Reduced Graphene Oxide/Congo Red-Molecular Imprinted Polymer Organic Thin Film Transistor For Serine Detection.

by

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LIST OF ABBREVIATIONS

AIBN	Azobisisobutyronitrile
AM1	Austin Model 1
C/O	Carbon to oxygen ratio
CR	Congo-red
GS	Graphene sheets
GSCR	Graphene sheets Congo-red
I-V	Current-voltage
MAA	Methacrylic acid
MIP	Molecular Imprinted Polymer
NIP	Non Imprinted Polymer
NMDAR	N-methyl-D-aspartate receptor
OTFT	Organic thin film transistor
OFET	Organic field effect transistors
PET	Poly (ethylene terephtalate)
RF-IDs	Radio-frequency identification tags
rGO	Reduced graphene oxide
RMS	Root mean square
RPM	Revolutions per minute
TFTs	Thin film transistors
TIPS Pentacene	6,13-bis(triisopropylsilylethynyl)pentacene

LIST OF SYMBOLS

C_i	Initial concentration
C_f	Final concentration
e	Electron speed
$E_{Complex}$	Total energy of a serine – MAA complex
E_{Serine}	Total energy of a serine
E_{MAA}	Total energy of a MAA
h	Planck's constant
I	Magnitude of current
I_D	Drain voltage
n	Complexes of MAA that could bind with serine molecule
p	Subshell p
Q_{max}	Maximum adsorption capacity
S	Distance between the probes
T_{sub}	Substrate temperature
V	Magnitude of electric field
V_{DS}	Source-drain voltage
V_{GS}	Gate-source voltage
V_G	Gate voltage
V_D	Drain voltage
V_S	Source voltage
ΔE	Binding energy
μ	Carrier mobility

π_{sat}	Saturated field effect mobility
ρ	Resistivity of bulk sample
σ	Conductivity

Pengesanan Serine Menggunakan Graphene Oksida Terturun-Kongo Merah-Molekul Bercetak Polimer Transistor Organik Filem Tipis.

ABSTRAK

Serine adalah asid amino yang wujud di dalam tisu mamalia. Para penyelidik mencadangkan kekurangan kadar Serine mendorong kepada kegagalan neuro-psikatrik. Objektif penyelidikan ini adalah untuk membangunkan teknologi sensor pakai buang berdasarkan graphene oksida terturun (rGO)/Kongo merah (CR)- molekul bercetak polimer (MIP) di atas substrat Transistor Organik Filem Tipis (OTFT) untuk mengesan Serine. Substrat OTFT berdasarkan polyethylene terephthalate (PET) adalah substrat fleksibel. RGO-CR-MIP dipolimerkan diatas elektrod OTFT. Dalam tesis ini, permodelan molekul dibangunkan untuk mengkaji interaksi inter-molekul dalam proses pra-pempolimeran MIP. Perisian HYPERChem digunakan untuk mengkaji interaksi diantara monomer berfungsi dan templat. Ikatan tenaga yang optimum diperolehi daripada permodelan adalah nisbah 1:5. Bagi mengukuhkan data permodelan molekul, enam nisbah MIP dihasilkan untuk mengkaji interaksi MIP dan Serine. Kajian menunjukkan nisbah 1:5 mempunyai interaksi tertinggi dengan kapasiti serapan berjumlah 23.63 mg/g. Graphene oksida terturun-Kongo merah (rGO-CR) telah ditambahkan kepada matrik polimer MIP. Ujikaji konduktiviti rGO-CR-MIP mendapati, konduktivitinya meningkat dan amat berbeza kerana ciri intrinsik rGO-CR. Nilai konduktiviti rGO-CR-MIP adalah 3.10×10^{-3} Sm^{-1} pada kepekatan 0.4 % (w/v) rGO-CR. Pengaruh suhu substrat T_{sub} kepada prestasi elektrik OTFT turut dikaji. TIPS-Pentacene diletakkan pada T_{sub}, 100 °C, pada suhu tersebut OTFT yang dihasilkan mempunyai prestasi elektrik yang lebih baik, dengan arus saliran, (I_D), 0.07135 A. Malahan, dengan meningkatkan T_{sub}, saiz butiran dan mobiliti transistor juga meningkat. Prestasi sensor rGO-CR-MIP OTFT mempunyai kadar respon yang cepat kira-kira 14 saat. Selain daripada itu, ujikaji kepilihan terhadap sensor tersebut menunjukkan I_D yang lebih tinggi apabila sensor didedahkan kepada Serine berbanding apabila didedahkan kepada Valine dan Isoluecine. Melalui analisis kepekaan juga, sensor menunjukkan had pengesanan pada 20 ppm. Sensor yang dihasilkan mempunyai kepilihan dan kepekaan yang tinggi untuk pengesanan Serine.

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ABSTRACT

Serine is an amino acid that exists in mammalian tissues. Researchers suggest that low level of Serine may contribute to neuropsychiatric disorders. The objective of this research is to develop a new disposable reduced Graphene oxide- Congo red-molecular imprinted polymer (rGO-CR-MIP) sensor using organic thin film transistor (OTFT) on polyethylene terephthalate (PET) flexible substrate for serine detection. The rGO-CR-MIP, as sensing material, was polymerized on interdigitated electrodes of OTFT. In this thesis, a molecular modeling was developed to study the intermolecular interactions in the pre-polymerization mixture of MIP. Using HYPERChem software the optimum binding energy was obtained at a 1:5 ratio. In order to confirm the results of molecular modeling, six different ratios MIP were synthesized for binding study. From the study, it is shown that 1:5 ratio have the highest binding with the adsorption capacity of 23.63 mg/g. The rGO-CR was introduced in order to improve conductivity of MIP. The conductivity of rGO-CR-MIP differs significantly due to the intrinsic characteristic of rGO-CR. The resulting rGO-CR-MIP exhibit bulk conductivity of 3.10×10^{-3} Sm^{-1} at 0.4 % (w/v) rGO-CR. The influences of the temperature of substrate temperature (T_{sub}) on electrical performance of TIPS-Pentacene OTFT have been investigated. TIPS-Pentacene deposited at substrate temperature T_{sub}, 100 °C exhibited a better performance. With the drain current I_D, 0.07135 A. By increasing T_{sub} temperature will increase grain size and carrier mobility of transistors. The performance of rGO-CR-MIP OTFT sensor exhibited a fast response with a response time of 14 seconds. During the selectivity test the I_D is much higher than valine and isoluecine, implying a highly selective recognition of rGO-CR-MIP OTFT sensor to Serine. From the sensitivity analysis, the sensor exhibited a limit of detection at 20 ppm.The sensor exhibited a high sensitivity and good selectivity for Serine and it was successfully applied to its detection.

CHAPTER 1

INTRODUCTION

1.1 Overview

Amino acids are the fundamental of all life process. Thus, amino acid identification is often necessary for biotechnology applications. Furthermore by using biotechnology to detect and treat disease, the levels amino acid in human body also is a potential method to identify disease in human body (Al-Abbasi, 2012).

In this research, serine is selected a target for the sensor due to its importance for chemical reactions in neurotransmitter. L-serine is an essential amino acid for neurotransmitter synthesis. It is biosynthesized from the glycolytic intermediate 3-phosphoglycerate, a metabolite of glucose in the brain that requires three enzymatic steps, namely 3-phosphoglycerate dehydrogenase (3-PGDH), phosphoserine aminotransferase (PSAT) and phosphoserine phosphatase (PSPH) (Tabatabaie, et. al., 2010). L-serine formed the precursor for neuromodulator, which are D-serine and glycine, both bioactive amino acids play important role in the regulation of N-methyl-D-aspartate receptor (NMDAR) in the central nervous system (Ozeki, et. al., 2011). NMDAR in nerve cell is to bind with D-serine and glycine and allows positively charged ion to flow through the cell membrane (Labrie, et. al., 2012). L-serine also plays an important precursor for neuronal membrane lipids such as sphingolipids and phosphatidyl serine. Neuronal membrane lipids play important role as lipid messenger in apoptosis signaling pathways. Interestingly, in matured central nervous system

(CNS), majority of L-serine is synthesized through astrocytes. Astrocytes plays a role in releasing L-serine throughout neurons to supply surrounding neurons the necessary precursor for neurotransmitter and phospholipid synthesis (Tabatabaie, et. al., 2010). Diagnosis of L-serine level in the brain may leads to new approaches for neuroprotection against various neurodegenerative diseases such as schizophrenia, Parkinson, bipolar disorder and Alzheimer (Hashimoto, et. al., 2015; Hashimoto, et. al., 2004). Most of detection and quantification of L-serine level were required expensive dedicated instrument such as high-performance-liquid-chromatography (HPLC) and ion chromatography.

This study is aim to develop a method of molecular identification for detection of serine using chemically reduced graphene oxide/Molecular Imprinted Polymer-organic thin film transistor biosensor. Biosensor is a transducer that converts a biological response between the sensing material and the target analyte into an electric signal. This biosensor considers as a group of sensing devices called biomimetic, and its recognition utilizing molecular imprinted polymer plays an important role in signal transduction. Potential applications for molecular imprinted polymer are for sensors, protein immobilization, separation and purification and etc (Börje Sellergren, 1997).

Molecular imprinted is a technique to produce template-shape cavities in polymer matrices with memory of the template molecules to be used in molecular recognition. The molecular recognition on MIP matrices provides strong and specific binding between molecule and substrate (Moreno-bondi, et. al., 2008). Molecular imprinted polymer (MIP) are cross linked polymers that synthesized by the existing of template molecule that binds with functional monomer during the copolymerization of the functional monomer and cross linking agent (Piletsky, et. al., 1999). After polymerization the template are removed during the washing procedure and leaving cavities. These cavities provide recognition sites for the template molecules that own the same geometrical and binding properties of the template. Template molecules can rebind selectively in these cavities (Ameli & Alizadeh, 2012). But for conventional MIP, the low mobility of "σ-bonding electrons" contribute to low conductivity of polymer (Sharma, et. al., 2012). By introducing graphene into MIP matrices it will exhibit satisfactory recognition ability and increase the conductivity of MIP (Khanam & Ponnamma, 2015).

Graphene is a sp^2-hybridized carbon atoms that owing exceptional mechanical, thermal and electrical properties (Levchenko, et. al., 2010). These remarkable properties have attracted many scientists due to its outstanding applications that successfully shown to be able to detect proteins, gas molecules, small molecules, bacteria, DNA and etc (Zhong, et. al., 2010). Furthermore graphene with is one dimensional structure have good characteristic which are high selectivity, high sensitivity, high surface to volume being utilize as sensing material for the fabrication of fast response biosensor. It is a new technique to integrate graphene with molecular imprinted polymer and it will lead to develop a stable and high sensitivity sensor (Wong, et. al., 2015). The outstanding mechanical properties and the high surface-to-volume ratio of graphene stabilize a wide range of enzymes, the latter characteristic enables high catalytic loading without diffusional limitations (Sobon, et. al., 2012).

Organic thin film transistor (OTFT) has been choose as the transducer due to its high mobility, cost effective fabrication process, fast-response time, disposable possible sensor application and its ability to amplify electronic signal. Small-molecule semiconductor such as pentacene is use for biosensor fabrication. Pentacene is among the highest mobility organic semiconductor because of its large grain size. Furthermore, OTFT performance can be controlled by adjusting its morphology and structure. This process will enhanced selective and sensitivity of the biosensor. The detection limits of pentacene-organic thin film transistor also depends on its morphology and structure of pentacene. Pentacene-organic transistor also offers good advantages due to its flexibility and biological compatibility that leads to good advantages in terms of integration with chemical and biological system (eg. molecular imprinted polymer). This thesis will explore the fabrication of chemically reduced graphene oxide/Molecular Imprinted Polymer-organic thin film transistor biosensor and the detection of amino acid using this biosensor.

1.2 Reduced graphene oxide-MIP composite novel sensing platform

Apparently, utilization of reduced graphene oxide (rGO) as mimetics for biosensor application is reasonably effective because it's extremely high surface-to-volume ratio (theoretically, 2600 m^2 g^{-1}) (Zhong, et. al., 2010), makes rGO perfectly accessible with substrate that owing a low adsorption and desorption process rate. Moreover, abundant functional groups and defects on rGO surface create a good sensing material by enhanced charge transfer and ensure high chemical activity. Thus it would be an effective way to increase the sensitivity and selectivity of biosensor (L. Li, et. al., 2015). MIP, among the best synthetic biomimetic interfaces to detect target molecules. To perform a selective detection of target molecules, it is necessary for MIP to integrate with carbon-based material such as rGO. The sensing mechanism of MIP is about binding/rebinding of target molecules, by introducing rGO into MIP polymeric matrices it will function as donors or acceptors of electrons (Alizadeh & Hamedsoltani, 2014). According to Kibechu, et. al., they recorded faster response when sensor exposed to analyte with concentration from 0.5 to 10 ppb (Kibechu, et. al., 2014). It proves that rGO improved biosensor performance by decreasing detection limits. However, rGO is not soluble in water and organic solvent and polymerization techniques require the use of organic solvent. Techniques to disperse rGO in organic solvent are important in order to avoid rGO aggregation in solvent. Recently, soluble rGO was synthesized by functionalizing rGO with congo-red (CR) (B. Li, et. al., 2014). By functionalizing CR, many soluble $-SO_3Na$ groups from CR were uniformly distributed onto the entire surface of rGO-CR composite and also improved the number of active sites on rGO-CR surface (F. Li, et. al., 2010).

Organic thin film transistor (OTFT) has been choosen as the transducer due to its high mobility, cost effective fabrication process, fast-response time, for disposable sensor application and its ability to amplify electronic signal (Zhang, et. al., 2010). Small-molecule semiconductor such as pentacene is use for biosensor fabrication. Pentacene is among the highest charge mobility organic semiconductor because of its large grain size (Devices 2009). Furthermore, OTFT performance can be controlled by adjusting the morphology and structure of TIPS-Pentacene. This process will enhanced selective and sensitivity of the sensor. Pentacene-organic transistor also offers good advantages due to its flexibility and biological compatibility that leads to good advantages in terms of integration with chemical and biological system (eg. molecular imprinted polymer) (Gui, et. al., 2015). This thesis will explore the fabrication of chemically reduced graphene oxide/Molecular Imprinted Polymer-organic thin film transistor biosensor for the detection of serine.