



UNIVERSITI PUTRA MALAYSIA

MICROWAVE-BASED TECHNIQUE FOR GLUCOSE DETECTION

**NORA SALINA BINTI MD SALIM
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MICROWAVE-BASED TECHNIQUE FOR GLUCOSE DETECTION

By

NORA SALINA BINTI MD SALIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirement for the Degree of Master of Science

April 2010



DEDICATION

**Specially dedicated to my beloved family
and all my friends.**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
Fulfillment of the Requirement for the Degree of Master of Science

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Chairman : Prof. Dr. Kaida bin Khalid, PhD

Faculty : Science

Glucose biosensor is generally based on reaction between glucose and enzyme glucose oxidase (GOD) that produces gluconic acid and hydrogen peroxide. The gluconic acid is a conducting medium while hydrogen peroxide is a polar molecule. This work discovers the changes of dielectric properties due to conductive loss below 4 GHz and dipole orientation of above 4 GHz of this reaction. The difference between the dielectric properties of an enzyme and glucose-enzyme reaction can be related to the glucose concentration in the sample. The dielectric properties of glucose solutions, enzyme GOD and glucose-enzyme reaction were measured using the Open Ended Coaxial Probe with frequency range from 200 MHz to 20 GHz at room temperature (25 °C). Two types of juice are used in this study; blackcurrant juice and lychee juice. The actual glucose content in juice samples were analyzed using High Performance Liquid Chromatography method. This



technique has also been applied using the microstrip sensor for measuring glucose concentration in glucose solution, blackcurrant juice and lychee juice. The result shows that the highest sensitivity for the differences in dielectric changes with glucose concentrations due to the effect of ionic conductivity and dipole orientation were found at 0.99 GHz and 16.44 GHz respectively. The changes in dielectric loss are preferable for derivation of glucose concentration. In this proposed technique, the detection limit of glucose concentration is as low as 0.01 M (0.20 g/100 ml) with optimum ratio of 1:3 for an enzyme and glucose. Lychee juice has a higher dielectric loss difference for both frequencies followed by blackcurrant juice and glucose solution due to the contribution of free ions in the juice. The sensitivity of attenuation measurement using microstrip sensor is dependent on the dielectric loss of materials. The sensitivity of measurement about 0.002 dB/(mg/ml) at 0.99 GHz and 0.004 dB/(mg/ml) at 16.44 GHz which are comparable to the current microwave techniques. This technique gives benefit to the future development of microwave biosensor by which both ionic conductivity and dipole effects are occurred simultaneously.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi syarat keperluan untuk ijazah Master Sains

**TEKNIK BERASASKAN MIKROGELOMBANG UNTUK
MENGESAN GLUKOSA**

Oleh

NORA SALINA BINTI MD SALIM

April 2010

Pengerusi : Prof. Dr. Kaida bin Khalid, PhD

Fakulti : Sains

Biosensor glukosa secara umumnya berasaskan tindakbalas antara glukosa dan enzim glukosa oksidase (GOD) yang menghasilkan asid glukonik dan hidrogen peroksida. Asid glukonik adalah bahan konduktif manakala hidrogen peroksida adalah molekul berkutub. Penyelidikan ini menemukan perubahan sifat dielektrik pada tindakbalas adalah berdasarkan pada kehilangan pengkonduksian elektrik bawah 4 GHz dan orientasi dwikutub atas 4 GHz. Perubahan di antara sifat dielektrik enzim dan glukosa-enzim digunakan untuk menghubungkan kepekatan glukosa dalam sampel. Sifat dielektrik larutan glukosa, enzim GOD dan tindakbalas glukosa-enzim diukur menggunakan sensor dwipaksi terbuka hujung dengan julat frekuensi dari 200 MHz hingga 20 GHz pada suhu bilik (25 °C). Dua jenis jus digunakan dalam penyelidikan ini; jus blackcurrant dan jus laici. Nilai asal kandungan glukosa dalam sampel jus di analisis menggunakan kaedah cecair kromatografi berkuasa tinggi. Teknik ini juga diaplikasikan

menggunakan microstrip sensor untuk mengukur kepekatan glukosa dalam larutan glukosa, jus blackcurrant dan jus laici. Hasil menunjukkan bahawa sensitiviti paling tinggi bagi perubahan dielektrik dengan kepekatan berdasarkan kesan konduktiviti ionik dan orientasi dwikutub masing-masing telah dikenalpasti pada 0.99 GHz dan 16.44 GHz. Perubahan kehilangan dielektrik adalah bersesuaian dalam menentukan kepekatan glukosa. Dalam teknik yang digunakan ini, had untuk mengesan kepekatan glukosa adalah serendah 0.01 M (0.20 g/100 ml) dengan nisbah optimum 1:3 untuk enzim dan glukosa. Jus laici mempunyai perubahan kehilangan dielektrik yang tinggi untuk kedua-dua frekuensi diikuti jus blackcurrant dan larutan glukosa disebabkan kehadiran ion bebas yang terdapat di dalam jus. Sensitiviti pengukuran penghantaran menggunakan sensor microstrip bergantung kepada kehilangan dielektik bahan. Sensitiviti penghantaran pengukuran adalah 0.002 dB/ (mg/ml) pada 0.99 GHz dan 0.004 dB/ (mg/ml) pada 16.44 GHz yang mana ianya boleh dibandingkan dengan teknik mikrogelombang yang sedia ada. Teknik ini akan memberi faedah untuk pembangunan biosensor mikrogelombang pada masa hadapan dengan mengambilkira kesan konduktiviti ionik dan dwikutub secara serentak.

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I certify that a Thesis Examination Committee has met on 8 April 2010 to conduct the final examination of Nora Salina Binti Md Salim on her thesis entitled "Microwave-based Technique for Glucose Detection" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Azmi Zakaria, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jumiah Hassan, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Wan Mohd. Daud Wan Yusoff, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Muhammad Mat Salleh, PhD

Professor
Institute of Microengineering and Nanoelectronics (IMEN)
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

BUJANG KIM HUAT, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:



This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

KAIDA KHALID, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

NOR AZAH YUSOF, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10 June 2010



DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declared that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

NORA SALINA BINTI MD SALIM

Date: 8 April 2010

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xx
LIST OF SYMBOLS	xxi
CHAPTER	
1 INTRODUCTION	
1.1 Microwaves	1
1.2 Advantages of Microwave Method	2
1.3 Glucose Biosensor	3
1.3.1 Glucose Reaction	4
1.4 Microwave-Based Technique for Glucose Detection	8
1.5 Objectives	9
1.6 Thesis Outline	10
2 LITERATURE REVIEW	
2.1 Biosensor Transducer	12
2.2 Previous Research of Glucose Biosensor Detection System	
2.2.1 Electrochemical Sensor	15
2.2.2 Field Effect Transistor	18
2.2.3 Optical transducer	19
2.3 Microwave Techniques for Glucose Detection	19
3 THEORETICAL AND BASIC THEORY	
3.1 Dielectric Polarization	21
3.2 Theory of Permittivity	24
3.2.1 Frequency Effect	25
3.2.2 Temperature Effects	29
3.2.3 Moisture Effects	31
3.3 Technique for Microwave Dielectric Properties Measurement	32
3.4 Open-Ended Coaxial Probe	33



3.5	Microstrip Transmission Lines	35
3.5.1	System Signal Flow Graph	37
3.5.2	Dielectric Loss in Microstrip	39
4	MATERIALS AND METHODS	
4.1	Sample Preparation	43
4.1.1	Glucose Monohydrate	44
4.1.2	Glucose Oxidase	44
4.1.3	Gluconic Acid	44
4.1.4	Hydrogen Peroxide	45
4.1.5	Fruit Juices	45
4.2	Dielectric Properties Measurement	45
4.2.1	Calibration Procedures	46
4.2.2	Experimental Procedures	46
4.3	Standard Methods of Measuring Glucose Content	48
4.4	Attenuation Measurement of Glucose Reaction	48
4.4.1	Calibration Procedures	49
5	RESULTS AND DICUSSION	
5.1	Dielectric Properties of Glucose	51
5.2	Dielectric Properties of Glucose Oxidase	54
5.2.1	Repeatability of Bottle Dilution	55
5.2.2	Variation with Temperature	56
5.3	Dielectric Properties of Glucose Reaction with Glucose Oxidase	59
5.3.1	Gluconic Acid	59
5.3.2	Hydrogen Peroxide	60
5.3.3	Optimized Ratio and Best Frequency of Glucose-Enzyme Reaction	61
5.3.4	Detection Limit	68
5.4	Dielectric loss of glucose oxidase,gluconic acid and mixture of glucose-enzyme reaction at 1:3 (enzyme:glucose)	69
5.5	High Performance Liquid Chromatography (HPLC) Method	72
5.6	Microwave-based Technique Applied in Fruit Juices	73
5.6.1	Blackcurrant Juice	74
5.6.2	Lychee Juice	78
5.6.3	Variations of the Dielectric Loss Factor of the Sample before Reaction and Dielectric Loss Changes between Glucose-Enzyme Reaction and Enzyme.	82
5.7	Attenuation Measurement Using Microstrip Sensor	84

5.7.1	Optimum Volume	84
5.7.2	Variation of Attenuation for Glucose-Enzyme Reaction	85
5.7.3	Variation of Attenuation with Glucose Concentration in Blackcurrant Juice	88
5.7.4	Variation of Attenuation with Glucose Concentration in Lychee Juice	91
5.7.5	Variations of Attenuation of the Sample before Reaction and Difference in Attenuation for Glucose-Enzyme Reaction with Enzyme	93
6	CONCLUSION AND FUTURE WORKS	
6.1	Conclusion	96
6.2	Future Works	98
	REFERENCES	99
	APPENDICES	107
	BIODATA OF STUDENT	123
	LIST OF PUBLICATIONS	124



LIST OF TABLES

Table		Page
1.1	General characteristics of gluconic acid	7
3.1	Dielectric Properties of Water and Ice at 2.4 GHz	32
5.1	Comparison of dielectric properties of enzyme between without freeze and after freeze at temperature, 25 °C	58
5.2	Composition of sugar analysis by HPLC	73



LIST OF FIGURES

Figure		Page
1.1	The electromagnetic spectrum	1
1.2	Configuration of a biosensor showing biochemical recognition, interface, and transduction elements	4
1.3	Molecule chain for glucose reaction with glucose oxidase	5
1.4	Lock and key theory	6
2.1	A glucose biosensor based on the Clark oxygen electrode	16
2.2	Schematic layout of a Clark biosensor for glucose	17
3.1	Various Types of Polarisation	23
3.2	The probable occurrence of the various types of polarisation and the dependence of permittivity with respect to frequency.	23
3.3	Mechanisms contributing to the effective loss factor of moist material as a function of frequency in Hz: i , Maxwell-Wagner polarization; c , dc conductivity; b , dipolar polarization of bonded water; w , dipolar polarization of free water	26
3.4	The dielectric behavior of free water at a constant temperature	28
3.5	Real and imaginary part of the complex permittivity, ϵ of water plotted versus frequency, ν .	29
3.6	Effect of temperature on dielectric constant, ϵ' and loss factor, ϵ'' of free water ($\omega=2\pi f$, f = frequency in Hz)	30
3.7	Effect of increasing temperature for conductivity at low frequencies and free water at higher frequencies	31

3.8	A coaxial probe, showing the electric field lines which fringe from the end of the sensor into the dielectric that is being measured	33
3.9	(a) Microstrip sensor. (b) Cross section of microstrip sensing region	36
3.10	Semi-infinite double covered microstrip line	36
3.11	Flow Graph of the Sensor as a Cascaded Two-port Network	38
3.12	Simplified signal flow graph using Mason's nontouching loop rule. (a) Simplified signal flow graph. (b) Final form in terms of scattering parameters of the input and output ports	38
4.1	Experimental Set-up for Dielectric Properties of glucose solutions and glucose-enzyme reaction using Open Ended Coaxial Probe (OECF) coupled with computer controlled software automated network analyzer (ANA)	47
4.2	Experimental Set-up for attenuation measurement of glucose solutions and glucose-enzyme reaction using microstrip sensor connected to automated network analyzer (ANA)	50
5.1	Dielectric constant, ϵ' of various concentration of glucose and deionized water	52
5.2	Dielectric loss, ϵ'' of various concentration of glucose and deionized water	53
5.3	Dielectric properties of glucose oxidase at frequencies 0.2 GHz up to 20 GHz	54
5.4	Repeatability dielectric properties at each bottle dilution vary with 5 different frequencies: (a) dielectric constant, ϵ' , (b) dielectric loss, ϵ''	55
5.5	Dielectric properties of stored enzyme vary with 5 different frequencies for every 30 minutes at temperature 4 °C to 25 °C: (a) dielectric constant, ϵ' , (b) dielectric loss, ϵ''	57

5.6	Dielectric properties of gluconic acid at frequency 0.2 GHz to 20 GHz	59
5.7	Dielectric properties of hydrogen peroxide (H ₂ O ₂) at frequency 0.2 GHz to 20 GHz.	60
5.8	Experimental spectra of various concentrations of glucose, glucose oxidase and glucose-enzyme reaction at 1:1 : (a) dielectric constant, ϵ' , (b) dielectric loss, ϵ'' .	62
5.9	Experimental spectra of various concentrations of glucose, glucose oxidase and glucose-enzyme reaction at 1:3: (a) dielectric constant, ϵ' , (b) dielectric loss, ϵ'' .	63
5.10	Experimental spectra of various concentrations of glucose, glucose oxidase and glucose-enzyme reaction at 1:7: (a) dielectric constant, ϵ' , (b) dielectric loss, ϵ'' .	64
5.11	Difference of dielectric changes at 0.99 GHz: (a) dielectric constant changes, $\Delta\epsilon'$, (b) dielectric loss changes, $\Delta\epsilon''$ at ratio 1:1, 1:3 and 1:7	66
5.12	Difference of dielectric changes at 16.44 GHz: (a) dielectric constant changes, $\Delta\epsilon'$, (b) dielectric loss changes, $\Delta\epsilon''$ at ratio 1:1, 1:3 and 1:7	67
5.13	Limitation detection for dielectric loss changes between glucose-enzyme reaction with enzyme at 1:3 of an enzyme and glucose respectively at: (a) 0.99 GHz and (b) 16.44 GHz	68
5.14	Experimental spectra for dielectric loss of glucose oxidase, gluconic acid and mixture of glucose-enzyme at 1:3 (enzyme:glucose)	70
5.15	Variation of dielectric loss changes, $\Delta\epsilon''$ between glucose-enzyme reaction and enzyme at 1:3 for frequencies: (a) 0.99 GHz and (b) 16.44 GHz	72
5.16	Dielectric properties of glucose in blackcurrant juice with frequencies: (a) the dielectric constant, ϵ' , (b) the dielectric loss, ϵ''	75

5.17	Dielectric properties of glucose-enzyme reaction in blackcurrant juice at 1:3 with frequencies: (a) the dielectric constant, ϵ' , (b) the dielectric loss, ϵ''	76
5.18	Variation of dielectric loss changes, $\Delta\epsilon''$ between glucose-enzyme reaction and enzyme in blackcurrant juice at 1:3 for frequencies: (a) 0.99 GHz and (b) 16.44 GHz	77
5.19	Dielectric properties of glucose in lychee juice with frequencies: (a) the dielectric constant, ϵ' , (b) the dielectric loss, ϵ''	78
5.20	Dielectric properties of glucose-enzyme reaction in lychee juice at 1:3 with frequencies: (a) the dielectric constant, ϵ' , (b) the dielectric loss, ϵ'' .	80
5.21	Variation of dielectric loss changes, $\Delta\epsilon''$ between glucose-enzyme reaction and enzyme in lychee juice at 1:3 : (a) 0.99 GHz and (b) 16.44 GHz	81
5.22	Variations of dielectric loss factor, ϵ'' of the sample before reaction and dielectric loss changes, $\Delta\epsilon''$ between glucose-enzyme reaction and enzyme at: (a) 0.99 GHz and (b) 16.44 GHz	83
5.23	Measured attenuation for deionized water at frequency 0.99 GHz and 16.44 GHz	84
5.24	Measured attenuation for glucose solution and glucose-enzyme reaction at: (a) 0.99 GHz and (b) 16.44 GHz	86
5.25	Variation of difference in attenuation for glucose-enzyme reaction with an enzyme at : (a) 0.99 GHz and (b) 16.44 GHz	87
5.26	Measured attenuation for glucose in blackcurrant juice and glucose-enzyme reaction at frequencies: (a) 0.99 GHz and (b) 16.44 GHz.	89
5.27	Variation of difference in attenuation for glucose-enzyme reaction with an enzyme for blackcurrant juice at: (a) 0.99GHz and (b) 16.44GHz	90



5.28	Measured attenuation for glucose in lychee juice and glucose-enzyme reaction at: (a) 0.99 GHz and (b) 16.44 GHz.	91
5.29	Variation of difference in attenuation for glucose-enzyme reaction with an enzyme for lychee juice at: (a) 0.99 GHz and (b) 16.44 GHz.	92
5.30	Variations of attenuation of the sample before reaction and difference in attenuation for glucose-enzyme reaction with an enzyme at: (a) 0.99 GHz and (b) 16.44 GHz.	94



LIST OF ABBREVIATIONS

H ₂ O ₂	Chemical formula for hydrogen peroxide
O ₂	Chemical formula for oxygen
GOD	Glucose oxidase
e.m.f	Electric and Magnetic Field
FET	Field Effect Transistor
EnFET	Enzyme Field Effect Transistor
ISFET	Ion-sensitive Field Effect transistor
Pt	Platinum
SnO ₂	Chemical formula for Stannic Oxide
ITO	Chemical formula for Indium Tin Oxide
MNO ₂	Chemical formula for Manganese dioxide
H ₂ O	Chemical formula for water
LoC	Lab-on-chip
LED	Light emitting diode
NFMM	Near-field Microwave microprobe
NA	Network Analyzer
EM	Electromagnetic
ANA	Automated Network Analyzer
HPLC	High Performance Liquid Chromatography
OECP	Open Ended Coaxial Probe



LIST OF SYMBOLS

ϵ^*	Complex permittivity
ϵ'	Dielectric constant
ϵ''	Dielectric loss factor
j	$\sqrt{-1}$
V	Volt
E_{app}	Polarizing Voltage
mV	miliVolt
f	Frequency
Δ	Difference
$\tan \delta$	Loss tangent
ϵ_0	Permittivity of free space ($\epsilon_0 = 8.85 \times 10^{-12}$ F/m)
ϵ_r^*	Relative permittivity
ϵ_r'	Relative dielectric constant
ϵ_r''	Relative dielectric loss
ϵ_c''	Conductive loss
ϵ_d''	Dipolar polarization
ϵ_e''	Electronic polarization
ϵ_a''	Atomic polarization
ϵ_i''	Interfacial polarization
ϵ_s	Static dielectric constant
ϵ_∞	Dielectric constant at infinite frequencies
ω	Angular frequency



τ	Relaxation time
\varnothing	Angle coordinate of point at aperture probe (rad)
f_c	Critical frequency
π	pi ($\pi=3.124$)
Z_0	Characteristic impedance
C_0	Capacitance of the air-filled parallel plate capacitor
C_f	Fringe field capacitance
l_1	Length of stripline section
l_2	Length semi-infinite layer of microstrip
ϵ_{r1}	Permittivity of the substrate
ϵ_{r2}	Permittivity of the protective layer
ϵ_{r3}	Permittivity of the sample
ϵ_{r4}	Permittivity of the air
h	Thickness of the substrate
s	Thickness of the protective layer
d	Thickness of the sample
P_1	Incident power at port 1
P_2	Output power at port 2
Γ_a	Reflection coefficients at coaxial stripline transition input
Γ_b	Reflection coefficients at coaxial stripline transition output
γ_m	Complex propagation constant for the microstrip section
γ_s	Complex propagation constant for the stripline section

S_{11}	Input reflection coefficient of 50W terminated output.
S_{21}	Forward transmission coefficient of 50W terminated output.
S_{12}	Reverse transmission coefficient of 50W terminated input
S_{22}	Output reflection coefficient of 50W terminated input
α	Attenuation
β	Phase constant
λ_0	Free space wavelength
σ	Conductivity of the medium
$\tan \delta_{eff}$	Effective values of loss tangent
ϵ_{eff}	Effective dielectric constant
q_1	Dielectric filling fractions of substrate
q_2	Dielectric filling fractions of protective layer
q_3	Dielectric filling fractions of sample
α_m	Final attenuation of the whole structure
$\tan \delta_1$	Loss tangents for substrate
$\tan \delta_2$	Loss tangents for protective layer
$\tan \delta_3$	Loss tangents for sample
$\tan \delta_4$	Loss tangents for air

CHAPTER 1

INTRODUCTION

Glucose biosensor with high sensitivity, fast response and stability are becoming increasingly needed in clinical monitoring, biological research and in the food processing industry. In order to contribute to the accelerative development of glucose biosensor, the capabilities of using microwave method are applied. In this chapter, the microwave-based technique for glucose detection is introduced.

1.1 Microwaves

The term microwaves are used to describe electromagnetic waves with frequency ranging from 300 MHz to 300 GHz as shows in Figure 1.1.

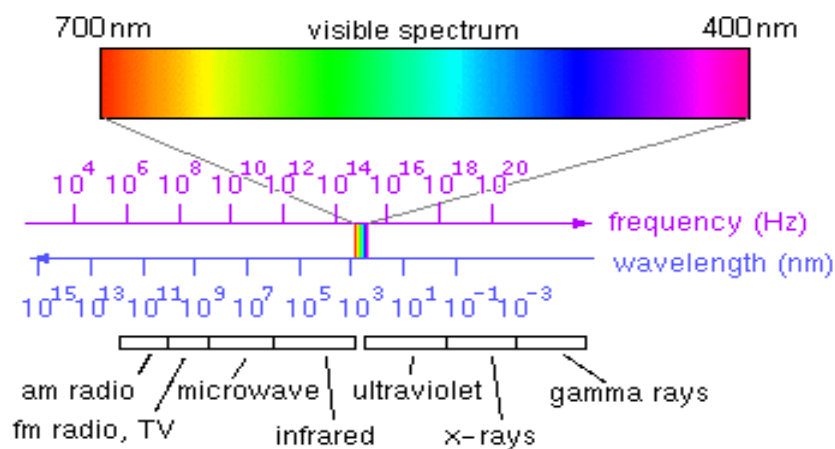


Figure 1.1: The electromagnetic spectrum.