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## Sensors and actuators for the cochlear implant using inherently conducting polymers

Yanzhe Wu  
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**SENSORS AND ACTUATORS FOR THE  
COCHLEAR IMPLANT USING INHERENTLY  
CONDUCTING POLYMERS**

**A thesis submitted in fulfilment of  
the requirements for the award of the degree**

**DOCTOR OF PHILOSOPHY**

from

**UNIVERSITY OF WOLLONGONG**

by

**YANZHE WU, BSc (HONS), MSc**

**Intelligent Polymer Research Institute**

**Department of Chemistry**

**June 2006**

**To my parents for their endless love.**

**To my wife Yun Dai for her support and  
patience.**

## **CERTIFICATION**

I, Yanzhe Wu, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Department of Chemistry, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Yanzhe Wu

June 2006

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## PUBLICATIONS

1. Wu, Y., Alici, G., Spinks, G.M., and Wallace, G.G., "Fast trilayer polypyrrole bending actuators for high speed applications", *Synthetic Metals*, Submitted.
2. Wu, Y., Zhou, D., Spinks, G.M., Innis, P.C., Megill, W.M. and Wallace G.G., "TITAN: A conducting polymer based microfluidic pump", *Smart Mater Struct* 14 (2005) 1511-1516.
3. Wu, Y., Moulton, S. E., Too, C.O., Wallace, G. G., and Zhou, D., "Use of inherently conducting polymers and pulsed amperometry in flow injection analysis to detect oligonucleotides" *Analyst*, 129 (2004) 585-588.
4. Spinks, G.M., Zhao, L., Li, W., Wu, Y., Zhou, D., Wallace, G.G., "Synthesis, modelling and characterization of conducting polymers", *SPIE International Symposium on Smart Materials, Nano-, and Micro-Smart Systems*, Sydney, Australia, Dec 2004.
5. Li, W., Spinks, G.M. Zhao, L., Wu, Y., Zhou, D., Wallace, G.G., "Characterisation of conducting polymer based bimorph vibration sensors", *SPIE International Symposium on Smart Materials, Nano-, and Micro-Smart Systems*, Sydney, Australia, Dec 2004.
6. Wu, Y., Moulton, S.E., Too, C.O., Wallace, G.G., and Zhou, D., "Detection of Oligonucleotides: Polypyrrole - Oligonucleotide Modified Electrodes Using a Pulsed Potential Method", *The International Conference on The Science and Technology of Synthetic Metals*, University of Wollongong, Australia, July 2004.



7. Wu, Y., Zhou, D., Wallace, G.G., Spinks, G.M., Cowan, R., and Newbold, C., "Polypyrrole/PVDF Laminates as Mechanical Sensor", *26<sup>th</sup> Australasian Polymer Symposium*. Noosa, Australia, July 2003.
8. Zhou, D, Wallace, G.G., Spinks, G.M., Wu, Y., Cowan, R., and Newbold, C., "High Performance Polypyrrole Based Electromechanical Actuators", *26<sup>th</sup> Australasian Polymer Symposium*. Noosa, Australia, July 2003.

## ABSTRACT

This study considered the use of various inherently conducting polymer (ICP)-based devices for utilisation with the cochlear implant. Investigations centred on the use of polypyrrole (PPy) to produce a mechanical sensor, actuators and controlled release devices. The development of a novel force sensor using the electrodes that are an integrated part of the cochlear implant itself was also investigated.

Investigation into mechanically induce electrical signals using PPy-based mechanical sensors showed that the polarity of the voltage output was dependent on the dopant ion in the conducting polymer. In addition, it was found that the signal amplitude was related to the redox state of the PPy and the concentration of mobile dopant ions within the PPy. This led to the “stress induced ion flux” mechanism being proposed for the first time to explain such observations.

Actuator systems developed in this study included a PPy trilayer bending actuator, a PPy microfluidic pump and a PPy-coated hollow fibre. The study of PPy trilayer actuators led to several findings including a high amplitude harmonic vibration using a PPy/TFSI trilayer actuator, the first time that such behaviour has been observed for ICP-based mechanical actuators. A study of the blocking forces generated using such actuators in ionic liquid electrolytes suggested that switching from cathodic contraction to cathodic expansion occurs under the application of reducing potentials. This switching behaviour was found to depend on the amplitude and time of the electrochemical stimulation employed. It was shown that the expulsion of the dopant anion ( $\text{PF}_6^-$ ) from the reduced polymer ( $-0.8\text{ V vs. Ag/Ag}^+$ ) did not support the previously claimed cathodic expansion model.

An ion diffusion controlled mechanism was proposed to explain the results obtained.

Investigations into the novel “tube in tube actuator nodule” (TITAN) microfluidic pump based on PPy had led to the significant finding that, for the first time, the intrinsic resistance of PPy can be utilised to carry out peristaltic actuation for the purpose of fluid transport.

The electrochemically controlled release of a model anion from the internal volume of a PPy-coated platinised PVDF hollow fibre was successfully demonstrated. Such controlled release was ascribed to the electrochemically activated incorporation / expulsion of small anions upon redox switching of polypyrrole resulting in enhanced ion transport across the concentration gradient from the internal volume of the hollow fibre to the receiving solution. The experimental findings suggested that electrochemically controlled release of anionic drugs is a real possibility using a device configuration consisting of a reservoir coated with an ICP membrane.

By studying the electrochemical impedance changes in response to impact forces on the tip of a cochlear implant in artificial perilymph solution, it was found that the cochlear implant electrode itself can be used to detect impact forces. The findings were significant because such an approach provides a simple and safe method for the detection of possible dangers during surgical implantation of the cochlear implant. Factors influencing the response were investigated and these included solution composition and the orientation of the impact forces encountered.

## ABBREVIATIONS

A	Ampere
$A^-$	Anion
AC	Alternating current
ACN	Acetonitrile
$Ag/Ag^+$	Silver/silver ion reference electrode
$Ag/AgCl$	Silver/silver chloride reference electrode
BMI.BF <sub>4</sub>	1-Butyl-3-methyl-imidazolium tetrafluoroborate
C	Coulomb
C <sub>dl</sub>	Double layer capacitance
cm	Centimetre
conc.	Concentration
CV	Cyclic voltammetry
D	Diffusion coefficient
DBS <sup>-</sup>	Dodecylbenzene sulfonate
$e^-$	Electron
E	Potential
E <sub>app</sub>	Applied potential
EC	Electrochemical/Electrochemistry
EE	Electrochemical efficiency
EE <sub>ox</sub>	Electrochemical efficiency during oxidation process

$EE_{\text{red}}$	Electrochemical efficiency during reduction process
$E_f$	Final potential
$E_i$	Initial potential
EIS	Electrochemical impedance spectroscopy
$E_{\text{lower}}$	Lower limit potential
EMI.TFSI	1-ethyl-3-methylimidazolium (bis) trifluoromethanesulfonimide
$E_p$	Peak potential
$E_{\text{pa}}$	Anodic peak potential
$E_{\text{pc}}$	Cathodic peak potential
$E_{\text{upper}}$	Upper limit potential
F	Faraday constant
g	Gram
i	Current
$i_p$	Peak current
$i_{\text{pa}}$	Anodic peak current
$i_{\text{pc}}$	Cathodic peak current
iR	Ohmic drop
L	Litre
M	Molar
mA	Milliampere
min	Minute
ml	Millilitre

mV	Millivolt
n	Number of electrons
PAn	Polyaniline
PC	Propylene carbonate
PF <sub>6</sub> <sup>-</sup>	hexafluorophosphate
PPy	Polypyrrole
PPy/Cl	Polypyrrole chloride
PPy/ClO <sub>4</sub>	Polypyrrole perchlorate
PPy/NO <sub>3</sub>	Polypyrrole nitrate
PPy/DBS	Polypyrrole Dodecylbenzenesulfonate
PPy/PF <sub>6</sub>	Polypyrrole hexafluorophosphate
PPy/ <i>p</i> TS	Polypyrrole p-toluene sulphonate
PVDF	Polyvinylidene fluoride filter membrane
Pt	Platinum
<i>p</i> TS.Na	p-toluene sulphonic acid sodium salt
Q	Charge
R	Gas constant
R	Resistance
R <sub>s</sub>	Solution resistance
R <sub>p</sub>	Polarisation resistance
s	Second
S	Siemens
t	Time

T	Temperature
TBAP	Tetrabutylammonium perchlorate
TBA.PF <sub>6</sub>	Tetrabutylammonium hexafluorophosphate
TFSI <sup>-</sup>	(bis) trifluoromethanesulfonimide
V	Volt
μ	Micro (prefix)
ν	Scan rate
X <sup>+</sup>	Cation

## LIST OF FIGURES AND TABLES

### 1. FIGURES

- Figure 1-1** The cochlear implant consists of a speech processor and a cochlear implant electrode in order to create the sensation of sound in severely to profoundly deaf people [2]. 3
- Figure 1-2** Schematic illustrating insertion trauma that may occur during the surgical implantation of the cochlear implant. A. The electrode tip tears the spiral ligament in the lower basal turn, B. The tear has increased and there is slight upward movement of the basilar membrane, C. The electrode tip has met resistance against the outer wall in the upper basal turn causing slight buckling of the electrode, further tearing of the spiral ligament, and upward dislocation of the osseous spiral lamina and basilar membrane [12]. 5
- Figure 1-3** The Nucleus<sup>®</sup> 24 Contour<sup>™</sup> electrode. (a) the pre-curved electrode, (b) the pre-curved electrode straightened by a platinum stylet for ease of insertion and the suggested alternative technique if resistance is felt during surgical implantation [10]. 6
- Figure 1-4** Chemical structures of selected  $\pi$ -conjugated inherently conducting polymers (ICPs) in the dedoped form. 9
- Figure 1-5** Schematic showing the formation of polaron and bipolaron states in PPy [72, 73]. 10



- Figure 1-6** Mechanism of the electrochemical polymerisation of pyrrole to form PPy [100]. 13
- Figure 1-7** Chemical structure of di-2-butoxy-2-ethoxy-ethyl ester of sulfosuccinic acid (DBEESSA) [123]. 19
- Figure 1-8** A triple layer laminated actuator formed by a double-sided tape sandwiched between two layers of conducting polymer films. 21
- Figure 2-1** The potential waveform in a typical CV experiment. The potential is scanned between +600 mV and -400 mV at a scan rate of  $100 \text{ mV.s}^{-1}$  for 2 cycles. 40
- Figure 2-2** Cyclic voltammogram for a diffusion limited reversible redox couple where both the oxidized and reduced species are solution soluble. 42
- Figure 2-3** A typical cyclic voltammogram and the graphical method for determining peak potentials and currents for a reversible process. Data is from a CV experiment using a bare platinum working electrode in 5 mM potassium ferricyanide in aqueous 0.1 M sodium perchlorate supporting electrolyte at various scan rates. 44
- Figure 2-4** Cyclic voltammogram for a reversible surface immobilised electroactive species. 46
- Figure 2-5** Cyclic Voltammograms of polypyrrole/*p*-toluenesulfonate modified glassy carbon electrode in 100 mM aqueous sodium perchlorate supporting electrolyte at scan rates of 10 to 500  $\text{mV.s}^{-1}$ . 47

**Figure 2-6** A typical chronoamperometry experiment using a standard Pt disk electrode ( $\varnothing 1.5$  mm) for the electrochemical deposition of polypyrrole from an aqueous solution containing 0.2 M pyrrole and 0.05 M sodium *p*TS at a constant potential of 0.61 V vs. Ag/AgCl. 48

**Figure 2-7** A typical response of a chronopotentiometric experiment for the electrochemical polymerisation of pyrrole to form polypyrrole on a standard Pt disk electrode ( $\varnothing 1.5$  mm) in an aqueous solution containing 0.2 M pyrrole and 0.05 M sodium *p*TS. Constant current density of  $0.5 \text{ mA.cm}^{-2}$  was applied. 50

**Figure 2-8** Impedance spectra of (a) Nyquist plot and (b) Bode plot. 53

**Figure 2-9** EIS spectra of cochlear ring electrode in PBS buffer and its equivalent circuit model, where  $R_s$  stands for the solution resistance,  $\text{CPE}_{\text{dl}}$  for the nonlinear nature of double layer capacitance at the electrode-solution interface and  $R_p$  for the polarisation resistance (also called charge transfer resistance). 54

**Figure 2-10** Set-up using an Aurora Dual-Mode Lever Arm System for (a) the blocking force measurement and (b) the sensor testing. 57

**Figure 2-11** The four-point-probe for the measurement of electrical conductivity. Potential drop ( $\Delta V$ ) between inner electrodes was measured while a constant current ( $I$ ) was applied between outer electrodes. 59

**Figure 2-12** The two-electrode cell configuration for the preparation of polymer actuators and sensors. 63

**Figure 2-13** The three-electrode cell configuration used for ICP-modified electrode or device preparation and characterisation. Here a Ag/AgCl (3 M NaCl salt bridge) reference electrode was used for aqueous solutions and a Ag/Ag<sup>+</sup> reference electrode (0.1 M TBAP in acetonitrile salt bridge) was used for organic solvents. Platinum or stainless steel mesh was used as the auxiliary electrode. 63

**Figure 3-1** Cross-sectional schematic showing the structure of a laminated mechanical sensor. The porous PVDF membrane acted as a backing for the laminated device and as an electrolyte reservoir. 70

**Figure 3-2** Set-up using an Aurora Dual-Mode Lever Arm System to apply sinusoidal displacement at the free end of a laminated polypyrrole mechanical sensor. The tip of the lever arm was insulated and perpendicularly attached to the sensor, where the existence of liquid electrolyte helped this physical attachment during the test. 72

**Figure 3-3** Effect of dopant and redox states on the voltage output of mechanical sensors. The PPy/DBS sensor was preconditioned at either +0.6 V or -0.8 V in aqueous 0.2 M NaDBS for 5 minutes prior to testing. The PPy/ClO<sub>4</sub> sensor was preconditioned at either +0.6 V and -0.8 V in aqueous 0.1 M NaClO<sub>4</sub> for 5 minutes prior to testing. The sensor dimension was 20 mm × 2 mm × ~ 125 μm thick and the sinusoidal displacement was controlled at a constant amplitude of 8 mm

and at a constant frequency of 0.5 Hz. (a) Raw data, (b) dependency of induced voltage on dopant and redox state.

75

**Figure 3-4** Schematics describing the proposed model of the stress induced ion flux mechanism for (a) small dopants (e.g.  $\text{ClO}_4^-$ ) and (b) large dopants (e.g.  $\text{DBS}^-$ ).

77

**Figure 3-5** The effect of  $\text{BMI.PF}_6$  : PC molar ratio on the displacement sensing properties of polypyrrole mechanical sensors. The sensor dimension was  $20 \text{ mm} \times 2 \text{ mm} \times \sim 140 \text{ }\mu\text{m}$  thick and the peak-to-peak amplitude of sinusoidal displacement was controlled at 6 mm at a frequency of 0.5 Hz.

81

**Figure 3-6** Effect of frequency on the amplitude of sensor voltage output plot: (a) the real time waveform of the induced voltage and (b) relationship between the voltage amplitude and mechanical displacement frequency. A  $(\text{PPy}/\text{PF}_6)/\text{Pt}/\text{PVDF}/\text{Pt}/(\text{PPy}/\text{PF}_6)$  sensor soaked in 0.25 M  $\text{TBA.PF}_6$  in PC solution was used with dimensions of  $20 \text{ mm} \times 2 \text{ mm} \times 140 \text{ }\mu\text{m}$ . Sinusoidal displacement was controlled at a constant peak-to-peak amplitude of 4 mm.

83

**Figure 3-7** The effect of displacement frequency on the induced charge output of a  $(\text{PPy}/\text{PF}_6)/\text{Pt}/\text{PVDF}/\text{Pt}/(\text{PPy}/\text{PF}_6)$  sensor with dimensions of  $20 \text{ mm} \times 1 \text{ mm} \times 140 \text{ }\mu\text{m}$ . Sinusoidal displacement was controlled at a constant amplitude of 2 mm. The charge measured was the peak-to-peak charge difference.

84

- Figure 3-8** Correlation between induced charge output and displacement for a (PPy/PF<sub>6</sub>)/Pt/PVDF/Pt/(PPy/PF<sub>6</sub>) sensor. Dimensions: 20 mm × 1 mm × 140 μm. (a) Real-time data and (b) plot of sensor displacement vs. induced charge output. 86
- Figure 4-1** Chemical composition of (a) Nafion and (b) Flemion. 91
- Figure 4-2** The stretching frame (approximate 10 cm × 10 cm in size) used in the fabrication of polypyrrole bending trilayer actuators. Au sputter coated PVDF was fixed by four bolts at each corner on Teflon joints. The frame was fitted with four stainless springs to provide the stretching force along copper rods that were fixed at one end within a Teflon-joint and were able to slide freely inside another Teflon joint. 95
- Figure 4-3** Schematic showing setup used for ionic conductivity measurements. Dimensions of the set-up were 2 cm × 2 cm × 4 mm. 96
- Figure 4-4** Setup for testing the effect of bending frequency. The actuator measured 2 mm wide with various effective lengths between 10 mm and 40 mm, excluding the 2 mm part clamped between the platinum contacts. 97
- Figure 4-5** Configuration for bending torque measurements of Nucleus<sup>®</sup> 24 Contour<sup>™</sup> electrodes. 98
- Figure 4-6** Cross-sectional SEM image of electrodeposited polypyrrole on Au coated PVDF membrane. Electrodeposition was carried out in PC solution containing 0.05 M TBA.PF<sub>6</sub>, 0.06 M pyrrole and 0.5% water for 12 hours at a constant current density of 0.1 mA.cm<sup>-2</sup>. 100

**Figure 4-7** CV of PPy/PF<sub>6</sub> film on a standard platinum disc electrode. The third cycle is shown. Potential was scanned between + 650 mV and - 800 mV at 50 mV.s<sup>-1</sup> vs. Ag/Ag<sup>+</sup> in PC solution containing 0.25 M TBA.PF<sub>6</sub>. (A) The oxidation peak (-0.3 V), (B) the reduction peak (-0.55 V). 101

**Figure 4-8** CV obtained for PPy/PF<sub>6</sub> trilayer actuator. Lower potential limit = -1.0 V, upper potential limit = + 1.0 V, scan rate = 100 mV.s<sup>-1</sup>. Electrolyte: 0.05 M TBA.PF<sub>6</sub> in PC. 102

**Figure 4-9** The deflection of a polypyrrole trilayer actuator during a CV experiment. Sample dimensions: 10 mm wide, 50 mm long. Polypyrrole was grown galvanostatically for 12 hours at 0.1 mA.cm<sup>-2</sup>. Supporting electrolyte was 0.25 M TBA.PF<sub>6</sub> in PC. Mass load at the free end: 25 mg. Voltage cycled between +/- 1.0 V at a fixed scan rate of 100 mV.s<sup>-1</sup>. (A) The outmost left bending position, (B) an intermediate bending position, and (C) the outmost right bending position. 105

**Figure 4-10** Modelling of a bending polypyrrole trilayer actuator.

(A) The bending arc of a 50 mm long strip and the tip's locus defined by the coordinates,  $x$  and  $y$ ,  $r$  is the radius of bending curve,  $\theta$  is the angle of bending arc. (B) Cross-section of the actuator.  $L$  is the original length,  $d$  is the thickness of polypyrrole layer on both sides, and  $d_0$  is the thickness of the porous PVDF layer. 105

**Figure 4-11** One cycle of charge passed and strain produced in a CV experiment, where the voltage was scanned between +/- 1.0 V at a fixed rate of 100 mV.s<sup>-1</sup>. 107

**Figure 4-12** Plot of strain vs. charge data from Figure 4-11. 107

**Figure 4-13** CV of polypyrrole trilayer actuator between  $\pm 1.0$  V at scan rate of  $100 \text{ mV.s}^{-1}$ . PPy/PF<sub>6</sub> was grown galvanostatically at a current density of  $0.1 \text{ mA.cm}^{-2}$  for 12 hours from a solution containing 0.06 M pyrrole monomer, 0.05 M TBA.PF<sub>6</sub> and 0.5% (w/w) Milli-Q water in PC at the temperature of  $\sim -20^\circ\text{C}$ . 110

**Figure 4-14** Polypyrrole trilayer actuator subject to square wave pulsed potential input between  $\pm 1.0$  V. Each pulse was  $\sim 6$  seconds (i.e. cycle time  $\sim 12$  seconds). PPy/PF<sub>6</sub> was grown galvanostatically at a current density of  $0.1 \text{ mA.cm}^{-2}$  for 12 hours from a solution containing 0.06 M pyrrole monomer, 0.05 M TBA.PF<sub>6</sub> and 0.5% (w/w) Milli-Q water in PC at the temperature of  $\sim -20^\circ\text{C}$ . 111

**Figure 4-15** Polypyrrole trilayer actuator subject to square wave pulsed current input between  $\pm 20 \text{ mA.cm}^{-2}$ , each pulse was  $\sim 6$  seconds (i.e. cycle time  $\sim 12$  seconds). PPy/PF<sub>6</sub> was grown galvanostatically at a current density of  $0.1 \text{ mA.cm}^{-2}$  for 12 hours from a solution containing 0.06 M pyrrole monomer, 0.05 M TBA.PF<sub>6</sub> and 0.5% (w/w) Milli-Q water in PC at the temperature of  $\sim -20^\circ\text{C}$ . 112

**Figure 4-16** Effect of electrolyte on the free bending strain generation of polypyrrole trilayer actuators using CV input. The potential was scanned between  $-1.0$  V and  $+1.0$  V at 0.05 Hz. Actuator dimensions: 30 mm long, 3 mm wide. The strain was estimated based on the loops and diameter of the coiled actuator according to the Equations 4-3 and 4-4. 116

**Figure 4-17** Frequency bending displacement response of the PPy/TFSI bending actuator. The applied potential was a sine wave with amplitude of  $\pm 1.0$  V and frequencies ranging from 1 to 100 Hz. The width (W) of actuator was 2 mm, but its length (L) was varied from 10 mm to 40 mm, as indicated. 118

**Figure 4-18** Frequency bending displacement response of the PPy/PF<sub>6</sub> bending actuator. The applied potential was a sine wave with amplitude of  $\pm 1.0$  V and frequencies ranging from 1 to 60 Hz. The width (W) of the actuator was 2 mm, but its length (L) was varied from 10 mm to 40 mm, as indicated. 118

**Figure 4-19** The step responses of the PPy/TFSI and PPy/PF<sub>6</sub> actuators under a step potential of 1.0 V. Both actuators have a width of 2 mm and an effective length of 20 mm. 119

**Figure 4-20** The current passed through the PPy/TFSI and PPy/PF<sub>6</sub> actuators under a step potential of 1 V. Both actuators have a width of 2 mm and an effective bending length of 20 mm. 120

**Figure 4-21** The charge transferred to the PPy/TFSI and PPy/PF<sub>6</sub> actuators under a step potential of 1.0 V. Both actuators have a width of 2 mm and an effective bending length of 20 mm. 121

**Figure 4-22** Frequencies at the sharp maxima in Figure 4-17 and Figure 4-18 plotted against  $L^{-3/2}$  where L is the length of the trilayer actuator. As predicted by bending beam theory (Equation 4-7) the relationships are linear. 123

**Figure 4-23** Force generated (Figure 4-19) against charge injected (Figure 4-21) for the first 1 second after a step voltage of +1.0 V was applied. 125



- Figure 4-24** Blocking force vs. polypyrrole film thickness for a PPy/PF<sub>6</sub> trilayer actuator using 0.05 M TBA.PF<sub>6</sub> in PC electrolyte. Voltage applied: + 1.0 V. Actuator dimensions: 1 mm wide, 10 mm long. 126
- Figure 4-25** Blocking force vs. applied voltage for PPy/PF<sub>6</sub> trilayer actuator using 0.05 M TBA.PF<sub>6</sub> in PC or BMI.PF<sub>6</sub> electrolytes. PPy/PF<sub>6</sub> thickness: 30 μm. Actuator dimensions: 1 mm wide, 10 mm long. 128
- Figure 4-26** Blocking force vs. applied voltage for PPy/TFSI trilayer actuator using 0.05 M LiTFSI in PC or EMI.TFSI electrolyte. PPy/TFSI thickness: 30 μm. Actuator dimensions: 1 mm wide, 10 mm long. 128
- Figure 4-27** % (w/w) fraction of P and F in PPy/PF<sub>6</sub> by microanalysis of the fully oxidized (+ 0.65 V applied potential) and fully reduced (-0.80 V applied potential) states. 130
- Figure 4-28** Torque required to straighten the Nucleus<sup>®</sup> 24 Contour<sup>™</sup> electrode as a function of the distance relative to the electrode tip at which force was applied. 132
- Figure 5-1** Schematic diagram showing the TITAN assembly. A: porous PVDF fibre (OD: 650 μm) used to maintain the micropump cylindrical shape. B: platinised PU tube (OD: 1050 μm, ID: 950 μm) wrapped with ø50 μm platinum wire and coated with polypyrrole, used as the TITAN working electrode. C: inert PVDF membrane, used as an inert electrochemical cell separator and to hold the 0.25 M TBA.PF<sub>6</sub>/PC supporting electrolyte. D: platinised PVDF membrane coated with polypyrrole connected via stainless steel mesh, used as the

TITAN auxiliary electrode. E: plastic tube (3 cm long, OD: 5 mm, ID: 4 mm) used to pack the electrode assembly. 141

**Figure 5-2** Schematic diagram showing the electrochemical cell used to electrodeposit polypyrrole onto a platinised polyurethane tube with surrounding Pt wiring. 141

**Figure 5-3** The TITAN assembly. A water column was used to apply backpressure. 142

**Figure 5-4** Schematics showing 8 TITAN working electrodes constructed in series on a single polyurethane tube and their volume change in response to sequential switching of voltage. 144

**Figure 5-5** LabView switching cluster program for the dynamic switching of TITAN tube segments at  $\pm 1.0$  V. 144

**Figure 5-6** CV characterization of (A) TITAN micropump working electrode (polypyrrole coated PU tube), and (B) TITAN micropump auxiliary electrode (polypyrrole coated PVDF membrane); lower potential limit =  $-1.0$  V, upper potential limit =  $+0.65$  V, scan rate =  $50 \text{ mV.s}^{-1}$ ; electrolyte:  $0.25 \text{ M TBA.PF}_6$  in PC. 146

**Figure 5-7** CV of TITAN assembly using two-electrode setup. Potential (vs. auxiliary electrode) was swept from  $+2.0$  V to  $-2.0$  V at  $50 \text{ mV.s}^{-1}$  in  $0.25 \text{ M TBA.PF}_6 / \text{PC}$ . 147

**Figure 5-8** Sequence of video frames showing the displacement of dyed plug through an open-end glass capillary. (A)  $+1.0$  V applied (0-30 s), the TITAN working electrode expands and plug moves towards the pump. (B) voltage switched to  $-1.0$  V (30-60 s), the TITAN working electrode contracts and plug moves

away from the pump. (C) displacement reached after -1.0 V applied for 30 s. 148

**Figure 5-9** Pulsed potential waveform. Upper potential was held at +1V and the lower potential was varied to optimise the pump operating potential (-1.0 V shown as an example). 149

**Figure 5-10** Volume of fluid displaced as a function of the voltage applied to a TITAN micropump; volume taken as the amount of fluid displaced after 30 s for each applied voltage. 149

**Figure 5-11** Diagram representing the dimensional changes in the polypyrrole coated platinised PU tube working electrode of the TITAN micropump, for applied voltages of (a) +1.0 V and (b) -1.0 V. 150

**Figure 5-12** Volume of fluid displaced by TITAN micropump as a function of charge. The charge was the integration of the current obtained from the experiment shown in Figure 5-10. 151

**Figure 5-13** Volume of fluid displaced by a TITAN micropump as a function of applied back pressure. 153

**Figure 5-14** (a) Diagram of the valveless TITAN micropump in the oxidised (expansion) state, (b) schematic illustrating the pumping sequence of the valveless TITAN micropump. 155

**Figure 6-1** Chemical structure of sulforhodamine B, Mwt = 580.7. 162

**Figure 6-2** Schematic showing the configuration of a PPy-coated hollow fibre primed with aqueous SB dye solution for controlled release experiments. 164

- Figure 6-3** Schematic showing the three-electrode setup for controlled release experiments. 166
- Figure 6-4** Schematic showing the “wire in fibre” two electrode setup for controlled release experiments. The electrode assembly was immersed in PBS buffer as shown in Figure 6-3. 167
- Figure 6-5** Overlay of the UV-Vis spectra of a  $\sim 5$  ppm aqueous SB solution at pH of 3, 5 and 11. Solution pH was carefully adjusted by adding 0.1 M NaOH<sub>(aq)</sub> or 0.1 M HCl<sub>(aq)</sub> and monitored using pH paper. 168
- Figure 6-6** CV of aqueous 0.01 M SB on a standard glassy carbon electrode ( $\varnothing$  3mm); 0.1 M KCl<sub>(aq)</sub> was used as the supporting electrolyte. Potential was scanned between - 800 mV and + 600 mV (vs. Ag/AgCl) at a scan rate of 10 mV.s<sup>-1</sup> for 5 cycles. 169
- Figure 6-7** Plot of the sheet resistance of platinised PVDF hollow fibres at various Pt coating thicknesses. 170
- Figure 6-8** Release of SB with time from a bare PVDF hollow fibre, a PVDF hollow fibre coated with 145 nm of Pt or a PVDF hollow fibre coated with 288 nm of Pt. The receiving solution was 18 ml of PBS buffer. 10  $\mu$ L of 10 mM aqueous SB solution (total mass SB = 58  $\mu$ g) was loaded inside each of the hollow fibres prior to testing. 171
- Figure 6-9** Chronopotentiogram recorded during the electrodeposition of PPy onto a platinised PVDF hollow fibre at a current density of 1.0 mA.cm<sup>-2</sup> from an aqueous solution containing 0.1 M pyrrole monomer and 0.1 M Na *p*TS. 172

**Figure 6-10** CV of PPy/*p*TS-coated PVDF hollow fibre in PBS buffer. A: the oxidation peak, B: the reduction peak. Potential was scanned between – 800 mV and + 600 mV (*vs.* Ag/AgCl) at a scan rate of 50 mV.s<sup>-1</sup> for 7 cycles. 173

**Figure 6-11** SEM images of Pt/PVDF\_HF and 3min (PPy/*p*TS)-/Pt/PVDF\_HF showing (a) the outer surface of Pt/PVDF, (b) the outer surface, (c) the outer surface over ~ 5 mm length and (d) the cross section of 3min (PPy/*p*TS)/Pt/PVDF\_HF. 174

**Figure 6-12** Amount released of SB dye from PPy-coated platinised PVDF hollow fibres, where PPy was galvanostatically deposited for 1, 3 or 6 minutes. 175

**Figure 6-13** Release of the anionic SB from a sample of 3min(PPy/*p*TS)/Pt/PVDF\_HF in response to a pulsed electrical stimulation. The applied potential was pulsed between – 500 mV and + 600 mV at 30 s intervals. 178

**Figure 6-14** Release of the anionic dye SB from a sample of 3min(PPy/DBS)/Pt/PVDF\_HF with and without electrical stimulation. For the electrically stimulated sample, the applied potential was continuously pulsed between –500 mV and +600 mV at 30 s intervals. 179

**Figure 6-15** (a) Release of the anionic dye SB using “wire in fibre” two-electrode setup including a 3min(PPy/*p*TS)/Pt/PVDF\_HF working electrode with and without electrical stimulation. Electrical stimulation was achieved by applying a pulsed potential between +/– 1.0 V at 30 s intervals. (b) Current response during electrical stimulation experiment. 181

- Figure 6-16** Schematic showing the competing ion flows using the “wire in fibre” setup. 183
- Figure 7-1** Sectional view of a catheter tip transducer using a cylindrical elastic member and unbonded strain gauges [2]. 189
- Figure 7-2** The fibre optic sensor used to measure blood pressure [6]. 190
- Figure 7-3** Grahame’s model of the interfacial region in the immediate vicinity of the electrode. 191
- Figure 7-4** The cochlear implant showing the 22 ring electrodes from E1 to E22. 193
- Figure 7-5** Schematic of custom setup for the impedance / capacitance measurement as a function of impact force. (A) the cochlear implant electrode, (B) a digital mass balance used to measure the compressive force of implant tip, (C) weight on the fixed end of the ruler cantilever, (D) screw jack, (E) stainless steel cantilever, (F) screw used to adjust the distance between the implant tip and the cell bottom through a cantilever, (G) Ag/AgCl reference electrode, (H) platinum mesh counter electrode, (I) lead wires, (J) the electrochemical cell containing PBS or artificial perilymph solution. 194
- Figure 7-6** The experimental setup for a simulated implantation: (a) the cochlear replica made of Telfon (dimension: 3 cm × 5.2 cm × 1.1 cm) was placed upside down and clamped on the 10 N load cell and the cochlear implant was held by tweezers straightly aligned and pointed upwards the replica entry (b) The final position of cochlear implant electrode in the replica after the simulated implantation. 195

- Figure 7-7** Cyclic voltammograms of the ring electrode in artificial perilymph or PBS solution. Lower potential limit = -0.60 V, upper potential limit = +1.2 V, scan rate = 500 mV.s<sup>-1</sup>. The 50<sup>th</sup> cycle is shown for each solution. 196
- Figure 7-8** Impedance between E1 and E2 vs. Time after immersion in artificial perilymph solution at 1000 Hz. DC potential is set at open circuit potential, AC amplitude was set at 10 mV. 197
- Figure 7-9** Complex and Bode plots of impedance between two ring electrodes in buffer solution. DC: 0.000 V, AC: 10 mV in rms, Frequency: 100 to 10<sup>6</sup> Hz. 198
- Figure 7-10** Equivalent circuit model and data fitting. 199
- Figure 7-11** Complex and Bode plots of impedance for stepwise change in impact force applied to the implant electrode tip from 0 mN to 40 mN at a fixed frequency of 1000 Hz. Impedance was measured for the first ring electrode (E1) at the open circuit potential relative to Ag/AgCl. 200
- Figure 7-12** Cross-sectional schematic of the mechanism of surface area change of the cochlear implant ring electrode when (a) straightened by a stylet and (b) when subjected to an impact force. 201
- Figure 7-13** Triplicate experimental plots of capacitance vs. vertical impact force for ring electrode pairs on an implant electrode array. (a) E1/E2, (b) E1/E3 and (c) E1/E4. 203
- Figure 7-14** (A) Correlations between the insertion force, insertion depth and capacitance of a cochlear implant in a simulated insertion into a cochlear replica. A constant insertion speed of 1

mm.min<sup>-1</sup> was used, (B) a diagram illustrating the relative insertion depth along the cochlear replica. 205

**Figure 7-15** (A) Correlations between the resistive force, insertion depth and capacitance of implant E in a simulated insertion into a cochlear replica. A constant insertion speed of 1 mm.min<sup>-1</sup> was used. (B) A diagram illustrating the relative insertion depth along the cochlear replica. 207

**Figure 7-16** The three major insertion stages during implant insertion into a cochlear replica. 209

**Figure 7-17** Impedance / time plot of ring electrode transferred from PBS buffer to artificial perilymph at 1000 Hz. Impedance measured for one ring electrode at open circuit potential relative to Ag/AgCl. 210

**Figure 7-18** Schematics of a new cochlear implant electrode and the configuration of the ring electrodes showing the strategy for the compensation of ion compositional change. 211

**Figure 7-19** The equivalent circuit for the capacitance of ring electrode with a thin layer non conductive coating in buffer solution. 212

## 2. TABLES

**Table 4-1** Thickness and sheet resistance data for Au sputter coated PVDF and electrodeposited polypyrrole on Au sputter coated PVDF. 99



# CONTENTS

TITLE OF THESIS	I
DEDICATION	II
CERTIFICATION	III
ACKNOWLEDGEMENT	IV
PUBLICATIONS	V
ABSTRACT	VII
ABBREVIATIONS	IX
LIST OF FIGURES AND TABLES	XIII
CONTENTS	XXX

<b>CHAPTER 1</b>	<b>GENERAL INTRODUCTION</b>	<b>1</b>
1.1	MOTIVATION	2
1.1.1	BACKGROUND OF THE COCHLEAR IMPLANT	2
1.1.2	THE NEED FOR SENSORS AND ACTUATORS	4
1.1.3	WHY INHERENTLY CONDUCTING POLYMERS	7
1.2	INHERENTLY CONDUCTING POLYMERS	8
1.3	CONDUCTING POLYMER MECHANICAL ACTUATORS	17
1.4	ICPS FOR CONTROLLED RELEASE	22
1.5	ICP BASED MECHANICAL SENSORS	24
1.6	ORGANISATION OF THIS THESIS	27

1.7	REFERENCES	29
<b>CHAPTER 2</b>	<b>GENERAL EXPERIMENTAL</b>	<b>39</b>
2.1	INTRODUCTION	40
2.2	CYCLIC VOLTAMMETRY	40
2.2.1	CYCLIC VOLTAMMETRY OF SOLUBLE ELECTROACTIVE SPECIES	42
2.2.2	CYCLIC VOLTAMMETRY OF SURFACE IMMOBILISED ELECTROACTIVE SPECIES	45
2.3	CHRONOAMPEROMETRY	48
2.4	CHRONOPOTENTIOMETRY	49
2.5	ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY	51
2.6	ULTRAVIOLET VISIBLE (UV-VIS) SPECTROSCOPY	54
2.7	DUAL LEVER ARM SYSTEM	55
2.8	MAGNETRON SPUTTER COATING	57
2.9	ELECTRICAL CONDUCTIVITY MEASUREMENT	58
2.10	REAGENTS AND MATERIALS	60
2.11	COMMON ELECTROCHEMICAL INSTRUMENTATION SETUP	61
2.12	ELECTROCHEMICAL CELL	62
2.13	REFERENCES	64

**PART 1****CHAPTER 3 POLYPYRROLE MECHANICAL SENSORS 66**

3.1	INTRODUCTION	67
3.2	EXPERIMENTAL	69
3.2.1	REAGENTS AND MATERIALS	69
3.2.2	PREPARATION OF MECHANICAL SENSOR	69
3.2.3	SENSOR TEST	71
3.3	RESULTS AND DISCUSSION	73
3.3.1	THE EFFECT OF DOPANT AND REDOX STATE ON VOLTAGE OUTPUT	74
3.3.2	THE EFFECT OF DISPLACEMENT FREQUENCY OF SENSOR ON VOLTAGE OUTPUT	82
3.3.3	EFFECT OF DISPLACEMENT FREQUENCY ON INDUCED CHARGE	84
3.3.4	CORRELATION BETWEEN INDUCED CHARGE OUTPUT AND STATIC DISPLACEMENT	85
3.4	CONCLUSION	87
3.5	REFERENCES	88

**CHAPTER 4 POLYPYRROLE TRILAYER BENDING  
ACTUATORS 89**

4.1	INTRODUCTION	90
4.2	EXPERIMENTAL	93

4.2.1	REAGENTS AND MATERIALS	93
4.2.2	FABRICATION METHOD OF TRILAYER ACTUATOR	93
4.2.3	ELECTROCHEMICAL CHARACTERISATION	95
4.2.4	MECHANICAL ACTUATION TESTING	96
4.3	RESULTS AND DISCUSSION	98
4.3.1	SHEET RESISTANCE AND CROSS SECTIONAL STRUCTURE OF POLYPYRROLE TRILAYER ACTUATORS	99
4.3.2	CYCLIC VOLTAMMETRY OF POLYPYRROLE TRILAYER ACTUATOR	101
4.3.3	STRAIN DETERMINATION OF POLYPYRROLE TRILAYER BENDING ACTUATION AND CORRELATION WITH CHARGE	104
4.3.4	ELECTRICAL ENERGY CONSUMPTION OF POLYPYRROLE TRILAYER ACTUATORS	108
4.3.5	CYCLE LIFE	114
4.3.5.1	IMPROVED ADHESION OF POLYPYRROLE TO THE SUBSTRATE	114
4.3.5.2	USE OF IONIC LIQUID	115
4.3.6	EFFECT OF FREQUENCY OF ELECTRICAL STIMULATION ON BENDING ACTUATION	117

4.3.7	CORRELATION BETWEEN THE BLOCKING FORCE AND APPLIED VOLTAGE IN VARIOUS ELECTROLYTES	126
4.3.8	BENDING TORQUE REQUIRED TO STRAIGHTEN THE NUCLEUS <sup>®</sup> 24 CONTOUR <sup>TM</sup> ELECTRODE	131
4.4	CONCLUSIONS	133
4.5	REFERENCES	134
 <b>CHAPTER 5 POLYPYRROLE-BASED MICROPUMP</b>		
	<b>FOR CONTROLLED FLUID TRANSPORT</b>	137
5.1	INTRODUCTION	138
5.2	EXPERIMENTAL	139
5.2.1	REAGENTS AND MATERIALS	139
5.2.2	CONSTRUCTION OF TITAN MICROPUMP	139
5.2.3	CHARACTERISATION OF THE TITAN MICROPUMP	142
5.3	RESULTS AND DISCUSSION	145
5.3.1	CYCLIC VOLTAMMETRY OF TITAN COMPONENTS	145
5.3.2	FLUID MOVEMENT USING TITAN MICROPUMP	147
5.3.3	APPLICATION OF THE TITAN MICROPUMP TO PERISTALTIC PUMPING	153

5.3.3.1	UTILISATION OF THE ELECTRICAL CIRCUITRY FOR SEQUENTIAL SWITCHING	153
5.3.3.2	UTILISATION OF THE INTRINSIC RESISTANCE AND ELECTROCHEMICAL PROPERTIES OF THE TITAN MICROPUMP FOR SEQUENTIAL SWITCHING	154
5.3.4	FUTURE STUDIES	156
5.4	CONCLUSIONS	157
5.5	REFERENCES	158
<b>CHAPTER 6</b>	<b>CONTROLLED RELEASE USING POLYPYRROLE-COATED HOLLOW FIBRES</b>	160
6.1	INTRODUCTION	161
6.2	EXPERIMENTAL	162
6.2.1	REAGENTS AND MATERIALS	162
6.2.2	PREPARATION OF PLATINISED PVDF HOLLOW FIBRE	163
6.2.3	SYNTHESIS OF PPY ON PLATINISED HOLLOW PVDF FIBRES	163
6.2.4	PRIMING OF MODEL ANION INTO THE LUMEN OF POLYPYRROLE-COATED PLATINISED HOLLOW FIBRES	164

6.2.5	SETUP FOR CONTROLLED RELEASE STUDIES	165
6.3	RESULTS AND DISCUSSION	167
6.3.1	CHARACTERISATION OF THE ANIONIC DYE SULFORHODAMINE B	167
6.3.2	CHARACTERISATION OF PLATINISED PVDF HOLLOW FIBRE	169
6.3.3	CHARACTERISATION OF POLYPYRROLE- COATED PLATINISED PVDF HOLLOW FIBRE	171
6.3.4	EFFECT OF POLYPYRROLE THICKNESS ON DIFFUSION CONTROLLED RELEASE	175
6.3.5	ELECTROCHEMICALLY-CONTROLLED RELEASE	176
6.3.6	CONTROLLED RELEASE USING THE TWO- ELECTRODE “WIRE IN FIBRE” SETUP	179
6.3.7	FUTURE STUDIES	184
6.4	CONCLUSIONS	184
6.5	REFERENCES	186

## **PART 2**

<b>CHAPTER 7</b>	<b>MICRO FORCE SENSOR USING THE COCHLEAR IMPLANT ELECTRODE</b>	187
7.1	INTRODUCTION	188
7.2	EXPERIMENTAL	192
7.2.1	REAGENTS AND STANDARD SOLUTIONS	192

7.2.2	PREPARATION OF IMPLANT ELECTRODE	193
7.2.3	ELECTROCHEMICAL CHARACTERISATION	193
7.2.4	STANDARD IMPACT FORCE SENSING TEST	193
7.2.5	SIMULATED INSERTION WITH COCHLEAR REPLICA	194
7.3	RESULTS AND DISCUSSION	195
7.3.1	CYCLIC VOLTAMMETRY OF RING ELECTRODE	196
7.3.2	ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY	197
7.3.3	CORRELATION BETWEEN THE CAPACITANCE / AND APPLIED FORCE ON THE ELECTRODE TIP	201
7.3.4	SIMULATED INSERTION	204
7.3.5	INFLUENCE OF BUFFER COMPOSITION	209
7.4	CONCLUSIONS	213
7.5	REFERENCE	214
<b>CHAPTER 8</b>	<b>GENERAL CONCLUSIONS</b>	<b>216</b>