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Sensors and actuators for the cochlear implant using inherently conducting polymers

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SENSORS AND ACTUATORS FOR THE COCHLEAR IMPLANT USING INHERENTLY CONDUCTING POLYMERS

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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

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8. Zhou, D, Wallace, G.G., Spinks, G.M., Wu, Y., Cowan, R., and Newbold, C., "High Performance Polypyrrole Based Electromechanical Actuators", *26th 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 (PF_6^-) from the reduced polymer (- 0.8 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
$BMI.BF_4$	1-Butyl-3-methyl-imidazolium tetrafluoroborate
C	Coulomb
C_{dl}	Double layer capacitance
cm	Centimetre
conc.	Concentration
CV	Cyclic voltammetry
D	Diffusion coefficient
DBS^-	Dodecylbenzene sulfonate
e^-	Electron
E	Potential
E_{app}	Applied potential
EC	Electrochemical/Electrochemistry
EE	Electrochemical efficiency
EE_{ox}	Electrochemical efficiency during oxidation process

EE_{red}	Electrochemical efficiency during reduction process
E_f	Final potential
E_i	Initial potential
EIS	Electrochemical impedance spectroscopy
E_{lower}	Lower limit potential
EMI.TFSI	1-ethyl-3-methylimidazolium (bis) trifluoromethanesulfonimide
E_p	Peak potential
E_{pa}	Anodic peak potential
E_{pc}	Cathodic peak potential
E_{upper}	Upper limit potential
F	Faraday constant
g	Gram
i	Current
i_p	Peak current
i_{pa}	Anodic peak current
i_{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_6^-	hexafluorophosphate
PPy	Polypyrrole
PPy/Cl	Polypyrrole chloride
PPy/ClO_4	Polypyrrole perchlorate
PPy/NO_3	Polypyrrole nitrate
PPy/DBS	Polypyrrole Dodecylbenzenesulfonate
PPy/PF_6	Polypyrrole hexafluorophosphate
PPy/*p*TS	Polypyrrole p-toluene sulphonate
PVDF	Polyvinylidene fluoride filter membrane
Pt	Platinum
*p*TS.Na	p-toluene sulphonic acid sodium salt
Q	Charge
R	Gas constant
R	Resistance
R_s	Solution resistance
R_p	Polarisation resistance
s	Second
S	Siemens
t	Time

T	Temperature
TBAP	Tetrabutylammonium perchlorate
$TBA.PF_6$	Tetrabutylammonium hexafluorophosphate
$TFSI^-$	(bis) trifluoromethanesulfonimide
V	Volt
μ	Micro (prefix)
υ	Scan rate
X^+	Cation

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1. FIGURES

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PART 1