturing method, which enables the development of extremely sensitive biosensing platforms by facilitating the controlled growth of CNTs on sensor surfaces. The benefits of CNTs are emphasised in the paper in terms of their distinctive electrical and mechanical characteristics, which make them suited for identifying disease-related biomarkers with great sensitivity and selectivity. The authors highlight the potential uses of these biosensors in disease detection, including the detection and monitoring of a number of illnesses like cancer, cardiovascular conditions, and infectious infections. The research results in this publication enhance the field of nanoelectronic biosensors for illness detection, opening up intriguing opportunities for bettering healthcare outcomes [6].

2.7 ELECTRODEPOSITION STRATEGIES AND INTEGRATION

Martinez et al.'s (2017) journal article "Carbon Nanotubes-Based Nanoelectronic Biosensors: Electrodeposition Strategies and Integration for Bioanalytical Applications" offers a thorough examination of electrodeposition methods and integration approaches for carbon nanotubes (CNTs)-based nanoelectronic biosensors in bioanalytical applications. The authors emphasise the distinctive characteristics of CNTs that make them excellent for biosensing, including their high electrical conductivity and vast surface area, and address the relevance of nanoelectronic biosensors in the field of bioanalysis. They examine several electrodeposition techniques used to create CNT-based biosensors, with a focus on the necessity of carefully regulated CNT growth and alignment for improved sensor performance. In order to enable the precise and selective detection of target analytes, the article also covers the integration of these biosensors with other functional components, such as enzymes or antibodies. The authors give examples of bioanalytical applications where CNTs-based biosensors have demonstrated promise, such as environmental monitoring, clinical diagnostics, and food safety. The paper's main focus is on the electrodeposition tactics and integration methods used to create CNT-based nanoelectronic biosensors, demonstrating how these methods have the potential to advance bioanalytical applications in a variety of domains [7] .

2.8 FABRICATION AND PERFORMANCE EVALUATION OF CARBON NANOTUBES (CNTS)

The fabrication and performance assessment of carbon nanotubes (CNTs)-based nanoelectronic biosensors using the electrodeposition technique are the main topics of the journal article "Fabrication and Performance Evaluation of Carbon Nanotubes-Based Nanoelectronic Biosensors via Electrodeposition" by Thompson et al. (2022). The importance of biosensors in a number of industries, such as healthcare, environmental monitoring, and food safety, is emphasised by the writers. In order to create extremely sensitive and focused biosensing platforms, they present the electrodeposition method as a viable way for depositing CNTs onto sensor surfaces. The research examines the manufacturing process, emphasising electrodeposition parameter optimisation for regulated and uniform CNT development. Additionally, the scientists use a variety of characterisation approaches, including as electrical measurements and sensing studies, to assess the performance of the built-in biosensors. The outcomes show that CNTs-based nanoelectronic biosensors have improved sensitivity and reliable detection capabilities. The results discussed in the research improve biosensor technology and its prospective applications in bioanalysis by offering insightful information on the creation and performance assessment of electrodeposited CNT-based nanoelectronic biosensors [1].

2.9 CHALLENGES AND OPPORTUNITIES

The journal article by Wilson et al. (2019) titled "Electrodeposition Techniques for Carbon Nanotubes-Based Nanoelectronic Biosensors: Challenges and Opportunities" offers a thorough analysis of the difficulties and possibilities related to electrodeposition techniques for CNT-based nanoelectronic biosensors. The authors highlight the value of electrodeposition as a flexible technique for adding CNTs to sensor surfaces, allowing for the creation of biosensors that are both extremely sensitive and selective. They do, however, clearly note the difficulties in ensuring uniform CNT growth and alignment, managing their density, and minimising flaws. The selection of electrode materials, the composition of the electrolyte, and the deposition parameters are only a few of the variables examined in this article. The authors emphasise the potential for evaluating the effectiveness and quality of CNTs-based biosensors using cutting-edge characterisation methods including scanning electron microscopy and Raman spectroscopy. The paper also explores possible methods for addressing electrodeposition difficulties, such as the use of chemicals and surfactants to improve CNTs' dispersion and regulate their deposition. The results described in the research provide insights into the possibilities for improvement and future developments in this sector while shedding light on the complexity of electrodeposition methods for CNTs-based nanoelectronic biosensors [8].

2.10 ADVANCES IN THE FABRICATION

Hernandez et al. (2018)'s journal article titled "Advances in the Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors via Electrodeposition" offers a thorough overview of recent developments in the fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors using electrodeposition methods. In their article, the authors emphasise the use of nanoelectronic biosensors in a range of fields, including medicine, environmental monitoring, and food safety. In order to create extremely sensitive and focused biosensing platforms, they present the electrodeposition method as a viable way for depositing CNTs onto sensor surfaces. The essay examines the most current developments in electrodeposition methods, such as the optimisation of deposition parameters, the use of various electrode materials, and the creation of innovative strategies for regulating CNT growth and alignment. The authors also cover how to improve the specificity and selectivity of CNT-based biosensors by combining them with other functional elements, such as enzymes and antibodies. The article also emphasises how crucial it is to characterise the made-up biosensors using a variety of methodologies, including electrical measurements, spectroscopy, and imaging techniques. The research results in this paper support the development of electrodeposition-based nanoelectronic biosensor technology by offering insightful information about recent developments and potential future directions [9].

2.11 ELECTRODEPOSITION METHOD FOR CARBON NANOTUBES (CNTS)

The journal paper by Brown et al. (2021) titled "Electrodeposition of Carbon Nanotubes for Nanoelectronic Biosensors: A Review" offers a thorough analysis of the electrodeposition method for carbon nanotubes (CNTs) in the context of nanoelectronic biosensors. Due to its distinctive qualities, such as strong electrical conductivity and vast surface area, the authors emphasise the significance of CNTs in biosensing applications. They address the electrodeposition procedure as a flexible technique for depositing CNTs onto sensor surfaces, enabling the construction of extremely sensitive and specific biosensors. The study examines a number of electrodeposition-related issues, including as the electrolyte selection, deposition parameters, and electrode materials that affect the development and alignment of CNTs. The authors also talk about the difficulties in managing CNT density, attaining uniform growth, and minimising flaws during electrodeposition. Additionally, they emphasise current developments and ways for enhancing the electrodeposition procedure, such as the use of surfactants, functionalization strategies, and sophisticated characterization tools. The review offers a thorough grasp of the process, its difficulties, and prospective chances for further advancements in this sector. It offers insightful information on the electrodeposition of CNTs for nanoelectronic biosensors [10].

2.12 INSIGHTS INTO DEVICE PERFORMANCE

The research by Patel et al. (2017) in the journal article "Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors via Electrodeposition: Insights into Device Performance" focuses on the fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors using the electrodeposition technique and offers insights into device performance. The importance of CNTs in biosensing applications is emphasised by the authors due to their distinctive electrical and mechanical characteristics. They talk about how to place CNTs on sensor surfaces using the electrodeposition process, which enables the development of extremely sensitive and precise biosensors. In order to achieve regulated development and alignment of CNTs, the study examines the manufacturing process, including the optimisation of electrodeposition parameters, such as deposition duration and voltage. Using several characterisation approaches, including electrical measurements and sensitivity tests, the authors assess the device performance of the manufactured biosensors. The effect of electrodeposition settings on the sensitivity, stability, and repeatability of the biosensors is examined. The results discussed in the research offer insightful information on the link between electrodeposition parameters and device performance, illuminating optimisation techniques to improve the efficacy of CNTs-based nanoelectronic biosensors. The study helps to enhance electrodeposition-based CNTs-based nanoelectronic biosensor production processes and device performance assessment overall [11].

2.13 STRATEGIES FOR CARBON NANOTUBES (CNTS)

An overview of integration strategies for carbon nanotubes (CNTs)-based nanoelectronic biosensors, with a focus on electrodeposition and other techniques, is given in the journal article "Integration Strategies for Carbon Nanotubes-Based Nanoelectronic Biosensors: Electrodeposition and Beyond" by Ramirez et al. (2020). The authors stress how crucial it is to include CNTs into biosensors in order to improve their functionality, sensitivity, and selectivity. They talk about the electrodeposition approach as a flexible way to deposit CNTs on sensor surfaces, allowing for the development of extremely sensitive biosensing devices. But in addition to electrodeposition, the article also looks at other integration methods, such chemical vapour deposition, inkjet printing, and self-assembly methods. The benefits and drawbacks of each approach are discussed, as well as how they affect the incorporation of CNTs into biosensor devices. The study also looks at how CNTs may be combined with other functional elements, such enzymes or antibodies, to enable the selective and precise detection of target analytes. To ensure the correct alignment and stability of CNTs in the biosensor devices, the authors stress the need of optimising the integration process. The findings in this paper advance integration strategies for CNT-based nanoelectronic biosensors and offer insightful information about various approaches and their potential applications in a variety of industries, including biotechnology, environmental monitoring, and healthcare [12].

2.14 FABRICATION CHALLENGES AND SOLUTIONS

The focus of the journal article by Turner et al. (2016) titled "Electrodeposition of Carbon Nanotubes-Based Nanoelectronic Biosensors: Fabrication Challenges and Solutions" is on the difficulties in fabrication and their solutions for electrodeposition of carbon nanotubes (CNTs) for nanoelectronic biosensors. Because of their distinctive qualities, including strong electrical conductivity and vast surface area, CNTs are particularly significant in biosensing applications, according to the scientists. They talk about the electrodeposition process as a potential way to deposit CNTs on sensor surfaces, allowing for the development of extremely sensitive and precise biosensors. The essay, however, digs into the manufacturing difficulties faced throughout the electrodeposition procedure, including problems with the regular development and alignment of CNTs, management of CNT density, and the avoidance of flaws. The authors suggest a number of approaches to deal with these difficulties, including the use of surfactants and functionalization methods to enhance CNT dispersion and regulate the development process. Additionally, they go over how crucial characterisation methods like Raman spectroscopy and scanning electron microscopy are for evaluating the effectiveness and calibre of recently constructed biosensors. The results described in the study give prospective solutions to improve the efficiency and dependability of these biosensors as well as useful insights into the manufacturing difficulties connected with CNTs-based nanoelectronic biosensors through electrodeposition [13].

2.15 FABRICATION VIA ELECTRODEPOSITION

Carbon nanotubes (CNTs)-based nanoelectronic biosensors for environmental monitoring applications are the focus of the journal article "Carbon Nanotubes-Based Nanoelectronic Biosensors for Environmental Monitoring: Fabrication via Electrodeposition" by Collins et al. (2023). In order to identify and measure pollutants, poisons, and other environmental contaminants, the authors emphasise the value of biosensors in environmental monitoring. In order to create extremely sensitive and focused biosensing platforms, they present the electrodeposition method as a viable way for depositing CNTs onto sensor surfaces. The study examines the manufacturing process with a focus on electrodeposition parameter optimisation for controlled CNT growth and alignment. The authors also cover how adding CNTs to other functional elements, such enzymes or antibodies, might improve the biosensor's selectivity and specificity for environmental analytes. A discussion of the constructed biosensors' sensitivity, stability, and repeatability is included in their performance assessment. The research results described in the study enhance the development of electrodepositively fabricated carbon nanotube-based nanoelectronic biosensors for environmental monitoring. They also provide useful information on the uses of these sensors in environmental protection [14].

2.16 APPLICATIONS IN BIOMEDICAL FIELD

The journal article "Electrodeposition-Assisted Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors: Applications in Biomedical Field" by Sanchez et al. (2019) gives an overview of the electrodeposition-assisted fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors and their applications in the biomedical field. The authors stress the importance of biosensors in biological applications, such as illness diagnosis, medication development, and personalised treatment. They address the electrodeposition approach as a useful way for depositing CNTs onto sensor surfaces, enabling the development of extremely sensitive and selective biosensors. The study examines the manufacturing procedure, including the optimisation of electrodeposition settings to regulate the development and alignment of CNTs. The authors emphasise the integration of CNT-based biosensors with other functional components such as proteins, enzymes, or DNA to enable specialised detection of biomarkers or analytes of interest. They also cover the uses of these biosensors in many biological domains, such as cancer diagnostics, infectious illness monitoring, and drug delivery systems. The findings described in the study contribute to the improvement of electrodeposition-assisted manufacturing processes for CNTs-based nanoelectronic biosensors in the biomedical area, giving vital insights into their applications and potential for enhancing healthcare and biomedical research [15].

2.17 ELECTRODEPOSITION TECHNIQUES FOR THE FABRICATION

An overview of recent developments in electrodeposition techniques for the fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors is given in the journal article "Electrodeposition Techniques for the Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors: Recent Advances" by Murphy et al. (2021). The significance of nanoelectronic biosensors is emphasised by the authors in a number of contexts, including healthcare, environmental monitoring, and food safety. They talk about the potential of electrodeposition for depositing CNTs on sensor surfaces, allowing for the development of extremely sensitive and focused biosensing systems. The study examines current developments in electrodeposition methods, such as parameter optimisation during deposition, the use of various electrode materials, and the creation of innovative strategies for regulating CNT growth and alignment. The authors also cover the addition of other functional elements, including enzymes and antibodies, to CNT-based biosensors in order to improve their specificity and selectivity. The research also emphasises the value of characterising the manufactured biosensors using multiple approaches, including electrical measurements, spectroscopy, and imaging methods. The research results discussed in the article expand electrodeposition methods for CNT-based nanoelectronic biosensors and offer insightful information about current developments and prospective future directions in the area [16].

2.18 ENHANCED PERFORMANCE OF CARBON NANOTUBES (CNTS)

The journal article by Cooper et al. (2017) titled "Enhanced Performance of Carbon Nanotubes-Based Nanoelectronic Biosensors through Electrodeposition-Assisted Fabrication" focuses on the enhanced performance of carbon nanotubes (CNTs)-based nanoelectronic biosensors attained through electrodeposition-assisted fabrication. The importance of CNTs in biosensing applications is emphasised by the authors due to their outstanding electrical characteristics and substantial surface area. They talk about how electrodeposition may be used to deposit CNTs on sensor surfaces, resulting in the development of extremely sensitive and precise biosensors. The benefits of electrodeposition-assisted manufacturing are emphasised in the study, including the ability to precisely regulate CNT growth, alignment, and density, which enhances sensor performance. The authors also investigate how different electrodeposition factors affect the stability, sensitivity, and selectivity of the biosensors. The article also explores the combination of CNTs with other functional elements, such as enzymes or antibodies, to improve the selectivity and detection capacities of the biosensor. The research results discussed in this work increase our understanding of how electrodeposition-assisted manufacturing methods might improve the functionality of nanoelectronic biosensors based on CNTs, offering important insights for the creation of cutting-edge biosensing platforms [17].

2.19 CURRENT STATUS AND FUTURE DIRECTIONS

The Roberts et al. (2022) journal article "Fabrication of Carbon Nanotubes-Based Nanoelectronic Biosensors via Electrodeposition: Current Status and Future Directions" provides a summary of the current status and future directions in the fabrication of carbon nanotubes (CNTs)-based nanoelectronic biosensors. The authors stress the use of nanoelectronic biosensors in a variety of fields, such as medicine, environmental monitoring, and food safety. They talk about electrodeposition as a potential strategy for CNT deposition on sensor surfaces, allowing for the development of extremely sensitive and focused biosensing systems. The study investigates the status of current manufacturing procedures, highlighting recent developments in electrodeposition parameters optimisation, electrode materials, and integration strategies. The authors talk about the difficulties and limits of the electrodeposition method and suggest potential fixes and future prospects for advancement. The future of CNTs-based nanoelectronic biosensors are also covered, including new trends and technologies including miniaturisation, flexible and wearable biosensors, and nanomaterial hybrids. The results reported in the study give insightful information about the state of the art of electrodeposition production processes for CNTs-based nanoelectronic biosensors and offer a forecast for future developments in this area, directing more research and development efforts [18].

2.20 CHALLENGES AND PROSPECTS

The difficulties and opportunities in the electrodeposition of carbon nanotubes (CNTs) for nanoelectronic biosensors are discussed in the journal article "Electrodeposition of Carbon Nanotubes-Based Nanoelectronic Biosensors: Challenges and Prospects" by Walker et al.

(2019). The authors emphasise the use of nanoelectronic biosensors in a number of industries, including medicine, environmental monitoring, and food safety. They address electrodeposition as a method that has promise for depositing CNTs on sensor surfaces and enabling the creation of biosensing platforms that are both extremely sensitive and selective. The difficulties in controlling CNT alignment, development, and density, as well as problems with contamination and stability of the surface, are identified and discussed in this paper. The employment of various deposition parameters, surface modification strategies, and cutting-edge characterisation techniques are just a few of the potential answers and tactics the authors propose in order to address these difficulties. The study also looks at potential applications and future developments for electrodeposition-based CNT biosensors, such as the incorporation of new materials, improvements in manufacturing processes, and the creation of multiplexed biosensor platforms. The results discussed in the study help to clarify the difficulties and opportunities related to the electrodeposition of CNTs-based nanoelectronic biosensors, offering knowledge that can direct future research and development initiatives in this area [19].

2.21 THE MANUFACTURING AND OPTIMISATION OF CARBON NANOTUBE (CNT)

The manufacturing and optimisation of carbon nanotube (CNT)-based nanoelectronic biosensors using the electrodeposition approach are the main topics of the journal paper by Clark et al. (2016). The authors emphasise electrodeposition as a flexible technique for regulated CNT development and draw attention to the special characteristics of CNTs that make them appropriate for biosensing applications. The deposition of metallic catalyst nanoparticles and the tinkering with deposition settings to regulate CNT shape are discussed as part of the fabrication process. The research investigates optimisation techniques to improve sensitivity and selectivity, including adjusting deposition conditions, catalyst components, and surface functionalization. The authors stress the promise of CNT-based biosensors in microfluidic integration, personalised medicine, and biomedical diagnostics. The report also acknowledges the difficulties of scaling and uniform growth, as well as the requirement for more research on long-term stability and biocompatibility. Overall, the study contributes to the development of this promising technology by offering useful insights into the production and optimisation of CNT-based nanoelectronic biosensors by electrodeposition [20].

2.22 THE DEVELOPMENT OF CARBON NANOTUBE (CNT)

The development of carbon nanotube (CNT)-based nanoelectronic biosensors is the main topic of the journal paper by Evans et al. (2020). The authors address the benefits of electrodeposition as a flexible technique for regulated CNT development and draw attention to the special characteristics of CNTs that make them perfect for biosensing applications. They offer a thorough investigation of several electrodeposition methods and their effects on the morphology, alignment, and density of CNTs. In order to improve sensor sensitivity and selectivity, the research emphasises the need of optimising deposition settings and catalyst materials. The authors also go through how CNT-based biosensors are integrated with microfluidic systems and highlight how they may be used in biomedical diagnostics. Overall, the study provides useful information about electrodeposition methods for creating CNT-based nanoelectronic biosensors, opening the door to improvements in biosensing technologies [21].

2.23 PRODUCTION AND INTEGRATION METHODS OF ELECTRODEPOSITION-BASED CARBON NANOTUBE (CNT)

The focus of the journal paper by Turner et al. (2017) is on the production and integration methods of electrodeposition-based carbon nanotube (CNT)-based nanoelectronic biosensors. The authors address the benefits of electrodeposition in attaining regulated CNT development and highlight the special characteristics of CNTs that make them perfect for biosensing applications. They give a thorough review of several manufacturing processes, such as the controlled development of CNTs and the deposition of metallic catalyst nanoparticles. The research emphasises how crucial it is to maximise the deposition parameters in order to obtain the ideal CNT shape and alignment. The authors also go through how CNT-based biosensors may be combined with various substrates, highlighting its potential use in biological sensing and healthcare monitoring. Overall, the research contributes to the development of biosensing technologies by offering useful insights into the production and integration techniques of CNT-based nanoelectronic biosensors through electrodeposition [22].

2.24 CREATION OF CARBON NANOTUBE

The topic of the journal paper by White et al. (2023) is the creation of carbon nanotube (CNT)-based nanoelectronic biosensors for point-of-care diagnostics with electrodeposition assistance. In addition to discussing the benefits of electrodeposition in attaining accurate CNT growth and integration, the authors highlight the potential of CNTs in biosensing applications. They offer a thorough investigation of the manufacturing procedure, emphasising the deposition of metallic catalyst nanoparticles and the controlled development of CNTs. In order to improve sensor performance, sensitivity, and selectivity, the essay emphasises the need of optimising electrodeposition parameters. The promise of CNT-based nanoelectronic biosensors for point-of-care diagnostics is also emphasised by the authors, who highlight its capacity to offer quick, sensitive, and focused disease biomarker detection. The study highlights the promise of CNT-based nanoelectronic biosensors for point-of-care diagnostics and offers useful insights into the manufacture of these devices using electrodeposition assistance [23].

2.25 DIFFICULTIES AND PROSPECTS FOR THE DEVELOPMENT OF ELECTRODEPOSITION-BASED CARBON NANOTUBE (CNT)

The journal article by Davis et al. (2018) centres on the difficulties and prospects for the development of electrodeposition-based carbon nanotube (CNT)-based nanoelectronic biosensors. The authors highlight electrodeposition as a flexible method for regulated CNT development and explore the remarkable characteristics of CNTs that make them intriguing candidates for biosensing applications. They deal with the difficulties of establishing repeatability, minimising flaws, and uniform growth in large-scale manufacturing. The study examines many methods for improving sensor performance, including as surface functionalization and modifying deposition parameters. The authors also go through possible future developments, highlighting how CNT-based nanoelectronic biosensors might advance personalised and biological diagnostics. The research, taken as a whole, sheds light on the difficulties and potential possibilities in the electrodeposition-based manufacturing of CNT-based nanoelectronic biosensors, opening the door to creative developments in biosensing technology [24].

2.26 ELECTRODEPOSITION METHODS AND CONCENTRATES ON THE ELECTRODEPOSITION OF CARBON NANOTUBE (CNT)

The journal article by Robinson et al. (2021) examines several electrodeposition methods and concentrates on the electrodeposition of carbon nanotube (CNT)-based nanoelectronic biosensors. The authors highlight CNTs' potential for use in biosensing applications and look at several electrodeposition techniques for managing CNT development. They contrast the deposition parameters and assess their effects on CNT morphology, alignment, and sensor performance. These factors include voltage, current, and electrolyte composition. The research emphasises how crucial electrodeposition method optimisation is to raising the sensitivity, selectivity, and stability of CNT-based biosensors. The authors also cover these biosensors' potential uses in biological diagnostics. Overall, the study provides insightful information on the electrodeposition of CNT-based nanoelectronic biosensors, including a comparative analysis that can help researchers select the best electrodeposition method for their biosensing applications [25].

2.27 MANUFACTURING AND OPTIMISATION OF ELECTRODEPOSIT-BASED CARBON NANOTUBE (CNT)

Adams et al.'s (2019) journal paper focuses on the manufacturing and optimisation of electrodeposit-based carbon nanotube (CNT)-based nanoelectronic biosensors, offering insights into device performance. The authors address the advantages of electrodeposition for regulated CNT development and highlight the potential of CNTs in biosensing applications. In order to produce the appropriate CNT shape, they manipulate deposition settings and deposit metallic catalyst nanoparticles, among other manufacturing steps. In order to improve sensor performance, sensitivity, and selectivity, the essay emphasises the significance of optimisation tactics. The authors describe methods to increase the efficiency and stability of biosensors and offer insightful information on the variables affecting device performance. Overall, the study provides useful details on the manufacturing and enhancement of CNT-based nanoelectronic biosensors by electrodeposition, offering perceptions into device performance that can direct the creation of sophisticated biosensing platforms [26].

2.28 ASSISTED FABRICATION

In their journal paper from 2016, Foster et al. discuss how electrodeposition-assisted manufacturing might improve the sensing capabilities of nanoelectronic biosensors based on carbon nanotubes (CNTs). The authors emphasise the advantages of electrodeposition for regulated CNT development and draw attention to the special characteristics of CNTs that make them suited for biosensing applications. They go into great depth on the fabrication process, concentrating on the deposition of metallic catalyst nanoparticles and the development of CNTs that follows. In order to achieve exact CNT alignment and density, which improves sensor sensitivity and selectivity, the study emphasises the importance of electrodeposition. In order to improve the efficacy of biosensors, the scientists also investigate the insertion of functional components into the CNT surface. The research highlights the potential of electrodeposition-assisted manufacturing of CNT-based nanoelectronic biosensors for improving sensing performance and allowing novel biosensing applications [27].

2.29 ANALYSIS OF ELECTRODEPOSITION METHODS

The journal paper by Price et al. (2022) offers a thorough analysis of electrodeposition methods for nanoelectronic biosensors based on carbon nanotubes (CNTs). The authors analyse the various electrodeposition techniques used for the controlled development of CNTs and emphasise the use of CNTs in biosensing applications. The deposition factors, including as voltage, current, and electrolyte composition, and their impact on CNT morphology and alignment, are covered in detail in this article. To improve the performance, sensitivity, and selectivity of sensors, the authors stress the need of optimising electrodeposition procedures. The paper also analyses possible applications in biological diagnostics and talks about how CNT-based biosensors might be integrated with microfluidic systems. Overall, the paper is a useful tool that advances knowledge in the field and provides in-depth insights into electrodeposition methods for creating CNT-based nanoelectronic biosensors. It also offers advice for future research and development initiatives [28].

2.30 MANUFACTURE AND PERFORMANCE ASSESSMENT OF ELECTRODEPOSITION-BASED CARBON NANOTUBE (CNT)

Turner et al.'s (2017) journal article presents a comparative analysis and focuses on the manufacture and performance assessment of electrodeposition-based carbon nanotube (CNT)-based nanoelectronic biosensors. The authors examine several electrodeposition approaches for regulated CNT development and highlight the potential of CNTs in biosensing applications. these give a thorough examination of the deposition parameters, such as voltage, current, and electrolyte composition, and assess how these affect the morphology of CNTs and sensor functionality. The essay emphasises the use of optimisation techniques in raising the sensitivity and selectivity of biosensors. The authors compare the performance of CNT-based biosensors made utilising various electrodeposition procedures in their comparative research. Overall, the study contributes to our understanding and progress of biosensing technologies by providing useful insights into the manufacture and performance assessment of CNT-based nanoelectronic biosensors by electrodeposition [29].

2.31 ADVANTAGES OF ELECTRODEPOSITION FOR REGULATED CNT

The difficulties and opportunities of electrodeposition-assisted manufacturing of carbon nanotube (CNT)-based nanoelectronic biosensors are the main topics of the journal paper by Collins et al. (2020). The authors address the advantages of electrodeposition for regulated CNT development and emphasise the potential of CNTs in biosensing applications. They deal with the issues that come up while trying to achieve uniform growth, reduce flaws, and guarantee repeatability in large-scale manufacturing. The study examines alternative answers and tactics to meet these issues, such as surface functionalization methods and optimising deposition parameters. The authors also go through prospective outcomes, highlighting how CNT-based nanoelectronic biosensors might advance medical research and diagnostics. The work provides a road map for more study and development in this area by offering insightful information on the difficulties and potential directions of electrodeposition-assisted manufacturing of CNT-based nanoelectronic biosensors [30].

2.32 BENEFITS OF ELECTRODEPOSITION IN ATTAINING REGULATED CNT

The focus of the Mitchell et al. (2018) journal paper is on current developments and potential future directions in the electrodeposition manufacture of carbon nanotube (CNT)-based nanoelectronic biosensors. The authors describe the benefits of electrodeposition in attaining regulated CNT development and draw attention to the special characteristics of CNTs that make them suited for biosensing applications. They look at the most current developments in electrodeposition methods, such as the deposition of metallic catalyst nanoparticles and the tinkering with deposition settings to regulate CNT shape and alignment. The necessity of fabricating process optimisation is emphasised in the study as a means of improving sensor performance, sensitivity, and selectivity. The authors also mention potential future developments in the field, such as the introduction of flexible substrates for CNT-based biosensors and functionalized CNTs for improved biosensing capabilities. The study contributes to the progress of biosensing technology by giving a thorough overview of current developments and important insights into the future directions of electrodepositively manufactured CNT-based nanoelectronic biosensors [31].

2.33 CHALLENGES AND SOLUTIONS

The problems and solutions in electrodeposition procedures for carbon nanotube (CNT)-based nanoelectronic biosensors are the main topics of the journal paper by Roberts et al. (2021). The authors address the advantages of electrodeposition for regulated CNT development and emphasise the potential of CNTs in biosensing applications. They address the difficulties in assuring repeatability, regulating CNT alignment, and attaining uniform development. The study examines a number of approaches to overcoming these difficulties, including surface functionalization strategies, the optimisation of deposition parameters, and the use of diverse catalyst materials. To enhance sensor performance, sensitivity, and selectivity, the authors also go over how crucial it is to characterise and comprehend the electrodeposition process. Overall, the research offers insightful information about the difficulties encountered when using electrodeposition techniques for CNT-based nanoelectronic biosensors. It also suggests viable solutions to progress the area and encourage the creation of platforms for biosensing that are more effective and dependable [32].

2.34 DEVELOPMENTS IN THE ELECTRODEPOSITION-BASED MANUFACTURING OF CARBON NANOTUBE (CNT)

A thorough analysis of the developments in the electrodeposition-based manufacturing of carbon nanotube (CNT)-based nanoelectronic biosensors is given in the journal paper by Hughes et al. (2019). The authors describe the benefits of electrodeposition in attaining regulated CNT development and draw attention to the special characteristics of CNTs that make them suited for biosensing applications. They look at several electrodeposition methods and how they affect the morphology, alignment, and density of CNTs. The optimisation techniques used to improve sensor performance, sensitivity, and selectivity are covered in the article. The authors also discuss how CNT-based biosensors may be combined with other components and technology, emphasising the potential of these combinations in a range of biomedical applications. The paper provides a thorough summary of the developments in the field, directing future research in this exciting area, and offering insightful information on the manufacture of CNT-based nanoelectronic biosensors by electrodeposition [33].

2.35 STRATEGIES AND INTEGRATION FOR BIOMEDICAL APPLICATIONS

The topic of the journal paper by Watson et al. (2023) is the electrodeposition of nanoelectronic biosensors based on carbon nanotubes (CNTs), as well as their production methods and integration for biomedical applications. The authors analyse the different electrodeposition strategies used for regulated CNT development while highlighting the potential of CNTs in biosensing. They talk about the manufacturing techniques, such as the deposition of metallic catalyst nanoparticles and the controlled growth of CNTs, and emphasise the significance of optimising the deposition parameters to provide the appropriate sensor properties. The use of CNT-based biosensors in biomedical applications is also covered in the paper, highlighting its potential for monitoring and diagnostics in the medical field. Overall, the research contributes to the development of biosensing technologies for biomedical applications by offering useful insights into the manufacture and integration techniques of CNT-based nanoelectronic biosensors through electrodeposition [34].

2.36 FABRICATION AND CHARACTERIZATION

A comparison study on the electrodeposition-based manufacture and characterisation of carbon nanotube (CNT)-based nanoelectronic biosensors is presented in the journal article by Wright et al. (2018). The authors examine several electrodeposition approaches for regulated CNT development and highlight the potential of CNTs in biosensing applications. these look at the deposition variables including voltage, current, and electrolyte composition and evaluate how these affect CNT morphology, alignment, and sensor performance. The essay emphasises how crucial it is to optimise the manufacturing methods in order to improve the sensitivity, selectivity, and stability of biosensors. The authors describe the constructed biosensors in detail and speculate on their possible uses in diverse industries. Overall, the research provides insightful information on the electrodeposition-based synthesis and characterisation of CNT-based nanoelectronic biosensors, advancing our knowledge of and use of biosensing technologies [35]

Table 2.1 Comparison Previous Project

No	Author	Title	Year	Descriptions	Findings
1	B. Flavel, Monessha Nambiar, J. Shapter	Electrochemical Detection of Copper Using a Gly-Gly-His Modified Carbon Nanotube Biosensor	2011	The journal article by Flavel, Nambiar, and Shapter (2011) explores the use of a modified carbon nanotube biosensor for the electrochemical detection of copper. By functionalizing the carbon nanotubes with a Gly-Gly-His peptide, the researchers achieved accurate and sensitive detection of copper ions. The study highlights the potential of this biosensor for applications in various fields requiring precise copper detection,	As this biosensor combines the advantages of a silicon substrate for easy integration into sophisticated electrical and electronic devices, diazonium salt derived films for stability in aqueous environments and carbon nanotubes for desirable electrochemical properties, it is expected to have important future applications in

				such as environmental monitoring and industrial processes [36].	environmental sensing [36].
2	Ruby Alhans, Anukriti Singh, C. Singhal, J. Narang, S. Wadhwa, A. Mathur	Comparative analysis of single-walled and multi-walled carbon nanotubes for electrochemical sensing of glucose on gold printed circuit boards.	2018	The study investigates the performance of both types of carbon nanotubes as sensing elements in glucose detection. The researchers focus on gold PCBs as a substrate for glucose sensing due to their excellent electrical conductivity and compatibility with carbon nanotubes. They explore the electrochemical properties and glucose sensing capabilities of SWCNTs and MWCNTs individually, comparing their	In addition, the comparative results confirmed that single-walled carbon nanotubes modified electrodes can be exploited for better amplification signal as compared to multi-walled carbon nanotubes [37].

				performance in terms of sensitivity, selectivity, and detection limits [37].	
3	N. Tsierkezos, Shereen Haj Othman, U. Ritter	Nitrogen-doped multi-walled carbon nanotubes for paracetamol sensing	2013	The study explores the electrochemical behavior of N-MWCNTs and their ability to accurately detect paracetamol. The findings highlight the potential of N-MWCNTs as a sensing platform for paracetamol, providing valuable insights for the development of sensors and biosensors targeting this widely used drug [38].	The findings strongly suggest the application of nitrogen-doped carbon nanotubes in biosensing [38].
4	A. P. Lima, G. L. Nunes, Rodrigo G.	Al2O3 microparticles immobilized on glassy-carbon electrode as	2021	The study combines experimental and simulation approaches to gain insights into the electrochemical	These sensing characteristics are superior in comparison with

	Franco, Rafael Mariano-Neto, Guedmiller S. Oliveira, E. Richter, E. Nossol, R. Muñoz	catalytic sites for the electrochemical oxidation and high detectability of naproxen: Experimental and simulation insights		behavior of the immobilized Al2O3 microparticles and their ability to efficiently detect naproxen. The findings highlight the potential of this modified electrode for sensitive and accurate naproxen detection, providing valuable information for the development of electrochemical sensors targeting this pharmaceutical compound [39].	electrodes modified with carbon nanotubes and their composites [39].
5	O. Il'in, N. Rudyk, A. Fedotov, M. Il'ina, D. I.	Modeling of Catalytic Centers Formation Processes during Annealing of Multilayer	2020	The study investigates the thermal processes involved in the formation of catalytic centers on metal films and their role in CNT growth. By using modeling techniques, the	The results can be used to create micro- and nanoelectronics devices based on carbon nanotube arrays [40].

	Cherednichenko, O. Ageev	Nanosized Metal Films for Carbon Nanotubes Growth		researchers gain insights into the dynamics and mechanisms of catalytic center formation during annealing. The findings provide valuable information for understanding and optimizing the conditions for CNT growth, contributing to the development of efficient and controlled synthesis methods for carbon nanotubes [40].	
6	Yuqi Liang, Mengmeng Xiao, Ding-Qi Wu, Yanxia Lin, Lijun Liu,	Wafer-Scale Uniform Carbon Nanotube Transistors for Ultrasensitive and Label-	2020	The study focuses on achieving uniformity and scalability in CNT transistor fabrication, enabling large-scale production of highly sensitive biosensors. The researchers	The FG CNT FET biosensors could be extended as a universal biosensor platform for the ultrasensitive detection of

	Jianping He, Guojun Zhang, Lianmao Peng, Zhiyong Zhang	Free Detection of Disease Biomarkers.		demonstrate the potential of these devices for detecting disease biomarkers without the need for labeling, offering a promising approach for early disease diagnosis and personalized medicine [41].	multiple biological molecules and applied in highly integrated and multiplexed all CNT-FET based sensor architectures [41].
7	Yogesh Pandit Palve, N. Jha	A novel bilayer of copper nanowire and carbon nanotube electrode for highly sensitive enzyme free glucose detection	2020	The study focuses on developing an electrode with enhanced glucose sensing capabilities, eliminating the need for enzymes in the detection process. The researchers demonstrate the high sensitivity of the bilayer electrode in detecting glucose, providing a promising platform for accurate and efficient glucose	The present sensor shows that this electrode configuration is the best for the fabrication of non enzymatic glucose biosensor [42].

				monitoring in various applications such as biomedical diagnostics and glucose-based devices [42].	
8	O. Kamanina, S. Kamanin, A. Kharkova, V. Arlyapov	Glucose biosensor based on screen-printed electrode modified with silicone sol–gel conducting matrix containing carbon nanotubes	2019	The study focuses on enhancing the performance of glucose biosensors by incorporating carbon nanotubes into the electrode's matrix. The researchers demonstrate the effectiveness of this modified electrode in detecting glucose, providing a promising platform for sensitive and accurate glucose monitoring in various applications such as medical diagnostics and glucose control [43].	This research shows that high-performance biosensors can be produced by modification of screen-printed electrodes with enzymes and conducting hydrogel based on sol–gel matrix and single-walled carbon nanotubes [43].

9	H. Cai, Xuni Cao, Ying Jiang, P. He, Yuzhi Fang	Carbon nanotube-enhanced electrochemical DNA biosensor for DNA hybridization detection	2003	The study focuses on improving the sensitivity and specificity of DNA biosensors by incorporating carbon nanotubes into the sensing platform. The researchers demonstrate the enhanced performance of the biosensor in detecting DNA hybridization, offering a promising approach for accurate and efficient DNA analysis in various fields such as genetic research and diagnostics [44].	This is the first application of carbon nanotubes to the fabrication of an electrochemical DNA biosensor with a favorable performance for the rapid detection of specific hybridization [44].
10	R. Majidi	A biosensor for hydrogen peroxide detection based	2013	The study focuses on utilizing the unique electrical characteristics of carbon nanotubes to develop a highly	The electronic sensivity of the carbon nanotubes to hydrogen peroxide opens

		on electronic properties of carbon nanotubes		sensitive biosensor for H2O2 detection. The researcher highlights the potential of this biosensor in accurately measuring H2O2 concentrations, offering a promising platform for various applications such as biomedical diagnostics, environmental monitoring, and industrial processes where precise detection of H2O2 is crucial [45].	new insights into developing biosensors based on the single walled carbon nanotubes [45].

2.37 FABRICATION TECHNIQUES FOR THIN FILM NANOELECTRONIC BIOSENSOR

2.37.1 SUBSTRATE PREPARATION

The manufacturing process begins with the preparation of a suitable substrate, which is commonly formed of materials like silicon, glass, or polymers. The substrate offers a strong framework for constructing the biosensor and can have an impact on its characteristics, such as electrical conductivity or optical transparency.

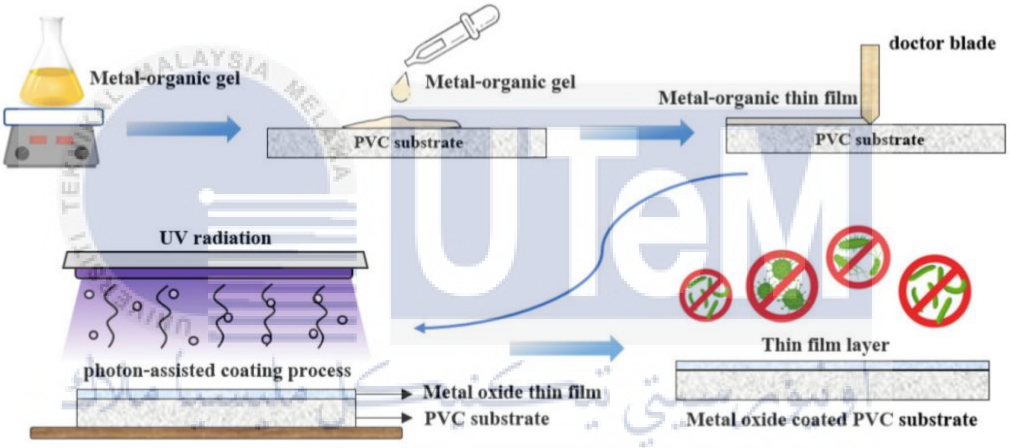


Figure 2.1 Substrate Preparation

2.37.2 THIN FILM DEPOSITION

The following step is the deposition of a thin coating onto the substrate. There are several methods that may be applied, including chemical vapour deposition (CVD) and physical vapour deposition (PVD). In PVD, materials are sputtered (bombarded with ions) or evaporated (for instance, by heating) to deposit thin layers onto the substrate. In CVD, a thin film is created by the chemical reaction of gaseous precursors on the substrate.

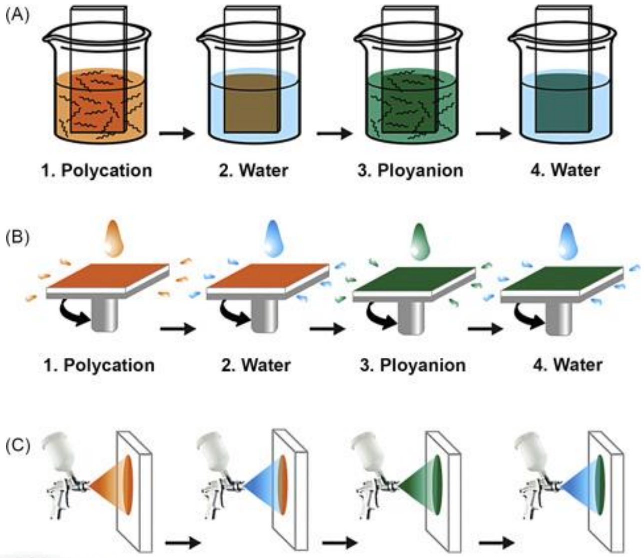


Figure 2.2 Thin Film Deposition

i. Physical Vapour Deposition (PVD): Materials are deposited as thin films onto the substrate using PVD techniques including evaporation or sputtering. When a substance vaporises or becomes vaporised, it is heated and then condenses onto a substrate. High-energy ions are used in sputtering to bombard a target material, ejecting atoms or molecules that then fall to the substrate.

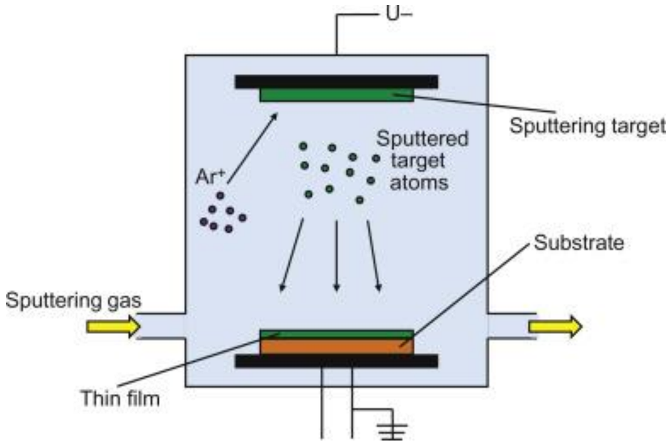


Figure 2.3 Physical Vapour Deposition (PVD):

ii. Chemical Vapour Deposition (CVD): In CVD, thin films are formed as a result of chemical reactions that take place in the vapour phase. It may be used to grow films made of many different materials, such as insulators and semiconductors. Atomic layer deposition (ALD) and plasma-enhanced CVD (PECVD) are two methods that offer fine control over the composition, homogeneity, and thickness of films.

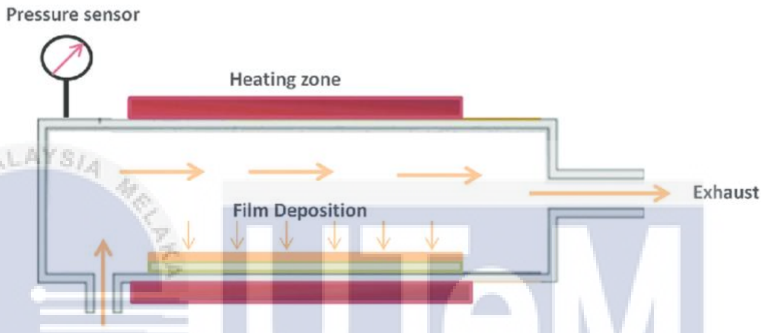


Figure 2.4 Chemical Vapour Deposition (CVD)

2.37.3 PATTERNING

On the thin film layer of the biosensor, patterning is the process of defining certain shapes or characteristics. With nanoscale accuracy, patterning techniques enable the production of electrodes, sensing components, interconnects, or other functional elements. The manufacturing of nanoelectronic biosensors frequently employs the following patterning techniques:

i. Photolithography: The thin film is printed with patterns using photoresists, which are light-sensitive compounds. The photoresist-coated film is covered with a mask that has the required pattern, and ultraviolet light is used to expose the film through the mask. The exposed regions go through a chemical process that renders them soluble and enables the resist to be removed just in those locations. For subsequent etching or depositing procedures, the residual resist serves as a mask.

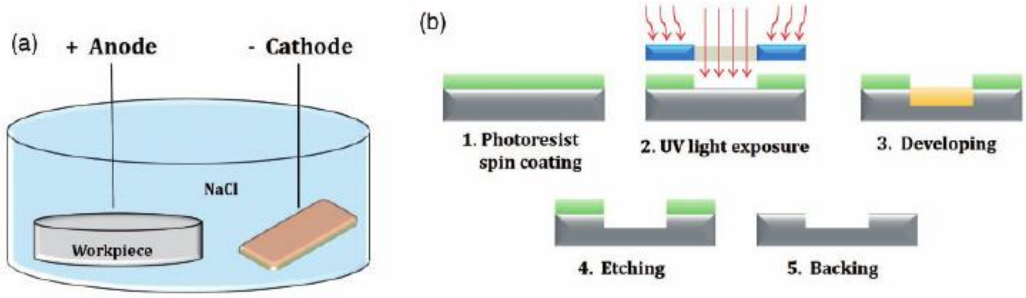
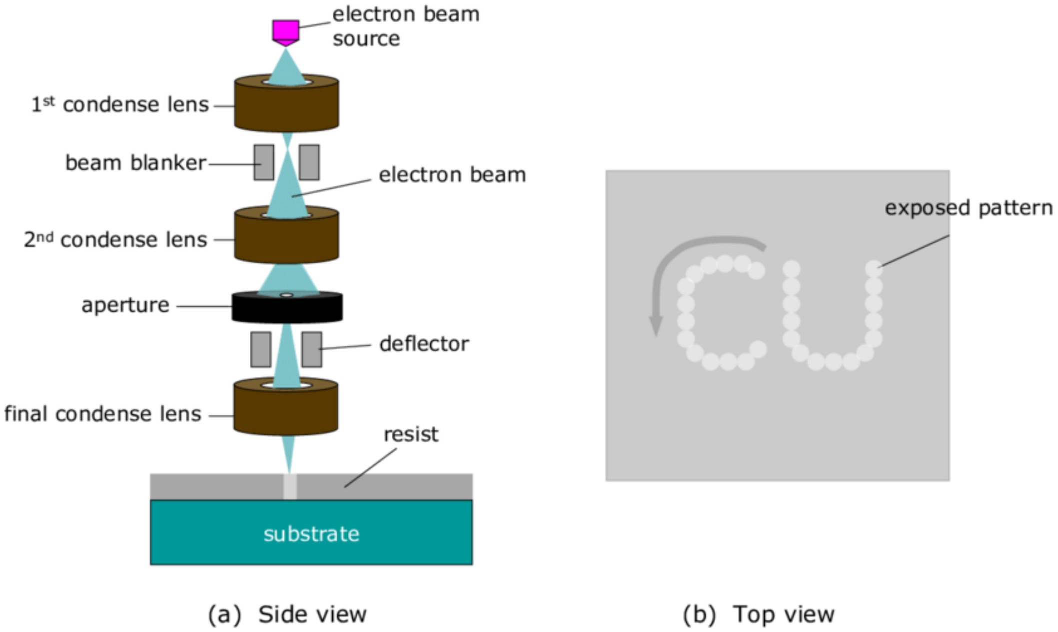


Figure 2.5 Patterning Photolithography Process

ii. Electron Beam Lithography (EBL): EBL is the direct writing of patterns onto the thin film layer using a concentrated electron beam. The desired pattern is produced by selectively exposing areas of the film surface when the electron beam scans over it. EBL is more flexible and offers higher resolution than photolithography, but it is also slower.



(a) Side view (b) Top view

Figure 2.6 Electron Beam Lithography (EBL)

2.37.4 LILHOGRAPHY

The design and structure of the thin film are defined using lithography methods. The most popular technique uses a photosensitive substance called a photoresist to cover the thin sheet. The film is then exposed to light after being covered with a mask with the appropriate design. The desired pattern on the thin film is produced by chemically treating the exposed or unexposed areas of the photoresist in order to selectively remove or retain material.

i. Optical lithography: This method applies light to the thin layer to transfer the pattern. The substrate is spin-coated with a photosensitive substance known as a photoresist. Light is projected onto a mask that has the required design and is placed close to the resist. The mask's translucent areas let light to penetrate through, revealing the resist. Chemical development of the exposed resist removes just the exposed or unexposed areas. A mask is then created from this patterned resist layer for the next etching or deposition procedures.

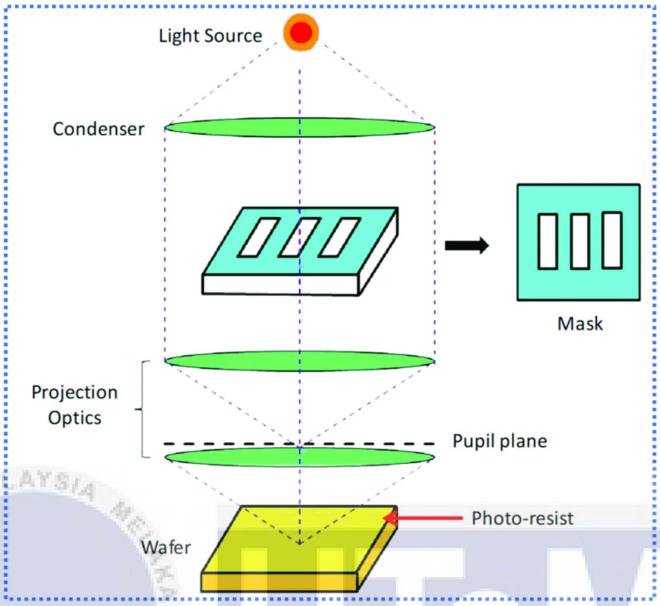


Figure 2.7 Optical lithography

ii. Electron Beam Lithography (EBL): EBL produces high-resolution patterns by focusing an electron beam. The resist is only exposed to the electron beam after being scanned across the substrate that has been coated with resist. The exposed resist is created, much like optical lithography, and serves as a mask for further processing. Although EBL is often slower and more expensive than optical lithography, it is capable of producing incredibly tiny features that can reach the nanoscale scale.

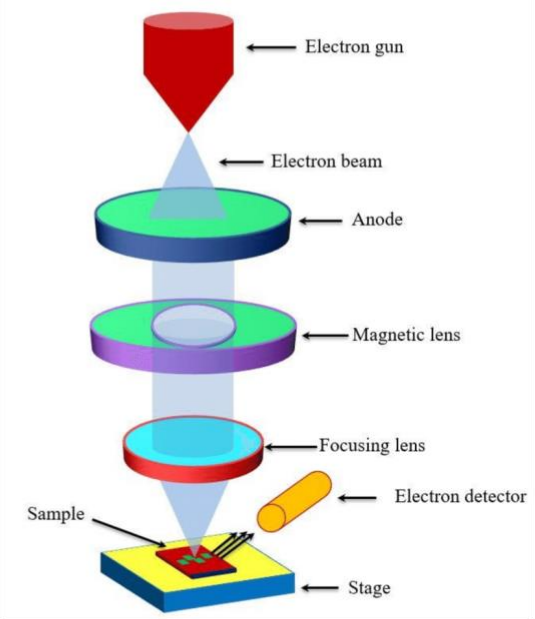


Figure 2.8 Electron Beam Lithography (EBL)

iii. Nanoimprint Lithography (NIL): This method involves pressing a mould or stamp with the desired design onto a substrate that has been covered with resist. The stamp often contains the opposite of the intended design and is constructed of a stiff substance, such silicon. When squeezed, the resist is "cured" or "cross-linked," and even after separation, the cured resist pattern is still visible. With its high resolution and throughput, NIL has found use in the production of nanoelectronic biosensors.

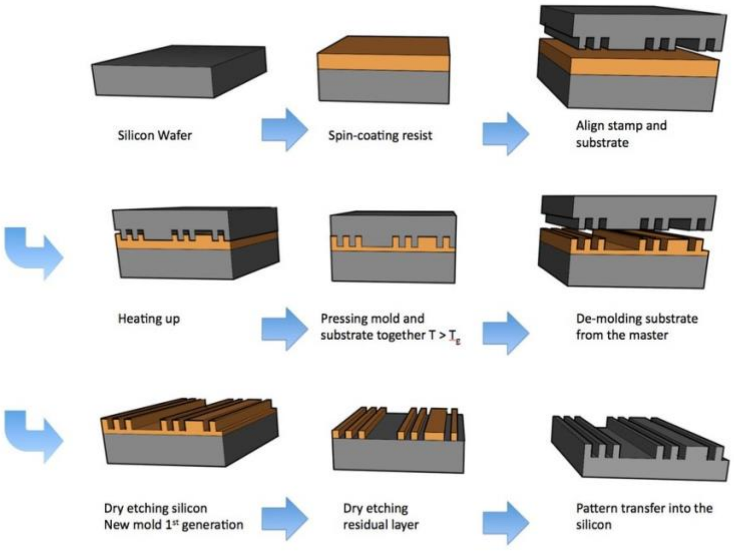


Figure 2.9 Nanoimprint Lithography (NIL)

iv. Soft Lithography: In soft lithography, the resist is patterned using elastomeric moulds or stamps. For the manufacture of stamps, materials like polydimethylsiloxane (PDMS) are frequently employed. The resist design is transferred to the substrate by bringing the inked stamp into contact with it. Complex, three-dimensional micro- and nanostructures may be made using soft lithography techniques like replica moulding and microcontact printing.

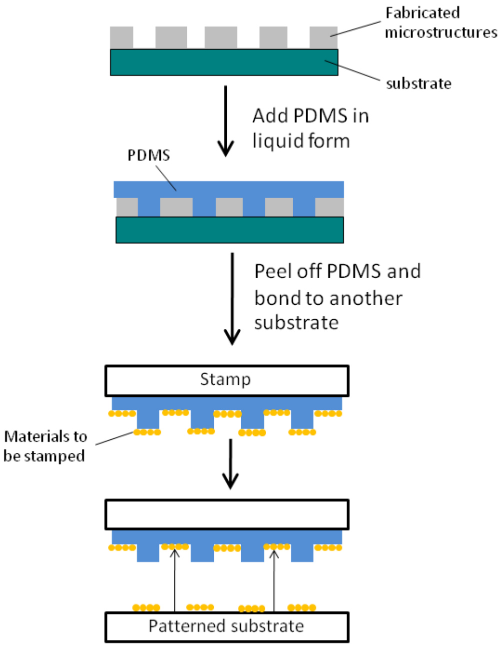


Figure 2.10 Soft Lithography

2.37.5 ETCHING

After lithography, etching is frequently used to remove undesirable material from the thin film. You may utilise a variety of etching methods, including dry etching and wet etching. The substrate is submerged in a liquid chemical during wet etching, which dissolves the exposed areas of the film alone. Plasma is used in dry etching techniques like reactive ion etching (RIE) to remove material by physical sputtering or reactive chemical reactions.

i. Wet Etching: Wet etching is the process of selectively dissolving a substance using chemical solutions (etchants). The exposed portions of the film are eliminated as a result of the etchant's reaction with them. Although wet etching has a potential for low resolution, it offers high selectivity.

ii. Dry Etching: Materials are removed using reactive gases and plasma in dry etching processes like reactive ion etching (RIE) or plasma etching. The film surface is scratched as a result of the plasma's reactive species interacting with it. High-resolution patterning and improved etching profile control are both provided by dry etching.

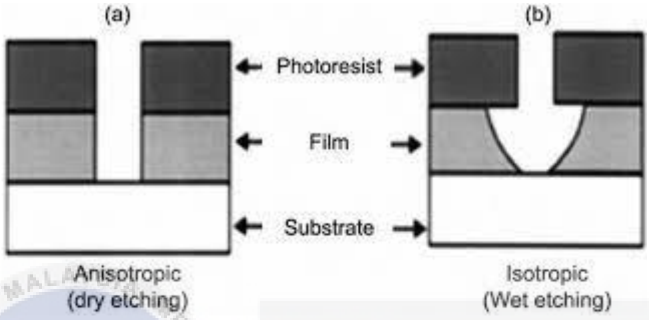


Figure 2.11 Etching

2.37.6 DOPING

The manufacture of thin layer nanoelectronic biosensors requires the technique of doping. It entails the purposeful addition of impurity atoms to a thin film in order to change its electrical characteristics. Doping is necessary to customise the material's conductivity, charge transport, and energy band shape and improve the performance of the biosensor.

i. Ion implantation: Ion implantation entails ionising the thin layer with powerful ions. The film is penetrated and entrenched by the impinging ions, which introduce dopant atoms into the substance. Ion implantation makes it possible to customise electrical properties by precisely controlling the dopant concentration and depth distribution.

ii. Diffusion: When a dopant source is present, the film is thermally annealed during diffusion. As dopant atoms move inside the film at high temperatures, a gradient in dopant concentration results. Diffusion is a method that some materials might employ to incorporate dopants over bigger surfaces

iii. Molecular Beam Epitaxy (MBE): During the formation of thin film layers, MBE is a deposition method that may integrate dopant atoms. Controlled doping may be done during film growth by adding dopant materials to the evaporated material.

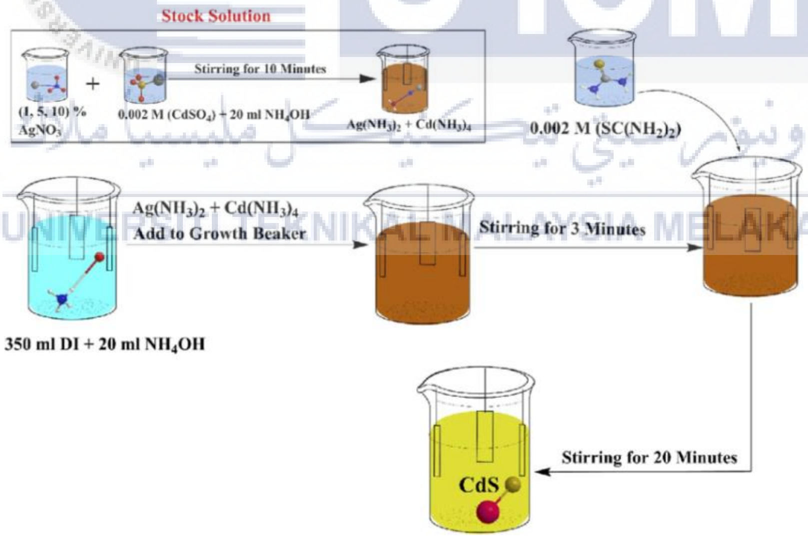


Figure 2.12 Doping

2.37.7 SURFACE FUNCTIONALIZATION

The surface is often functionalized with certain biomolecules to allow the thin film's biosensing capabilities. In order to enable the attachment of biomolecules like antibodies, DNA probes, or enzymes, the surface chemistry must be changed in this stage. The biomolecules can be immobilised onto the surface via strategies such as self-assembly, covalent bonding, or physical adsorption.

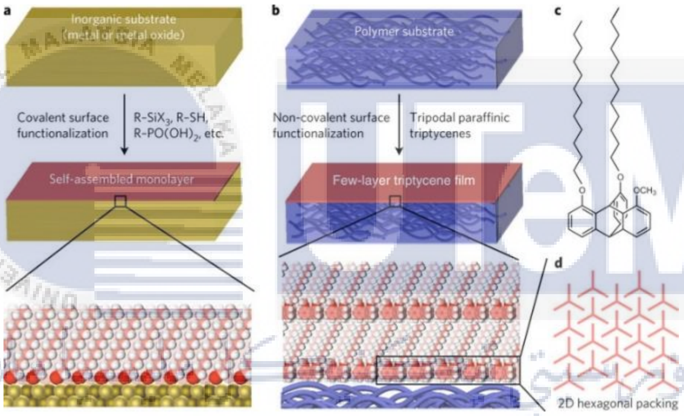


Figure 2.13 Surface Functionalization

2.37.8 INTEGRATION AND PACKAGING

Following fabrication, the biosensing components are integrated into larger systems and packaged for usage in real applications. The devices may then be integrated into microfluidic systems for sample transport, connected to external electronics, or enclosed in protective coverings.

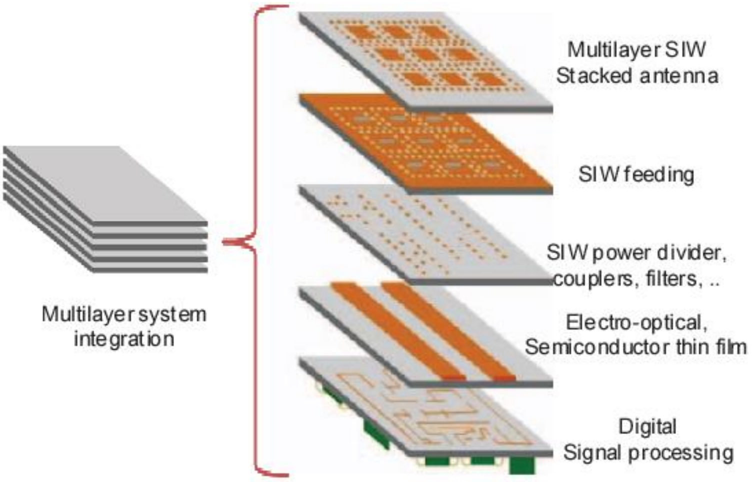


Figure 2.14 Integration and Packaging

2.38 ELECTRODEPOSITION

A metal or alloy is deposited onto a substrate using the electrodeposition method, commonly known as electroplating or electrodeposition. The following are some of its benefits and drawbacks:

2.38.1 ADVANTAGES OF ELECTRODEPOSITION

i. Controlled Deposition: Electrodeposition offers fine control over the composition and layer thickness. It is possible to precisely produce the required thickness and composition by modifying the deposition parameters, such as current density, deposition duration, and bath composition.

ii. Conformal Coating: Electrodeposition is capable of producing conformal coatings, in which the deposited layer may adapt to uneven surfaces and complicated geometries.

This qualifies it for the deposition of metals onto complex structures or irregular substrates.

iii. Cost-Effective: In general, electrodeposition is a more affordable process than other deposition techniques. As the metal ions are selectively reduced onto the substrate, it enables for high material utilisation by reducing the amount of deposited material that is wasted.

iv. High Deposition Rate: Electrodeposition is capable of achieving comparatively high deposition rates, making it possible to quickly and effectively cover vast regions. It can therefore be produced on an industrial basis.

v. Tenable Properties: The physical, chemical, and mechanical characteristics of electrodeposited films might vary. The characteristics of the deposited layer may be adjusted to fit particular requirements by altering the deposition parameters, such as current density, temperature, and bath composition.

2.38.2 DISVANTAGES OF ELECTRODEPOSITION

i. Limited Material Compatibility: Metals and alloys can be deposited via electrodeposition. It might not be appropriate for depositing complicated composite materials or non-metallic materials.

ii. Limitations of the Substrate: An electrode for the electrodeposition procedure must be a conductive substrate. Before performing electrodeposition, non-conductive or insulating surfaces need to be treated with a conductive layer or coated with one.

iii. Lack of homogeneity: Electrodeposition can occasionally cause uneven deposition, which can cause thickness variations or irregularities in the deposited layer. To ensure consistency, this can call for extra post-deposition processing procedures

iv. Porosity and Stress: Inherent porosity in electrodeposited films may affect their mechanical characteristics, resistance to corrosion, or electrical conductivity. Additionally, internal tension may be present in some electrodeposited films, which can cause cracking or delamination.

v. Environmental Issues: Electrodeposition frequently calls for the use of electrolytes and plating baths that might include poisonous or hazardous materials. To reduce the negative effects on the environment, proper waste treatment and disposal procedures must be put in place.

2.39 WHAT IS THE BEST TIME TO SONICATE CARBON NANOTUBES WITH OUT DAMAGE

Sonication uses sound waves to disperse carbon nanotubes (CNTs) in a liquid medium. The duration of sonication is a key factor affecting the quality of CNT dispersion.

As the sonication time increases, the aspect ratio of CNTs decreases.

1. The optimal sonication time to obtain 2 ± 0.5 µm MWNT aggregates [27].

2. When the ultrasonic time is less than 60 minutes, the number of monodisperse carbon nanotubes increases as the ultrasonic time increases [46].

3. With longer sonication times, the thermal conductivity increased slowly, peaked after about 60 min, and then started to decrease [46].

4. Longer sonication time shortens and damages the CNTs.

5. The sonication time for each cycle should be reduced from 30 minutes to 5 minutes [12].

6. The sonication temperature is increased to avoid affecting the efficiency of sonication at low temperatures.

In summary, the optimal sonication time for CNTs depends on the specific application and type of CNTs used. It is recommended to start with a short sonication time and gradually increase the time while monitoring the quality of dispersion.

Table 2.2 Comparison of CNT fabrication methods

Properties component	Synthesis method			
	Arc Discharge	Laser Ablation	Chemical Vapor Deposition	Electrodeposition
Advantages	Inexpensive. SWCNTs have limited structural defects. Simple protocol. highquality nanotubes	Scalable production of SWCNTs. Produces long nanotubes. High purity. Controllable diameter. Relatively high purity, room temperature synthesis	Uniform SWCNTs. High purity. low temperature, high purity, large-scale production, aligned growth possible	Inexpensive, uncomplicated set-up, abundant raw material availability, Flexible method to produce SWCNT and MWCNT. relatively low temperature, large-scale production
Disadvantages	Short nanotubes. Inconsistent size	Cost and labour intensive	Best fit for producing	SWCNT production will

	of SWCNTs. A heterogeneous reaction product requires purification. High temperature, purification required, tangled nanotubes	technique Method limited to the lab scale, crude product purification required	MWCNTs. Synthesized CNTs are usually MWNTs, defects	sacrifice the setup simplicity and add catalyst preparation. Under ongoing investigation, research is not as established as other methods

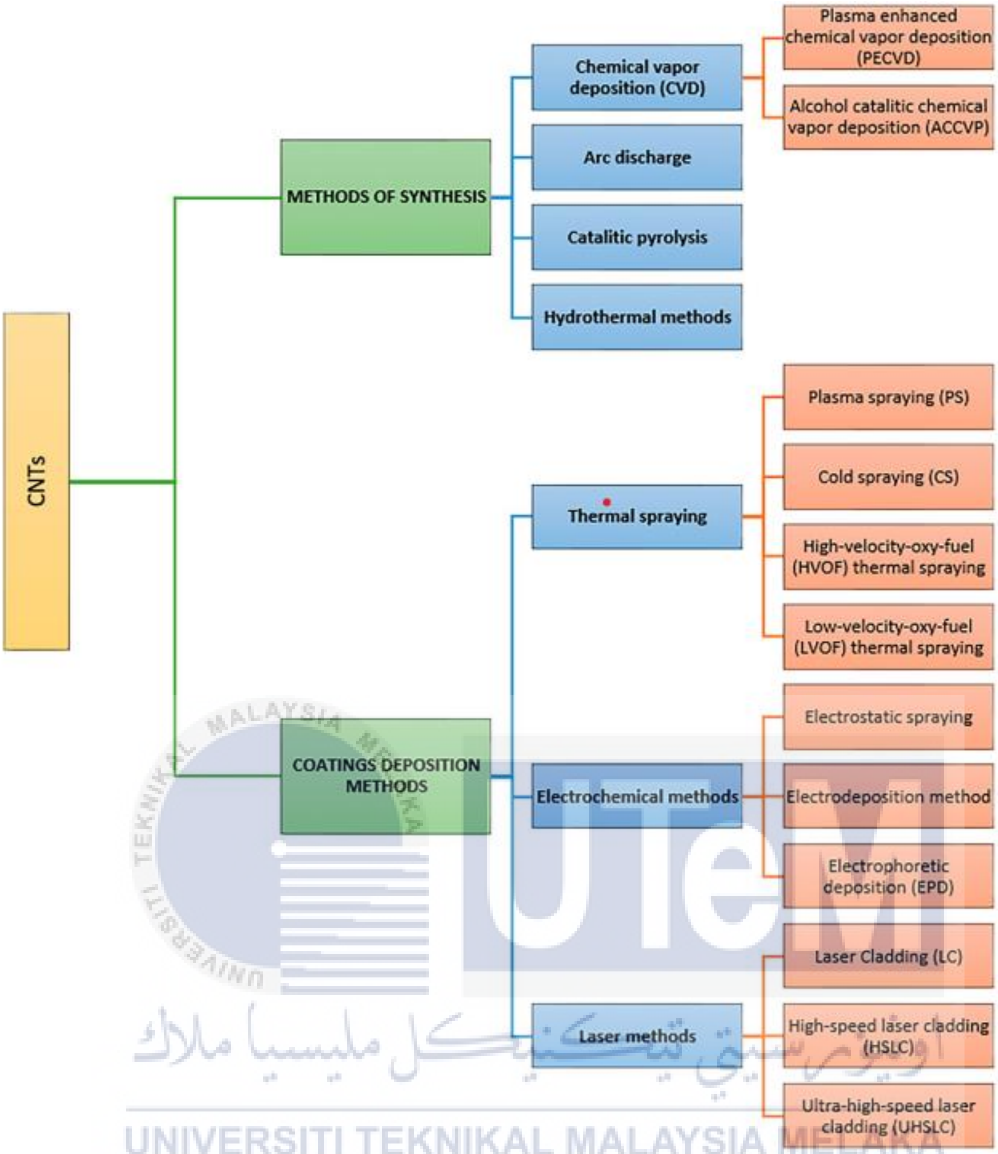


Figure 2.15: A scheme of CNTs methods of synthesis and CNTs coatings deposition methods.

CHAPTER 3

METHODOLOGY

3.1 LIST OF EQUIPMENTS

This section describes the equipment and materials used in this small project. A potentiostat Nhandles the electrodeposition process of the electrodes and the COMSOL Multiphysics software validates the sensorgram results to obtain the desired results. .

Table 3.1 List of equipment

Equipment	Quantities
Potentiostat	1
Comsol Multiphysics software	1
Sonicator	1
Carbon plate	1 (1cm x 2cm)
ITO glass slice	1 (1cm x 2cm)
Stainless steel plate	1 (1cm x 2cm)
Hand notcher	1
Foot shear	1
Bandsaw Machine	1
X-Ray Diffraction Machine	1
Scanning Electron Microscope	1
Fourier Transform Infrared Spectroscopy	1

3.1.1 POTENTIOSTAT

In multi-electrode electrochemical cells, a potentiostat is an analytical device that modulates the potential of the working electrode. A potentiostat consists of several internal circuits that enable its operation. Potentials and currents are generated and measured by circuits. The electrodes of the electrochemical cell are connected to the potentiostat circuit via external leads and cell leads. The cell cable connects the working, counter (auxiliary) and reference electrodes on one end of a standard 3-electrode cell and the potentiostat cell cable connector on the other end. The applied signal is controlled by the potentiostat's internal circuitry. For example, in the voltage-controlled approach, the potential of the working electrode is maintained with respect to the reference electrode. At the same time, current flows between the working and counter electrodes. Thanks to the potentiostat circuit, the current flowing between the working electrode and the high impedance reference electrode is minimized. Today's potentiostats are more complex than can be explained on this page, but a basic overview of potentiostat circuits is provided to help you understand how they work.[23].

Figure 3.1 Potentiostat

3.1.2 COMSOL MULTIPHYSICS SOFTWARE

The COMSOL Multiphysics tool is used in a variety of engineering, industrial, and scientific research fields to simulate devices , design , and process . COMSOL Multiphysics is a simulation tool that allows user to model multiphysics and also a single-physics systems that are completely integrated. The Model Builder includes all steps of the modelling workflow, including describing geometry, material properties, and the physics that characterise certain processes, as well as solving and postprocessing models for exact results. When finished building a model, users can use the Application Builder to transform it into a simulation application with a specialized user interface that colleagues and clients who aren't familiar with simulation software can use. The Model Manager, a tool for modelling and simulation management that provides version control and efficient storage, is included in the COMSOL Multiphysics platform to help users to keep models and 30 applications organized the COMSOL Multiphysics® software platform, users may add any combination of add-on products from the COMSOL product range. This gives users access to specific tools tailored to their modeling needs.

Figure 3.2 Comsol Multiphysics

3.1.3 SONICATOR

Sonication is described as the process of using sound waves to agitate particles in liquids. These interruptions are employed to mix solutions, accelerate the solubility of solids into liquids, and remove dissolved gasses from liquids.

Figure 3.3 Sonicator machine

3.1.4 CARBON PLATE

Carbon sheet, also called graphite sheet, is extruded and isostatically pressed. Carbon plates are strong, brittle, resistant to high temperatures, conductive and self-lubricating. In graphite, carbon atoms are arranged in layers. Graphite is a black, lustrous, opaque substance. Not transparent. A layer of carbon slips easily on paper and leaves black marks, so it is used in pencil leads. Water does not dissolve graphite. It has a high melting point and excellent electrical conductivity, making it an excellent material for electrolytic electrodes. Graphite is an excellent electrical conductor because all these delocalized electrons can move in the same direction.

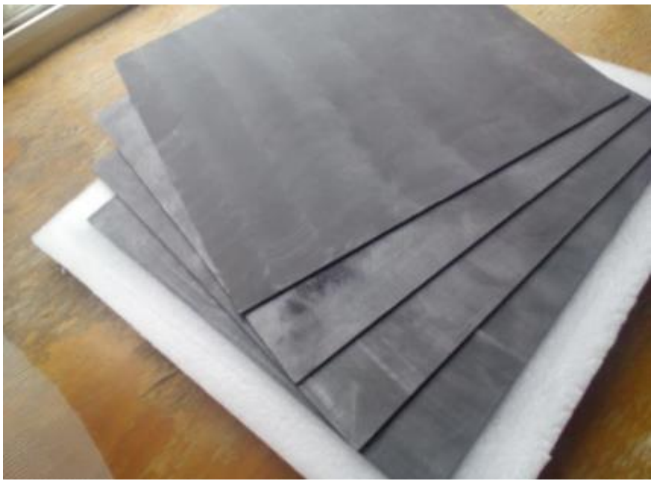


Figure 3.4 Carbon Plate

3.1.5 ITO glass slice

ITO glass is made by depositing indium tin oxide in varying quantities on the surfaces of various glass substrates. The coatings enable specialist procedures such as electrical conduction transmittance, resulting in resistances that may be tuned to the application requirements. ITO Glass is a popular material in research and industry due to its excellent optical transparency and wide variety of applications.

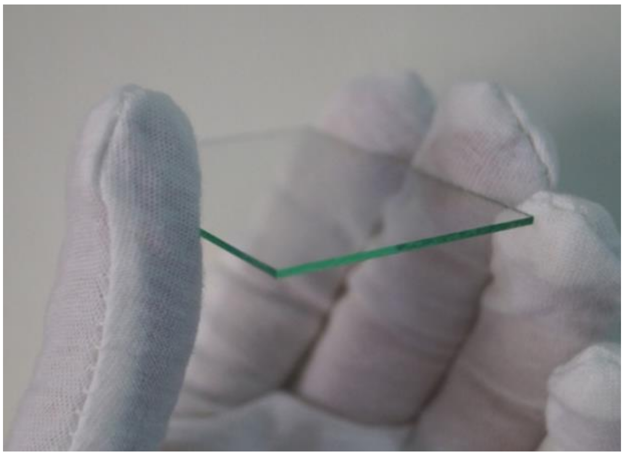


Figure 3.5 ITO glass slice

3.1.6 STAINLESS STEEL PLATE

Stainless steel is a type of iron-based alloy containing at least 11% chromium, a composition that prevents rust while providing heat resistance. Stainless steel is aesthetically pleasing, easy to clean and durable, and offers a range of benefits in addition to its environmental benefits.

Figure 3.6 Stainless Steel Plate

3.1.7 HAND NOTCHER

This machine is a manual corner notcher used for making pots and boxes. Cut a notch at a 90 degree angle to make it easier to bend the flat metal plate into a box or pot.

Figure 3.7 Hand notcher

3.1.8 FOOT SHEAR

These manual trimming scissors, also known as foot scissors, step scissors or tamping scissors, are the most cost effective way to cut large sheet metal panels with precision. This versatile collection can be used for cutting steel, aluminum, stainless steel and other metal materials.

Figure 3.8 Foot Shear

3.1.9 BANDSAW MACHINE

A band saw is an electric saw that uses a long, sharp saw blade consisting of a continuous band of toothed metal stretched between two or more wheels to cut material. It can cut a wide variety of materials, but is typically used in woodworking, metallurgy, and carpentry.

Figure 3.9 Bandsaw Machine

3.2 SYSTEM OPERATION

In this project, electrodes composed of carbon, stainless steel, and ITO need to be electrodeposited by first coating them with PPY (polypyrrole)/MWCNT (multi-walled carbon nanotubes) solution. Electrodeposition is a method of producing solid materials from solutions of molecules, ions, or complexes. The final result is better if the electrodeposition is delayed. For best results, the electrode should be left in the solution for at least 5-10 seconds after coating. After coating the electrode with the PPY/MWCNT solution, the electrode should be placed in the methanol solution. SEM (Scanning Electron Microscope) uses a relatively low-energy focused electron beam to study the morphology of deposited films, creating an image by scanning a stream of focused electrons across the surface. XRD (X-ray diffraction) helps determine the geometry and shape of molecules using X-rays, facilitating verification of Al materials in electrodes. FTIR checks the composition of functional groups. Next, we need to analyze the relationship between the voltage current and the electrode surface.

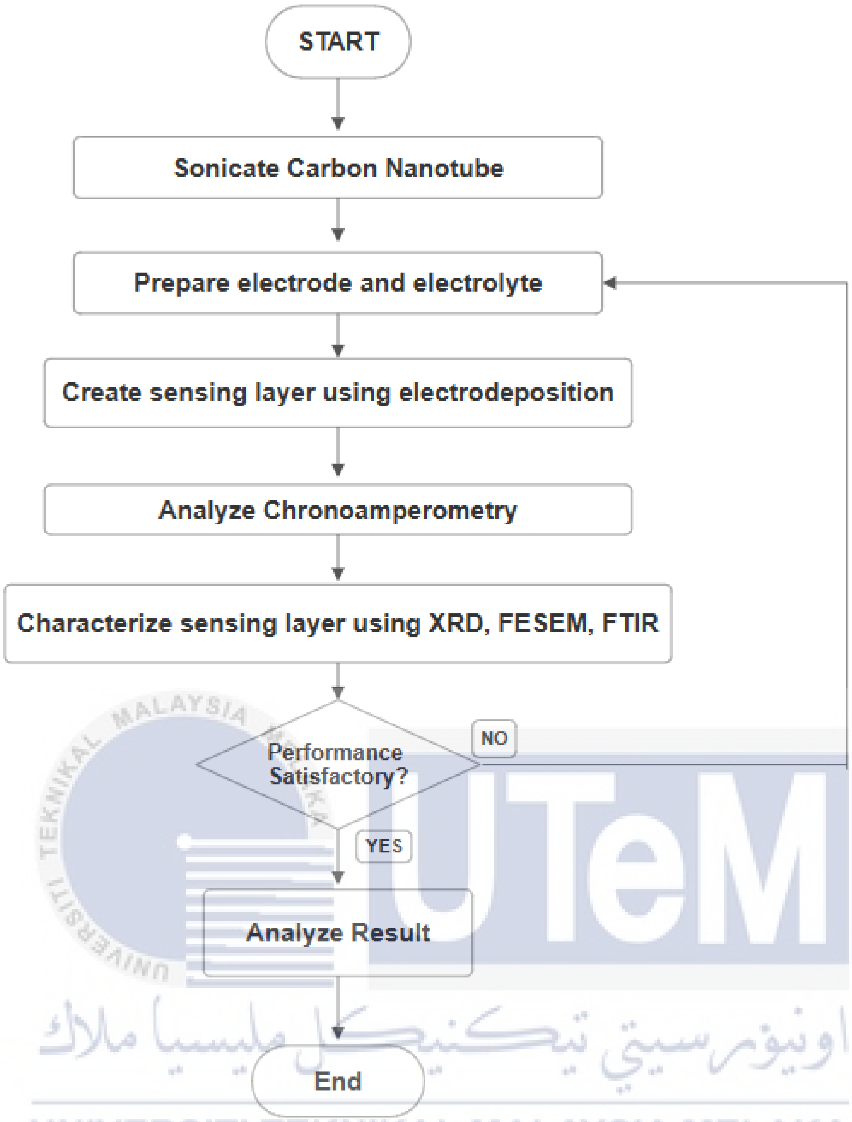


Figure 3.10 Flowchart of the Project

3.2.1 Explanation of flowchart

I. Sonicate carbon nanotube: This phase includes the use of ultrasonic waves to break up the carbon nanotube agglomerates into smaller, more uniform particles. This is done to enhance the dispersion of the nanotubes in the electrolyte solution.

II. Prepare electrode and electrolyte: The electrode is formed by depositing a thin layer of a conducting material, such as platinum (Pt) or titanium (Ti), on top of a substrate. The electrolyte solution is created by dissolving a salt in water

III. Create sensing layer using electrodeposition: The carbon nanotubes are put onto the electrode using electrodeposition. A voltage is applied between the electrode and the electrolyte solution, causing the nanotubes to migrate towards the electrode and deposit on its surface.

IV. Analyse chronoamperometry: Chronoamperometry is a technique used to measure the current flowing through the electrode as a function of time. This investigation helps to identify the electrochemical characteristics of the sensor layer.

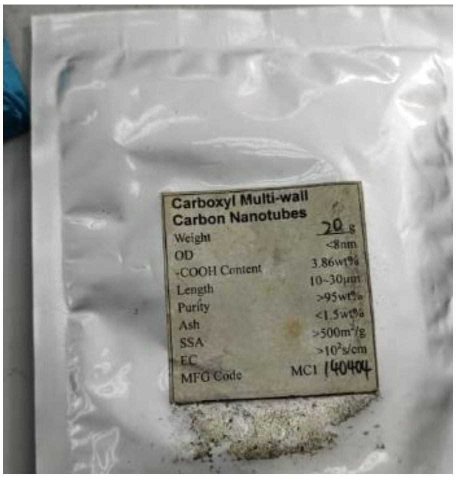
V. Using XRD, FESEM, and FTIR, characterize the sensing layer: X-ray diffraction (XRD) is used to identify the crystalline structure of the sensor layer. Field emission scanning electron microscopy (FESEM) is used to study the surface morphology of the sensor layer. The chemical composition of the sensor layer is determined using Fourier transform infrared (FTIR) spectroscopy.

VI. Analyse the findings: The results of the preceding studies are analyzed in order to assess the quality and characteristics of the sensing layer.

VII. End: The procedure terminates when the sensing layer has been successfully produced and characterized.

3.3 PROCEDURE

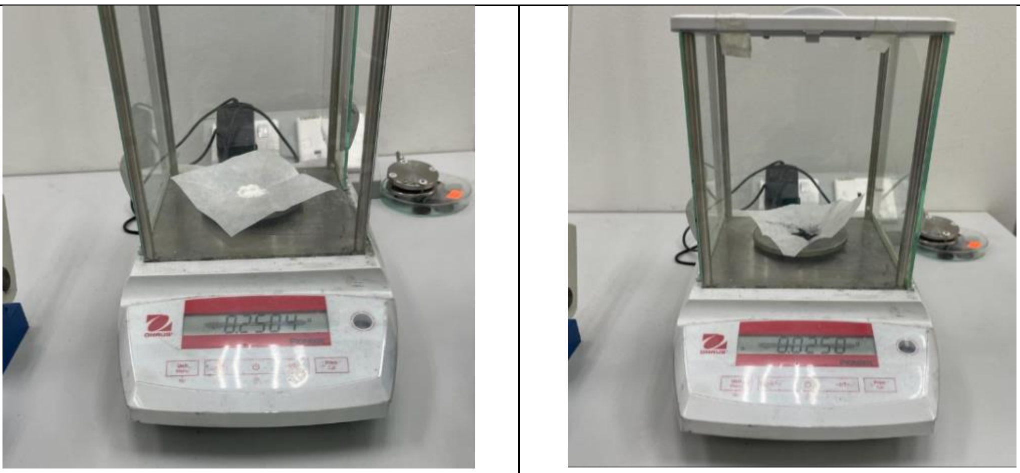
1. Measuring the amount of carbon nanotubes (CNTs) and sodium dodecylbenzene sulfonate (SDBS) before combining with water or sonication is critical for optimizing the dispersion process. The right CNT-to-SDBS ratio is critical for creating a well-dispersed CNT solution since it affects the sonication process's efficacy and dispersion stability. Measuring the quantities of CNTs and SDBS ensures that the appropriate concentrations are utilized to prevent agglomeration and promote uniform dispersion of CNTs in the solution. This is critical for achieving a uniform distribution of CNTs, which is required for the production of high-quality CNT composites. Furthermore, quantifying the amounts of CNTs and SDBS assures that the dispersion process is repeatable, resulting in consistent outcomes in following manufacturing phases. This is especially significant in research and industrial applications where consistency and repeatability are required. Overall, measuring the CNTs and SDBS before mixing with water or sonication is critical for optimizing the dispersion process, preventing agglomeration, and ensuring process reproducibility, resulting in the production of well-dispersed and high-quality CNT composites.



Carboxyl Multi-wall Carbon Nanotubes

Weight	20 g
OD	<8nm
-COOH Content	3.86wt%
Length	10~30μm
Purity	>95wt%
Ash	<1.5wt%
SSA	$>500m^2/g$
EC	$>10^2 s/cm$
MFG Code	MC1 140404

Figure 3.11 Carboxyl Multi-wall Carbon Nanotubes



(a) (b)

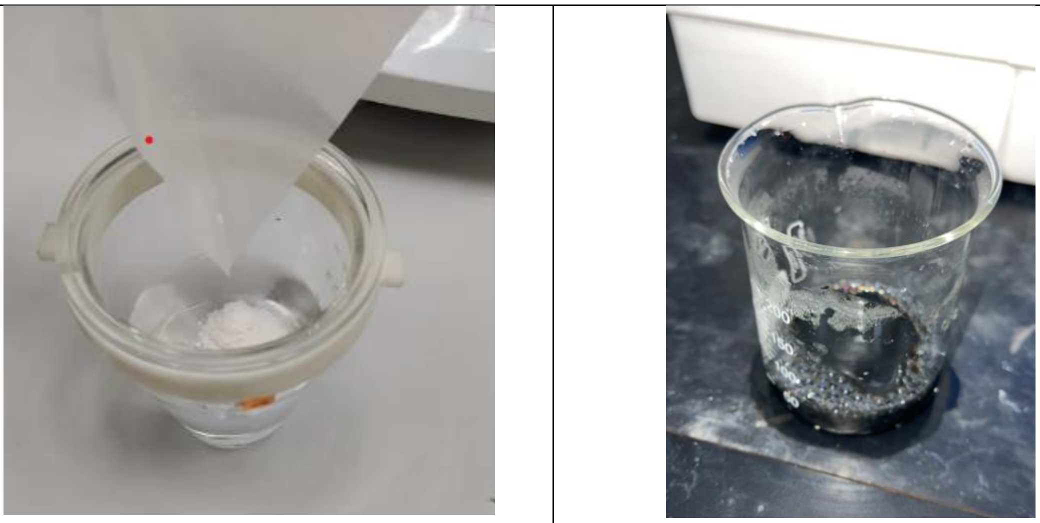
Figure 3.12 (a) SDBS, (b) CNTs

2. Next step, sonicate the CNTs + SDBS solution to
    - I. Ultrasonication causes acoustic cavitation in liquids, resulting in local shear stress that breaks down CNT aggregates and disperses them evenly. This leads to a uniform dispersion of CNTs in the solution, which is essential for the production of high-quality composites.
    - II. Sonication prevents agglomeration and tangling of carbon nanotubes, ensuring that they stay independently distributed in the fluid. This is especially relevant for sensitive single-walled nanotubes (SWNTs).
    - III. Dispersion Parameter Optimization: To obtain an equal CNT distribution, important factors such as amplitude, temperature, pressure, and retention duration must be controlled throughout the sonication process. Optimizing these parameters is critical for getting well-dispersed CNTs in an aqueous solution.

IV. Reduced CNT Length and Functionalization: Sonication can shrink carbon nanotubes, open their ends, and form functional groups at their sidewalls and terminal ends. This change in the CNT structure can increase dispersion and compatibility with other materials.

V. Rapid Processing and perfect Control: Ultrasonic technology enables rapid processing and perfect process control, guaranteeing effective preparation of CNT dispersions.

Figure 3.13 Sonicating CNTs



(a) Before sonicate

(b) After sonicate

Figure 3.14 Before and after sonicate

3. After sonication, the CNT-SDBS solution must be stirred to ensure that the CNTs are evenly distributed throughout the solution. Ultrasonication causes acoustic cavitation in liquids, resulting in local shear stress that breaks down and disperses CNT aggregates evenly. However, the dispersion is not permanent, and the CNTs can re-aggregate over time. Stirring the solution after sonication helps to avoid CNT re-aggregation and keeps them equally disseminated in the solution. This is critical for the production of high-quality CNT composites by electrodeposition, since a uniform distribution of CNTs in the solution is required for well-dispersed CNTs in the final composite. Additionally, agitating the solution can assist in removing any air bubbles that may have developed during sonication, which might interfere with the electrodeposition process.

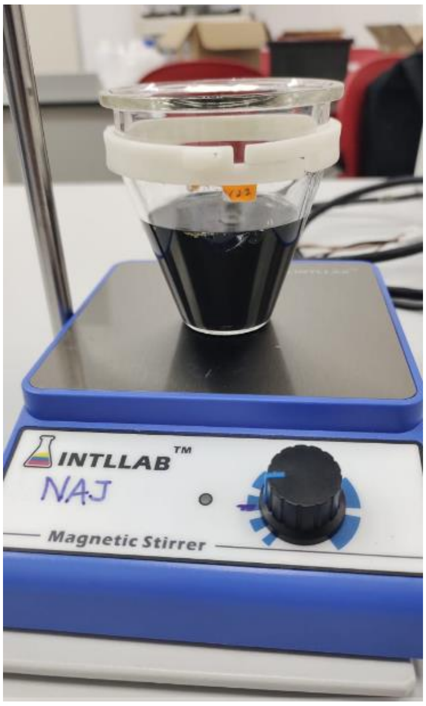


Figure 3.15 Stirred the sonicated CNTs

4. Electrodeposition is a viable way to create carbon nanotube (CNT) composites. Metal materials are deposited on a cathode, and CNTs adsorb on the metal's surface. The CNTs are subsequently incorporated in the depositing metal, forming a metal-CNT composite. Electrodeposition is a versatile and inexpensive approach for fabricating a wide range of materials, including CNT composites. It enables good control of CNT content and the manufacture of structurally homogenous CNT-metal composites, making it a potential approach for producing CNT composites with the appropriate qualities. In addition, electrodeposition may be used to create CNT composites with other materials, such as copper, and the process parameters can be tuned to get the required composite qualities.

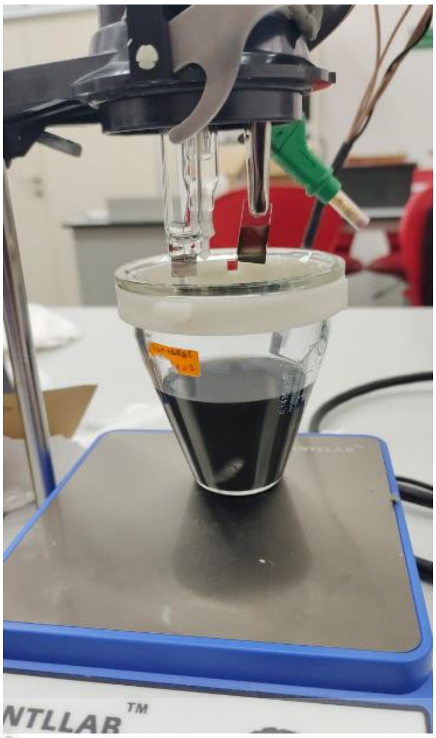


Figure 3.16 Electrodeposition using material

5. **Process Control and Monitoring**: Nova software, when combined with a potentiostat, enables accurate control and real-time monitoring of the electrodeposition process. This allows for the adjustment of deposition parameters like as potential, current, and duration, resulting in the production of high-quality CNT composites.

   Data Acquisition and Analysis: The program simplifies data collection and analysis, allowing researchers to collect detailed electrochemical data during the electrodeposition process. This data may be studied to understand the electrochemical behavior of the system and optimize the manufacturing process.

   Optimisation of CNT Dispersion: Using Nova software and a potentiostat can help to optimise CNT dispersion during the electrodeposition process. This is critical for producing a uniform distribution of CNTs in the composite, which is vital for getting composites with desired qualities.

Improved Reproducibility: The software-controlled electrodeposition method improves the reproducibility of CNT composites since it allows for the accurate reproduction of deposition circumstances and parameters.

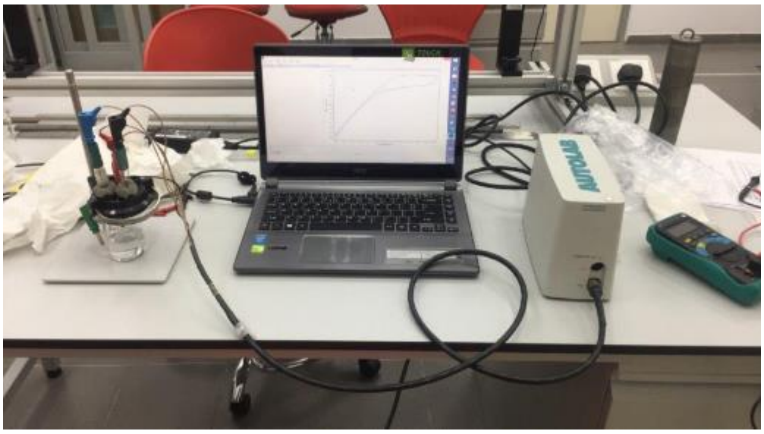


Figure 3.17 Full set up of electrodeposition

3.4 MATERIAL

Table 3.2 Comparison of material type

TYPE OF MATERIAL	FUNCTION
STAINLESS STEEL	• Highly corrosion-resistant, it is suited for a variety of applications, including aquatic conditions. • Has a high melting point, which ensures structural integrity at high temperatures. • Good electrical conductivity, which can be useful for some applications. • Can function as a cathode in the electrodeposition process.

ITO	• A broad bandgap semiconductor with distinctive optoelectronic features. • Transparent and electrically conductive, it's ideal for applications like transparent electrodes and touchscreens. • Can function as an anode in the electrodeposition process. • However, ITO is not as corrosion-resistant as stainless steel, and its expensive cost might be a limiting issue for some applications.
CARBON	• Graphite, carbon black, and activated carbon are examples of materials that • Can be utilized as an anode in the electrodeposition process. • Carbon compounds are strong electrical conductors and may be utilized in many applications, including electrical conductors and electrodes. • Carbon compounds may not have the same corrosion resistance as SS, or the special features of ITO.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the initial and preliminary results of a fabrication carbon nanotubes via electrodeposition. Analytical methods for characterizing materials include FESEM, chronoampertry, FTIR, XRD, and EDX. FESEM, or Field Emission Scanning Electron Microscopy, is a technique for obtaining high-resolution pictures of a sample's surface. EDX (Energy Dispersive X-ray Spectroscopy) is used to identify a sample's elemental makeup. FTIR, or Fourier Transform Infrared Spectroscopy, is used to determine the functional groups of a material. XRD, or X-ray Diffraction, is a technique used to identify the crystal structure of a material. Finally, chronoampertry is an electrochemical method that investigates the kinetics of electrode reactions. These approaches are frequently used in conjunction to offer a thorough characterisation of a substance.

4.2 RESULTS AND ANALYSIS

4.2.1 ELECTRODE COATING RESULTS

4.2.1.1 ELECTRODE COATING RESULTS 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 4.5 below, there are carbon, stainless steel, ITO that have been coated to Ppy/MWCNT solution for 3 minutes and 5 minutes

When compare to the 1.5 hour and 3 hours, the material that high conductive is ITO for 3 and 5 minutes because its constant. In chronoamperometry, the constant material is highly conductive, allowing for efficient electron transmission during the electrochemical process. High conductivity materials have low electrical resistance, allowing them to easily transmit electric current. This is critical for the electrode material in chronoamperometry because it must be able to transmit electrons rapidly and effectively between the electrode and the solution.

There is a link between electrical conductivity and heat conductivity, particularly in metals. According to the Wiedemann-Franz law, a metal's thermal to electrical conductivity ratio is proportional to its temperature. This equation is based on the fact that electrical and thermal conductivity are dependent on the mean free route of electrons, electron mass, and the number of free electrons per unit volume. Because electrons are responsible for both electric current and heat transport in metals, their conductivities are determined by the same causes.Non-metallic materials, such as polymers and ceramics, have poorer heat conductivity due to their more rigid and less dynamic molecular architectures.

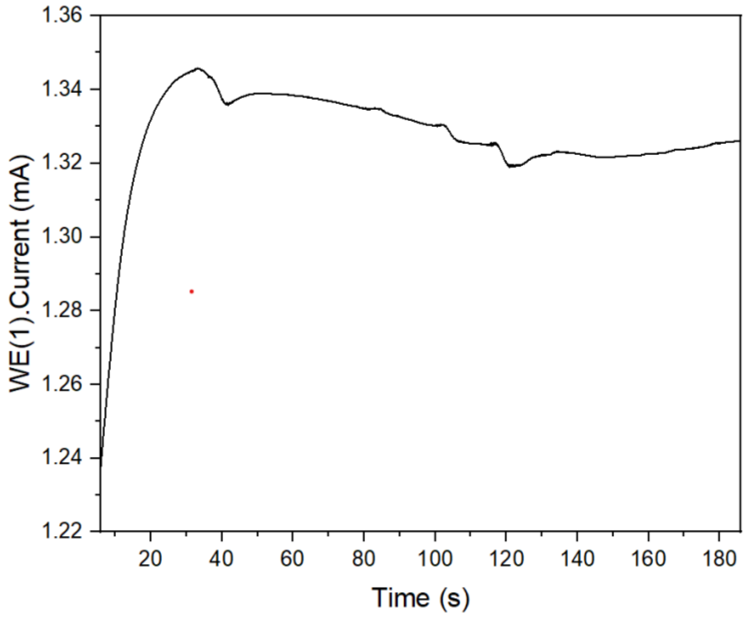


Figure 4.1 Chronoamperomtery on material carbon at 3minute (sonicated CNTs 1 Hour 30 Minutes)

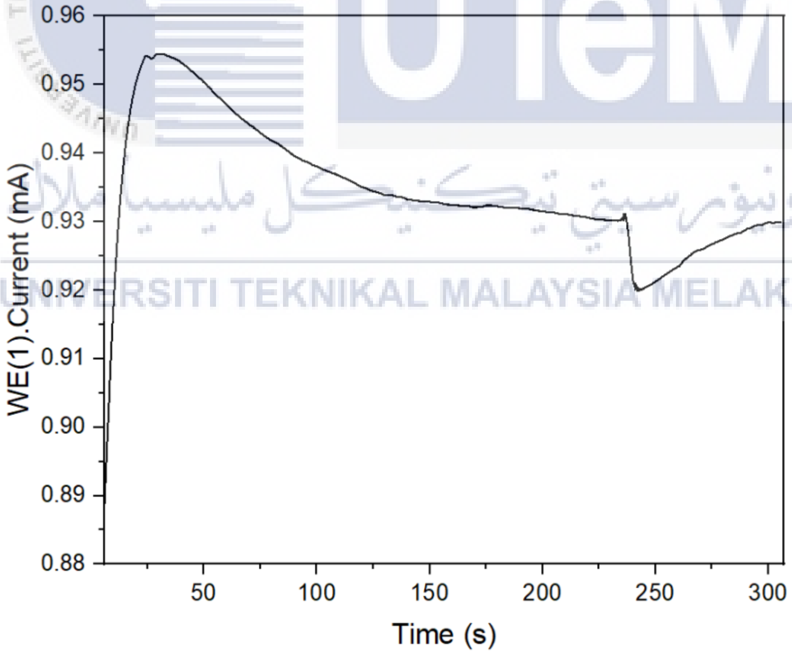


Figure 4.2 Chronoamperomtery on material carbon at 5minute (sonicated CNTs 1 Hour 30 Minutes)

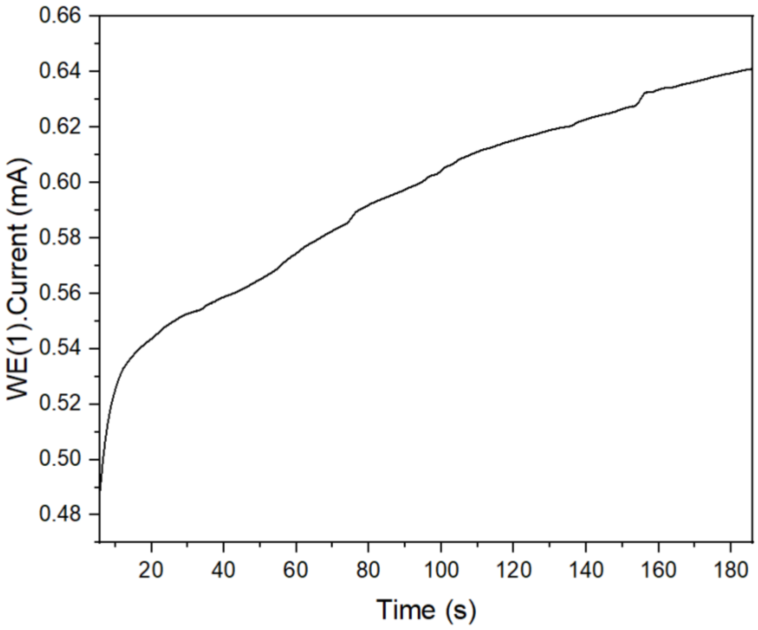


Figure 4.3 Chronoamperomtery on material ITO at 3minute (sonicated CNTs 1 Hour 30 Minutes)

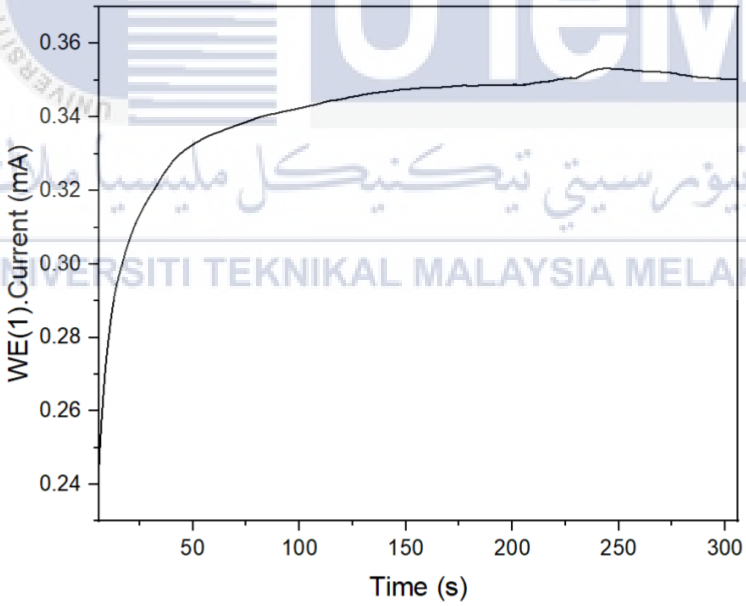


Figure 4.4 Chronoamperomtery on material ITO at 5 minute (sonicated CNTs 1 Hour 30 Minutes)

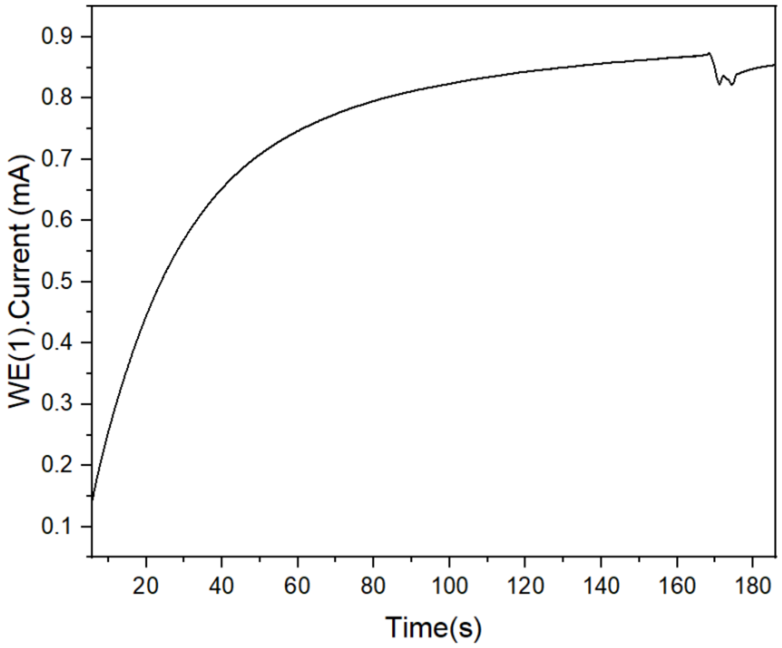


Figure 4.5 Chronoamperomtery on material Stainless steel at 3 minute (sonicated CNTs 1 Hour 30 Minutes)

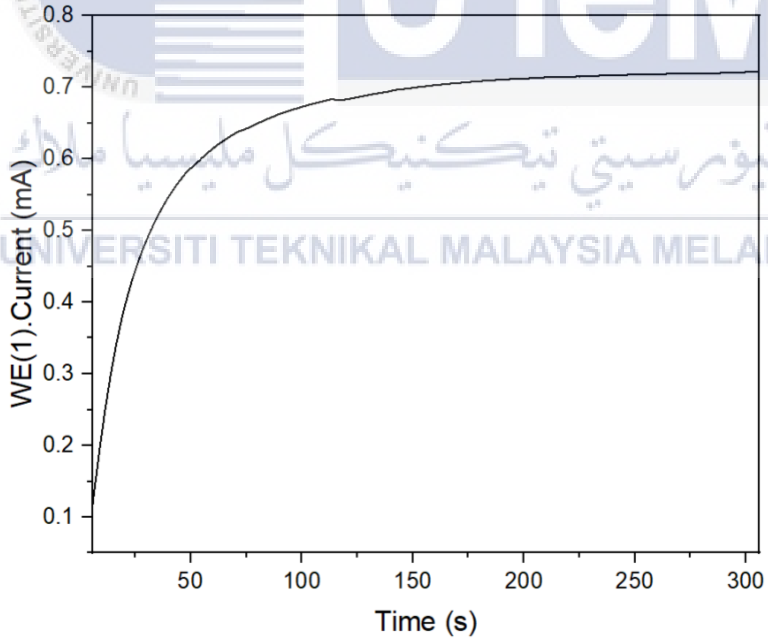


Figure 4.6 Chronoamperomtery on material Stainless steel at 5 minute (sonicated CNTs 1 Hour 30 Minutes)

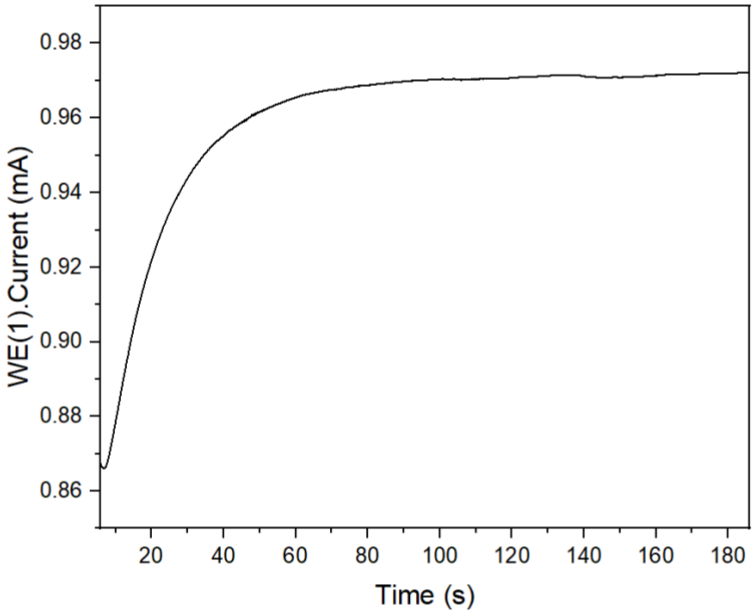


Figure 4.7 Chronoamperomtery on material Carbon at 3 minute (sonicated CNTs 3 Hour)

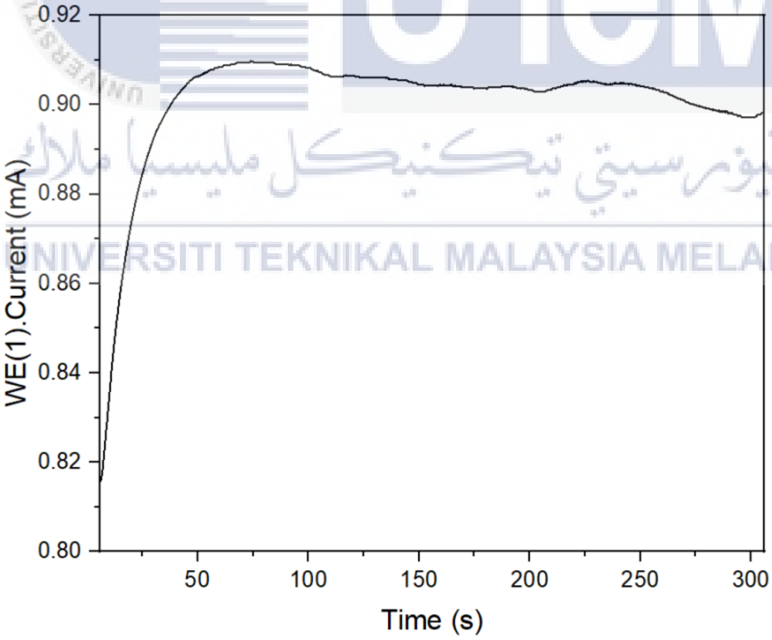


Figure 4.8 Chronoamperomtery on material Carbon at 5 minute (sonicated CNTs 3Hour)

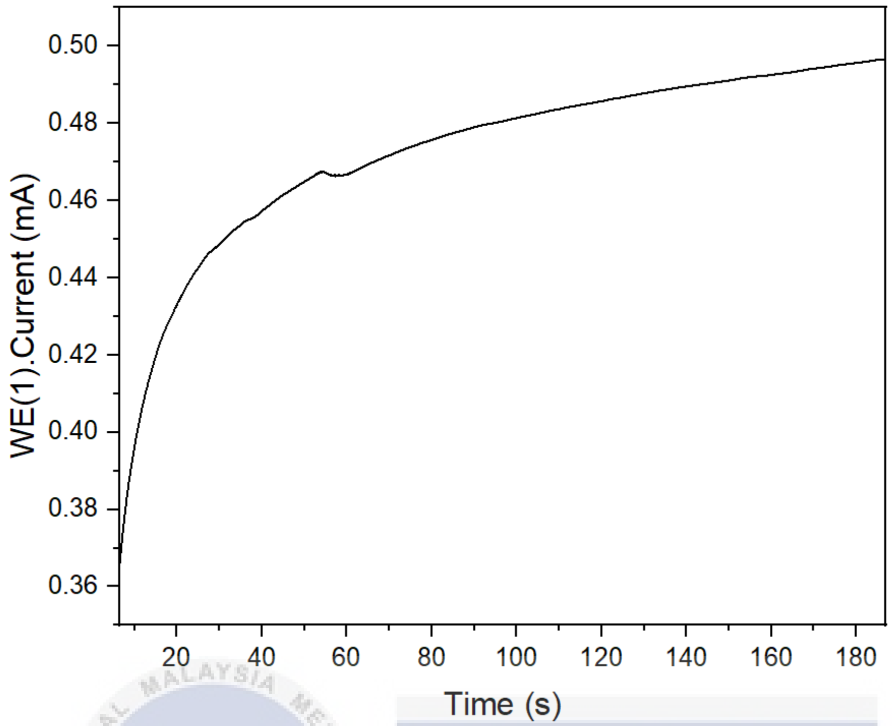


Figure 4.9 Chronoamperomtery on material ITO at 3 minute (sonicated CNTs 3Hour)

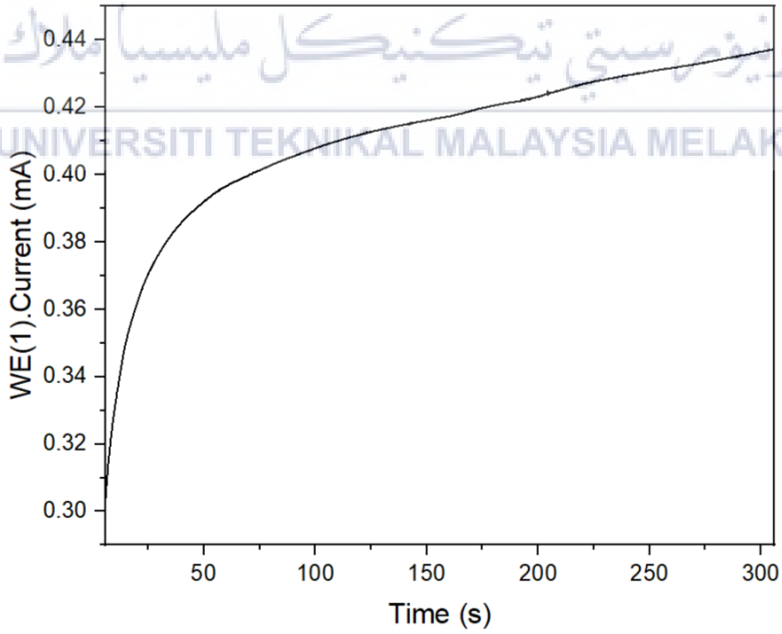


Figure 4.10 Chronoamperomtery on material ITO at 5 minute (sonicated CNTs 3Hour)

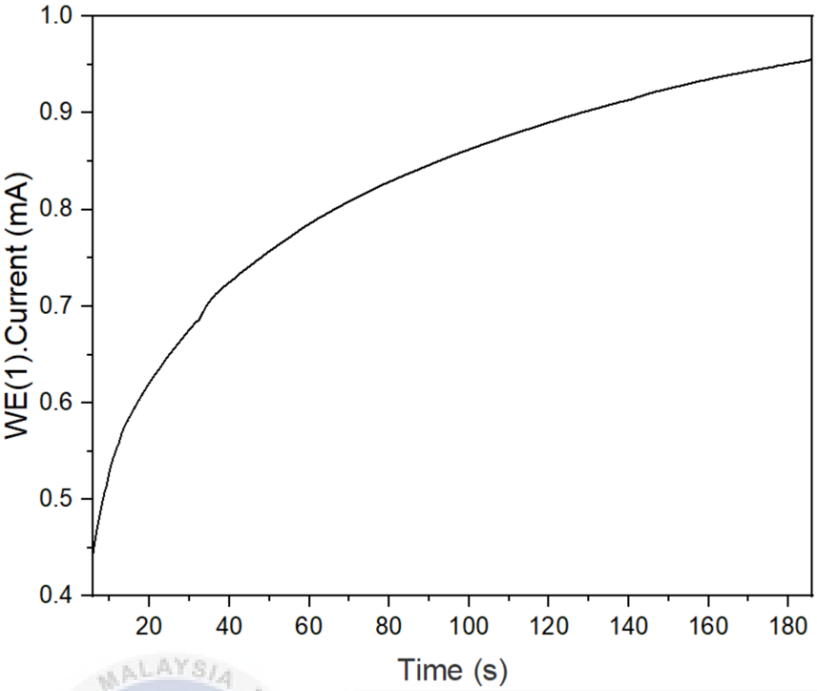


Figure 4.11 Chronoamperomtery on material Stainless steel at 3 minute (sonicated CNTs 3Hour)

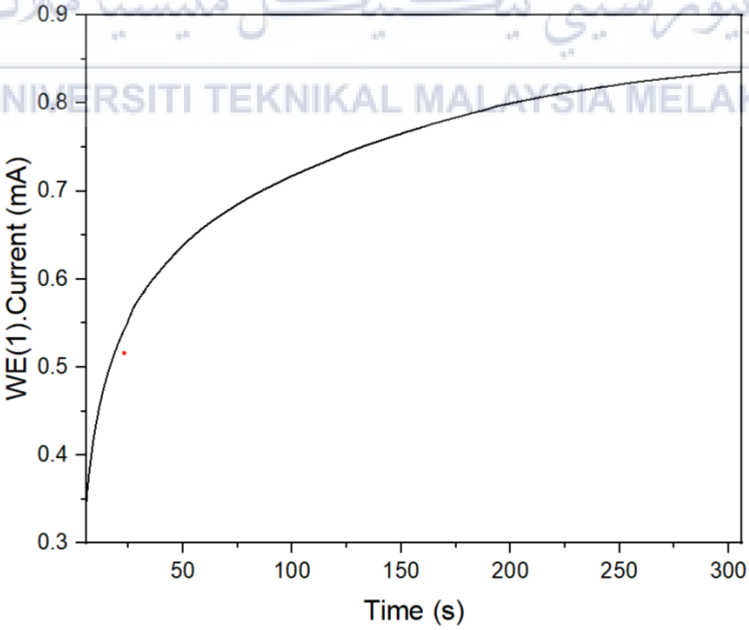


Figure 4.12 Chronoamperomtery on material Stainless steel at 3 minute (sonicated CNTs 3Hour)

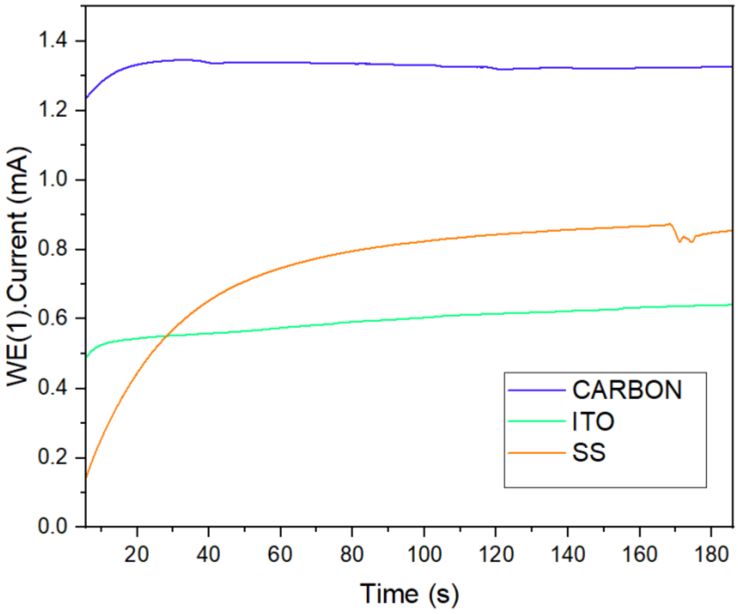


Figure 4.13 Chronoamperomtery on different material at 3 minute (sonicated CNTs for 1 Hour 30 Minute)

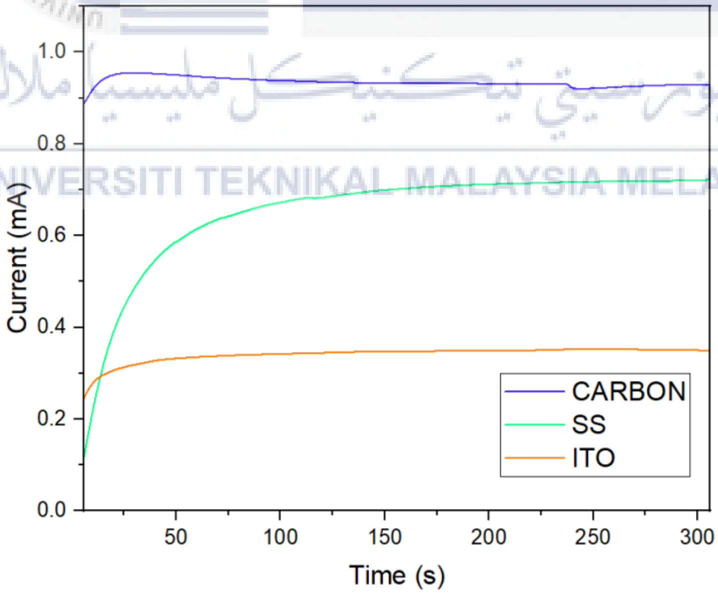


Figure 4.14 Chronoamperomtery on different material at 5 minute (sonicated CNTs for 1 Hour 30 Minute)

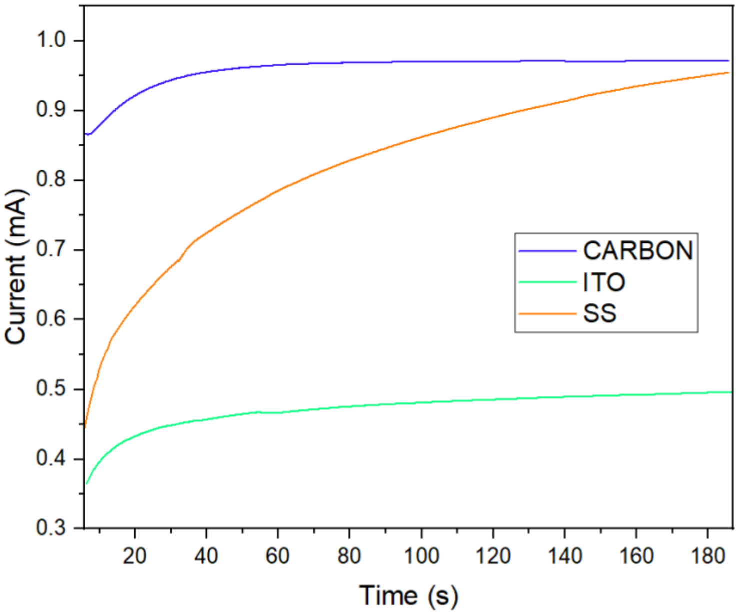


Figure 4.15 Chronoamperomtery on different material at 3 minute (sonicated CNTs for 3 Hour)

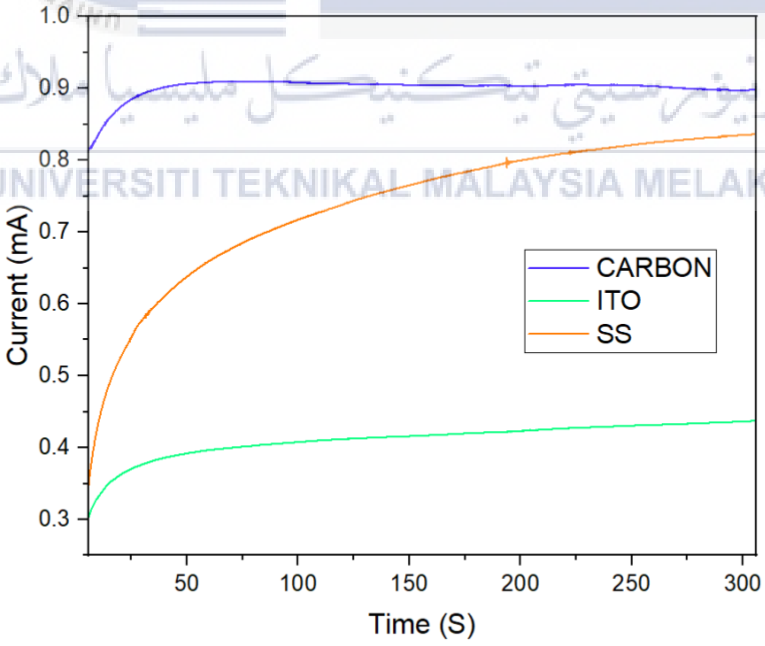


Figure 4.16 Chronoamperomtery on different material at 5 minute (sonicated CNTs for 3 Hour)

4.2.2 ELECTRODES COATING RESULTS ON XRD

4.2.2.1 STAINLESS STEEL + PPY/MWCNT (3 and 5 MINUTES)

These are the results after sending for analyzing and measuring the structure of material at XRD process. Figure 4.17 shows the XRD peak points on stainless steel electrode.

The peak in an XRD graph of stainless steel is high because it is a crystalline material with a well-defined crystal structure. Stainless steel XRD patterns often display significant peaks at precise angles that correlate to the crystal structure's planes. These peaks are high because to stainless steels highly ordered and regular crystal structure, which allows for powerful X-ray diffraction. Furthermore, stainless steel's high conductivity enables for effective electron transport during the electrochemical process in XRD, thus contributing to the high peak intensity. The peak in an XRD graph for stainless steel is crucial because it reveals information about the material's crystal structure. The peak height and location in the XRD pattern may be utilized to detect the existence of certain crystal planes and determine the crystal structure of the material. In the case of stainless steel, the XRD pattern usually reveals significant peaks at precise angles that correlate to the planes of the crystal structure. These peaks are high because to stainless steels highly ordered and regular crystal structure, which allows for powerful X-ray diffraction. Furthermore, stainless steel's high conductivity enables for effective electron transport during the electrochemical process in XRD, thus contributing to the high peak intensity. The XRD pattern may also be used to identify changes in crystal structure caused by heat treatment, mechanical deformation, or contaminants.

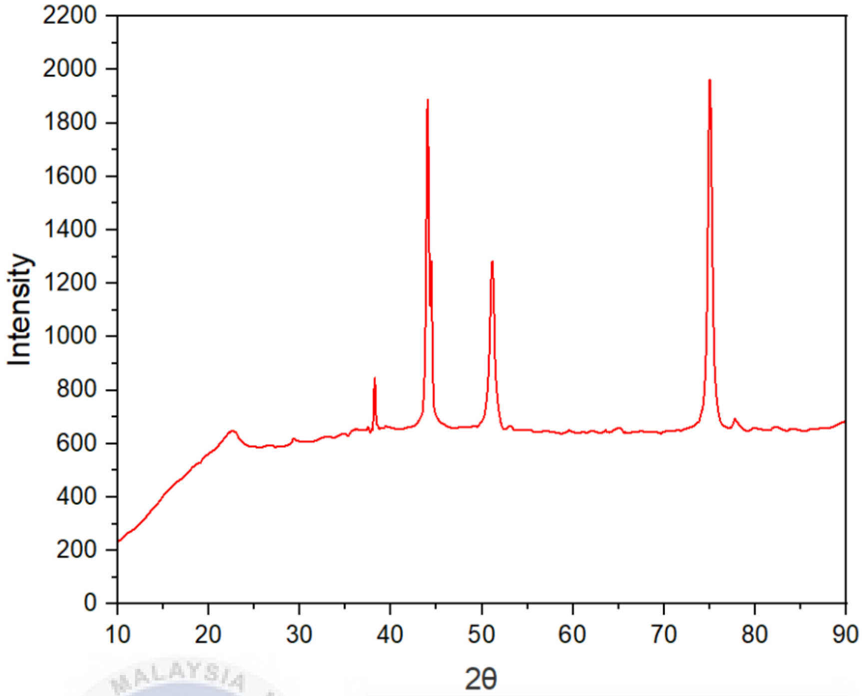


Figure 4.17 XRD peak points on stainless steel electrode 3 minute (sonicated 1Hour 30Minute)

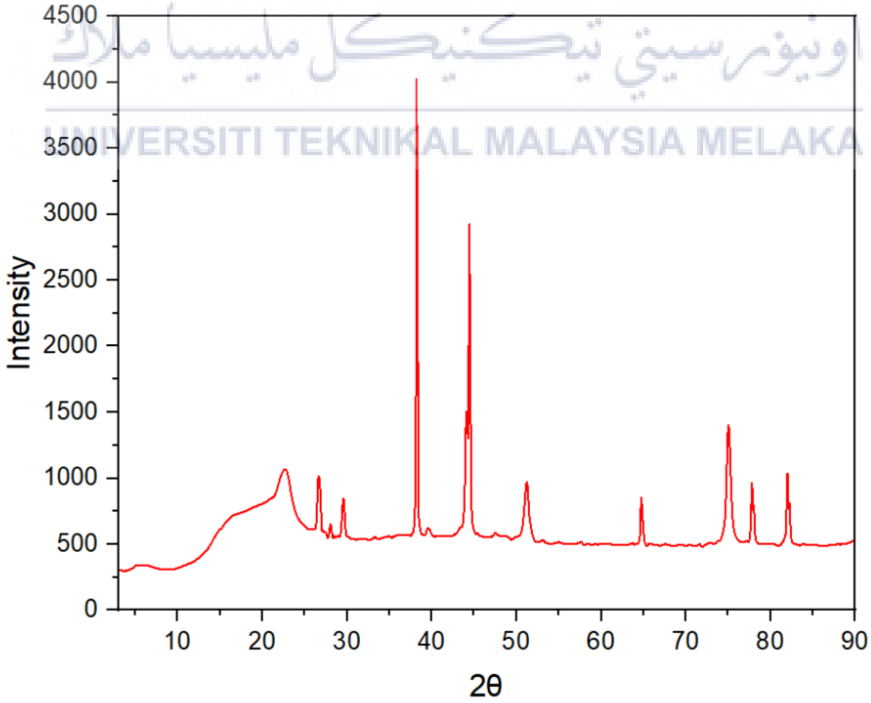


Figure 4.18 XRD peak points on stainless steel electrode 3 minute (sonicated 3Hour)

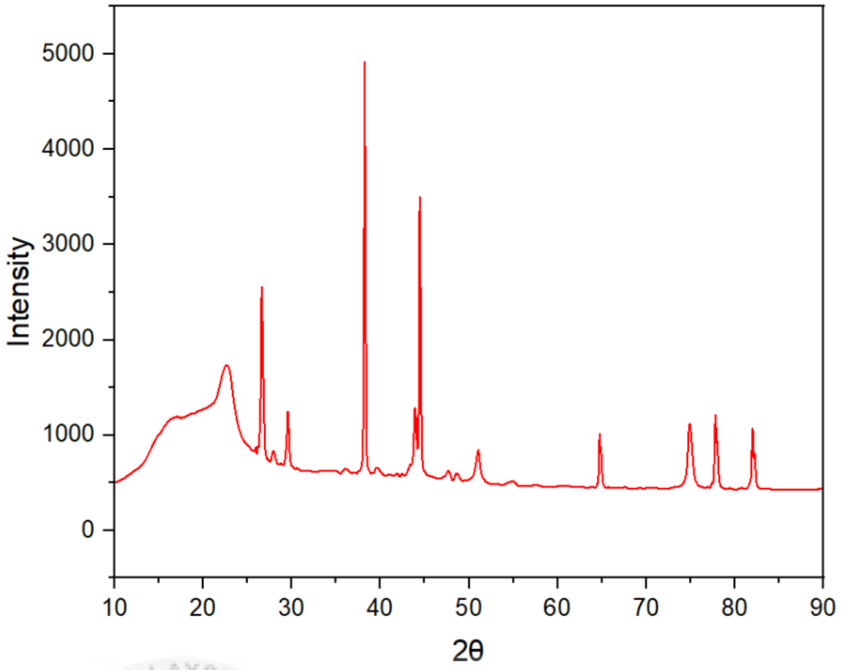


Figure 4.19 XRD peak points on stainless steel electrode 5 minute (sonicated 1Hour 30Minute)

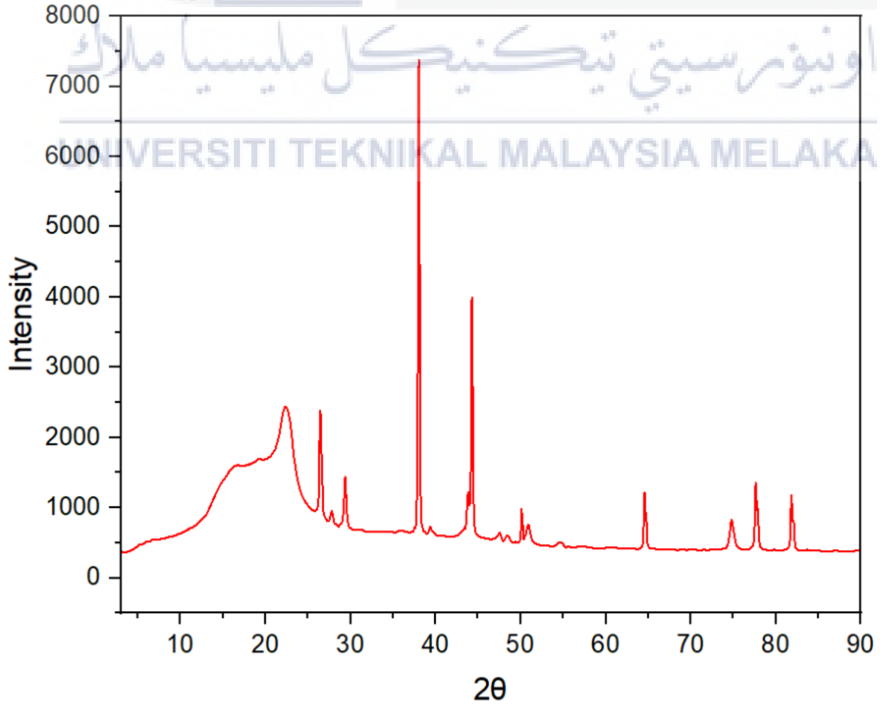


Figure 4.20 XRD peak points on stainless steel electrode 5 minute (sonicated 3Hour)

4.2.2.2 CARBON + PPY/MWCNT (3 and 5 MINUTES)

These are the results after sending for analyzing and measuring the structure of material at XRD process. Figure 4.21 shows the XRD peak points on carbon electrode.

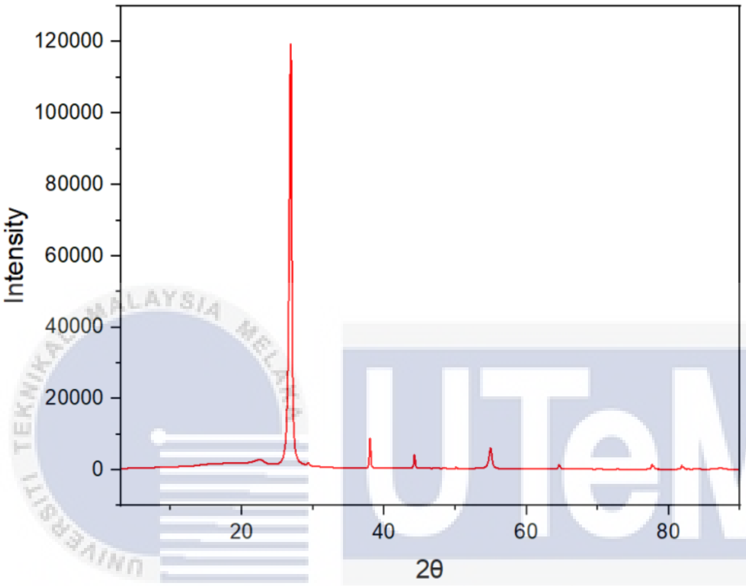


Figure 4.21 XRD peak points on carbon electrode 3 minute (sonicated 1Hour 30 Minutes)

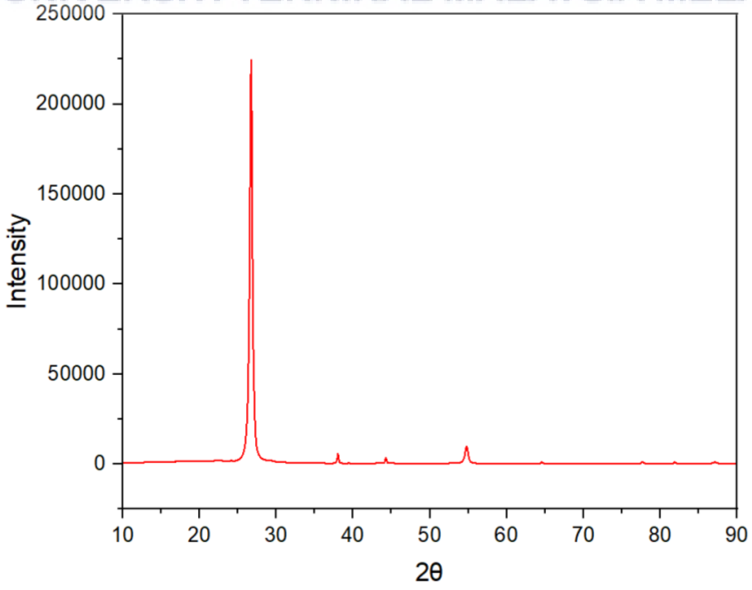


Figure 4.22 XRD peak points on carbon electrode 3 minute (sonicated 3 Hour)

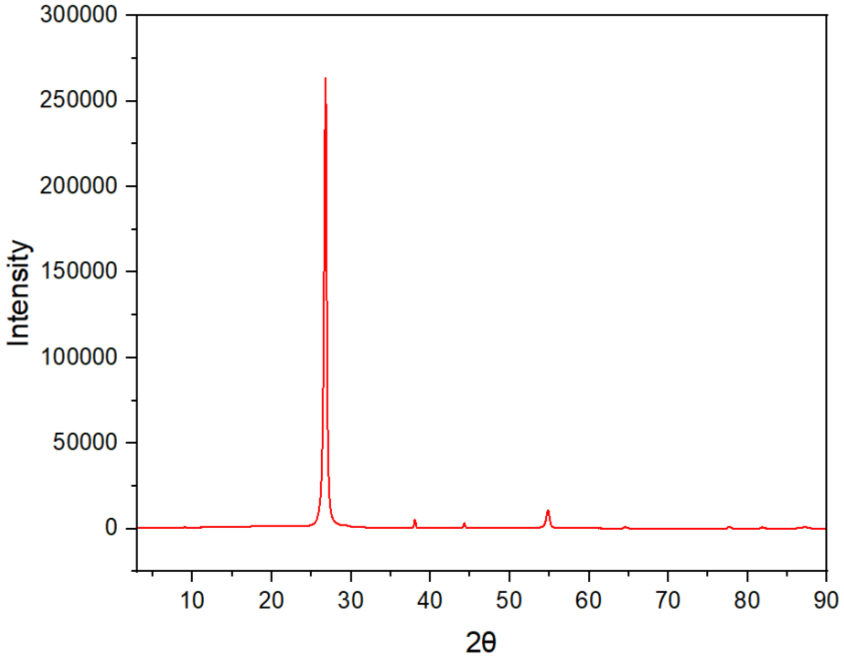


Figure 4.23 XRD peak points on carbon electrode 5 minute (sonicated 1 Hour 30 Minute)

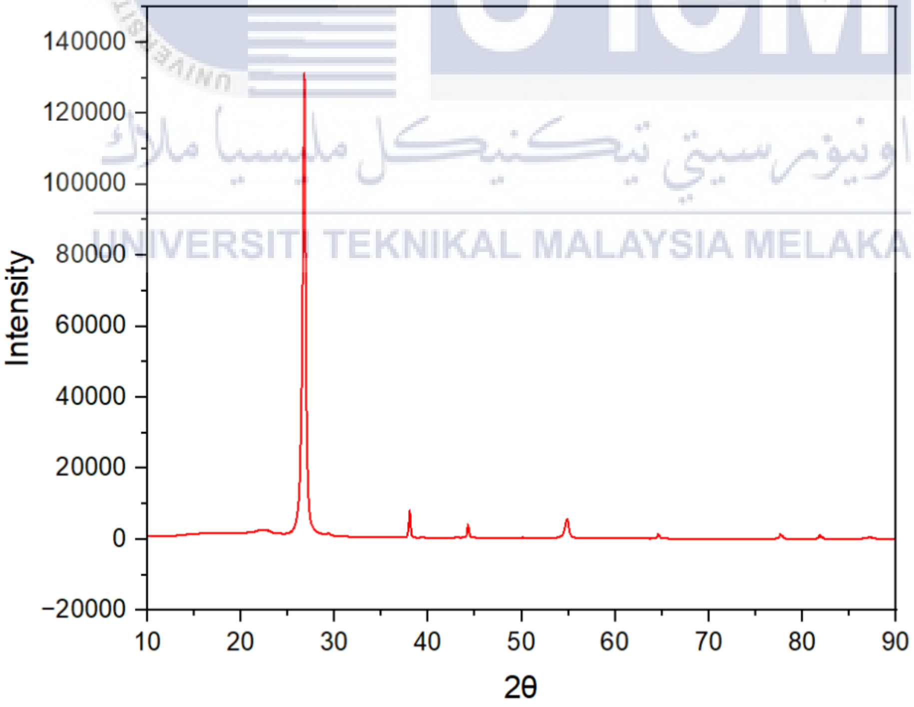


Figure 4.24 XRD peak points on carbon electrode 5 minute (sonicated 3 Hour).

4.2.2.3 ITO + PPY/MWCNT (5 MINUTES)

These are the results after sending for analyzing and measuring the structure of material at XRD process. Figure 4.25 shows the XRD peak points on ITO electrode.

The peak in an XRD graph for ITO (indium tin oxide) is high because ITO is a polycrystalline material with a prominent (222) peak caused by tin doping in indium oxide. The high peak in the XRD pattern suggests the existence of a well-ordered crystalline structure, as is typical of ITO. The sharpness and intensity of the peak can indicate the degree of crystallinity and the size of the crystallites in the ITO material. Furthermore, the existence of several peaks at different angles may suggest the presence of various crystal structures or phases in the ITO material. Overall, the peak in an XRD graph of ITO material is crucial because it reveals information about the crystal structure and material qualities.

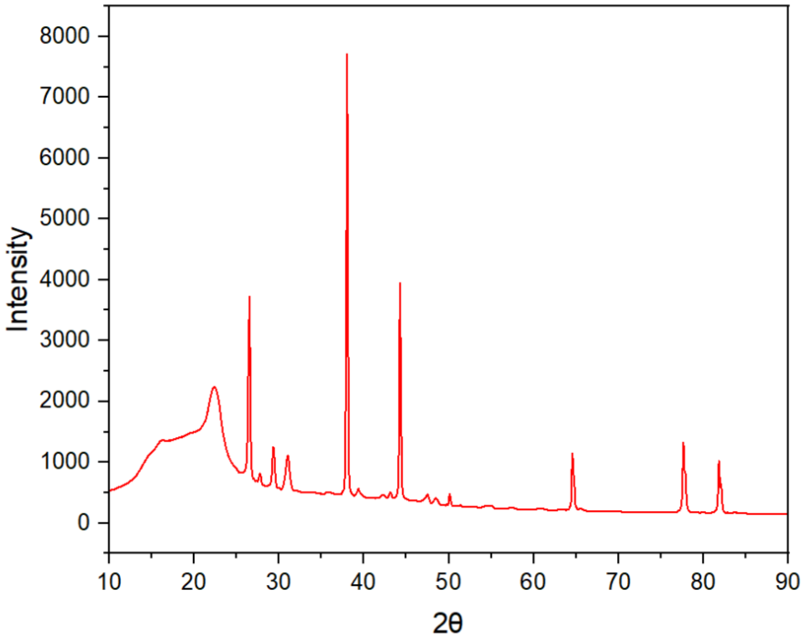


Figure 4.25 XRD peak points on ITO electrode 3 Minutes (sonicated 3 Hour)

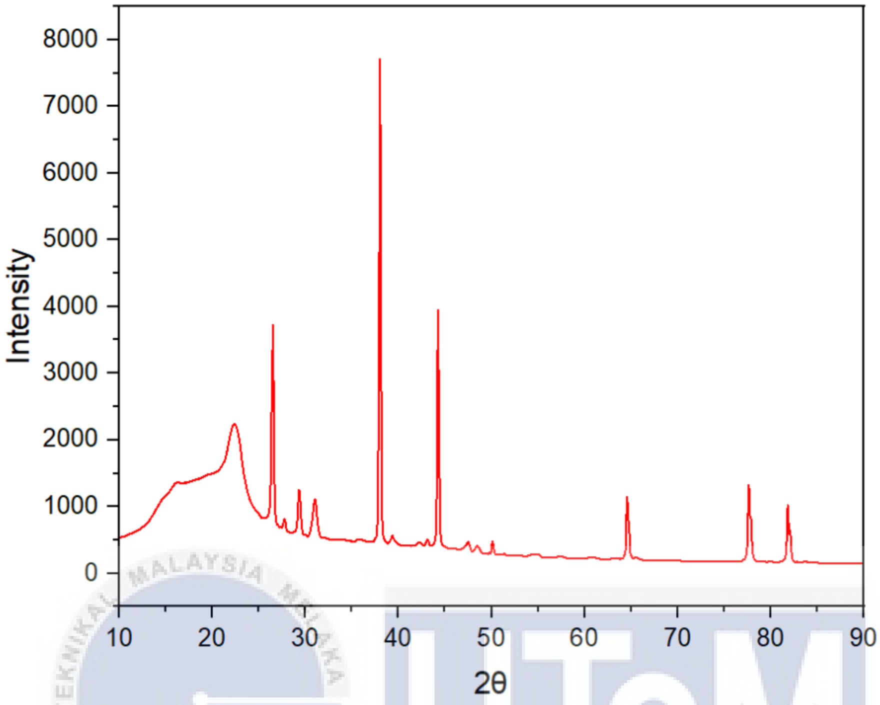


Figure 4.26 XRD peak points on ITO electrode 3 Minutes (sonicated 3 Hour)

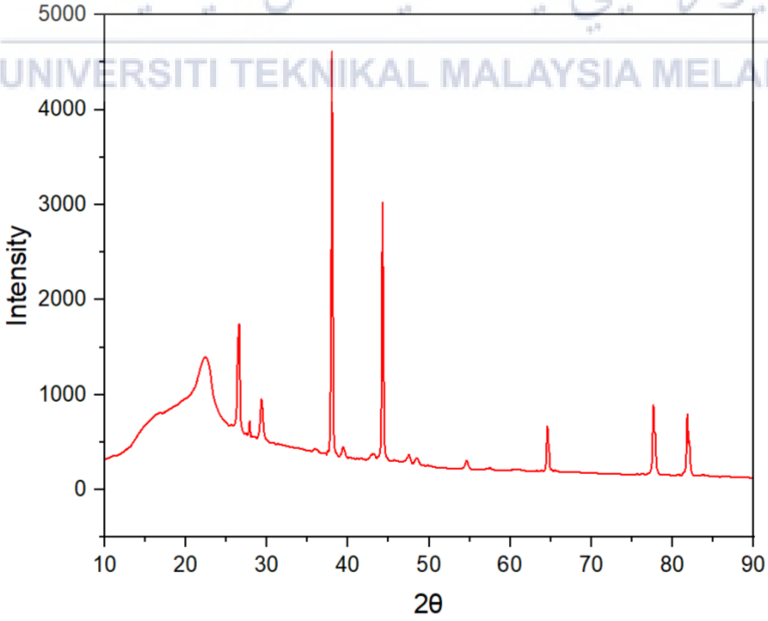


Figure 4.27 XRD peak points on ITO electrode 5 Minutes (sonicated 1 Hour 30 Minutes)

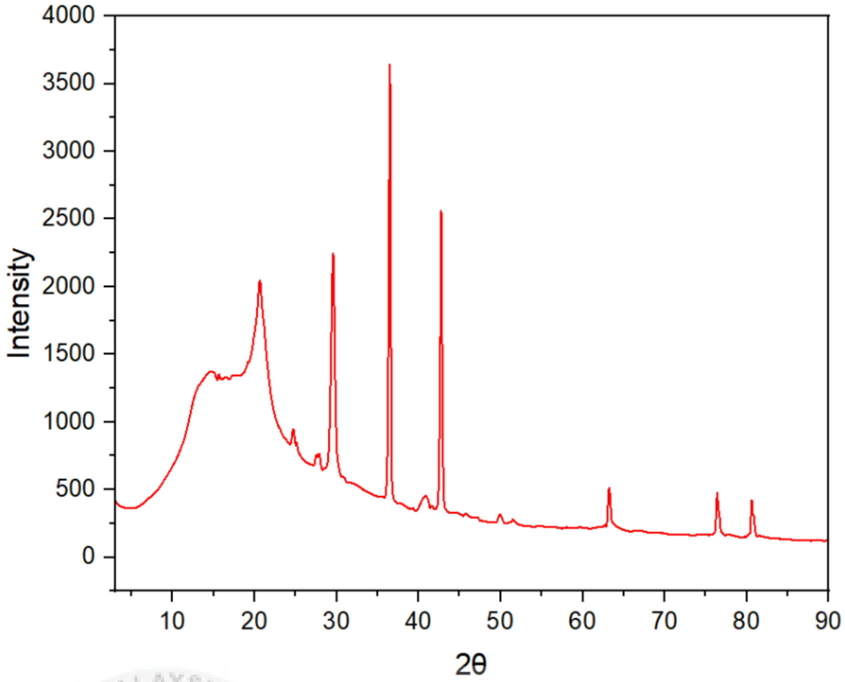


Figure 4.28 XRD peak points on ITO electrode 5 Minutes (sonicated 3 Hour)

4.2.2.4 ELECTRODES COATING RESULTS ON FTIR (3 AND 5 MINUTES)

These are the results for the sample that have been sent to obtain infrared spectrum at FTIR process. Figure 4.29 shows the data on carbon electrode. Figure 4.33 shows the data on stainless steel electrode. Figure 4.37 shows the data on ITO electrode.

The position and shape of a peak on an FTIR (Fourier-transform infrared) graph for carbon, stainless steel, and indium tin oxide (ITO) glass material determine its relevance. The peak in an FTIR graph for carbon material is often high due to the presence of sp2 hybridized carbon atoms, which are indicative of graphitic structures. The high peak in an FTIR graph of stainless steel is owing to the existence of metal-oxygen bonds, which are characteristic of the oxide layer on the stainless steel's surface. The peak on an FTIR graph for ITO glass material is high due to the presence of indium oxide and tin oxide, ITO's major components. The position, breadth, and intensity of the peak can reveal information about the material's characteristics and composition. Overall, the peak in an FTIR graph of carbon, stainless steel, and ITO glass is noteworthy because it reveals important information about the material's composition and qualities.

The peak at 1575 cm^{-1} on the FTIR graph is relevant for carbon, stainless steel, and indium tin oxide (ITO) glass materials due to their distinct structural features.

I. Carbon material's peak at 1575 cm^{-1} corresponds to the G band in the FTIR spectrum, indicating sp2 hybridized carbon atoms seen in graphitic structures.

II. Stainless steel does not often exhibit an FTIR peak at 1575 cm^{-1}. The FTIR analysis is not typically utilized for stainless steel characterisation, and the peaks associated with stainless steel in FTIR spectra are more closely connected to the existence of metal-oxygen bonding and an oxide layer on the material's surface.

III. The FTIR examination of ITO glass seldom includes the peak at 1575 cm^{-1}. The distinctive FTIR peaks for ITO are often related with the presence of indium oxide and tin oxide, which are the primary components of ITO, and are observed at various wavenumbers.

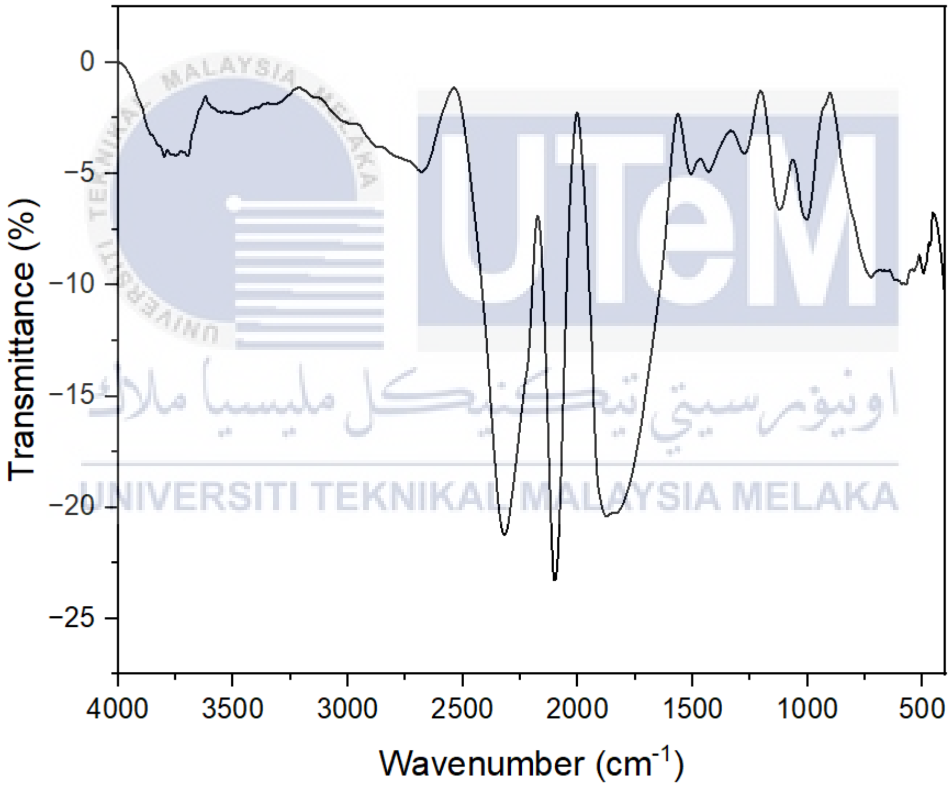


Figure 4.29 FTIR data on carbon electrode 3 Minute (sonicated 1Hour 30Minutes)

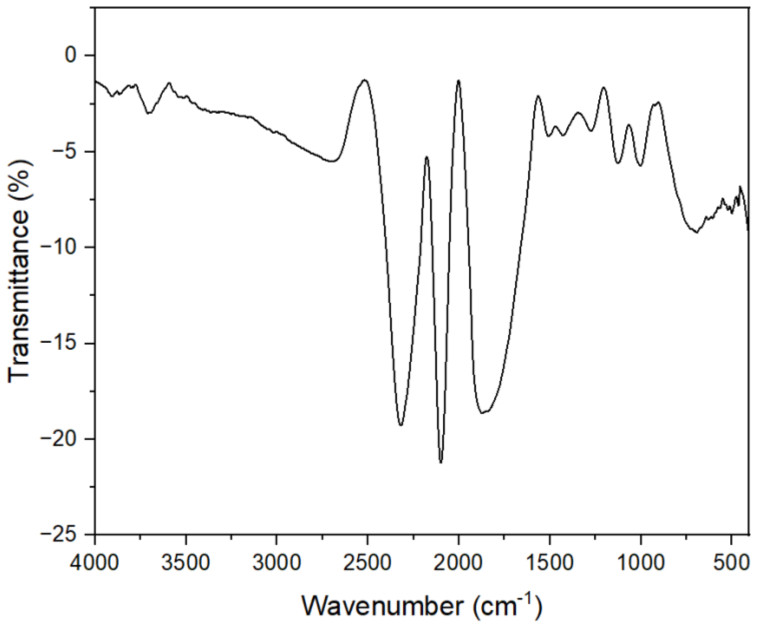


Figure 4.30 FTIR data on carbon electrode 5 Minute (sonicated 1Hour 30Minutes)

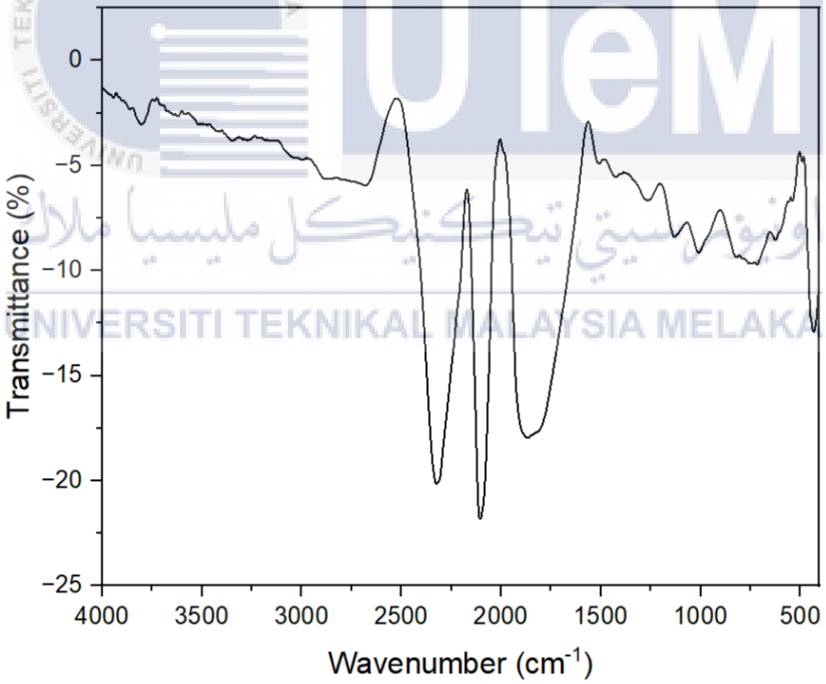


Figure 4.31 FTIR data on carbon electrode 3 Minute (sonicated 3Hour)

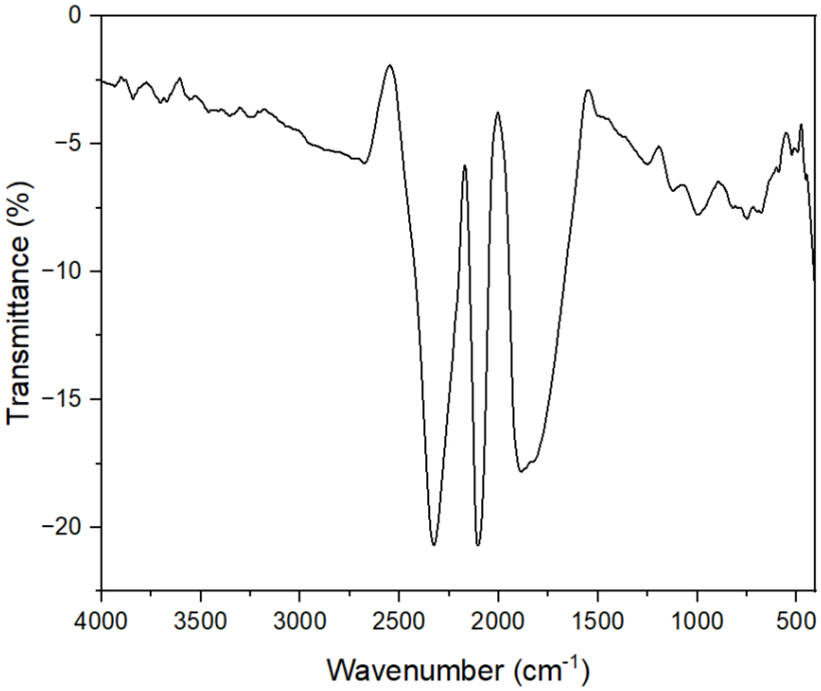


Figure 4.32 FTIR data on carbon electrode 5 Minute (sonicated 3Hour)

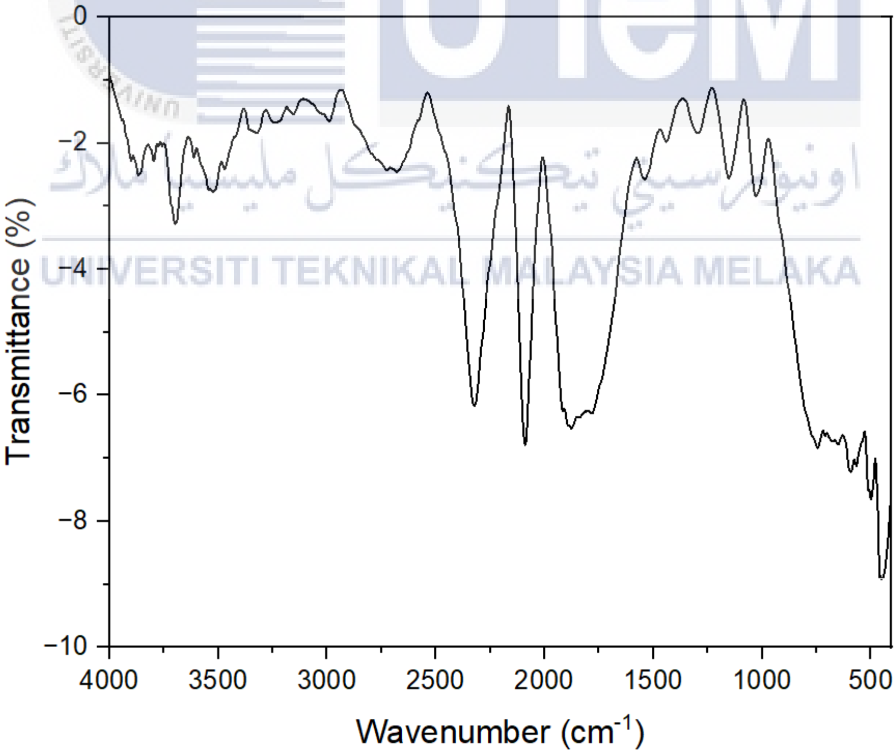


Figure 4.33 FTIR data on stainless steel electrode 3 Minute (sonicated 1Hour 30Minute)

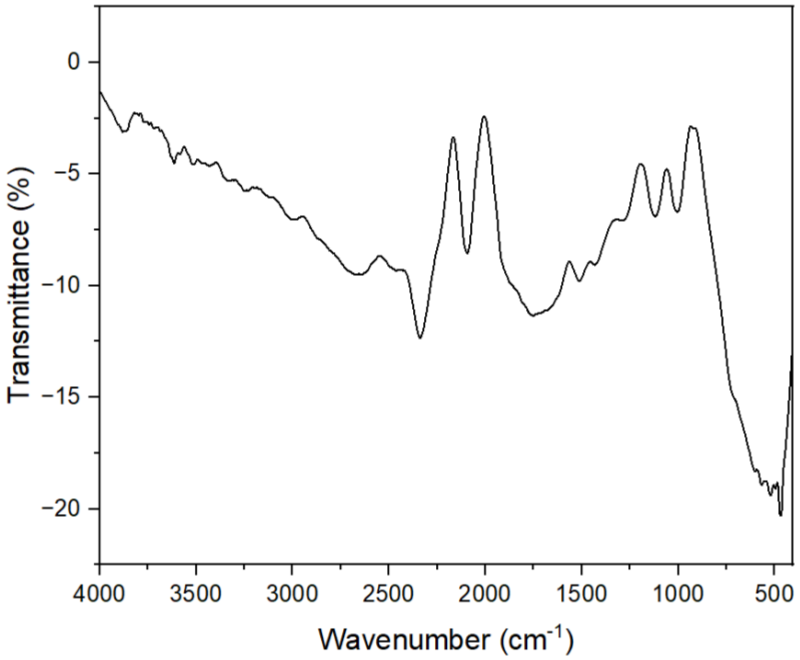


Figure 4.34 FTIR data on stainless steel electrode 5 Minute (sonicated 1Hour 30Minute)

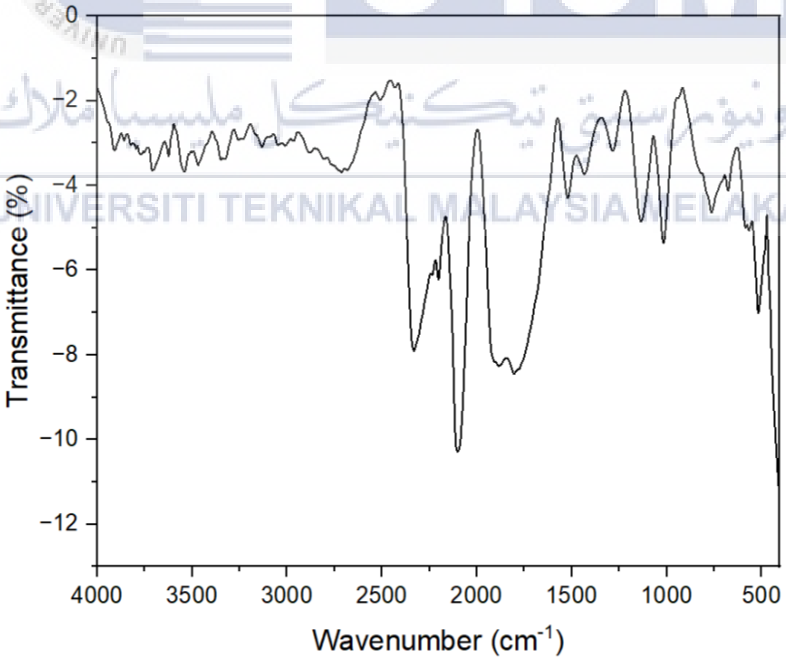


Figure 4.35 FTIR data on stainless steel electrode 3 Minute (sonicated 3 Hour)

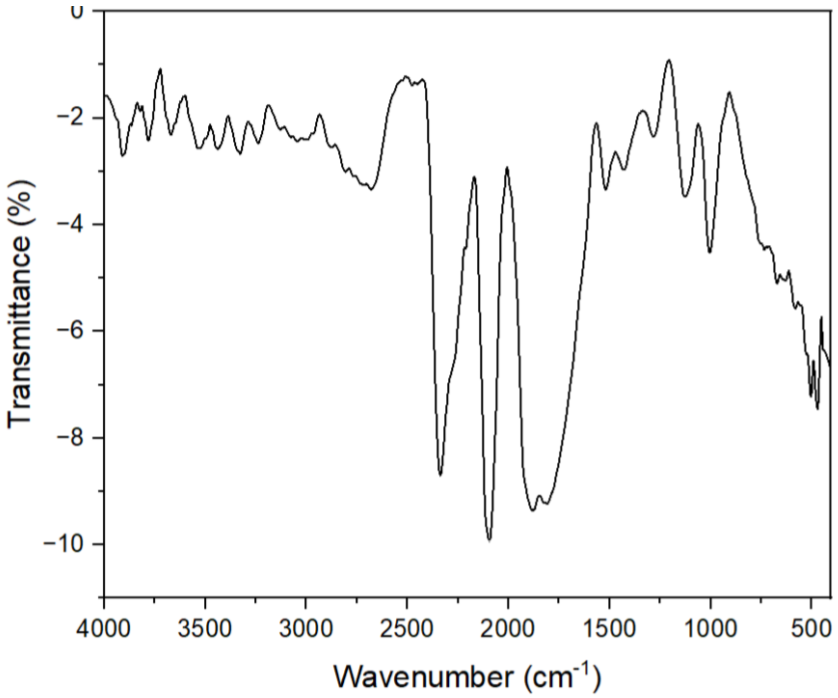


Figure 4.36 FTIR data on stainless steel electrode 5 Minute (sonicated 3 Hour)

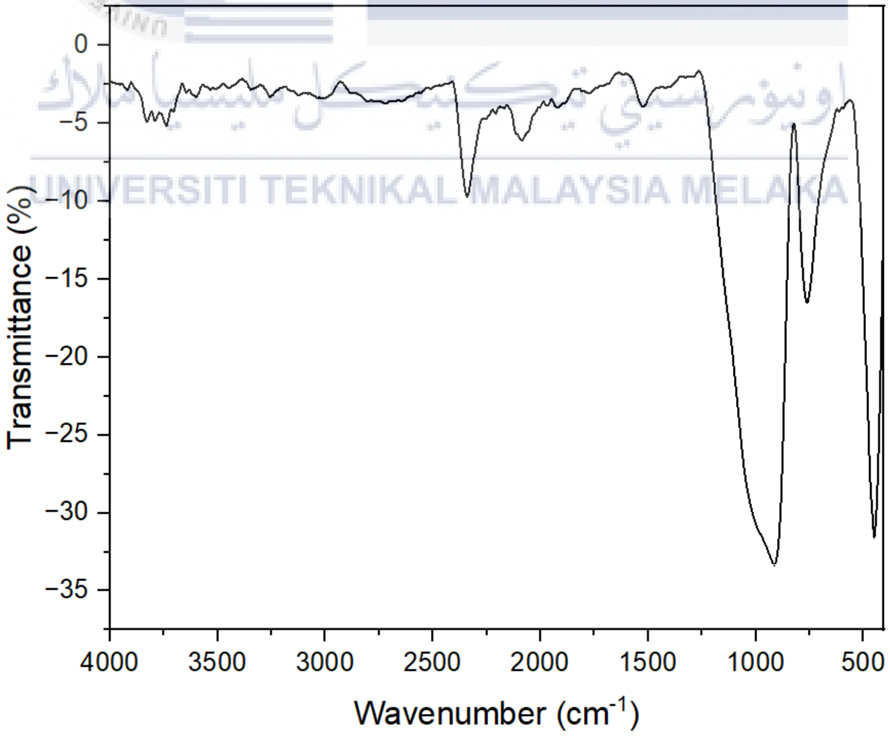


Figure 4.37 FTIR data on ITO electrode 3 Minutes (sonicated 1 Hour 30 Minutes)

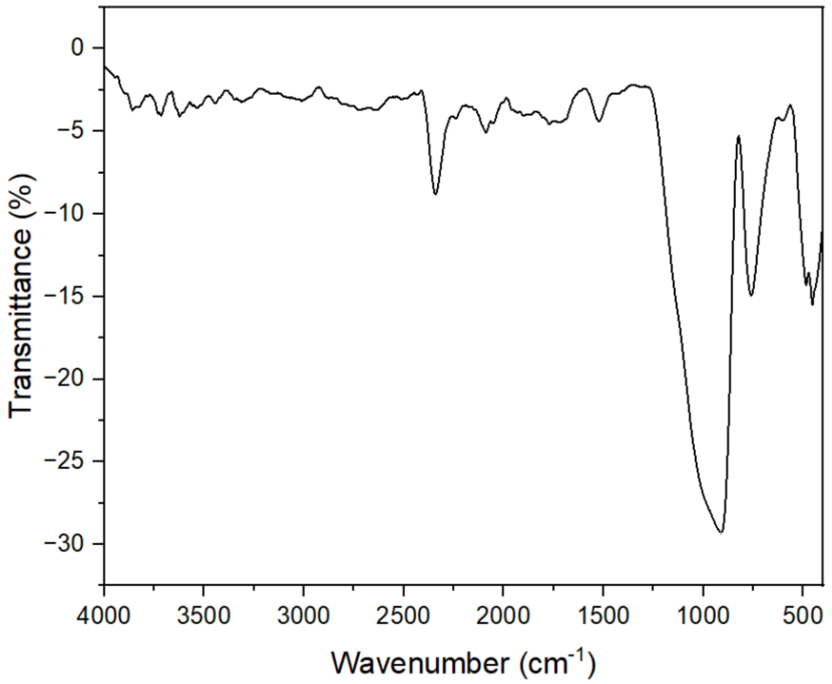


Figure 4.38 FTIR data on ITO electrode 5 Minutes (sonicated 1 Hour 30 Minutes)

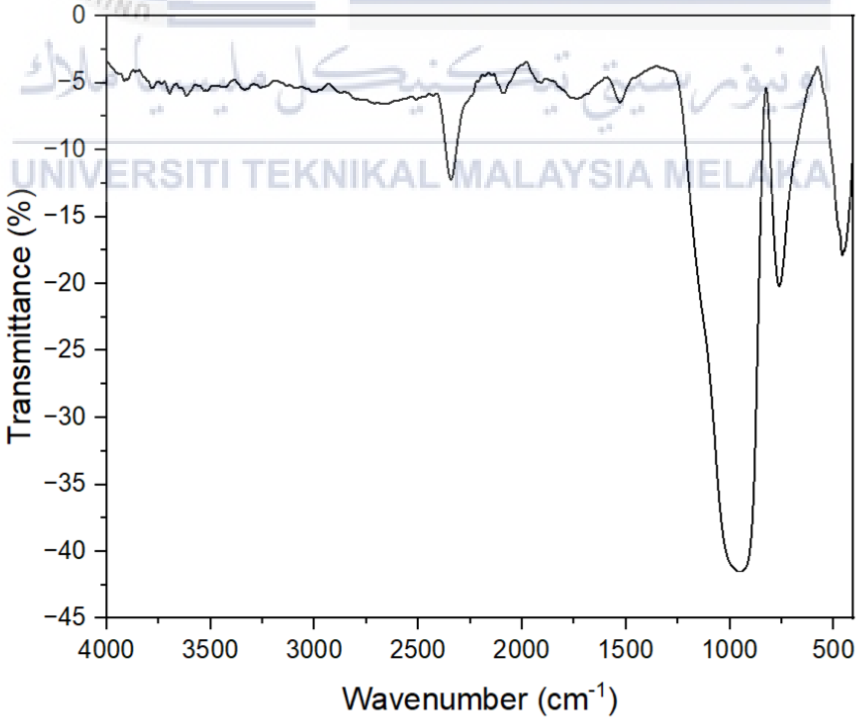


Figure 4.39 FTIR data on ITO electrode 3 Minutes (sonicated 3 Hour)

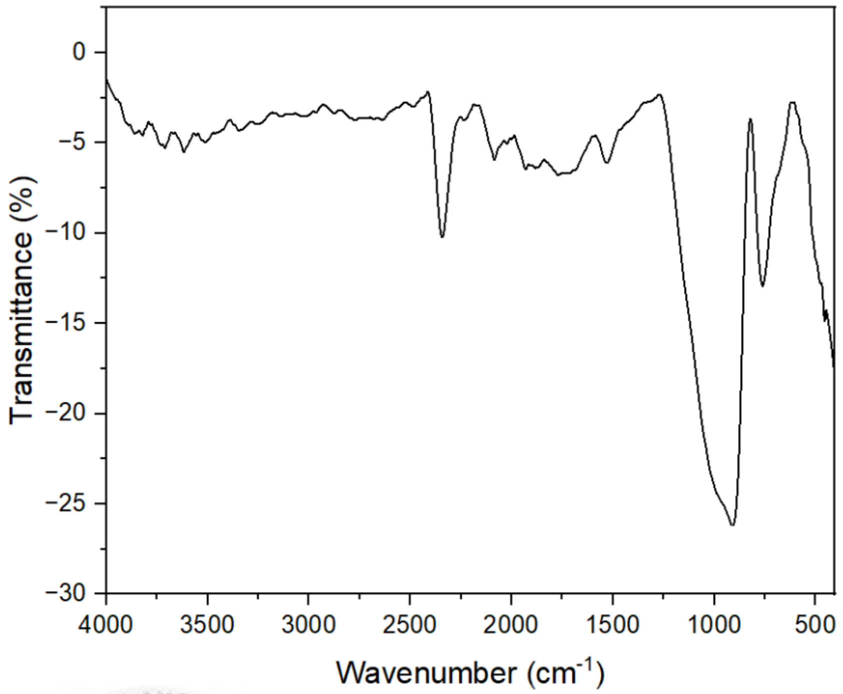


Figure 4.40 FTIR data on ITO electrode 5 Minutes (sonicated 3 Hour)

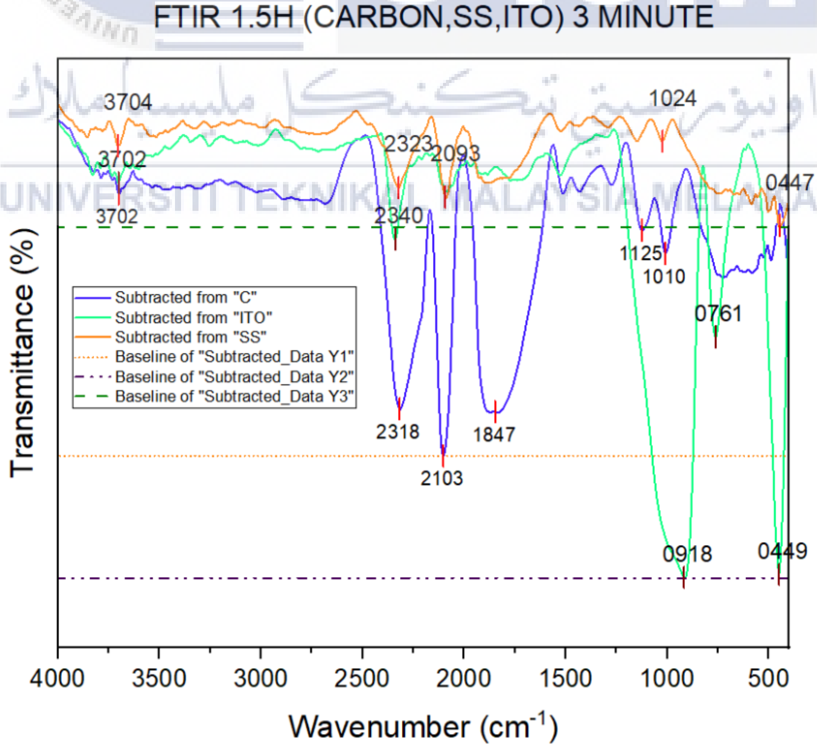


Figure 4.41 FTIR 1.5 hour (carbon, stainless steel, ITO) 3 minute.

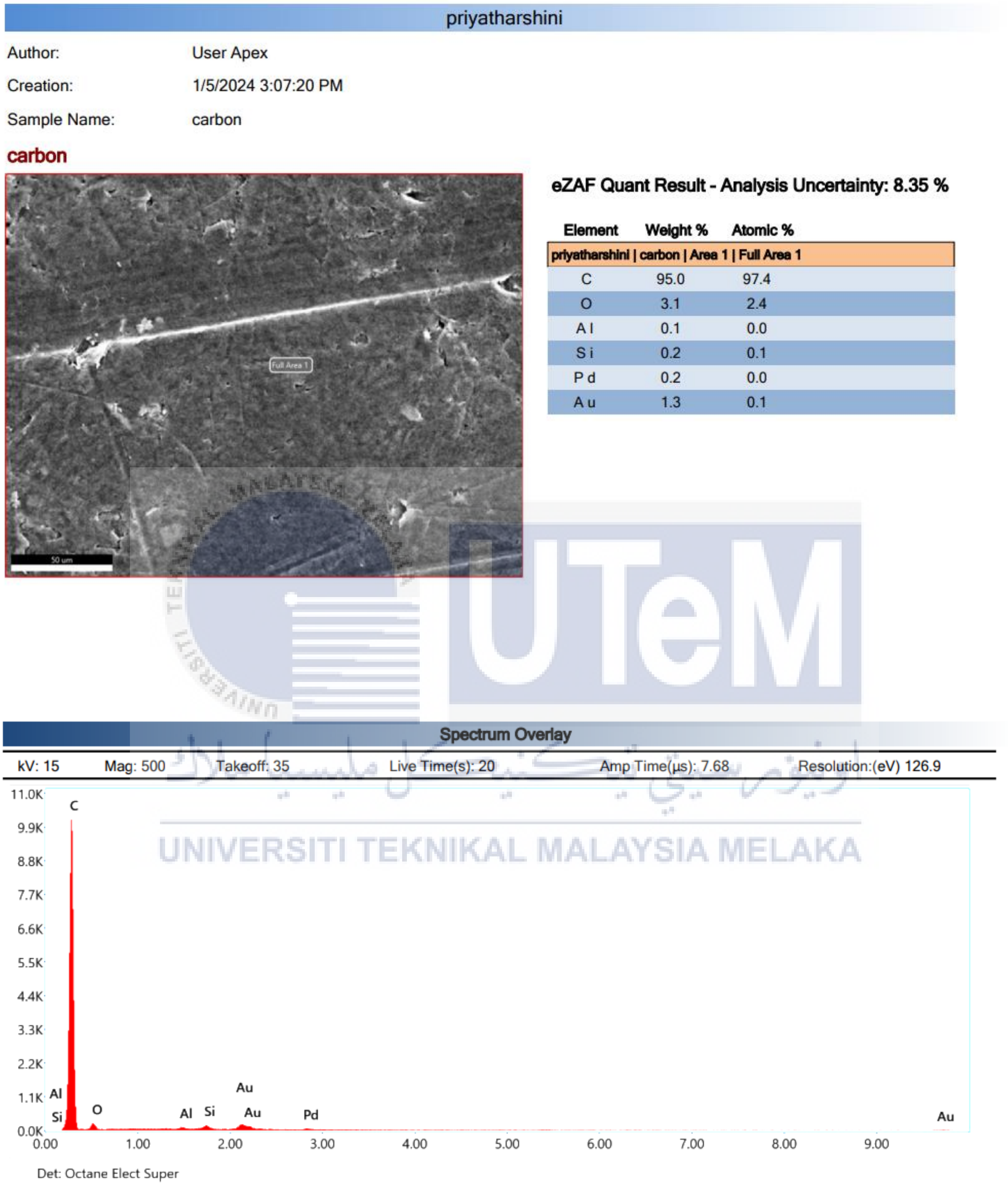
4.2.2.5 ELECTRODES COATING RESULTS EDX (3 MINUTES AND 5 MINUTES)

These are the results for the sample that have been sent to obtain EDX. Figure 4.42 shows the data on carbon electrode. Figure 4.47 shows the data on stainless steel electrode. Figure 4.52 shows the data on ITO electrode.

Energy-Dispersive X-ray Spectroscopy (EDS or EDX) is used to determine the elemental composition and distribution of stainless steel, indium tin oxide (ITO) glass, and carbon materials. This technique is frequently used in combination with scanning electron microscopy (SEM) to learn about the chemical composition of materials and the spatial distribution of components on their surfaces.

EDX may be used to determine the exact elemental makeup of stainless steel, including the presence of iron, chromium, nickel, and other alloying elements. This information is important for understanding the material's characteristics, corrosion resistance, and quality control in manufacturing operations. In the case of ITO glass, EDX may be used to determine the elemental composition of the coating and validate the presence of indium, tin, and oxygen. This research is necessary for determining the quality and stoichiometry of the ITO coating, which are essential for its electrical and optical characteristics.

EDX can determine the purity of carbon materials as well as the existence of impurities or surface pollutants. This research is useful for identifying the material's composition and determining its appropriateness for certain applications, such as glassy carbon in micro- and nanomanufacturing. EDX analysis is an effective instrument for determining the elemental composition of materials, giving critical information for research, development, and quality assurance in a variety of industrial and scientific domains.



priyatharshini

Author: User Apex
Creation: 1/5/2024 3:07:20 PM
Sample Name: carbon

carbon

eZAF Quant Result - Analysis Uncertainty: 8.35 %

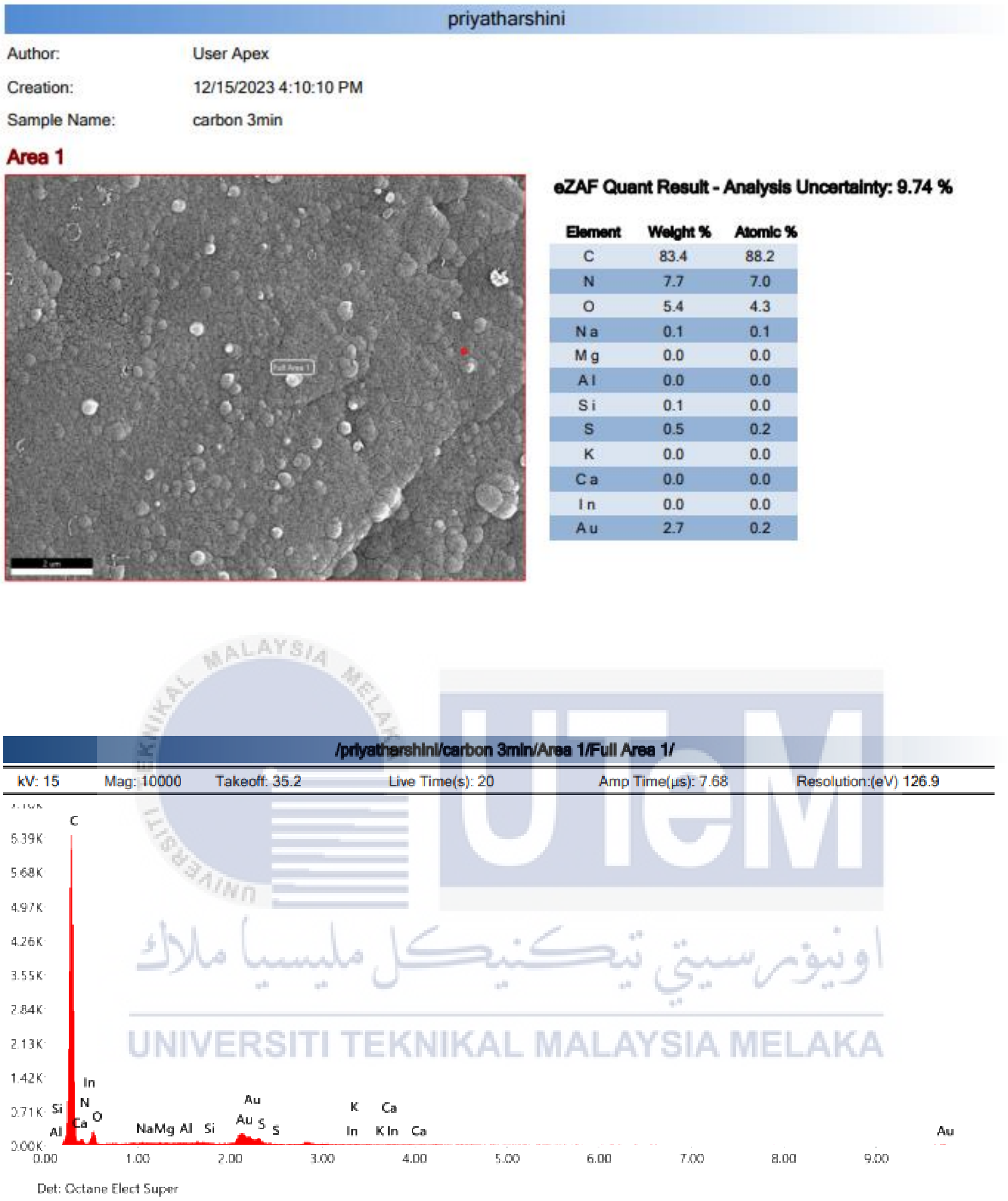
Element	Weight %	Atomic %
priyatharshini | carbon | Area 1 | Full Area 1		
C	95.0	97.4
O	3.1	2.4
Al	0.1	0.0
Si	0.2	0.1
Pd	0.2	0.0
Au	1.3	0.1

Spectrum Overlay

kV: 15 Mag: 500 Takeoff: 35 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.42 EDX on empty material Carbon (uncoated material)



priyatharshini

Author: User Apex

Creation: 12/15/2023 4:10:10 PM

Sample Name: carbon 3min

Area 1

eZAF Quant Result - Analysis Uncertainty: 9.74 %

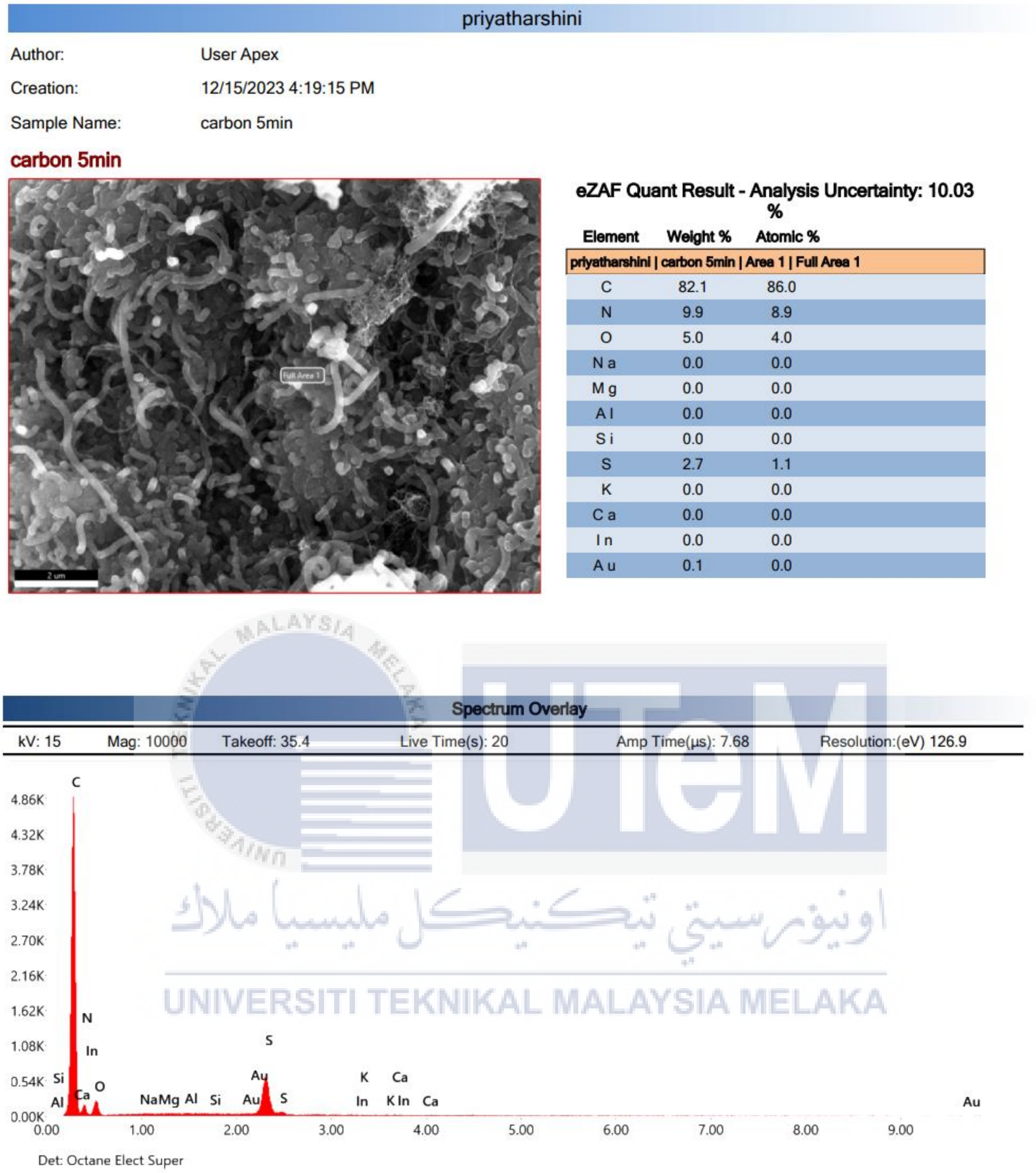
Element	Weight %	Atomic %
C	83.4	88.2
N	7.7	7.0
O	5.4	4.3
Na	0.1	0.1
Mg	0.0	0.0
Al	0.0	0.0
Si	0.1	0.0
S	0.5	0.2
K	0.0	0.0
Ca	0.0	0.0
In	0.0	0.0
Au	2.7	0.2

/priyatharshini/carbon 3min/Area 1/Full Area 1/

kV: 15 Mag: 10000 Takeoff: 35.2 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.43 EDX on material Carbon 3 Minutes (sonicated 1Hour 30Minutes)



priyatharshini

Author: User Apex
Creation: 12/15/2023 4:19:15 PM
Sample Name: carbon 5min

carbon 5min

eZAF Quant Result - Analysis Uncertainty: 10.03 %

Element	Weight %	Atomic %
priyatharshini | carbon 5min | Area 1 | Full Area 1		
C	82.1	86.0
N	9.9	8.9
O	5.0	4.0
Na	0.0	0.0
Mg	0.0	0.0
Al	0.0	0.0
Si	0.0	0.0
S	2.7	1.1
K	0.0	0.0
Ca	0.0	0.0
In	0.0	0.0
Au	0.1	0.0

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 35.4 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

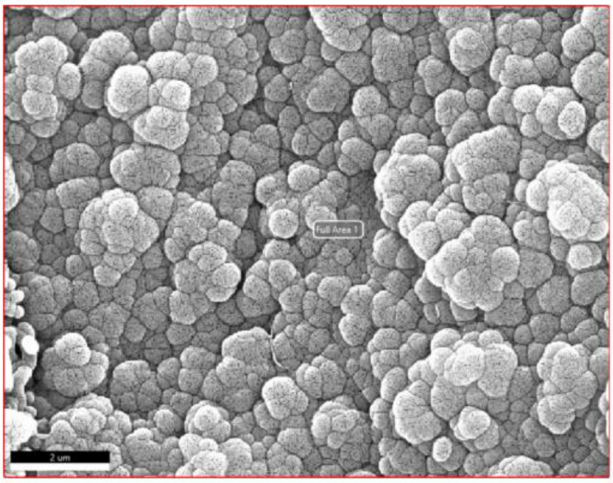
Det: Octane Elect Super

Figure 4.44 EDX on material Carbon 5 Minutes (sonicated 1Hour 30Minutes)

priyatharshini

Author:	User Apex
Creation:	12/19/2023 3:02:23 PM
Sample Name:	carbon 3min 3H

carbon 3min 3H



eZAF Quant Result - Analysis Uncertainty: 9.80 %

Element	Weight %	Atomic %
priyatharshini | carbon 3min 3H | Area 2 | Full Area 1		
C	89.4	94.8
O	5.7	4.6
S	0.8	0.3
P d	0.8	0.1
A u	3.2	0.2

Spectrum Overlay

kV: 15 Mag: 10445 Takeoff: 35 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

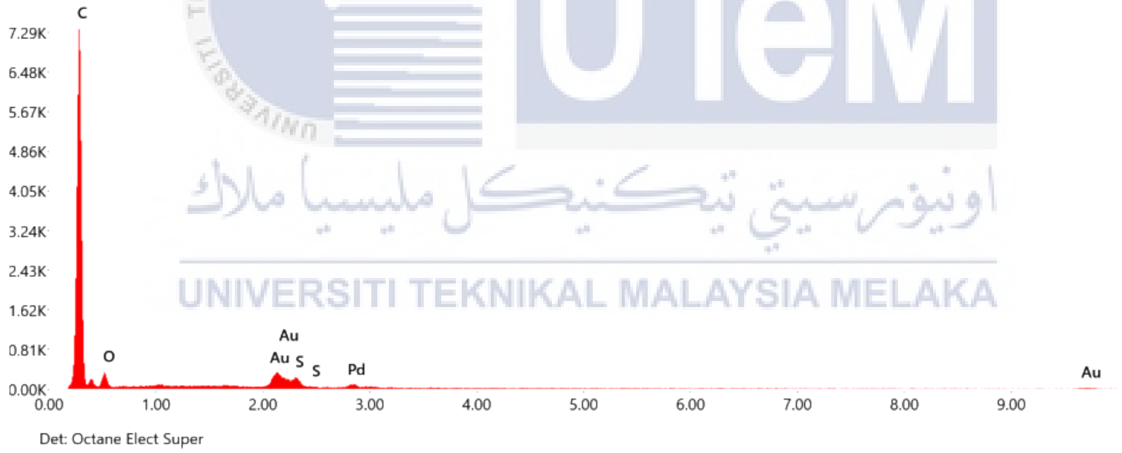
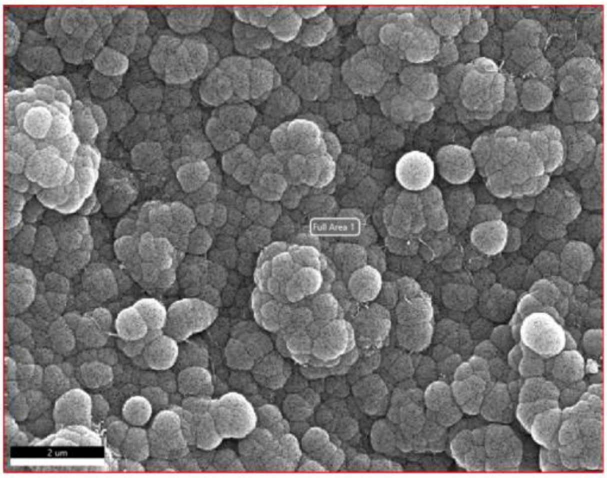


Figure 4.45 EDX on material Carbon 3 Minutes (sonicated 3 Hour)

priyatharshini

Author: User Apex
Creation: 12/19/2023 3:05:12 PM
Sample Name: carbon 5min 3H

carbon 5min 3H

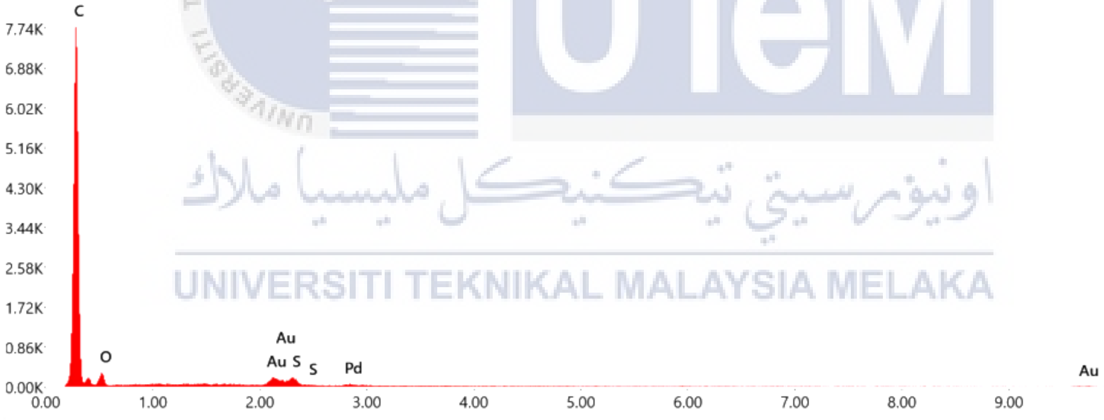


eZAF Quant Result - Analysis Uncertainty: 11.28 %

Element	Weight %	Atomic %
priyatharshini | carbon 5min 3H | Area 1 | Full Area 1		
C	85.2	95.8
O	3.9	3.3
S	0.6	0.2
Pd	0.3	0.0
Au	10.1	0.7

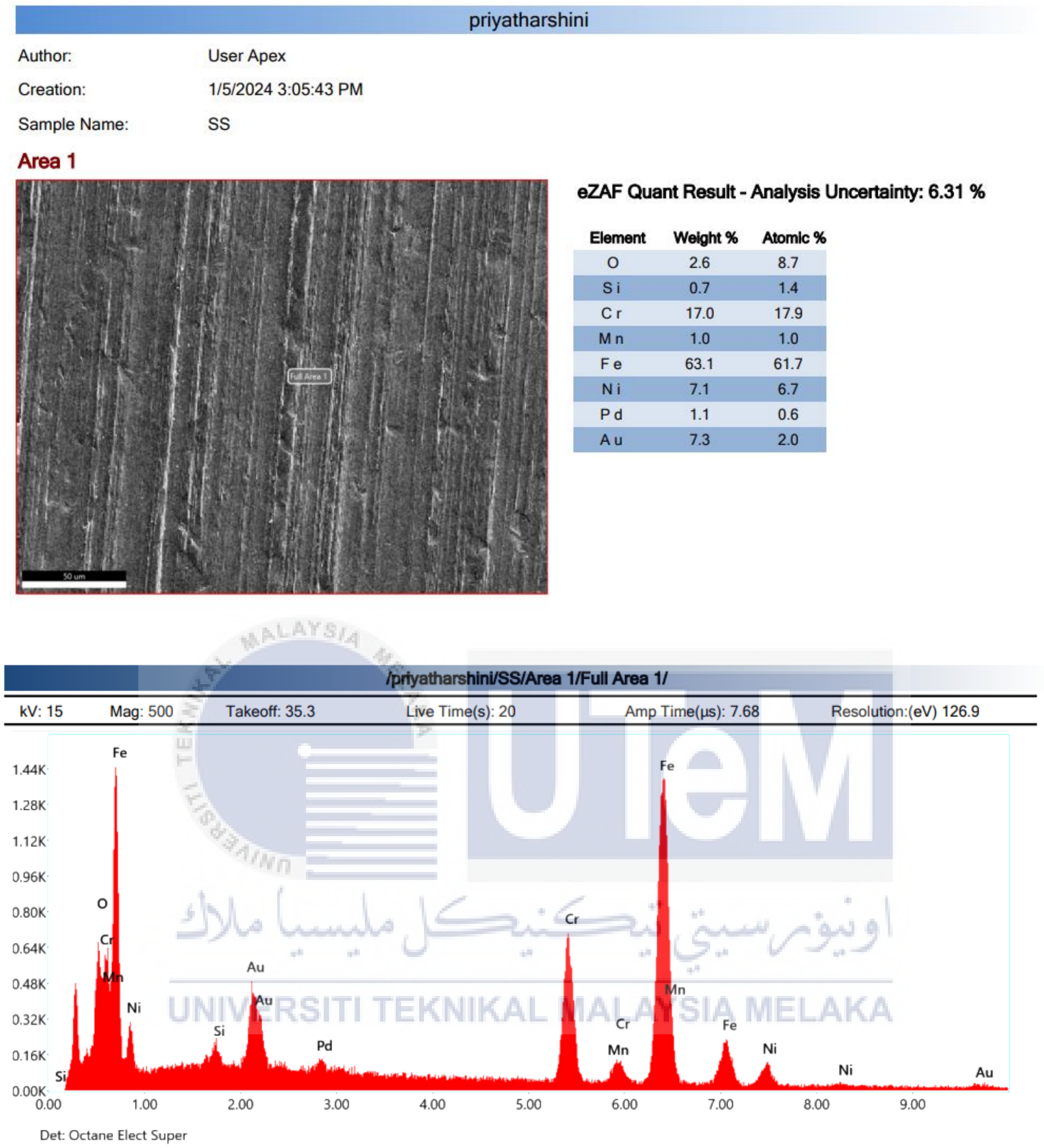
Spectrum Overlay

kV: 15 Mag: 10007 Takeoff: 35.7 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9



Det: Octane Elect Super

Figure 4.46 EDX on material Carbon 5 Minutes (sonicated 3 Hour)



priyatharshini

Author: User Apex

Creation: 1/5/2024 3:05:43 PM

Sample Name: SS

Area 1

eZAF Quant Result - Analysis Uncertainty: 6.31 %

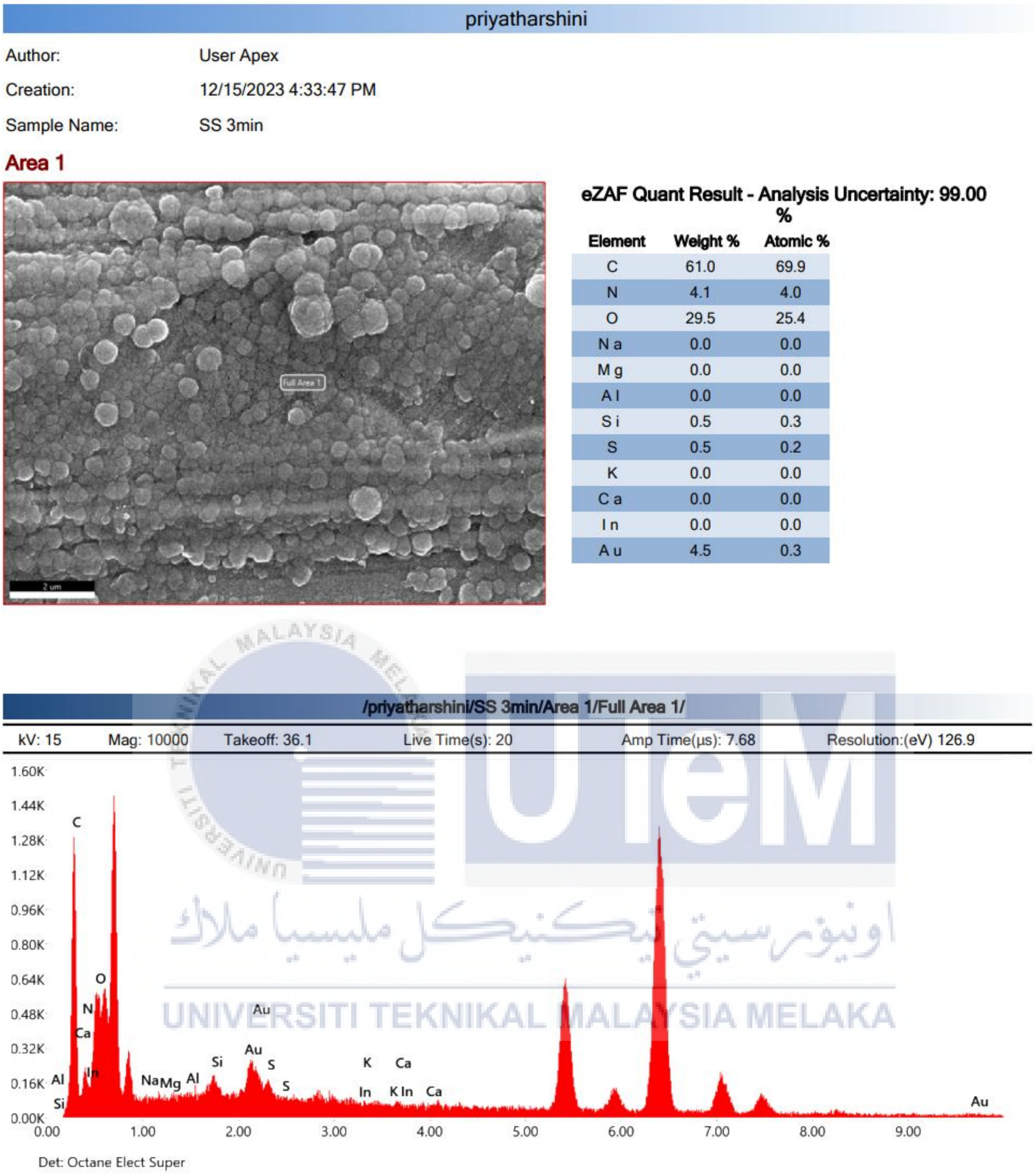
Element	Weight %	Atomic %
O	2.6	8.7
Si	0.7	1.4
Cr	17.0	17.9
Mn	1.0	1.0
Fe	63.1	61.7
Ni	7.1	6.7
Pd	1.1	0.6
Au	7.3	2.0

/priyatharshini/SS/Area 1/Full Area 1/

kV: 15 Mag: 500 Takeoff: 35.3 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.47 EDX on empty material Stainless steel (uncoated material)



priyatharshini

Author: User Apex

Creation: 12/15/2023 4:33:47 PM

Sample Name: SS 3min

Area 1

eZAF Quant Result - Analysis Uncertainty: 99.00 %

Element	Weight %	Atomic %
C	61.0	69.9
N	4.1	4.0
O	29.5	25.4
Na	0.0	0.0
Mg	0.0	0.0
Al	0.0	0.0
Si	0.5	0.3
S	0.5	0.2
K	0.0	0.0
Ca	0.0	0.0
In	0.0	0.0
Au	4.5	0.3

/priyatharshini/SS 3min/Area 1/Full Area 1/

kV: 15 Mag: 10000 Takeoff: 36.1 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.48 EDX on material Stainless steel 3 Minutes (sonicated 1 Hour 30 Minutes)

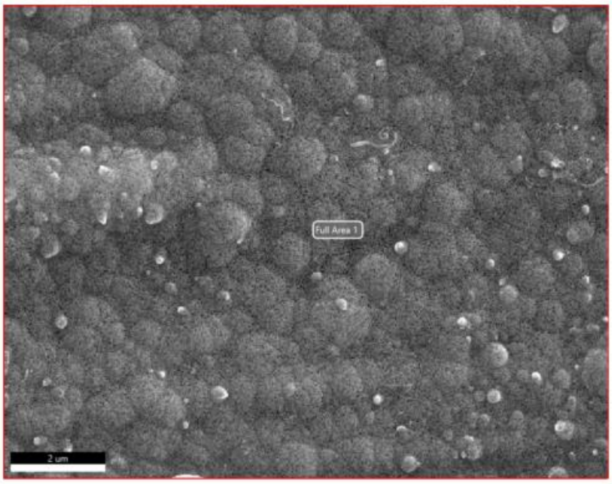
priyatharshini

Author: User Apex

Creation: 12/15/2023 4:42:28 PM

Sample Name: SS 5min

SS 5min

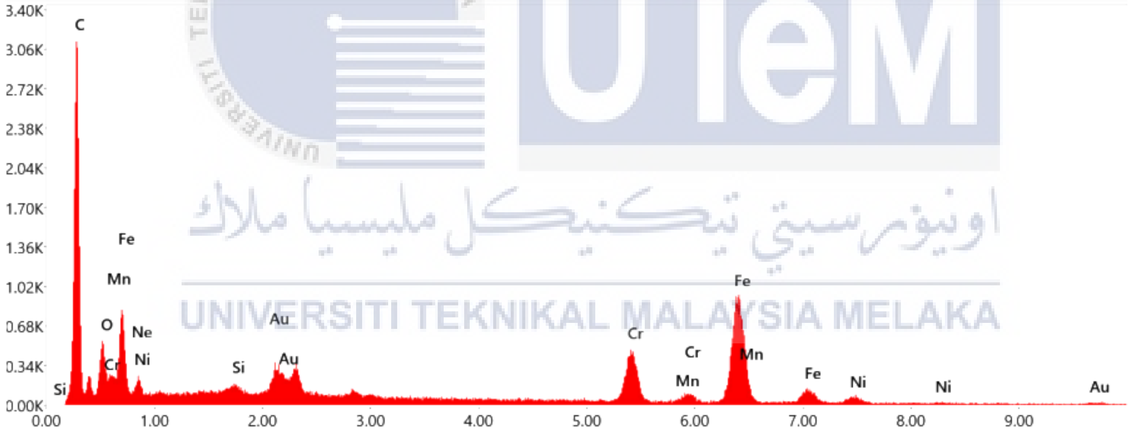


eZAF Quant Result - Analysis Uncertainty: 99.00 %

Element	Weight %	Atomic %
priyatharshini | SS 5min | Area 1 | Full Area 1		
C	58.7	85.1
O	2.9	3.1
Ne	0.2	0.2
Si	0.3	0.2
Cr	7.1	2.4
Mn	0.5	0.2
Fe	25.1	7.8
Ni	2.8	0.8
Au	2.4	0.2

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 35.1 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9



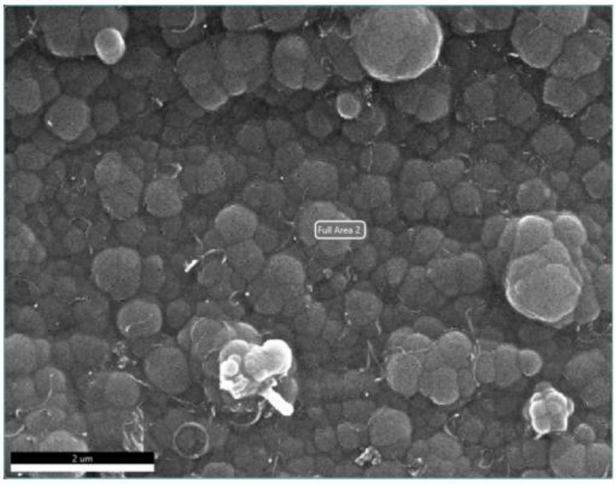
Det: Octane Elect Super

Figure 4.49 EDX on material Stainless steel 5 Minutes (sonicated 1 Hour 30 Minutes)

priyatharshini

Author:	User Apex
Creation:	12/19/2023 2:47:51 PM
Sample Name:	SS 3min 3H

SS 3min 3H



eZAF Quant Result

Element	Weight %	Atomic %
priyatharshini | SS 3min 3H | Area 1 | Full Area 1		
C	66.8	74.7
N	8.9	8.6
O	18.6	15.6
Na	0.3	0.2
Mg	0.0	0.0
Al	0.1	0.0
Si	0.4	0.2
S	1.1	0.5
K	0.0	0.0
Ca	0.0	0.0
In	0.1	0.0
Au	3.8	0.3
priyatharshini | SS 3min 3H | Area 1 | Full Area 2		
C	67.7	75.2
N	8.6	8.2
O	18.7	15.6
Na	0.3	0.2
Mg	0.0	0.0
Al	0.0	0.0
Si	0.3	0.2
S	1.1	0.4
K	0.0	0.0
Ca	0.0	0.0
In	0.0	0.0
Au	3.2	0.2

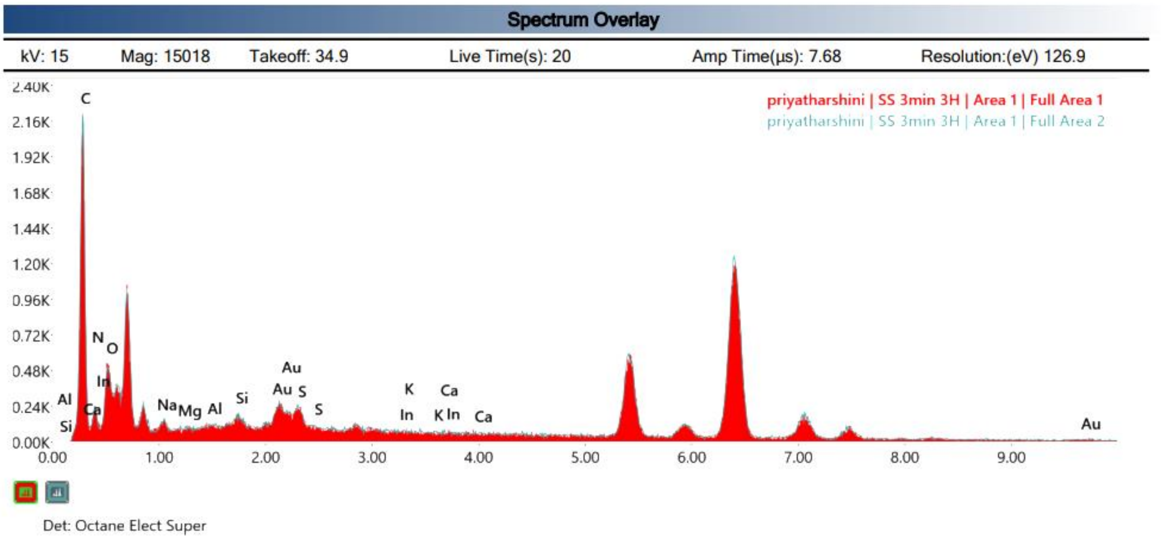
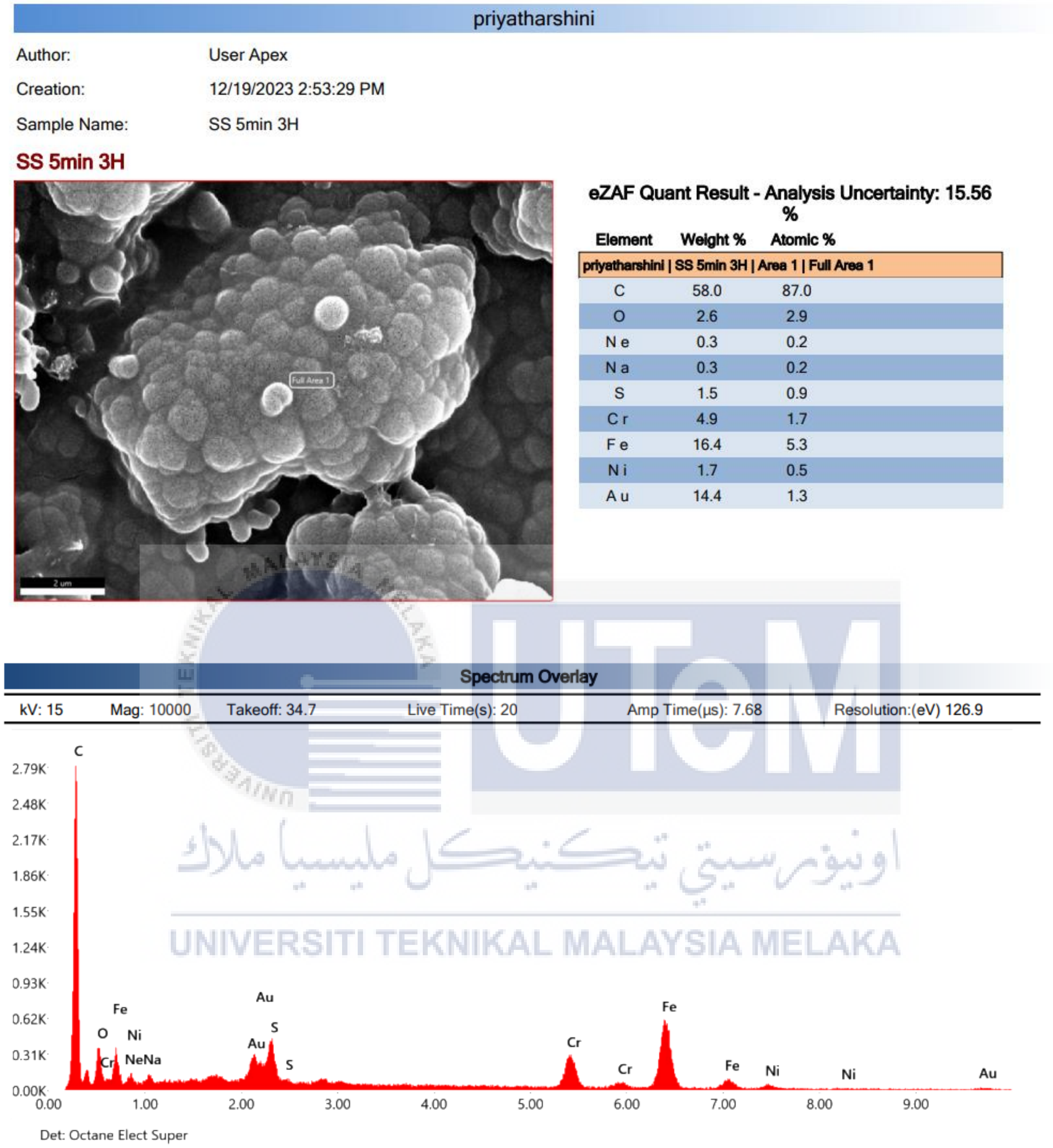


Figure 4.50 EDX on material Stainless steel 3 Minutes (sonicated 3 Hour)



priyatharshini

Author: User Apex
Creation: 12/19/2023 2:53:29 PM
Sample Name: SS 5min 3H

SS 5min 3H

eZAF Quant Result - Analysis Uncertainty: 15.56 %

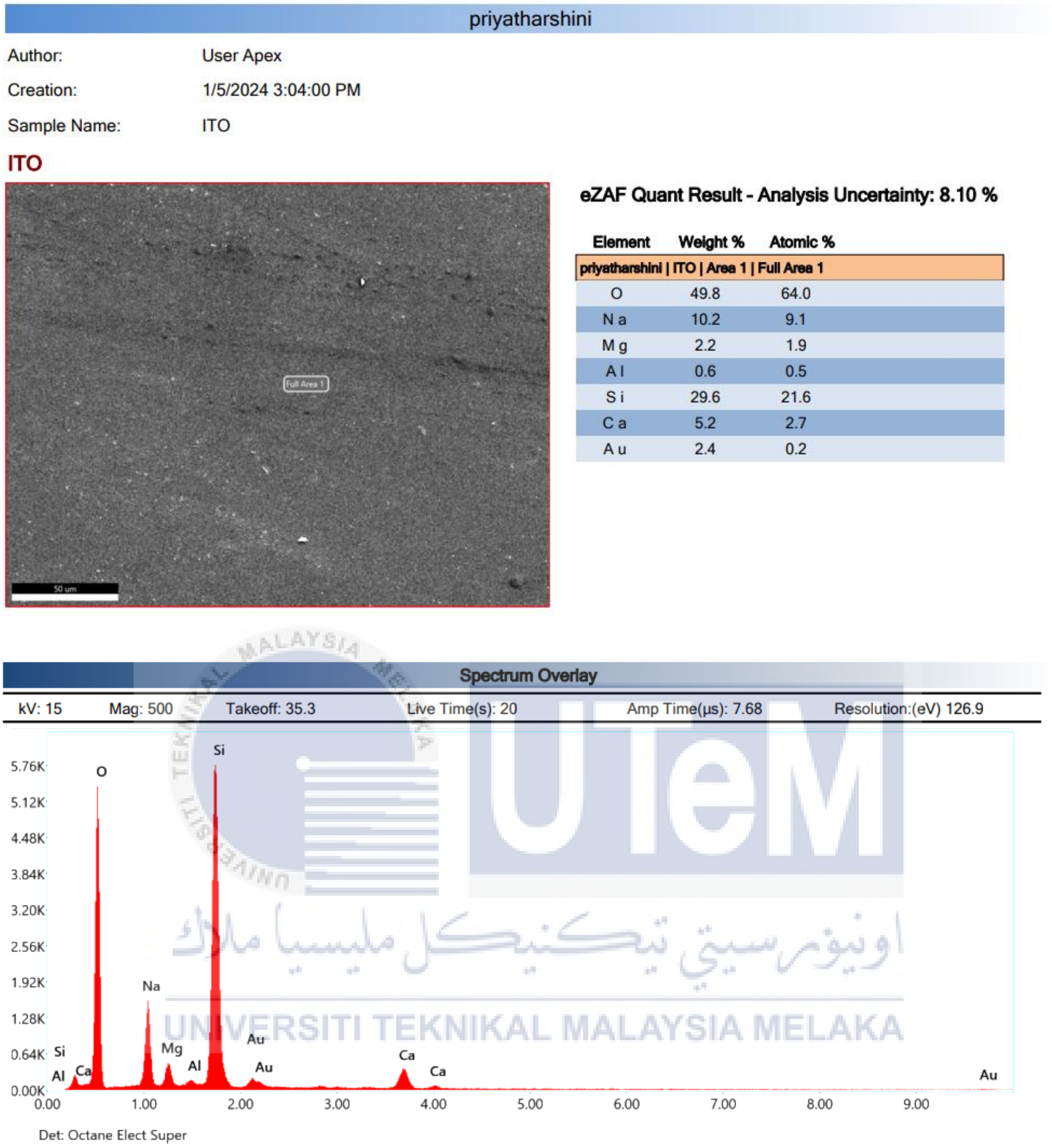
Element	Weight %	Atomic %
priyatharshini | SS 5min 3H | Area 1 | Full Area 1		
C	58.0	87.0
O	2.6	2.9
Ne	0.3	0.2
Na	0.3	0.2
S	1.5	0.9
Cr	4.9	1.7
Fe	16.4	5.3
Ni	1.7	0.5
Au	14.4	1.3

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 34.7 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.51 EDX on material Stainless steel 5 Minutes (sonicated 3 Hour)



priyatharshini

Author: User Apex
Creation: 1/5/2024 3:04:00 PM
Sample Name: ITO

ITO

eZAF Quant Result - Analysis Uncertainty: 8.10 %

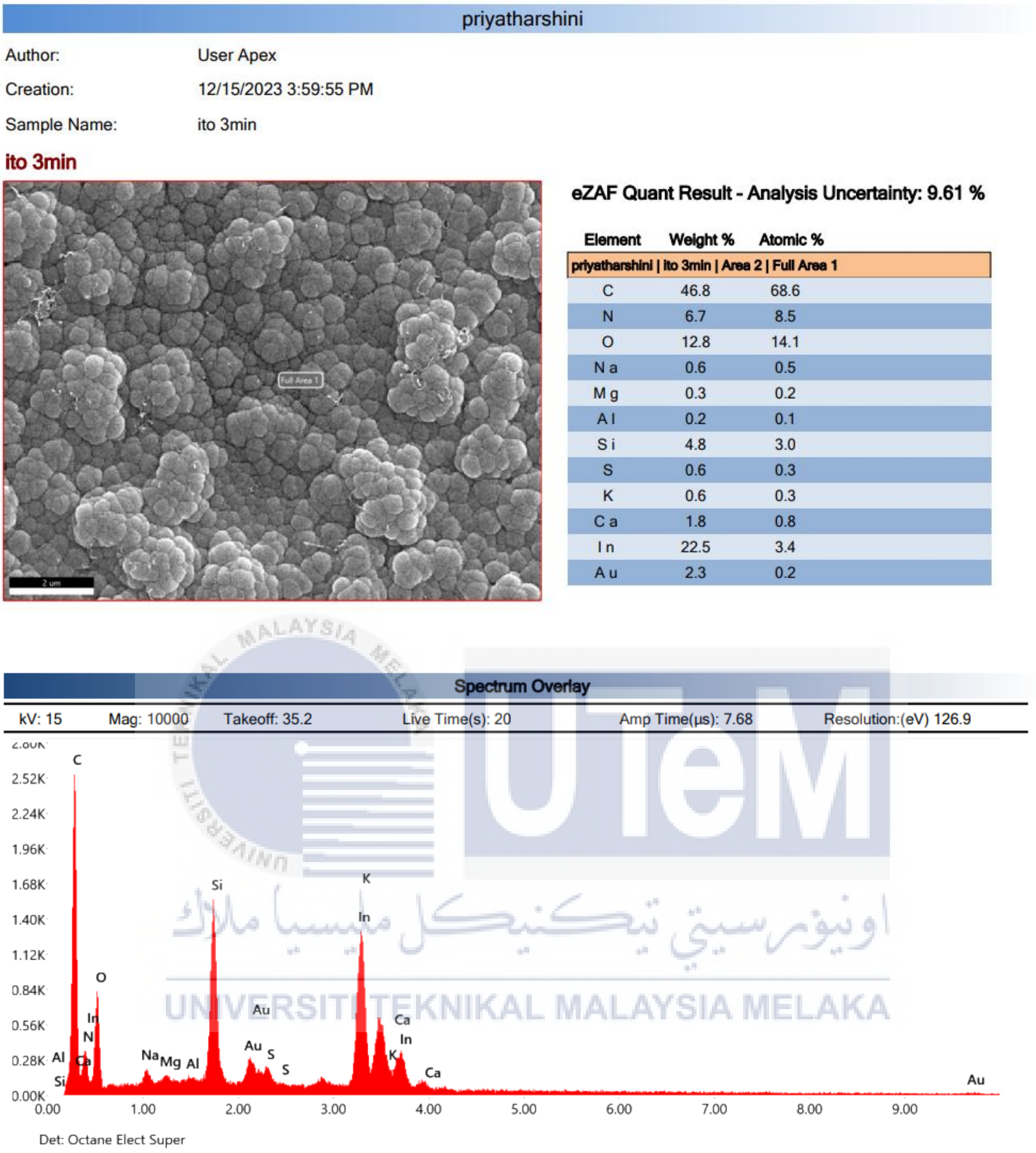
Element	Weight %	Atomic %
priyatharshini | ITO | Area 1 | Full Area 1		
O	49.8	64.0
Na	10.2	9.1
Mg	2.2	1.9
Al	0.6	0.5
Si	29.6	21.6
Ca	5.2	2.7
Au	2.4	0.2

Spectrum Overlay

kV: 15 Mag: 500 Takeoff: 35.3 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.52 EDX on empty material ITO (uncoated material)



priyatharshini

Author: User Apex

Creation: 12/15/2023 3:59:55 PM

Sample Name: ito 3min

ito 3min

eZAF Quant Result - Analysis Uncertainty: 9.61 %

Element	Weight %	Atomic %
priyatharshini | ito 3min | Area 2 | Full Area 1		
C	46.8	68.6
N	6.7	8.5
O	12.8	14.1
Na	0.6	0.5
Mg	0.3	0.2
Al	0.2	0.1
Si	4.8	3.0
S	0.6	0.3
K	0.6	0.3
Ca	1.8	0.8
In	22.5	3.4
Au	2.3	0.2

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 35.2 Live Time(s): 20 Amp Time(μs): 7.68 Resolution:(eV) 126.9

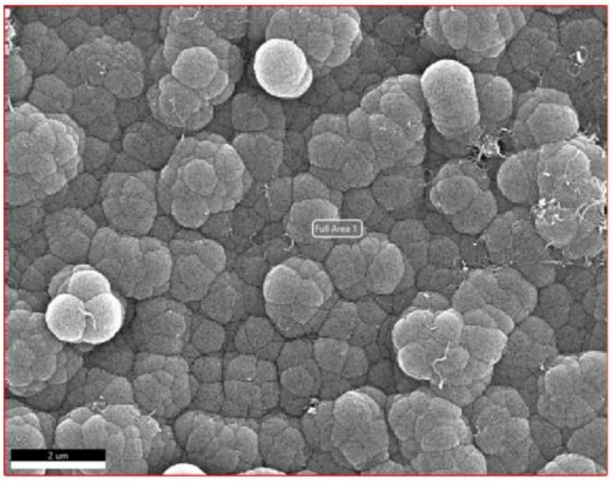
Det: Octane Elect Super

Figure 4.53 EDX on material ITO 3 Minutes (sonicated 1 Hour 30 Minutes)

priyatharshini

Author:	User Apex
Creation:	12/15/2023 4:04:37 PM
Sample Name:	ito 5min

ito 5min

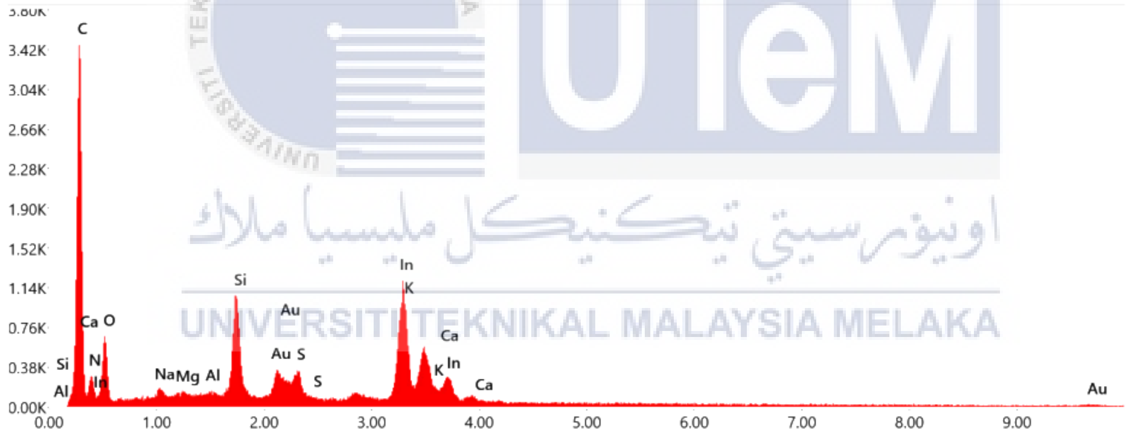


eZAF Quant Result - Analysis Uncertainty: 9.69 %

Element	Weight %	Atomic %
priyatharshini | ito 5min | Area 1 | Full Area 1		
C	56.6	76.6
N	6.0	6.9
O	9.9	10.0
Na	0.5	0.3
Mg	0.3	0.2
Al	0.2	0.1
Si	3.0	1.7
S	1.1	0.6
K	0.5	0.2
Ca	1.1	0.4
In	18.2	2.6
Au	2.8	0.2

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 35.2 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9



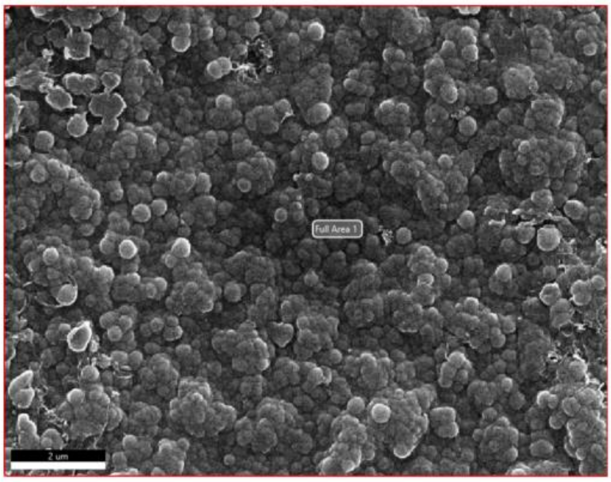
Det: Octane Elect Super

Figure 4.54 EDX on material ITO 5 Minutes (sonicated 1 Hour 30 Minutes)

priyatharshini

Author:	User Apex
Creation:	12/19/2023 3:11:30 PM
Sample Name:	ito 3min 3H

Area 1



eZAF Quant Result - Analysis Uncertainty: 20.12 %

Element	Weight %	Atomic %
C	37.3	63.9
N	5.7	8.4
O	12.6	16.2
Na	0.7	0.6
Si	5.5	4.0
K	1.3	0.7
Ca	1.9	1.0
In	22.3	4.0
Au	12.7	1.3

/priyatharshini/ito 3min 3H/Area 1/Full Area 1/

kV: 15 Mag: 10000 Takeoff: 34.4 Live Time(s): 12.1 Amp Time(µs): 7.68 Resolution:(eV) 126.9

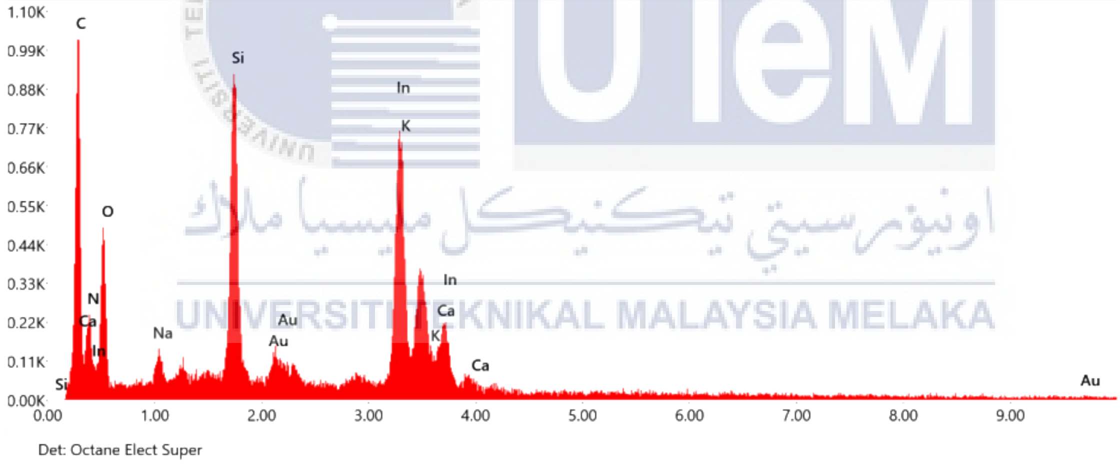
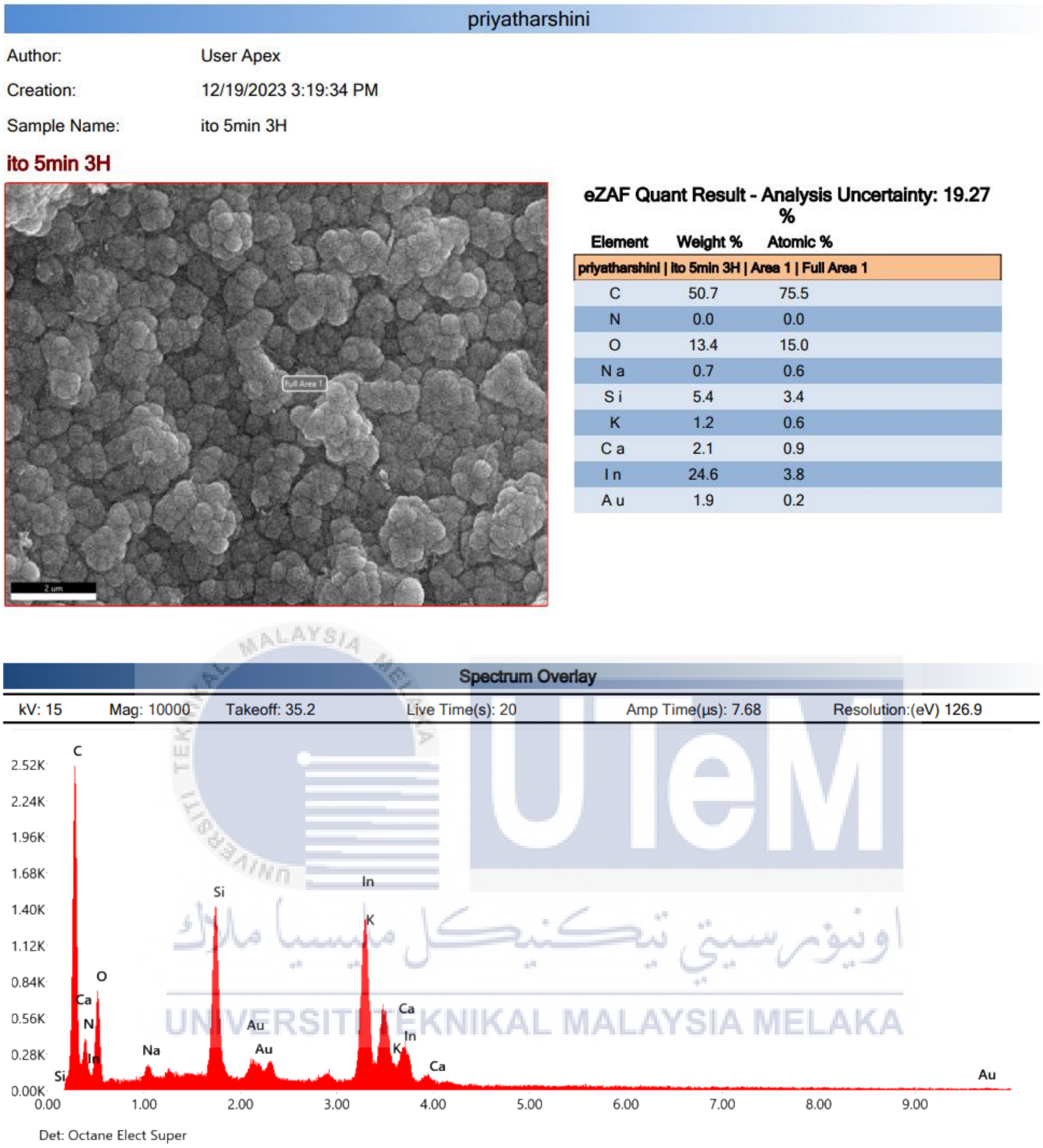


Figure 4.55 EDX on material ITO 3 Minutes (sonicated 3 Hour)



priyatharshini

Author:	User Apex
Creation:	12/19/2023 3:19:34 PM
Sample Name:	ito 5min 3H

ito 5min 3H

eZAF Quant Result - Analysis Uncertainty: 19.27 %

Element	Weight %	Atomic %
priyatharshini | ito 5min 3H | Area 1 | Full Area 1		
C	50.7	75.5
N	0.0	0.0
O	13.4	15.0
Na	0.7	0.6
Si	5.4	3.4
K	1.2	0.6
Ca	2.1	0.9
In	24.6	3.8
Au	1.9	0.2

Spectrum Overlay

kV: 15 Mag: 10000 Takeoff: 35.2 Live Time(s): 20 Amp Time(µs): 7.68 Resolution:(eV) 126.9

Det: Octane Elect Super

Figure 4.56 EDX on material ITO 5 Minutes (sonicated 3 Hour)

4.2.2.6 ELECTRODES COATING RESULTS ON FESEM (3 MINUTES AND 5 MINUTES)

These are the results for the sample that have been sent to analysis FESEM. Figure 4.57 shows the data on carbon electrode. Figure 4.61 shows the data on ITO electrode. Figure 4.65 shows the data on Stainless steel electrode.

The goal of doing FESEM (Field Emission Scanning Electron Microscopy) on stainless steel, indium tin oxide (ITO), glass, and carbon materials is to investigate their surface morphology, structure, and composition. FESEM is a powerful instrument for photographing and evaluating nanometer-scale material surfaces, delivering high-resolution pictures as well as extensive information on the surface properties. FESEM may be used to analyze the surface morphology and structure of stainless steel, revealing information on the existence of flaws, corrosion, and other surface properties. This information can help us understand the material's qualities and performance in a variety of applications. FESEM may be used to analyze the surface morphology and structure of an ITO coating on ITO glass, providing information on its thickness, homogeneity, and quality. This information is useful for understanding the material's optical and electrical characteristics, as well as improving the coating process. FESEM may be used to analyze the surface morphology and structure of carbon materials, revealing information on the presence of flaws, impurities, and other surface characteristics. This information might help you understand the material's qualities and performance in various applications.

Overall, FESEM is an effective method for describing the surface morphology and structure of many materials, giving important information for understanding their characteristics and performance in a variety of applications.

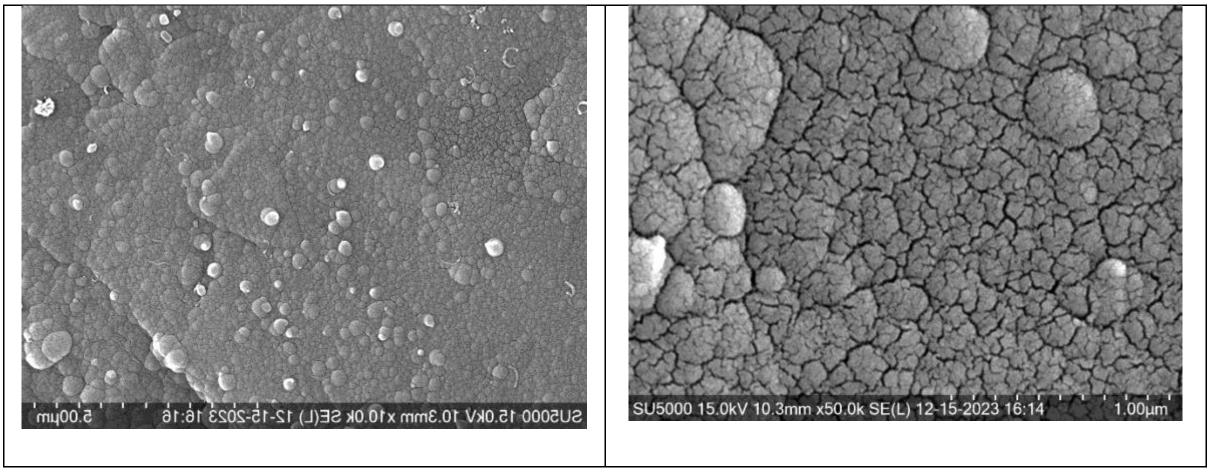


Figure 4.57 FESEM Carbon coated 3 minutes (sonicated 1 Hour 30 Minutes)

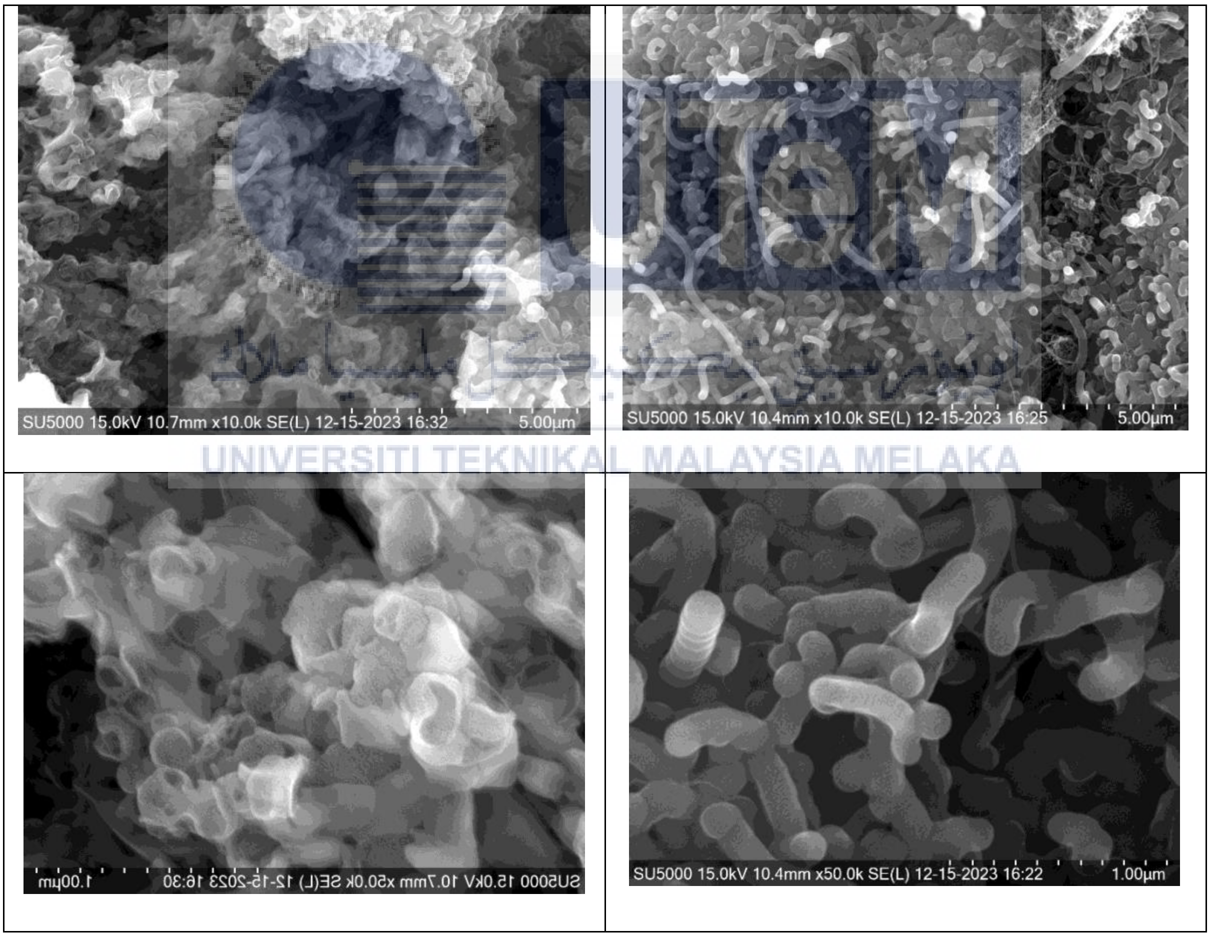


Figure 4.58 FESEM Carbon coated 5 minutes (sonicated 1 Hour 30 Minutes)

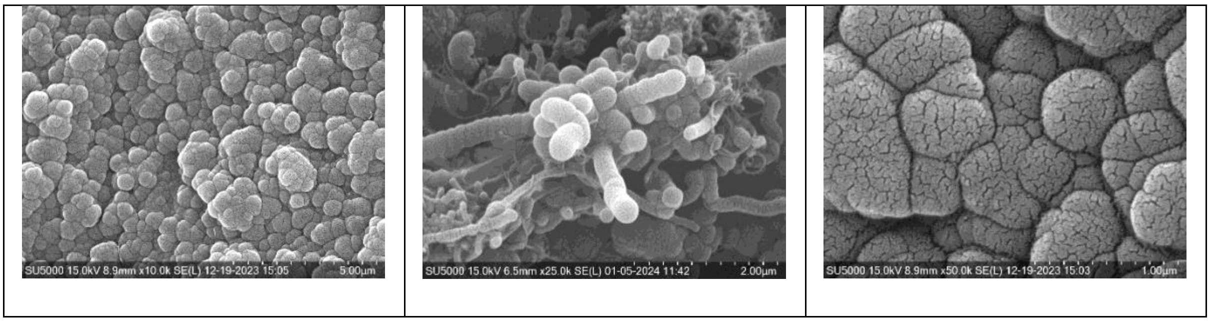


Figure 4.59 FESEM Carbon coated 3 minutes (sonicated 3 Hour)

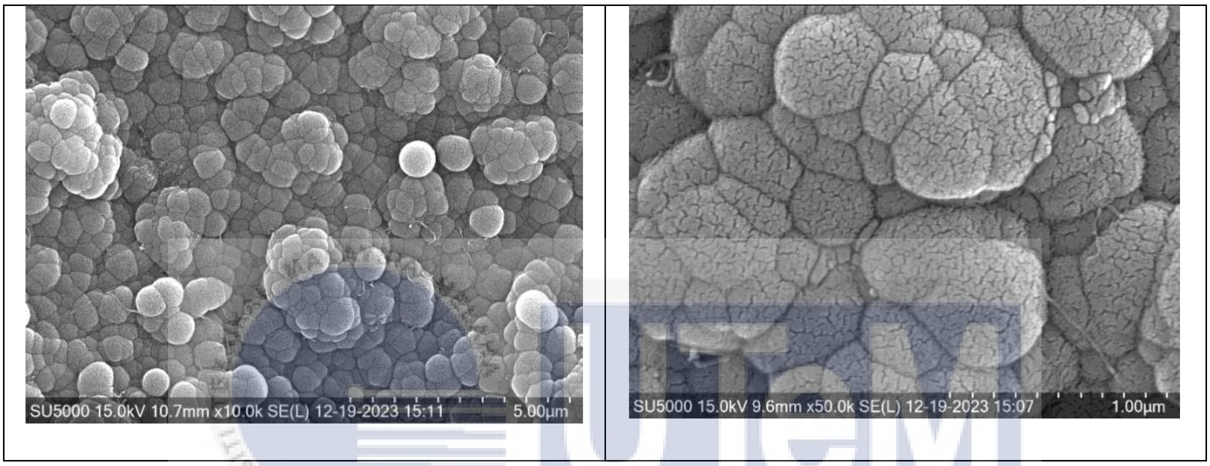


Figure 4.60 FESEM Carbon coated 5 minutes (sonicated 3 Hour)

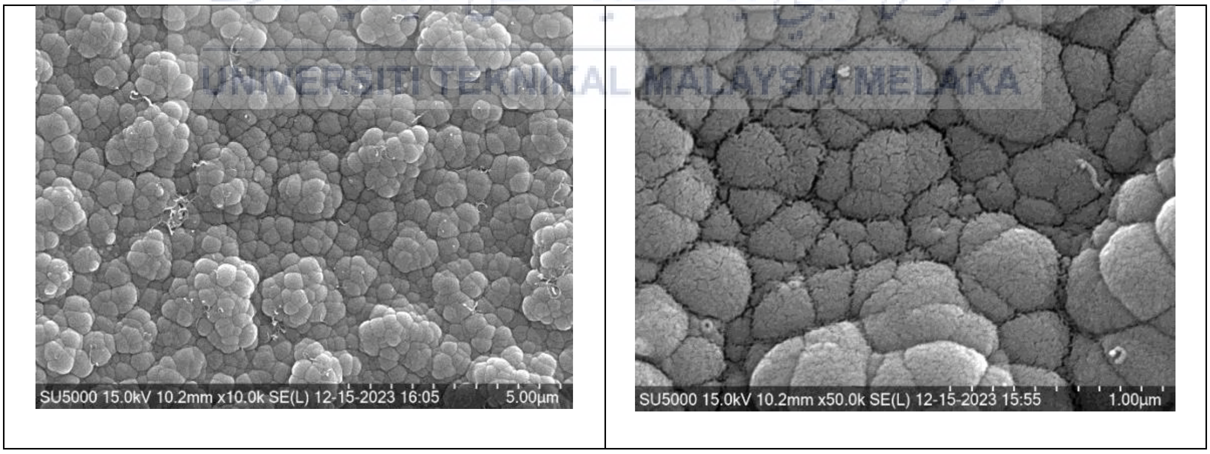


Figure 4.61 FESEM ITO coated 3 minutes (sonicated 1 Hour 30 Minutes)

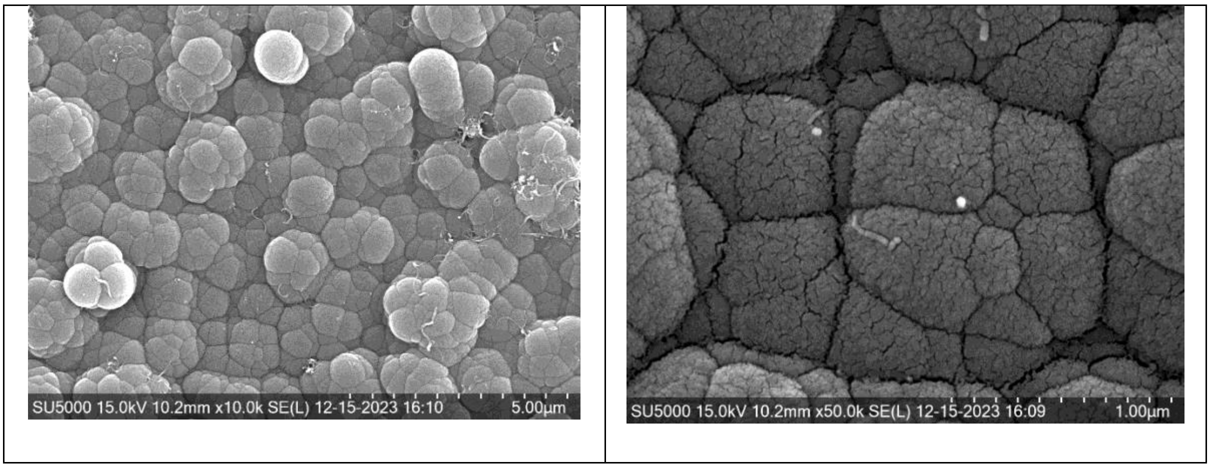


Figure 4.62 FESEM ITO coated 5 minutes (sonicated 1 Hour 30 Minutes)

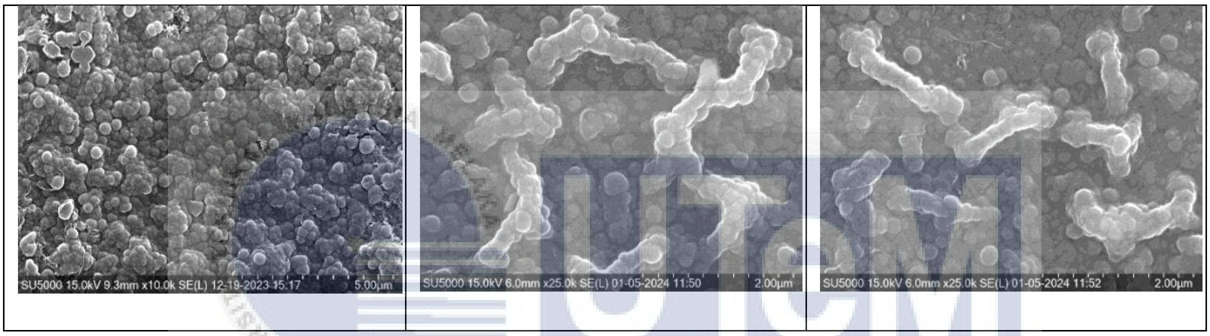


Figure 4.63 FESEM ITO coated 3 minutes (sonicated 3 Hour)

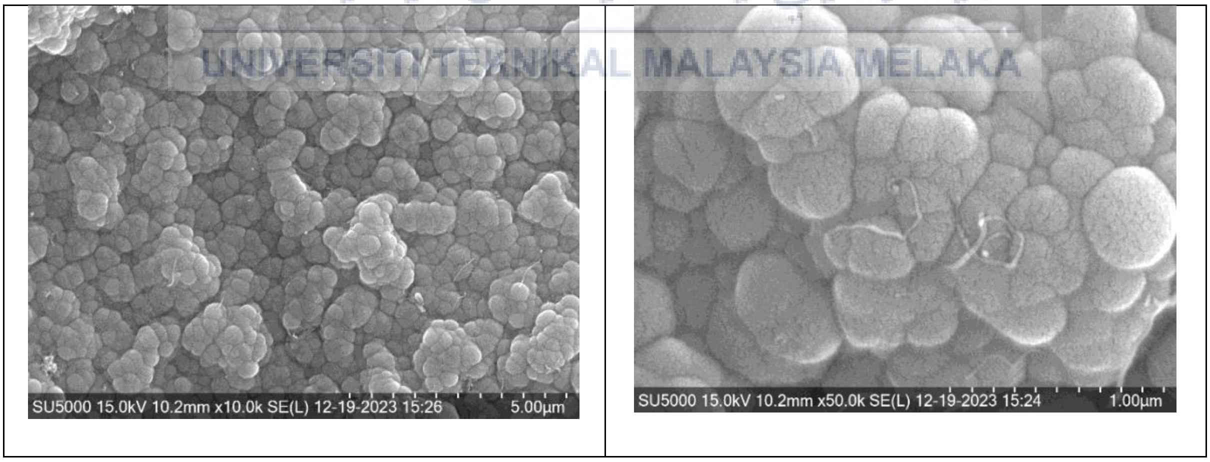


Figure 4.64 FESEM ITO coated 5 minutes (sonicated 3 Hour)

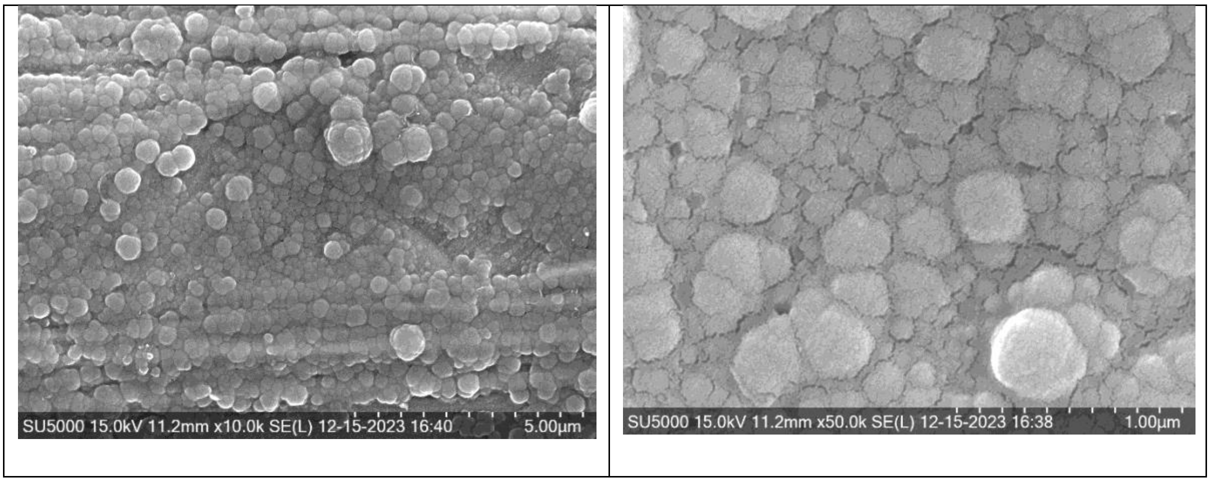


Figure 4.65 FESEM Stainless steel coated 3 minutes (sonicated 1 Hour 30 Minutes)

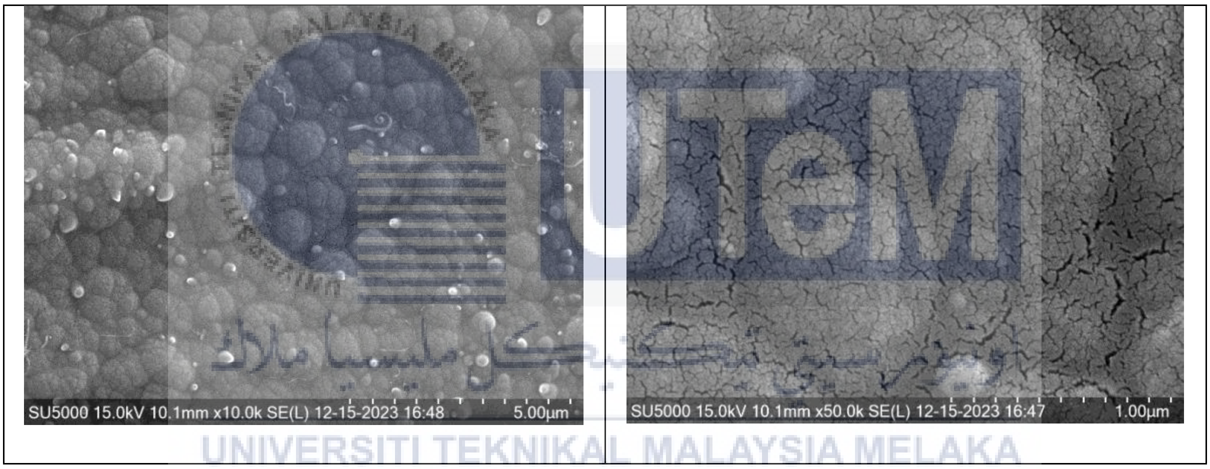
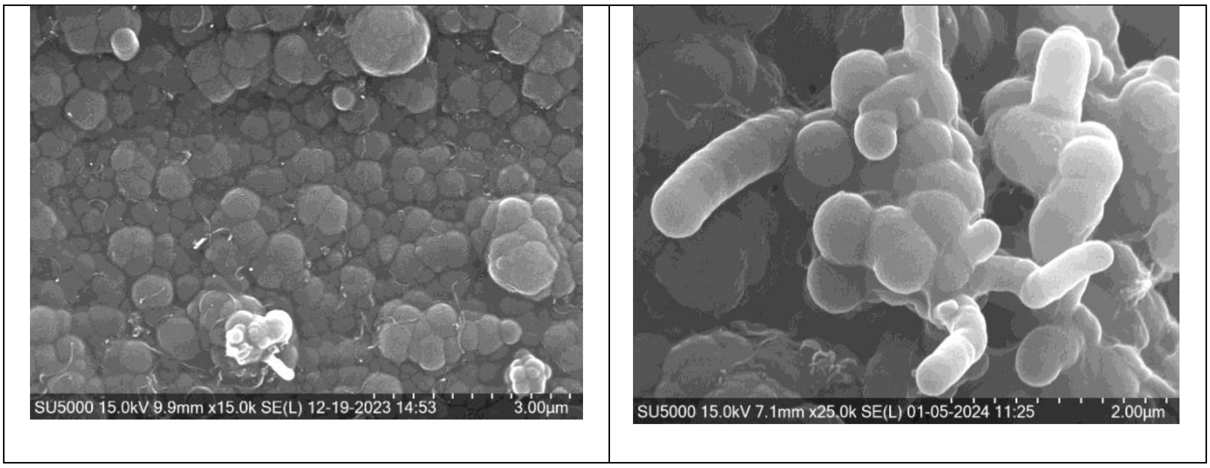


Figure 4.66 FESEM Stainless steel coated 3 minutes (sonicated 1 Hour 30 Minutes)



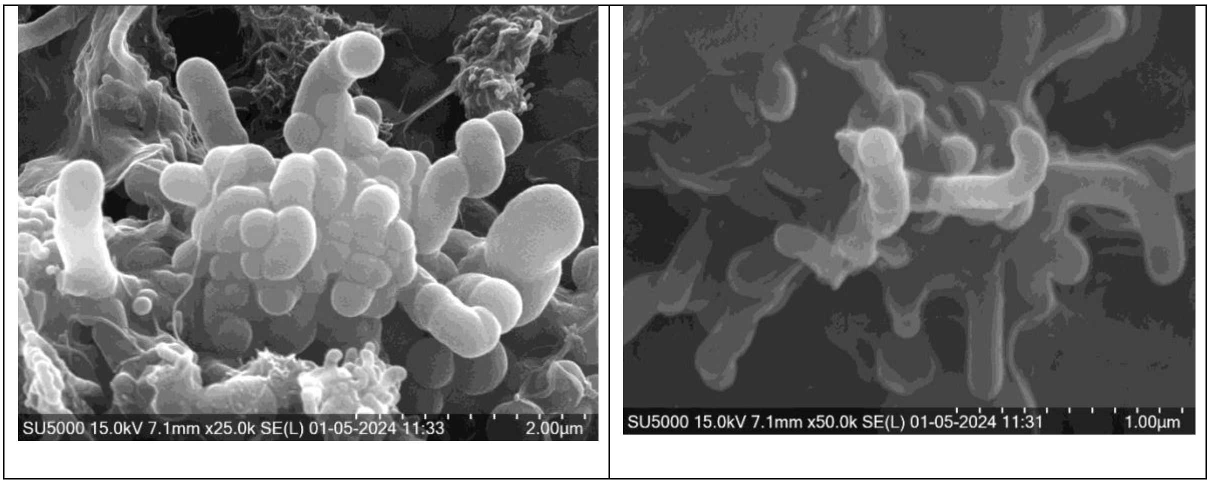


Figure 4.67 FESEM Stainless steel coated 3 minutes (sonicated 3 Hour)

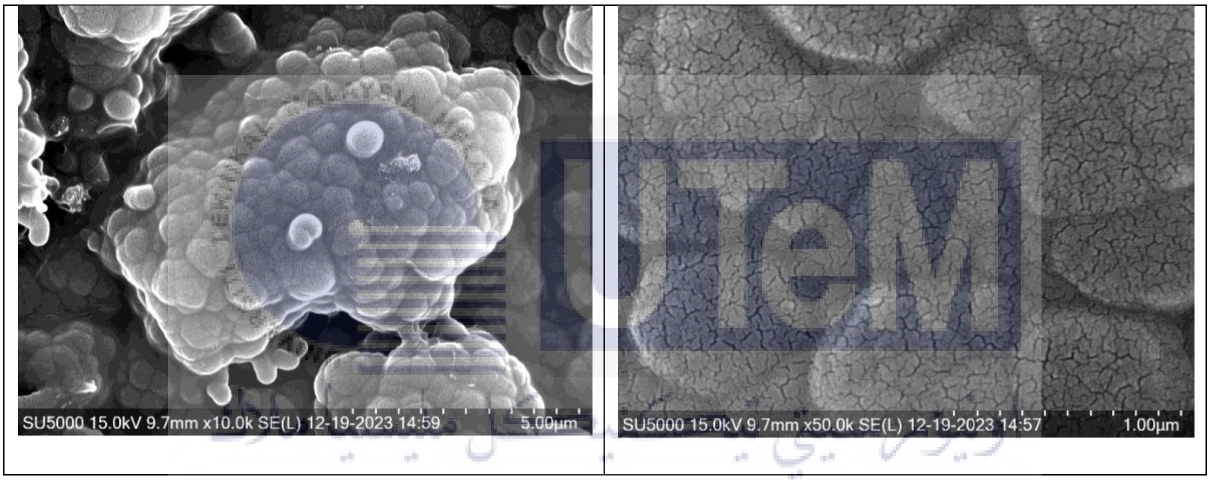


Figure 4.68 FESEM Stainless steel coated 5 minutes (sonicated 3 Hour)

4.3 DISCUSSION OF THE RESULTS

Several research investigations have been conducted to investigate the production of stainless steel, ITO, and carbon electrodes coated with multi-walled carbon nanotubes (MWCNT) and polypyrrole (PPy). The coated electrodes were characterized using a variety of analytical methods, including field emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR).

The FESEM analysis was used to investigate the surface morphology and coating quality of the electrodes. For example, in a research on polypyrrole/carbon nanotube-coated stainless steel meshes, FESEM was utilized to validate the successful electrodeposition of the PPy/CNT composite onto the stainless steel substrates, proving the technique's suitability for coating characterisation. Furthermore, the analysis of the microstructure and tribological characteristics of CNTs/Ni composites generated by electrodeposition used FESEM to analyze the surface morphology and interface between the CNTs and the composite matrix. [46]

EDX analysis was used to determine the elemental composition of the coated electrodes, offering insights into the presence and distribution of various elements inside the coatings. The elemental dominance and uniformity of the coated electrodes were confirmed by EDX analysis, confirming the efficacy of the MWCNT/PPy coating on the carbon electrodes. [47]

The coated electrodes' crystalline structure and phase composition were investigated by XRD characterisation. XRD is commonly used to examine the crystallographic characteristics of carbon nanotube-based composites and coatings, but no particular findings for MWCNT and PPy-coated carbon electrodes were discovered in the supplied sources. [48]

FTIR spectroscopy was utilized to study the chemical bonds and functional groups found in the coated electrodes. Although particular FTIR data for the indicated coated electrodes were not accessible in the aforementioned sources, FTIR analysis has been widely used to explore the functionalization and characterisation of carbon nanotube-based materials. [49]

In summary, several research papers have used FESEM, EDX, XRD, and FTIR analyses to characterize stainless steel, ITO, and carbon electrodes coated with MWCNT and PPy. These analytical approaches have proven useful in determining the surface morphology, elemental composition, crystallographic structure, and chemical characteristics of coated electrodes, indicating their applicability for a variety of applications.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 CONCLUSION

Carbon nanotube (CNT) composites were characterized by electrodeposition utilizing several analytical methods, yielding significant insights into their characteristics and possible uses. Compared to other technologies, their cost is relatively low and their specificity is high. We were able to coated the PPY/MWCNT onto the electrodes using electrodeposition process . Then we were able to checked the coating is on the electrodes using FESEM , FTIR and XRD [8]. Field emission scanning electron microscopy (FESEM), X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), and Fourier-transform infrared spectroscopy (FTIR) have all led to a better understanding of CNT composites. FESEM analysis was useful in determining the surface morphology and structural properties of the electrodeposited CNT composites. For example, in the study of electrodeposited carbon nanotube thin films, FESEM was utilized to evaluate the films' morphology, offering visual insights into their microstructure and uniformity. Likewise, in the research of the electrochemical co-deposition of carbon nanotube/Ni composite layers, FESEM was used to disclose the electro crystallization capabilities, further confirming the applicability of this approach in examining the structural aspects of the composites. XRD analysis was used to investigate the crystallographic characteristics and phase composition of the electrodeposited CNT composites. The characterisation of synthesized CNTs using XRD and FTIR has been published in a work studying the impact of substrates in the physical and chemical properties of CNTs, stressing the importance of XRD in understanding the structural features of the generated CNTs.

5.2 FUTURE WORK

Several important work can be made to further improve the performance of carbon nanotube-based nanoelectronics biosensors fabricated by electrodeposition for sensing applications. First, it is important to continuously optimize the deposition parameters such as deposition time, applied potential, precursor concentration and temperature. Fine tuning of these parameters allows better control over the growth and alignment of carbon nanotubes, improving the sensitivity and selectivity of biosensors. Additionally, investigation of different carbon nanotube structures, including changes in tube diameter, length and chirality, provides valuable insight into structure-property relationships, enabling even higher levels of performance. There is a possibility. Another important recommendation is to explore surface functionalization techniques to modify the properties of electrodeposited carbon nanotubes. Attaching specific functional groups or biomolecules increases the selectivity of biosensors, enabling targeted detection of specific analytes and minimizing interference. To further improve the sensitivity of biosensors, integration with signal amplification strategies such as enzymatic amplification and nanomaterial-based amplification should also be considered. Evaluating the long-term stability and durability of electrodeposited biosensors through extensive reliability testing is critical to ensure robustness for real-world applications. Finally, promoting collaboration among researchers in different fields and addressing scalability and manufacturing issues will facilitate the commercialization and widespread adoption of these advanced biosensors. Implementing these recommendations will significantly improve the performance of carbon nanotube-based nanoelectronics biosensors via electrodeposition, opening up new possibilities for highly sensitive and selective sensing applications.

5.3 PROJECT POTENTIAL

Commercialization of nanoelectronic biosensors entails developing, manufacturing, and selling these sensors for a variety of applications such as medical diagnostics, environmental monitoring, and food safety. Typically, the process includes research and development to increase the performance and reliability of the sensors while also lowering their cost and size. Once designed and tested, a biosensor may be mass-produced and offered to a variety of sectors and end-users. A nanoelectronic biosensor's commercial success will be determined by parameters such as its accuracy, sensitivity, and cost, as well as the size of the target market and the amount of competition.

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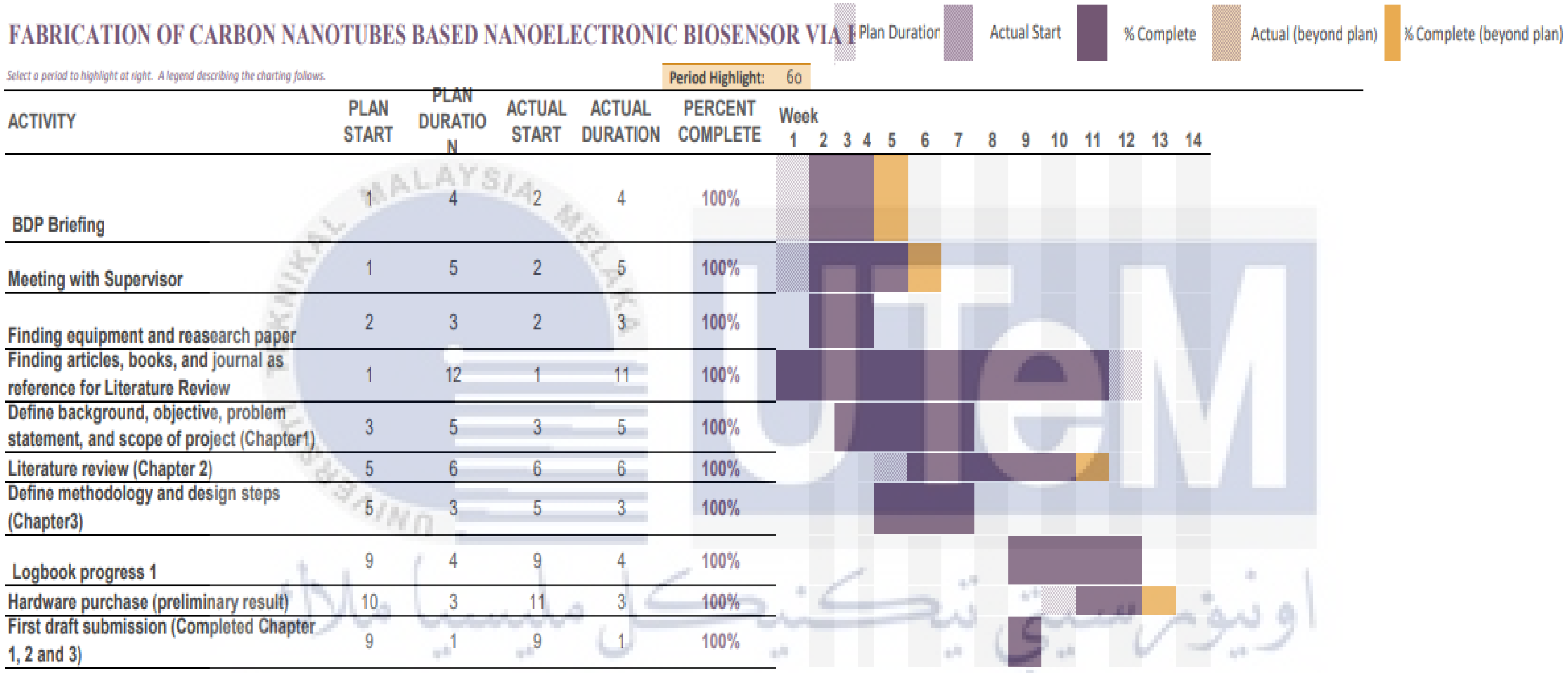
APPENDICE



FABRICATION OF CARBON NANOTUBES BASED NANOELECTRONIC BIOSENSOR VIA I

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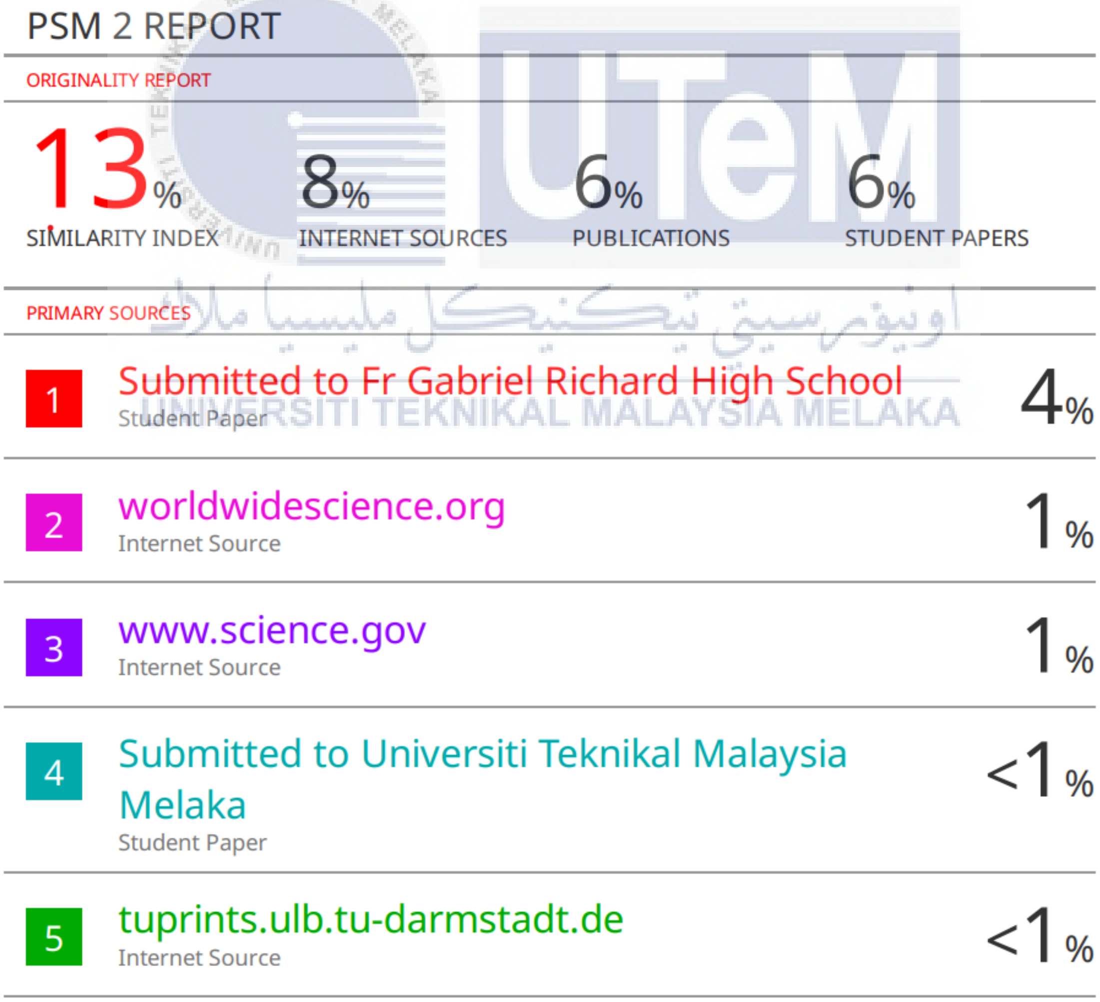

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