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Faculty of Electronics & Computer Technology and Engineering

DEVELOPMENT OF MICRO PATTERNS USING LASER ENGRAVER FOR BIOSENSOR APPLICATION

THEVAPRASAN A/L S SARVANAN

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DEDICATION

In profound gratitude and love, I dedicate this Final Year Project report to my unwavering pillars of support, my parents, S Sarvanan and B Virayi. Your enduring encouragement, boundless sacrifices, and unwavering belief in my abilities have been the driving forces propelling me through the challenges of this academic journey. To my esteemed supervisor, Dr. Vigneswaran Narayanamurthy, your guidance, wisdom, and mentorship have been instrumental in shaping the trajectory of this project. Your commitment to fostering academic growth and fostering a passion for research has been a source of inspiration. This accomplishment is a tribute to your collective influence, and I am grateful for the invaluable lessons learned under your guidance. This work stands as a testament to the profound impact of familial support and academic mentorship, for which I am deeply thankful.

ABSTRACT

The design and development of micro patterns with enhanced surface area is crucial for improving the performance of biosensors. This study focuses on utilizing the laser engraving method to increase the surface area of micro patterns, thereby enhancing the sensitivity and selectivity of biosensors. Laser engraving provides precise control over the micro pattern geometry, allowing for the creation of intricate structures that promote efficient biomolecule immobilization. By optimizing the laser parameters, such as fluence, pulse duration, and scanning speed, high-resolution micro patterns can be achieved, resulting in increased surface roughness and maximized surface area. The fabricated laser-engraved micro patterns offer improved binding capacity and faster mass transport, enabling enhanced biosensor performance. This research aims to explore the potential of laser engraving as a method for improving the surface area of micro patterns in biosensors and advancing their analytical capabilities.

ABSTRAK

Reka bentuk dan pembangunan corak mikro dengan kawasan permukaan yang diperbaiki adalah penting bagi meningkatkan prestasi biosensor. Kajian ini memberi tumpuan kepada penggunaan kaedah pahatan laser untuk meningkatkan kawasan permukaan corak mikro, dengan meningkatkan kepekaan dan kebolehpilih biosensor. Pahatan laser memberikan kawalan yang tepat terhadap geometri corak mikro, membolehkan penciptaan struktur yang rumit untuk meningkatkan pengikatan biomolekul secara berkesan. Dengan mengoptimumkan parameter laser seperti fluens, tempoh denyutan, dan kelajuan pengimbasan, corak mikro berkualiti tinggi dapat dicapai, menghasilkan kasar permukaan yang meningkat dan kawasan permukaan yang maksimum. Corak mikro yang dihasilkan melalui pahatan laser menawarkan kapasiti pengikatan yang lebih baik dan pengangkutan jisim yang lebih cepat, membolehkan prestasi biosensor yang diperbaiki. Kajian ini bertujuan untuk meneroka potensi pahatan laser sebagai kaedah untuk meningkatkan kawasan permukaan corak mikro dalam biosensor dan memajukan keupayaan analisis mereka.

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CHAPTER 1

INTRODUCTION

1.1 Background

Biosensors have revolutionized the field of diagnostics and analysis by enabling rapid and accurate detection of specific biological molecules. These devices have found applications in various sectors, including healthcare, environmental monitoring, food safety, and drug discovery. Biosensors consist of a bioreceptor, which recognizes and binds to the target analyte, and a transducer, which converts the binding event into a measurable signal. The performance of biosensors depends on several factors, with surface area being a critical parameter.

The surface area of biosensors plays a pivotal role in capturing and interacting with target analytes. The greater the surface area available for binding, the more efficient the detection process becomes. Increased surface area allows for the immobilization of a higher density of bioreceptors, leading to enhanced sensitivity and lower detection limits. Moreover, a larger surface area facilitates a higher probability of analyte binding events, improving the signal-to-noise ratio and overall accuracy of the biosensor.

To achieve higher surface area, various strategies have been employed in biosensor design. Traditional approaches include the use of porous materials, nanoparticles, and nanowires, which provide increased surface roughness and active binding sites. While these methods have shown promise, they often involve complex fabrication processes, limited scalability, and high production costs.

Micro patterning techniques offer an alternative approach to enhance the surface area of biosensors. These techniques involve creating well-defined microstructures on the sensor surface, which significantly increase the available binding sites within a compact area. Micro patterns can be fabricated using various methods such as photolithography, soft lithography, and nanoimprint lithography. However, these techniques often require expensive equipment, intricate procedures, and specialized expertise.

In recent years, laser engraving has emerged as a promising technique for micro pattern fabrication in biosensors. Laser engraving utilizes a focused laser beam to selectively remove material from the sensor surface, creating precise and intricate patterns. This technique offers several advantages, including high precision, versatility, and ease of implementation. Laser engraving allows for the fabrication of complex micro patterns with control over depth, width, and shape. It also enables the customization of patterns for specific analytes or applications.

Despite the potential of laser engraving for micro pattern design in biosensors, research in this area is still limited. There is a need for comprehensive studies to investigate the impact of surface area enhancement on biosensor performance, optimize laser engraving parameters, and evaluate the scalability and cost-effectiveness of this technique. This research aims to address these gaps and contribute to the advancement of biosensor technology by focusing on the design and development of micro patterns using laser engraving to enhance the surface area.

1.2 Significance of Research

The sensitivity and selectivity of biosensors are directly influenced by the effective surface area available for capturing and interacting with target analytes. By increasing the surface area, more binding sites can be incorporated, leading to improved detection limits and enhanced performance. Micro patterning techniques have shown promise in achieving this goal, and laser engraving is a particularly attractive method due to its precision and versatility. However, further research is needed to explore the full potential of laser engraving for micro pattern design in biosensors. This study aims to address this research gap and contribute to the advancement of biosensor technology.

1.3 Problem Statement

The current problem in biosensor design is the limited methods available for enhancing the surface area, which directly affects the sensitivity and performance of the device. Existing techniques often involve complex fabrication processes that are not easily scalable for large-scale production. Additionally, these methods can be costly and require specialized expertise. Therefore, there is a pressing need to develop a cost-effective and scalable approach to increase the surface area of micro patterns in biosensors, specifically focusing on the utilization of laser engraving. This research aims to address these challenges and explore the potential of laser engraving as a viable method for enhancing surface area in biosensor design, ultimately improving the sensitivity and performance of these devices.

1.4 Project Objective

The primary objective of this research is centered around the design, development, and performance analysis of micro patterns for biosensors using laser engraving. The specific objectives are as follows:

a) To design micro pattern with the aid of Tinkercad to maximize surface area for high binding capacity in biosensors.

b) To develop fabrication techniques for creating the designed micro patterns with enhanced surface area using laser engraving.

c) To analyze the performance of laser-engraved micro patterns in biosensors.

1.5 Scope of Project

This project focuses on enhancing the surface area of micro patterns using laser engraving to improve biosensor performance. The study will involve the design and fabrication of micro patterns using different laser engraving parameters. The performance of these patterns will be evaluated through experimental characterization and analysis. The research will explore the correlation between surface area, biosensor performance and the optimization of laser engraving parameters. Additionally, the scalability and cost-effectiveness of laser-engraved micro patterns will be investigated. However, the complete integration of laser-engraved micro patterns into the biosensor system and the development of signal transduction mechanisms are beyond the scope of this research. The scope also acknowledges the limitations that this is just another such effort to create a simple and inexpensive way that help the advancement of future micro pattern fabrication.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Biosensors are indispensable tools in various fields, offering rapid and sensitive detection of analytes. The design and development of novel sensing platforms play a crucial role in enhancing biosensor performance. Micropatterning has emerged as a promising approach in this regard. Micropatterning involves arranging functional materials at the microscale level to create specific binding sites, improving sensitivity, selectivity, and response time. It also enables the integration of multiple sensing elements into a single device, facilitating miniaturization and multiplexing. Designing and developing micropatterns for biosensors require a multidisciplinary approach, encompassing materials science, nanotechnology, surface chemistry, and bioengineering. Various techniques, including top-down and bottom-up fabrication, nanomaterial-based patterning, and advanced surface modification methods, have been employed to overcome limitations in conventional sensing platforms. This literature review provides an overview of current research in micropattern design and development for biosensors. It summarizes different approaches, highlights advantages and challenges, and discusses potential applications and prospects. By synthesizing existing knowledge, this review contributes to the advancement of biosensor technology and inspires further innovations in micropattern design for biosensing. Integrating micropatterns into biosensors holds promise for developing highly sensitive, selective, and efficient sensing platforms. The ability to control the spatial arrangement of functional elements opens new possibilities for analyte detection and analysis. This review sheds light on advancements and future directions in micropattern design, paving the way for next-generation sensing devices with improved performance and broader applications.

2.2 Laser Engraver

Laser engraving is a modern method of engraving that uses laser technology to etch designs, logos, and images onto a variety of materials. Laser engravers have become increasingly popular in recent years due to their versatility, accuracy, and speed. Laser engravers offer a range of benefits over traditional engraving methods, including precision, speed, versatility, and safety. While they do have some limitations, their versatility and accuracy make them a popular choice for a wide range of applications, from industrial manufacturing to artistic engraving.

2.2.1 History of Laser

The history of laser engraving dates to the 1960s when the first laser was developed. The first laser engraving system was invented in the early 1970s by a researcher named Donald E. Johnson. The first laser engraver was used to engrave metal plates used in the printing industry. In the early days, laser engraving was primarily used in the manufacturing industry for marking and engraving products. However, study by (Danson et al., 2021) shows that the technology became more advanced and affordable, it found its way into a variety of applications.

The first laser engraving machines were bulky and expensive, but as the technology advanced, they became smaller and more affordable. In the 1990s, laser engraving machines were developed for use in the jewelry industry, allowing jewelers to create intricate designs on metal surfaces. In the 2000s, laser engravers became popular in the awards and recognition industry, allowing companies to create custom awards and trophies with intricate designs and personalized text. Today, laser engravers are used in a wide variety of applications, including industrial manufacturing, artistic engraving, and promotional products. The technology has advanced to the point where laser engravers are now able to engrave on a wide range of materials, including wood, metal, plastic, leather, and glass.

In recent years, the development of desktop laser engravers has made the technology more accessible to small businesses and individuals, allowing them to create custom products and designs without the need for expensive equipment or specialized skills. Overall, the history of laser engraving has been one of constant innovation and advancement, with the technology continuing to evolve and find new applications in a wide variety of industries.

2.2.2 Main Component of Laser Engraver

(Singh et al., 2022) mentioned that the laser is the most important component of a laser engraving machine. It emits a beam of light that is focused onto the surface of the material to be engraved. The laser can be either CO2 or fiber, depending on the application. The table below shows the information about different types of lasers commonly used in laser etching, including their feature size, wavelength, and laser width.

Table 2.1 Laser Type with Feature Size, Wavelength and Laser Width

Laser Type	Feature Size	Wavelength	Laser Width
CO2 Laser	Medium to large	10.6 μm	0.1 - 1 mm
Fibre Laser	Small to medium	1.06 μm	10 - 100 μm
Nd:YAG Laser	Small to medium	1.064 μm	10 - 100 μm
Excimer Laser	Micro to small	Varies (UV range)	< 10 μm
Diode Laser	Small to medium	Varies (near-IR)	< 100 μm

The controller is the brain of the laser engraving machine. It controls the motion of the laser head and the intensity of the laser beam. The laser head is the part of the machine that directs the laser beam onto the material to be engraved. It can move in multiple axes to follow the design that needs to be engraved. These are the main components of a laser engraving machine. Depending on the application, additional components such as rotary attachments, air compressors, and chiller systems may also be used.

2.3 Biosensor and Micropattern

2.3.1 Biosensor and Their Significance

(Touhami, n.d.) stated that biosensors are analytical devices that combine biological recognition elements (such as enzymes, antibodies, or nucleic acids) with transducers to convert a biological response into a measurable signal. These devices have gained significant importance in various fields due to their numerous advantages and applications.

One of the key advantages of biosensors is their ability to provide rapid and real-time analysis. They offer fast detection and quantification of target analytes, enabling timely decision-making and intervention in fields such as healthcare, environmental monitoring, and food safety. Biosensors can provide results within minutes or even seconds, reducing the time and effort required for traditional laboratory-based analyses.

Another significant advantage of biosensors is their high sensitivity and specificity. The biological recognition elements used in biosensors exhibit high affinity and selectivity towards their target analytes, enabling the detection of even trace amounts of substances. This sensitivity makes biosensors particularly useful in medical diagnostics, where early detection of diseases or pathogens can significantly improve treatment outcomes.

Biosensors also offer portability and miniaturization capabilities. With advancements in nanotechnology and microfabrication techniques, biosensors can be integrated into compact and handheld devices. This portability enables on-site and point-of-care testing, eliminating the need for sample transportation and reducing the time required for analysis. Portable biosensors have proven invaluable in remote or resource-limited areas, providing access to diagnostic tools in regions with limited healthcare infrastructure.

The versatility of biosensors allows for the detection of a wide range of analytes, including biomarkers, toxins, pollutants, and pathogens. They find applications in fields such as clinical diagnostics, environmental monitoring, agriculture, and bioprocessing. Biosensors have been employed in monitoring glucose levels in diabetes management, detecting pathogens in food samples, and measuring pollutants in water sources, among many other applications.

In addition to their analytical capabilities, biosensors also offer cost-effectiveness. By reducing the need for specialized laboratory equipment and skilled personnel, biosensors can provide affordable and decentralized testing solutions. This affordability makes biosensors particularly beneficial in resource-limited settings, where traditional laboratory-based methods may be impractical or inaccessible.

In summary, biosensors have become significant tools in various fields due to their rapid analysis, high sensitivity, specificity, portability, versatility, and cost-effectiveness. As technology continues to advance, biosensors are expected to play an even more prominent role in improving healthcare, environmental monitoring, and other applications, contributing to better decision-making, improved safety, and enhanced quality of life.

2.3.2 Role of Micro Patterns in Biosensor

Micro patterns play a crucial role in enhancing the performance and functionality of biosensors. By arranging functional elements at the microscale level, micro patterning offers several advantages and benefits in biosensor design and development. Micro patterns provide a larger surface area for immobilizing biological recognition elements, such as enzymes, antibodies, or nucleic acids. The increased surface area allows for a higher density of recognition elements, resulting in improved sensitivity and detection limits of the biosensor. This enhanced surface-to-volume ratio enables efficient capture and interaction with target analytes, leading to enhanced signal generation and response.

Micro patterns enable the precise positioning of different recognition elements within the biosensor. By arranging multiple binding sites in specific locations, micro patterning facilitates selective binding of target analytes while minimizing non-specific interactions. This spatial control helps in reducing cross-reactivity and interference, enhancing the selectivity and accuracy of biosensor measurements.

Micro patterning allows for the integration of multiple sensing elements or assays within a single biosensor device. By incorporating different micro patterns for different analytes, it becomes possible to perform simultaneous detection of multiple targets, known as multiplexing. This capability enables high-throughput analysis, saving time and resources by reducing the need for separate tests or samples.

Micro patterns can be designed to optimize the signal-to-noise ratio of biosensors. By precisely controlling the arrangement and spacing of sensing elements, micro patterning reduces background noise and non-specific interactions, leading to improved signal quality. This enhancement in signal-to-noise ratio increases the sensitivity, accuracy, and reliability of biosensor measurements.

Micro patterns can contribute to the stability and longevity of biosensors. By immobilizing recognition elements in defined locations, micro patterning helps protect them from degradation or denaturation, preserving their activity and performance over time. Additionally, micro patterns can assist in the creation of stable and biocompatible surfaces, reducing fouling and improving the robustness of biosensors during repeated use.

Micro patterning enables the miniaturization and integration of biosensors into compact and portable devices. By shrinking the size of biosensors, micro patterns allow for on-site or point-of-care testing, bringing diagnostic capabilities closer to the patient. The integration of micro patterns with other microfluidic components, such as channels and valves, enables the development of fully integrated lab-on-a-chip systems, further enhancing the functionality and versatility of biosensors.

Overall, micro patterns play a vital role in enhancing the sensitivity, selectivity, multiplexing capabilities, stability, and miniaturization of biosensors. They provide spatial control and optimization, enabling improved performance and expanding the range of applications in fields such as healthcare, environmental monitoring, and food safety. The integration of micro patterning techniques with biosensor design continues to drive advancements in sensing technologies, paving the way for more sensitive, selective, and efficient biosensors.

2.4 Fabrication Techniques for Micro Patterns

2.4.1 Photolithography

According to (Derkus, 2016), photolithography is a microfabrication technique that uses light-sensitive materials to transfer precise patterns onto a substrate. It involves exposing a coated substrate to light through a photomask, followed by development and etching steps to create intricate patterns with high resolution. (Fruncillo et al., 2021) stated that the photolithographic method is widely used in the semiconductor industry and other fields of microelectronics for producing integrated circuits and microscale devices.

2.4.2 Soft lithography

(Sen et al., 2019) mentioned that soft lithography is used to create patterns and structures on soft and flexible materials. It involves the use of elastomeric stamps or molds to transfer patterns onto the target substrate. Soft lithography is a versatile and cost-effective method, allowing for the fabrication of microscale features with high resolution and excellent control. It finds applications in areas such as microfluidics, tissue engineering, and flexible electronics.

2.4.3 Nanoimprint Lithography

Nanoimprint lithography is a high-resolution nanofabrication technique used to create patterns and structures on a substrate by pressing a mold with nanoscale features into a soft resist material. It involves a two-step process: imprinting, where the mold is pressed onto the resist, and subsequent curing or solidification of the resist to retain the pattern. Nanoimprint lithography enables the production of intricate nanostructures with high resolution and fidelity over large areas. These findings are supported by the findings of (Yang et al., 2020).

2.4.4 Electrochemical Deposition

Electrochemical deposition, also known as electrodeposition, is a process in which metal ions from a solution are selectively reduced and deposited onto a substrate using an electric current. It involves placing the substrate, typically a conductive material, as the cathode, and an electrode made of the desired metal as the anode, into an electrolyte solution. When a voltage is applied, metal cations in the electrolyte are attracted to the cathode and undergo reduction, forming a thin metal layer on the substrate. Electrochemical deposition allows for controlled and precise growth of metallic coatings, films, or structures with desired properties such as thickness, composition, and morphology. It is commonly used in various fields, including electronics, metallurgy, and surface engineering, for applications such as corrosion protection, decorative coatings, and microelectronic device fabrication. These findings are supported by the findings of (S. A. Lee et al., 2021).

2.5 Micro Pattern in Surface Functionalization

Micro patterns play a crucial role in surface functionalization, a process aimed at modifying the properties and behavior of surfaces for specific applications. By designing and creating microscale patterns on surfaces, it becomes possible to achieve precise control over surface features such as roughness, wettability, and chemical composition. These micro patterns enable enhanced adhesion, improved biocompatibility, controlled cell growth, and selective molecular immobilization. Various techniques, including lithography, self-assembly, and microfluidics, are employed to create these micro patterns. Surface functionalization through micro patterns finds applications in diverse fields, including biomedical engineering, microelectronics, sensing devices, and microfluidics. It offers promising opportunities for tailoring surface properties and creating complex surface architectures, contributing to the development of advanced materials and devices with enhanced performance and functionality.

2.6 Types of Micro Patterns

Various types of micro patterns are employed to enhance the performance and functionality of these devices. Some of the most common types are microwells, microchannels, micropillars, nanopatterns. Microwells are small, localized depressions or cavities on a substrate that can immobilize biomolecules or capture target analytes. They are often used in biosensors for high-throughput screening, DNA analysis, and cell-based assays.

Microchannels are narrow, fluidic pathways or channels that allow for controlled sample flow and manipulation. They are utilized in microfluidic biosensors for precise transport and mixing of samples and reagents, enhancing reaction efficiency and reducing analysis time.

Micropillars or microstructures are tiny, protruding structures on the substrate surface that can provide increased surface area for immobilizing biomolecules or enhancing analyte capture. They are commonly used in biosensors to improve sensitivity and detection limits.

Nanopatterns involve the creation of nano-sized features on the substrate surface. They provide increased surface area and unique surface properties for enhanced molecular interactions and improved biosensor performance.

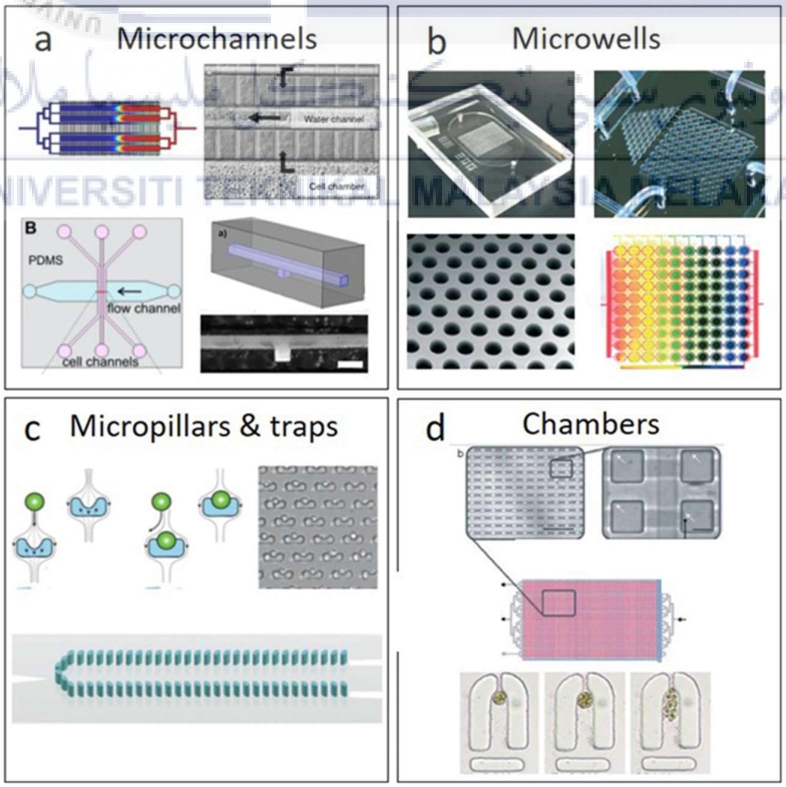


Figure 2.1 Types of Micro Patterns

2.7 Materials for Micro Patterns

Several common materials are used to fabricate micro patterns for biosensors. The choice of material depends on factors such as the desired pattern resolution, compatibility with biological molecules, and fabrication techniques. Polymers-based materials, such as polydimethylsiloxane (PDMS), are commonly used in soft lithography techniques. They offer flexibility, biocompatibility, and ease of fabrication. PDMS is particularly popular due to its transparency, gas permeability, and compatibility with microfluidic systems.

If we look at metal-based materials, metals like gold (Au) and platinum (Pt) are frequently used for fabricating microelectrode arrays or conductive patterns in biosensors. These metals provide excellent electrical conductivity and compatibility with biomolecules, allowing for efficient electrochemical sensing and signal transduction.

Other than that, silica-based materials, such as silicon dioxide (SiO2), are utilized in fabrication processes like reactive ion etching (RIE) to create micro patterns. Silica offers high etching selectivity, stability, and compatibility with biological molecules, making it suitable for biosensor applications.

Glass substrates, such as borosilicate or fused silica, are commonly used in biosensor fabrication. Glass provides a smooth and flat surface for pattern deposition, and it offers excellent transparency and chemical resistance. These materials, among others, provide a diverse range of properties and functionalities necessary for fabricating micro patterns in biosensors. The selection of a specific material depends on the desired pattern characteristics, compatibility with the biosensing application, and the chosen fabrication techniques.

2.8 Impact of Micro Patterns on Biosensor Performance

Micro patterns have a significant impact on the performance of biosensors. The incorporation of micro patterns can enhance various aspects of biosensor functionality, sensitivity, selectivity, and overall performance. One of the key impacts is increased surface area. Micro patterns, such as microwells, nanopillars, or gratings, can significantly increase the available surface area for biomolecule immobilization or analyte capture. This increased surface area allows for more efficient interactions between the target analyte and the sensing elements, leading to improved sensitivity and detection limits.

Micro patterns can provide precise and controlled locations for immobilizing biomolecules, such as antibodies, enzymes, or DNA probes. These patterns ensure uniform distribution and proper orientation of the immobilized biomolecules, resulting in improved binding efficiency and enhanced specificity.

Micro patterns, particularly microchannels and nanopores, can facilitate controlled fluid flow and efficient mass transport within the biosensor. They enable rapid and uniform distribution of samples and reagents, reducing diffusion limitations and enabling faster reaction kinetics.

Micro patterns can be designed to create specific recognition sites or capture regions for target analytes, increasing the selectivity of the biosensor. By incorporating functionalized micro patterns or molecularly imprinted polymers (MIPs), biosensors can achieve high specificity by selectively capturing the target analyte while minimizing interference from non-specific binding.

Micro patterns can help reduce non-specific binding and background noise in biosensors. By precisely controlling the surface properties, such as roughness or surface chemistry, micro patterns can minimize non-specific interactions, enhancing the signal-to-noise ratio and improving the biosensor's sensitivity and accuracy.

Micro patterns offer the ability to create precise spatial arrangements of sensing elements, allowing for multiplexed analysis and spatially resolved measurements. This capability enables simultaneous detection of multiple analytes and enhances the overall information content of the biosensor.

Micro patterns can be utilized to integrate additional functional components, such as microelectrodes, optical waveguides, or microfluidic channels, within the biosensor. This integration allows for enhanced signal transduction, miniaturization, and integration of multiple functionalities into a single device.

Overall, micro patterns play a crucial role in optimizing the performance of biosensors by improving sensitivity, selectivity, and functionality. They enable efficient analyte capture, controlled mass transport, and enhanced signal-to-noise ratio, leading to more accurate and reliable biosensing capabilities.

2.9 Applications of Micro Patterned Biosensors

Micro patterned biosensors have gained significant attention and found diverse applications across several fields. These biosensors utilize carefully designed and fabricated micro patterns to enhance their performance and enable unique functionalities. According to (Riveiro et al., 2018) micro patterned biosensors have made significant contributions to biomedical diagnostics. They can be used for the detection and monitoring of various biomarkers, including proteins, nucleic acids, and cells. The incorporation of micro patterns allows for increased surface area, improved biomolecule immobilization, and enhanced sensitivity, enabling the early detection of diseases, personalized medicine, and point-of-care diagnostics.

Micro patterned biosensors find application in environmental monitoring and analysis. They can be utilized to detect and measure pollutants, heavy metals, and pathogens in water, air, or soil samples. The micro patterns enhance the biosensor's sensitivity and selectivity, enabling accurate and rapid detection of contaminants, thereby facilitating environmental assessment and pollution control.

Micro patterned biosensors play a crucial role in ensuring food safety and quality control. They can be employed for the detection of foodborne pathogens, allergens, and contaminants. The micro patterns enable efficient capture and recognition of target analytes, enhancing the biosensor's specificity and reliability. These biosensors can be integrated into portable devices for on-site testing, facilitating real-time monitoring and ensuring the safety of food products.

(Che et al., 2022) claimed that micro patterned biosensors have applications in drug discovery and pharmaceutical research. They can be used for high-throughput screening of drug candidates, monitoring drug efficacy, and studying cellular interactions. The micro patterns provide controlled environments for cellular assays, allowing for precise manipulation and analysis of cells and tissues. These biosensors enable rapid and accurate analysis, contributing to the development of new drugs and therapies.

2.10 Literature Review Discussion

Studies done by (Ma et al., 2020) and(Myeong et al., 2022) shows photolithography plays a crucial role in the biosensor micro-pattern sector, facilitating the fabrication of precise patterns for biosensors. It enables the creation of intricate and well-defined electrode, channel, and functionalization patterns on substrates, providing high resolution and scalability. These patterns are essential for accurate sensing and detection of biological targets. While challenges exist in material selection, process integration, and biocompatibility, photolithography remains a valuable tool, driving advancements in biosensor technology with improved sensitivity and performance. Continued progress in photolithography techniques and optimization is expected to further expand the applications and impact of biosensors in areas such as healthcare and environmental monitoring. These findings are supported by (Derkus, 2016; Ginestra et al., 2019; Sebastian et al., 2020).

According to (Rose et al., 2019) soft lithography is a highly versatile technique extensively used in the biosensor micro-pattern sector, enabling precise pattern transfer onto substrates. It offers advantages such as intricate and well-defined pattern creation, simplicity, cost-effectiveness, compatibility with biological samples, and integration of multiple functionalities within a biosensor device. (Qiu et al., 2021) found that techniques like microcontact printing, a subset of soft lithography, allow for precise biomolecule deposition, enhancing sensitivity and specificity. However, challenges exist in achieving high-resolution patterns and addressing material compatibility. Despite these limitations, soft lithography continues to advance biosensor technology, improving detection capabilities and expanding applications in medical diagnostics, environmental monitoring, and personalized healthcare. These findings are supported by (C. Lee et al., 2020; Wahid et al., 2021).

Moreover, study done by (Fruncillo et al., 2021) shows that lithography is a crucial fabrication technique employed in various industries, including the biosensor micro-pattern sector, to create intricate patterns on substrates. X-ray lithography and Plasmonic lithography are two advanced forms of lithography with specific applications and advantages. X-ray lithography utilizes X-ray radiation to achieve high-resolution patterning, making it suitable for manufacturing high-density microelectronics and biosensors. Its advantages include excellent resolution and the ability to pattern thick substrates, but it requires expensive X-ray sources and complex masks. Plasmonic lithography employs surface plasmons to create nanoscale patterns with high resolution, enabling the development of biosensors and other nanophotonic devices. It offers advantages like subwavelength resolution and compatibility with diverse materials, but it requires careful design optimization and suffers from limited pattern uniformity. In the biosensor micro-pattern sector, both X-ray and Plasmonic lithography play critical roles in fabricating complex patterns for biosensors, enabling high-performance sensing capabilities and integration of multiple functionalities within a single device. These advanced lithography techniques continue to advance biosensor technology, although challenges such as cost, resolution limitations, and process complexity need to be addressed to further enhance their practical applications. These finding are supported by (Hong & Blaikie, 2019; Xue et al., 2017).

Another important fabrication methods that need to be addressed is electrochemical deposition. (Filik & Avan, 2019; Tonelli et al., 2019) claimed that Electrochemical deposition is a widely used technique in the biosensor micro-pattern sector for depositing metallic or conductive thin films onto substrates. It involves the use of an electrolyte solution and the application of an electric current to induce the deposition process. Electrochemical deposition offers several advantages, including high precision, conformal coating, and the ability to create complex micro-patterns. It is particularly useful in biosensor fabrication, where it is employed to deposit electrodes, interconnects, and other conductive elements. The technique allows for the integration of microscale features, enabling the creation of miniaturized biosensors with improved sensitivity and performance. However, electrochemical deposition also has disadvantages, such as the potential for film defects, limited control over film thickness uniformity, and the need for careful process optimization. Despite these challenges, electrochemical deposition remains a valuable method in the biosensor micro-pattern sector, contributing to the advancement of biosensor technology for applications in medical diagnostics, environmental monitoring, and beyond.

Table 2.2 Micro Pattern Fabrication Method Comparison and Application

Author	Fabrication method	Application	Advantage	Disadvantage
Ma et al., 2020	Photolithographic	Flexible Micro pattern	High resolution, Scalability, Suitable for mass production	Complex process, Requires cleanroom facilities, Expensive
Myeong et al., 2022	Photolithographic	Micro logo pattern	Capable of mass manufacture	Limited by next-gen display
Derkus, 2016	Photolithographic	Miniaturization technologies	Easy-to-manufacture, allow creation of lower micron-sized patterns	Expensive equipment and specialized facilities required
Ginestra et al., 2019	Photolithographic	Carbonized micro-patterns	Simple to manufacture, allowing the production of designs with lower micron resolution.	Specialised equipment required.
Sebastian et al., 2020	Photolithographic	Nanofabrication	versatile nanopattern fabrication, well-established commercially	high-cost process
Rose et al., 2019	Soft lithography	Polymeric Microstructure	Low-cost fabrication method	Limited resolution and feature size,

				compatibility issues
C. Lee et al., 2020	Soft lithography	Micro-patterned electrode/electrolyte	Can produce finer pattern then other methods	Extra step needed to form stamp
Wahid et al., 2021	Soft lithography	Conductive bioimprint fabrication	High Resolution Patterning	Complex Process Optimization
Qiu et al., 2021	Micro Contact Printing (µCP)	Micro contact printing	Precise, cost effective, long shelf live	Stamp deformation, substrate contamination
Fruncillo et al., 2021	Lithography	Fabrication of Nanostructures	Capable of large-scale, mass fabrication of biosensors	Use of chemicals
Xue et al., 2017	X-ray lithography	Fabrication of periodic nanostructure	Sub-nm features are theoretically possible.	Long-term exposure required for resistance.
Hong & Blaikie, 2019	Plasmonic lithography	Surface nanostructures	Could achieve subwavelength resolution	The plasma effect is extremely sensitive to the roughness of the substrate's surface.
Wang et al., 2017	E-Jet technique	Nanostructures	High resolution, Direct printing	Slow, Cost considerations,
Tonelli et al., 2019	Electrochemical Deposition	Nanomaterials	Can create nanostructures with precise morphologies	Complex surface characterizatio n

Filik & Avan, 2019	Electrochemical Deposition	Electrochemical immunosensors fabrication	Provides a versatile method for the immobilization of biomolecules	Complex Fabrication Process

2.11 Summary

Micro patterns play a crucial role in biosensors, enhancing their performance and functionality. These patterns can be created using techniques like photolithography, soft lithography, and nanoimprint lithography. In biosensors, micro patterns have a significant impact on surface functionalization, allowing for precise control over surface properties and facilitating applications such as improved adhesion, controlled cell growth, and selective molecular immobilization. They are used in various fields, including biomedical engineering, microelectronics, sensing devices, and microfluidics. In terms of biosensor fabrication, micro patterns can be created using materials such as photoresists, polymers, metals, silica, conductive polymers, and glass. Each material offers specific properties and compatibility with different fabrication techniques, enabling the creation of tailored micro patterns for specific biosensing applications. Micro patterns significantly influence biosensor performance. They increase surface area, enabling efficient biomolecule immobilization and enhanced analyte capture. The controlled fluid flow facilitated by microchannels improves mass transport, reducing diffusion limitations and enhancing reaction kinetics. Micro patterns also enhance selectivity by providing specific recognition sites for target analytes and reducing non-specific binding. The integration of micro patterns in biosensors leads to improved sensitivity, selectivity, and functionality. They enhance signal-to-noise ratios, allowing for more accurate and reliable biosensing. Micro patterns also enable spatially resolved measurements and the integration of functional components like microelectrodes and microfluidic channels, further enhancing the biosensor's performance. Overall, micro patterns in biosensors have diverse applications, including biomedical diagnostics, environmental monitoring, food safety, and pharmaceutical research. They contribute to advancements in these fields by enabling sensitive detection, precise control over surface properties, and the development of innovative sensing technologies. The integration of micro patterns opens new opportunities for biosensor design and paves the way for future advancements in biosensing applications.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology chapter provides a detailed explanation of the research approach, procedures, and techniques employed to achieve the objectives of the study. In this chapter, methodology have been presented for the design and development of micro patterns for biosensors, with a specific focus on improving surface area using laser engraving. Biosensors have emerged as valuable tools for various applications, ranging from medical diagnostics to environmental monitoring. The performance of biosensors is strongly influenced by the available surface area for molecular interactions. Therefore, enhancing surface area through micro pattern design has become a key area of interest in biosensor research.

3.2 Project Flow Chart

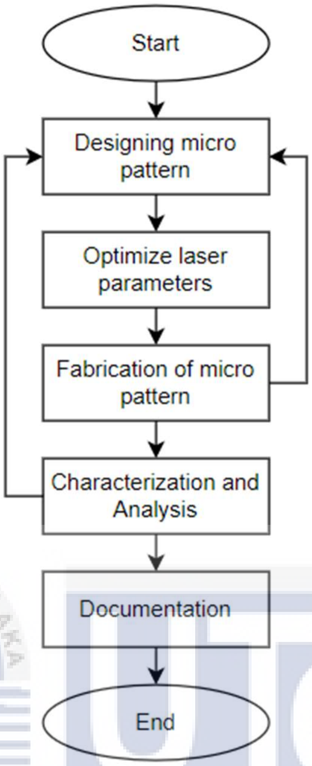


Figure 3.1 Project Flowchart

First and foremost, with the knowledge acquired from the literature review, I developed conceptual designs for the micro patterns. Various factors, such as pattern geometries, dimensions, and materials, are considered during this phase to optimize the surface area enhancement. Computer-aided design (CAD) software is employed to create virtual models of the proposed micro patterns, facilitating visualization and evaluation.

Next, I focused on laser engraving process. Laser engraving process itself is a critical step in this methodology. I carefully selected and optimize parameters such as laser power and scanning speed to achieve the desired pattern depth and resolution while maximizing the surface area of the micro patterns. Through iterative experimentation and analysis, I refined the engraving parameters to achieve the best results.

Following the fabrication of the micro patterns, I relied on visual inspection to evaluate the quality of the fabricated patterns and ensure the successful achievement of the objectives. This examination was crucial for assessing the overall appearance and integrity of the patterns without the need for additional techniques like AFM or SEM.

Then, I compared the laser-engraved micro patterns to those with conventional patterns, so that I can assess the impact of the surface area enhancement on sensitivity. Finally, all the results and observations documented systematically. A comprehensive report prepared by emphasize the significance and potential applications of the designed and developed micro patterns for biosensors.

3.3 Experimental Design

The experimental design phase of this study encompasses a comprehensive approach to achieving the desired outcomes, involving intricate processes and meticulous planning. This section delves into four key components that form the foundation of our experimental design: designing micro patterns, material selection and preparation, the fabrication of micro patterns, and the method employed for data collection. Each facet plays a pivotal role in the successful execution of our study, contributing to the precision and reliability of the results obtained. By detailing the strategic steps taken in the experimental design, this section aims to provide a clear understanding of the methodology employed, ensuring transparency and reproducibility in the pursuit of our research objectives.

3.3.1 Designing Micro Patterns

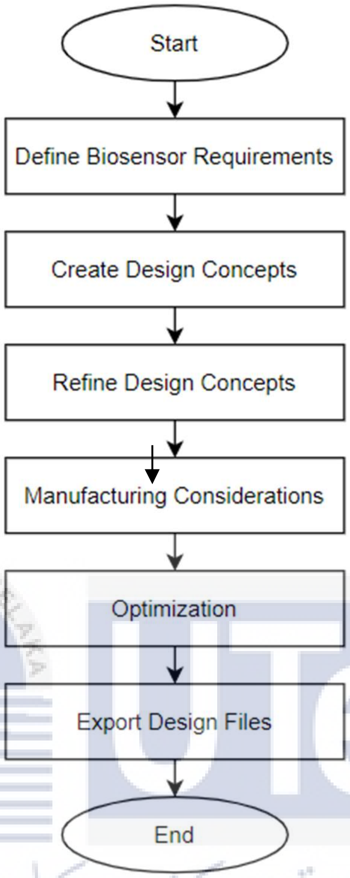


Figure 3.2 Flowchart for Designing Micro Pattern

The micro pattern design begins with a clear understanding of the biosensor's functional requirements and performance goals. Then, design concepts are created using LightBurn and Tinkercad by utilizing tools and features available in the software. After design concept, quick modifications and refinements to optimize the micro pattern design. Moving forward, feasibility of the design and its compatibility with the manufacturing process are considered. Then, design is being optimized to enhance the micro pattern's performance. Finally, design files from LightBurn are exported in a format compatible with the subsequent steps of the fabrication process.

3.3.2 Material Selection and Preparation

Prior to laser engraving process, appropriate biosensor substrate material that is compatible with laser engraving need to be selected. The substrate material should possess the necessary mechanical and chemical properties for biosensor functionality. Considerations such as biocompatibility, stability, and adhesion properties are crucial when choosing the biosensor substrate. Once the selection part is completed, then proper substrate preparation needs to carry out. This includes cleaning the substrate surface to remove any contaminants or particles that could interfere with the engraving process or affect the quality of the micro patterns. Suitable cleaning techniques, such as ultrasonic cleaning or chemical cleaning, may be employed depending on the substrate material.

Figure 3.3 Acrylic Sheet

Figure 3.3 shows a piece of Acrylic sheet, known for its transparency, durability, and biocompatibility, proves to be an excellent choice for biosensor applications. Its optical clarity allows for easy visualization of microchannels, facilitating enhanced monitoring and analysis of biological samples. Additionally, the inherent biocompatibility of acrylic ensures minimal interference with biological entities, making it suitable for biosensing applications where interactions with analytes are crucial.

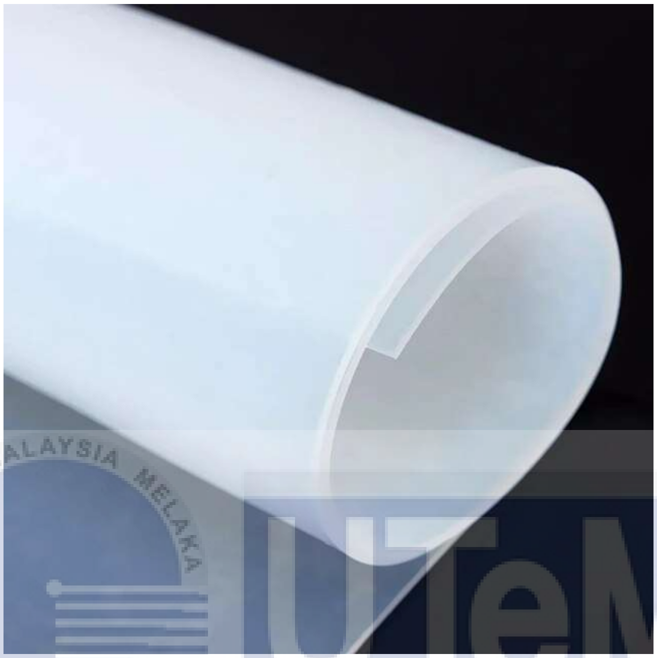


Figure 3.4 Silicone Rubber Sheet

Figure 3.4 shows Silicone Rubber Sheet which is used to fabricate the micropatterns. Silicone rubber is selected for its flexibility, elasticity, and biocompatibility. These properties make it an ideal material for the fabrication of microchannel biosensors, especially when the device requires flexibility to conform to different surfaces or undergo deformations during operation. The biocompatibility of silicone rubber is advantageous when dealing with biological samples, ensuring minimal impact on the integrity of the analyzed substances. Utilizing a diode laser engraver for silicone rubber allows for precise customization of microchannel patterns, enhancing the adaptability and functionality of the biosensor.

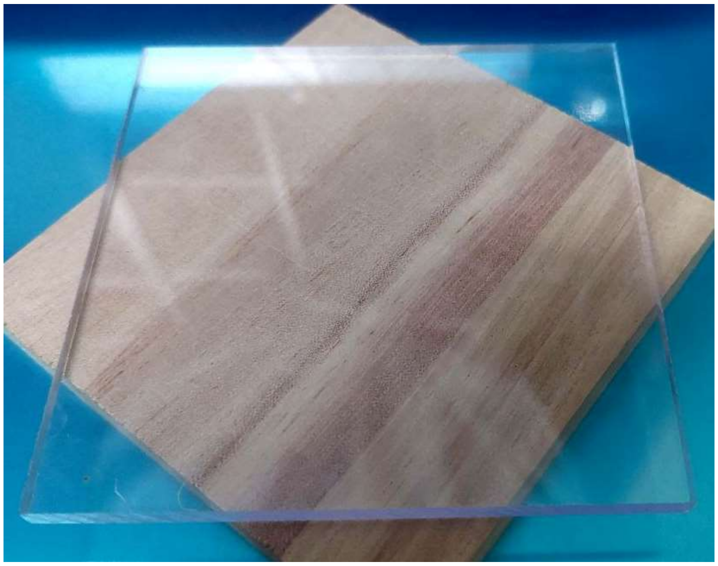


Figure 3.5 Polycarbonate Sheet

Figure above shows Polycarbonate which is an alternative for Acrylic. Polycarbonate sheet emerges as a viable alternative for microchannel biosensor fabrication. Its inherent strength, transparency, and resistance to chemicals make it suitable for biosensing applications. The versatility and affordability of polycarbonate make it an attractive option for microchannel biosensor development, offering an alternative avenue for researchers exploring material options. In conclusion, the strategic selection of acrylic and silicone rubber, coupled with the precision of a diode laser engraver, forms a robust foundation for microchannel biosensor fabrication. Moreover, the inclusion of alternative materials like polycarbonate sheet expands the scope of material choices, catering to diverse biosensing needs and preferences.

3.3.3 Fabrication of Micro Pattern

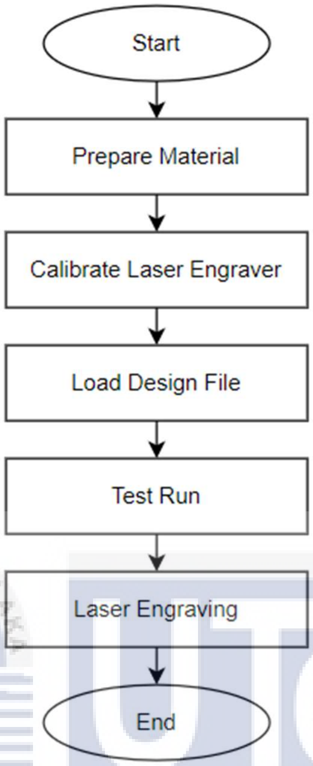


Figure 3.6 Fabrication Flowchat

In the initial stages of micropattern fabrication using a laser engraver, the process begins with the meticulous preparation of the chosen material, be it acrylic, silicone rubber, or polycarbonate sheet. This crucial step involves thorough cleaning of the material surface to eliminate any potential contaminants that could interfere with the engraving process. Following material preparation, the laser engraver undergoes a calibration process to fine-tune its settings according to the specific characteristics of the material and the design parameters. This calibration includes adjustments to the laser power and speed to ensure optimal engraving depth and precision.

Once the material is prepared and the laser engraver is calibrated, the next step involves loading the detailed design file into the laser engraver's software. This file contains comprehensive specifications for the micropattern, including dimensions, layout, and features. Loading the design file is critical as it guides the laser engraver throughout the subsequent fabrication steps.

Prior to the actual micropattern engraving, a test run is conducted to validate the effectiveness of the calibrated settings. This pre-engraving assessment involves running the laser engraver over a small portion of the material to confirm that the laser's parameters are appropriately configured. The test run serves as a diagnostic tool, allowing for any necessary adjustments to be made before moving forward.

With material preparation, laser engraver calibration, and successful test run completed, the main laser engraving process commences. The laser systematically follows the predefined design, intricately etching the micropattern onto the material surface. The precision and accuracy of this engraving step are paramount to achieving the desired results and ensuring that the fabricated micropattern meets the specified requirements. These initial stages collectively form a systematic and controlled process, laying the foundation for the subsequent phases of micropattern fabrication in this study.

3.3.4 Data Collection Method

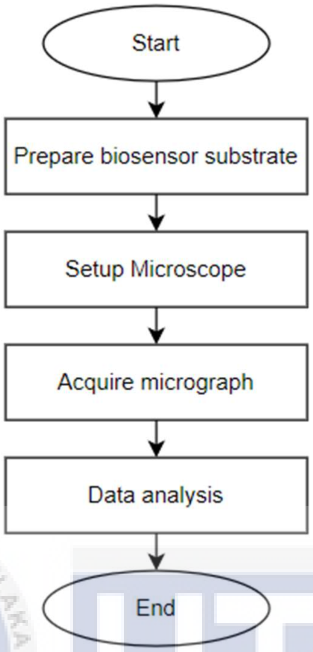


Figure 3.7 Data Collection Flowchart

Flow chart 3.7 shows the flow of gathering data and analysis of data. Before conducting visual analysis, the biosensor substrate with the micro patterns needs to be appropriately prepared. This may involve cleaning the surface to remove any contaminants or particles that could interfere with the measurements. The appropriate microscope is chosen based on factors like sample properties, desired resolution. Then, microscope need to be calibrated. Calibration ensures accurate and clear visual and other relevant parameters. Once the microscope image is obtained, data analysis is performed to extract quantitative information about the micro pattern features. Analysis involves measuring pattern dimensions, such as height, width, spacing and surface area. The data obtained from microscope are interpreted to evaluate the quality and performance of the micro patterns.

3.4 Parameters

Parameter optimization is a crucial step in the design and development of micro patterns for biosensors using laser engraving. It involves fine-tuning the laser engraver parameters and optimizing the micro pattern design using computer-aided design (CAD) software. The following sections elaborate on the laser engraver parameters and micro pattern design parameters.

3.4.1 Laser Engraving Parameters

First, the laser power determines the amount of energy delivered to the biosensor substrate during engraving. It directly affects the depth and quality of the micro patterns. The optimal laser power should be determined experimentally to achieve the desired pattern depth without causing substrate damage or excessive heat generation.

Second, the scanning speed of laser which refers to the rate at which the laser beam moves across the biosensor substrate during engraving. It plays a critical role in controlling the spatial resolution and surface quality of the micro patterns. Adjusting the scanning speed allows for customization of pattern intricacy and precision. However, it is important to find a balance between speed and accuracy to ensure that the micro patterns are accurately replicated.

Third, the beam spot size which represents the diameter of the laser beam at the point of interaction with the biosensor substrate. It determines the resolution and precision of the micro patterns. A smaller beam spot size results in finer details and higher resolution patterns, while a larger spot size may be suitable for larger feature sizes. The beam spot size can be adjusted by manipulating the laser optics or by using beam-expanding or beam-focusing lenses.

The last parameter is pulse frequency and duration. Some laser engraving systems allow control over pulse frequency and duration. These parameters determine the timing and duration of laser pulses during engraving. Optimizing these parameters can influence the heat distribution, material removal rate, and overall engraving quality. Careful adjustment of pulse frequency and duration is necessary to achieve precise and consistent micro patterns. Figure 3.8 show how power and speed affect the quality and depth of the design that have been engraved.

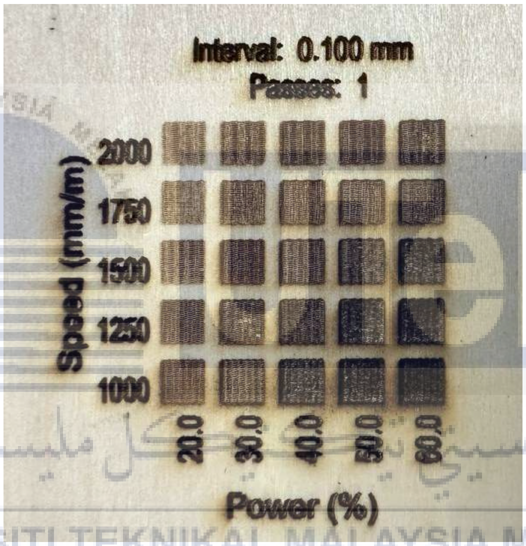


Figure 3.8 Material Test Done on Plywood

3.4.2 Micro Pattern Design Parameters

The first parameter is geometrical features. CAD software enables the design of micro patterns with various geometrical features, such as lines, curves, circles, squares, or more complex shapes. The choice of geometrical features depends on the specific requirements of the biosensor application and the desired molecular interactions. The dimensions and arrangement of these features can be customized to optimize the surface area available for analyte binding and detection.

Moreover, the density and spacing of micro patterns significantly impact the surface area enhancement. By adjusting the pattern density and spacing, researchers can control the amount of surface coverage and the distance between individual patterns. Higher pattern density and closer spacing can maximize the surface area for analyte interaction, while allowing for efficient fluid flow through the biosensor.

The next parameter that needs to be considered is pattern depth and height. CAD software allows precise control over the depth and height of micro patterns. Optimizing these parameters is crucial for achieving the desired surface area enhancement without compromising the structural integrity of the biosensor substrate. The depth and height should be carefully adjusted based on the substrate material properties, laser engraver capabilities, and the intended biosensor performance requirements.

The last one is pattern alignment and orientation. CAD software facilitates accurate pattern alignment and orientation on the biosensor substrate. Proper alignment ensures consistent and uniform patterning across the substrate surface. The orientation of the patterns can be tailored to enhance specific molecular interactions or to align with the biosensor's detection mechanism.

By optimizing these laser engraver parameters and micro pattern design parameters using CAD software, surface area and performance of biosensors can be enhanced systematically. The parameters can be adjusted iteratively based on experimentation and analysis of the resulting micro patterns, ultimately leading to optimized designs for specific biosensor applications.

3.5 Equipment and Tools

The equipment used in the design and development of micro patterns for biosensors using laser engraving comprises the main components of the laser engraver and the tools employed for micro pattern design. Each component and tool play a vital role in ensuring precise engraving and efficient pattern creation. The significance and importance of these elements are discussed below. The laser engraver is the central piece of equipment used to create micro patterns on the biosensor substrate. It consists of several key components. The equipment can be divided into two parts, laser engraver and LightBurn software. A laser engraver consists of a laser module and control system. LightBurn software have been used to design and manipulating the micro pattern design.

3.5.1 Diode Laser Module

Figure 3.9 Diode Laser Module

The laser source generates a focused beam of light with a specific wavelength. The choice of laser source depends on the material properties of the biosensor substrate and the desired engraving depth and precision. Common laser sources for engraving include diode lasers, fiber lasers, and CO2 lasers. This project takes advantage of diode laser which obsess their own advantages. They have a small form factor, very versatile, have a longer life span and the controller may regulate the power while working to generate a grayscale look. The focus and intensity can be controlled by varying the focal length. Focusing the laser beam to a desired spot size and directing the laser beam precisely onto the biosensor substrate is important for ensuring accurate positioning.

3.5.2 Control System

The control system of the laser engraver allows for precise adjustment and regulation of laser parameters such as power and scanning speed. It ensures consistent and reliable engraving results by providing control over the laser parameters during the engraving process. A typical laser engraver will be consisting of a main processor and stepper motor controller. The main processor will be used to regulate laser power and speed.

3.5.3 LightBurn Software

Lightburn software offers a range of tools for designing and manipulating diverse geometrical shapes, lines, curves, and patterns. These tools empower users to tailor micro pattern designs according to specific surface area enhancement goals and biosensor requirements. Lightburn provides precise control over micro pattern dimensions and supports accurate alignment and orientation. Additionally, the software offers visualization tools, allowing researchers to examine and analyze micro pattern designs within a virtual environment.

3.6 Limitation of Proposed Methodology

While the design and development of micro patterns for biosensors using laser engraving offer numerous advantages, it is important to consider the limitations associated with this approach. One limitation is the restriction imposed by the laser engraver's minimum engraving depth, which may limit the achievable surface area enhancement. Additionally, the choice of materials for the biosensor substrate and the micro patterns can impact the engraving quality and compatibility, as not all materials are suitable for laser engraving. Another limitation is the potential for thermal damage or distortion of the substrate during the engraving process, particularly when working with delicate or heat-sensitive materials. Finally, while laser engraving can enhance surface area, other factors such as non-specific binding, analyte diffusion, and fabrication scalability should also be considered for comprehensive biosensor performance optimization. Understanding these limitations is crucial for effectively applying laser engraving in biosensor development and for exploring complementary techniques to address specific challenges.

3.7 Summary

This methodology chapter provides a comprehensive overview of the design and development of micro patterns for biosensors using laser engraving. The presented flow chart, experimental setup, parameter optimization, equipment, and limitations serve as a guide for researchers aiming to enhance surface area and improve biosensor performance through laser engraving techniques. By understanding the methodology and its limitations, researchers can develop effective strategies to overcome challenges and advance the field of biosensor technology.

3.8 Societal and Global Issues

The design and development of micro patterns for biosensors, with a specific focus on improving surface area using laser engraving methods, holds great potential for addressing various societal and global issues. One crucial area where this advancement can make a significant impact is healthcare accessibility. By enhancing the surface area of micro patterns on biosensors, their sensitivity and accuracy can be improved, leading to the development of more efficient and affordable diagnostic tools. This breakthrough can help expand access to healthcare services, particularly in underserved regions and resource-limited settings.

Furthermore, the improved surface area of micro patterns can enhance the detection of biomarkers associated with different diseases, thereby facilitating early diagnosis and timely treatment. This, in turn, contributes to better disease management and improved patient outcomes. Additionally, the compact and portable nature of biosensors with enhanced surface area makes them ideal for point-of-care testing. This enables healthcare professionals to perform diagnostics at or near the location of patient care, revolutionizing healthcare delivery in remote areas and emergency situations.

The benefits of micro patterns with improved surface area extend beyond human health. Biosensors can also be utilized for environmental monitoring, particularly in detecting pollutants, toxins, and hazardous substances. By enhancing the sensitivity of biosensors through laser-engraved micro patterns, even trace amounts of contaminants can be detected, allowing for early identification of environmental hazards and more effective mitigation strategies.

Food safety is another critical area where biosensors play a crucial role. By improving the surface area of micro patterns, biosensors become more effective in detecting contaminants, pathogens, and adulterants in food products. This enhancement contributes to improved food safety standards and the prevention of foodborne illnesses.

In the agricultural sector, biosensors with increased surface area can revolutionize crop monitoring, soil analysis, and water quality assessment. By improving their performance in detecting specific agricultural markers, biosensors can optimize resource utilization, improve agricultural efficiency, and promote sustainable farming practices.

Lastly, the advancements in micro pattern design for biosensors also have implications for biotechnology. The enhanced surface area improves sensitivity and facilitates cellular interactions, making biosensors valuable tools in drug development, genetic engineering, and bioprocessing. These applications have the potential to accelerate biotechnological research, streamline drug discovery processes, and enhance the efficiency of bioengineering endeavors.

In summary, the design and development of micro patterns for biosensors, particularly through laser engraving methods to improve surface area, hold promise in addressing societal and global issues. These advancements can improve healthcare accessibility, enable early disease detection, enhance environmental monitoring, ensure food safety, optimize agricultural practices, and drive advancements in biotechnology.

3.9 Sustainable Development Goals

The design and development of micro patterns for biosensors, with a specific focus on improving the surface area using laser engraving, can contribute to the achievement of several Sustainable Development Goals (SDGs). Firstly, in line with SDG 3 (Good Health and Well-being), enhancing the surface area of micro patterns using laser engraving technology enables biosensors to exhibit higher sensitivity and detection capabilities. This advancement translates into more accurate disease diagnosis, improved monitoring of health conditions, and more effective treatment strategies, ultimately promoting good health and overall well-being.

Furthermore, the utilization of laser engraving for enhancing the surface area of micro patterns aligns with SDG 9 (Industry, Innovation, and Infrastructure). By adopting this innovative approach, the biotechnology industry is propelled forward, fostering technological advancements and driving sustainable infrastructure development in healthcare and diagnostics. The precision and efficiency of laser engraving contribute to the creation of advanced biosensors that can revolutionize medical diagnostics and enhance healthcare accessibility.

In terms of SDG 11 (Sustainable Cities and Communities), biosensors with improved surface area, fabricated using laser engraving, play a vital role in urban environmental monitoring. These biosensors provide real-time measurements of air quality, water pollution, and other crucial parameters, supporting sustainable urban planning and the development of healthier and more resilient communities. By enhancing our ability to monitor and respond to environmental challenges, this technology contributes to creating sustainable and livable cities.

Additionally, the application of laser engraving technology to improve the surface area of micro patterns aligns with SDG 12 (Responsible Consumption and Production). The precise material removal offered by laser engraving optimizes material usage, reducing waste and promoting responsible production practices. This approach aligns with the goal of sustainable consumption and production, minimizing resource consumption and environmental impact in the fabrication of biosensors.

Lastly, the use of biosensors with increased surface area, manufactured through laser engraving, contributes to SDG 13 (Climate Action). These biosensors enable accurate and real-time environmental monitoring, providing valuable data on climate-related parameters such as greenhouse gas emissions, air quality, and pollutant levels. By facilitating informed decision-making and supporting efforts to mitigate climate change, this technology contributes to climate action and the global pursuit of a more sustainable future.

In summary, the design and development of micro patterns for biosensors, with a focus on improving surface area using laser engraving, aligns with multiple SDGs. By enhancing biosensor performance, promoting innovation, supporting sustainable cities, enabling responsible production practices, and facilitating climate action, this technology holds significant potential to contribute to a more sustainable and inclusive society.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Chapter 4 delve into micro pattern designs, encompassing both theoretical 2D and 3D constructs. Beginning with an introduction to these conceptual designs, we then seamlessly transition into the practical realm, exploring the tangible outcomes of the laser-engraving method. The chapter unfolds with visual representations and concise explanations of the fabricated micro patterns, featuring examples such as the 2.5mm, 0.5mm, and 0.25mm microchannel biosensors. A critical analysis takes center stage, involving a surface area comparison that sheds light on variations in pattern characteristics. This chapter serves as a crucial bridge between theory and practice, offering a comprehensive view of the micropattern fabrication process. The visuals and analyses provided lay the groundwork for an in-depth discussion on the implications of these findings for biosensing applications. By presenting a holistic picture of both the envisioned designs and their real-world counterparts, Chapter 4 sets the stage for a nuanced exploration of the significance and potential improvements in micro pattern fabrication.

4.2 Results and Analysis

4.2.1 Theoretical Micro Pattern Design

4.2.1.1 2D Design

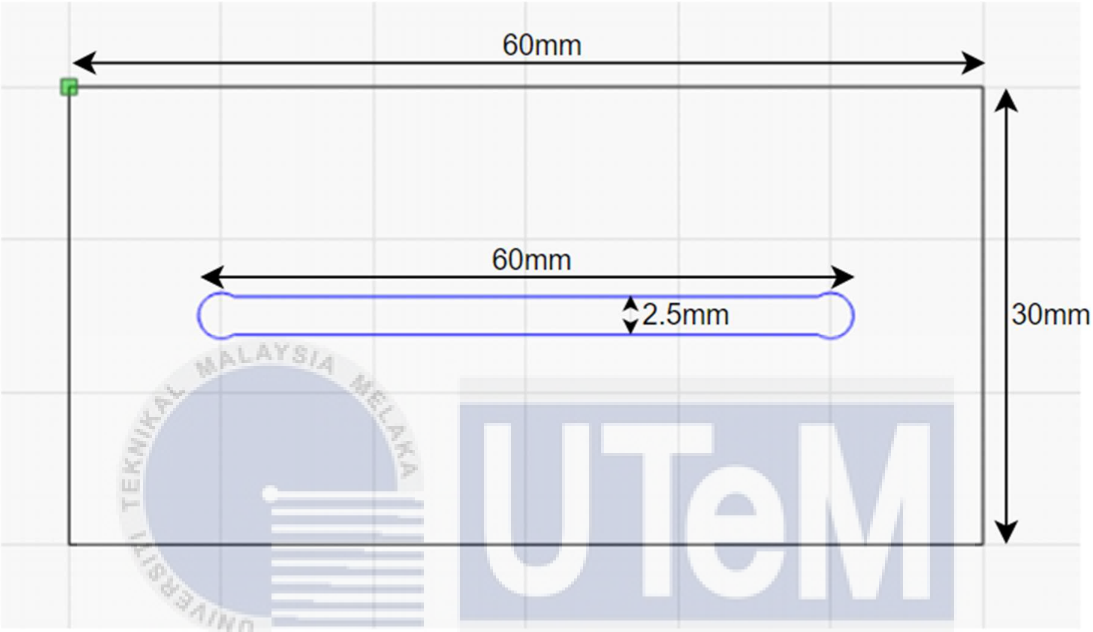


Figure 4.1 Initial Microchannel Design

Figure 4.1 shows the initial single microchannel design made using Lightburn Software. The advantage of a single microchannel design in biosensors, especially when considering high binding capacity, lies in its ability to create a confined and controlled environment for molecular interactions. A single, well-defined microchannel allows for efficient capture and binding of target molecules to the sensor surface, maximizing the available binding sites. The microchannel geometry influences mass transport, ensuring that the target molecules come into contact with the sensor surface in a uniform and controlled manner. This controlled environment enhances the binding kinetics and increases the probability of successful molecular interactions, leading to a higher binding capacity.

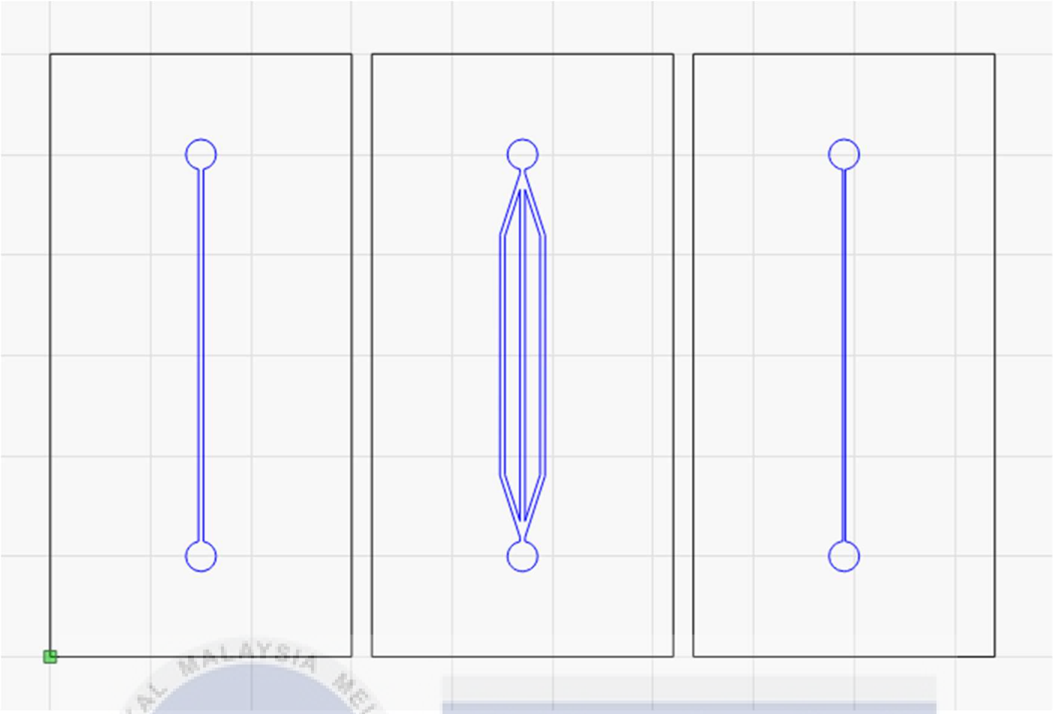


Figure 4.2 Improved Microchannel Designs

Figure 4.2 shows single micro channel with a width of 0.5mm (left), triple microchannel design (middle) and single micro channel with a width of 0.25mm (right). The choice of smaller microchannel width in a biosensor design has several implications for performance. The advantages of a single microchannel biosensor with smaller widths, including increased surface-to-volume ratio, enhanced mass transport, improved spatial resolution, reduced non-specific binding, increased signal-to-noise ratio, and compatibility with small-scale systems, collectively contribute to its improved performance. The higher surface-to-volume ratio provides more binding sites along the microchannel surface, enhancing sensitivity to target analytes. Faster mass transport within narrower microchannels leads to quicker response times, contributing to the biosensor's efficiency. Improved spatial resolution allows for finer control over the location and concentration of binding events. Reduced non-specific binding enhances specificity, ensuring a cleaner signal for more accurate detection. The increased signal-to-noise ratio further contributes to the biosensor's precision. Additionally, the compatibility with small-scale systems makes single microchannel biosensors more practical for diverse applications, including point-of-care diagnostics and portable biosensing devices, enhancing their overall performance and versatility

The triple microchannel biosensor with shared inlet and outlet boasts several advantages that synergistically enhance its overall performance. Its ability for parallel analysis enables simultaneous examination of multiple samples, increasing efficiency and throughput. The incorporation of multiplexed sensing allows for the detection of diverse targets within the same device. Enhanced binding capacity, spatial resolution, and uniformity in fabrication collectively contribute to heightened sensitivity and reliability. The redundancy of independent microchannels minimizes the risk of failure, ensuring the biosensor's robustness. This design also provides experimental flexibility by dedicating microchannels to specific purposes, further enhancing versatility. Overall, the triple microchannel biosensor excels in throughput, versatility, sensitivity, reliability, and spatial precision, making it a powerful tool for diverse biosensing applications.

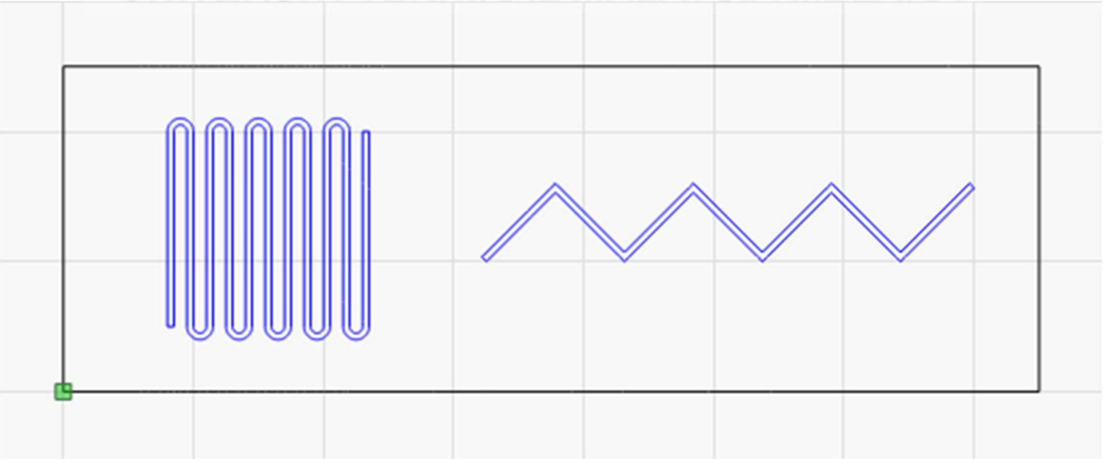


Figure 4.3 Serpentile and ZigZag Microchannel Design

Figure above shows some other experimental design that have been designed. The one on the left is called Serpentine Microchannel and the one on the right is called Zigzag Microchannel. In a serpentine microchannel, the fluid path takes a winding or meandering shape resembling the curves of a serpent. This design is often used to increase the effective channel length within a compact space. The serpentine configuration allows for extended interaction between the sample and the sensor surface, improving mixing and reaction efficiency. It is commonly employed in applications where longer residence times or enhanced mass transfer are desired, contributing to improved sensitivity in biosensing.

A zigzag microchannel feature a series of sharp turns or angles in the fluid path, resembling the pattern of a zigzag. This design is effective for inducing turbulence and promoting efficient mixing of fluids. Zigzag microchannels are employed to enhance the transport of analytes and reagents, optimizing reaction kinetics. The increased mixing can be beneficial in biosensing applications where rapid and uniform interactions between the sample and the sensor surface are crucial for achieving accurate and timely measurements. Both serpentine and zigzag microchannel designs offer advantages in terms of fluidic control and interaction, and their specific applications depend on the requirements of the biosensing system. These designs are often tailored to optimize reaction kinetics, enhance sensitivity, and improve overall performance in microfluidic-based biosensors.

4.2.1.2 3D Design

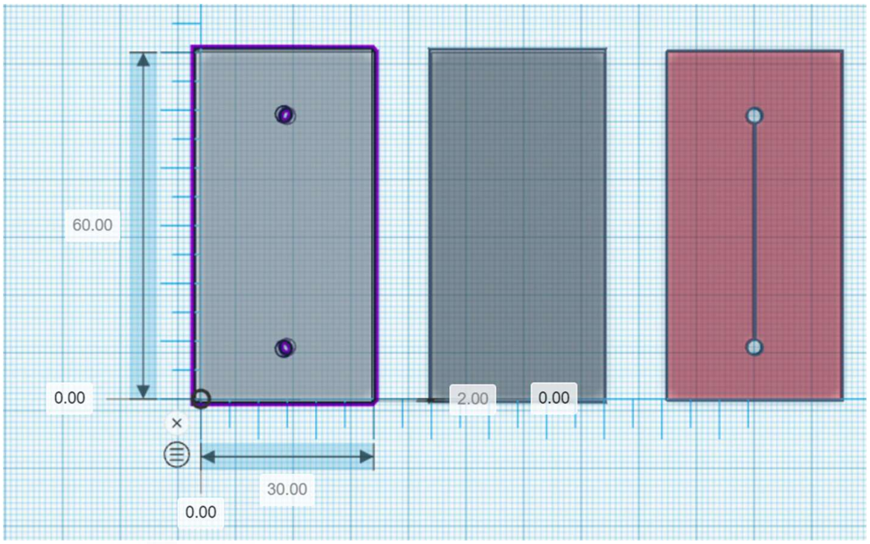


Figure 4.4 Top View of Microchannel Biosensor Layers

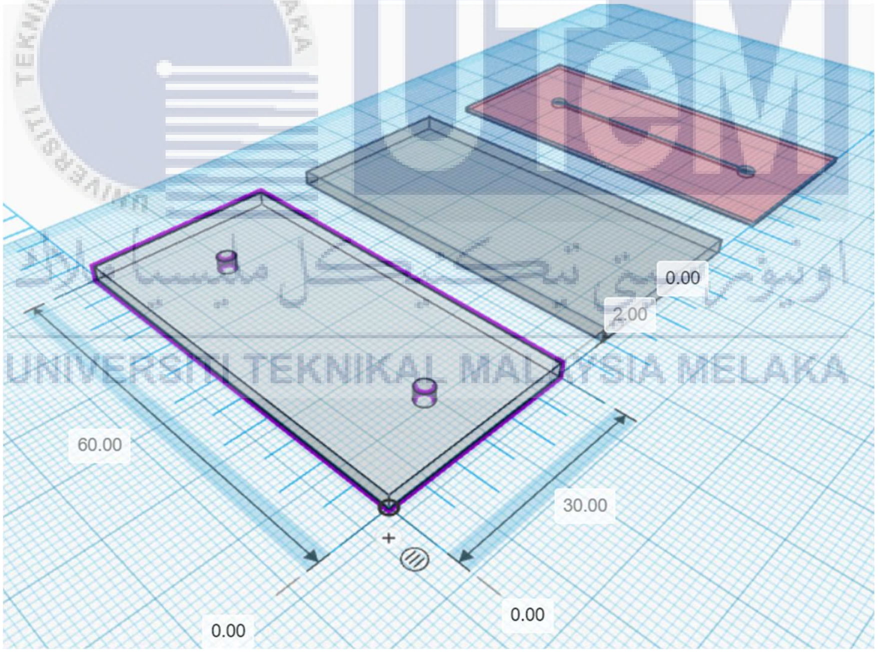


Figure 4.5 Front Upper Left Corner View of Microchannel Biosensor Layers

Figures 4.4 and 4.5 shows the 3D Design that is made using Tinkercad which is an online 3D modelling program owned by Autodesk. In order to showcase the pattern, it needed a body or structure to support it. So, the design above shows that there are three parts, a top layer, a middle layer and a bottom layer. The top and bottom layer is there to support the middle layer and work as an enclosure for the pattern. Figures 4.6 and 4.7 below show the final product which looks close to an actual single microchannel biosensor.

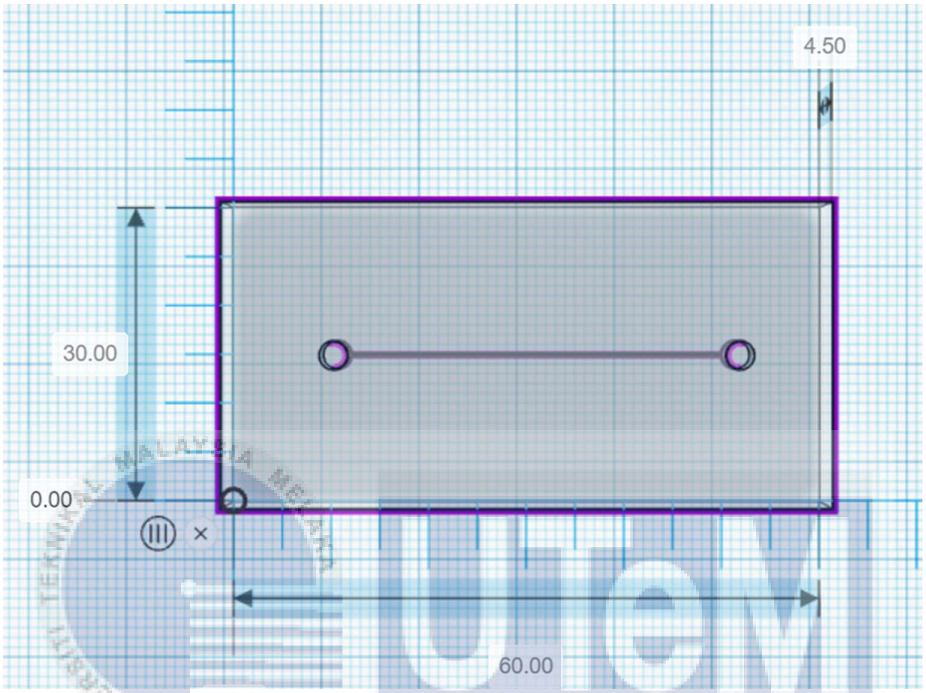


Figure 4.6 Top View of Expected Microchannel Biosensor

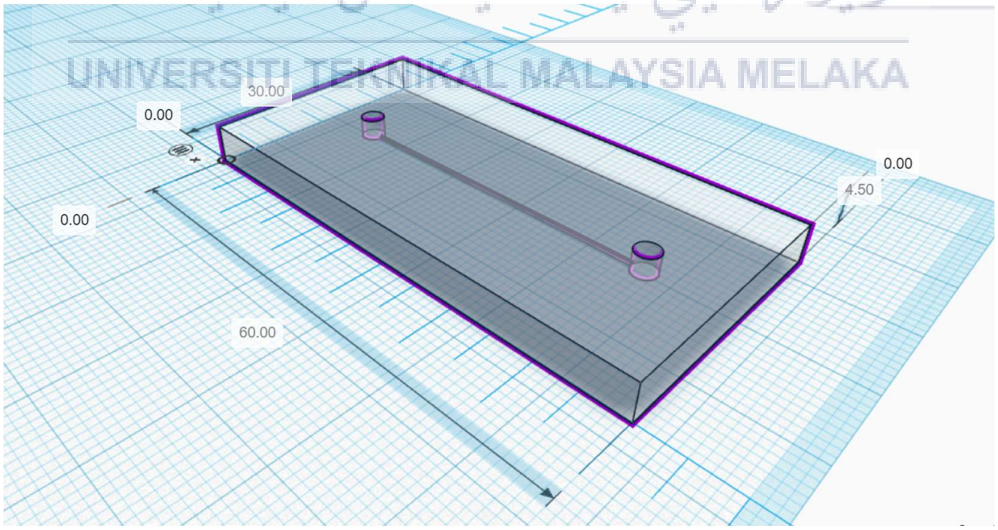
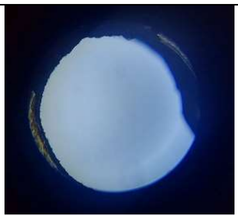
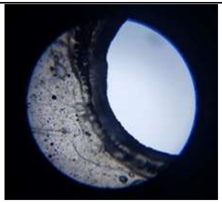
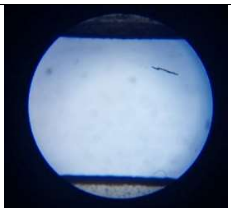
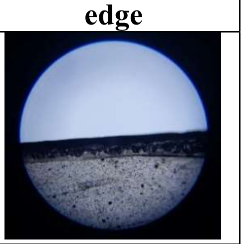
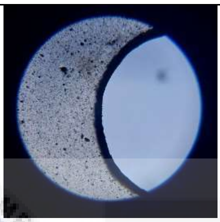
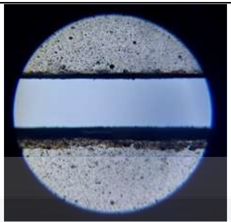
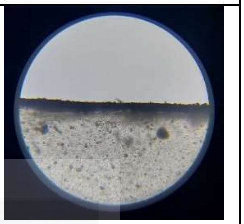
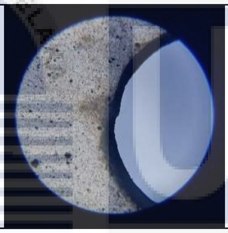
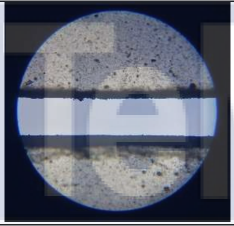


Figure 4.7 Front Upper Left Corner of Expected Microchannel Biosensor

4.2.2 Fabricated Micro Pattern Design

Table 4.1 Microscopic Images of Micropattern Fabricated on Silicone Rubber Sheet through Laser Engraving

	Inlet/outlet	**Inlet/Outlet edge**	**Microchannel**	**Microchannel edge**
2500 µm				
500 µm				
250 µm				

The laser engraving technique ensures a high level of precision, resulting in well-defined microchannels with consistent dimensions. This precision contributes to the reproducibility of biosensors, a crucial factor in maintaining the reliability of experimental results. The versatility of laser engraving allows for the customization of microchannel patterns based on the specific needs of biosensor applications. This adaptability opens up new possibilities for designing sensors with enhanced sensitivity and selectivity.

Figure 4.8 2.5mm Microchannel Biosensor Fabricated using Laser Engraving Method

Figure 4.9 0.5mm Microchannel Biosensor Fabricated using Laser Engraving Method

Figure 4.10 0.25mm Microchannel Biosensor Fabricated using Laser Engraving Method

The three figures above showcase the fabrication of single microchannel biosensors accomplished through the laser engraving method. Primarily, the 2.5mm microchannel biosensor served as a trial to assess the feasibility of achieving high-quality micropatterns. Figure 4.8 clearly indicates the success of this attempt, demonstrating the attainment of a well-defined and precise micropattern.

Figures 4.9 and 4.10 feature 0.5mm and 0.25mm microchannel biosensors, respectively. Prior to fabrication, designs were conceptualized for even thinner microchannels using Tinker cad. Despite the intricacy of the designs, the fabricated micropatterns appear clean and well-defined even upon close examination. Microscopic images of each pattern are detailed in Table 4.1, providing a complete visual representation.

However, it is noteworthy that the actual width of the 0.25mm microchannel, as observed in Figure 4.10, does not precisely match the intended dimension. Table 4.1 further elucidates this discrepancy by illustrating that the width of the 0.25mm microchannel design is not exactly half of the 0.5mm microchannel design. This observation prompts a subtle consideration of the fabrication process and raises potential areas for refinement in future iterations of micropattern design and laser engraving.

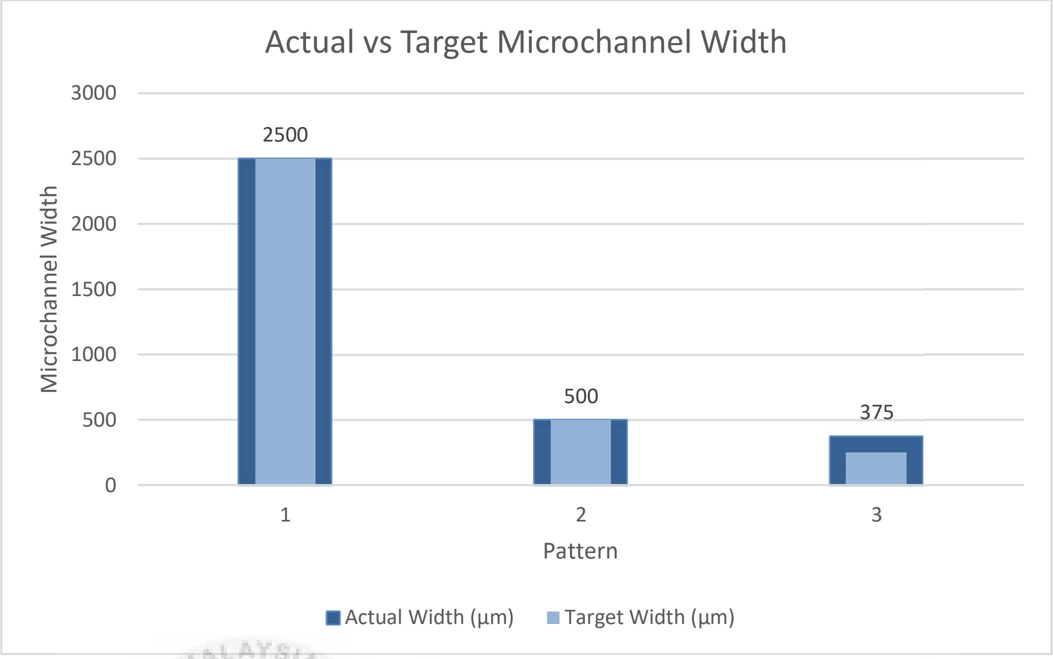


Figure 4.11 Actual vs Target Microchannel Width Graph

4.2.3 Area and Volume Comparison

Table 4.2 Area and Volume of Fabricated Design

Design	Area (mm^2)	Volume (mm^3)
2.5mm	107.57	53.78
0.5mm	32.56	16.28
0.25mm	23.32	11.66

The surface area and volume of microchannel designs play a pivotal role in shaping the binding capacity of single microchannel biosensors. As revealed through our exploration, there exists a dynamic interplay between these two parameters, offering valuable insights into the potential efficacy of biosensing applications.

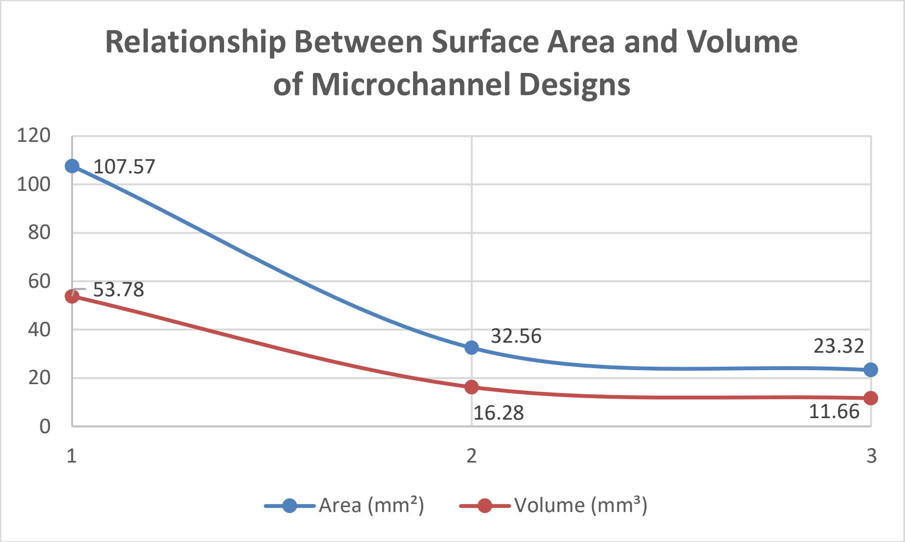


Figure 4.12 Relationship between Surface Area and Volume of Microchannel Design

A larger surface area, as seen in microchannels with broader dimensions, provides an expanded landscape for biomolecular interactions. This abundance of available binding sites holds the potential to significantly elevate the binding capacity of the microchannel. The increased surface area facilitates more binding events between target analytes and immobilized molecules, fostering a heightened sensitivity in biosensor responses.

Volume, intricately linked to surface area, contributes to the overall capacity of the microchannel to accommodate binding events. While a larger volume may afford more space for binding, it is essential to strike a balance to ensure efficient interactions within confined spaces. An optimal volume ensures that the binding capacity is maximized without compromising the kinetics of biomolecular interactions.

Smaller microchannel designs, although presenting reduced surface areas and volumes, may find relevance in specific biosensing applications. Minimizing sample volume or refining binding kinetics could be critical in certain scenarios, making these diminutive designs well-suited for particular use cases. However, careful consideration is necessary to prevent undue restrictions on binding capacity.

Understanding the nuanced relationship between surface area and volume is fundamental in tailoring biosensors for enhanced binding capacity. A judicious selection of microchannel dimensions can significantly impact the efficiency of biomolecular interactions, influencing the sensor's ability to capture and detect target analytes. Therefore, the optimization of both surface area and volume is integral to achieving a biosensor with heightened binding capacity, thus advancing the effectiveness and sensitivity of biosensing applications

4.2.4 Challenges and Considerations

The decision not to expose the three-layered single microchannel biosensor to a series of standard solutions is primarily grounded in the device's current status at a preliminary development stage. The complex layered structure, incorporating clear acrylic and silicone rubber, necessitates meticulous refinement of design and fabrication processes. At this nascent stage, concerns related to sealing and potential leakage are paramount. Achieving a complete and reliable seal within the intricate layers poses challenges that may compromise the accuracy of exposure to standard solutions. Prioritizing the resolution of sealing issues is crucial before subjecting the biosensor to rigorous standard solution testing, ensuring the device's stability and reliability in future calibration efforts.

4.3 Summary

In summary, Chapter 4 provides a comprehensive exploration into the core processes of the project, "Development of Micro Patterns Using Laser Engraver for Biosensor Application." The subtopic on fabricating micro patterns unravels the intricacies involved in material preparation, laser engraver calibration, design file loading, test runs, and the pivotal laser engraving process. The visual inspection of the fabricated single microchannel biosensors, featuring widths of 3mm, 0.5mm, and 0.25mm, serves as a lens into the quality and precision achieved. Figure 4.8 serves as a visual testament to the success of the 3mm microchannel biosensor, showcasing the feasibility of generating high-quality micropatterns. Figures 4.9 and 4.10 extend this success to the 0.5mm and 0.25mm microchannels, revealing well-defined patterns, as corroborated by the microscopic images in Table 4.1. However, the nuanced observation that the 0.25mm microchannel width does not precisely halve the 0.5mm width introduces a layer of complexity, prompting a deeper exploration into fabrication precision. Overall, Chapter 4 not only illuminates the intricate processes of laser engraving but also visually celebrates the successful fabrication of micro patterns, establishing a robust platform for subsequent analyses and discussions in the concluding chapters.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The culmination of the project, "Development of Micro Patterns Using Laser Engraver for Biosensor Application," signifies a significant leap forward in the pursuit of optimizing biosensor performance. The initial objective, centered on designing micro patterns with to maximize surface area for heightened binding capacity, not only proved successful but also underscored the importance of thoughtful design in biosensor development. The intricate patterns, meticulously crafted to amplify surface area, showcase the potential for elevating binding capacities critical for biosensor efficacy. Moving on to the second objective, the development of robust fabrication techniques through laser engraving, marks a critical milestone. The precision and versatility offered by the laser engraver not only translated the Tinkercad designs into tangible micro patterns but also opened avenues for scalable and automated manufacturing processes. The successful execution of these first two objectives solidifies the foundation for advanced biosensor technologies that leverage microscale patterns for improved analytical performance. The third objective, while presenting challenges during the preliminary development stage and grappling with sealing and leakage concerns, has provided invaluable insights. The single microchannel biosensor, constructed from three layers of clear acrylic and silicone rubber sheet, demonstrates a potential breakthrough despite the encountered setbacks. The microscopic analysis underscores the visual promise of the fabricated micro patterns, highlighting their potential application in real-world biosensing scenarios.

The challenges faced during the preliminary stage, particularly with sealing and leakage, serve as signposts for future research and development efforts. These challenges, rather than impeding progress, offer critical guidance for refining the biosensor's structural integrity and enhancing its sealing mechanisms. Future iterations of this work should prioritize comprehensive investigations into material compatibility, optimization of fabrication processes, and fine-tuning of microchannel design. In essence, the journey from conceptualization and design through fabrication and visual analysis provides a robust foundation for future advancements. This project contributes not only to the immediate goals but also sets the stage for continued research and development in biosensor technology. The laser-engraved micro patterns, showcasing enhanced surface area and binding capacities, embody a promising future for biosensor applications across diverse industries. As we look ahead, the lessons learned and the challenges overcome become catalysts for innovative solutions, steering the trajectory of biosensor development towards unprecedented heights.

5.2 Potential for Commercialization

The potential for commercialization lies in the adaptability of the laser-engraved micro patterns for various biosensor applications. As Industry 4.0 drives innovation and automation, the precision offered by laser engraving aligns seamlessly with the demands of modern manufacturing. The developed biosensor, with its optimized surface area, holds promise for industries requiring high binding capacity, such as medical diagnostics and environmental monitoring. Aligning with Sustainable Development Goals (SDGs), the biosensor's potential applications extend to health, clean water, and responsible production, fostering a positive impact on global challenges.

5.3 Future Works

The challenges faced during the preliminary development stage highlight areas for future exploration and improvement. To address sealing and leakage concerns, a comprehensive investigation into material compatibility, fabrication processes, and microchannel design optimization is recommended. Future iterations should focus on refining the biosensor's structural integrity and enhancing the sealing mechanisms. Additionally, quantitative analyses, such as sensitivity and detection limit evaluations, are essential steps to validate the biosensor's performance more rigorously. Integrating Industry 4.0 principles for automation and precision could streamline the fabrication process, making it more scalable for commercial production. The end-users, including medical practitioners and environmental monitoring agencies, stand to benefit from biosensors with enhanced binding capacities, contributing to improved diagnostics and data quality.

In conclusion, this project not only achieves its immediate goals but also paves the way for continued advancements in biosensor technology. The journey from design to fabrication provides valuable insights and sets the stage for future research and development efforts. Through meticulous refinement and a commitment to addressing challenges, the laser-engraved micro patterns showcase significant potential for commercialization and application across diverse industries, aligning with the broader goals of sustainability and technological innovation.

REFERENCES

[1] Adams-McGavin, R. C., Chan, Y., Gabardo, C. M., Yang, J., Skreta, M., Fung, B. C., & Soleymani, L. (2017). Nanoporous and wrinkled electrodes enhance the sensitivity of glucose biosensors. *Electrochimica Acta*, *242*, 1–9. https://doi.org/10.1016/j.electacta.2017.04.108

[2] Attar, H., Abu-Jassar, A. T., Amer, A., Lyashenko, V., Yevsieiev, V., & Khosravi, M. R. (2022). Control System Development and Implementation of a CNC Laser Engraver for Environmental Use with Remote Imaging. *Computational Intelligence and Neuroscience*, *2022*. https://doi.org/10.1155/2022/9140156

[3] Che, H., Selig, M., & Rolauffs, B. (2022). Micro-patterned cell populations as advanced pharmaceutical drugs with precise functional control. *Advanced Drug Delivery Reviews*, *184*, 114169. https://doi.org/https://doi.org/10.1016/j.addr.2022.114169

[4] Danson, C. N., White, M., Barr, J. R. M., Bett, T., Blyth, P., Bowley, D., Brenner, C., Collins, R. J., Croxford, N., Dangor, A. E. B., Devereux, L., Dyer, P. E., Dymoke-Bradshaw, A., Edwards, C. B., Ewart, P., Ferguson, A. I., Girkin, J. M., Hall, D. R., Hanna, D. C., … Winstone, T. (2021). A history of high-power laser research and development in the United Kingdom. In *High Power Laser Science and Engineering*. Cambridge University Press. https://doi.org/10.1017/hpl.2021.5

[5] Derkus, B. (2016). Applying the miniaturization technologies for biosensor design. In *Biosensors and Bioelectronics* (Vol. 79, pp. 901–913). Elsevier Ltd. https://doi.org/10.1016/j.bios.2016.01.033

[6] Eidi, A., Shamsi, M., & Badri Ghavifekr, H. (2022). Design and evaluation of a micro resonator structure as a biosensor for droplet analysis with a standard fabrication method. *Sensor Review*, *42*(2), 263–273. https://doi.org/10.1108/SR-07-2021-0209

[7] Filik, H., & Avan, A. A. (2019). Nanostructures for nonlabeled and labeled electrochemical immunosensors: Simultaneous electrochemical detection of cancer markers: A review. In *Talanta* (Vol. 205). Elsevier B.V. https://doi.org/10.1016/j.talanta.2019.120153

[8] Fruncillo, S., Su, X., Liu, H., & Wong, L. S. (2021). Lithographic Processes for the Scalable Fabrication of Micro- And Nanostructures for Biochips and Biosensors. In *ACS Sensors* (Vol. 6, Issue 6). American Chemical Society. https://doi.org/10.1021/acssensors.0c02704

[9] Ginestra, P. S., Madou, M., & Ceretti, E. (2019). Production of carbonized micro-patterns by photolithography and pyrolysis. *Precision Engineering*, *55*, 137–143. https://doi.org/10.1016/j.precisioneng.2018.08.019

[10]Haldar, S., Vashisht, G., Ghosh, U. K., Jaiswal, A. K., Porwal, S., Khakha, A., Sharma, T. K., & Dixit, V. K. (2019). Development of a simple cost-effective maskless-photolithography system. *AIP Conference Proceedings*, *2115*(1), 030219. https://doi.org/10.1063/1.5113058

[11]Hong, F., & Blaikie, R. (2019). Plasmonic Lithography: Recent Progress. In *Advanced Optical Materials* (Vol. 7, Issue 14). Wiley-VCH Verlag. https://doi.org/10.1002/adom.201801653

[12]Lee, C., Shin, S. S., Choi, J., Kim, J., Son, J. W., Choi, M., & Shin, H. H. (2020). A micro-patterned electrode/electrolyte interface fabricated by soft-lithography for facile oxygen reduction in solid oxide fuel cells. *Journal of Materials Chemistry A*, *8*(32), 16534–16541. https://doi.org/10.1039/d0ta03997g

[13]Lee, S. A., Yang, J. W., Choi, S., & Jang, H. W. (2021). Nanoscale electrodeposition: Dimension control and 3D conformality. *Exploration*, *1*(3), 20210012. https://doi.org/10.1002/exp.20210012

[14]Ma, D., Chon, S., Cho, S., Lee, Y., Yoo, M., Kim, D., Lee, D. Y., & Lim, J. K. (2020). A novel photolithographic method for fabrication of flexible micro-patterned glucose sensors. *Journal of Electroanalytical Chemistry*, *876*. https://doi.org/10.1016/j.jelechem.2020.114720

[15]Myeong, S., Chon, B., Kumar, S., Son, H. J., Kang, S. O., & Seo, S. (2022). Quantum dot photolithography using a quantum dot photoresist composed of an organic-inorganic hybrid coating layer. *Nanoscale Advances*, *4*(4), 1080–1087. https://doi.org/10.1039/d1na00744k

[16]Papazoglou, S., & Zergioti, I. (2017). Laser Induced Forward Transfer (LIFT) of nano-micro patterns for sensor applications. *Microelectronic Engineering*, *182*, 25–34. https://doi.org/https://doi.org/10.1016/j.mee.2017.08.003

[17]Perl, A., Reinhoudt, D. N., & Huskens, J. (2009). Microcontact Printing: Limitations and Achievements. *Advanced Materials*, *21*(22), 2257–2268. https://doi.org/https://doi.org/10.1002/adma.200801864

[18]Prashant, K., Khatib, M. I., Shahrukh, A., Mirza, N. A., Sattar, S. M., & Muqeeth Kazim, M. A. (2020). Design and Fabrication of Laser Engraving Machine. *International Journal of Scientific Research in Science, Engineering and Technology*, 250–262. https://doi.org/10.32628/ijsrset207366

[19]Qiu, S., Ji, J., Sun, W., Pei, J., He, J., Li, Y., Li, J. J., & Wang, G. (2021). Recent advances in surface manipulation using micro-contact printing for biomedical applications. *Smart Materials in Medicine*, *2*, 65–73. https://doi.org/https://doi.org/10.1016/j.smaim.2020.12.002

[20]Riveiro, A., Maçon, A. L. B., del Val, J., Comesaña, R., & Pou, J. (2018). Laser surface texturing of polymers for biomedical applications. In *Frontiers in Physics* (Vol. 5, Issue FEB). Frontiers Media S.A. https://doi.org/10.3389/fphy.2018.00016

[21]Rose, M. A., Bowen, J. J., & Morin, S. A. (2019). Emergent Soft Lithographic Tools for the Fabrication of Functional Polymeric Microstructures. In *ChemPhysChem* (Vol. 20, Issue 7, pp. 909–925). Wiley-VCH Verlag. https://doi.org/10.1002/cphc.201801140

[22]Sebastian, E. M., Jain, S. K., Purohit, R., Dhakad, S. K., & Rana, R. S. (2020). Nanolithography and its current advancements. *Materials Today: Proceedings*, *26*, 2351–2356. https://doi.org/https://doi.org/10.1016/j.matpr.2020.02.505

[23]Sen, A. K., Raj, A., Banerjee, U., & Iqbal, S. R. (2019). Soft lithography, molding, and micromachining techniques for polymer micro devices. In *Methods in Molecular Biology* (Vol. 1906, pp. 13–54). Humana Press Inc. https://doi.org/10.1007/978-1-4939-8964-5_2

[24]Singh, A. P., Tripathi, A., Nagar, A., & Choudhary, H. (2022). Design and Fabrication of CNC Laser Engraver using Microcontroller: A Review. In *IPEC Journal of Science & Technology* (Vol. 01, Issue 01).

[25]Tonelli, D., Scavetta, E., & Gualandi, I. (2019). Electrochemical deposition of nanomaterials for electrochemical sensing. In *Sensors (Switzerland)* (Vol. 19, Issue 5). MDPI AG. https://doi.org/10.3390/s19051186

[26]Touhami, A. (n.d.). *Biosensors and Nanobiosensors: Design and Applications*. https://scholarworks.utrgv.edu/pa_fac

[27]Wahid, N. A. A., Hashemi, A., Evans, J. J., & Alkaisi, M. M. (2021). Conductive bioimprint using soft lithography technique based on PEDOT:PSS for biosensing. *Bioengineering*, *8*(12). https://doi.org/10.3390/bioengineering8120204

[28]Wang, D., Zhao, X., Lin, Y., Ren, T., Liang, J., Liu, C., & Wang, L. (2017). Fabrication of micro/nano-structures by electrohydrodynamic jet technique. In *Frontiers of Mechanical Engineering* (Vol. 12, Issue 4, pp. 477–489). Higher Education Press. https://doi.org/10.1007/s11465-017-0461-y

[29]Xue, C., Zhao, J., Wu, Y., Yu, H., Yang, S., Wang, L., Zhao, W., Wu, Q., Zhu, Z., Liu, B., Zhang, X., Zhou, W., & Tai, R. (2017). Fabrication of large-area high-aspect-ratio periodic nanostructures on various substrates by soft X-ray interference lithography. *Applied Surface Science*, *425*, 553–557. https://doi.org/10.1016/j.apsusc.2017.07.010

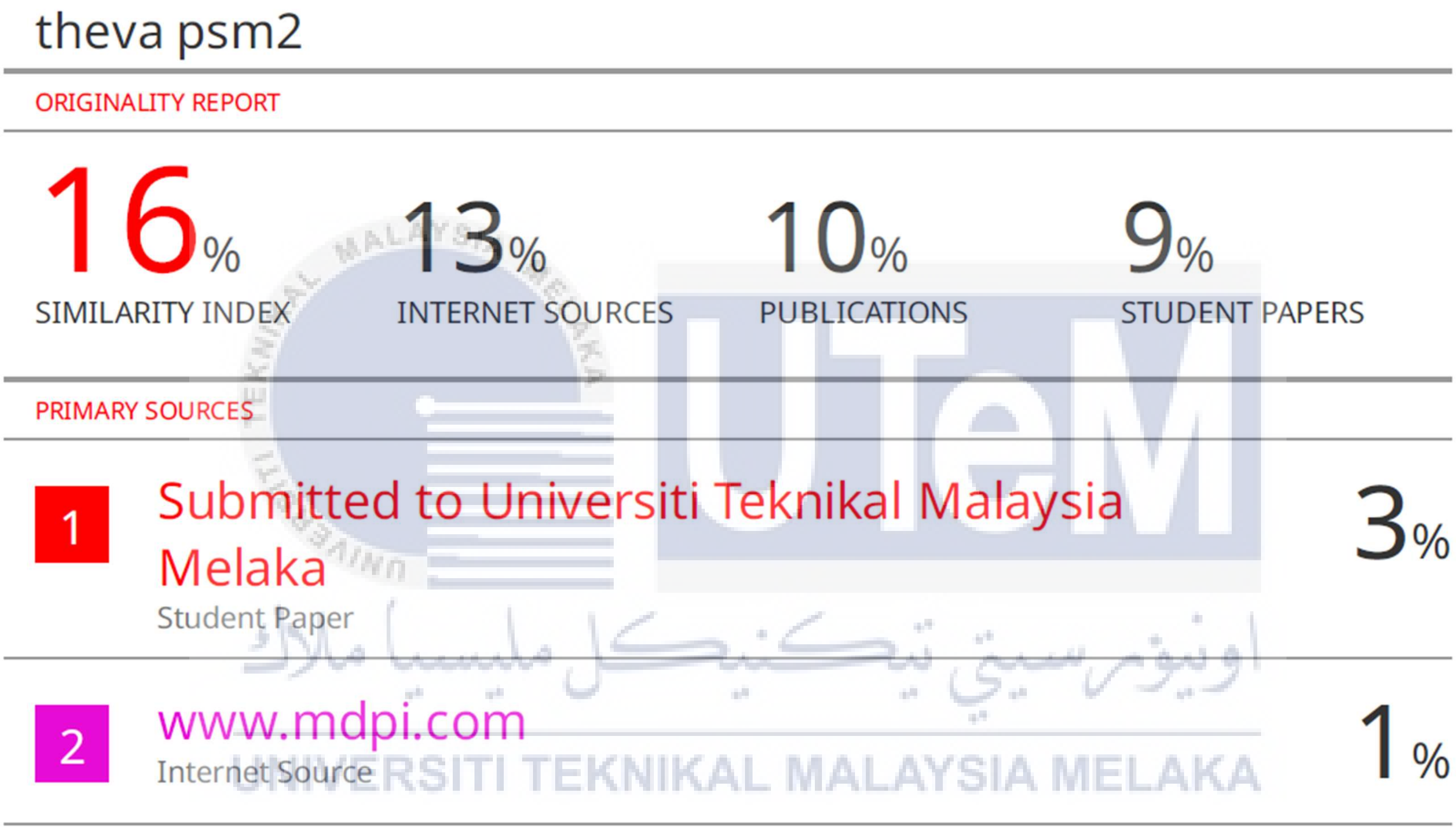
[30]Yang, B., Yu, M., & Yu, H. (2020). Azopolymer-Based Nanoimprint Lithography: Recent Developments in Methodology and Applications. In *ChemPlusChem* (Vol. 85, Issue 9, pp. 2166–2176). Wiley-VCH Verlag. https://doi.org/10.1002/cplu.202000495

APPENDICES

Appendix 1 Gantt Chart for BDP 2

UNIVERISITI TEKNIKAL MALAYSIA MELAKA	**DOC**	**PREPARED BY**		**CHECK BY**	
DEVELOPMENT OF MICRO PATTERNS USING LASER ENGRAVER FOR BIOSENSOR APPLICATION	PSM 2	THEVAPRASAN A/L S SARVANAN		*DR. VIGNESWARAN NARAYANAMURTHY*	
		B082010431		**DATE**	JAN, 2024

NO	**DESCRIPTION OF TASK**		**WEEK** 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Setup and Literature Review	PLAN	🟩	🟩													
		ACTUAL			🟩	🟩											
2	2D Micro Pattern Design	PLAN		🟩	🟩												
		ACTUAL					🟩	🟩									
3	3D Design and Material Selection	PLAN			🟩	🟩											
		ACTUAL					🟩	🟩									
4	Tool and Material Acquisition	PLAN				🟩	🟩										
		ACTUAL						🟩	🟩								
5	Micro Pattern Fabrication	PLAN					🟩	🟩	🟩	🟩							
		ACTUAL							🟩	🟩	🟩	🟩					
6	Data Analysis	PLAN								🟩	🟩	🟩	🟩				
		ACTUAL										🟩	🟩	🟩	🟩		
7	Presentation of PSM 2	PLAN														🟩	
		ACTUAL														🟩	
8	PSM 2 complete with Q&A	PLAN															🟩
		ACTUAL															🟩



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