Design and Fabrication of Glucose Meter Chip

Senior design project report

BY

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Supervised by

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Faculty of Engineering Sciences

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May 2024

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submitted in partial fulfillment of the requirements for the degree of bachelor of science

Faculty of Engineering Sciences

GIK Institute of Engineering Sciences & Technology

May 2024

Senior Design Project Status/Completion Certificate

Group No: 04

Title: Design and Fabrication of Glucose Meter Chip

This is to certify that senior year design project has satisfied the following:

(i) The design part of the project is completed to a sufficient level. Specifically, the project has achieved.

a.	Key functionalities and design specifications.
b.	Schematic layout.
c.	Prototype development

(ii) The students have engaged in weekly meetings and demonstrated gradual progression of work.

(iii) The defined Scope / Objectives are:

Sr.#	**Objectives**	**KPI (min. 50%) achieved**	
		Advisor	**Ext. Examiner**
a.	Enhancing indigeneity		
b.	Economical glucose chip.		
c.	Hands on experience in fabrication micro-chips.		
d.	Reduces reliance on imported glucose chip.		
e.	Quality of Report (Technical content, breadth/depth)		

(iv) Based on the above score, the project stands_______________. (complete/incomplete)

(v) I (Advisor) understand that the report may be subjected to external review.

________________ ____________________

Advisor **External Examiner**

(**To be filled by SDP Coordinator**)		**Good**	**Average**	**Poor**
(vi)	Overall structure of report is in-line with the provided FES guidelines.			
(vii)	Students followed the given deadlines by SDP committee			

____

SDP Coordinator

____

Dean FES

SDP-CEP MAPPING

SDP Title	Design and Fabrication of Glucose Meter Chip
Complex Engineering Problem Attributes	
Engineering problems which cannot be resolved without in-depth engineering knowledge, and have some or all of the characteristics listed below:	**Please write your comments against each attribute in the space below. Attach more sheets if necessary.**
Involve wide-ranging or conflicting technical, engineering and other issues.	Yes, photolithography process involve varied and conflicting technical, engineering, and other issues.
Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	It has the obvious solutions but the methodology is not well defined and requires validation.
Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	Yes, it involves research based knowledge for photolithography process, crucial for the development of glucose meter chips using.
Involve infrequently encountered issues	Yes, this process has been tested for the first time in Pakistan.
Are outside problems encompassed by standards and codes of practice for professional engineering.	Yes, still we are in that process of validation, but we have got the basic results.
Involve diverse groups of stakeholders with widely varying needs	We have developed the process to accommodate diverse stakeholder needs.
Have significant consequences in a range of contexts	It can have significant consequences in healthcare and biotechnology.

Are high level problems including many component parts or sub-problems.	Yes, high-level problems typically consist of multiple component parts or sub-problems.

Advisor: <u>Dr. Tahseen Amin Khan Qasuria</u>

Signature: _______________

Adherence to the Sustainable Development Goals (SDGs)

SDP Title		**Design and Fabrication of Glucose Meter Chip**
Sustainable Development Goals (SDGs)		
S. No.	**SDG**	**Adhere of SDP to SDG (Justification)**
1.	No Poverty	
2.	Zero Hunger	
3.	Good Health and Well-Being	Promoting good health and well being, particularly for individuals with diabetes
4.	Quality Education	We've achieved a groundbreaking milestone in Pakistan by creating the first-ever glucose, poised for upcoming batch.
5.	Gender Equality	
6.	Clean Water and Sanitation	
7.	Affordable and Clean Energy	
8.	Decent Work and Economic Growth	
9.	Industry, Innovation and Infrastructure	The fabrication process involves innovation in microelectronics and manufacturing infrastructure.
10.	Reduced Inequalities	
11.	Sustainable Cities and Communities	
12.	Responsible Consumption and Production	
13.	Climate Action	
14.	Life Below Water	
15.	Life on Land	
16.	Peace, Justice and Strong Institutions	
17.	Partnerships	

Advisor: Dr. Tahseen Amin Khan Qasuria

ACKNOLEDGEMENT

First of all, we would like to express our deepest gratitude to Almighty Allah, the Creator, the most Merciful and the Beneficent, for His countless blessing and to enable us achieve this goal. We also offer our praises to Holy Prophet MUHAMMAD (S.A.W) and his companions who laid the foundation of Islamic civilization and paved the way for social, moral, economic and cultural revolution.

We would like to express our sincere appreciation to our esteemed advisor, Dr. Tahseen Amin Khan Qasuria and co-advisor, Dr. Memoon Sajid, whose unwavering guidance and support were invaluable throughout every stage of the project and their expertise significantly contributed to the successful completion of this project.

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Lastly, our gratitude extends to all our group members, whose collaboration and teamwork were essential in achieving our goals. Their collective expertise and commitment played a pivotal role in the successful completion of this project.

ABSTRACT

The escalating prevalence of diabetes worldwide necessitates reliable and cost-effective glucose monitoring solutions. Despite technological advancements, many countries, including Pakistan, heavily rely on imported glucose meter chips, leading to economic strain and limited accessibility. Addressing this challenge, this project focuses on designing and fabricating a glucose meter chip using the photolithography process, offering a locally produced alternative that is economically viable and technologically proficient.

The proposed glucose meter chip responds to Pakistan's scarcity of domestically manufactured options. Currently, most glucose meter chips available in the market are imported, resulting in increased costs and logistical challenges. Leveraging photolithography, a precise and scalable manufacturing technique, the project aims to establish a sustainable framework for in-country production and promoting self-sufficiency in medical device manufacturing.

The chip's design revolves around microchannel-based architecture, integrating multiple layers of specialized chemicals to enable accurate glucose detection. Through fabrication processes, including spin coating, pre-baking, masking and exposure, post-baking, and development, each layer is precisely patterned and deposited onto a substrate. In addition to the chip, an electrical circuit is designed to detect glucose levels, featuring an LCD display for real-time glucose level visualization. This integrated circuit enhances the functionality of the glucose meter chip.

Furthermore, the project's focus on domestic fabrication aligns with broader initiatives aimed at enhancing local industry and fostering technological innovation in Pakistan. By establishing a framework for the production of essential medical devices within the country, this project contributes to economic growth and technological advancement while addressing critical healthcare needs.

In summary, the design and fabrication of a glucose meter chip using photolithography represent a significant stride towards achieving self-sufficiency in medical device manufacturing in Pakistan. Through the utilization of advanced fabrication techniques and prioritization of local production, this project offers a locally produced alternative to imported glucose meter chips.

Keywords:

- *Fabrication of glucose chip.*
- *Microchannel architecture.*
- *Photolithography process.*
- *Domestic production.*
- *Healthcare innovation.*

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Nomenclature

PEDOT:PSS	Po3,4-ethylene dioxythio-pheneene:polystyrene sulfonate
rGO	Reduces Graphene Oxide
GO	Graphene Oxide
GOx	Glucose Oxidase
ITO	Indium Tin Oxide
PBS	Phosphate buffered saline
PCB	Printed Circuit Board
mg/dL	Milligrams per decilitre
Ω	Ohm
BOM	Bill of Materials

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CHAPTER I: INTRODUCTION

1.1. Background and Motivation

The prevalence of diabetes is a global health concern, prompting the continuous advancement of glucose monitoring technology. Despite these advancements, many countries face challenges in accessing affordable and locally produced glucose meter chips. In Pakistan, reliance on imported chips presents economic burdens and limits accessibility to essential healthcare devices [1]. This project aims to address this issue by designing and fabricating a glucose meter chip using the photolithography process, offering a cost-effective and domestically produced alternative.

1.2. Problem statement

The dependency on imported glucose meter chips in Pakistan not only incurs higher costs but also poses logistical challenges. Additionally, the lack of locally manufactured options hampers the country's self-sufficiency in healthcare technology production. This project seeks to mitigate these challenges by developing a glucose meter chip through photolithography, thereby promoting domestic production and accessibility to vital medical devices [2].

1.3. Scope of the work and expected outcomes

The scope of this project encompasses the design and fabrication of a glucose meter chip using photolithography techniques. Key steps include spin coating, pre-baking, masking and exposure, post-baking, and development. An electrical circuit will also be designed to integrate with the chip for glucose level detection, displaying results on an LCD screen. The expected outcomes include a locally produced, cost-effective glucose meter chip capable of accurate glucose detection, contributing to self-sufficiency in medical device manufacturing in Pakistan.

1.4. Report Outline

INTODUCTION:

This chapter provides an overview of the project, including background information, motivation, problem statement, scope of work, and expected outcomes.

LITERATURE REVIEW:

The literature review explores existing research and technologies related to glucose monitoring devices, photolithography fabrication techniques, and microfluidic systems. It examines the strengths and limitations of current approaches to provide context for the project.

Design and Analysis:
This chapter details the initial design concepts and analysis methodologies employed in developing the glucose meter chip. It discusses the theoretical framework, design considerations, and analytical tools used to optimize the chip's performance.

Design Development and Testing:
Here, the iterative design process and experimental testing procedures are described. The chapter outlines the steps taken to refine the initial design, including fabrication techniques, material selection, and validation testing to ensure the chip's functionality and reliability.

Results and Discussion:
This chapter presents the results of the design development and testing phases. It includes data analysis, experimental findings, and discussions on the performance metrics of the glucose meter chip. The implications of the results are discussed in relation to the project objectives.

Impact and Economic Analysis:
An assessment of the potential impact of the project on healthcare accessibility and affordability is provided in this chapter. Additionally, an economic analysis evaluates the cost-effectiveness of domestically produced glucose meter chips compared to imported alternatives.

Project Management:
This chapter outlines the project management approach, including planning, scheduling, resource allocation, and risk management strategies employed throughout the project lifecycle.

Conclusion and Future Recommendations:

The final chapter summarizes the key findings, conclusions, and contributions of the project. It also provides recommendations for future research directions and potential enhancements to the glucose meter chip design.

CHAPTER II

LITERATURE REVIEW

2.1 Literature review

In this section, a thorough examination of current research and technological advancements in the fields of fabrication of glucose chip, photolithography technique is undertaken. The objective is to gain an in-depth understanding of the latest developments and trends within these areas and to identify potential areas for innovation and improvement. The literature review delves into the realm of glucose monitoring devices, which are critical tools in managing diabetes [2]. It explores traditional methods such as finger-prick testing using blood glucose meters. However, despite their advantages, challenges such as accuracy, calibration, and cost-effectiveness are also discussed, highlighting areas for further research and development.

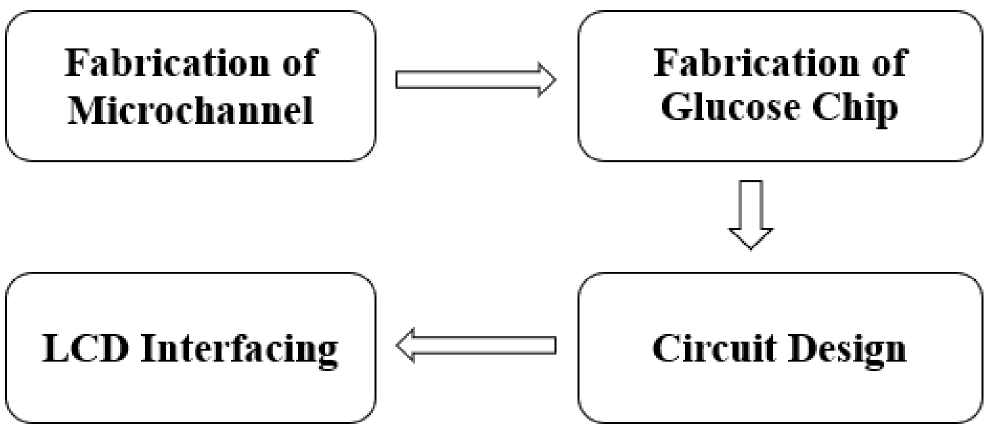

Figure 1: Flow Chart

2.1.1 Photolithography Process

The process of photolithography is a fundamental technique used in sensors fabrication, including the production of glucose meter chips. It involves several sequential steps to transfer a pattern onto a substrate using photoresist. Following are the basic steps for photolithography process [10].

2.1.1.1 Applying Photoresist:

The process begins with the deposition of a light-sensitive material called photoresist onto the substrate [11]. The photoresist is typically applied as a liquid coating using techniques such as spin coating or spray coating. The thickness of the photoresist layer is critical and is controlled to ensure precise patterning.

2.1.1.2 Spin Coating:

Spin coating is a common technique used to achieve a uniform and thin layer of photoresist on the substrate. The substrate is placed on a spin coater, which spins rapidly while the photoresist is dispensed onto its surface. The centrifugal force spreads the photoresist evenly, resulting in a uniform coating [14].

2.1.1.3 Pre-baking:

After the photoresist is deposited, the substrate is subjected to a pre-baking process. This involves heating the substrate to a specific temperature for a predetermined duration. Pre-baking helps to remove solvent from the photoresist, ensuring proper adhesion to the substrate and minimizing defects in the final pattern [12].

2.1.1.4 Mask Alignment:

A photomask, containing the desired pattern, is aligned with the coated substrate using specialized alignment equipment. The photomask consists of opaque regions that block light and transparent regions that allow light to pass through, defining the desired pattern to be transferred onto the substrate [12].

2.1.1.5 Exposure:

The substrate, coated with photoresist and aligned with the photomask, is exposed to ultraviolet (UV) light. The UV light passes through the transparent regions of the photomask, exposing the underlying photoresist to light [12]. The exposure causes a chemical reaction in the photoresist, altering its solubility properties based on the pattern defined by the photomask.

2.1.1.6 Post-baking:

Following exposure, the substrate undergoes a post-baking process to further stabilize the patterned photoresist. Post-baking involves heating the substrate to a specific temperature for a predetermined duration. This step enhances the durability of the patterned photoresist and helps to remove any residual solvents [12].

2.1.1.7 Development:

The substrate is immersed in a developer solution that selectively dissolves either the exposed or unexposed regions of the photoresist, depending on the type of photoresist used [13]. This step reveals the desired pattern on the substrate's surface by removing the soluble regions of the photoresist. The substrate is then rinsed and dried, leaving behind the patterned photoresist.

2.1.2 Electric Circuit

For the detection of glucose level in blood, the integration of electronic circuits is essential within the glucose meter chip design. Among the key circuitry involved are the Wheatstone bridge and the instrumentation amplifier. These circuits play critical roles in converting sensor signals into measurable glucose levels, thereby enabling reliable glucose monitoring [15]. By exploring the principles of these circuits, the literature review provides valuable insights into the electronic component integration necessary for the functionality of the glucose meter chip.

2.1.2.1 Wheatstone Bridge:

Wheatstone bridge circuit, a fundamental component in the detection mechanism of glucose meter chips. This circuit configuration, consisting of four resistive arms, is pivotal for measuring small changes in resistance, which correspond to variations in glucose concentration. By examining existing research and methodologies surrounding the Wheatstone bridge, the literature review elucidates its role in converting sensor signals into quantifiable glucose levels. Moreover, by identifying challenges and opportunities for innovation in Wheatstone bridge design, the literature review contributes to the refinement of detection mechanisms, ensuring the glucose meter chip's efficiency [15].

2.1.2.2 Instrumentation Amplifier:

In parallel, the literature review explores the instrumentation amplifier circuit, another key element in the electronic architecture of glucose meter chips. This specialized amplifier configuration is designed to amplify small differential signals while rejecting common-mode noise, thereby enhancing the accuracy and reliability of glucose measurements [16]. By analyzing existing literature on instrumentation amplifier design and performance, the review provides valuable insights into circuit optimization techniques [17]. Understanding the intricacies of this circuitry is essential for integrating electronic components seamlessly into the glucose meter chip's design.

2.2 Inferences drawn out of Literature

The literature review illuminates several critical inferences pertinent to the design and fabrication of glucose meter chips. Firstly, it underscores the significance of photolithography as a fundamental technique in sensor fabrication, highlighting its sequential steps for pattern transfer onto substrates. This emphasizes the meticulous control required over parameters such as photoresist deposition, spin coating, and post-baking to ensure precise patterning.

Additionally, the exploration of electric circuitry reveals the indispensable roles of the Wheatstone bridge and instrumentation amplifier in converting sensor signals into measurable glucose levels. Understanding the principles behind these circuits provides valuable insights into electronic component integration, essential for the chip's functionality. Moreover, the review identifies challenges and opportunities for innovation, particularly in enhancing detection mechanisms and optimizing circuit design. These inferences collectively inform the subsequent chapters, guiding the design, development, and fabrication of glucose meter chips with improved performance and reliability.

2.3 Summary

In summary, the literature review provides a comprehensive examination of current research and technological advancements in glucose meter chip fabrication and photolithography techniques. It sheds light on traditional glucose monitoring methods and their associated challenges, emphasizing the need for innovation in accuracy, calibration, and cost-effectiveness. The review delves into the photolithography process, elucidating its sequential steps for pattern transfer and highlighting the critical parameters governing each stage. Furthermore, it explores the integration of electric circuits, specifically the Wheatstone bridge and instrumentation amplifier, essential for glucose detection [15]. By identifying areas for improvement and innovation, the literature review sets the stage for subsequent chapters, guiding the design, development, and fabrication of glucose meter chips with enhanced performance and reliability for clinical applications.

CHAPTER III: Design and Analysis

3.1 Design Methodology

The fabrication of the glucose meter chip encompasses meticulous preparation of chemical solutions and precise execution of the photolithography process. The process begins with the preparation of key chemical solutions, including the PEDOT: PSS solution, glucose oxidase solution, and Nafion solution. Each solution is prepared with specific concentrations to ensure optimal performance in the subsequent steps of the fabrication process [7]. Following solution preparation, the drop casting method is employed for the deposition of essential components onto the substrate.

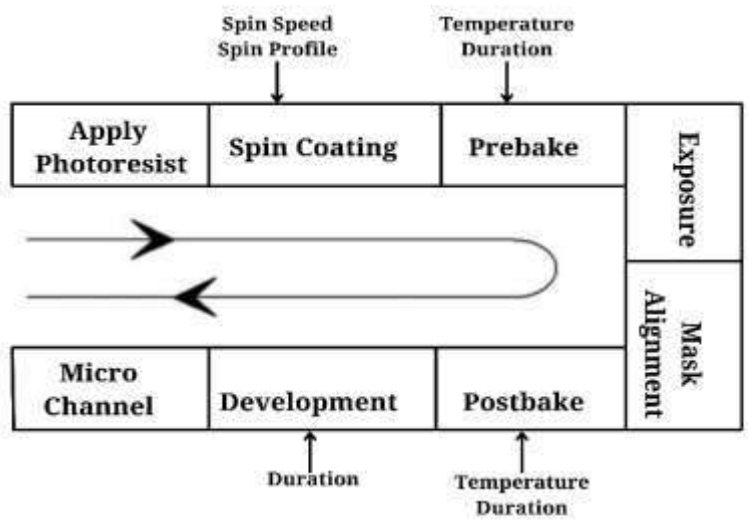

Figure 2: Fabrication Process

3.2 Governing Equations/Mathematical modelling

This project mainly depends upon the chemical equation for an electrochemical reaction and the mathematical equations for circuit designing.

3.2.1 Electro-chemical Reaction

The fabrication of the glucose chip is fundamentally based on the enzymatic reaction involving glucose, water, oxygen, gluconic acid, and hydrogen peroxide. The main equation governing this reaction is:

$$\text{D - Glucose} + H_2O + O_2 \rightarrow \text{Gluconic acid} + H_2O_2$$

This equation describes the conversion of glucose and oxygen into gluconic acid and hydrogen peroxide. This enzymatic reaction is catalysed by glucose oxidase, an enzyme immobilized on the chip's surface. The production of hydrogen peroxide is a key indicator of glucose concentration, as it directly correlates with the amount of glucose present in the sample.

$$H_2O_2 \rightarrow O_2 + 2H_2^+ + 2e^-$$

This equation illustrates the conversion of hydrogen peroxide into oxygen gas, protons, and electrons. The generated electrons contribute to the electrical current measured by the glucose meter chip, providing a quantitative indication of the glucose concentration in the sample.

Overall electro-chemical reaction is given as:

$$\text{D - Glucose} + H_2O + O_2 \rightarrow \text{Gluconic acid} + H_2O_2$$

$$H_2O_2 \rightarrow O_2 + 2H_2^+ + 2e^-$$

3.2.2 Mathematical Equations

This section consists of key mathematical equations governing the operation of the electronic circuits designed for the detection of glucose level in human blood.

3.2.2.1 Wheatstone Bridge Equation:

In the design of the glucose meter chip's electronic circuitry, the Wheatstone bridge configuration plays a pivotal role in measuring small changes in resistance [15], corresponding to variations in glucose concentration. It consists of 4 resistor and input voltage as shown in the figure:

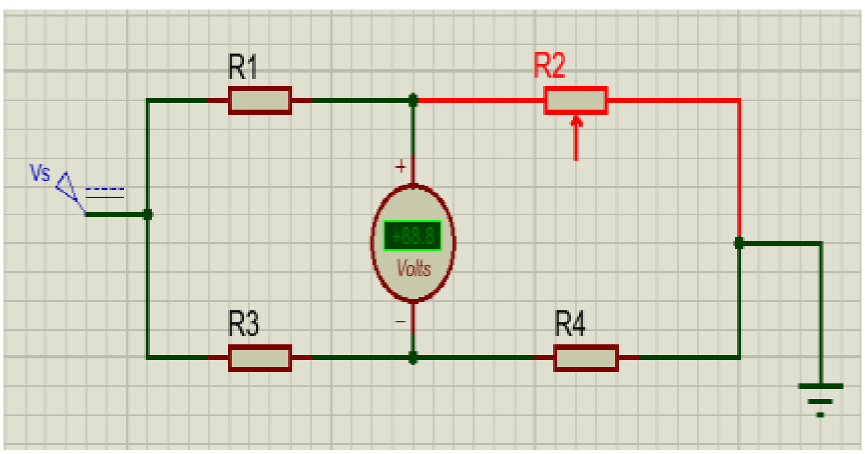

Figure 3: Wheatstone Bridge

The Wheatstone bridge equation can be represented as:

$$V_1 = \frac{R2}{R1 + R2} \times Vs$$

$$V_2 = \frac{R3}{R4 + R3} \times Vs$$

$$V_0 = V_2 - V_1$$

Where:

V_1 is the voltage between R1 and R2.

V_2 is the voltage between R3 and R4.

R1, R3 and R4 are the resistance of Wheatstone bridge arms.

R2 is the resistance of the glucose sensor connected to Wheatstone bridge.

V_0 is the voltage difference between V_2 and V_1.

In addition to the Wheatstone bridge equation's representation of the relationship between output and excitation voltages, balancing the Wheatstone bridge circuit is crucial for accurate glucose concentration measurements [15]. Balancing involves adjusting the resistances of the bridge arms to ensure that the voltage across the output terminals is zero when the bridge is in an unstrained or balanced state. This balance condition is achieved by varying one or more resistances until the bridge circuit is in equilibrium, providing a reference point for accurate measurement of resistance changes caused by variations in glucose concentration. Balancing the Wheatstone bridge circuit maximizes its sensitivity and ensures precise detection of small changes in resistance.

3.2.2.2 Instrumentational Amplifier Equation:

The instrumentation amplifier consists of three op-amps, two input sources and seven resistors as shown in the figure.

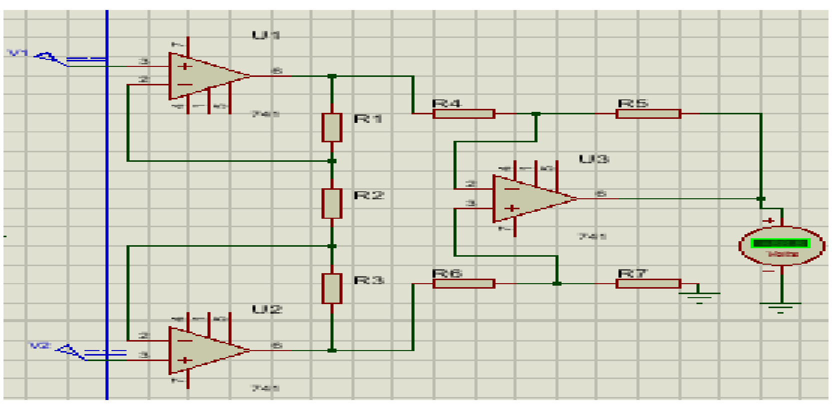

Figure 4: Instrumentational Amplifier

Where:

V_1 and V_2 are the input voltage sources.

R2 (Rg) is the gain resistor.

Resistance of R1 = R3, R4 = R6 and R5 = R7.

Gain (Ao) of the instrumentation amplifier is:

$$Ao = \left(1 + \frac{2R1}{Rg}\right) \times \frac{R3}{R4}$$

Output is given as:

$$V_0 = (V_2 - V_1) \times Ao$$

It determines how much the input signal is amplified before being processed further [16]. This equation is crucial for designing the instrumentation amplifier circuit to achieve the desired level of signal amplification and accuracy in glucose level detection.

3.3 Analysis/ Codes and Standards

In this section, we conduct a thorough analysis of the glucose meter chip's design methodology, electro-chemical reaction, and mathematical modelling, while also considering relevant codes and standards to ensure compliance with industry regulations and safety requirements.

We also delve into the safety standards pertinent to the photolithography lab environment for the fabrication of the glucose chip. Adherence to safety protocols is paramount to ensure the well-being of personnel and the integrity of the fabrication process.

Safety standards in the photolithography lab encompass various aspects, including chemical handling, equipment operation, and personal protective equipment (PPE) usage. Chemicals used in the photolithography process, such as photoresists and developers, may pose hazards if mishandled. Therefore, strict protocols for chemical storage, handling, and disposal are implemented to mitigate risks of exposure and environmental contamination.

The design methodology encompasses meticulous preparation of chemical solutions and precise execution of the photolithography process, crucial steps in fabricating the glucose meter chip. The electro-chemical reaction, fundamental to the chip's operation, is governed by enzymatic processes involving glucose, water, oxygen, gluconic acid, and hydrogen peroxide [8]. Mathematical equations describe these reactions and the behaviour of electronic circuits, such as the Wheatstone bridge and instrumentation amplifier, utilized for glucose detection.

Throughout the analysis, adherence to industry standards and codes is paramount to ensure the chip's performance, safety, and environmental sustainability. By evaluating the chip's performance characteristics, sensitivity, accuracy, and reliability are scrutinized to meet regulatory requirements and societal expectations.

3.4 Summary

This chapter provides a comprehensive exploration of the design intricacies of the glucose meter chip, spanning its methodology, electro-chemical reactions, mathematical models, and compliance with industry standards. It begins by detailing the meticulous steps involved in the fabrication process, emphasizing the precise preparation of chemical solutions and the execution of photolithography techniques. The electro-chemical reaction mechanism, central to glucose detection, is then elucidated, with a focus on the essential equations governing enzymatic processes and glucose transformations. Moreover, the chapter unveils the mathematical foundations of key circuitry components, namely the Wheatstone bridge and instrumentation amplifier circuits, crucial for accurate glucose detection [6]. By highlighting the importance of adhering to industry codes and standards, the chapter underscores the significance of regulatory compliance and safety in both the fabrication and usage of the glucose meter chip. This comprehensive analysis serves as a precursor to forthcoming chapters, which will delve into the fabrication, testing, and performance evaluation of the glucose meter chip.

CHAPTER IV: Design, Development and Testing

During design development, we meticulously fine-tune parameters such as dimensions for fabricating micro-channel for the blood flow, solution concentrations, spin coating techniques, and exposure times to enhance the functionality, reliability, and manufacturability of the glucose meter chip. This iterative approach allows us to address any challenges or shortcomings in the initial design, ultimately leading to an optimized and robust final product.

Subsequently, the testing phase plays a critical role in validating the performance, reliability, and safety of the glucose meter chip. Through a series of rigorous experiments and simulations, we assess key performance metrics such as sensitivity, and response time under various conditions. By systematically validating and verifying the chip's functionality, we ensure that it meets or exceeds specified requirements.

4.1 Development Processes

The development processes consist of:

- Fabrication of glucose chip.
- Fabrication of micro-channel.
- Circuit designing.

4.1.1 Fabrication of Glucose Chip:

For the fabrication of glucose chip, chemical solutions were prepared and for the deposition of these chemical layers, drop costing method is used. Drop costing is a crucial step in fabrication of glucose meter chip.

4.1.1.1 Preparation of Chemical Solutions:

- PEDOT: PSS:
  Prepared PEDOT: PSS solution in water. This solution is crucial for enhancing the conductivity and stability of the electrode material [9].
- Glucose Oxidase:
  Prepared Glucose oxidase solution in PBS (Phosphate Buffered Saline). Glucose oxidase is an enzyme responsible for catalysing the oxidation of glucose in the presence of oxygen [1].

4.1.1.2 Drop Coating Method:

Drop costing method is crucial step in the fabrication processes. This method is applied for the for the deposition of different chemical layers.

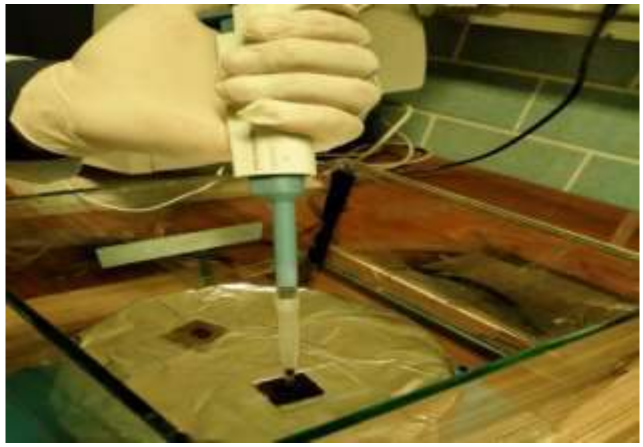

Figure 5: Drop Costing

- **Electrode Deposition:**

Copper or gold is deposited as the electrode material onto a substrate.

- **Graphene Oxide Deposition:**

Maintained 70˚C temperature, 60 µL of graphene oxide solution is deposited onto the substrate, followed by 30 µL of PEDOT: PSS solution. These layers contribute to the conductivity and stability of the electrodes [5].

- **Glucose Oxidase Deposition:**

30 µL of the glucose oxidase solution is deposited onto the substrate and allowed to incubate for 12 hours at 4˚C. This step immobilizes the enzyme onto the electrode surface, facilitating glucose detection [6].

- **Nafion Deposition:**

Finally, 10 µL of Nafion solution is deposited onto the substrate to provide a protective coating over the fabricated microchannels, ensuring their stability and preventing contamination [4]. NAFION serves as a filtration medium due to its porous nature. The pore size of NAFION membranes can be tailored to selectively allow glucose molecules, while blocking larger molecules or contaminants.

4.1.2 Fabrication of Micro-channel:

For the fabrication of micro-channel, photolithography process is used.

4.1.2.1 Photolithography Process:

The microchannel fabrication process begins with the deposition of photoresist (AZ 40XT Photoresist) onto the substrate. This photoresist is chosen for its high resolution and reliability in producing fine patterns.

- **Spin Coating:**
  The substrate is subjected to spin coating at 1000 RPM for 1 minute to achieve a uniform layer of photoresist. This step ensures consistent coating thickness, essential for accurate pattern transfer [14].

- **Pre-baking:**
  The substrate is heated at 125˚C for 7 minutes to remove excess solvent and optimize the performance of the photoresist before pattern transfer [12].

Figure 6: Pre-Baking

- **Mask Alignment:**
  Proper alignment of the photomask with the coated substrate is ensured using a Mask Aligner. This step is crucial for achieving accurate pattern transfer [12].

Figure 7: Mask Pattern

- **Exposure:**
  The substrate, coated with photoresist and aligned with the photomask, is exposed to UV light for 3 minutes [12]. UV light passes through the transparent regions of the photomask, transferring the desired pattern onto the photoresist.

Figure 8: Exposure

- **Post-baking:**
  The substrate is heated at 105˚C for 7 minutes to stabilize the patterned photoresist, enhancing its durability and stability [12].

Figure 9: Post Baking

- **Development:**
  The substrate is immersed in AZ 326 MIF developer for 4 minutes. The developer selectively dissolves the unexposed regions of the photoresist, revealing the desired pattern of microchannels on the substrate [13].

Figure 10: Developing Of Microchannel

4.1.3 Circuit Designing:

In addition to the fabrication processes for the glucose meter chip, the development phase also encompasses the design and implementation of electronic circuits crucial for glucose detection.

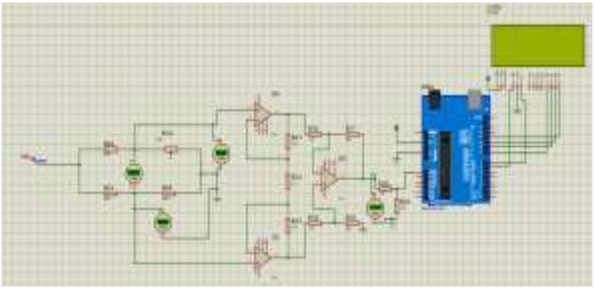

Figure 11: Circuit Diagram

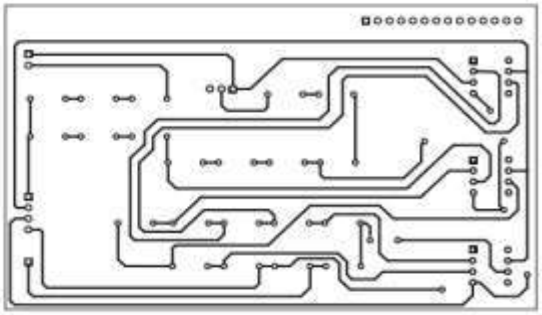

Figure 12: PCB View

4.1.3.1 Wheatstone Bridge:

The Wheatstone bridge configuration, meticulously designed and simulated on Proteus, features four resistors: R1, R2 (glucose sensor), R3, and R4, collectively forming a balanced bridge circuit as shown in figure.

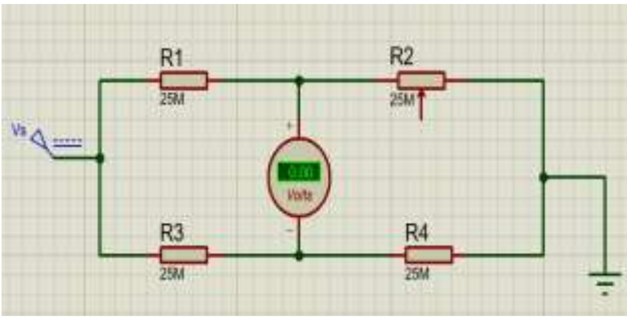

Figure 13: Wheatstone Bridge

The values of R1, R3, and R4 are set to 25 MΩ each, providing balanced resistance across the bridge. The glucose sensor, represented by R2, introduces a variable resistance depending on the glucose concentration, causing an imbalance in the bridge circuit.

The incorporation of a 25 MΩ resistor within the Wheatstone bridge configuration serves a critical role in balancing the circuit. This resistor's value is strategically chosen to align with the resistance of the glucose chip before dropping blood, ensuring initial circuit is in equilibrium. This pre-balanced condition optimizes the sensitivity and responsiveness of the Wheatstone bridge, enhancing its ability to detect subtle changes in the glucose sensor's resistance upon blood droplet deposition. Thus, the inclusion of the 25 MΩ resistor contributes to the overall precision and reliability of the glucose meter chip's sensing mechanism.

The output voltage of the Wheatstone bridge, V_0 is measured across the midpoints of R1 and R3, and R2 and R4. This output voltage (V_0) varies with changes in the resistance of the glucose sensor, allowing for the detection of glucose levels.

4.1.3.2 Instrumentation Amplifier:

The instrumentation amplifier is designed and simulated on Proteus features to amplify the small differential voltage (V_0) signal produced by the Wheatstone bridge, improving sensitivity and accuracy in glucose level detection. Circuitry for instrumentational amplifier is given as:

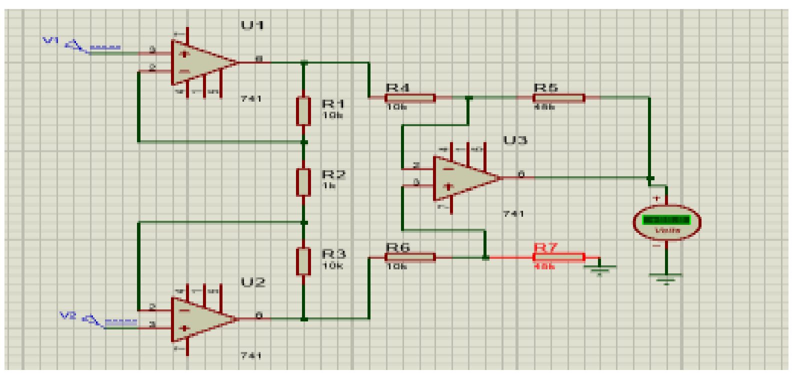

Figure 14: Instrumentational Amplifier

Where:

V_1 and V_2 are the input voltages.

R2 = 1 kΩ.

R1, R3, R4 and R6 are set to 10 kΩ.

R5 and R7 are set to 45 kΩ

Gain of the instrumentational amplifier is given as:

$$A_0 = \left(1 + \frac{2R1}{Rg}\right) \times \frac{R3}{R4}$$

$$A_0 = \left(1 + \frac{2(10k)}{1k}\right) \times \frac{45k}{100k}$$

$$A_0 = 9.45$$

The input voltage sources, V_1 and V_2, are connected to the non-inverting and inverting terminals of the op-amp, respectively. The amplified output voltage, V_0, is calculated based on the difference between V_1 and V_2, multiplied by the amplifier gain as show:

$$V_0 = (V_2 - V_1) \times Ao$$

4.2 Integration and Instrumentation

In the integration of the glucose meter chip, seamless operation and accurate measurement of glucose levels are achieved through the incorporation of various components and advanced techniques. The integration process and the instrumentation techniques utilized to optimize the chip's performance, including the interface with external devices for data processing and display.

4.2.1 Integration of Components:

The careful assembly and alignment of individual components to create a functional glucose meter chip. This includes integrating the fabricated glucose sensor, microchannels, and electronic circuits ensuring their proper alignment and interaction.

The glucose sensor, fabricated using drop casting methods, is integrated onto the substrate, forming a crucial component for glucose detection. Its placement within the microchannels facilitates the controlled interaction with blood samples, allowing for efficient glucose oxidation.

Microchannels, fabricated through photolithography processes, are aligned and integrated with the glucose sensor to provide a confined space for blood flow. These microchannels enhance sensitivity and accuracy by ensuring consistent sample interaction with the sensor surface.

Electronic circuits, such as the Wheatstone bridge and instrumentation amplifier, are integrated into the chip to convert sensor signals into measurable glucose levels. These circuits are designed and simulated to ensure compatibility and functionality within the chip's architecture.

The output of the instrumentation amplifier is connected to an Arduino uno microcontroller, facilitating data processing and display. The Arduino is interfaced with a liquid crystal display (LCD) to visualize glucose levels in real-time. Through this interface, users can conveniently access glucose level readings and track changes over time.

4.2.2 Instrumentation Techniques:

Instrumentation techniques are vital for optimizing the chip's sensitivity and accuracy in glucose detection. Signal amplification, noise reduction, and calibration techniques are employed to enhance performance.

In summary, integration and instrumentation are crucial aspects of the glucose meter chip's design and development, ensuring seamless operation and accurate glucose measurements. By incorporating advanced techniques and interfacing with external devices, the chip provides a reliable platform for glucose monitoring in medical and research applications.

4.3 Testing/Experimental Procedures

The testing and experimental procedures conducted on the developed glucose meter chip model are outlined to assess its functionality and performance.

4.3.1 Micro-channel Testing:

The functionality of the microchannel was tested by introducing a liquid into the channel and observing its flow dynamics. A liquid was carefully dropped into the microchannel, and its movement was monitored. The liquid was observed to flow smoothly within the microchannel, indicating proper fabrication and functionality of the channel.

This testing procedure confirmed the effectiveness of the microchannel in facilitating fluid flow and demonstrated its suitability for use in the glucose meter chip.

4.3.2 Testing of Glucose chip:

Initially, the resistance of the glucose chip was measured, confirming its initial value at 25 MΩ. Upon dropping a blood sample onto the chip, the resistance was observed to change from 25 MΩ to at 21 MΩ. This alteration in resistance is attributed to the formation of ions and their movement within the chip's sensing layer, indicating successful interaction with the glucose molecules.

Figure 15: Testing Glucose Chip

4.3.3 Circuit Testing:

The electronic circuits, including the Wheatstone bridge and instrumentation amplifier, underwent rigorous testing to assess their performance. These circuits were simulated on Proteus software to validate their designs and functionality. Subsequently, the circuits were implemented on hardware, and their performance was compared against simulation results. Comparative analysis between simulated and hardware-based testing was conducted to identify any discrepancies and refine the designs as necessary.

Additionally, the output of the instrumentation amplifier was interfaced with an Arduino microcontroller, which was further connected to an LCD display. This setup allowed for real-time monitoring and display of glucose level readings, enhancing the usability and practicality of the glucose meter chip.

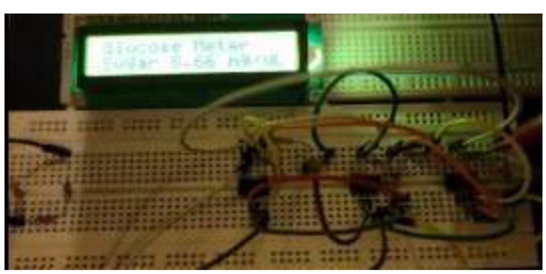

Figure 16: Testing Circuit

4.4Summary

The development of the glucose meter chip was a comprehensive process that involved various stages, including fabrication, circuit designing, integration, and testing.

For the fabrication of the chip, precise chemical solutions were prepared, and the drop coating method was employed to deposit layers onto the substrate. This included PEDOT:PSS, glucose oxidase, and nafion, each serving a specific purpose in enhancing conductivity, facilitating glucose detection, and providing protective coatings. The microchannels, essential for fluid flow and interaction with the glucose sensor, were fabricated using photolithography techniques, ensuring precise patterns and efficient sample handling.

Circuit design was another crucial aspect of the development process, involving the meticulous design and simulation of electronic circuits such as the Wheatstone bridge and instrumentation amplifier. These circuits played a vital role in converting sensor signals into measurable glucose levels and amplifying them for accurate detection. Integration of components was carefully executed to ensure proper alignment and functionality. The microchannels, glucose sensor, and electronic circuits were assembled to form a cohesive and functional glucose meter chip.

Testing and experimental procedures were conducted to validate the functionality and performance of the chip. Microchannel testing confirmed smooth fluid flow, while testing of the glucose chip demonstrated successful interaction with glucose molecules, as evidenced by resistance changes upon blood sample deposition. Rigorous circuit testing, including simulation and hardware implementation, ensured the accuracy and reliability of electronic circuits. The interfacing of the instrumentation amplifier with an Arduino microcontroller and LCD display allowed for real-time monitoring and visualization of glucose levels.

CHAPTER V: Results and Discussion

5.1 Results

This chapter includes linear relationship between the change in resistance (ΔR) and the corresponding glucose levels (mg/dL). This linear relationship assumes a direct proportionality between the change in resistance of the glucose sensor and the measured glucose concentration. The following table summarizes the obtained results:

Change in Resistance (ΔR)	Glucose Level (mg/dL)
2	112
3	115
4	117
5	120
6	123
7	125
8	128
9	130
10	132
11	135
12	138

Table 1: Data Samples

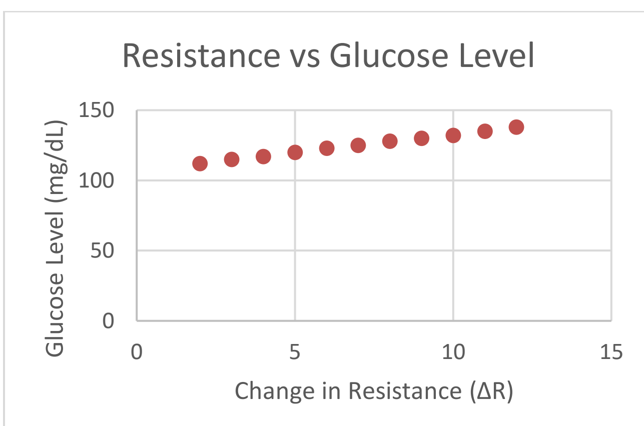

Figure 17: Sample Data

The above scatter plot visually shows the relationship between the change in resistance (in MΩ) and the corresponding glucose concentration (in mg/dL). Each data point on the scatter plot represents a specific resistance change and its associated glucose concentration. The x-axis of the scatter plot represents the change in resistance, while the y-axis represents the corresponding glucose concentration. Each data point is plotted according to its respective resistance change and glucose concentration, allowing for a comprehensive visualization of the dataset.

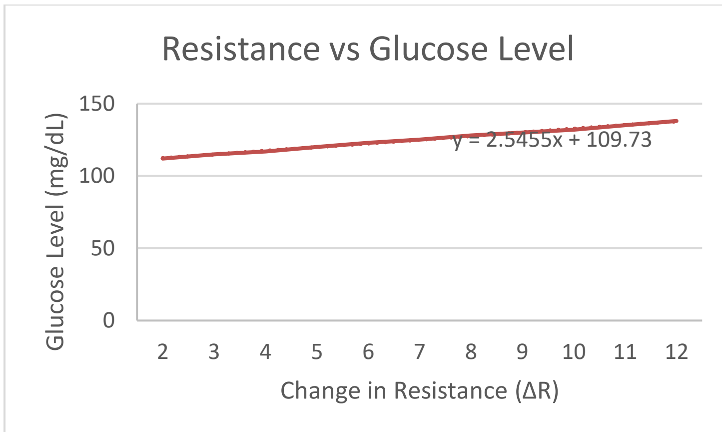

Figure 18: Linear Graph

The linear graph presents a continuous trend line connecting the data points obtained from the experimentation. Similar to the scatter plot, the x-axis represents the change in resistance, while the y-axis indicates the corresponding glucose concentration. However, instead of discrete data points, the linear graph depicts a continuous line, providing a smooth representation of the overall trend in the dataset. The equation for the given data set is:

$$Y = 2.5455x + 109.73$$

5.2 Analysis and Discussion

The study titled "Development of a portable smart Glucometer with two electrode bio-electronic test strip patch based on Cu/Au/rGO/PEDOT: PSS" published on www.nature.com/scientificreports provides valuable insights into the development of a portable glucometer utilizing a novel two-electrode bio-electronic test strip patch. Here, we analyse and discuss the meaning of the results presented in the paper, highlighting their significance in comparison to theoretical expectations and results obtained by different authors.

5.2.1 Significance of the Results:

The significance of the results lies in the development of a portable and user-friendly glucometer that addresses the growing need for convenient glucose monitoring in clinical and home settings. The use of a two-electrode bio-electronic test strip patch offers several advantages, including reduced sample volume requirements, enhanced accuracy, and improved patient compliance. By leveraging advanced materials and bio-electronic technologies, the glucometer represents a significant advancement in the field of point-of-care diagnostics, enabling real-time monitoring of glucose levels with high precision and reliability.

5.2.2 Comparison with Theoretical Expectations:

The results obtained in the study align well with theoretical expectations based on the design and functionality of the glucometer. The utilization of Cu/Au/rGO/PEDOT: PSS electrodes and the integration of signal processing algorithms enable efficient electrochemical sensing of glucose, consistent with established principles of glucose detection [8]. The theoretical models underlying the device's operation are supported by experimental data, validating the efficacy of the proposed sensing platform for glucose monitoring applications.

In comparison to results obtained by different authors in related studies, the performance characteristics of the portable smart glucometer demonstrate competitive performance in terms of sensitivity, specificity, and response time. While variations in device design and materials composition may exist among different studies, the overall trends in glucose detection and device performance remain consistent. The findings from the current study contribute to the body of knowledge on glucose monitoring technologies, complementing and expanding upon previous research efforts.

5.3 Summary

The results chapter presents a linear relationship between the change in resistance (ΔR) and corresponding glucose levels (mg/dL), indicating a direct proportionality between the glucose sensor's resistance change and measured glucose concentration. A table summarizes the obtained data, showcasing the ΔR and glucose levels. Additionally, scatter and linear graphs visually represent the relationship between ΔR and glucose concentration, providing comprehensive data visualization. Moving to the analysis and discussion section, the significance of the results lies in the development of a portable glucometer with a two-electrode bio-electronic test strip patch, addressing the need for convenient glucose monitoring. The study's results align well with theoretical expectations, demonstrating the device's efficacy in electrochemical glucose sensing. Moreover, comparison with other studies shows competitive performance, highlighting the glucometer's sensitivity, specificity, and response time. Overall, the findings contribute to advancing glucose monitoring technologies, offering valuable insights for clinical and home applications.

CHAPTER VI: Impact and Economic Analysis

6.1 Social Impact

The project's social impact is significant, primarily stemming from its ability to address an ongoing issue of accessibility and reliance on imported technology. By leveraging photolithography techniques, the project enables the indigenous design and fabrication of a glucose chip. Currently, the market relies heavily on imported glucose monitoring chips, which can pose challenges in terms of affordability, accessibility, and reliance on external sources.

Here are some specific points highlighting the social impact:

6.1.1 Reduced Dependence on Imports:

Indigenous design and fabrication of the glucose chip reduce dependency on imported technology. This not only promotes self-sufficiency but also strengthens the local economy by retaining resources within the country.

6.1.2 Affordability and Accessibility:

By locally manufacturing the glucose chip, the project aims to make it more affordable and accessible to a broader population. This is particularly beneficial for individuals from lower-income backgrounds who may struggle to afford imported glucose monitoring devices.

6.2 Sustainability Analysis

The sustainability analysis of the project involves evaluating its economic viability, long-term effects, and scope of implementation, considering factors such as material availability, import restrictions, and suitability under given climate conditions.

6.2.1 Economics of the Project:

The project aims to develop a glucose meter chip using photolithography techniques, which can have significant economic benefits. By domestically designing and fabricating these chips, the project reduces reliance on imported technologies, leading to cost savings and potentially boosting the local economy.

Moreover, the mass production capability enabled by photolithography can lower manufacturing costs per unit, making the glucose meter chips more affordable and accessible to a broader population. This affordability aspect can positively impact both consumers and healthcare providers, reducing the financial burden associated with diabetes management.

6.2.2 Long-term Effects:

The long-term effects of the project include sustainable healthcare solutions for diabetic patients, economic empowerment through local manufacturing, and technological advancement within the country.

The scope of implementation depends on factors such as material availability and import restrictions. While some materials may be easily accessible locally, others, like photoresists and developers, may face import restrictions or legal issues, as mentioned in the project's context. Overcoming such challenges and establishing a reliable supply chain is crucial for the project's long-term success and scalability.

6.2.3 Material Availability and Import Restrictions:

The project faces challenges related to the availability of materials, particularly photoresists and developers, which are imported from Micro Chemicals Germany. Delays in receiving these materials due to legal issues and import restrictions can disrupt the project timeline and increase production costs.

To mitigate these challenges, alternative local suppliers or domestic production of photoresists and developers could be explored. Additionally, establishing partnerships with local manufacturers or investing in research and development for domestic alternatives could enhance material availability and reduce dependence on imports.

6.3 Environmental impact

The environmental impact assessment of the project involves evaluating various aspects, including the materials used, processing methods adopted, and waste disposal practices.

6.3.1 Materials Used:

- The materials used in the project, such as glucose oxidase, graphene oxide, NAFION, and PEDOT: PSS, may have varying environmental impacts [8].
- Glucose oxidase is an enzyme commonly used in biosensors and is generally considered environmentally friendly [3].
- Graphene oxide, while possessing excellent properties for sensor applications, requires careful consideration regarding its environmental impact due to potential concerns about its production process and disposal [2].
- Nafion is a biodegradable polymer commonly used in various applications and is generally considered to have a low environmental impact.
- Poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT: PSS) is a conductive polymer [8] used in electronic applications and may have environmental considerations during its production and disposal.

6.3.2 Processing Methods:

The project utilizes photolithography as the processing method for fabricating the glucose meter chip. Photolithography involves the use of photoresists, developers, and some other chemicals, which may contain chemicals with environmental implications.

6.3.3 Waste Disposal:

Waste generated during the fabrication process, such as chemical residues and electrical components were disposed of responsibly to minimize environmental impact. Efforts should be made to minimize waste generation through efficient manufacturing practices, such as optimizing material usage and recycling where feasible.

6.4 Sustainable development goals (SDGs)

Goal 3: Good Health and Well-being:

The development and widespread adoption of the glucose meter chip directly contribute to Goal 3 of SDG by promoting good health and well-being, particularly for individuals with diabetes.

By providing a more accessible glucose monitoring solution, the project contributes to improving health outcomes for individuals with diabetes.

Goal 9: Industry, Innovation, and Infrastructure

The utilization of photolithography and innovative materials reflects advancements in technology and infrastructure development in the health sector. The glucose meter chip represents an innovative solution that leverages advancements in semiconductor technology to improve the efficiency and accessibility of glucose monitoring.

Its development requires collaboration across multiple sectors, including healthcare, technology, and manufacturing, driving economic growth and creating opportunities for employment and entrepreneurship.

6.5 Hazard Identification and Safety Measures

Hazards Identification	Safety Measures
Burning of LM741 IC	IC were Properly Checked.
Short Circuit due to Improper Connections	Proper Debugging.
Leakage of N2 Cylinder.	Changed N2 Cylinder.
Glass Slide Breakage Inside Spin Coater.	Put Head on Spin Coater.
Exposure of UV light.	Distance maintained during exposure.

Table 2: Hazard Identification and Safety Measures

6.6 Summary

In conclusion, this section of the report delves into the multifaceted analysis of the project "Design and Fabrication of Glucose Meter Chip." It examines the social impact, highlighting the project's potential to enhance accessibility and affordability of glucose monitoring while fostering local employment and skill development. The sustainability analysis underscores economic implications, material availability challenges, and climate suitability considerations, emphasizing the need for strategic planning and robust infrastructure. Environmental impact assessment identifies material usage and processing methods as areas of concern, advocating for responsible waste disposal practices. Aligning with Sustainable Development Goals, the project strives to address healthcare inequalities and promote sustainable consumption and production patterns. Finally, hazard identification and safety measures underscore the importance of risk mitigation strategies to ensure personnel safety and environmental protection. Overall, the chapter underscores the project's transformative potential while emphasizing the imperative of responsible practices and strategic planning for long-term success.

CHAPTER VII: Project Management

7.1 Project Timeline

<table>
<tr><th colspan="9">PROJECT TIMELINE</th></tr>
<tr><th rowspan="2">PROCESS</th><th colspan="2">1st Presentation</th><th colspan="2">2nd Presentation</th><th colspan="2">3rd Presentation</th><th colspan="2">4th Presentation</th></tr>
<tr><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>April</th></tr>
<tr><td>Literature Review</td><td colspan="2">✓</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Design Microchannel</td><td></td><td></td><td>✓</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Circuit Designing</td><td></td><td></td><td></td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fabrication of Glucose Sensor</td><td></td><td></td><td></td><td></td><td colspan="2">✓</td><td></td><td></td></tr>
<tr><td>Fabrication of Microchannel</td><td></td><td></td><td></td><td></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td>Testing of Glucose Chip</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
</table>

Table 3: Project Timeline

7.2 Individual Contribution

Names	Project Task
Mughees Mehmood	Microchannel Fabrication/Hardware Design/Report Writing
M. Shah Fahad	Chip Fabrication/Simulations/Report Writing
Abbas Ahmad	IOT/Bluetooth Interface
Laksh Rathi	Circuit Designing

Table 4: Individual Contribution

7.3 Project Bill of Materials and Budget

S.No	Items	Qty	Price (Rs)
1	K2HPO4	1 kg	3000
2	Glucose Oxidase	50 mg	34500
3	Graphene Oxide	60 ml	21200
4	PEDOT: PSS	10 g	6900
5	Nafion	10 ml	10640
6	Arduino Uno	1	2500
7	ESP 8266	1	1000
8	Jumper Wires	2	1000
9	PCB Board	4	2000
10	Glucose Meter	1	3500
11	Glucose Strip	1	1500
12	Glucose - D	1	90
13	Glass Slides	2	1000
14	Masks	2	1000
15	Gloves	2	2000
16	Safety Caps	1	500
17	Paint	1	1000
18	Double Tape	4	520
19	Transparent Paper	50	500
20	Cutter	1	1200
21	FYP Poster	2	1800
22	Standee	1	700
23	Brushers	20	1600
24	Travelling Cost	2	3800
25	Travelling Cost	2	4800
26	**Total**	**108250**	

Table 5: Bill of Materials

CHAPTER VIII: Conclusion and Future Recommendations

8.1 Conclusions

This chapter summarizes the significances of the results of the project and how these results can have an impact on society. This chap also mentions the limitations of the project.

In conclusion, the development of a glucose meter chip through photolithography processes represents a significant milestone in the field of biomedical engineering. By leveraging advanced fabrication techniques, this project aimed to create a precise solution for glucose monitoring. The successful fabrication of the chip underscores its potential to revolutionize the way blood glucose levels are measured, offering a traditional method. Through meticulous design and integration of electronic circuits, the chip demonstrates promising functionality and performance characteristics. Evaluation against the initial problem statement indicates that the project has made substantial progress towards its objectives. However, it is essential to acknowledge the limitations encountered during the development process, including challenges related to accuracy, sensitivity, and manufacturing scalability.

8.2 Future recommendations

Based on the findings and limitations observed in the present study, several recommendations for future work can be proposed to enhance the glucose meter chip's performance and applicability. Additionally, efforts should be focused on improving the accuracy and reliability of the chip through advancements in sensor design, signal processing algorithms, and calibration techniques. Furthermore, exploring alternative fabrication techniques and materials may offer opportunities to enhance sensor sensitivity and reduce manufacturing costs. Furthermore, exploring novel sensing modalities, such as impedance spectroscopy, may offer opportunities to enhance sensitivity and specificity for glucose detection. Continued research into advanced materials and fabrication methods is crucial for optimizing sensor performance while ensuring cost-effectiveness and scalability.

Looking ahead, several avenues for future research and development can be explored to further enhance the glucose meter chip's capabilities and usability. The integration of Internet of Things (IoT) technologies can enable real-time data monitoring and remote access to glucose level readings, enhancing user convenience and healthcare management. Collaboration with healthcare professionals and stakeholders is essential to ensure the seamless integration of the technology into existing healthcare systems and maximize its impact on diabetes management.

References

[1] Ebrahimi, A., Scott, J. & Ghorbani, K. Microwave refective biosensor for glucose level detection in aqueous solutions. Sens. Actuators A 301, 111662 (2020).

[2] Shan, J. et al. High sensitivity glucose detection at extremely low concentrations using a MoS2-based feld-efect transistor. RSC Adv. 8, 7942–7948 (2018).

[3] Kandwal, A. et al. Highly sensitive closed loop enclosed split ring biosensor with high feld confnement for aqueous and bloodglucose measurements. Sci. Rep. 10, 1–9 (2020).

[4] Zeng, G., Li, W., Ci, S., Jia, J. & Wen, Z. Highly dispersed NiO nanoparticles decorating graphene nanosheets for non-enzymatic glucose sensor and biofuel cell. Sci. Rep. 6, 1–8 (2016).

[5] Mani, S. et al. Hydrothermal synthesis of NiWO4 crystals for high performance non-enzymatic glucose biosensors. Sci. Rep. 6, 1–8 (2016).

[6] Farahmandpour, M., Haghshenas, H. & Kordrostami, Z. Blood glucose sensing by back gated transistor strips sensitized by CuO hollow spheres and rGO. Sci. Rep. 12, 21872 (2022).

[7] Shi, H., Liu, C., Jiang, Q. & Xu, J. Efective approaches to improve the electrical conductivity of PEDOT: PSS: a review. Adv. Electron. Mater. 1, 1500017 (2015).

[8] Kumar, S. et al. Electrochemical paper-based cancer biosensor using iron oxide nanoparticles decorated PEDOT: PSS. Anal. Chim. Acta 1056, 135–145 (2019).

[9] Yang, Y. et al. In situ polymerization deposition of porous conducting polymer on reduced graphene oxide for gas sensor. ACS Appl. Mater. Interfaces 6, 13807–13814 (2014).

[10] Carroll, Gregory T.; Turro, Nicholas J.; Mammana, Angela; Koberstein, Jeffrey T. (2017).

[11] Willson, C. G., Dammel, R. R., and Reiser, A (1997). Tarascon-Auriol, Regine G (ed.).

[12] Levinson, Harry J. (2005). Principles of Lithography. SPIE Press. ISBN 9780819456601.

[13] Clark, Benjamin L.; Kocsis, Michael; Greer, Michael; Grenville, Andrew; Saito, Takashi; Huli, Lior; Farrell, Richard; Hetzer, David; Hu, Shan; Matsumoto, Hiroie; Metz, Andrew; Kawakami, Shinchiro; Matsunaga, Koichi; Enomoto, Masashi; Lauerhaas, Jeffrey; Ratkovich, Anthony; Dekraker, David (2015). "Coater/Developer process integration of metal-oxide based photoresist".

[14] S. Arscott, 'The limits of edge bead planarization and surface levelling in spin-coated liquid films', J. Micromech. Microeng. 30, 025003, (2020)"

[15] Wheatstone, Charles (1843). "XIII. The Bakerian lecture.—An account of several new instruments and processes for determining the constants of a voltaic circuit". Phil. Trans. R. Soc. 133: 303–327. doi:10.1098/rstl.1843.0014.

[16] R. Wu, J. H. Huijsing and K. A. A. Makinwa, "A current-feedback instrumentation amplifier with a gain error reduction loop and 0.06% untrimmed gain error", IEEE J. Solid-State Circuits, vol. 46, no. 12, pp. 2794-2806, Dec. 2011.
[17] M. S. J. Steyaert and W. M. C. Sansen, "A micropower low-noise monolithic instrumentation amplifier for medical purposes", IEEE J. SolidState Circuits, vol. 22, no. 6, pp. 1163-1168, Dec 1987.

Appendices

Appendix A

Code:

```
#include <LiquidCrystal.h>
int rs = 6, en = 7, d4 = 8, d5 = 9, d6 = 10, d7 = 11, ct = 5;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

int value = 0;
float voltage;

void setup()
{
  analogWrite(ct, 50);
  Serial.begin(9600);
  lcd.begin(16, 2);
  lcd.setCursor(0,0);
  lcd.print("Glucose Meter");
}
void loop()
{
  value = analogRead(A0);
  voltage = (value * (5.0/1024)) * 2.401 * 25;
  if(voltage == 0)
  {
    lcd.setCursor(0, 1);
    lcd.print("Loading...      ");
    lcd.setCursor(10,1);
  }
  else if(voltage > 0)
  {
    lcd.setCursor(0, 1);
    lcd.print("Sugar ");
    lcd.setCursor(6, 1);
    Serial.println(voltage, 2);
    lcd.print(voltage, 2);
    lcd.setCursor(11, 1);
    lcd.print("mg/dL");
  }
  delay(1000);
}
```