DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

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FABRICATION OF D-SHAPED OPTICAL FIBER FOR SENSING APPLICATIONS

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INTRODUCTION

- Conventional optical fibers are robust and transmit light with minimum loss. To detect changes in the surrounding environment, there is a requirement for increased sensitivity and precision.
- D-shaped optical fibres are a significant advancement in optical fibre technology. They feature exceptional optical qualities and unique mode field features that enable them to detect even minute variations in the refractive index of the surrounding material with high accuracy [6][3].
- In order to fabricate D-shaped fibers, a methodical side polishing procedure must be followed, entailing many stages to remove the cladding and reveal the evanescent field. The fiber's sensitivity is greatly increase by this exposure, which makes it ideal for biochemical sensing [2].

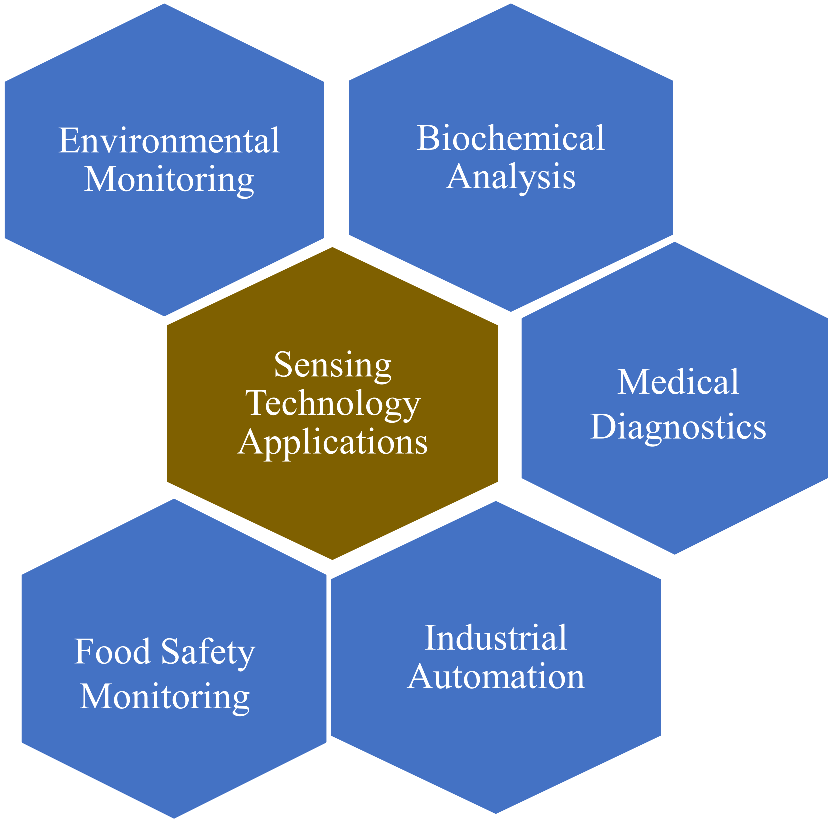


Figure 1 : Application of Sensing Technology

AIMS & OBJECTIVES

- The aim of this project is to design and refine D-shaped optical fibre fabrication systems for biochemical sensing. By using cutting-edge methods including precise polishing techniques and encapsulation inside unique moulds, then polishing the sides to change the D-shaped cut's length, depth, and curvature.
- The purpose of systematic manufacturing process refinement is to produce enhance performance characteristics such as enhanced sensitivity, durability, stability and minimal loss.

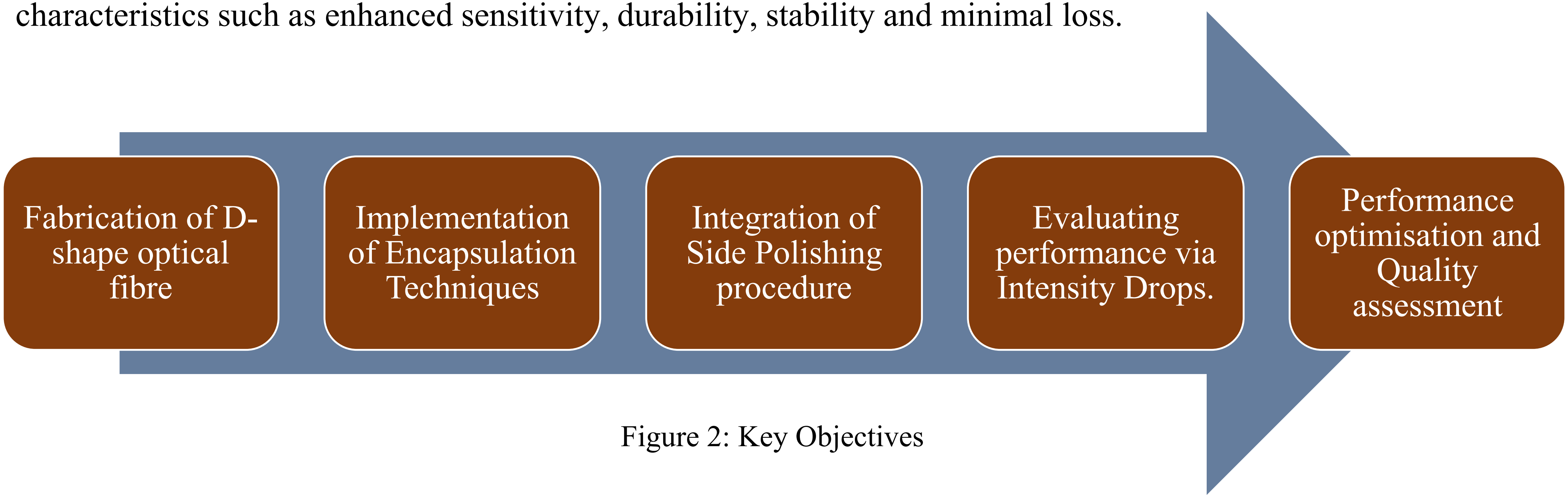


Figure 2: Key Objectives

PROJECT DELIVERABLES

Refined D-Shaped Fabrication Process

- Consistent, D-shaped Fibers with Increased Sensitivity and less bending loss

Optimized Side-Polishing Protocol

- Facilitates future replication and adapts to specific fibre forms or sensing application needing side-polishing for enhanced sensitivity

Characterization Data and Analysis Technique

- Comprehensive fibre validation and analysis techniques for D-Shaped fibres

Database for D-shaped Fiber Sensor Development

- Compilation of detailed information and learning from the project as resource.

Figure 3: Outcome of this research

LITERATURE REVIEW

Journal Article 1: From D-Shaped to D-shape Optical Fibre – Universal Solution for Sensing and Biosensing Application [6]

- **Authors:** Grzegorz Stepniewski et al
- **Publication**: Elsevier's Measurement, 2023.
- **Summary**: Devised a Novel Method for creating D-shaped optical fibres without the need for mechanical or chemical post-processing with improved fibre dependability and sensitivity by flattening the sensor surface

Journal Article 2: Highly Sensitive and Wide Dynamic Range Side-Polished Fiber optic Taste Sensor [5]

- **Authors:** Alireza Khalilian et al
- **Publication:** Sensors and Actuators B,2017.
- **Summary:** Developed a side-polished optical fiber sensor with a high degree of sensitivity to detect flavour compounds at low concentration using solvatochromic dye-coated sensor membrane to track flavours by evanescent field absorption.

Journal Article 3: A High-Precision D-Shaped Fiber Polishing Method and its Sensing Characteristics of Different Polishing Depths [4]

- **Authors:** Huiqing Niu et al
- **Publication**: Springer, 2024.
- **Summary:** Proposed an affordable process for creating D-shaped optical fibers with excellent accuracy. Designed a side-wheel polishing machine with wheels to produce fiber consistently demonstrating the efficacy of the technique for SPR sensing applications by achieving a maximum sensitivity of 3317.14 nm/RIU for RI detection

Book Chapter: Fibre-Optic Chemical Sensor Approaches Based on Nano-assembled Thin Films: A Challenge to Future Sensor Technology [1]

- **Authors:** Sergiy Korposh et al.
- **Publication:** IntechOpen, 2013.
- **Summary**: Examined the LPG, tapered fibre-optic chemical sensors highlighting the value of fiber-optic sensor in a number of applications, including environmental monitoring and health diagnostics.

METHODOLOGY

Preliminary Experiment: Analysis of Bending Loss

- The goal was to comprehend the effects of fibre bending on light propagation, with a focus on Single-Mode Fibres (SMF). Since severe bending may significantly attenuate the optical signal, bending loss is a crucial issue in evaluating the effectiveness of fibre optic systems.

- In-depth investigation of this connection was the goal of this initial effort, which contributed to the design of further experiments in the study and offered significant insights about the behaviour of light inside bent fibres.

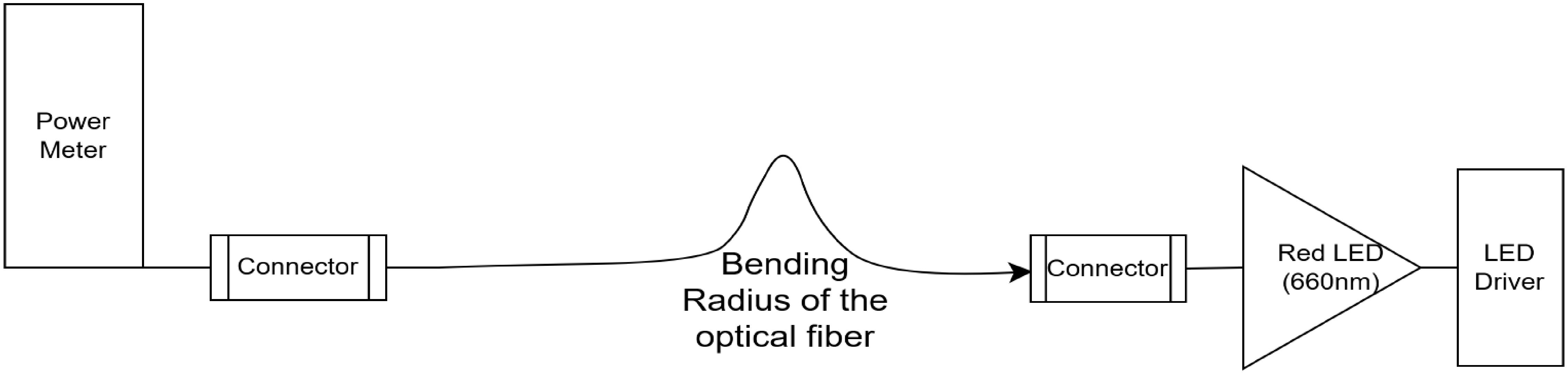


Figure 4: Schematic representation of the bending radius losses of optical fibre experiment.

RESULTS AND DISCUSSION

Bending Loss Analysis in SMF

Table 1: Analysis of power loss acquired at different bending radii

Radius	Power
0.2	968.6nw
0.4	1.419 µw
0.5	1.607 µw
1	1.925 µw
1.5	2.002 µw
2	2.026 µw
2.5	2.068 µw
3	2.081 µw
3.5	2.119 µw
4	2.125 µw
4.5	2.135 µw
5	2.137 µw
5.5	2.143 µw
6	2.147 µw
6.5	2.150 µw
7	2.152 µw
7.5	2.158 µw
8	2.167 µw
8.5	2.169 µw
9	2.178 µw
9.5	2.181 µw
10	2.185 µw

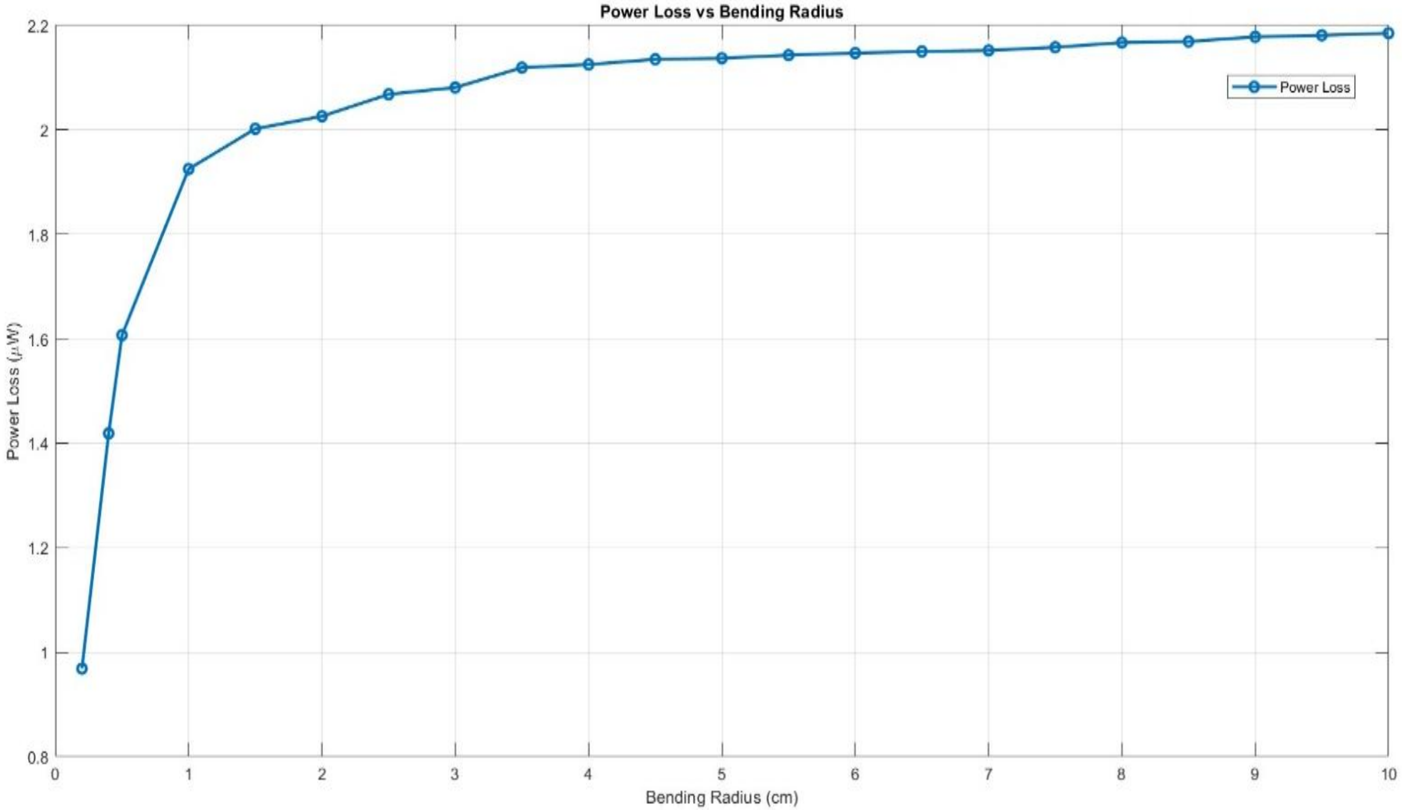


Figure 5: Graph of the power loss at different bending radii

METHODOLOGY

Fabrication of D-Shaped Fibers with Acrylic Mould/Epoxy Resin Encapsulation

- **Mixing Instructions for Acrylic Mould:** Combine 1-part SamplKwik Liquid (20-3564) with 2 parts by volume of SamplKwik Powder (20-3562). Alternately, use two parts liquid to three parts powder for a larger quantity.
- **Mixing Instructions for Epoxy Resin:** Combine one component Epokwick FC Hardener (20-3453-032) with four parts Epokwick FC Resin (20-3453-128).

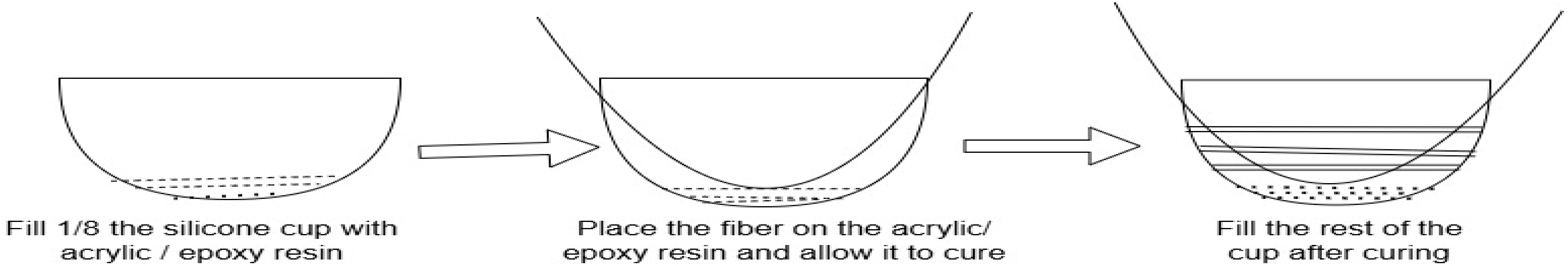


Figure 6: Initial plan: Steps for encapsulation through partial curing

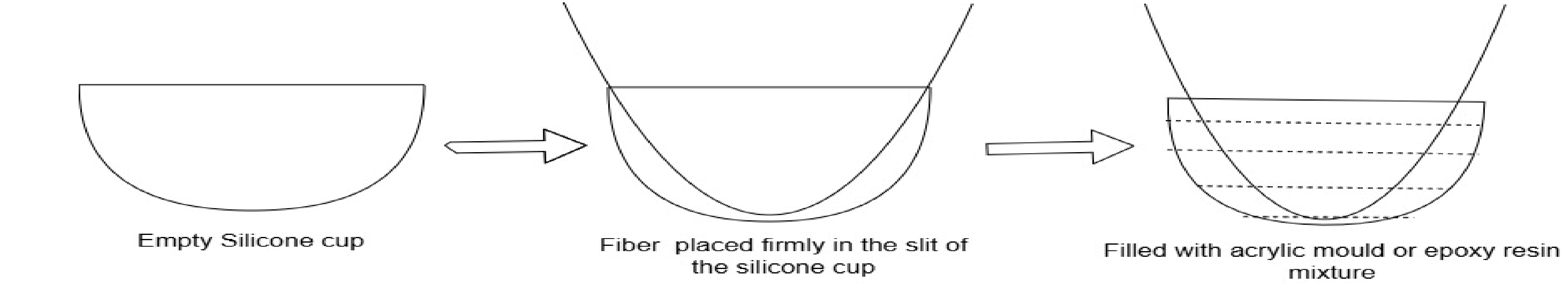


Figure 7: Encapsulation steps of the fibre

METHODOLOGY

Fiber Fixation and Polishing Procedures

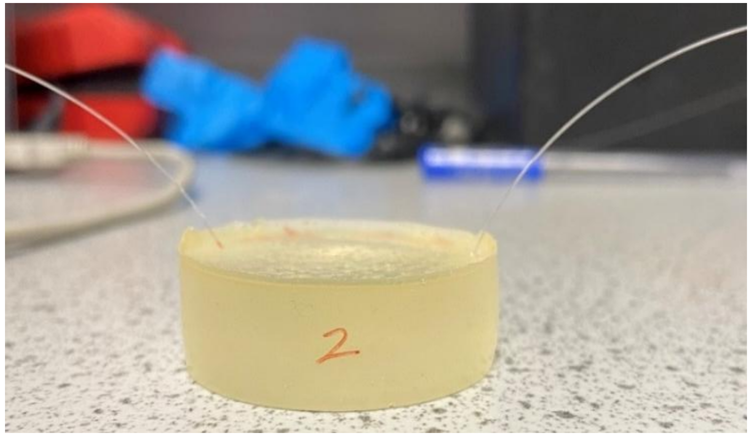


Figure 8: Sample of fibre encapsulation in acrylic mould

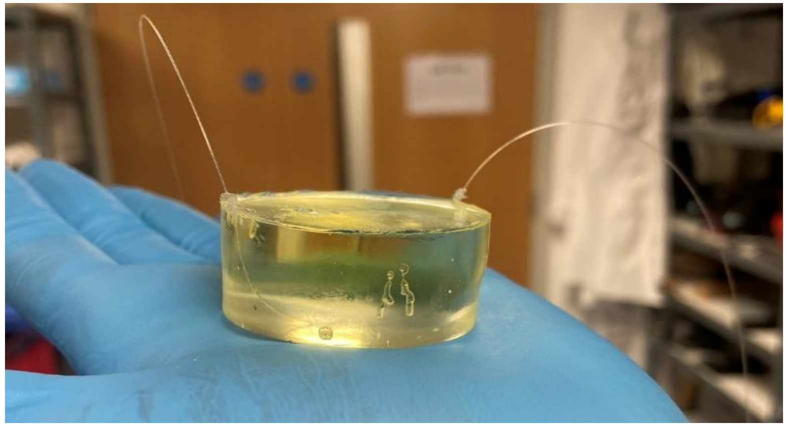


Figure 9: Sample of fibre encapsulation in epoxy resin

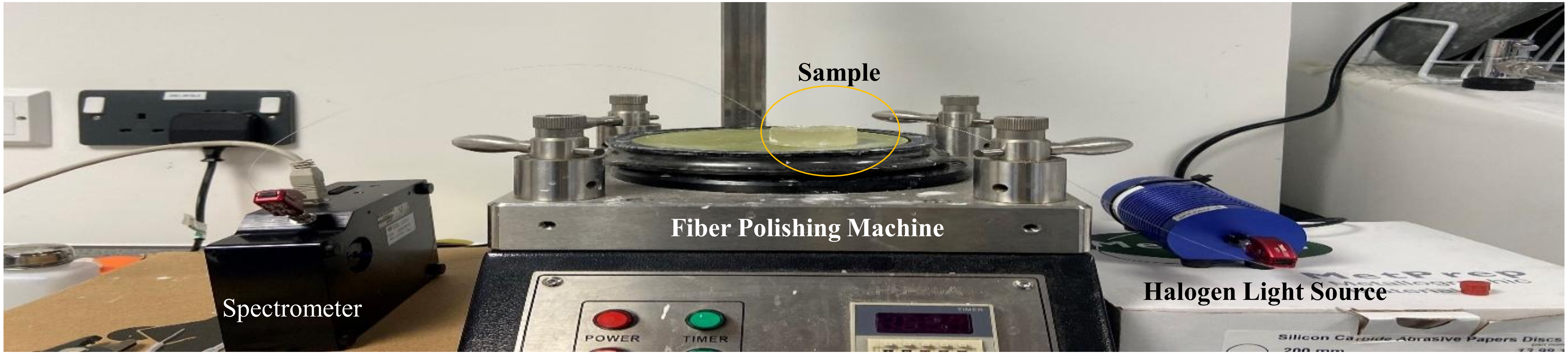


Figure 10: Fiber polishing setup for fabrication of D-Shaped fibres with acrylic and epoxy resin encapsulation

RESULTS AND DISCUSSION

Effectiveness D-Shaped Fiber Fabrication Using Acrylic Mould

Table 2: D-Shaped Fibre Fabrication: Polishing Time vs. Intensity and Percentage Drop

Polishing Time (Minutes)	Intensity (Counts)	Intensity drop percentage
8.233	15234	0%
13.525	14745	3.2%
13.958	13647	10.4%
14.083	11129	27%
14.167	7615.9	50%
14.208	5232.5	65.7%

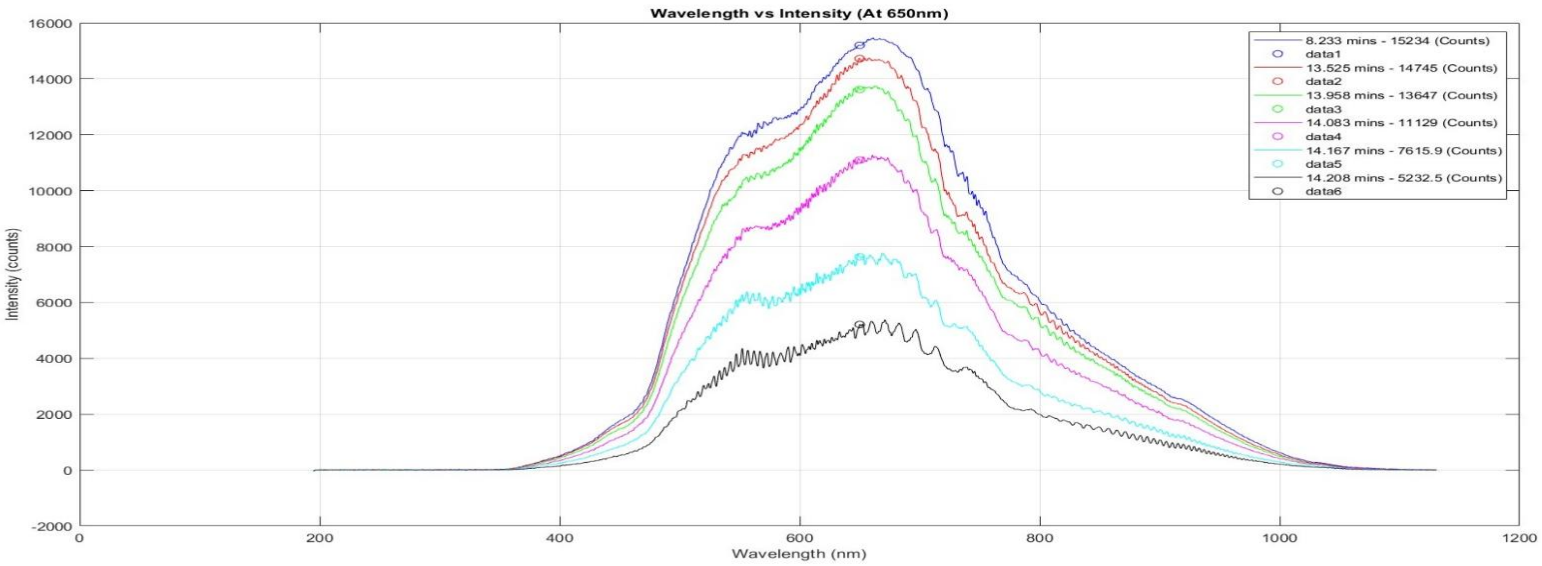


Figure 11: Intensity Drop Graph for Fabricating D-Shaped Fibres Using Acrylic Mould

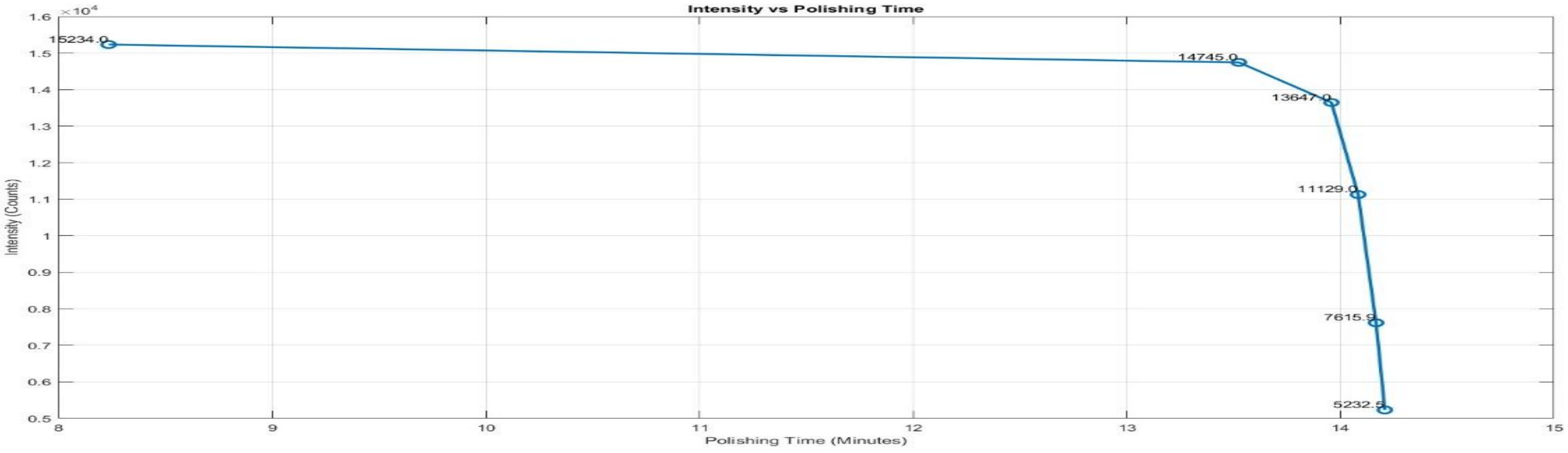


Figure 12: Intensity vs Polishing time for Fabricating D-Shaped Fibres Using Acrylic Mould

METHODOLOGY

Fabrication of D-Shaped Fiber by Wheel Polishing

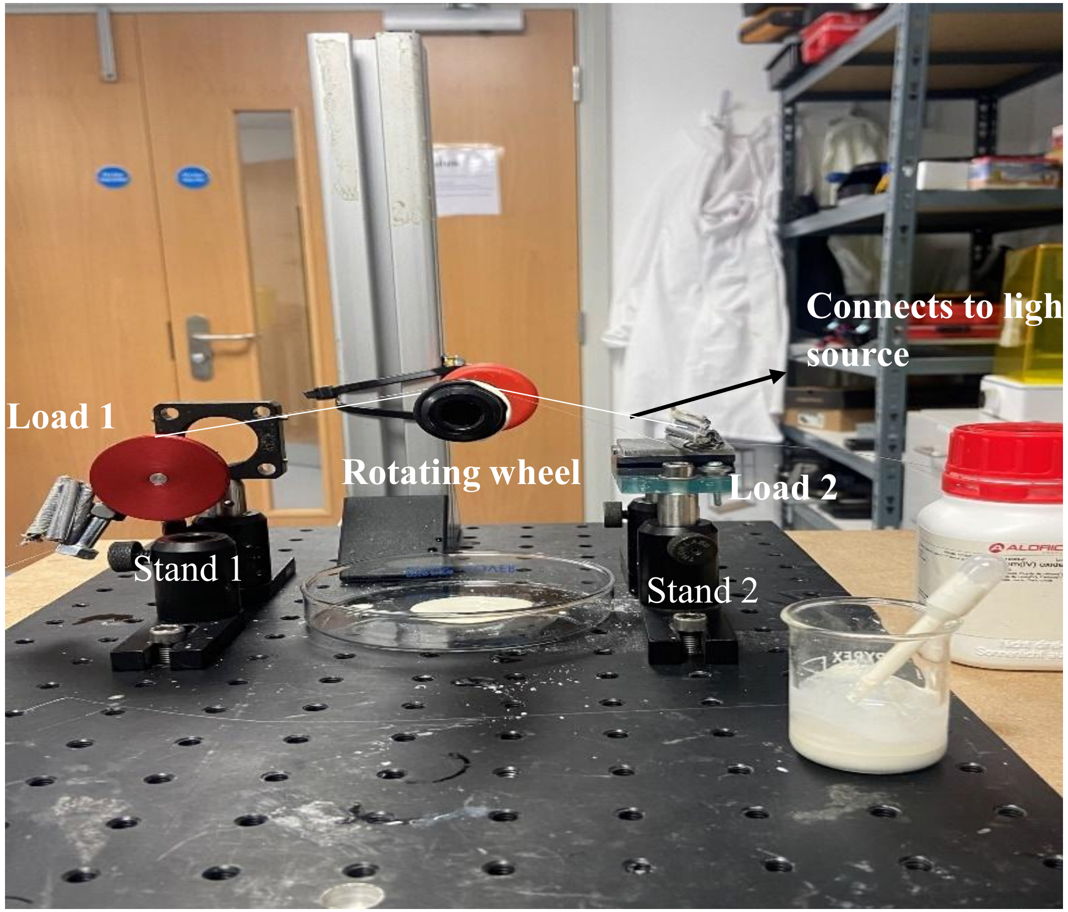


Figure 13: Front view of wheel polishing setup

Figure 14: Side view of wheel polishing setup

RESULTS AND DISCUSSION

Effectiveness of D-Shaped Fiber Fabrication by Wheel Polishing Mechanism

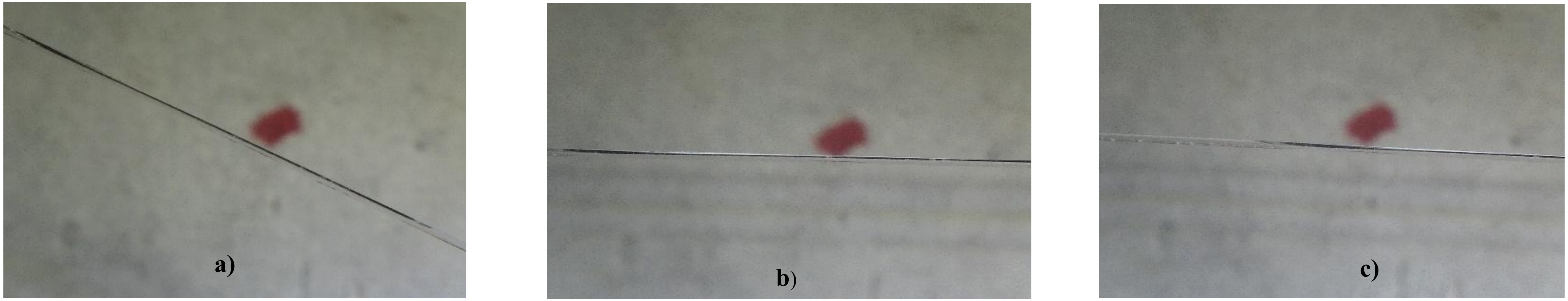


Figure 15: a), b) & c) Different view of the 40 % intensity drop (approx.) d-shaped fibre under digital microscope.

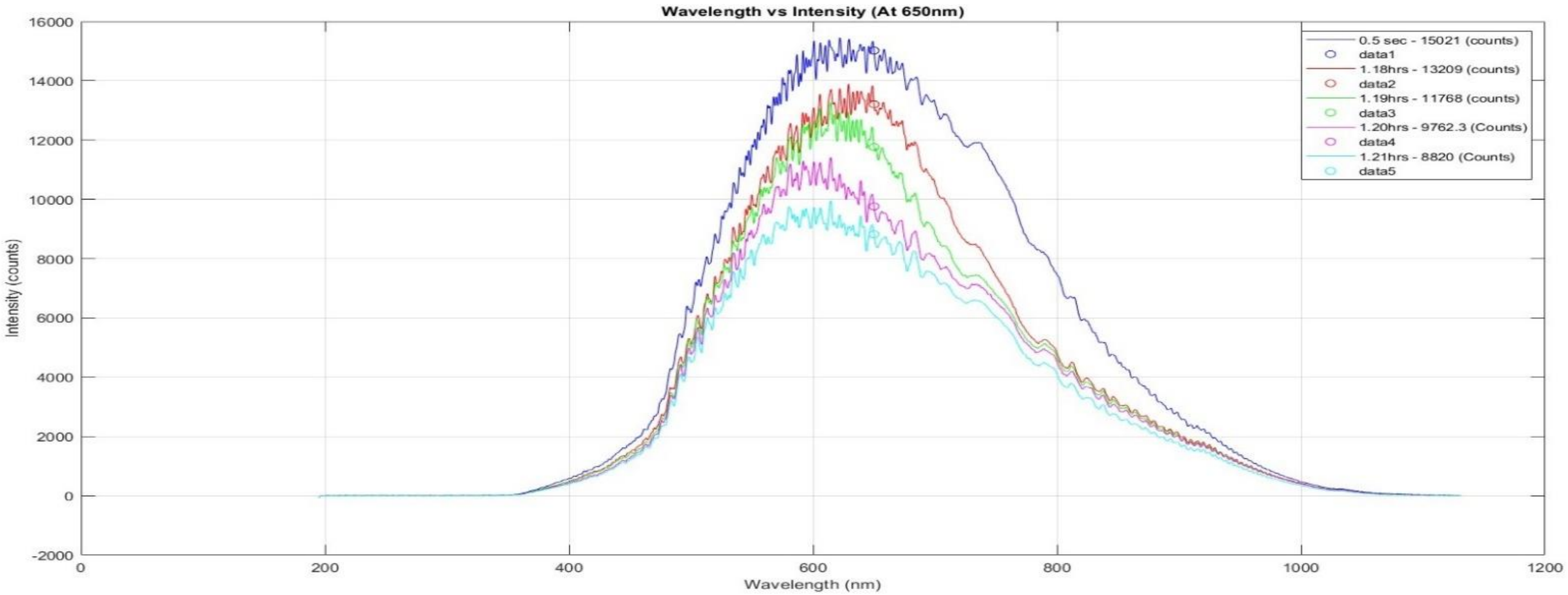


Figure 16: Fabrication of 41.27% (40% approx.) intensity drop D-shaped Fiber

RESULTS AND DISCUSSION

Effectiveness of D-Shaped Fiber Fabrication by Wheel Polishing Mechanism

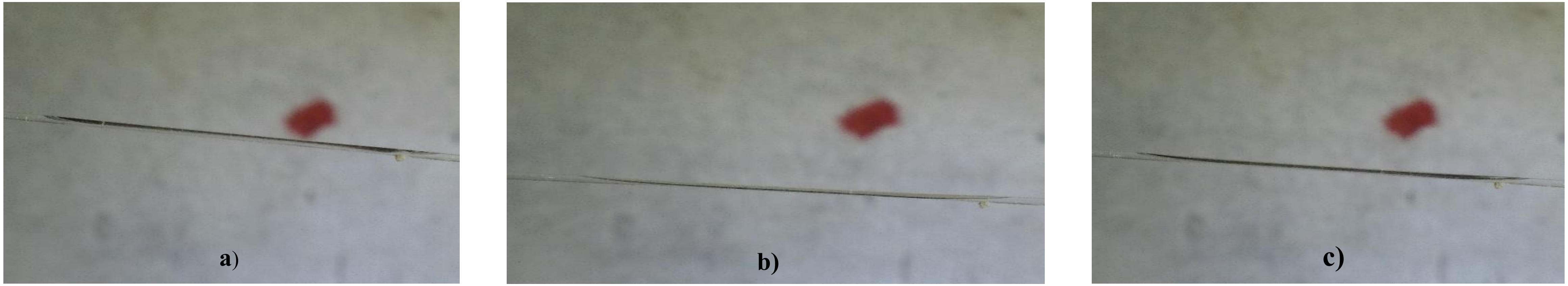


Figure 17: a), b) & c) Different view of the 20 % (approx.) intensity drop d-shaped fiber under digital microscope.

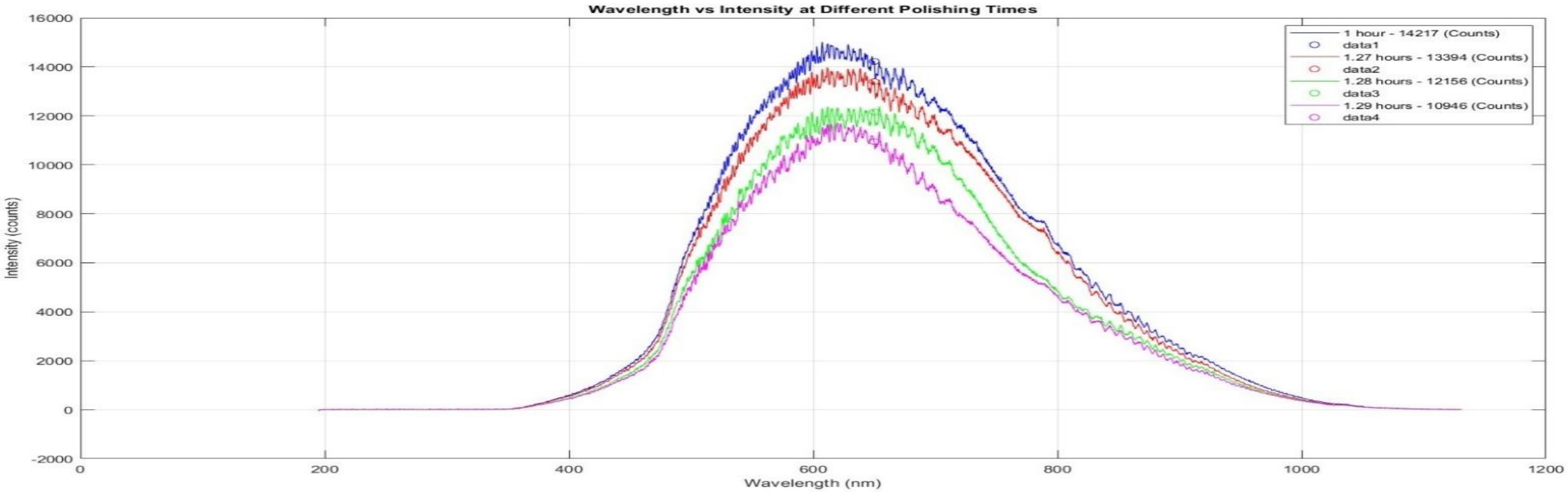


Figure 18: Fabrication of 23.01% (20% approx.) intensity drop D-shaped Fiber

RESULTS AND DISCUSSION

Effectiveness of D-Shaped Fiber Fabrication by Wheel Polishing Mechanism

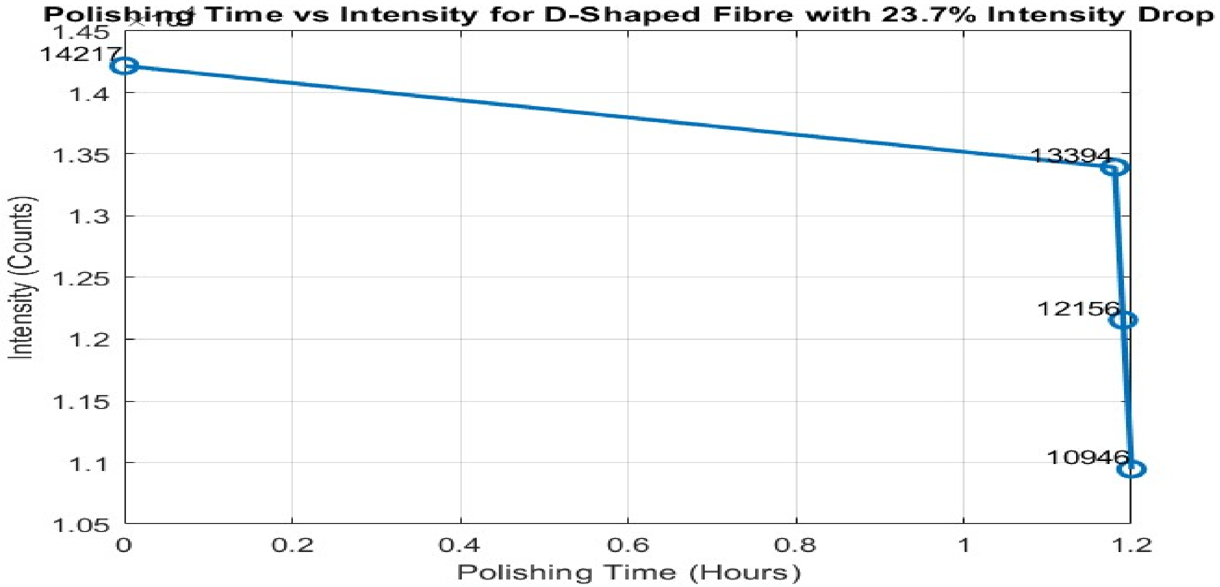


Figure 19: Polishing time vs Intensity for D-shaped fibre with 23.7 % Intensity drop

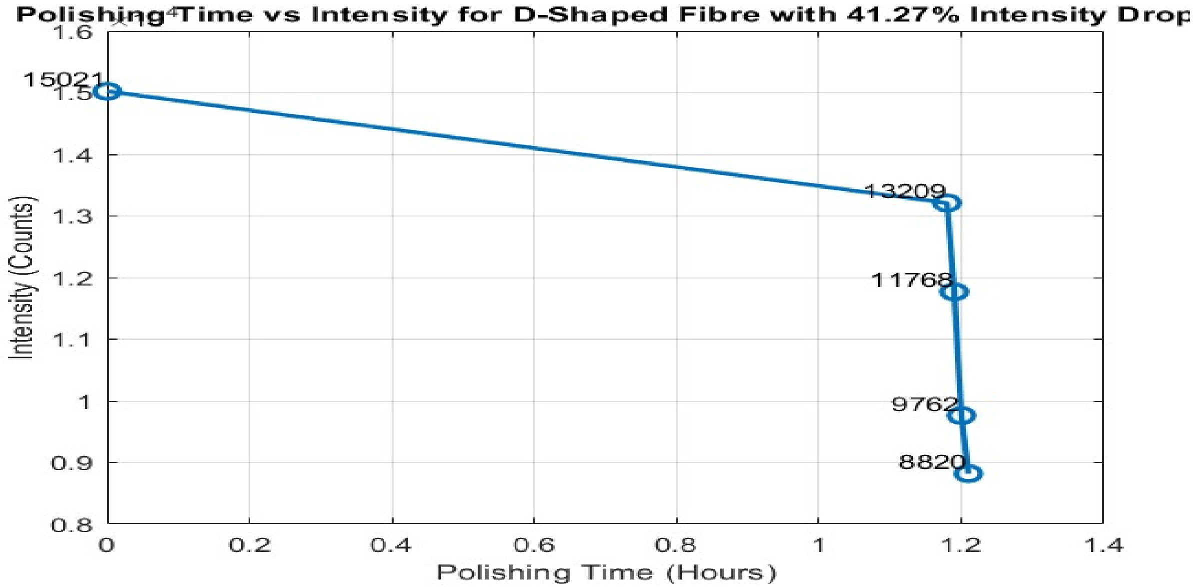


Figure 20: Polishing time vs Intensity D-shaped fibre with 41.27 % Intensity drop

Table 5: Polishing Parameters and Drop in Intensity for D-Shaped Fibres at Varying Polishing speed and Stand Elevations

D-shaped fibre with 23.7 % Intensity drop (Speed of Polishing Wheel – 11.28RPM, Stand 2 - 10cm)		**D-shaped fibre with 41.27 % Intensity drop (Speed of Polishing Wheel – 10.007RPM, Stand 2 – 10.5cm)**	
Polishing Time (Hours)	Intensity (Counts)	Polishing Time (Hours)	Intensity (Counts)
1	14217	0.000139	15021
1.27	13394	1.18	13209
1.28	12156	1,19	11768
1.29	10946	1.20	9762.3
		1.21	8820

METHODOLOGY

Layer by Layer (LBL) of DAR/TSPP Deposition Protocol

- **KOH Solution Preparation**: Dissolve 1 weight percent KOH into a 2:3 water-ethanol solvent. For the deposition procedure, this combination aids in surface preparation of the fibre.
- **DAR Solution Preparation**: Disodium 4,4'-diazoaminobenzene-2,2'-disulfonate) should be diluted with water to a weight percentage of 0.1–0.2 wt%. Cover the vessel with aluminium foil or an opaque container to keep the solution shielded from outside light.
- **TSPP Solution Preparation**: Tetrasodium 4,4',4'',4'''-porphyrin-5,10,15,20-tetrasulfonate hydrate, Mw = 934.99) should be prepared as a 1 mM solution in water.

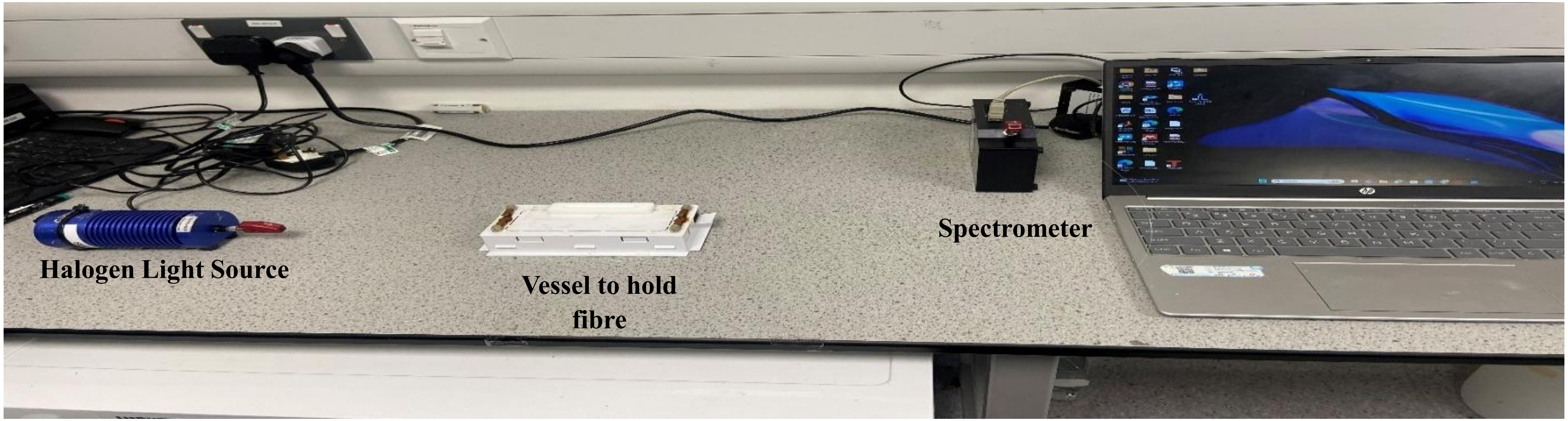


Figure 21: Layer by Layer (LBL) deposition setup

RESULTS AND DISCUSSION

Effectiveness D-Shaped Fiber Fabrication Using Acrylic Mould: Analysis of LBL Deposition Protocol

Table 6: Intensity drop during LBL deposition

Layers	Intensity (Counts)
1 – KOH	11911
2 – DAR	12302
3 – TSPP	11881
4 – KOH	11560
5 – DAR	10445
6 – TSPP	9815
7 – KOH	9612.8

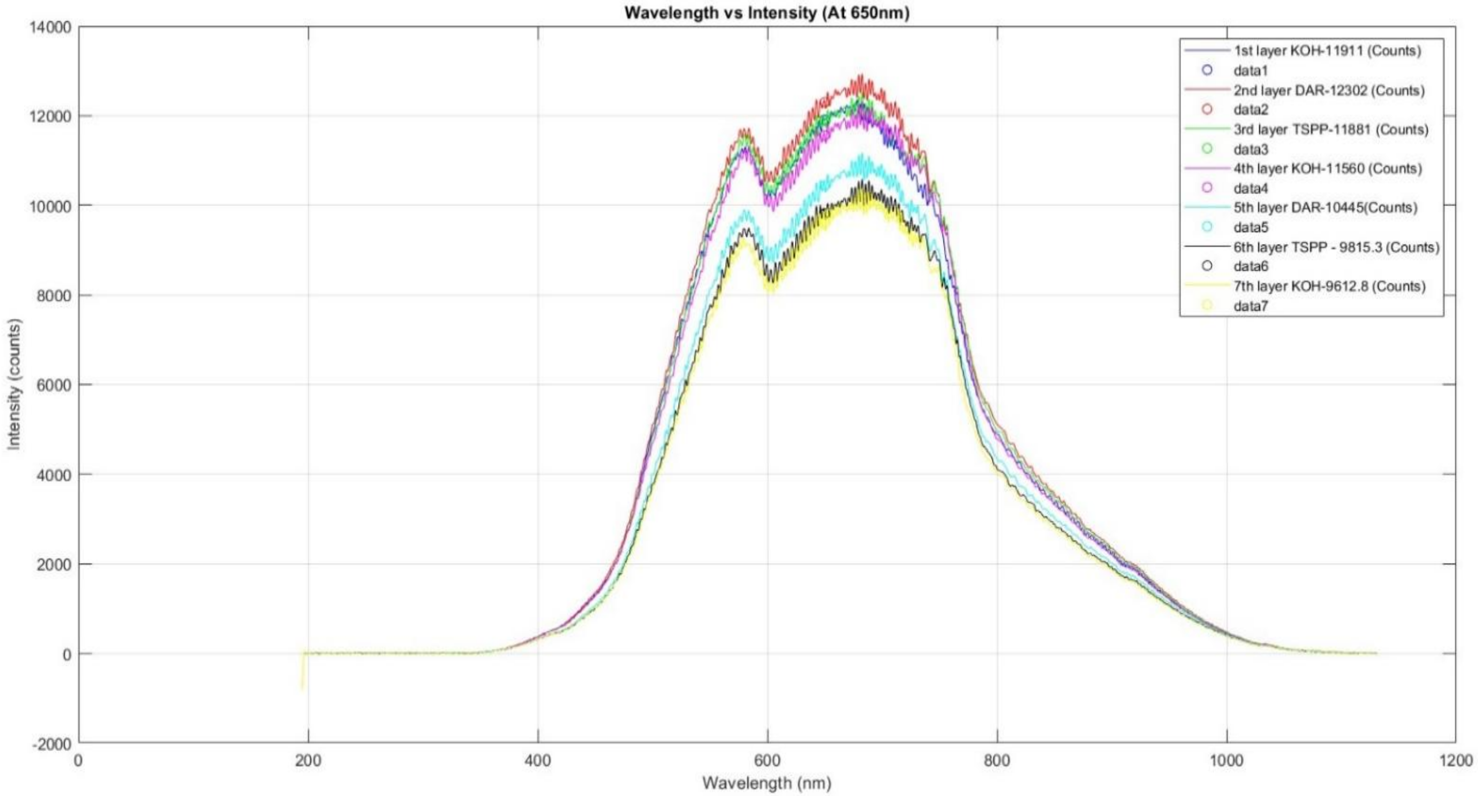


Figure 22: 7 Layers of LBL Deposition (DAR/TSPP Protocol)

METHODOLOGY

Fiber Validation Process

- **Analysis of Different Concentrations of IPA and Deionized Water :** This protocol describes the ideal procedures for assessing how the refractive index and intensity of the polished fibre alter in response to different ratios of IPA to deionised water (DI water).
- **Ammonia Sensing:** To ensure that the sensor operates reliably and precisely, the fibre validation procedure is essential for ammonia sensing.

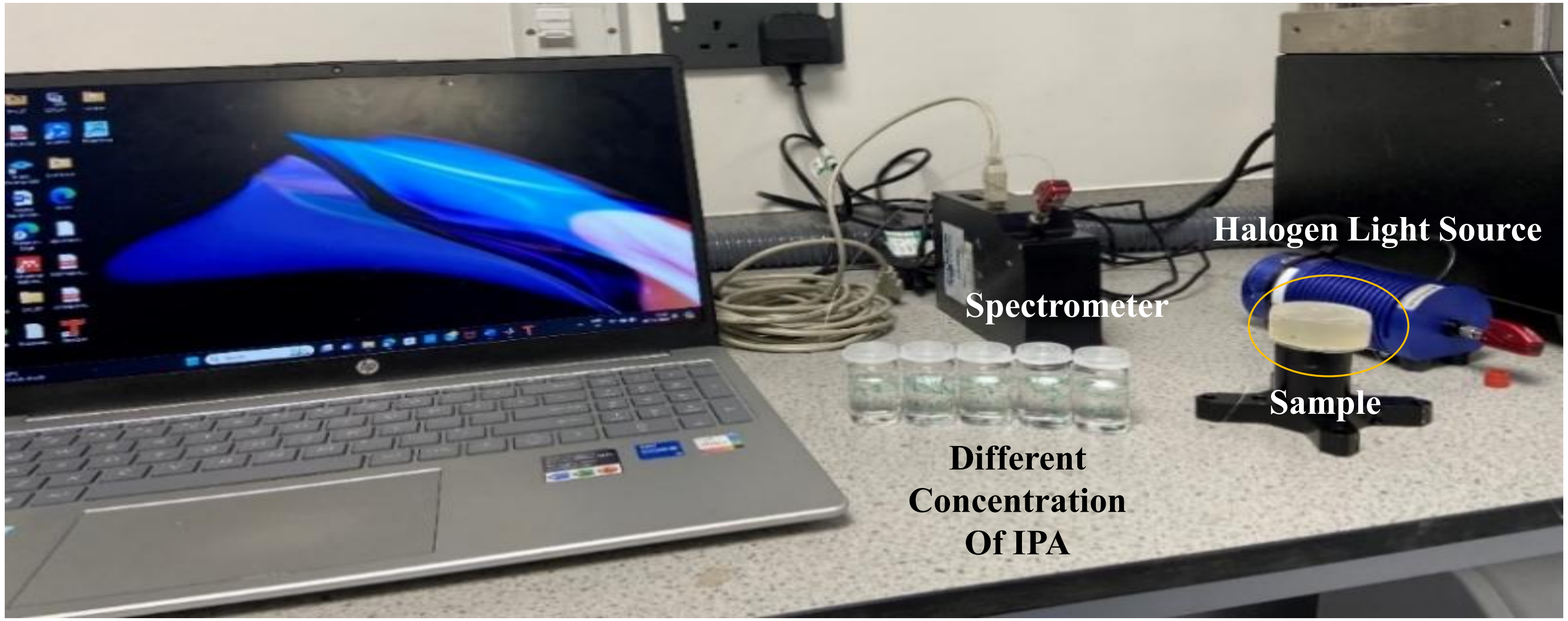


Figure 23: Setup for Analysis of varied IPA Concentrations

RESULTS AND DISCUSSION

Effectiveness D-Shaped Fiber Fabrication Using Acrylic Mould: Analysis of Different Concentrations of IPA and Deionized Water In Increasing Concentrations

Table 3: Increasing IPA Concentrations in Deionised Water: Refractive Index and Intensity at 650 nm

IPA Concentration with Deionised water	Refractive Index	Intensity at 650nm (Counts)
No liquid	1	3260.1
Pure H2O	1.333	8124.3
25% IPA	1.355	8931.2
50% IPA	1.3654	9600.2
75% IPA	1.3741	10517
Pure IPA	1.3780	11008

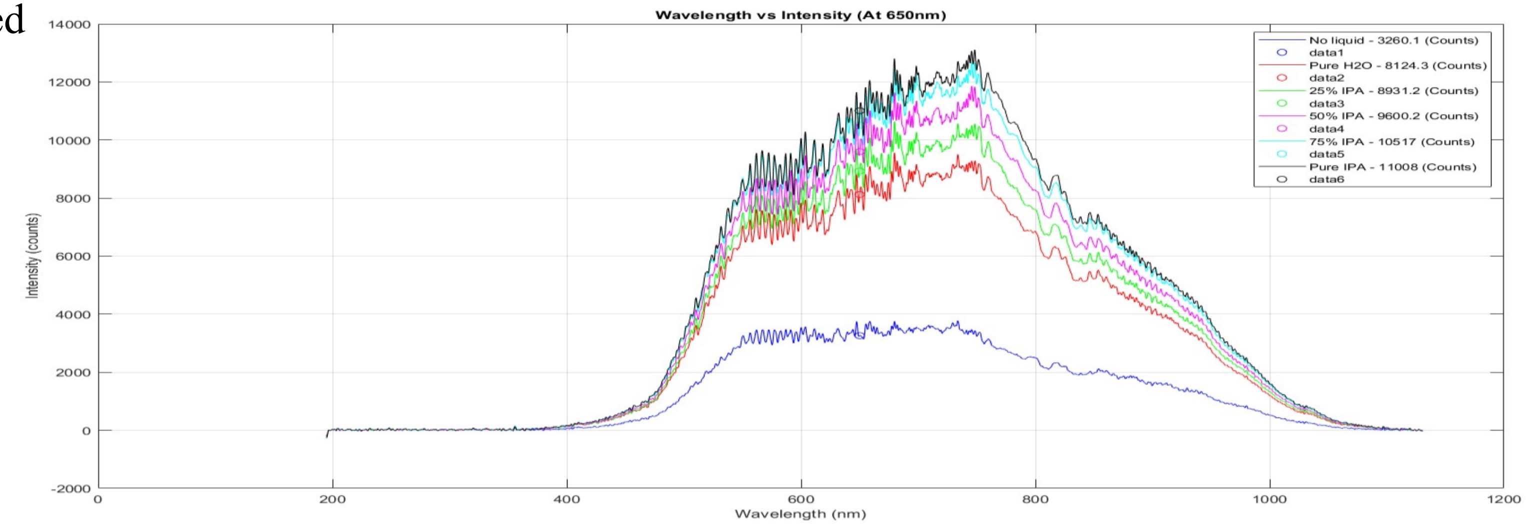


Figure 24: Graph of increasing IPA concentration on D-Shaped fibre in acrylic mould

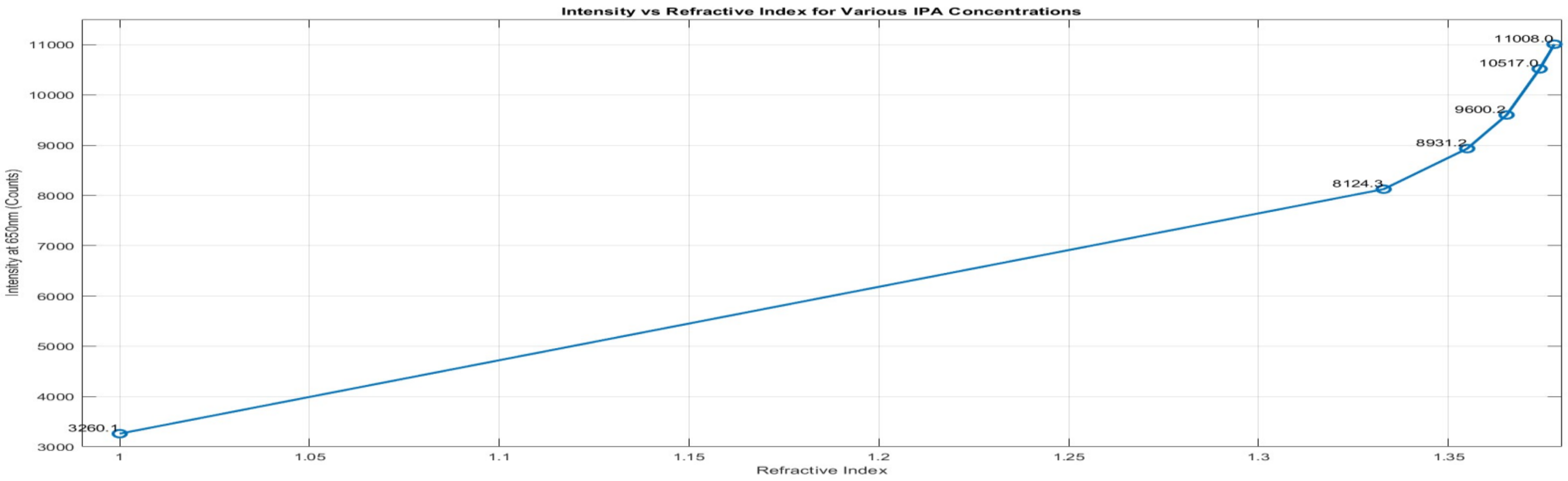


Figure 25: Refractive Index vs intensity for increasing IPA concentration on D-Shaped fibre in acrylic mould

RESULTS AND DISCUSSION

Effectiveness D-Shaped Fiber Fabrication Using Acrylic Mould: Analysis of Different Concentrations of IPA and Deionized Water In Decreasing Concentrations

Table 4: Decreasing IPA Concentrations in Deionised Water: Refractive Index and Intensity at 650 nm

IPA Concentration with Deionised water	Refractive Index	Intensity at 650nm (Counts)
Pure H2O	1.333	8364.3
25% IPA	1.355	9625.9
50% IPA	1.3654	10274
75% IPA	1.3741	10702
Pure IPA	1.3780	11469

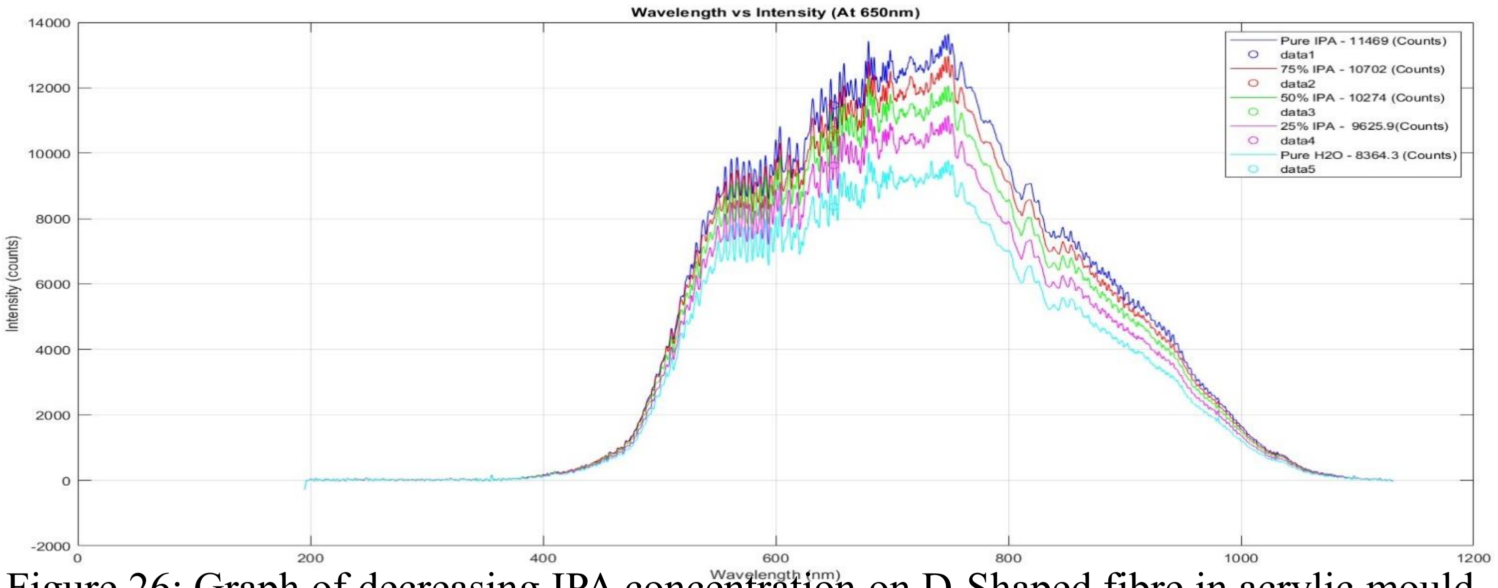


Figure 26: Graph of decreasing IPA concentration on D-Shaped fibre in acrylic mould

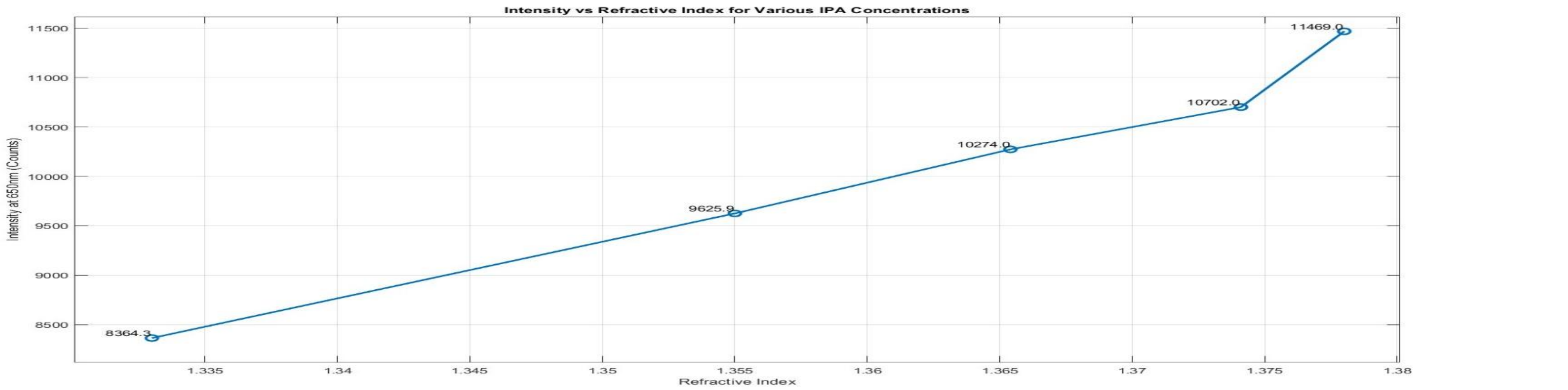


Figure 27: Refractive Index vs intensity for decreasing IPA concentration on D-Shaped fibre in acrylic mould

RESULTS AND DISCUSSION

Effectiveness D-Shaped Fiber Fabrication Using Acrylic Mould: Ammonia Sensing

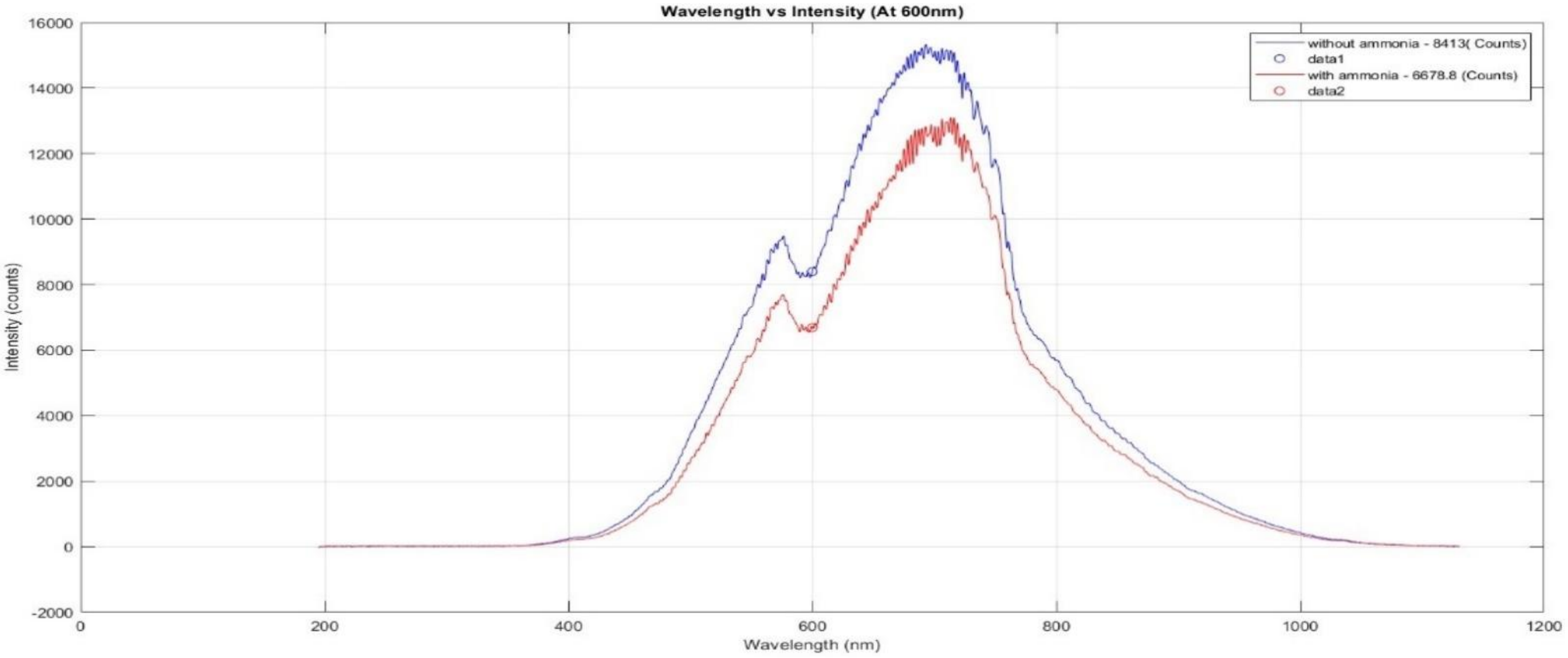


Figure 28: Graph of ammonia sensing with 20% intensity drop

RESULTS AND DISCUSSION

Effectiveness of D-Shaped Fiber Fabrication Using Epoxy Resin

Figure 29: Limitations with fabrication of D-shaped fibre with Epoxy resin

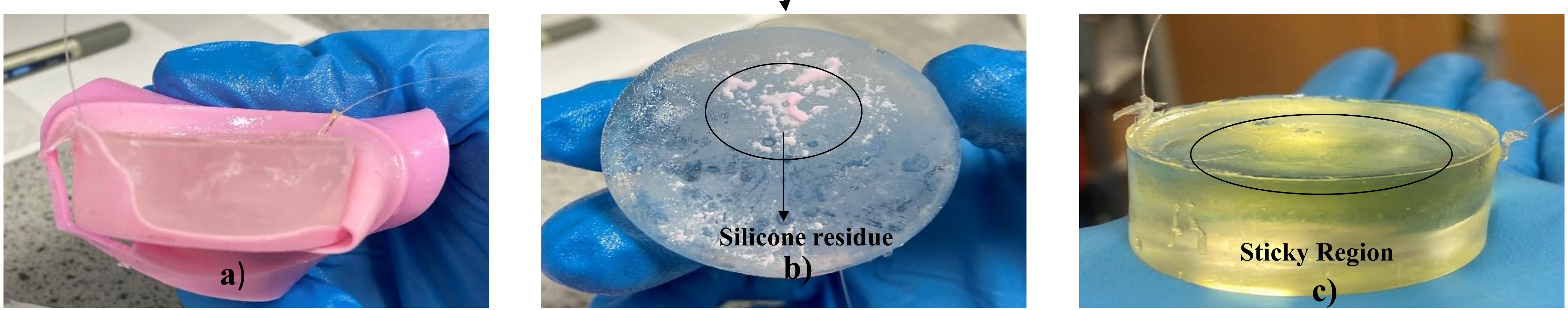


Figure 30: a) Epoxy resin sample with silicone residue, b) Epoxy resin sample with upper sticky region, c) Ripped silicone cup during fabrication process with epoxy resin

RESULTS AND DISCUSSION

CHALLENGES AND LIMITATIONS: Limitations Faced During the Fibre Encapsulation Process

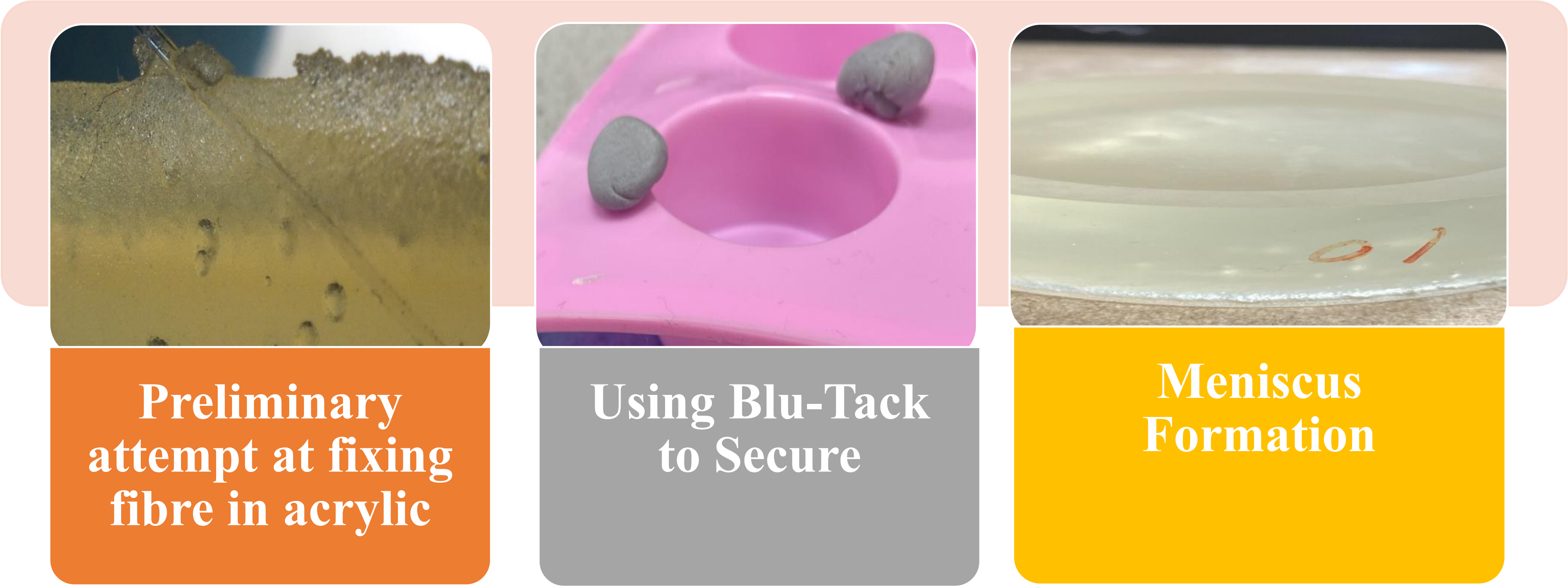


Figure 31: Fiber encapsulation challenges

RESULTS AND DISCUSSION

CHALLENGES AND LIMITATIONS: Fluctuation Based on the Fibers Load Application

A compression effect is specifically shown by a sharp reduction in intensity when the fibre is exposed to the stress.

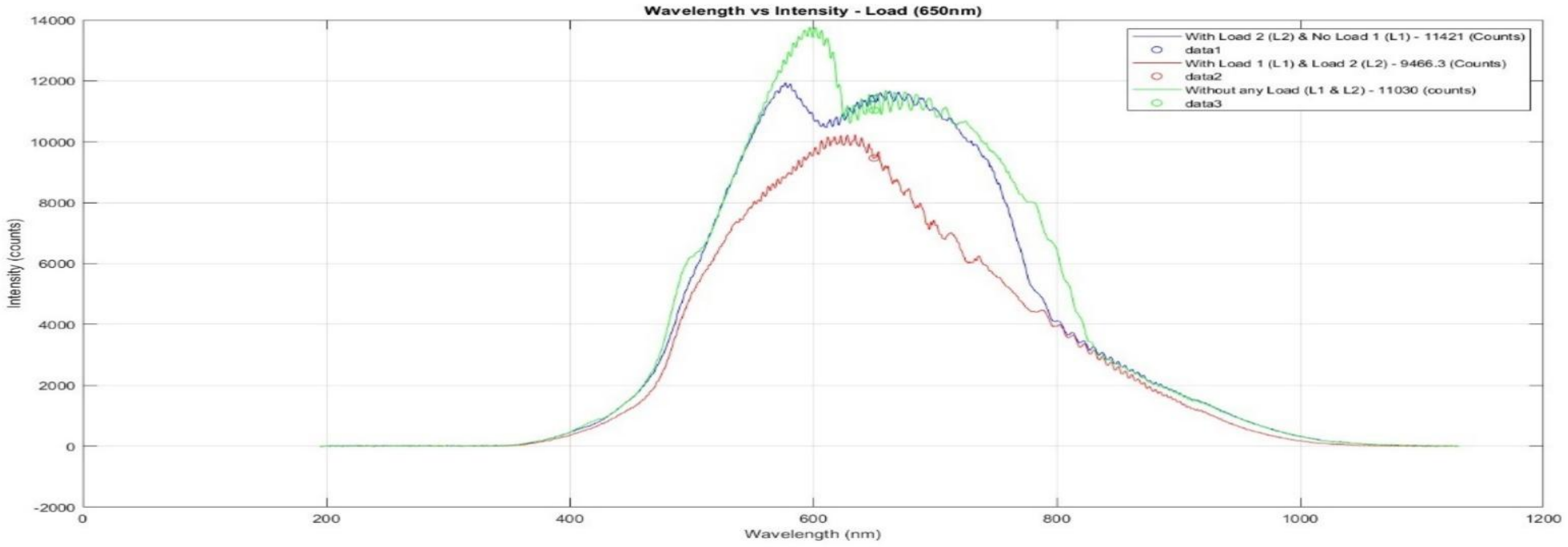
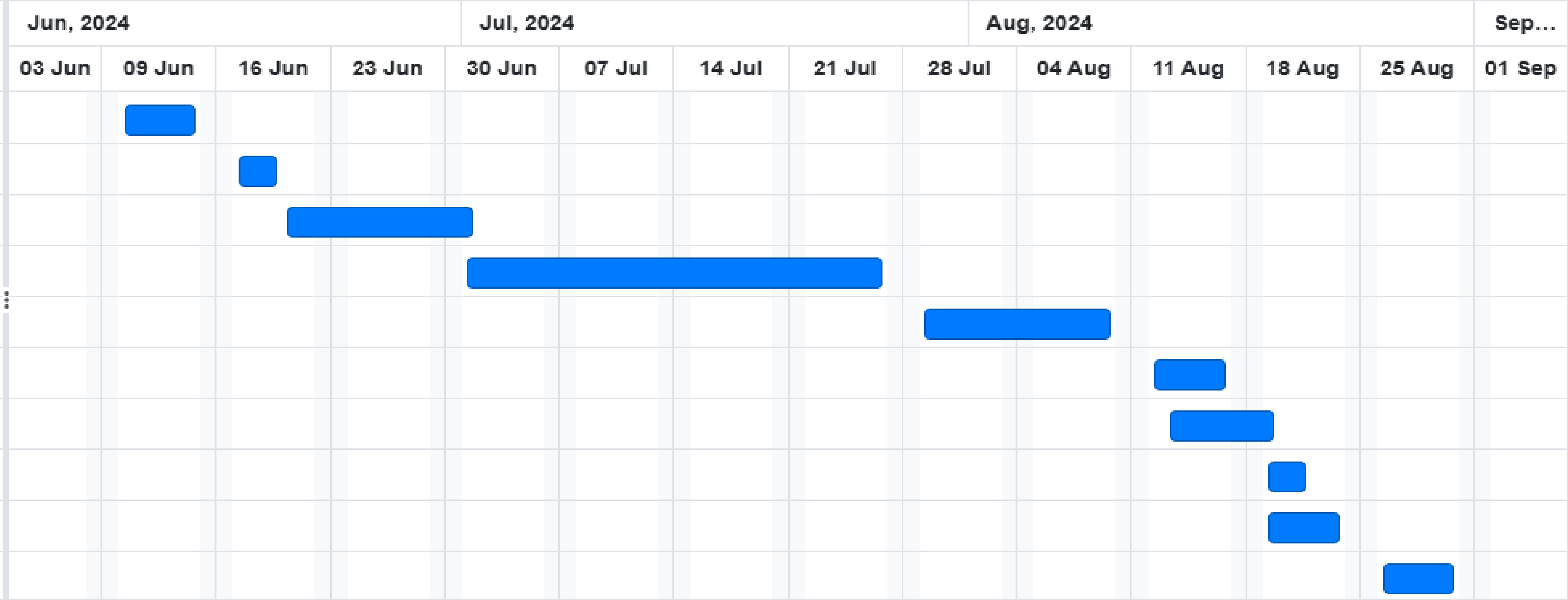


Figure 32: Variation due to Load L1 & L2

REVISED TIMELINE

ID	Name
1	Literature Review
2	Material Selection
3	Preliminary Design and Fabrication
4	Fabrication and Construction of Prototype
5	Design and Testing of D-shaped Fibers Protot…
6	Optimization of the sensor prototype
7	Evaluation of Sensor Performance Metric
8	Testing for Fiber Stability and Durability
9	Technical Report and Presentation Preparation
10	Project Presentation and Finalization



FUTURE WORK

- Proposal to create sensors that use fibres that have 50% intensity drop, which would provide greater sensitivity for applications in biochemical sensing
- Employed in medical diagnostics, such as the biomarkers, the real-time monitoring of blood sugar levels, or vital health indicators
- Investigating the coating of D-Shaped fibres with cutting-edge materials, such Graphene or Nanocomposites, to improve their sensitivity and robustness
- Analysing various D-shaped fibre geometrical alterations and diameter to maximise their performance for certain applications.
- Examine methods of microfabrication to produce D-shaped fibres that are minuscule and sensitive for incorporation into microfluidic system
- Create Bragg Grating on D-shaped sensors

CONCLUSION

- Techniques such as wheel polishing and acrylic mould encapsulation were successfully used to create D-shaped optical fibers.
- Wheel polishing was a successful way to increase the evanescent field interaction which is important for biochemical sensing, through the elimination of cladding
- DAR/TSPP Layer-by-Layer deposition was used to fabricate sensors with 20% intensity drop for identifying minute biochemical interactions such as detection of ammonia.
- This research lays a solid foundation for the development of optical fibre sensors in the future, especially in the field of biochemical sensing.

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