FABRICATION OF NANOCOMPOSITE MEMBRANE VIA COMBINED ELECTROSPINNING AND CASTING TECHNIQUE FOR DIRECT METHANOL FUEL CELL

HAZLINA BINTI JUNOH

UNIVERSITI TEKNOLOGI MALAYSIA

FABRICATION OF NANOCOMPOSITE MEMBRANE VIA COMBINED ELECTROSPINNING AND CASTING TECHNIQUE FOR DIRECT METHANOL FUEL CELL

HAZLINA BINTI JUNOH

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Gas)

Faculty of Chemical and Energy Engineering
Universiti Teknologi Malaysia

AUGUST 2016

My understanding husband
Mohd Helmi Bin Abdullah
Thanks for understanding and always support me in no matter what conditions

My precious little daughter
Nur Aisya Faqehah Binti Mohd Helmi
Thanks for being part of my life and motivate me to finish the study

My supportive parents
Junoh Bin Awang Soh
Aishah Binti Jusoh
There are no perfect words to explain their love for me and encouraging me to believe in myself

My lovely sisters and brothers
Norliza Binti Junoh, Mazlin Binti Junoh, Suhaimi Bin Junoh, Normala Binti Junoh, Maziah Binti Junoh, Rosmawati Binti Junoh, Shamsul Bin Junoh, Mohd Arif Afirul Bin Junoh, Mohd Hafiz Bin Junoh
Thanks for always being my side and support me either in bad or good conditions

ACKNOWLEDGEMENT

Alhamdulillah, first of all, I want to express my sincere thanks to ALLAH, The Almighty in supporting me to finish my research study and not excluded to the persons whom I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Juhana Jaafar, for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisors Dr. Muhammad Noorul Anam Mohd Norddin for his advice and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master study as well as to Advance Membrane Research Technology Centre (AMTEC) for supporting my research activities. Special thanks also go to Mr. Sohaimi, Mr. Ng Be Cheer and Mr. Mohammad Abdul Razis Saidin for their support in laboratorial activities.

My fellow postgraduate friends should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provide assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful for being a part in this study.

ABSTRACT

In the past decades, the emerging of nanotechnology has brought to the introduction of electrospinning process in polymer electrolyte nanocomposite membrane due to its specialty in providing a very large specific surface area which contributed by a small size of fillers and an outstanding nanovoids interconnectivity between the fillers. The objective of this study was to fabricate and characterize sulfonated poly (ether ether ketone) (SPEEK) nanocomposite membrane consist of electrospun Cloisite15A® (e-spun CL) for direct methanol fuel cell (DMFC) applications. Poly (ether ether ketone) polymer was sulfonated by sulfuric acid to obtain degree of sulfonation of 63%. SPEEK63/e-spun CL nanofibers were fabricated via electrospinning process in which SPEEK63 was used as carrier polymer while SPEEK63/e-spun CL nanocomposite membrane was obtained by casting method. Characterizations on physical, morphological and thermal properties of SPEEK63/e-spun CL were conducted and compared to SPEEK nanocomposite membrane with 2.5wt.% Cloisite15A® and 5.0wt.% triaminopyrimidine (SPEEK63/2.5CL/5.0TAP). Scanning electron microscopy (SEM) showed that Cloisite15A® was well electrospun with the nanofiber diameter ranging from 62.5 to 375 nm. Moreover, field emission scanning electron microscopy (FESEM) revealed that Cloisite15A® particles at nanometer range were uniformly distributed and 66% smaller than in SPEEK63/2.5CL/5.0TAP. In addition, x-ray diffraction proved that the dispersion state of Cloisite15A® fell into intercalated phase. A very small amount of Cloisite15A® (0.05wt.%) in SPEEK63/e-spun CL had successfully enhanced the proton conductivity up to 50% whereas, methanol permeability value was unfortunately 27 times higher than SPEEK63/2.5CL/5.0TAP. Proton conductivity and methanol permeability of SPEEK63/e-spun CL were 24.49×10^{-3} Scm^{-1} and 3.74×10^{-7} cms^{-1}, respectively. Even though this study contributed to a selectivity of 95% lower than SPEEK63/2.5CL/5.0TAP, the electrospinning process had shown a promising technique to further reduce the original size of Cloisite15A® particles from mixed size (µm and nm) to nanometer size as well as by fine tuning the dispersion of Cloisite15A® can enhance SPEEK63/e-spun CL performance in DMFC applications.

ABSTRAK

Pada dekad yang lalu, kemunculan teknologi nano telah membawa kepada pengenalan proses elektro pemintalan dalam membran polimer elekroli nanokomposit disebabkan oleh keistimewaannya dalam menyediakan luas permukaan spesifik dan yang kasar disebabkan oleh pengisi yang bersaiz kecil dan kesalinghubungan rongga nano yang cemerlang antara pengisi. Objektif kajian ini adalah untuk menghasilkan dan mencirikan membran nano komposit poli (eter eter keton) tersulfonasi (SPEEK) yang terdiri daripada Cloisite15A® terelektropintal (e-spun CL) untuk aplikasi bahan api metanol terus (DMFC). Polimer poli (eter eter keton) telah disulfonasi dengan asid sulfurik untuk mendapatkan darjah sulfonasi 63%. Gentian nano SPEEK63/e-spun CL telah dihasilkan melalui proses elektro pemintalan yang mana SPEEK63 digunakan sebagai polimer pembawa manakala membran nanokomposit SPEEK63/e-spun CL diperoleh melalui kaedah penuangan. Pencirian sifat-sifat fizikal, morfologi dan kestabilan terma dijalankan ke atas SPEEK63/e-spun CL dan dibandingkan dengan membran nanokomposit SPEEK63 dengan 2.5% jisim Cloisite15A® dan 5.0% jisim triaminopyrimidina (SPEEK63/2.5CL/5.0TAP). Mikroskop imbasan elektron (SEM) menunjukkan Cloisite15A® telah dielektropintal dengan baik dan diameter gentian dalam lingkungan 62.5 hingga 375 nm. Mikroskop medan pancaran imbasan elektron (FESEM) menunjukkan taburan zarah Cloisite15A® adalah seragam pada julat nanometer dan 66% lebih kecil daripada yang dalam SPEEK63/2.5CL/5.0TAP. Pembelauan x-ray membuktikan bahawa penyebaran Cloisite15A® jatuh ke fasa interkalasi. Cloisite15A® yang sangat sedikit (0.05% jisim) dalam SPEEK63/e-spun CL telah berjaya meningkatkan kekonduksian proton sehingga 50%, manakala, kebolehtelapan metanol adalah 27 kali lebih tinggi berbanding SPEEK63/2.5CL/5.0TAP. Kekonduksian proton dan kebolehtelapan metanol SPEEK63/e-spun CL menunjukkan 24.49 x 10^{-3} Scm^{-1} dan 3.74 x 10^{-7} cms^{-1} masing-masing. Walaupun kajian ini menyebabkan kememilihan 95% lebih rendah berbanding SPEEK63/2.5CL/5.0TAP, telah menunjukkan bahawa proses pemintalan elektro adalah teknik yang berpotensi dalam mengurangkan saiz asal zarah Cloisite15A® daripada campuran saiz (μm dan nm) kepada saiz nanometer dan juga dengan keadaan penyebaran Cloisite15A® boleh meningkatkan prestasi SPEEK63/e-spun CL dalam aplikasi DMFC.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CLTE	-	Coefficient of Linear Thermal Expansion
DMAc	-	Dimethyl Acetamide
DMF	-	Dimethyl Formamide
DS	-	Degree of Sulfonation
EDX	-	Energy Dispersive X-ray
e-spun CL	-	Electrospun Cloisite15A®
FESEM	-	Field Emission Scanning Electron Microscopy
H_2SO_4	-	Sulphuric Acid
H^1NMR	-	Hydrogen Nuclear Magnetic Resonance
HDT	-	Heat Distortion Temperature
PEEK	-	Poly(ether ether ketone)
PEM	-	Polymer Electrolyte Membrane/Proton Electrolyte Membrane
PVDF	-	Polyvinylidene Fluoride
R&D	-	Research and Development
SEM	-	Scanning Electron Microscopy
SPEEK,SP	-	Sulfonated Poly(ether ether ketone)
Si	-	Silica
TGA	-	Thermogravimetric Analyzer
XRD	-	X-ray Diffraction

LIST OF SYMBOL

$^\circ C$ - Degree Celsius

σ - Proton Conductivity

P - Methanol Permeability

R - Resistance

Θ - Angle of Maximum Point of The First Peak (Lowest Θ) In The Spectra

λ - Wavelength

g - Gram

cm^3 - Centimeter Cubic

mg - Miligram

wt.% - Percentage Weight

d- - Spacing Between The Layers of The Clay

L - Thickness of Hydrate Membrane

D - Methanol Diffusivity

t_o - Time Lag

V_B - Volume of Water Compartment

A - Volume Cross Section Area of Membrane

Φ - Selectivity of The Membrane

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

The current scenario of uncertainty in oil price increase is beyond any governments' control. An uprising problem regarding on these issues which eventually contributes to increment of household cost as well as electricity and transportation cost. The reason for uncertainty in fossil fuels price is mainly due to the rapid depletion which will increase the energy price (Wong, 2006). In order to avoid this to happen, the alternative choice should be made available. Until this moment, the research and development of renewable energy are increasing yearly. Among several well-known types of renewable energy which are solar energy, wind energy, geothermal energy, bioenergy, hydropower and ocean energy. Meanwhile, fuel cell is also gaining attention as promising alternative in providing energy sources.

The research and development (R&D) on proton electrolyte membrane (PEM) is foreseen to generate more significant contribution as compared to other parts in fuel cell system. PEM is always expressed as the "nerve" or "heart" of a fuel cell system as it plays the most crucial task in allowing and repelling the protons and electrons, respectively. These characteristics will determine the efficiency of a fuel cell as a whole, directly. As in directly, an efficient fuel cell system could provide a beneficial impact on environmental as well as economic views.

Layered silicates-polymer nanocomposite is a new polymer electrolyte membrane (PEM) that lately concerned a great deal of interest due to the improvement in the mechanical, thermal and barrier properties of the pure polymer (Tien and Wei, 2001). Compared to the corresponding pure polymer membranes as well as commercial Nafion® membranes, many polymer-inorganic nanocomposite membranes are shown much lower fuel permeability along with similar or improved proton conductivities due to the nano-dispersion of layered silicates throughout polymer matrix (Wang and Dong, 2007).

The combination of the advantages from the base materials: i.e., the flexibility and process ability of polymer, as well as the selectivity and thermal stability of the inorganic fillers are contributed to the aforementioned properties. By adding the inorganic nanofillers, it may affect the membrane cell in two ways: 1) the uniform nanosized distribution of inorganic filler particles produces a winding diffusion pathway which can hinder the fuel to transfer through the nanocomposite membrane, and 2) the complete morphological structure allows more cations to mobile and available for conduction (Wang and Dong, 2007). Furthermore, the smaller the particles size, the larger surface area of dispersed nanosized particles within polymer matrix which can decrease the degree of crystallinity of polymer segments and yet will contribute to the larger ionic mobility that eventually increased the proton conduction (Croce *et al.*, 1998; Golodnitsky *et al.*, 2002).

Electrospinning seem to be a good solution in providing a nanosized particles as well as altering the structure of polymer-inorganic electrolyte membrane due to the versatility possessed by electrospinning. The electrospinning process are favorable to be used in developing a highly porous, patterned, nano-fibrous polymeric materials of nanofibers (Zucchelli *et al.*, 2009). Other than producing a nanofiber, the advantages possessed by electrospinning due to its low cost, capability and high speed makes it has a high potential in producing nanocomposite fiber (Zhang *et al.*, 2009). The unique properties such as extremely long, large surface area, complex pore size and complex alignment on either woven or nonwoven fiber possessed by electrospun nanofibers makes it practicable in various applications (Fang *et al.*, 2011; Cavaliere *et al.*, 2011; Sautter, 2005; Thavasi *et al.*, 2008) especially in polymer electrolyte membrane. Thus, the combination of nanosized particles and specialty of the polymer electrolyte brings the focus to the study on nanocomposite polymer electrolyte membrane within laboratory as well as in industrial aspect.

1.2 Problem Statement

Several methods have been studied and developed to fabricate nanofibers, such as template, self-assembly, melt-blowing and phase separation as well as electrospinning (Doshi and Reneker, 1995; Fang *et al.*, 2010). However, except electrospinning process, the other methods cannot produce continuous nanofibers on a large scale as well as simply altering the diameter from nanometers to micrometers and vice versa of the nanofibers. Electrospinning is competent in producing conductive fibrous membranes with high specific area, high porosity and tunable fiber diameters, which further broadened conductive polymers applicability in energy applications. Experimental parameters such as molecular weight, solubility, viscosity, surface tension, electrical conductivity, solvent vapor pressure, relative humidity, electric field and feed rate of the solution must be precisely controlled in getting desirable properties of the fibers and by tuning these conditions, a wide range of polymers can be processed.

Nafion, a sulfonated tetrafluoroethylene developed by Walther Grot (DuPont), is an interesting and most commonly materials used as proton exchange membrane in PEM fuel cells (Cason, 2010). Unfortunately, in electrospinning process, Nafion are difficult to electrospin due to its insolubility properties within solvents (Cason, 2010). The inability to electrospin happened due to the formation of micelles that leads to the decreasing in chain entanglement and thus, a high molecular weight carrier is needed to cater the problem facing by Nafion (Thompsett, 2010).

Previously, Jaafar *et al*. (2011) had successfully fabricated Cloisite15A® within SPEEK matrix which is comparable to Nafion. However, their method is still limited due to the size distribution of Cloisite15A® particles. Therefore, in this study by introducing the electrospinning process of SPEEK as the base polymer matrix, while the Cloisite15A® nanoclay as an inorganic filler, it is strongly believed that a novel polymer-nanocomposite electrolyte membrane with reducing filler size up to nanostructure can be successful developed.

1.3 Objective of Study

The aim of this study is to fabricate a conductive SPEEK/e-spun Cloisite15A® nanocomposite membrane with an increasing value of proton conductivity and reducing methanol permeability at acceptable value for direct methanol fuel cell system. The specific objectives of the study are:

1. To establish the best electrospinning condition for spinnable solution.
2. To fabricate SPEEK/Cloisite15A® nanocomposite membrane from the dope formulation of SPEEK and electro-spun SPEEK/Cloisite15A® nanofibers.
3. To characterize the performance of membrane based on Cloisite15A® dispersion state in term of physical and thermal stability.

1.4 Scope of Study

In order to achieve the aforementioned objectives of the research, the following scopes are outlined:

1. Fabricating electrospun Cloisite15A® at the least amount that is spinnable (0.05 wt. %) via electrospinning process by introduction of SPEEK (20 wt. % at DS 63%) as a carrier polymer and controlling the electrospinning parameters such as voltage (0 ~ 16kV), flow rate (0.6 ml/hr) and needle to collector distance (20 cm).

2. Preparing SPEEK/e-spun Cloisite15A® nanocomposite membrane by stirring-mixing 16wt. % of SPEEK at DS 63% and the electrospun Cloisite15A® nanofiber.

3. Observing the dispersion of the Cloisite15A® particles in electrospun nanofiber mat via SEM.

4. Determining the dispersion state of the Cloisite15A® particles in nanocomposite membrane via FESEM and XRD.

5. Characterizing the physical and thermal properties of the prepared membrane in term of water uptake, proton conductivity, methanol permeability and SPEEK/e-spun Cloisite15A® membrane materials degradation at certain temperature.

1.5 Significance of Study

The application of membrane consists of polymer and inorganic filler is interesting within the past two decades in fuel cell applications. In this study, a continuing work in fabricating a series of SPEEK and Cloisite15A® based proton electrolyte membrane for direct methanol fuel cell application was performed by employing electrospinning technique. This route is basically in producing nanosized filler in nanocomposite structure within a short period of time. The contribution of electrospinning on the size reduction and dispersion state of Cloisite15A® has led to the improvement of proton conductivity as well as methanol permeability of the membrane. This research is also in the significance of developing a sophisticated fuel cells device in order to reduce environmental problem as well as reducing the relying cost on transportation and stationary usage of more compact design.

REFERENCES

Abdel-Hady, F., Alzahrany, A. and Hamed, M. (2011). Experimental Validation of Upward Electrospinning Process. *ISRN Nanotechnology*, 1-14.

AdElmoula, M. (2011). *Optical, Electrical and Catalytic Properties of Titania Nanotubes*. Doctor of Philosophy. Northeastern University Boston, Massachusetts.

Agmon, N. (1995). The Grotthuss Mechanism. *Chemical Physics Letter*, 244: 456-462.

Alexandre, M. and Dubois, P. (2000). Polymer-Layered Silicate Nanocomposites: Preparation, Properties and Uses of A New Class of Materials. *Materials Science and Engineering: R: Reports*, 28(1-2): 1–63.

Andújar, J. M. and Segura, F. (2009). Fuel Cells: History and Updating. A Walk along Two Centuries. *Renewable and Sustainable Energy Reviews*, 13(9): 2309–2322.

Appleby J. (1990). From Sir William Grove to today: Fuel Cells and the Future. *Journal of Power Sources*.29 (1-2):3–11.

Aricò, A. S., Baglio, V. and Antonucci, V. (2009). Direct Methanol Fuel Cells : History, Status and Perspectives. In Liu, H. and Zhang, J. (Eds.) Electrocatalysis of Direct Methanol Fuel Cells. Weinheim: Verlag GmbH & Co.

Azad, A. M. (2006). Fabrication of Transparent Alumina (Al2O3) Nanofibers by Electrospinning. *Materials Science and Engineering A*, 435-436: 468-473.

Bafna, A. A. (2004). Polyethylene-clay Nanocomposites : Processing-Structure-Property Relationship. Doctor of Philosophy. Universiti of Cincinnati, Cincinnati, Ohio, USA.

Baji, A., Mai, Y.-W., Wong, S.-C., Abtahi, M. and Chen, P. (2010). Electrospinning of Polymer Nanofibers: Effect of Oriented Morphology, Structure and Tensile Properties. *Journal of Composite Science and Technology* 70(5): 703-718.

Baker, W. R. (2004). Membrane Technology and Applications. (2nd ed.). West Sussex, England.: John Wiley & Sons Ltd.

Ban, C. M., Chernova, N. A. and Whittingham, M. S. (2009). Electrospun Nano-vanadium Pentoxide Cathode. *Electrochem. Commun.*, 11: 522-525.

Barber, G. D., Calhoun, B. H. and Moore, R. B. (2005). Poly (ethylene terephthalate) Ionomer Based Clay Nanocomposites Produced via Melt Extrusion. *Polymer*, 46: 6706-6714.

Bognitzki, M., Czado, W., Frese, T., Schaper, A., Hellwig, M., Steinhart, M., Greiner, A. and Wendorff, J. H. (2001). Nanostructured Fibers via Electrospinning. *Adv. Mater.* 13: 70-72.

Boudghene, S. A. and Traversa,E. (2002). Solid Oxide Fuel Cells (SOFCs): A Review of an Environmentally Clean and Efficient Source of Energy. *Renewable and Sustainable Energy Reviews*. 6(5):433–55.

Cason, M. W. (2010). Electrospun Nafion® Nanofibers for Proton Exchange Membranes. Literature Seminar. 23 September.Cavaliere, S., Subianto, S., Savych, I., Jones, D. J. and Rozière, J. (2011). Electrospinning: Designed Architectures for Energy Conversion and Storage Devices. *Energy Environmental Science,* 4(12): 4761–4785.

Cebe,P. and Hong, S.-D. (1986). Crystallization Behaviour of Poly (ether ether ketone). *Polymer*, 27.

Chakrabarty, T., Kumar, M., Rajesh, K. P., Shahi, V. K. and Natarajan, T. S. (2010). Nano-fibrous Sulfonated Poly (Ether Ether Ketone) Membrane for Selective Electro-transport of Ions. *Separation and Purification Technology.* 75: 174-182.

Chaurasia P. B. L., Ando Y. and Tanaka T. (2003). Regenerative Fuel Cell with Chemical Reactions. *Energy Conversion and Management.* 44(4):611–28.

Chen, W. S., Huang, D. A., Chen, H. C., Shie, T. Y., Hsieh, C. H., Liao, J. D. and Kuo, C. (2009). Fabrication of Polycrystalline ZnO Nanotubes from the Electrospinning of ZnV Poly (acrylic acid), *Crystal Growth & Design,* 9 (9): 4070.

Chivrac, F., Pollet, E. and Avérous, L. (2009). Progress in Nano-Biocomposites Based on Polysaccharides and Nanoclays. *Materials Science and Engineering.* 67: 1-17.

Choi, S. S., Lee, S. G., Im, S. S., Kim, S. H. and Joo, Y. L. (2003). Silica nanofibers from Electrospinning/Sol-gel Process. *J. Mater. Sci. Lett.,* 22: 891-893.

Chronakis, I. (2005). Novel Nanocomposites and Nanoceramics Based on Polymer Nanofibers Using Electrospinning Process—A Review. *Journal of Materials Processing Technology,* 167(2-3): 283–293.

Croce, F., Appetecchi, G. B., Persi, L. and Scrosati, B. (1998). Nanocomposite Polymer Electrolytes for Lithium Batteries. *Nature,* 394: 456-458.

Dai, Y., Liu, W., Formo, E., Sun, Y. and Xia, Y. (2011). Ceramic Nanofibers Fabricated by Electrospinning and Their Applications in Catalysis, Environmental Science, and Energy Technology. *Polymer Adv. Technol,* 22: 326-338.

Deitzel, J. M., Kleinmeyer, J., Harris, D. and Beck Tan, N. C. (2001). The Effect of Processing Variables on the Morphology of Electrospun Nanofibers and Textiles. *Polymer,* 42(1): 261–272.

Dicks A. L. (2004). Molten Carbonate Fuel Cells. *Current Opinion in Solid State and Materials Science.* 8(5):379–83.

Ding, B., Ogawa, T., Kim, J., Fujimoto, K. and Shiratori, S. (2008). Fabrication of a Super Hydrophobic Nanofibrous Zinc Oxide Film Surface by Electrospinning. *Thin Solid Films,* 516: 2495-2501.

Doğan, H., Inan, T. Y., Koral, M. and Kaya, M. (2011). Organo-Montmorillonites and Sulfonated PEEK Nanocomposite Membranes for Fuel Cell Applications. *Applied Clay Science,* 52(3): 285–294.

Dong, B., Gwee, L., Salas-de la Cruz, D., Winey, K. I. and Elabd, Y. A. (2010). Super Proton Conductive High-Purity Nafion Nanofibers. *Nano Lett.* 10: 3785-3790.

Donnan, F. G. (1911). Theory of Membrane Equilibria and Membrane Potentials in the Presence of Non-dialyzing Electrolytes, Z. *Elektrochem,* 17: 572.

Doshi, J. and Reneker, D. H. (1995). Electrospinning Process and Applications of Electrospun Fibers. *Journal of Electrostatics,* 35: 151-160.

Eisenberg, A. and Yeager, H. L. (1982). Perfluorinated Ionomer Membranes, ACS Symposium Series Number 180. American Chemical Society, Washington, DC.

Elias, E., Chandran C, S., Chandran, N., Jr. Sauza, F. G. and Thomas, S. (2016). Segmental Dynamics, Morphology and Thermomechanical Properties of

Electrospun Poly (ε-caprolactone) Nanofibers in the Presence of an Interacting Filler. *RSC Adv.,* 6: 21376-21386.

Esfandiari, A., Nazokdast, H., Rashidi, A. - S. and Yazdanshenas, M - E. (2008). Review of Polymer-Organoclay Nanocomposites. *Journal of Applied Science,* 8: 545-561.

Fan, Q. and Whittingham, M. S. (2007). Electrospun Manganese Oxide Nanofibres as Anodes for Lithium-Ion Batteries. *Electrochemical Solid State Letters,* 10: A48-A51.

Fang, J., Wang, X. and Lin, T. (2011). Functional Applications of Electrospun Nanofibers. In Lin, T. (Ed.) Nanofibers-Production, Properties and Functional Applications (pp. 287-326). InTech.

Fang, J., Wang, H., Niu, H., Lin, T. and Wang, X. (2010). Evolution of Fiber Morphology during Electrospinning. *Journal of Applied Polymer Science,* 118: 2553-2561.

Feng, C., Khulbe, K. C. and Matsuura, T. (2010). Recent Progress in the Preparation, Characterization, and Applications of Nanofibers and Nanofiber Membranes via Electrospinning/Interfacial Polymerization. *Journal of Applied Polymer Science,* 115: 756-776.

Fong, H., Chun, I. and Reneker, D. H. (1999). Beaded Nanofibers Formed During Electrospinning. *Polymer,* 40(16), 4585–4592.

Formhals, A. (1934). U.S. Patent No. 1, 975,504. United States Patent Office.

Formo, E., Camargo, P. H. C., Lim, B., Jiang, M., and Xia, Y. (2009). Functionalization of ZrO2 Nanofibers with Pt Nanostructures: The Effect of Surface Roughness on Nucleation Mechanism and Morhology Control. *Chemical Physics Letters,* 476: 56-61..

Formo, E., Yavuz, M. S., Lee, E. P., Lane, L. and Xia, Y. (2009). Fuctionalization of Electrospun Ceramic Nanofibre Membranes with Noble-Metal Nanostructures for Catalytic Applications.*J.Mater.Chem.*, 19(23): 3878-3882.

Frenot, A. and Chronakis, I. S. (2003). Polymer Nanofibers Assembled by Electrospinning. *Science and Technology*, 8(1): 64–75.

Garcia-Diaz, B. L. (2007). Kinetics and Mass Transfer in a Direct Methanol Fuel Cell. South Carolina.: ProQuest.

Gierke, T. D. (1977). Ionic Clustering in Nafion Perfluorosulfonic Acid Membranes and Its Relationship to hydroxyl Rejection and Chlor-Alkali Current

Efficiency. Paper presented at the Electrochemical Society Fall Meeting, Atlanta, GA.

Golodnitsky, D., Ardel, G. and Peled, E. (2002). Ion-transport Phenomena in Concentrated PEO-based Composite Polymer Electrolytes. *Solid State Ionics,* 47: 141-155.

Gosalawit, R., Chirachanchai, S., Shishatskiy, S. and Nunes, S. P. (2008). Sulfonated Montmorillonite/Sulfonated Poly (ether ether ketone) (SMMT/SPEEK) Nanocomposite Membrane for Direct Methanol Fuel Cells (DMFCs). *Journal of Membrane Science,* 323: 337-346.

Grotheer, M. P. (1992). Electrochemical Processing (Inorganic). In Kirk Othmer. Encyclopedia of Chemical Technology, 4th ed. (9: 124). New York: Wiley Interscience.

Gu, Y., Jian, F. and Wang, X. (2008). Synthesis and Characterization of Nanostructured Co3O4 Fibers used as Anode Materials for Lithiumm Ion Batteries. *Thin Solid Films,* 517(2): 652-655.

Guhan, S., Muruganantham, R. and Sangeetha, D. (2012). Development of a Solid Plymer Electrolyte Membrane Based on Sulfonated Poly (Ether Ether) Ketone and Polysulfone for Fuel Cell Applications. *Canadian Journal of Chemistry,* 90(2): 205-213.

Hacquard, A. (2005). Improving and Understanding Direct Methanol Fuel Cell (DMFC) Performance. Degree of Master of Scince. Faculty of Worcester Polytechnic Institute.

Hafiz, A. A. A. (2013). Synthesis and Characterization of EVA-Cloisite Clay Nanocomposites. Master of Science in Nanotechnology. The American University in Cairo.

Hakim, A. R., Purbasari, A., Kusworo, T. D. and Dewi, E. L. (2012). Composite sPEEK with Nanoparticles for Fuel Cell's Applications: Review. Proceeding of *International Conference on Chemical and Material Engineering* 2012. 12-13 September. Semarang, Indonesia. MSD 19: 1-11.

Hasani-Sadrabadi, M. M., Dashtimoghadam, E., Sarikhani, K., Majedi, F. S. and Khanbabaei, G. (2010). Electrochemical Investigation of Sulfonated Poly (ether ether ketone)/Clay Nanocomposite Membranes for Moderate Temperature Fuel Cell Applications. *Journal of Power Sources,* 195: 2450-2456.

Hasani-Sadrabadi, M. M., Shabani, I., Soleimani, M. and Moaddel, H. (2011). Novel Nanofiber-based Triple-Layer Proton Exchange Membranes for Fuel Cell Applications. *Journal of Power Sources,* 196: 4599-4603.

Hongwei, Z., Fei, Y. and Danying, Z. (2013). Fabrication and Characterization of Electrospun Sulfonated Poly (phthalazinone ether ketone) Mats as Potential Matrix of Reinforced Proton Exchange Membranes. *J. Appl. Polym.Sci.* 1-6.

Huang, R. Y. M., Shao, P., Burns, C. M. and Feng, X. (2001). Sulfonation of Poly (Ether Ether Ketone)(PEEK): Kinetic Study and Characterization. *Journal of Applied Polymer Science,* 82(11): 2651–2660.

Huang, Z.-M., Zhang, Y.-Z., Kotaki, M. and Ramakrishna, S. (2003). A Review on Polymer Nanofibers by Electrospinning and their Applications in Nanocomposites. *Composite Science and Technology,* 63: 2223-2253.

Jaafar, J. (2006). Development and Characterization of Sulfonated Poly (Ether Ether Ketone) Membrane for Direct Methanol Fuel Cell (DMFC) Application. Degree of Master of Engineering. Universiti Teknologi Malaysia.

Jaafar, J., Ismail, A. F. and Mustafa, A. (2007). Physicochemical Study of Poly (Ether Ether Ketone) Electrolyte Membranes Sulfonated with Mixtures of Fuming Sulfuric Acid and Sulfuric Acid for Direct Methanol Fuel Cell Application. *Journal of Materials Science and Enginnering,* 460-461: 475-484.

Jaafar, J., Ismail, A. F., and Matsuura, T. (2009). Preparation and Barrier Properties of SPEEK/Cloisite 15A®/TAP Nanocomposite Membrane for DMFC Application. *Journal of Membrane Science,* 345(1-2): 119–127.

Jaafar, J., Ismail, A. F., Matsuura, T. and Nagai, K. (2011). Performance of SPEEK Based Polymer–Nanoclay Inorganic Membrane for DMFC. *Journal of Membrane Science*, 382(1-2): 202–211.

Jalili, R., Hosseini, S. A. and Morshed, M. (2005). The Effects of Operating Parameters on the Morphology of Electrosun Polyacrilonitrile Nanofibres. *Iranian Polymer Journal,* 14(12): 1074–1081.

Jeon, I.-Y. and Baek, J.-B. (2010). Nanocomposites Derived from Polymers and Inorganic Nanoparticles. *Materials,* 3(6): 3654–3674.

Jones, D. P., Leach, D. C. and Moore, D. R. (1985). Mechanical Properties of Poly (ether ether ketone) for Engineering Applications. *Polymer,* 26: 1385-1393.

Kaliaguine, S., Mikhailenko, S. D., Wang, K. P., Xing, P., Robertson, G. and Guiver, M. (2003). Properties of SPEEK based PEMs for Fuel Cell Application. *Catalysis Today,* 82: 213-222.

Kenawy, E. -R., Layman, J. M., Watkins, J. R., Bowlin, G. L., Matthews, J. A., Simpson, D. G. and Wnek, G. E. (2003). Electrospinning of POly (ethylene-co-vinyl alcohol) Fibers. *Biomaterials,* 24: 907-913.

Kim, H. S., Kim, K., Jin, H. J. and Chin, I.-J. (2005). Morphological Characterization of Electrospun Nano-Fibrous Membranes of Biodegradable Poly (L-lactide) and Poly(lactide-co-glycolide). *Macromol. Symp.,* 224: 145-154.

Kreuer, K. D. (2001). On the Development of Proton Conducting Polymer Membranes for Hydrogen and Methanol Fuel Cells. *Journal of Membrane Science,* 185: 29-39.

Kumar, G. G. and Nahm, K. S. (2011). Polymer Nanocomposites-Fuel Cell Applications. In Dr. Reddy, B. (Ed.) Advances in Nanocomposites-Synthesis, Characterization and Industrial Applications (pp. 639-660). InTech.

Kumar, P. (2012). Effect of Collector on Electrospinning to Fabricte Aligned Nanofiber. Bachelor Degree. National Institute of Technology Rourkela.

Lee, C., Jo, S. M., Choi, J., Baek, K.-Y., Truong, Y. B., Kyratzis, I. L. and Shul, Y. G. (2013). SiO2/Sulfonated Poly Ether Ether Ketone (SPEEK) Composite Nanofiber Mat Supported Proton Exchange Membranes for Fuel Cells. *J. Mater. Sci.,* 48: 3665-3671.

Li, S., Shao, C., Liu, Y., Tang, S. and Mu, R. (2006). Nanofibers and Nanoplatelets of MoO3 via an Electrospinning Technique. *J. Phys. Chem. Solid,* 67: 1869.

Li, D. and Xia, Y. (2003). Fabrication of Titania Nanofibers by Electrospinning. *Nano Letters,* 3(4): 555-560.

Li, D. and Xia, Y. (2004). Direct Fabrication of Composite and Ceramic Hollow Nanofibers by Electrospinning. *Nano Letters,* 4(5): 933-938.

Li, D. and Xia, Y. (2004). Electrospinning of Nanofibers: Reinventing the Wheel? *Advanced Materials,* 16(14): 1151–1170.

Li, F., Zhao, Y. and Song, Y. (2010). Core-Shell Nanofibers. In Kumar, A. (Ed.). Nano Channel and Capsule by Coaxial Electrospinning, Nanofibers. InTech.

Li, L., Zhang, J. and Wang, Y. (2003). Sulfonated Poly (Ether Ether Ketone) Membranes for Direct Methanol Fuel Cell. *Journal of Membrane Science,* 226(1-2): 159–167.

Li, Y. and Zhan, S. (2009). Electrospun Nickel Oxide Hollow Nanostructured Fibers. *Journal of Dispersion Science and Technology,* 30(2): 245.

Li, Z. and Wang, C. (2013). Effect of Working Parameters on Electrospinning. In Li, Z. and Wang, C. (Eds.). One-Dimensional Nanostructures. (pp: 15-28). Springer.

Li, X., Hao,X. and Na, H. (2007). Preparation of Nanosilver Particles into Sulfonated Poly (ether ether ketone) (S-PEEK) Nanostructures by Electrospinning. *Materials Letters,* 61: 421-426.

Lin, H.-L. and Wang, S.-H. (2014). Nafion/Poly (vinyl alcohol) Nano-fiber Composite and Nafion/Poly(vinyl alcohol) Blend Membranes for Direct Methanol Fuel Cells. *Journal of Membrane Science,* 452: 253-262.

Lin, D., Wu, H., Zhang, R. and Pan, W. (2007). Preparation of ZnS Nanofibers via Electrospinning. *Journal of the American Ceramic Society,* 90: 3664–3666.

Litchfield, D. W. and Baird, D. G. (2006). The Rheology of High Aspect Ratio Nano-Particle Filled Liquids. *Rheology Reviews,* 1-60.

Liu, H. and Hsieh, Y.-L. (2002). Ultrafine Fibrous Cellulose Membranes from Electrospinning of Cellulose Acetate. *Journal of Polymer Science,* 40: 2119-2129.

Liu, Y., He, J.-H., Yu, J.-Y. and Zeng, H.-M. (2008). Controlling Numbers and Sizes of Beads in Electrospun Nanofibers. *Polymer International,*636(57):632–636.

Lu, P. and Ding, B. (2008). Applications of Electrospun Fibers. *Recent Patents on Nanotechnology,* 2(3): 169-182.

Maleki, M., Latifi, M. and Amani-Tehran, M. (2010). Optimizing Electrospinning Parameters for Finest Diameter of Nano Fibers. *World Academy of Science, Engineering and Technology,* 4(4): 347-350.

Marani, D., D'Epifanio, A., Traversa, E., Miyayama, M. and Licocia, S. (2010). Titania Nanosheets (TNS)/Sulfonated Poly Ether Ether Ketone (SPEEK) Nanocomposite Proton Exchange Membranes for Fuel Cells. *Chem. Mater.,* 22: 1126-1133.

Matsumoto, H. and Tanioka, A. (2011). Fuctional in Electrospun Nanofibrous Membranes Based on Fiber's Size, Surface Area, and Molecular Orientation. *Membranes (Basel),* 1(3): 249-264.

Mauritz, K. A. and Moore, R. B. (2004). State of Understanding of Nafion. *Chem. Rev.,* 104: 4535-4585.

Mekhilef, S., Saidur, R. and Safari, A. (2012). Comparative Study of Different Fuel Cell Technologies. Renewable and Sustainable *Energy Reviews,* 16(1): 981–989.

Mishra, A. K., Bose, S., Kuila, T., Kim, N. H. and Lee, J. H. (2012). Silicate-Based Polymer-Nanocomposite Membranes for Polymer Electrolyte Membrane Fuel Cells. *Progress in Polymer Science,* 37: 842-869.

Mohtar, S. S., Ismail, A. F. and Matsuura, T. (2011). Preparation and Characterization of SPEEK/MMT-STA Composite Membrane for DMFC Application. *Journal of Membrane Science,* 371(1-2): 10–19.

Mollá, S. and Compañ, V. (2011). Polyvinyl Alcohol Nanofiber Reinforced Nafion Membranes for Fuel Cell Applications. *Journal of Membr. Sci.,*372: 191-200.

Neppalli, R., Wanjale, S., Birajdar, M. and Causin, V. (2013). The Effect of Clay and of Electrospinning on the Polymorphism, Structure and Morphology of Poly (vinylidene fluoride). *European Polymer Journal,* 49: 90-99.

Okada, A. and Usuki, A. (2006). Twenty Years of Polymer-Clay Nanocomposites. Macromol. *Mater. Eng.,* 291(12): 1449–1476.

Okamoto, M. (2006). Polymer/Layered Silicate Nano-composites. *Intern. Polymer Processing XXI,* 5: 487-496.

Olad, A. (2011). Polymer/Clay Nanocomposites. In Dr. Boreddy Reddy (Ed.). Advances in Diverse Industrial Applications of Nanocomposites. (pp.: 113-139). InTech.

Olphen, H. van. (1956). Forces Between Suspended Bentonite Particles. Shell Development Company, Houston, Texas.

Othman, M. H. D., Ismail, A. F. and Mustafa, A. (2007). Physico-chemical Study of Sulfonated Poly (Ether Ether Ketone) Membranes for Direct Methanol Fuel Cell Application. *Malaysian Polymer Journal (MPJ),* 2(1): 10-28.

Pan, C., Wu, H., Wang, C., Wang, B., Zhang, L., Cheng, Z., Hu, P., Pan, W., Zhou, Z., Yang, X. and Zhu, J. (2008). Nanowire-Based High-Performance "Micro Fuel Cells": One Nanowire, One Fuel Cell. *Adv. Mater.,* 20: 1644-1648.

Park, J. A., Moon, J., Lee, S. J., Kim, S. H., Chu, H. Y. and Zyung, T. (2010). SnO2-ZnO Hybrid Nanofibers-Based Highly Sensitive Nitrogen Dioxides Sensor. *Sensors and Actuotors B. Chemical,* 145(1): 592-595.

Peinemann, K.-V. and Nunes, S. P. (2008). Membrane Technology, Volume 2: Membrane for Energy Conversion. John Wiley & Son.

Pelipenko, J., Kristl, J., Janković, B., Baumgartner, S. and Kocbek, P. (2013). The Impact of Relative Humidity during Electrospinning on the Morphology and Mechanical Properties of Nanofibers. *International Journal of Pharmaceutics.*

Pham, Q. P., Sharma, U. and Mikos, A. G. (2006). Electrospining of Polymeric Nanofibers for Tissue Engineering Applications: A Review. *Tissue Engineering,* 12(5): 1197-1211.

Pluart, L., L. (2010). Epoxy-Based Nanocomposites. In Thomas, S., Zaikov, G., Valsaraj and Meera (Eds.). Recent Advances in Polymer Nanocomposite: Synthesis and Characterization. (pp:75-136). CRC Press.

Rajesh, K. P. (2011). Studies on Ion Conducting Properties of Electrospun Polymer Fibers. Doctor of Philosophy. Indian Institute of Technology Madras.

Ramani, V. (2006). Fuel Cells. The Electrochemical Society Interface, 41-44.

Rana, U. A., Forsyth, M., MacFarlane, D. R. and Pringle, J. M. (2012). Toward Protic Ionic Liquid and Organic Ionic Plastic Crystal Electrolytes for Fuel Cells. *Electrochemica Acta,* 84: 213-222.

Ray, S. S. and Okamoto, M. (2003). Polymer/Layered Silicate Nanocomposites: A Review from Preparation to Processing. Prog. *Polym. Sci.,*28 (11):1539-1641.

Ren, H., Ding, Y., Jiang, Y., Xu, F., Long, Z. and Zhang, P. (2009). Synthesis and Properties of ZnO Nanofibers prepared by electrospinning *J Sol-Gel Sci Technol.,* 52(2): 287-90.

Robertson, G. P., Mikhailenko, S. D., Wang, K., Xing, P., Guiver, M. D. and Kaliaguine, S. (2003). Casting Solvent Interactions with Sulfonated Poly (Ether Ether Ketone) during Proton Exchange Membrane Fabrication. *Journal of Membrane Science,* 219: 113-121.

Roelofs, K. S. (2010). Sulfonated Poly (Ether Ether Ketone) Based Membranes for Direct Ethanol Fuel Cells. Doctor of Engineering. University Stuttgart.

Sakaguchi, Y., Kitamura, K., Nakao, J., Hamamoto, S., Tachimori, H. and Takase, S. (2007). Preparation and Properties of Sulfonated or Phosponated Polybenzimidazoles and Polybenzazoles. In Charles E., Carraher Jr. and Swift, G. G. (Eds.). Functional Condensation Polymers. (pp: 101). Springer Science & Business Media.

Sakil, M., Singh, A. K. and Roy, G. S. (2013). Study of the Properties of Nanocomposite Cadmium Sulphide (CdS)\Polythiophene (PTh) by

TGA/DTA, XRD, UV-VIS Spectroscopy, SEM-EDXA and FTIR. *Researcher,* 5(1): 51-54.

Sautther, B. P. (2005, August 5). Continuous Polymer Nanofibers using Electrospinning. NSF-REU Summer 2005 Program. Universities of Illinois, Chicago.

Selman, J. R. (2006). Molten-Salt Fuel Cells—Technical and Economic Challenges. *Journal of Power Sources*. 160(2):852–7.

Shabani, I., Hasani-Sadrabadi, M. M., Haddadi-Asl, V. and Soleimani, M. (2011). Nanofiber-based Polyelectrolytes as Novel Membranes for Fuel Cell Applications. *Journal of Membr. Sci,* 368: 233-240.

Sill, T. J. and A. von Recum, H. (2008). Electrospinning: Applications in Drug Delivery and Tissue Engineering. *Biomaterials,* 29: 1989-2006.

Smithsonian Institution (2004). Phosphoric Acid Fuel Cells-National Museum of American History. Retrieved May 5, 2016, from http://americanhistory.si.edu/fuel cells/phos/pafcmain.htm.

Song, M.-K., Park, S.-B., Kim, Y.-T., Rhee, H.-W. and Kim, J. (2003). Nanocomposite Polymer Membrane Based on Cation Exchange Polymer and Nano-Dispersed Clay Sheets. *Molecular Crystals and Liquids Crystals,*407 (1): 15-23.

Song, M.-K., Park, S.-B., Kim, Y.-T., Kim, K.-H., Min, S.-K. and Rhee, H.-W. (2004). Characterization of Polymer-Layered Silicates Nanocomposite Membrane for Direct Methanol Fuel Cells. *Electrochemical Acta,*50:639-643.

Su, Y. -H., Liu, Y. -L., Sun, Y. -M., Lai, J. -Y., Wang, D. -M., Gao, Y., Liu, B. and Guiver, M. D. (2007). Proton Exchange Membranes Modified with Sulfonated Silica Nanoparticles for Direct Methanol Fuel Cells. *Journal of Membrane Science*, 296: 21-28.

Subbiah, T., Bhat, G. S., Tock, R. W., Parameswaran, S. and Ramkumar, S. S. (2005). Electrospinning of Nanofibers. *Journal of Applied Polymer Science,* 96: 557-569.

Tamura, T. and Kawakami, H. (2010). Aligned Elctropun Nanofiber Composite Membranes for Fuel Cell Electrolytes. *Nano Lett.* 10: 1324-1328.

Tan, S.-H., Inai, R., Kotaki, M. and Ramakrishna, S. (2005). Systematic Parameter Study for Ultra-Fine Fiber Fabrication via Electrospinning Process. *Polymer,* 46(16): 6128–6134.

Tang, C.-C., Chen, J.-C., Long, Y.-Z., Yin, H.-X., Sun, B. and Zhang, H.-D. (2011). Preparation of Curled Microfibers by Electrospinning with Tip Collector. Chin. *Phys. Lett.* 28(5): 056801(1-3).

Thavasi, V., Singh, G. and Ramakrishna, S. (2008). Electrospun Nanofibers in Energy and Environmental Applications. *Energy Environ. Sci.,* 1: 205-221.

Thomassin, J.-M., Pagnoulle, C., Caldarella, G., Germain, A. and Robert, J. (2006). Contribution of Nanoclays to the Barrier Properties of A Model Proton Exchange Membrane for Fuel Cell Application. *Journal of Membrane Science,* 270(1-2): 50–56.

Thompsett, D. (2010). Proton Exchange Membrane Fuel Cells. In Wilkinson, D. P. (Ed.). pp. 1-60.

Tien, Y. I. and Wei, K. H. (2001). Hydrogen Bonding and Mechanical Properties in Segmented Montmorillonite/Polyurethane Nanocomposites of Different Hard Segment Ratios. *Polymer,* 42: 3213-3221.

Tucker, N., Stanger, J. J., Staiger, M. P., Razzaq, H. and Hofman, K. (2012). The History of the Science and Technology of Electrospinning from 1600 to 1995. *Journal of Engineered Fibers and Fabrics* (SPECIAL ISSUE-July-FIBERS). pp: 63-73.

Uttayarat, P., Perets, A., Li, M., Pimton, P., Stachelek, S. J., Alferiev, I., Composto, R. J., Levy, R. J. and Lelkes, P. I. (2010). Micropatterining of Three-Dimension Electrospun Polyurethene Vascular Grafts. *Acta Biomaterialia.* 6: 4229-4237.

Viswanathamurthi, P., Bhattarai, N., Kim, H. Y., Khil, M. S., Lee, D. R. and Suh, E. K. (2004). GeO2 Fibers: Preparation, Morphology and Photoluminescence Property. *J. Chem. Phys.,* 121(1): 441-5.

Wan, T. and Wang, B. (2013). Clay Platelets Alter the Thermal Properties of Nylon. Plastics Research Online. Society of Plastic Engineers (SPE).

Wang, G., Ji, Y., Huang, X., Yang, X., Gouma, P.-I. and Dudley, M. (2006). Fabrication and Characterization of Polycrystalline WO3 Nanofibers and Their Application for Ammonia Sensing. *J. Phys. Chem. B.,* 110(47): 23777-82.

Wang, M. and Dong, S. (2007). Enhanced Electrochemical Properties of Nanocomposite Polymer Electrolyte based on Copolymer with Exfoliated Clays. *Journal of Power Sources,* 170: 425-432.

Wang, Y., Chen, K. S., Mishler, J., Cho, S. C. and Adroher, X. C. (2011). A Review of Polymer Electrolyte Membrane Fuel Cells: Technology, Applications, and Needs on Fundamental Research. *Applied Energy,* 88: 981-1007.

Wang, Y., Li, M., Rong, J., Nie, G., Qiao, J., Wang, H., Wu, D., Su, Z., Niu, Z. and Huang, Y. (2013). Enhanced Orientation of PEO Polymer Chains Induced by Nanoclays in Electrospun PEO/clay Composite Nanofibers. Colloid Polym Sci.

Williams, M. C. (2011). Fuel Cells. In Shekhawat, D., Spivey, J. J. and Berry, D. A. (Eds.). *Technologies for Fuel Processing.* (pp.: 11-27). Elsevier.

Wong, B. (2006, August 28). This Why We Need Alternative Energy Sources. Retrieved March 4, 2013, from www.articlesbase.com/environment-articles/this-why-we-need-alternative-energy-sources-50135.html.

Xing, P., Robertson, G. P., Guiver, M. D., Mikhailenko, S. D., Wang, K. and Kaliaguine, S. (2004). Synthesis and Characterization of Sulfonated Poly (Ether Ether Ketone) for Proton Exchange Membranes. *Journal of Membrane Science,* 229: 95-106.

Xiong, X., Li, Q., Zhang, X. - C., Wang, L., Guo, Z. -X. and Yu, J. (2013). Poly (vinylidene fluoride)/Silica Nanocomposite Membrane by Electrospinning. *J. Appl. Polym. Sci.* pp.: 1089-1095.

Xu, F., Li, L. and Cui, X. (2012). Fabrication of Aligned Side-by-Side TiO2/SnO2 Nanofibers via Dual-Opposite-Spinneret Electrospinning. *Journal of Nanomaterials,* 1-5.

Yan, L. and Xie, L. (2012). Molecular Dynamics Simulations of Proton Transport in Proton Exchange Membranes Based on Acid-Base Complexes. In Prof. Aurelia Meghea (Ed.). Molecular Interactions. (pp.: 335-360). InTech.

Yang, B. and Manthiram, A. (2003). Sulfonated Poly (ether ether ketone) Membranes for Direct Methanol Fuel Cells. *Electrochemical and Solid-State Letters,* 6: A229-A231.

Yang, X., Shao, C., Liu, Y., Mu, R. and Guan, H. (2005). Nanofibers of CeO2 via an Electrospinning Technique. *Thin Solid Films,* 478(1-2): 228-231.

Yang, A., Tao, X., Pang, G. K. H. and Siu, K. G. G. (2008). Preparation of porous Tin Oxide Nanobelts Using the Electrospinning Technique. *Journal of the American Ceramic Society,* 91(1): 257-262.

Yang, X., Shao, C., Guan, H., Li, X. and Gong, J. (2004). Preparation and Characterization of ZnO Nanofibers by Using Electrospun PVA/zinc Acetate Composite Fiber as Precursor. Inorganic Chemistry Communications, 7(2): 176-178.

Zaidi, S. M. J. (2005). Preparation and Characterization of Composite Membranes Using Blends of SPEEK/PBI with Boron Phosphate. *Electrochimica Acta,* 50(24): 4771–4777.

Zhang, D., Karki, A. B., Rutman, D., Young, D. P., Wang, A., Cocke, D., Ho, T. H. and Guo, Z. (2009). Electrospun Polyacrylonitrile Nanocomposite Fibers Reinforced with Fe3O4 Nanoparticles: Fabrication and Property Analysis. *Polymer,* 50(17): 4189–4198.

Zhang, L., Chae, S.-R., Hendren, Z., Park, J.-S. and Wiesner, M. R. (2012). Recent Advances in Proton Exchange Membranes for Fuel Cell Applications. *Chemical Engineering Journal,* 204-206: 87-97.

Zhang, Y., He, X., Li, J., Miao, Z. and Huang, F. (2008). Fabrication and Ethanol-Sensing Properties of Micro-Gas Sensor Based on Electrospun SnO2 Nanofibers. *Sens. Actuators B Chem.,* 132: 67-73.

Zhang, Z., Li, X., Wang, C., Wei, L., Liu, Y. and Shao, C. (2009) ZnO Hollow Nanofibers Fabrication from Facile Single Capillary Electrospinning and Applications in Gas Sensors. *J. Phys. Chem.,* 113: 19397-19403.

Zheng, W., Li, Z., Zhang, H., Wang, W., Wang, Y. and Wang, C. (2009). Electrospinning Route for α-Fe2O3 Ceramic Nanofibers and Their Gas Sensing Properties. *Mater. Res. Bull,* 44: 1432-1436.

Zhu, N. and Chen, X. (2013). Biofabrication of Tissue Scaffolds. In Advances in Biomaterials Science and Biomedical Applications. InTech.

Zucchelli, A., Fabiani, D. and Gualandi, C. (2009). An Innovative and Versatile Approach to Design Highly Porous, Patterned, Nanofibrous Polymeric Materials. *J. Mater Sci.,* 44: 4969-4975.