The Development of Enzyme Based Printable Glucose Sensors

by

Sundus A. Al-Zuhairi

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Declaration

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains published scholarly work of which I am a co-author. For each such work a written statement, endorsed by my co-authors, attesting to my contribution to the joint work has been included.

The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

Sundus Al-Zuhairi

9 March 2021

Dedication

To souls of my father, Abdulrazzaq, and my nephews, Nabil, and Adam, who left early before achieving their dreams in this life, and to my mother, brothers, and sisters, who taught me nothing is impossible. Patience, positivity, caring and happiness have come from you and your unfailing support.

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hard and trying times when courage dwindled. I can rejoice in my accomplishment with them.

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Abstract

The main goal of this thesis is to develop an easy to fabricate and sensitive biosensor based on organic materials capable of monitoring saliva glucose concentration in people with diabetes.

In Chapter 3 we focus on designing, fabricating and characterising flexible organic thin film transistor- (OTFT-) based sensors suitable for salivary glucose sensing. We employed different device architectures utilising poly-3-hexylthiophene (P3HT) as the semiconductor layer, dielectric layers of either poly(vinyl-pyridine) (PVPy) or poly(vinyl-phenol) (PVP) and poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) as a gate material, to produce trial OTFTs. Our results demonstrated that compared with the initial architecture of ITO/P3HT/PVPy/PEDOT:PSS, when PVPy was replaced with PVP the off current was increased. Nafion was chosen as an appropriate replacement for PEDOT: PSS in the final (ITO/P3HT/Nafion:GOX) sensor device due to the acidity of PEDOT:PSS, with the dielectric layer being removed to improve device response time. The mechanism of signal transduction in these devices is via protonic doping of the P3HT channel and thus acidic PEDOT:PSS leads to a large off current in the device. Upon the replacement of PEDOT:PSS by the Nafion:GOX mixture, a working prototype sensor was produced of architecture ITO/P3HT/PVP/Nafion:GOX.

Chapter 4 focuses on the establishing the mechanisms behind the formation and the effect of mixed interlayers between the Nafion proton transport layer and P3HT semiconductor material. Surprisingly high conductivity was obtained for P3HT/Nafion bilayers, in excess of the native conductivity of either pristine

material, due to intermixing of the materials and doping of the P3HT. Our results suggested that the annealing condition giving the best device performance is a postproduction treatment at 50 °C. A full study of the effect of thermal annealing and the addition of water to pristine P3HT and Nafion and bilayers was undertaken.

Chapter 5 explores the use of a porous capping layer to encapsulate GOX in the device and control the volume and location of added analyte. The phase inversion technique was used to produce the porous polyacrylonitrile (PAN) films for this purpose. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) techniques were employed to investigate the resultant membrane morphology of the PAN films. Our results show that the PAN films are highly porous and suitable for the capping application and ITO/P3HT/Nafion:GOX/PAN devices showed improved sensitivity to glucose in to the range of salivary glucose levels (SGL) in humans.

Finally, in Chapter 6, the device architecture was redesigned to incorporate a non-GOX containing reference sensor in an attempt to mitigate device-based variation. Sources of sensor output variation is discussed and we observe that the addition of a reference sensor seems to merely add an additional source of variance.

Chapter 7 summarises results and discusses potential further studies.

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List of Abbreviations

OLEDs	organic light-emitting diodes
OTFTs	organic thin-film transistors
P3HT	poly (3-hexylthiophene)
Si-NW	silicon nano-wires
ZnO	zinc oxide
V_{DS}	drain source voltage
I_D	drain current
Au	gold
Pt	platinum
C	carbon
Ag	silver
AgCl	silver chloride
GOX	glucose oxidase
ISE	ion-selective electrode
BW	bulk wave
SAW	surface acoustic wave
QCM	quartz-crystal microbalances
DNA	redox proteins (cytochrome)
GluOx	glucose oxidase
BGL	blood glucose levels
GDH	glucose dehydrogenase
SGL	salivary glucose level
UV - vis	UV- visible spectroscopy
OPV	organic photovoltaic
Mw	weight average molecular weight

Mn	number average molecular weight
COE	Centre for Organic Electronics
PAN	polyacrylonitrile
FAD	flavin adenine dinucleotide
Ω	ohm
nm	nano metre
°C	degree celsius
rpm	revolutions per minute
PVP	poly (4 - vinyl phenol)
PVPy	poly (vinyl - pyridine)
SEM	scanning electron microscopy
AFM	atomic force microscopy
µL	micro
PoC	point of care
ITO	indium tin oxide
I - V	current - voltage
V	voltage
mM	molar
DD1	dual device unbroken with pan, single drop of analyte
DD2	dual device unbroken without pan, two drops
DD3	dual device broken with pan, two drops
PET	polyethylene terephthalate
cm	centimetre
DMSO	dimethyl sulfonate
DMF	N, N-dimethylformamide
C_3H_6O	acetone

$CHCl_3$	chloroform
CH_3OH	methanol
C_3H_8O	isopropanol
CH_5OH	ethanol
T_g	glass transition temperature