A NALYTICAL MODELING OF CARBON NANOTUBE TRANSISTOR BASED BIOSENSOR FOR GLUCOSE DETECTION

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I would like to dedicate this dissertation to my beloved father, Alireza Hosseingholipourasl, who taught me how to be strong and ambitious. It is also dedicated to my beloved mother, Fardaneh Hasanzadeh, who taught me how to be patience and love people kindly. Without their patience, understanding, support, and most of all love, the completion of this work would not have been possible. I would like to dedicate this thesis to my dear sister, whose positive energy always support me the best way.

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ABSTRACT

The industry in sensory devices, nowadays, has become overflowed with the development of carbon nanotubes based sensor. So far, wide ranges of potential and practical applications of CNTs have been reported, including chemical sensors electronic devices and so on. CNT possess enhanced electron transfer property when used as electrodes in electrochemical reactions and serves as a good solid support for easy protein immobilization that retains their native activity for use as potential biosensors. The determination of glucose levels using biosensors, particularly in the medical diagnostics and food industries, is gaining mass appeal. The glucose biosensors detect the glucose molecule by catalyzing glucose to the gluconic acid and H2O2 in the presence of oxygen. In this study, a single-wall carbon nanotube field-effect transistor (SWCNT FET) biosensor for glucose detection is analytically modelled. In the proposed model, the glucose concentration is presented as a function of gate voltage. Subsequently, the proposed model is compared with existing experimental data. A good consensus between the model and the experimental data is reported. The simulated data demonstrate that the analytical model can be employed with an electrochemical glucose sensor to predict the behavior of the sensing mechanism in biosensors.

ABSTRAK

Sejak kebelakangan ini, industri alat deria memberi fokus kepada pembangunan alat deria berasaskan nanotube karbon. Setakat ini, banyak potensi dan aplikasi praktikal CNTs telah dilaporkan, dan ini termasuklah sensor kimia electronik dan sebagainya. CNT mempunyai kelebihan dalam pemindahan elektron apabila digunakan sebagai elektrod dalam tindak balas electrokimia, dan berfungsi sebagai sokongan yang baik dan kukuh kepada immobilisasi protein yang mengekalkan activity asal untuk digunakan sebagai biosensor yang berpotensi. Penentuan paras glukosa dengan penggunaan biosensor, terutamanya dalam diagnostik perubatan dan industry makanan, semakin diberi perhatian. Biosensor glukosa mengesan molekul glukosa dengan memangkinkan glukosa kepada asid glukonik dan H2O2 dalam kehadiran oksigen. Dalam kajian ini, satu dinding-tunggal nanotube karbon transistor (SWCNT FET) biosensor dimodelkan secara analitikal untuk pengesanan glukosa. Dalam model yang dicadangkan, kepekatan glukosa adalah fungsi daripada voltan get. Selepas itu, model yang dicadangkan itu dibandingkan dengan data eksperimen yang sedia ada. Persetujuan yang baik antara model dan data eksperimen dilaporkan. Data simulasi menunjukkan bahawa model analitikal ini boleh digunakan dengan sensor glukosa elektrokimia untuk meramalkan kelakuan mekanisme penderiaan dalam sensor bio.

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CHAPTER 1

INTRODUCTION

1.1 Background

The advent of nanotechnology provides a new perspective for the development of nanosensors and nanoprobes with nanometer dimensions and is appropriate for biological and biomolecular measurements [8]. The use of tools capable of detecting and monitoring the biomolecular process can create enormous advances in the detection and treatment of diseases and thereby revolutionize cell biology and medical science [9]. A biosensor is an electronic device which has a biological probe and a transducer that is connected to a monitor. The demand for a wide variety of applications for a biosensor in industrial, environmental and biomedical diagnostics is dramatically increasing [8-10].

Because of economical and medical motivations biosensors have attracted great interests of research centers and related companies. In order to reach higher sensitivity, faster response time and higher accuracy as sensors parameters, sensor technology should be developed to meet these demands. The biosensors performance improvement to a large extends depend on material which is used in their structure. Because of amazing characteristics and structure, CNT is a good candidate for potential applications in biosensors due to their special geometry and unique electronic, mechanical, chemical, and thermal properties such as high carrier mobility, long mean free path and potential of carrying high current density.

In comparison with conventional materials used in electrode which showed good conductance and high chemical stability, CNTs exhibited superior performance [3]. Owing to subtle electronic properties, CNTs are capable to enhance electron transfer property in electrochemical reactions with electroactive species when used as electrodes. They also can be a good solid support to facilitate immobilization [11, 12].

So far, researches have illustrated the superiority of CNT base electrode over other derivation of carbon electrodes for glucose detection in biosensors in terms of reaction rate, reversibility and detection limit [3]. For diagnosing and monitoring the blood glucose level, glucose oxidase (GOx) based enzyme sensors have been immensely used. They have economical production process and easily available in the market and possess rapid response, high sensitivity and good selectivity. Choosing proper matrix for GOx immobilization always has been on the challenges in biosensors. Because of excellent mechanical stability, high conductivity, and antifouling properties, CNTs have been widely employed for GOx immobilization in biosensors. By including CNTs to the immobilization matrixes, can reach high sensitivity and good stability of the immobilized enzyme. Moreover, CNT platform provides more appropriate environment for immobilized GOx and therefore provides quick shuttling of electrons with the surface of electrode [3, 11-13].

1.2 Problem Statement

Diabetes mellitus is a wide-reaching public health problem which is one of the main causes of death and disability in the world [14]. Thanks to the importance of the diabetes diagnoses, the glucose detection has become an attractive research area to detect and monitor the blood glucose level [13]. Hence it is reported that 85% of entire biosensor market, accounts for glucose biosensors. Thus a tight monitoring of blood glucose level is urgent in order to prevent and manage and diabetes mellitus [14].

On the other hand Because of some constraints of glucose detection approaches such as ultra low detection, large detection range, high cost and complexity to understanding, the implementation of effective approaches by using nanomaterials such as carbon nanotubes (CNTs) with superior performance is essential to design modern biosensors [15-18]. Hence, so far a lot of researches have been conducted to study the performance of carbon nanotube based FET biosensors [3, 19-21]. In the sensor technology analytical modelling based on the experimental finding is still continuing. This study is going to propose CNT-FET based biosensor analytical model to predict the performance of a biosensor.

1.3 Objectives

This project focuses on analytical modelling of carbon nanotube transistor based biosensor to detect and monitor glucose. After modelling single wall carbon nanotube field effect transistor the sensor model based on CNT-FET will be proposed and the performance of biosensor will be analyzed based on the experimental data. The objectives of project are as follow:

1) To develop SWCNT-FET I-V model for modelling of glucose biosensor.
2) To propose highly sensitive biosensor model and obtain glucose sensing equation $V_{Glucose}(F_g)$, to predict glucose biosensor manner
3) To reach good agreement between proposed sensor model and experimental data from paper [4].

1.4 Research Scope

The scope of study is listed as below:

1) The schematic of SWCNT-FET based electrode will be proposed.
2) Matlab software will be used to model the SWCNT-FET.
3) SWCNT-FET will be developed to model biosensor.
4) Sensing parameters $V_{Glucose}$, V_{PBS} will be obtained based on iteration method for different concentrations of glucose.
5) Based on the sensing parameters the sensing factor equation $V_{Glucose}$ (F_g), which is function of glucose concentration will be presented.
6) Matlab software will be employed to model biosensor.
7) To validate presented biosensor model, the sensor model for different concentrations of glucose will be compared with experimental data.

1.5 Significance of the study

The experimental Glucose detection approaches have some constraints such as ultra low detection, large detection range, high cost and complexity to understanding. Modelling of glucose biosensors using nanomaterials such as carbon nanotubes (CNTs) with excellent performance is an economical and proper way to overcome the constraints of experimental approaches.

1.6 Thesis Organization

This study includes six chapters. First chapter provides motivation and introduction to the carbon nanotube based glucose biosensor, background on the importance of the nanoscale electrochemical biosensors, statement of the problem, objective of the study, scope of the study and finally the significance of study which illustrates how biosensor modelling can overcome sensing constraints and is very

economical simulated sensing mechanism. Chapter two describes carbon nanotube transistors, different sensing approaches and techniques and then it gives a comprehensive literature review on carbon nanotube based glucose biosensors. Finally, based on the literature review the problem is identified. Chapter three defines the research structure and identifies the research methodology which will be used in order to explain the steps of modelling of carbon nanotube biosensor. In chapter four glucose biosensor modelling mechanism will be explained presents carbon nanotube FET based electrode schematic, SWCNT-FET I-V model and the procedure of developing glucose biosensor model. Finally, the case study which is going to be used will be provided. Chapter five provides the experimental results which are performed by MATLAB software and presents the related discussions and the comparison of taken result with experimental data. Finally, chapter six will presents the final conclusions and future research potentials.

1.7 Summary

This chapter is the foundation of this research. After a brief introduction in carbon nanotube based glucose biosensors, problem is clearly stated. Based on problem statement the objectives of the research are identified. Scope of the study which identifies research boundaries is completely identified. Significance of this research is addressed in order to make the research justifiable. Finally, organization of the whole thesis is written.

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