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MICROWAVE-BASED TECHNIQUE FOR GLUCOSE DETECTION

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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

MICROWAVE-BASED TECHNIQUE FOR GLUCOSE DETECTION

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NORA SALINA BINTI MD SALIM

April 2010

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.

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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:

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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

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LIST OF ABBREVIATIONS

H_2O_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_2O	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 (ε_0 =8.85 x 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
$\emptyset$	Angle coordinate of point at aperture probe (rad)
f_c	Critical frequency
π	pi (π=3.124)
Z_0	Characteristic impedance
C_o	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
λo	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.

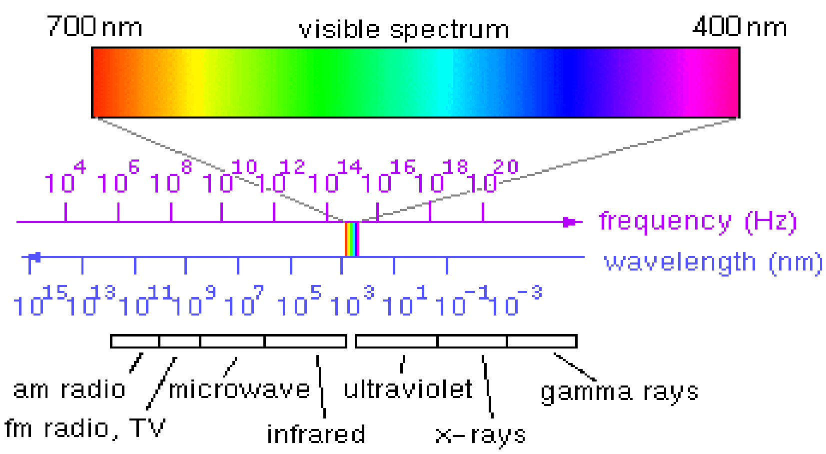

Figure 1.1: The electromagnetic spectrum.