UNIVERSITI PUTRA MALAYSIA

PREPARATION AND CHARACTERIZATION OF POLYVINYL ALCOHOL-GRAPHENE OXIDE/POLY(3,4-ETHYLENEDIOXYTHIOPHENE) COMPOSITE NANOFIBER

NUR AFIFAH BINTI ZUBAIR

PREPARATION AND CHARACTERIZATION OF POLYVINYL ALCOHOL-GRAPHENE OXIDE/POLY(3,4-ETHYLENEDIOXYTHIOPHENE) COMPOSITE NANOFIBER

By

NUR AFIFAH BINTI ZUBAIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

August 2016

COPYRIGHT

DEDICATION

To my beloved parents
Mr Zubair Ahmad & Mrs Radziah Abdul Ghani

For always believing in me, encouraging me, and loving me unconditionally…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

PREPARATION AND CHARACTERIZATION OF POLYVINYL ALCOHOL-GRAPHENE OXIDE/POLY(3,4-ETHYLENEDIOXYTHIOPHENE) COMPOSITE NANOFIBER

By

NUR AFIFAH BINTI ZUBAIR

August 2016

Chairman : Yusran Sulaiman, PhD
Faculty : Science

Electrically conductive nanofibers are nanostructured materials which attracted extensive interest for their superior properties. These materials are being studied in various research fields include, electrochemistry, material science and electronic applications. In this work, conducting nanofibers composed of polyvinyl alcohol (PVA), graphene oxide (GO) and poly(3,4-ethylenedioxythiophene) (PEDOT) were fabricated *via* a combined method using electrospinning and electropolymerization techniques. During electrospinning, the concentration of PVA or PVA-GO solution, and the applied voltage were deliberately altered in order to determine the optimized electrospinning conditions. The optimized parameters with 0.1 mg/mL of GO and 10 w/v% of PVA concentration with electrospinning voltage of 15 kV were obtained. The electrospun PVA and PVA-GO nanofiber mats were further modified by coating with the conjugated polymer, PEDOT using electropolymerization techniques which is a facile approach for coating the nanofibers. SEM images of the obtained nanofibers revealed that PEDOT grew well on the surface of the electrospun nanofibers during the potentiostatic mode of the electropolymerization process. The presence of GO and PEDOT in nanofiber was confirmed by FTIR and Raman spectroscopy analyses. The optimum electropolymerization of PEDOT was at potential of 1.2 V in 5 mins. The electrochemical measurements demonstrated that the PVA–GO/PEDOT composite nanofiber could enhance the current response and reduce the charge transfer resistance of the nanofiber. The equivalent circuit models were used to fit the impedance spectra of PEDOT, PVA/PEDOT and PVA-GO/PEDOT nanofibers where the spectra were fitted well.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PENYEDIAAN DAN PENCIRIAN NANOFIBER KOMPOSIT POLIVINIL ALKOHOL-GRAFIN OKSIDA/ POLI(3,4-ETILENADIOKSITIOFENA)

Oleh

NUR AFIFAH BINTI ZUBAIR

Ogos 2016

Pengerusi : Yusran Sulaiman, PhD
Fakulti : Sains

Nanofiber pengalir elektrik adalah bahan berstruktur nano yang telah menarik perhatian luas kerana sifat-sifat unggul yang dimilikinya. Bahan ini telah dikaji dalam pelbagai bidang penyelidikan termasuk elektrokimia, sains bahan dan aplikasi elektronik. Dalam kajian ini, nanofiber konduktor yang terdiri daripada polivinil alkohol (PVA), grafin oksida (GO) dan poli(3,4-etilenadioksitiofina) (PEDOT) telah dihasilkan melalui kaedah gabungan menggunakan teknik elektroputaran dan elektroenapan. Semasa proses elektroputaran, kepekatan larutan PVA atau PVA-GO, dan voltan yang digunakan diubah untuk menentukan keadaan elektroputaran yang optimum. Parameter optimum dengan kepekatan 0.1 mg/mL GO, 10 w/v% PVA dan 15 kV voltan elektroputaran telah diperolehi. Nanofiber PVA dan PVA-GO yang telah dielektroputar diubahsuai selanjutnya dengan menyadurinya menggunakan polimer konjugat, PEDOT melalui teknik pengelektroenapan yang merupakan pendekatan ringkas untuk menyalut nanofiber. Imej SEM daripada nanofiber yang diperolehi mendedahkan bahawa PEDOT berkembang dengan baik pada permukaan nanofiber yang telah dielektroputaran semasa proses pengelektroenapan melalui mod potentiostatik. Kehadiran GO dan PEDOT dalam nanofiber telah disahkan oleh analisis spektroskopi FTIR dan Raman. Keadaan optimum pengelektroenapan PEDOT adalah pada keupayaan 1.2 V dalam masa 5 minit. Pengukuran elektrokimia menunjukkan bahawa nanofiber komposit PVA-GO/PEDOT boleh meningkatkan tindak balas arus dan mengurangkan rintangan pemindahan cas pada nanofiber itu. Padanan model litar telah digunakan untuk disesuaikan dengan spektrum impedans PEDOT, PVA/PEDOT dan PVA-GO/PEDOT yang mana menunjukkan kesemua spektrum itu telah disesuaikan dengan baik.

ACKNOWLEDGEMENTS

First of all, in humble way I wish to give all the praise to Allah, the Almighty God for His mercy has given me the strength, blessing and time through this journey. Alhamdulillah.

I would like to express my sincere thanks to my main supervisor Dr Yusran Sulaiman for his passion, supervision and guidance throughout this research. I would also like to convey my appreciation to my supervisory committee Dr Norizah Abdul Rahman, Dr Janet Lim Hong Ngee and Dr Ruzniza Mohd Zawawi, for their opinion, encouragement and valuable suggestions in this work.

My gratitude also goes to all my group members for their kindness, assistance in the laboratory besides sharing their knowledge with me. Indirectly, there are so many new things that I have learned throughout my studies here. I am also pleased to acknowledge Ministry of Higher Education and Universiti Putra Malaysia Research Grant for the financial support to conduct this research.

Most importantly, I would also like to express my greatest appreciations to my beloved parents, Mr Zubair Ahmad and Mrs Radziah Abdul Ghani who always stood behind me and inspired me in all the ways possible. Special thanks also to my siblings and all family members for their endless support, prayers and motivation. I am so grateful to have you all in my life. Thank you.

I certify that a Thesis Examination Committee has met on 12 August 2016 to conduct the final examination of Nur Afifah binti Zubair on her thesis entitled "Preparation and Characterization of Polyvinyl Alcohol-Graphene Oxide/Poly(3,4-Ethylenedioxythiophene) Composite Nanofiber" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Nor Azah binti Yusof, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jaafar bin Abdullah, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Nor Aziah Buang, PhD
Associate Professor
University of Technology, Malaysia
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 September 2016

This thesis was submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Yusran Sulaiman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Norizah Abdul Rahman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

Lim Hong Ngee, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature : ________________________ Date : ______________________

Name and Matric No : Nur Afifah binti Zubair (GS38665)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:________________________
Name of
Chairman of
Supervisory
Committee:______________________

Signature:________________________
Name of
Member of
Supervisory
Committee:______________________

Signature:________________________
Name of
Member of
Supervisory
Committee:______________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol		Unit
A	electrode area	cm^2
C*	concentration of redox species	mol cm^{-3}
D	diffusion coefficient	cm^2 s^{-1}
ΔE	peak potential	V
i_{pa}	anodic peak current	A
i_{pc}	cathodic peak current	A
R_{ct}	resistance of charge transfer	Ω
R_s	resistance of solution	Ω
v	scan rate	V s^{-1}
T	diffusion element	Ω
W	warburg impedance	Ω
χ^2	chi squared	-

LIST OF ABBREVIATIONS

ACN	acetonitrile
AFM	Atomic force microscopy
ATR	attenuated total reflectance
BET	Brunauer-Emmett-Teller
CE	counter electrode
CPE	constant phase element
CS	chitosan
CV	cyclic voltammetry
DI	deionized
EIS	electrochemical impedance spectroscopy
$[Fe(CN)_6]^{3-/4-}$	ferricyanide and ferrocyanide ion
FESEM	field emission scanning electron microscopy
FTIR	Fourier transform infrared spectroscopy
GO	graphene oxide
ICPs	intrinsically conducting polymers
ITO	indium tin oxide
kV	kilovolt
mA	milliampere
min	minute
mM	millimolar
mPa.s	millipascal-second
mV	millivolt
nm	nanometer
OCP	open circuit potential
PANI	polyaniline
PEDOT	poly(3,4-ethylenedioxythiophene)
PEDOT:PSS	poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate)
PLGA	poly(lactide-co-glycolide)
PPy	polypyrrole
PVA	polyvinyl alcohol
PVA-GO	polyvinyl alcohol-graphene oxide
PVA/PEDOT	polyvinyl alcohol/poly(3,4-ethylenedioxythiophene)
PVA-GO/PEDOT	polyvinyl alcohol-graphene oxide/ poly(3,4-ethylenedioxythiophene)
RE	reference electrode
rGO	reduced graphene oxide
SEM	scanning electron microscopy
$TBAPF_6$	tetra(n-butyl) ammonia hexafluorophosphate
WE	working electrode

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nanotechnology has become a prominent area of research in future with immense potential in terms of various applications. According to the National Science Foundation (NSF) and science related literature, nanotechnology deals with matter in the length scale of approximately 1 - 100 nanometer range (Lines, 2008, Roco, 2007) at atomic, molecular or macromolecular levels where having novel properties and functions due to the arrangement of their atoms in nanoscales. In the advancements of nanotechnology, a diverse range of nanomaterials are being explored include carbon nanotubes, graphene-based materials, nanofibers, nanocomposites, nanoparticles, nanowires, quantum dots, nanorods, nanofilms, and nanopores (Schwirn *et al.*, 2014). Recently, nanofibers have been broadly investigated as high-performance materials due to their unique and remarkable properties which exhibit tremendous advantages. Nanofibers have attracted a great deal of attention because of their excellent characteristics including a high surface area to volume ratio, low specific mass and extensive porosity (Greiner and Wendorff, 2007) which make them appropriate for a diverse range of applications.

Additionally, the interest in electrically conductive nanofibers has increased markedly. This can be seen by a large number of publications and a broad spectrum of the application was studied. These nanofibers have been utilized extensively as electrochromic devices, chemical sensors (Ding *et al.*, 2009), drug delivery (Nima Khadem *et al.*, 2013), wound dressings (Catherine *et al.*, 2014) and photovoltaic devices (Katsuhiro *et al.*, 2006). In conjunction with increased throughput, the fabrication of nanofibers with various adjustments is preferable. There are several techniques to produce nanofibers namely electrospinning, phase separation, self-assembly and template synthesis (Khajavi and Abbasipour, 2012). Electrospinning has been found to be the most versatile process for producing nanoscale fibers with relatively low cost, scalability, high productivity and ability to produce long continuous fibers. At present, various attempts were made in the modification of electrospun nanofibers to improve their properties for specific applications (Hong, 2005, Zhang *et al.*, 2010b).

1.2 Problem Statement

Recently, conductive polymer nanofibers have emerged as excellent supporting materials in the production of nanostructures with narrow diameter distribution. However, it is difficult to use intrinsically conducting polymers (ICPs) in the electrospinning process for nanofiber production due to its intrinsic high crystallinity (Park *et al.*, 2013) low solubility in general solvents (Xu *et al.*, 2009) and too stiff to be electrospun by themselves (Laforgue and Robitaille, 2010). Therefore, a combination of ICPs with another electrospinnable polymer is effectively considered to fabricate nanofibers but this may lead to the detriment of the electronics properties. Hence, despite declining its special characteristics, a facile method was studied to fabricate highly conductive nanofiber by coating electrospun nanofibers with conductive materials. This method is adjustable and essentially enhances the electrical properties of the electrospun nanofiber. Additionally, introducing conducting polymer onto the polymer nanofiber has a potential for producing electroactive nanomaterials. Current studies reported upon the deposition of conducting polymers on electrospun nanofiber structures, the template could potentially produce a promising class of nanomaterials with highly porous structure, large surface area to volume ratio, (Zhang *et al.*, 2006b) and an ultrathin conducting layer (Greiner and Wendorff, 2007), thus make such materials attractive for various applications. The modification of the electrospun polymer nanofiber could enhance the properties of the electrically conductive nanofiber mats in order to achieve some requirement for spesific uses. As reported in the literature, PEDOT coated TiO_2 nanofibers were shown to have increased in electrical conductivity and high sensitivity for sensing applications (Wang *et al.*, 2009b). PEDOT as one of the conductive polymer from polythiophene derivatives has been widely explored due to its excellent environmental and thermal stability, high-speed electron transfer, good mechanical strength and relatively high optical transparency when in its electrically conductive state (Jin *et al.*, 2013).

Another important approach in producing polymer-based composites is the incorporation of carbon-based materials such as carbon nanotubes (CNT) and graphene derivatives into the nanofibers. The complete dispersion of nanofiller represents another challenge that can be countered by specific material, in order to increase their affinity for the polymer matrix in an appropriate solvent. This issue can be overcome by selecting a kind of effective nanofiller to be encapsulated into an electrospun nanofiber matrix. Graphene oxide (GO) is appointed as the best candidate for nanofillers to be reinforced with a hydrophilic polymer such as polyvinyl alcohol (PVA) due to its abundance of hydrophilic groups on its surface. Additionally, PVA is considered as a commonly used electrospinnable polymer due to its processibility, good biodegradability, non-toxicity and good mechanical properties (Cai *et al.*, 2015). Therefore, the high dispersibility of GO in water makes it the best material as nanofiller to be incorporated with PVA matrices. Moreover, GO as one of the most important graphene derivatives has attracted tremendous interest because of their unique properties which are high surface area and good electrical conductivity.

As reported by Rose *et al.*, (2015), polymers will exhibit excellent properties after being reinforced with nanofillers, which contribute to the high performances of materials. The incorporation of nanofillers into electrospun nanofibers improves their properties to a certain extent. Hence, the special criteria of nanofibers which make them commercially important are their role in enhancing the electroactive nature, high surface area and high flexibility in surface functionalities. Consequently, in order to generate conductive nanofibers, significant efforts are being deployed to develop nanofibrous materials for applications. The unique combination of PEDOT as conducting polymers and GO as nanofiller to produce highly conductive materials has sparked an interest in the development of electrospun nanofibers.

1.3 Objectives

The primary aim of this research is to study the unique properties of electrically conductive PVA-GO/PEDOT composite nanofibers produced by a combination of two controllable techniques, electrospinning and electropolymerization. The fabrication of this conductive polymer nanofiber is beneficial as its applicability in various potential applications.

To that aim, this research work has three specific objectives:

1. To prepare PVA/PEDOT and PVA-GO/PEDOT nanofibers by a combination of electrospinning and electropolymerization techniques.
2. To characterize the physical properties of the prepared nanofibers using scanning electron microscope (SEM), Fourier transform infrared spectrometer (FTIR) and Raman spectrometer.
3. To study the electrochemical behavior of PVA/PEDOT and PVA-GO/PEDOT nanofibers by cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS).

REFERENCES

Abbasizadeh, S., Keshtkar, A. R. and Mousavian, M. A. (2013) Preparation of a novel electrospun polyvinyl alcohol/titanium oxide nanofiber adsorbent modified with mercapto groups for uranium(VI) and thorium(IV) removal from aqueous solution. *Chemical Engineering Journal.* 220**.** 161-171.

Abdul Rahman, N. (2012) Electrospun conducting polymer nanofibers for biomedical applications. ResearchSpace@ Auckland.

Abdul Rahman, N., Gulur Srinivas, A. R. and Travas-Sejdic, J. (2014) Spontaneous stacking of electrospun conjugated polymer composite nanofibers producing highly porous fiber mats. *Synthetic Metals.* 191**.** 151-160.

Alanyalıoğlu, M., Segura, J. J., Oró-Solè, J. and Casañ-Pastor, N. (2012) The synthesis of graphene sheets with controlled thickness and order using surfactant-assisted electrochemical processes. *Carbon.* 50**.** 142-152.

Arvand, M., Ghodsi, N. and Zanjanchi, Mohammadâ a. (2016) A new microplatform based on titanium dioxide nanofibers/graphene oxide nanosheets nanocomposite modified screen printed carbon electrode for electrochemical determination of adenine in the presence of guanine. *Biosensors and Bioelectronics.* 77**.** 837-844.

Ates, M. (2011) Review study of electrochemical impedance spectroscopy and equivalent electrical circuits of conducting polymers on carbon surfaces. *Progress in Organic Coatings.* 71**.** 1-10.

Ates, M. (2013) A review study of (bio)sensor systems based on conducting polymers. *Materials Science and Engineering: C.* 33**.** 1853-1859.

Badr, Y. A., Abd El-Kader, K. M. and Khafagy, R. M. (2004) Raman spectroscopic study of CdS, PVA composite films. *Journal of Applied Polymer Science.* 92**.** 1984-1992.

Bai, J., Li, Y., Yang, S., Du, J., Wang, S., Zheng, J., Wang, Y., Yang, Q., Chen, X. and Jing, X. (2007) A simple and effective route for the preparation of poly(vinylalcohol) (PVA) nanofibers containing gold nanoparticles by electrospinning method. *Solid State Communications.* 141**.** 292-295.

Beachley, V. and Wen, X. (2009) Effect of electrospinning parameters on the nanofiber diameter and length. *Materials Science and Engineering: C.* 29**.** 663-668.

Bhardwaj, N. and Kundu, S. C. (2010) Electrospinning: A fascinating fiber fabrication technique. *Biotechnology Advances.* 28**.** 325-347.

Bhattarai, N., Edmondson, D., Veiseh, O., Matsen, F. A. and Zhang, M. (2005) Electrospun chitosan-based nanofibers and their cellular compatibility. *Biomaterials.* 26**.** 6176-6184.

Bock, N., Woodruff, M. A., Hutmacher, D. W. and Dargaville, T. R. (2011) Electrospraying, a reproducible method for production of polymeric microspheres for biomedical applications. *Polymers.* 3**.** 131-149.

Borhani, S., Hosseini, S. A., Etemad, S. G. and Militký, J. (2008) Structural characteristics and selected properties of polyacrylonitrile nanofiber mats. *Journal of Applied Polymer Science.* 108**.** 2994-3000.

Cai, R., Wang, H., Cao, M., Hao, L., Zhai, L., Jiang, S. and Li, X. (2015) Synthesis and antimicrobial activity of mesoporous hydroxylapatite/zinc oxide nanofibers. *Materials & Design.* 87**.** 17-24.

Catherine, M. R., Gavin, E. M., Toby, W. A. G., Robert, B., Sotiria, T., Helen, H., James, E. D., Kevin, M. S., Joel, S. and Felicity, R. A. J. R. (2014) A novel technique for the production of electrospun scaffolds with tailored three-dimensional micro-patterns employing additive manufacturing. *Biofabrication.* 6**.** 035003.

Chen, H. J. H., Huang, M.-T. and Liu, Y. B. (2010a) Fabrication of Au/PEDOT stacked electrodes for organic thin film transistors by imprinting technology. *Microelectronics Reliability.* 50**.** 717-721.

Chen, W., Yan, L. and Bangal, P. R. (2010b) Chemical reduction of graphene oxide to graphene by sulfur-containing compounds. *The Journal of Physical Chemistry C.* 114**.** 19885-19890.

Cho, D., Hoepker, N. and Frey, M. W. (2011) Fabrication and characterization of conducting polyvinyl alcohol nanofibers. *Materials Letters.* 68**.** 293-295.

Cho, H. J., Yoo, Y. J., Kim, J. W., Park, Y. H., Bae, D. G. and Um, I. C. (2012) Effect of molecular weight and storage time on the wet- and electro-spinning of regenerated silk fibroin. *Polymer Degradation and Stability.* 97**.** 1060-1066.

Costa, S., Borowiak-Palen, E., Kruszynska, M., Bachmatiuk, A. and Kalenczuk, R. J. (2008) Characterization of carbon nanotubes by Raman spectroscopy. *Mater Sci-Poland.* 26**.** 433-441.

Demerlis, C. C. and Schoneker, D. R. (2003) Review of the oral toxicity of polyvinyl alcohol (PVA). *Food and Chemical Toxicology.* 41**.** 319-326.

Ding, B., Kim, H.-Y., Lee, S.-C., Lee, D.-R. and Choi, K.-J. (2002a) Preparation and characterization of nanoscaled poly(vinyl alcohol) fibers via electrospinning. *Fibers and Polymers.* 3**.** 73-79.

Ding, B., Kim, H.-Y., Lee, S.-C., Shao, C.-L., Lee, D.-R., Park, S.-J., Kwag, G.-B. and Choi, K.-J. (2002b) Preparation and characterization of a nanoscale poly(vinyl alcohol) fiber aggregate produced by an electrospinning method. *Journal of Polymer Science Part B: Polymer Physics.* 40**.** 1261-1268.

Ding, B., Wang, M., Yu, J. and Sun, G. (2009) Gas sensors based on electrospun nanofibers. *Sensors.* 9**.** 1609.

Doğan, H. Ö., Ekinci, D. and Demir, Ã. (2013) Atomic scale imaging and spectroscopic characterization of electrochemically reduced graphene oxide. *Surface Science.* 611**.** 54-59.

Doshi, J. and Reneker, D. H. (1993) Electrospinning process and applications of electrospun fibers. *Industry Applications Society Annual Meeting, 1993., Conference Record of the 1993 IEEE.* IEEE.

Dreyer, D. R., Park, S., Bielawski, C. W. and Ruoff, R. S. (2010) The chemistry of graphene oxide. *Chemical Society Reviews.* 39**.** 228-240.

Du, X. and Wang, Z. (2003) Effects of polymerization potential on the properties of electrosynthesized PEDOT films. *Electrochimica Acta.* 48**.** 1713-1717.

El-Rafei, A. M. (2015) Optimization of the electrospinning parameters of Mn_2O_3 and Mn_3O_4 nanofibers. *Ceramics International*. 41**.** 12065-12072.

Elschner, A., Kirchmeyer, S., Lovenich, W., Merker, U. and Reuter, K. (2010) *PEDOT: principles and applications of an intrinsically conductive polymer.* CRC Press.

Fabretto, M., Zuber, K., Hall, C. and Murphy, P. (2008) High conductivity PEDOT using humidity facilitated vacuum vapour phase polymerisation. *Macromolecular Rapid Communications.* 29**.** 1403-1409.

Fei, C., Xinwen, P., Tingting, L., Shuiliang, C., Xiang-Fa, W., Darrell, H. R. and Haoqing, H. (2008) Mechanical characterization of single high-strength electrospun polyimide nanofibres. *Journal of Physics D: Applied Physics.* 41**.** 025308.

Feng, Z.-Q., Wu, J., Cho, W., Leach, M. K., Franz, E. W., Naim, Y. I., Gu, Z.-Z., Corey, J. M. and Martin, D. C. (2013) Highly aligned poly(3,4-ethylenedioxythiophene) (PEDOT) nano- and microscale fibers and tubes. *Polymer*. 54**.** 702-708.

Fong, H., Chun, I. and Reneker, D. H. (1999) Beaded nanofibers formed during electrospinning. *Polymer.* 40**.** 4585-4592.

Gao, M., Xu, Y., Bai, Y. and Jin, S. (2014) Effect of electropolymerization time on the performance of poly(3,4-ethylenedioxythiophene) counter electrode for dye-sensitized solar cells. *Applied Surface Science.* 289**.** 145-149.

Geltmeyer, J., Van Der Schueren, L., Goethals, F., De Buysser, K. and De Clerck, K. (2013) Optimum sol viscosity for stable electrospinning of silica nanofibres. *Journal of Sol-Gel Science and Technology.* 67**.** 188-195.

Genies, E. M., Bidan, G. and Diaz, A. F. (1983) Spectroelectrochemical study of polypyrrole films. *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry.* 149**.** 101-113.

Giray, D., Balkan, T., Dietzel, B. and Sezai Sarac, A. (2013) Electrochemical impedance study on nanofibers of poly(m-anthranilic acid)/polyacrylonitrile blends. *European Polymer Journal.* 49**.** 2645-2653.

Greiner, A. and Wendorff, J. H. (2007) Electrospinning: A fascinating method for the preparation of ultrathin fibers. *Angewandte Chemie International Edition.* 46**.** 5670-5703.

Grinou, A., Yun, Y. and Jin, H.-J. (2011) Polyaniline nanofiber-coated polystyrene/graphene oxide core-shell microsphere composites. *Macromolecular Research.* 20**.** 84-92.

Groenendaal, L., Jonas, F., Freitag, D., Pielartzik, H. and Reynolds, J. R. (2000) Poly(3,4-ethylenedioxythiophene) and Its Derivatives: Past, Present, and Future. *Advanced Materials.* 12**.** 481-494.

Guo, H.-L., Wang, X.-F., Qian, Q.-Y., Wang, F.-B. and Xia, X.-H. (2009) A Green Approach to the Synthesis of Graphene Nanosheets. *ACS Nano.* 3**.** 2653-2659.

Haider, S., Al-Zeghayer, Y., Ali, F. A. A., Haider, A., Mahmood, A., Al-Masry, W. A., Imran, M. and Aijaz, M. O. (2013) Highly aligned narrow diameter chitosan electrospun nanofibers. *Journal of Polymer Research.* 20**.** 1-11.

He, J.-H., Wan, Y.-Q. and Yu, J.-Y. (2008) Effect of concentration on electrospun polyacrylonitrile (PAN) nanofibers. *Fibers and Polymers.* 9**.** 140-142.

Heeger, A. J. (2001) Semiconducting and metallic polymers: the fourth generation of polymeric materials (Nobel lecture). *Angewandte Chemie International Edition.* 40**.** 2591-2611.

Hong, K. H., Oh, K. W. And Kang, T. J. (2005) Preparation of conducting nylon-6 electrospun fiber webs by the in-situ polymerization of polyaniline. *Journal of Applied Polymer Science.* 96**.** 983.

Huang, V. M., Wu, S.-L., Orazem, M. E., Pã©Bã¨Re, N., Tribollet, B. and Vivier, V. (2011) Local electrochemical impedance spectroscopy: A review and some recent developments. *Electrochimica Acta.* 56**.** 8048-8057.

Huang, Y.-C., Lo, T.-Y., Chen, C.-H., Wu, K.-H., Lin, C.-M. and Whang, W.-T. (2015) Electrospinning of magnesium-ion linked binder-less PEDOT:PSS nanofibers for sensing organic gases. *Sensors and Actuators B: Chemical.* 216**.** 603-607.

Huang, Z.-M., Zhang, Y. Z., Kotaki, M. and Ramakrishna, S. (2003) A review on polymer nanofibers by electrospinning and their applications in nanocomposites. *Composites Science and Technology*. 63**.** 2223-2253.

Inozemtseva, O. A., Salkovskiy, Y. E., Severyukhina, A. N., Vidyasheva, I. V., Petrova, N. V., Metwally, H. A., Stetciura, I. Y. and Gorin, D. A. (2015) Electrospinning of functional materials for biomedicine and tissue engineering. *Russian Chemical Reviews.* 84**.** 251.

Jang, J., Chang, M. and Yoon, H. (2005) Chemical Sensors Based on Highly Conductive Poly (3, 4â€•ethylenedioxythiophene) Nanorods. *Advanced Materials.* 17**.** 1616-1620.

Jannesari, M., Varshosaz, J., Morshed, M. and Zamani, M. (2011) Composite poly(vinyl alcohol)/poly(vinyl acetate) electrospun nanofibrous mats as a novel wound dressing matrix for controlled release of drugs. *International Journal of Nanomedicine.* 6**.** 993-1003.

Jiang, F., Yao, Z., Yue, R., Du, Y., Xu, J., Yang, P. and Wang, C. (2012) Electrochemical fabrication of long-term stable Pt-loaded PEDOT/graphene composites for ethanol electrooxidation. *International Journal of Hydrogen Energy.* 37**.** 14085-14093.

Jiang, T., Carbone, E. J., Lo, K. W. H. and Laurencin, C. T. (2014) Electrospinning of polymer nanofibers for tissue regeneration. *Progress in Polymer Science.* 46**.** 1-24.

Jin, L., Wang, T., Feng, Z.-Q., Leach, M. K., Wu, J., Mo, S. and Jiang, Q. (2013) A facile approach for the fabrication of core-shell PEDOT nanofiber mats with superior mechanical properties and biocompatibility. *Journal of Materials Chemistry B.* 1**.** 1818-1825.

Kakhki, S., Barsan, M. M., Shams, E. and Brett, C. M. A. (2012) Development and characterization of poly(3,4-ethylenedioxythiophene)-coated poly(methylene blue)-modified carbon electrodes. *Synthetic Metals.* 161**.** 2718-2726.

Kashyap, S., Pratihar, S. K. and Behera, S. K. (2016) Strong and ductile graphene oxide reinforced PVA nanocomposites. *Journal of Alloys and Compounds.*

Katsuhiro, O., Bin, D., Yosuke, T., Takayuki, N., Michiyo, Y., Shinichiro, S., Shingo, O., Masato, Y. and Seimei, S. (2006) Electrospinning processed nanofibrous TiO 2 membranes for photovoltaic applications. *Nanotechnology.* 17**.** 1026.

Katti, D. S., Robinson, K. W., Ko, F. K. and Laurencin, C. T. (2004) Bioresorbable nanofiber-based systems for wound healing and drug delivery: Optimization of fabrication parameters. *Journal of Biomedical Materials Research Part B: Applied Biomaterials.* 70B**.** 286-296.

Kauppila, J., Kunnas, P., Damlin, P., Viinikanoja, A. and Kvarnström, C. (2013) Electrochemical reduction of graphene oxide films in aqueous and organic solutions. *Electrochimica Acta.* 89**.** 84-89.

Khajavi, R. and Abbasipour, M. (2012) Electrospinning as a versatile method for fabricating coreshell, hollow and porous nanofibers. *Scientia Iranica.* 19**.** 2029-2034.

Khanna, P. K., Singh, N., Charan, S., Subbarao, V. V. V. S., Gokhale, R. and Mulik, U. P. (2005) Synthesis and characterization of Ag/PVA nanocomposite by chemical reduction method. *Materials Chemistry and Physics.* 93**.** 117-121.

Kirchmeyer, S. and Reuter, K. (2005) Scientific importance, properties and growing applications of poly (3, 4-ethylenedioxythiophene). *Journal of Materials Chemistry.* 15**.** 2077-2088.

Kuila, T., Mishra, A. K., Khanra, P., Kim, N. H. and Lee, J. H. (2013) Recent advances in the efficient reduction of graphene oxide and its application as energy storage electrode materials. *Nanoscale.* 5**.** 52-71.

Laforgue, A. and Robitaille, L. (2010) Deposition of ultrathin coatings of polypyrrole and poly(3,4-ethylenedioxythiophene) onto electrospun nanofibers using a vapor-phase polymerization method. *Chemistry of Materials.* 22**.** 2474-2480.

Lawrence, N. S., Deo, R. P. and Wang, J. (2004) Biocatalytic carbon paste sensors based on a mediator pasting liquid. *Analytical Chemistry.* 76**.** 3735-3739.

Li, Y., Cao, Y., Gao, J., Wang, D., Yu, G. and Heeger, A. J. (1999) Electrochemical properties of luminescent polymers and polymer light-emitting electrochemical cells. *Synthetic Metals.* 99**.** 243-248.

Lim, Y. S., Tan, Y. P., Lim, H. N., Huang, N. M. and Tan, W. T. (2013) Preparation and characterization of polypyrrole/graphene nanocomposite films and their electrochemical performance. *Journal of Polymer Research C7 - 156.* 20**.** 1-10.

Lines, M. G. (2008) Nanomaterials for practical functional uses. *Journal of Alloys and Compounds.* 449**.** 242-245.

Linh, N. T. B., Min, Y. K., Song, H.-Y. and Lee, B.-T. (2010) Fabrication of polyvinyl alcohol/gelatin nanofiber composites and evaluation of their material properties. *Journal of Biomedical Materials Research Part B: Applied Biomaterials.* 95B**.** 184-191.

Liu, Y., Dong, L., Fan, J., Wang, R. and Yu, J.-Y. (2010) Effect of applied voltage on diameter and morphology of ultrafine fibers in bubble electrospinning. *Journal of Applied Polymer Science.* 120**.** 592-598.

Liu, Y., He, J. H. and Yu, J. Y. (2008) Bubble-electrospinning: a novel method for making nanofibers. *Journal of Physics: Conference Series.* 96**.** 012001.

Lu, H.-H., Lin, C.-Y., Hsiao, T.-C., Fang, Y.-Y., Ho, K.-C., Yang, D., Lee, C.-K., Hsu, S.-M. and Lin, C.-W. (2009) Electrical properties of single and multiple poly (3,4-ethylenedioxythiophene) nanowires for sensing nitric oxide gas. *Analytica chimica acta.* 640**.** 68-74.

Lu, N., Shao, C., Li, X., Miao, F., Wang, K. and Liu, Y. (2016) CuO nanoparticles/nitrogen-doped carbon nanofibers modified glassy carbon electrodes for non-enzymatic glucose sensors with improved sensitivity. *Ceramics International.* 42**.** 11285-11293.

Luo, C. J., Nangrejo, M. and Edirisinghe, M. (2010) A novel method of selecting solvents for polymer electrospinning. *Polymer.* 51**.** 1654-1662.

Luo, L., Xu, W., Xia, Z., Fei, Y., Zhu, J., Chen, C., Lu, Y., Wei, Q., Qiao, H. and Zhang, X. (2016) Electrospun ZnO-SnO_2 composite nanofibers with enhanced electrochemical performance as lithium-ion anodes. *Ceramics International.* 42**.** 10826-10832.

Ma, J., Li, Y., Yin, X., Xu, Y., Yue, J., Bao, J. and Zhou, T. (2016) Poly(vinyl alcohol)/graphene oxide nanocomposites prepared by in situ polymerization with enhanced mechanical properties and water vapor barrier properties. *RSC Advances.* 6**.** 49448-49458.

Manivel, P., Dhakshnamoorthy, M., Balamurugan, A., Ponpandian, N., Mangalaraj, D. and Viswanathan, C. (2013) Conducting polyaniline-graphene oxide fibrous nanocomposites: preparation, characterization and simultaneous electrochemical detection of ascorbic acid, dopamine and uric acid. *RSC Advances.* 3**.** 14428-14437.

Mansur, H. S., Sadahira, C. M., Souza, A. N. and Mansur, A. A. P. (2008) FTIR spectroscopy characterization of poly (vinyl alcohol) hydrogel with different hydrolysis degree and chemically crosslinked with glutaraldehyde. *Materials Science and Engineering: C.* 28**.** 539-548.

Marin, E. and Rojas, J. (2014) Preparation and characterization of crosslinked poly(vinyl) alcohol films with waterproof properties. *International Journal of Pharmacy and Pharmaceutical Sciences.* 7.

Mkhoyan, K. A., Contryman, A. W., Silcox, J., Stewart, D. A., Eda, G., Mattevi, C., Miller, S. and Chhowalla, M. (2009) Atomic and electronic structure of graphene-oxide. *Nano letters.* 9**.** 1058-1063.

Mollá, S. and Compañ, V. (2011a) Performance of composite Nafion/PVA membranes for direct methanol fuel cells. *Journal of Power Sources.* 196**.** 2699-2708.

Mollá, S. and Compañ, V. (2011b) Polyvinyl alcohol nanofiber reinforced Nafion membranes for fuel cell applications. *Journal of Membrane Science.* 372**.** 191-200.

Nima Khadem, M., Amy, M. and Stephanie, M. W. (2013) Biomaterial-based drug delivery systems for the controlled release of neurotrophic factors. *Biomedical Materials.* 8**.** 022001.

Ocampo, C., Oliver, R., Armelin, E., Alemán, C. and Estrany, F. (2005) Electrochemical synthesis of poly(3,4-ethylenedioxythiophene) on steel electrodes: properties and characterization. *Journal of Polymer Research.* 13**.** 193-200.

Okutan, N., Terzi, P. N. and Altay, F. (2013) Affecting parameters on electrospinning process and characterization of electrospun gelatin nanofibers. *Food Hydrocolloids.* 39**.** 19-26.

Österholm, A., Lindfors, T., Kauppila, J., Damlin, P. and Kvarnströ¶M, C. (2012) Electrochemical incorporation of graphene oxide into conducting polymer films. *Electrochimica Acta.* 83**.** 463-470.

Pant, H. R., Park, C. H., Tijing, L. D., Amarjargal, A., Lee, D.-H. and Kim, C. S. (2012) Bimodal fiber diameter distributed graphene oxide/nylon-6 composite nanofibrous mats via electrospinning. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 407**.** 121-125.

Park, H., Lee, S. J., Kim, S., Ryu, H. W., Lee, S. H., Choi, H. H., Cheong, I. W. and Kim, J.-H. (2013) Conducting polymer nanofiber mats via combination of electrospinning and oxidative polymerization. *Polymer.* 54**.** 4155-4160.

Park, J.-C., Ito, T., Kim, K.-O., Kim, K.-W., Kim, B.-S., Khil, M.-S., Kim, H.-Y. and Kim, I.-S. (2010) Electrospun poly(vinyl alcohol) nanofibers: effects of degree of hydrolysis and enhanced water stability. *Polym J.* 42**.** 273-276.

Park, J., Kim, J. and Son, Y. (2006) Conducting polymer micro-tubules hosting electroactive species without guest modification. *Synthetic Metals.* 156**.** 714-720.

Park, J., Lee, A., Yim, Y. and Han, E. (2011) Electrical and thermal properties of PEDOT:PSS films doped with carbon nanotubes. *Synthetic Metals.* 161**.** 523-527.

Ping'an, S., Lina, L., Shenyuan, F., Youming, Y., Chunde, J., Qiang, W., Yan, Z. and Qian, L. (2013) Striking multiple synergies created by combining reduced graphene oxides and carbon nanotubes for polymer nanocomposites. *Nanotechnology.* 24**.** 125704.

Poverenov, E., Li, M., Bitler, A. and Bendikov, M. (2010) Major effect of electropolymerization solvent on morphology and electrochromic properties of PEDOT films. *Chemistry of Materials.* 22**.** 4019-4025.

Qi, G.-Q., Cao, J., Bao, R.-Y., Liu, Z.-Y., Yang, W., Xie, B.-H. and Yang, M.-B. (2013a) Tuning the structure of graphene oxide and the properties of poly(vinyl alcohol)/graphene oxide nanocomposites by ultrasonication. *Journal of Materials Chemistry A.* 1**.** 3163-3170.

Qi, X., Yao, X., Deng, S., Zhou, T. and Fu, Q. (2013b) Water-induced shape memory effect of graphene oxide reinforced polyvinyl alcohol nanocomposites. *Journal of Materials Chemistry A.* 2**.** 2240-2249.

Qiang, L., Zhidong, J., Ying, Y., Liming, W. and Zhicheng, G. (2007) Preparation and properties of poly(vinyl alcohol) nanofibers by electrospinning. *Solid Dielectrics, 2007. ICSD '07. IEEE International Conference on Solid Dielectrics.*

Ramakrishna, S., Fujihara, K., Teo, W.-E., Yong, T., Ma, Z. and Ramaseshan, R. (2006) Electrospun nanofibers: solving global issues. *Materials Today.* 9**.** 40-50.

Roco, M. C. (2007) National nanotechnology initiative-past, present, future.

Rose, A., Raghavan, N., Thangavel, S., Uma Maheswari, B., Nair, D. P. and Venugopal, G. (2015) Investigation of cyclic voltammetry of graphene oxide/polyaniline/polyvinylidene fluoride nanofibers prepared via electrospinning. *Materials Science in Semiconductor Processing.* 31**.** 281-286.

Sahoo, S., Dhibar, S., Hatui, G., Bhattacharya, P. and Das, C. K. (2013) Graphene/polypyrrole nanofiber nanocomposite as electrode material for electrochemical supercapacitor. *Polymer.* 54**.** 1033-1042.

Sakmeche, N., Aeiyach, S., Aaron, J.-J., Jouini, M., Lacroix, J. C. and Lacaze, P.-C. (1999) Improvement of the electrosynthesis and physicochemical properties of poly(3,4-ethylenedioxythiophene) using a sodium dodecyl sulfate micellar aqueous medium. *Langmuir.* 15**.** 2566-2574.

Sarker, S., Ahammad, A. J. S., Seo, H. W. and Kim, D. M. (2014) Electrochemical impedance spectra of dye-sensitized solar cells: Fundamentals and spreadsheet calculation. *International Journal of Photoenergy.* 2014**.** 17.

Sazou, D. and Georgolios, C. (1997) Formation of conducting polyaniline coatings on iron surfaces by electropolymerization of aniline in aqueous solutions. *Journal of Electroanalytical Chemistry.* 429**.** 81-93.

Schwirn, K., Tietjen, L. and Beer, I. (2014) Why are nanomaterials different and how can they be appropriately regulated under REACH? *Environmental Sciences Europe.* 26**.** 4.

Selvaganesh, S., Mathiyarasu, J., Phani, K. L. N. and Yegnaraman, V. (2007) Chemical synthesis of PEDOT-Au nanocomposite. *Nanoscale Research Letters.* 2**.** 546 - 549.

Sen, S., Davis, F. J., Mitchell, G. R. and Robinson, E. (2009) Conducting nanofibres produced by electrospinning. *Journal of Physics: Conference Series.* 183**.** 012020.

Sencadas, V., Correia, D. M., Ribeiro, C., Moreira, S., Botelho, G., Gã³mez Ribelles, J. L. and Lanceros-Mendez, S. (2012) Physical-chemical properties of cross-linked chitosan electrospun fiber mats. *Polymer Testing.* 31**.** 1062-1069.

Shahriary, L. and Athawale, A. A. (2014) Graphene oxide synthesized by using modified hummers approach. *IJREEE.* 2**.** 58-63.

Shang, N. G., Papakonstantinou, P., Mcmullan, M., Chu, M., Stamboulis, A., Potenza, A., Dhesi, S. S. and Marchetto, H. (2008) Catalyst-free efficient growth, orientation and biosensing properties of multilayer graphene nanoflake films with sharp edge planes. *Advanced Functional Materials.* 18**.** 3506-3514.

Sharma, D. K., Li, F. and Wu, Y.-N. (2014) Electrospinning of Nafion and polyvinyl alcohol into nanofiber membranes: A facile approach to fabricate functional adsorbent for heavy metals. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 457**.** 236-243.

Shenoy, S. L., Bates, W. D., Frisch, H. L. and Wnek, G. E. (2005) Role of chain entanglements on fiber formation during electrospinning of polymer solutions: good solvent, non-specific polymerâ€"polymer interaction limit. *Polymer.* 46**.** 3372-3384.

Shirakawa, H., Louis, E. J., Macdiarmid, A. G., Chiang, C. K. and Heeger, A. J. (1977) Synthesis of electrically conducting organic polymers: halogen derivatives of polyacetylene, (CH). *Journal of the Chemical Society, Chemical Communications.* 578-580.

Si, W., Lei, W., Zhang, Y., Xia, M., Wang, F. and Hao, Q. (2012) Electrodeposition of graphene oxide doped poly(3,4-ethylenedioxythiophene) film and its electrochemical sensing of catechol and hydroquinone. *Electrochimica Acta.* 85**.** 295-301.

Siju, C. R., Rao, K. N. and Sindhu, S. (2013) Enhanced performance characteristics of electropolymerized poly(3,4 ethylenedioxythiophene) films on ITO by one step cyclic voltammetry. *Journal of Optics.* 42**.** 67-72.

Sousa, A. M. M., Souza, H. I. K. S., Uknalis, J., Liu, S.-C., Gonã§Alves, M. P. and Liu, L. (2014) Electrospinning of agar/PVA aqueous solutions and its relation with rheological properties. *Carbohydrate Polymers.* 115**.** 348-355.

Sui, X.-M., Giordani, S., Prato, M. and Wagner, H. D. (2009) Effect of carbon nanotube surface modification on dispersion and structural properties of electrospun fibers. *Applied Physics Letters.* 95**.** 233113.

Sulaiman, Y. and Kataky, R. (2012) Effect of monomer modifications on the physical properties of electropolymerised PEDOT films. *Journal of The Electrochemical Society.* 159**.** F1-F9.

Supaphol, P. and Chuangchote, S. (2008) On the electrospinning of poly(vinyl alcohol) nanofiber mats: A revisit. *Journal of Applied Polymer Science.* 108**.** 969-978.

Tan, Y., Song, Y. and Zheng, Q. (2012) Hydrogen bonding-driven rheological modulation of chemically reduced graphene oxide/poly(vinyl alcohol) suspensions and its application in electrospinning. *Nanoscale.* 4**.** 6997-7005.

Tanahashi, M. (2010) Development of fabrication methods of filler/polymer nanocomposites: With focus on simple melt-compounding-based approach without surface modification of nanofillers. *Materials.* 3**.** 1593-1619.

Tang, L., Wang, Y., Li, Y., Feng, H., Lu, J. and Li, J. (2009) Preparation, structure, and electrochemical properties of reduced graphene sheet films. *Advanced Functional Materials.* 19**.** 2782-2789.

Thangappan, R., Kalaiselvam, S., Elayaperumal, A. and Jayavel, R. (2014) Synthesis of graphene oxide/vanadium pentoxide composite nanofibers by electrospinning for supercapacitor applications. *Solid State Ionics.* 268, Part B**.** 321-325.

Thompson, C. J., Chase, G. G., Yarin, A. L. and Reneker, D. H. (2007) Effects of parameters on nanofiber diameter determined from electrospinning model. *Polymer.* 48**.** 6913-6922.

Toh, S. Y., Loh, K. S., Kamarudin, S. K. and Daud, W. R. W. (2014) Graphene production via electrochemical reduction of graphene oxide: Synthesis and characterisation. *Chemical Engineering Journal.* 251**.** 422-434.

Tucker, N., Stanger Jj, Staiger Mp, Razzaq H and K, H. (2012) The history of the science and technology of electrospinning from 1600 to 1995. *Journal of Engineered Fibers and Fabrics.* 7**.** 63-73.

Valles, C., Nãºã±Ez, J. D., Benito, A. M. and Maser, W. K. (2012) Flexible conductive graphene paper obtained by direct and gentle annealing of graphene oxide paper. *Carbon.* 50**.** 835-844.

Vaseashta, A., Dimova-Malinovska, D. and Marshall, J. M. (2005) Nanostructured materials based next generation devices and sensors. *Nanostructured and Advanced Materials for Applications in Sensor, Optoelectronic and Photovoltaic Technology.* Springer Netherlands.

Wang, B., Chen, Z., Zhang, J., Cao, J., Wang, S., Tian, Q., Gao, M. and Xu, Q. (2014a) Fabrication of PVA/graphene oxide/TiO2 composite nanofibers through electrospinning and interface sol-gel reaction: Effect of graphene oxide on PVA nanofibers and growth of TiO2. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 457**.** 318-325.

Wang, C., Li, Y., Ding, G., Xie, X. and Jiang, M. (2012a) Preparation and characterization of graphene oxide/poly(vinyl alcohol) composite nanofibers via electrospinning. *Journal of Applied Polymer Science.* 127**.** 3026-3032.

Wang, C., Li, Y., Ding, G., Xie, X. and Jiang, M. (2013) Preparation and characterization of graphene oxide/poly(vinyl alcohol) composite nanofibers via electrospinning. *Journal of Applied Polymer Science.* 127**.** 3026-3032.

Wang, H., Hao, Q., Yang, X., Lu, L. and Wang, X. (2009a) Graphene oxide doped polyaniline for supercapacitors. *Electrochemistry Communications.* 11**.** 1158-1161.

Wang, Q., Du, Y., Feng, Q., Huang, F., Lu, K., Liu, J. and Wei, Q. (2012b) Nanostructures and surface nanomechanical properties of polyacrylonitrile/graphene oxide composite nanofibers by electrospinning. *Journal of Applied Polymer Science.* 128**.** 1152-1157.

Wang, Q., Li, G., Zhang, J., Huang, F., Lu, K. and Wei, Q. (2014b) PAN Nanofibers Reinforced with MMT/GO Hybrid Nanofillers. *Journal of Nanomaterials.* 2014**.** 10.

Wang, X. J. and Wong, K. Y. (2006) Effects of a base coating used for electropolymerization of poly(3,4-ethylenedioxythiophene) on indium tin oxide electrode. *Thin Solid Films.* 515**.** 1573-1578.

Wang, Y. (2009) Research progress on a novel conductive polymer-poly(3,4-ethylenedioxythiophene) (PEDOT). *Journal of Physics: Conference Series.* 152**.** 012023.

Wang, Y., Jia, W., Strout, T., Ding, Y. and Lei, Y. (2009b) Preparation, characterization and sensitive gas sensing of conductive core-sheath $TiO(_2)$-PEDOT nanocables. *Sensors (Basel, Switzerland).* 9**.** 6752-6763.

Xiong, J., Huo, P. and Ko, F. K. (2009) Fabrication of ultrafine fibrous polytetrafluoroethylene porous membranes by electrospinning. *Journal of Materials Research.* 24**.** 2755-2761.

Xu, B., Yue, S., Sui, Z., Zhang, X., Hou, S., Cao, G. and Yang, Y. (2011) What is the choice for supercapacitors: graphene or graphene oxide? *Energy & Environmental Science.* 4**.** 2826-2830.

Xu, Q., Li, Y., Feng, W. and Yuan, X. (2009) Fabrication and electrochemical properties of polyvinyl alcohol/poly(3,4-ethylenedioxythiophene) ultrafine fibers via electrospinning of EDOT monomers with subsequent in situ polymerization. *Synthetic Metals.* 160**.** 88-93.

Yasri, N., Sundramoorthy, A. K., Chang, W.-J. and Gunasekaran, S. (2014) Highly selective mercury detection at partially oxidized graphene/poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) nanocomposite film modified electrode. *Frontiers in Materials.* 1.

Yoon, H., Chang, M. and Jang, J. (2007) Formation of 1D poly(3,4-ethylenedioxythiophene) nanomaterials in reverse microemulsions and their application to chemical sensors. *Advanced functional materials.* 17**.** 431-436.

Yoshioka, Y. and Jabbour, G. E. (2006) Desktop inkjet printer as a tool to print conducting polymers. *Synthetic Metals.* 156**.** 779-783.

Zhang, C., Hua, C., Wang, G., Ouyang, M. and Ma, C. (2010a) A novel multichromic copolymer of 1,4-bis(3-hexylthiophen-2-yl)benzene and 3,4-ethylenedioxythiophene prepared via electrocopolymerization. *Journal of Electroanalytical Chemistry.* 645**.** 50-57.

Zhang, C., Yuan, X., Wu, L., Han, Y. and Sheng, J. (2005) Study on morphology of electrospun poly(vinyl alcohol) mats. *European Polymer Journal.* 41**.** 423-432.

Zhang, H., Nie, H., Yu, D., Wu, C., Zhang, Y., White, C. J. B. and Zhu, L. (2010b) Surface modification of electrospun polyacrylonitrile nanofiber towards developing an affinity membrane for bromelain adsorption. *Desalination.* 256**.** 141-147.

Zhang, X., Lee, J.-S., Lee, G. S., Cha, D.-K., Kim, M. J., Yang, D. J. and Manohar, S. K. (2006a) Chemical synthesis of PEDOT nanotubes. *Macromolecules.* 39**.** 470-472.

Zhang, Y. Z., Feng, Y., Huang, Z. M., Ramakrishna, S. and Lim, C. T. (2006b) Fabrication of porous electrospun nanofibres. *Nanotechnology.* 17**.** 901.

Zhao, Y., Li, X., Dong, L., Yan, B., Shan, H., Li, D. and Sun, X. (2015) Electrospun SnO_2-ZnO nanofibers with improved electrochemical performance as anode materials for lithium-ion batteries. *International Journal of Hydrogen Energy.* 40**.** 14338-14344.

Zhengping, Z., Xiang-Fa, W., Xueqin, G., Long, J., Yong, Z. and Hao, F. (2011) Parameter dependence of conic angle of nanofibres during electrospinning. *Journal of Physics D: Applied Physics.* 44**.** 435401.

Zhou, C., Liu, Z., Du, X. and Ringer, S. P. (2010) Electrodeposited PEDOT films on ITO with a flower-like hierarchical structure. *Synthetic Metals.* 160**.** 1636-1641.

Zhu, C., Zhai, J., Wen, D. and Dong, S. (2012) Graphene oxide/polypyrrole nanocomposites: one-step electrochemical doping, coating and synergistic effect for energy storage. *Journal of Materials Chemistry.* 22**.** 6300-6306.