A Fibre Optic Sensor on Acetone Concentration Detection Using Beam-through Technique

This report is submitted in accordance with the requirement of Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

by

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2015
TAJUK: A Fibre Optic Sensor on Acetone Concentration Detection Using Beam-through Technique

SESUAI PENGAJIAN: 2015/16 Semester 2

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I hereby, declare that this thesis entitled “A Fibre Optic Sensor on Acetone Concentration Detection Using Beam-through Technique” is the result of my own research except as cited in references.

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Date : ……….. January 2016
This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor’s Degree of Electronic Engineering Technology (Telecommunications) (Hons.). The member of the following supervisory is as follow:

(Project Supervisor)
ABSTRACT

The design of current sensor technology especially when related to the chemical still requires a certain degree of the quantitative reliability. The conventional chemical-related sensor may enable a cross sensitivity to happen as the chemical used as the parameter requires an ultra active electrode catalyst and a high operating potential for its oxidation. In this case, chemical substances that are more easily oxidised such as alcohol and carbon monoxide could interfere the sensitivity of the sensor. The chemical such as acetone is mostly to be found in the bodily fluid during the fasting period especially those who are in a diabetic condition. Along with glucose, the acetone level may also need to be monitored as it could indicate the severity of the diabetes. Thus a fibre optic sensor which is more inert to the oxidation reaction may be developed. Fibre optic sensor has gained much attention in the research field, as it is considered to be more sensitive, fast detection rate and reliable sensors. The development of fibre optic sensor on acetone detection by using beam-through technique could be a milestone in the health and sensor field.

*Keyword:* fibre optic sensor, acetone detection, beam-through technique
ABSTRAK

Rekaan teknologi sensor pada masa kini terutama yang melibatkan bahan kimia, masih memerlukan kebolehpercayaan pada tahap tertentu. Sensor konvensional yang berkaitan dengan kimia boleh menyebabkan berlakunya sensitiviti silang kerana bahan kimia yang digunakan sebagai perimeter memerlukan pemangkin elektrod yang sangat aktif dan potensi operasi yang tinggi untuk proses pengoksidaan. Dalam hal ini bahan kimia yang lebih senang untuk berlakunya proses pengoksidaan seperti alkohol dan karbon monoksida boleh mengganggu kepekaan sensor tersebut. Bahan kimia seperti aseton kebanyakannya boleh dijumpai dalam bendalir badan sewaktu tempoh berpuasa terutamanya bagi golongan yang mengidap diabetes. Selain glukosa, paras aseton dalam badan juga perlu untuk dipantau kerana ia boleh menunjukkan betapa tahap parah diabetes itu Oleh itu sensor berasaskan gentian optik yang lebih tidak reaktif kepada tindak balas pengkosidaan boleh dibangunkan. Sensor berasakan gentian optik telah mendapat sambutan meluas dalam bidang penyelidikan, kerana ia dianggap sebagai lebih sensitif, kadar pengesanan yang tinggi, san sensor yang booleh dipercayai. Pembangunan sensor berasaskan gentian optic terhadap pengesanan aseton menggunakan teknik pancaran-terus boleh menjadi bermakna dalam bidang kesihatan dan bidang sensor.

Kata kunci: sensor berasaskan gentian fiber, pengesanan aseton, teknik pancaran terus
DEDICATION

To my mother, Madam Agnes Mawal, who has taught me that knowledge is gold.
Thanks be to God, who with His willing; giving me the opportunity to complete this Final Year Project entitled Fibre Optic Sensor on Acetone Detection Using Beam-through Technique. This final year project report was prepared for Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), basically for student in final year to complete the undergraduate programme that leads to the Bachelor Degree in Electronic Engineering Technology (Telecommunications).

Firstly, I would like to express my deepest thanks to, Mr. Md Ashadi Md Johari, a lecturer at Faculty of Engineering Technology, UTeM, and also assigned as my supervisor who had guided me throughout this project. Many thanks also to Mr. Azham Akram Abdullah for allowing me to conduct this project in his laboratory.

With much gratitude and appreciation to my parents, family, special mate of mine, and others for their cooperations, encouragement, constructive suggestion and supports for the report completion, from the beginning till the end. Also thanks to all of my friends and everyone, that have been contributed by supporting my work and help myself during the final year project progress till it is fully completed.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>Degree Celcius</td>
</tr>
<tr>
<td>(CH₃)₂CO</td>
<td>Acetone / propane-2-one</td>
</tr>
<tr>
<td>[CH₃COCH₂COH(CH₃)₂]</td>
<td>Diacetone alcohol</td>
</tr>
<tr>
<td>Δ</td>
<td>Birefringence</td>
</tr>
<tr>
<td>μm</td>
<td>Micrometre</td>
</tr>
<tr>
<td>μm / rad</td>
<td>Micrometre per radian</td>
</tr>
<tr>
<td>Λ</td>
<td>Wavelength</td>
</tr>
<tr>
<td>2-[14C]-acetone</td>
<td>2-Carbon-14 acetone</td>
</tr>
<tr>
<td>3D</td>
<td>Three dimensional</td>
</tr>
<tr>
<td>A</td>
<td>Core radius</td>
</tr>
<tr>
<td>AO</td>
<td>Acousto-optics</td>
</tr>
<tr>
<td>AOT</td>
<td>Dioctyl sodium sulfosuccinate</td>
</tr>
<tr>
<td>CH₃•CO•CH₂•COH(CH₃)₂</td>
<td>Diacetone alcohol</td>
</tr>
<tr>
<td>CH₃•CO•CH₃</td>
<td>Acetone / propane-2-one</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CTL</td>
<td>Cataluminescence</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DKA</td>
<td>Diabetic Ketoacidosis</td>
</tr>
<tr>
<td>FBG</td>
<td>Fibre Bragg Gratings</td>
</tr>
<tr>
<td>FO-SPR</td>
<td>Fibre Optic Surface Plasmon Resonance</td>
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<td>FOBDS</td>
<td>Fibre Optic Bundle Displacement Sensor</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------------</td>
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<tr>
<td>FODS</td>
<td>Fibre optic displacement sensor</td>
</tr>
<tr>
<td>He-Ne</td>
<td>Helium-Neon</td>
</tr>
<tr>
<td>HRTEM</td>
<td>High-resolution transmission electron microscopy</td>
</tr>
<tr>
<td>IO</td>
<td>Inverse Opals</td>
</tr>
<tr>
<td>IUPAC</td>
<td>International Union of Pure and Applied Chemistry</td>
</tr>
<tr>
<td>LDO</td>
<td>Layered double oxide</td>
</tr>
<tr>
<td>MBK</td>
<td>Methyl iso-butyl Ketone</td>
</tr>
<tr>
<td>mFBG</td>
<td>Microfibre Bragg Gratings</td>
</tr>
<tr>
<td>mg / dL</td>
<td>Milligram per decilitre</td>
</tr>
<tr>
<td>mM</td>
<td>Millimole</td>
</tr>
<tr>
<td>MMZI</td>
<td>Microfibre Mach-Zehnder interferometre</td>
</tr>
<tr>
<td>MOX</td>
<td>Metal Oxide</td>
</tr>
<tr>
<td>mV / %</td>
<td>Millivolt per percentage</td>
</tr>
<tr>
<td>MWCNT</td>
<td>Multiwall carbon nanotubes</td>
</tr>
<tr>
<td>NH&lt;sup&gt;+&lt;/sup&gt;</td>
<td>Ammonium ion</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Ammonia</td>
</tr>
<tr>
<td>nm</td>
<td>Nanometre</td>
</tr>
<tr>
<td>Nm / %</td>
<td>Nanometre per percent</td>
</tr>
<tr>
<td>PAA-ran-PAAPBA</td>
<td>Borate polymer</td>
</tr>
<tr>
<td>PAni</td>
<td>Polyaniline</td>
</tr>
<tr>
<td>PdAu</td>
<td>Lead-Gold</td>
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<tr>
<td>PMMA</td>
<td>Polymethylmethacrylate</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts per million</td>
</tr>
<tr>
<td>RI</td>
<td>Refractive index</td>
</tr>
<tr>
<td>RIU</td>
<td>Refractive-index unit</td>
</tr>
<tr>
<td>RSD</td>
<td>Relative standard deviation</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning electron microscope</td>
</tr>
<tr>
<td>SMF</td>
<td>Single Mode Fibre</td>
</tr>
<tr>
<td>SMS</td>
<td>Single-mode-multi-mode-single-mode</td>
</tr>
<tr>
<td>SPA</td>
<td>Surface plasmon sensor</td>
</tr>
<tr>
<td>SnO$_2$</td>
<td>Tin Oxide</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>VOCs</td>
<td>Volatile Organic Compounds</td>
</tr>
<tr>
<td>WO$_3$</td>
<td>Tungsten trioxide</td>
</tr>
<tr>
<td>XPS</td>
<td>Xray Photoelectron Microscopy</td>
</tr>
<tr>
<td>XRD</td>
<td>Xray Powder Diffraction</td>
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<tr>
<td>ZnO-CuO</td>
<td>Zinc Oxide – Copper Oxide</td>
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CHAPTER 1
INTRODUCTION

1.1 Introduction

This chapter discusses about the project background, the problem statement, objectives of the project, project limitation and the scope of the project.

1.2 Background

A sensor is a device that is used to sense some characteristic of its environs. It detects events or changes in quantities and provides a corresponding output. Technological progress allows more and more sensors to be manufactured on a microscopic scale as micro-sensors. In most cases, a micro-sensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches.

In recent years, fibre optic sensors received more considerable research efforts as the need for more sensitive and reliable sensors to measure a large range of physical, chemical and biomedical quantities. These research efforts are done due to the fact that fibre optic sensor has a potential sensitivity, detection speed and abilities to the widely assay condition.

Acetone is an organic compound with the formula \((\text{CH}_3)_2\text{CO}\). It is a colourless, volatile, flammable liquid, and is the simplest ketone. Its IUPAC (International Union of Pure and Applied Chemistry) name is propan-2-one.

Along with acetoacetate and β-hydroxybutyrate, acetone is produced in periods of glucose deficiency or insulin insufficiency as an alternative energy source. All these three
substances are commonly known as ketone body. Measurements of ketone in urine and blood are widely used in the management of patients with diabetes as adjuncts for both diagnosis and ongoing monitoring of Diabetic Ketoacidosis (DKA).

Overall this project is mainly focusing on the fibre optic sensor of acetone detection using beam-through technique development.

1.3 Problem Statement

A precise and highly sensitive sensor is highly preferred when it comes to measurement and analyse a chemical substance. In medical laboratories for example, a blood sample is obtained from a diabetic ketoacidosis patient and thus it requires an accurate and precise acetone concentration information for further evaluation.

Various kind of sensors have been developed nowadays. In general, the chemical sensors are broadly classified into gas, liquid, and solid particulate sensors based on the phases of the analyte. They can be further categorised as optical, electrochemical, thermometric, and gravimetric (mass sensitive) sensors according to the operating principle of the transducer. The design of chemical sensors also requires appreciation of the needed degree of quantitative reliability (precision or accuracy).

An electrochemical sensor for an example, has been also introduced to determine the chemical concentration. Nonetheless, a cross sensitivity could happen because the chemical that is used as the might require a very active working electrode catalyst and high operating potential for its oxidation. In this case a chemical substance which are more easily oxidised such as alcohol and carbon monoxide could interfere the sensitivity of the sensor.

Thus, a fibre optic sensor is proposed and developed to overcome these problems. This fibre optic sensor could be a milestone in the health and sensor field.
1.4 Objective

The objectives of this project are:

i. To study fibre optic sensor
ii. To develop fibre optic sensor for acetone detection
iii. To analyse the performance of fibre optic for different value of acetone concentration

1.5 Limitation

This project would be implemented by optimising the usage of fibre optics sensor based on beam-through technique. This sensor will be used to detect the concentration of acetone.

1.6 Scope

Although there are various techniques used in fibre optic sensor, but this study will only cover fibre optic sensor based on beam-through technique. Neither the acetone physical properties nor the chemical properties of acetone will be studied in this paper. Instead, this study will mainly focus on the application of fibre optic as a sensor for the detection of acetone concentration.
CHAPTER 2
THEORETICAL BACKGROUND

2.1 Introduction

This chapter will provide the review form previous research that is related to this final year project. There are previous researches understanding on the fibre optic sensor, technique used in fibre optic sensor, the role of acetone in the diabetic ketoacidosis, acetone in industrial usage, and the current acetone sensor.

2.2 Fibre Optic

(a) A cylindrical glass fibre core cladded by lower refractive index glass.
(b) Light rays incident are trapped inside the fibre core.

Figure 2.1 Basic anatomy and mechanism of fibre optic

Figure 2.1 shows an optical fibre, which consists of a (cylindrical) central dielectric core (of refractive index \( n_1 \)) cladded by a material of slightly lower refractive index \( n_2 \) (\( < n_1 \)). The necessity for a cladded fibre rather than a bare fibre (i.e., without cladding), arises from the fact that for transmission of light from one place to another, the fibre must be...
supported, and supporting structures may distort the fibre considerably, thereby affecting the guidance of the light wave. This can be avoided by choosing a sufficiently thick cladding. When the core radius \( a \) is large (≈ 25 \( \mu \text{m} \) or more); \( a \) more detailed description of single and multimode fibre is given in the next section. For a typical (multimode) fibre, \( a \approx 25 \mu\text{m}, n_2 \approx 1.45 \) (pure silica), and \( \Delta \approx 0.01 \), giving a core index of \( n_1 \approx 1.465 \). The cladding is usually pure silica, while the core is usually silica doped with germanium; doping by germanium results in an increase in the refractive index.[1]

2.3 Fibre Optic Sensor

Figure 2.2 Schematic of a fibre optic sensing system

Figure 2.2 is a schematic diagram of a fibre optic sensor system. Light from a suitable source is coupled into an optical fibre. The external disturbance modifies some property of the light beam, which is then guided through the optical fibre to a detector. Fibre optic sensors can be classified broadly into two categories: extrinsic and intrinsic. In extrinsic sensors, the optical fibre simply acts as a device to transmit and collect light from a sensing element that is external to the fibre. The sensing element responds to the external perturbation, and the change in the characteristics of the sensing element is transmitted by the return fibre for analysis. The optical fibre here plays no role other than transmitting the light beam to and from the sensing region. Such fibre optic sensors are easy to design and fabricate and relatively inexpensive. Examples of such sensors are
Doppler anemometers, noncontact vibration measurement, and pressure sensors which find wide applications in automobiles and aerospace, for example.[1]

2.3.1 Fibre optic surface plasmon resonance sensor

Singh and Gupta (2013) [2] reported that the fabrication and characterisation of a surface plasmon resonance (SPR) based fibre optic sensor, working on wavelength interrogation method, to measure the low glucose concentration (similar to the human blood) in aqueous fluid. The sensing probe is prepared by coating of films of silver and silicon on the optical fibre core followed by immobilisation of enzyme (glucose oxidase) using gel entrapment method.

![Variation of resonance wavelength with the concentration of glucose](image)

**Figure 2.3** Variation of resonance wavelength with the concentration of glucose

Experimental results on SPR spectra show a blue shift in the resonance wavelength on increase in the concentration of the glucose in samples. Further, the sensitivity of the sensor decreases as the concentration of the glucose increases whereas the detection accuracy is almost independent of the glucose concentration. In addition, for 80 mg/dL glucose concentration, the influence of pH of the sample on the performance of the sensor