UNIVERSITI PUTRA MALAYSIA

IONIC CONDUCTIVITY AND DIPOLAR EFFECTS OF GLUCOSE ENZYMATIC SOLUTION AND FRUIT JUICES DETERMINED USING DEVELOPED DUAL-FREQUENCY MICROWAVE GLUCOSE BIOSENSOR

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By

FARIBA JAFARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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To
My lovely Family,
The most wonderful gift from God.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

IONIC CONDUCTIVITY AND DIPOLAR EFFECTS OF GLUCOSE ENZYMATIC SOLUTION AND FRUIT JUICES DETERMINED USING DEVELOPED DUAL-FREQUENCY MICROWAVE GLUCOSE BIOSENSOR

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February 2012

Chairman: Professor Kaida Khalid, PhD

Faculty: Science

A dual frequency microwave glucose biosensor is developed based on microwave attenuation and is used for measuring the concentration of glucose content of fruit juices. In this biosensor system two source frequencies 1GHz and 16.5GHz along with the electronic switch were used to send the signal through the power divider to the couple of microstrip sensors. Two wideband detectors were used to measure the amplitude of the reflected signal from the sensor. The whole system was interfaced to the labtop PC through the National Instruments data acquisition card, with the help of software written in Labview graphical panel. It guides the user to perform measurements easier and faster.

This biosensor is suitable for a broad range of glucose content ranging from 0.01M to 3M (Molar) which can help to control the quality of the juice in food industry. It is based on the variation of the dielectric properties of the glucose solution after reacting with the enzyme (GOx). Therefore the glucose content of solution sample can be finding by measuring the attenuation of the signal through the sample.
The microstrip sensor was fabricated using RT-Duriod with dielectric properties of 2.2-j0.002 as the substrate, with operating frequency at 16.5 GHz. Using this type of coaxial sensor only the small part of sample is needed to contact with the microstrip line, therefore the measurement can be done with lower cost, more accuracy and in a shorter time.

Theoretical analysis based on quasi-transverse electromagnetic mode (TEM mode) in four layered microstrip is carried out to evaluate design parameters such as microstrip characteristic impedance, effective dielectric constant, length and thickness due to the sensitivity of the sensor. The analysis of the complex electromagnetic waves in this system is presented using signal flow graphs and solved by Mason's non-touching loops rules. To this end Visual Fortran programs is written and documented to evaluate all the design parameters needed and to estimate the microstrip patterns.

In the other part of this study, investigation was made to find the optimum ratio of enzyme reaction with glucose solution and highest sensitivity of this technique, with the studying of the dielectric properties of the glucose samples. The ionic conductivity and dipolar effect on the polarization of the glucose solution after

reacting with enzyme has been studied using two frequencies; one was below 2GHz and one above that amount at room temperature.

In the purpose of verifying this sensing technique the results of the glucose solution samples has been compared with the results for some type of fresh fruit juice samples. It was found that the dielectric loss of the samples is affected by frequency, concentration of glucose and ratio of enzyme reaction. The results of the different for dielectric loss of the solution (glucose+ enzyme) and glucose, shows the changes are preferable for derivation of glucose concentration.

The dual frequency biosensor was used to measure the attenuation and analysis of the results at 1GHz and 16.5 GHz has been done completely. This biosensor tested on four types of fruit juices in the range of 0.5M to 3.1M glucose concentration. The biosensor has predicted glucose concentration with the accuracy of concentration detection ±0.14 M using average method and can goes even up to ±0.13 M using weighted average method. For the stability of this glucose biosensor, studying the effect of operating time on the stability of this biosensor and enzyme behavior within 45 minutes of operating glucose at room temperature (25°C).

This microwave glucose biosensor has the limit of detection of glucose concentration in solution in quiet higher than vivo measurement or medical application; therefore it can be used more in food industry. Therefore the study of the development of the dual frequency system using microwave technique will give benefit to the future application of this technique application in food industries especially for products such as juices, milk and etc, where both ionic conductivity and dipole effects are considering simultaneously.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Doctor Falsafah.

KESAN DIPOLAR DAN KEKONDUKSIAN IONIC LARUTAN GULKOSA ENZYIM DAN JUS BUAH-BUAHAN YANG DITEKTUKAN DENGAN MANGGUNAKAN BIOSENSOR GELOMBANG MIKRO KEKERAPAN DUA

Oleh

FARIBA JAFARI

Februari 2012

Pengerusi: Profesor Kaida Khalid, PhD

Fakulti: Sains

Satu biosensor glukosa dua frekuensi gelombang mikro dibangunkan berdasarkan pengecilan gelombang mikro dan digunakan untuk mengukur kepekatan kandungan glukosa jus buah-buahan. Dalam sistem biosensor ini dua frekuensi sumber 1 GHz dan 16.5 GHz bersama-sama dengan suis elektronik digunakan untuk menghantar isyarat melalui pembahagi kuasa kepada beberapa sensor microstrip. Dua pengesan Wideband digunakan untuk mengukur amplitud isyarat yang terpantul dari sensor. Keseluruhan sistem di antara muka kepada komputer riba melalui pemerolehan kad

data National Instruments, dengan bantuan perisian yang ditulis dalam panel grafik Labview. Ia memberi panduan kepada pengguna untuk melakukan pengukuran lebih mudah dan cepat.

Biosensor ini sesuai untuk julat kandungan glukosa antara 0.01M ke 3M (Molar) yang boleh membantu untuk mengawal kualiti jus dalam industri makanan. Ia adalah berdasarkan perubahan sifat-sifat dielektrik larutan glukosa selepas bertindak balas dengan enzim (GOx). Oleh itu, kandungan glukosa dalam larutan sampel penyelesaian boleh dicari dengan mengukur pengecilan isyarat melalui sampel.

Sensor mikrostrip telah direka dengan menggunakan RT-Duriod dengan sifat-sifat dielektrik 2.2 j0.002 sebagai substrat, dengan frekuensi operasi pada 16.5 GHz. Dengan menggunakan jenis sensor sepaksi ini hanya sebahagian kecil daripada sampel diperlukan untuk menyentuh talian mikrostrip, Oleh itu, pengukuran boleh dilakukan dengan kos yang lebih rendah, ketepatan yang lebih dan dalam masa yang singkat.

Analisis teori yang berdasarkan kuasi-melintang elektromagnet (TEM mod) dalam empat lapisan mikrostrip gunakan untuk menilai reka bentuk parameter seperti impedans ciri mikrostrip, pemalar dielektrik berkesan, panjang dan tebal disebakkan sensitiviti sensor. Analisis gelombang elektromagnet yang kompleks dalam sistem ini dibentangkan menggunakan graf aliran isyarat dan diselesaikan dengan petua gelung Mason tak menyentuh. Untuk tujuan ini program Visual Fortran program-program ditulis dan didokumenkan untuk menilai semua parameter reka bentuk yang

diperlukan dan anggaran corak mikrostrip.

Di bahagian lain kajian ini, penyiasatan telah dibuat untuk mencari nisbah optimum tindak balas enzim dengan larutan glukosa dan sensitiviti tertinggi teknik ini, dengan menghaji sifat-sifat dielektrik sampel glukosa. Kekonduksian ionik dan kesan dwikutub pada polarisasi larutan glukosa selepas bertindak balas dengan enzim telah dikaji dengan menggunakan dua frekuensi; salah satu berada di bawah 2 GHz dan satu lagi di atas amaun itu pada suhu bilik.

Untuk mengesahkan teknik penderiaan keputusan ini sampel larutan glukosa telah dibandingkan dengan keputusan untuk beberapa jenis sampel jus buah-buahan segar. Ini didapati bahawa kehilangan dielektrik sampel dipengaruhi oleh frekuensi, kepekatan glukosa dan nisbah tindak balas enzim. Keputusan yang berlainan bagi kehilangan dielektrik larutan (glukosa + enzim) dan glukosa, menunjukkan perubahan yang lebih baik untuk terbitan kepekatan glukosa.

Biosensor frekuensi dual telah digunakan untuk mengukur pengecilan dan analisis keputusan di 1 GHz dan 16.5 G Hz telah dilakukan sepenuhnya. Biosensor ini diuji ke atas empat jenis jus buah-buahan dalam lingkungan 0.5 M untuk 3.1 M kepekatan glukosa. Biosensor meramalkan kepekatan glukosa dengan ketepatan pengesanan kepekatan ± 0.14 M menggunakan kaedah purata dan boleh sehingga ± 0.13 M menggunakan kaedah purata wajaran. Kestabilan glukosa juga dengan mengkaji kesan masa operasi pada kestabilan biosensor dan tingkah enzim dalam masa 45 minit bagi glukosa yang beroperasi pada suhu bilik (25 $^{\circ}$ C).

Biosensor glukosa gelombang mikro ini mempunyai had pengesanan kepekatan glukosa dalam tenang yang lebih tinggi daripada ukuran vivo atau aplikasi perubatan, maka ia boleh digunakan dalam industri makanan. Oleh itu, kajian pembangunan sistem dua frekuensi yang menggunakan teknik gelombang mikro akan memberi manfaat kepada aplikasi masa hadapan teknik ini dalam industri makanan terutamanya untuk produk seperti jus, susu dan lain-lain, di mana kedua-dua kekonduksian ionik dan kesan dwikutub ditimbangkan serentah.

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I certify that an Examination Committee has met on 13th February 2012 to conduct the final examination of Fariba Jafari on her thesis entitled "Ionic Conductivity and Dipolar Effects of Glucose Enzymatic Solution and Fruit Juices Determinted Using Developed Dual Frequency Microwave Biosensor" in accordance with the Universities and University collegue Act 1971and the consititution of the Universiti Putra Malkaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosopy.

Members of the Examination Committee were as follows:

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Date: 28 June 2012

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

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DECLARATION

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

FARIBA JAFARI

Date: 13 February 2012

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