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| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                   |                                | Form Approved OMB NO. 0704-0188                           |                                                          |                                                 |
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA, 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p> |                   |                                |                                                           |                                                          |                                                 |
| 1. REPORT DATE (DD-MM-YYYY)<br>14-03-2011                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                   | 2. REPORT TYPE<br>Final Report |                                                           | 3. DATES COVERED (From - To)<br>25-Jan-2005 - 5-Sep-2010 |                                                 |
| 4. TITLE AND SUBTITLE<br>Selective and Responsive Nanopore-Filled Membranes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                   |                                | 5a. CONTRACT NUMBER<br>W911NF-05-1-0036                   |                                                          |                                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 5b. GRANT NUMBER                                          |                                                          |                                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 5c. PROGRAM ELEMENT NUMBER<br>206023                      |                                                          |                                                 |
| 6. AUTHORS<br>Yossef A. Elabd, Giuseppe R. Palmese                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                   |                                | 5d. PROJECT NUMBER                                        |                                                          |                                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 5e. TASK NUMBER                                           |                                                          |                                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 5f. WORK UNIT NUMBER                                      |                                                          |                                                 |
| 7. PERFORMING ORGANIZATION NAMES AND ADDRESSES<br>Drexel University<br>Office of Research Admin<br>Drexel University<br>Philadelphia, PA 19104 -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                   |                                | 8. PERFORMING ORGANIZATION REPORT NUMBER                  |                                                          |                                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>U.S. Army Research Office<br>P.O. Box 12211<br>Research Triangle Park, NC 27709-2211                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>ARO                   |                                                          |                                                 |
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| 13. SUPPLEMENTARY NOTES<br>The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                |                                                           |                                                          |                                                 |
| 14. ABSTRACT<br>The overall goal of this project is to develop a new class of breathable barrier membrane (i.e., selective for water vapor over harmful agents) with stimuli-responsive capabilities and the mechanical strength required for protective clothing for chemical and biological defense. These new materials are based on polymer-polymer nanocomposites of hydrophilic ionic polymer gels within a hydrophobic polymer host matrix. The specific tasks of this project include (1) synthesizing stimuli-responsive selective membranes based on polymer-polymer nanocomposites, (2)                                                                                                                                                                                                                                                                                                                                |                   |                                |                                                           |                                                          |                                                 |
| 15. SUBJECT TERMS<br>chem/bio protective clothing, membranes, nanoporous polymers, nanofibers, composites                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                   |                                |                                                           |                                                          |                                                 |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                | 17. LIMITATION OF ABSTRACT<br>UU                          | 15. NUMBER OF PAGES                                      | 19a. NAME OF RESPONSIBLE PERSON<br>Yossef Elabd |
| a. REPORT<br>UU                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | b. ABSTRACT<br>UU | c. THIS PAGE<br>UU             |                                                           |                                                          | 19b. TELEPHONE NUMBER<br>215-895-0986           |

## Report Title

### Selective and Responsive Nanopore-Filled Membranes

#### ABSTRACT

The overall goal of this project is to develop a new class of breathable barrier membrane (i.e., selective for water vapor over harmful agents) with stimuli-responsive capabilities and the mechanical strength required for protective clothing for chemical and biological defense. These new materials are based on polymer-polymer nanocomposites of hydrophilic ionic polymer gels within a hydrophobic polymer host matrix. The specific tasks of this project include (1) synthesizing stimuli-responsive selective membranes based on polymer-polymer nanocomposites, (2) measuring transport properties: breathable barrier selectivity and electrical stimuli-responsive capabilities, and (3) measuring and modeling multicomponent transport properties and materials optimization. This work focuses on two new membrane concepts: (1) Nanopore-Filled Membranes and (2) Encapsulated Nanofiber Mesh Membranes. The goals of this project were accomplished, where the details of these results are documented in the annual reports and attached manuscripts.

A recent result from this work of interest is the fabrication and super conducting properties of Nafion nanofibers, which was recently published in a high-impact journal Nano Letters. In this paper, we reported the high proton conductivity of single high purity Nafion nanofiber (1.5 S/cm), which is an order of magnitude higher than the bulk Nafion film (~ 0.1 S/cm). We also observed a nanosize effect, where proton conductivity increases sharply with decreasing fiber diameter. X-ray scattering provides a rationale for these findings, where an oriented ionic morphology was observed in the nanofiber in contrast to the isotropic morphology in the bulk film. This work also demonstrates the successful fabrication of high purity Nafion nanofibers (~ 99.9 wt%) via electrospinning and higher humidity sensitivity for nanofibers compared to the bulk. These results should have a significant impact on not only the development of breathable barrier membranes, but also other applications such as fuel cells and sensors.

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#### List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

##### (a) Papers published in peer-reviewed journals (N/A for none)

1. Dong, B.; Gwee, L.; Salas-de la Cruz, D.; Winey, K.I. Elabd, Y.A. Super Proton Conductive High Purity Nafion Nanofibers. Nano Letters 2010, 10, 3785-3790.
2. Rahmathullah, M. Aflal M.; Snyder, J.D.; Elabd, Y.A.; Palmese G.R. Nanoporous and Proton Conductive Hydrophobic-Hydrophilic Copolymer Thermoset Membranes. J. Polym. Sci. Pol. Phys. 2010, 48 (12), 1245-1255.
3. Rahmathullah, M. Aflal M.; Elabd, Y.A.; Palmese G.R. Kinetic and Thermomechanical Analysis of Hydrophobic-Hydrophilic Copolymer Thermosets Synthesized via Free-Radical Polymerization. J. Appl. Polym. Sci. 2010, 115 (3), 1419-1427.
4. Chen, H.; Snyder, J.D.; Elabd, Y.A. Electrospinning and Solution Behavior of Nafion and Poly(acrylic acid). Macromolecules 2008, 41, 128-135.
5. Rahmathullah, A.M.; Robinette, E.J.; Chen, H.; Elabd, Y.A.; Palmese G.R. Plasma-Assisted Synthesis of Hollow Nanofibers using Electrospun Sacrificial Templates. Nucl. Instrum. Meth. B 2007, 265, 23-30.
6. Hallinan, D.T., Jr.; Elabd, Y.A. Diffusion and Sorption of Methanol and Water in Nafion using Time-Resolved FTIR-ATR Spectroscopy. J. Phys. Chem. B 2007 111 (46), 13221-13230. Featured in Photonics Spectra, Jan 2008
7. Chen, H.; Elabd, Y.A.; Palmese, G.R. Plasma-Aided Template Synthesis of Inorganic Nanotubes and Nanorods. J. Mater. Chem. 2007, 17, 1593-1596.
8. Chen, H.; Palmese, G.R.; Elabd, Y.A. Electrosensitive Permeability of Membranes with Oriented Polyelectrolyte Nanodomains. Macromolecules 2007, 40, 781-782.
9. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. Chem. Mater. 2006, 18, 4875-4881.

Number of Papers published in peer-reviewed journals: 9.00

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##### (b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

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**(c) Presentations**

1. Chen, H.; Snyder, J.D.; Elabd, Y.A. Electrospinning Nafion Nanofibers. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.
2. Rahmathullah, A.M.; Elabd Y.A.; Palmese, G.R. Design of Nanoporous, Proton-Conductive Polymer Thermosets. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.
3. Schaeffer, H.; Chen, H.; Snyder, J.D.; Rahmathullah, A.M.; Palmese, G.R.; Elabd, Y.A. Electrosensitive Permeability of Polymer-Polymer Nanocomposite Membranes. Fall National Meeting of the American Chemical Society, Boston, MA, August 2007.
4. Elabd, Y.A. Transport Phenomena in Polymer Electrolyte Membranes for the Direct Methanol Fuel Cell. NATO Advanced Study Institute on Mini-Micro Fuel Cells as Electric Energy Generators, Cesme, Izmir, Turkey, July 2007. Invited Speaker
5. Hallinan, D.T., Jr.; Elabd, Y.A. Transport of Water in Nafion® using Time-Resolved FTIR-ATR Spectroscopy. Annual Meeting of the North American Membrane Society, Orlando, FL, May 2007.
6. Elabd, Y.A. Methanol Crossover: New Insights and Experimental Techniques. Fuel Cells 2007 Meeting, sponsored by The Division of Polymer Chemistry (POLY) of the American Chemical Society, Asilomar, CA, February 2007. Invited Speaker
7. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Plasma-Radiation Enhanced Nanofiber-Thermoplastic Composites. Materials Research Society Fall Meeting, Boston, MA, November 2006.
8. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Structure, Property and Cure Kinetics of Thermosetting Copolymers. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006.
9. Hallinan, D.T., Jr.; Elabd, Y.A. Multicomponent Transport of Water and Methanol in Nafion®. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006. Received Schering-Plough Research Institute Travel Award (\$2,000)
10. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. Fall National Meeting of the American Chemical Society, San Francisco, CA, September 2006.
11. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Polyelectrolyte Nanocomposite Membranes as Breathable and Responsive Barriers. Annual Meeting of the American Institute of Chemical Engineers, Cincinnati, OH, November 2005.
12. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Synthesis and Characterization of Thermosetting Copolymers as PEMs. Annual Meeting of the American Institute of Chemical Engineers, Cincinnati, OH, November 2005.
13. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Poly(methacrylic acid) Nanocomposite Membranes as Breathable Barriers. Fall National Meeting of the American Chemical Society, Washington, DC, August 2005.
14. Throckmorton, J.A.; Hallinan, D.T., Jr.; Elabd, Y.A. Diffusion of Water and Methanol in Nafion: In Situ Infrared Experiments and Multicomponent Models. Annual Meeting of the American Institute of Chemical Engineers, Philadelphia, PA, November 2008. Received 2nd Place Award in the Materials Science and Engineering Poster Competition
15. Chen, H.; Elabd, Y.A. Ionic Liquid Polymers: Electrospinning and Solution Properties. Fall National Meeting of the American Chemical Society, Philadelphia, PA, August 2008.
16. Schaeffer, H.; Elabd Y.A. Transport in Polymer-Polymer Nanocomposite Membranes. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.
17. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains as Breathable Barriers for Protective Clothing. 25th Army Science Conference, Orlando, FL, November 2006.
18. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Plasma-Radiation Enhanced Nanofiber-Thermoplastic Composites. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006.

19. Hallinan, D.T., Jr.; Elabd, Y.A. Multicomponent Transport of Water and Methanol in Nafion®. Annual Meeting of the North American Membrane Society, Chicago, IL, May 2006. Received NAMS Poster Award (\$500) and NAMS Annual Meeting Student Travel Award (\$1,000)

20. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymer Membranes: Synthesis and Characterization. Annual Meeting of the North American Membrane Society, Chicago, IL, May 2006. Received Elias Klein Founders' Travel Award (\$500)

21. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymers. American Chemical Society Local Section 6th Annual Poster Session, Villanova University, Philadelphia, PA, January 2006. Received the EssTech Polymers and Materials Science Award

22. Chen, H.; Rahmathullah, A.M.; Hallinan, D.T., Jr.; Napadensky, E.; Palmese, G.R.; Elabd, Y.A. Polymer-Polymer Nanocomposite Membranes as Breathable and Responsive Barriers. 2005 Scientific Conference on Chemical and Biological Defense Research, Timonium, MD, November 2005.

23. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymer Matrices. American Society of Composites Annual Meeting, Philadelphia, PA, September 2005.

24. Rahmathullah, A.M.; Palmese, G.R.; Elabd, Y.A. Proton Conductive Nanoporous Thermosetting Copolymers, Fall National Meeting of the American Chemical Society, Washington, DC, August 2005.

**Number of Presentations:** 24.00

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#### **Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

1. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains as Breathable Barriers for Protective Clothing. 25th Army Science Conference Proceedings 2006, MP-01.

2. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. ACS Polymeric Materials: Science and Engineering 2006, 95, 269-270.

3. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Poly(methacrylic acid) Nanocomposite Membranes as Breathable Barriers. ACS Polymer Preprints 2005, 46 (2), 1202-1203.

4. Mohamed Aflal, M.R.; Elabd, Y.A.; Palmese, G.R. Proton Conductive Nanoporous Thermosetting Copolymers. ACS Polymeric Materials: Science and Engineering 2005, 93, 564-565.

**Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):** 4

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#### **Peer-Reviewed Conference Proceeding publications (other than abstracts):**

**Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):** 0

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#### **(d) Manuscripts**

**Number of Manuscripts:** 0.00

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#### **Patents Submitted**

1. Elabd, Y.A.; Palmese G.R. Filled Nanoporous Polymer Membrane Composites for Protective Clothing and Methods for Making Them. World Patent, filed May 24, 2007, international application number PCT/US07/69658, pending approval. U.S. Patent, filed November 17, 2008, application number 12/301,176, pending approval. Featured in Homeland Security Daily Wire, February 2008.

#### **Patents Awarded**

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## Awards

NSF CAREER Award (2007), DuPont Science and Engineering Award (2005)

### Graduate Students

| <u>NAME</u>              | <u>PERCENT SUPPORTED</u> |
|--------------------------|--------------------------|
| M. Afzal M. Rahmathullah | 1.00                     |
| Daniel T. Hallinan, Jr.  | 0.25                     |
| Holly Schaeffer          | 0.25                     |
| <b>FTE Equivalent:</b>   | <b>1.50</b>              |
| <b>Total Number:</b>     | <b>3</b>                 |

### Names of Post Doctorates

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| Hong Chen              | 1.00                     |
| Bin Dong               | 1.00                     |
| <b>FTE Equivalent:</b> | <b>2.00</b>              |
| <b>Total Number:</b>   | <b>2</b>                 |

### Names of Faculty Supported

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> | National Academy Member |
|------------------------|--------------------------|-------------------------|
| Yossef A. Elabd        | 0.08                     | No                      |
| Giuseppe R. Palmese    | 0.08                     | No                      |
| <b>FTE Equivalent:</b> | <b>0.16</b>              |                         |
| <b>Total Number:</b>   | <b>2</b>                 |                         |

### Names of Under Graduate students supported

| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
|------------------------|--------------------------|
| <b>FTE Equivalent:</b> |                          |
| <b>Total Number:</b>   |                          |

### Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

|                                                                                                                                                                                                                          |      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| The number of undergraduates funded by this agreement who graduated during this period: .....                                                                                                                            | 0.00 |
| The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....                                                    | 0.00 |
| The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....           | 0.00 |
| Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):.....                                                                                                                                  | 0.00 |
| Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:.....                                                                                      | 0.00 |
| The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense .....                                                                            | 0.00 |
| The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ..... | 0.00 |

**Names of Personnel receiving masters degrees**

|                      |
|----------------------|
| <u>NAME</u>          |
| <b>Total Number:</b> |

**Names of personnel receiving PHDs**

|                          |
|--------------------------|
| <u>NAME</u>              |
| M. Aflal M. Rahmathullah |
| Daniel T. Hallinan, Jr.  |
| <b>Total Number:</b> 2   |

**Names of other research staff**

|                        |                          |
|------------------------|--------------------------|
| <u>NAME</u>            | <u>PERCENT SUPPORTED</u> |
| <b>FTE Equivalent:</b> |                          |
| <b>Total Number:</b>   |                          |

**Sub Contractors (DD882)**

**Inventions (DD882)**

**5 Filled Nanoporous Polymer Membrane Composites for Protective Clothing and Methods for Making Them.**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) Y

Was the assignment forwarded to the contracting officer? (5e) Y

Foreign Countries of application (5g-2): World Patent

5a: Giuseppe Palmese

5f-1a: Drexel University

5f-c: 3141 Chestnut St

Philadelphia

PA

19104

5a: Yossef A. Elabd

5f-1a: Drexel University

5f-c: 3141 Chestnut St

Philadelphia

PA

19104

**Scientific Progress**

See Attachment

**Technology Transfer**

## Final Report

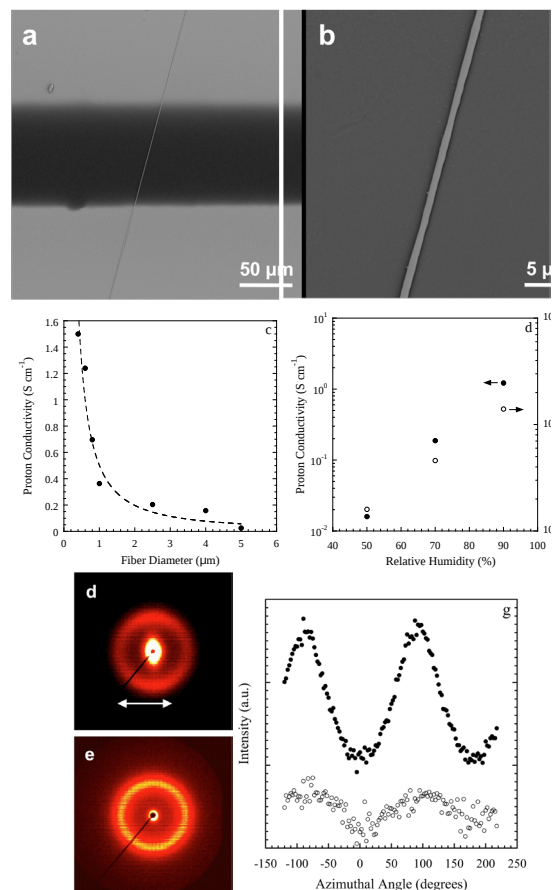
### Selective and Responsive Nanopore-Filled Membranes

PI: Y.A. Elabd

Co-PI: G.R. Palmese

The overall goal of this project is to develop a new class of breathable barrier membrane (i.e., selective for water vapor over harmful agents) with stimuli-responsive capabilities and the mechanical strength required for protective clothing for chemical and biological defense. These new materials are based on polymer-polymer nanocomposites of hydrophilic ionic polymer gels within a hydrophobic polymer host matrix. The specific tasks of this project include (1) synthesizing stimuli-responsive selective membranes based on polymer-polymer nanocomposites, (2) measuring transport properties: breathable barrier selectivity and electrical stimuli-responsive capabilities, and (3) measuring and modeling multicomponent transport properties and materials optimization. This work focuses on two new membrane concepts: (1) Nanopore-Filled Membranes and (2) Encapsulated Nanofiber Mesh Membranes. The goals of this project were accomplished, where the details of these results are documented in the annual reports and attached manuscripts.

A recent result from this work of interest is the fabrication and superconducting properties of Nafion nanofibers, which was recently published in a high-impact journal Nano Letters. In this paper, we reported the high proton conductivity of single high purity Nafion nanofiber (1.5 S/cm), which is an order of magnitude higher than the bulk Nafion film (~ 0.1 S/cm) (**Figure 1**). We also observed a nanosize effect, where proton conductivity increases sharply with decreasing fiber diameter. X-ray scattering provides a rationale for these findings, where an oriented ionic morphology was observed in the nanofiber in contrast to the isotropic morphology in the



**Figure 1.** (a) SEM image of a single high purity Nafion nanofiber bridging two electrodes; (b) enlarged image of (a); (c) proton conductivity (at 30 °C, 90% RH) versus fiber diameter for high purity Nafion nanofibers measured on individual nanofibers; (d) Humidity-dependent proton conductivity (30 °C) of a single high purity Nafion nanofiber (solid symbols) and a cast Nafion film (open symbols); 2-D X-ray scattering patterns (at 86% RH, 25 °C) of (e) macroscopically aligned high purity Nafion nanofibers (arrows indicating longitudinal direction of fibers) and (f) Nafion cast film; (g) X-ray scattering intensity as a function of azimuthal angle for macroscopically aligned high purity Nafion nanofibers (solid symbols) and a cast Nafion film (open symbols).

bulk film. This work also demonstrates the successful fabrication of high purity Nafion nanofibers (~ 99.9 wt%) via electrospinning and higher humidity sensitivity for nanofibers compared to the bulk. These results should have a significant impact on not only the development of breathable barrier membranes, but also other applications such as fuel cells and sensors.

## PUBLICATIONS

### **Publications** (*Peer-Reviewed Archival Manuscripts*)

1. Dong, B.; Gwee, L.; Salas-de la Cruz, D.; Winey, K.I. Elabd, Y.A. Super Proton Conductive High Purity Nafion Nanofibers. *Nano Letters* **2010**, *10*, 3785-3790.
2. Rahmathullah, M. Aflal M.; Snyder, J.D.; Elabd, Y.A.; Palmese G.R. Nanoporous and Proton Conductive Hydrophobic-Hydrophilic Copolymer Thermoset Membranes. *J. Polym. Sci. Pol. Phys.* **2010**, *48* (12), 1245-1255.
3. Rahmathullah, M. Aflal M.; Elabd, Y.A.; Palmese G.R. Kinetic and Thermomechanical Analysis of Hydrophobic-Hydrophilic Copolymer Thermosets Synthesized via Free-Radical Polymerization. *J. Appl. Polym. Sci.* **2010**, *115* (3), 1419-1427.
4. Chen, H.; Snyder, J.D.; Elabd, Y.A. Electrospinning and Solution Behavior of Nafion and Poly(acrylic acid). *Macromolecules* **2008**, *41*, 128-135.
5. Rahmathullah, A.M.; Robinette, E.J.; Chen, H.; Elabd, Y.A.; Palmese G.R. Plasma-Assisted Synthesis of Hollow Nanofibers using Electrospun Sacrificial Templates. *Nucl. Instrum. Meth. B* **2007**, *265*, 23-30.
6. Hallinan, D.T., Jr.; Elabd, Y.A. Diffusion and Sorption of Methanol and Water in Nafion using Time-Resolved FTIR-ATR Spectroscopy. *J. Phys. Chem. B* **2007** *111* (46), 13221-13230. **Featured in Photonics Spectra, Jan 2008**
7. Chen, H.; Elabd, Y.A.; Palmese, G.R. Plasma-Aided Template Synthesis of Inorganic Nanotubes and Nanorods. *J. Mater. Chem.* **2007**, *17*, 1593-1596.
8. Chen, H.; Palmese, G.R.; Elabd, Y.A. Electrosensitive Permeability of Membranes with Oriented Polyelectrolyte Nanodomains. *Macromolecules* **2007**, *40*, 781-782.
9. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. *Chem. Mater.* **2006**, *18*, 4875-4881.

### **Publications** (*Book Chapters*)

10. Chen, H.; Rahmathullah, A.M.; Palmese, G.R.; Elabd, Y.A. Polymer-Polymer Nanocomposite Membranes as Breathable Barriers with Electro-Sensitive Permeability; In *Nanoscience and Nanotechnology for Chemical and Biological Defense*. Nagarajan, R.; Zukas, W.; Hatton, T.A.; Lee, S., Eds.; Oxford University Press, 2009; ACS Symposium Series 1016, pp 307-322. **Invited Contribution**
11. Hallinan, D.T., Jr.; Elabd, Y.A. Sorption and Diffusion Selectivity of Methanol/Water Mixtures in Nafion®. In *Micro-Mini Fuel Cells – Fundamentals and Applications*; Kakac, S., Pramuanjaroenkij, A., Vasiliev, L., Eds; Springer: Netherlands, 2008; pp 189-208. **Invited Contribution**

### **Publications** (*Archival Proceedings, Preprints, and Technical Reports*)

12. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains as Breathable Barriers for Protective Clothing. *25<sup>th</sup> Army Science Conference Proceedings* **2006**, MP-01.
13. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. *ACS Polymeric Materials: Science and Engineering* **2006**, 95, 269-270.
14. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Poly(methacrylic acid) Nanocomposite Membranes as Breathable Barriers. *ACS Polymer Preprints* **2005**, 46 (2), 1202-1203.
15. Mohamed Aflal, M.R.; Elabd, Y.A.; Palmese, G.R. Proton Conductive Nanoporous Thermosetting Copolymers. *ACS Polymeric Materials: Science and Engineering* **2005**, 93, 564-565.

### **Publications** (*Patents*)

16. Elabd, Y.A.; Palmese G.R. Filled Nanoporous Polymer Membrane Composites for Protective Clothing and Methods for Making Them. World Patent, filed May 24, 2007, international application number PCT/US07/69658, pending approval. U.S. Patent, filed November 17, 2008, application number 12/301,176, pending approval. **Featured in Homeland Security Daily Wire, February 2008.**

## **PRESENTATIONS**

### **Presentations** (*Oral Presentations at Meetings and Conferences, presenter underlined*)

1. Chen, H.; Snyder, J.D.; Elabd, Y.A. Electrospinning Nafion Nanofibers. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.
2. Rahmathullah, A.M.; Elabd Y.A.; Palmese, G.R. Design of Nanoporous, Proton-Conductive Polymer Thermosets. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.

3. Schaeffer, H.; Chen, H.; Snyder, J.D.; Rahmathullah, A.M.; Palmese, G.R.; Elabd, Y.A. Electrosensitive Permeability of Polymer-Polymer Nanocomposite Membranes. Fall National Meeting of the American Chemical Society, Boston, MA, August 2007.
4. Elabd, Y.A. Transport Phenomena in Polymer Electrolyte Membranes for the Direct Methanol Fuel Cell. NATO Advanced Study Institute on Mini-Micro Fuel Cells as Electric Energy Generators, Cesme, Izmir, Turkey, July 2007. **Invited Speaker**
5. Hallinan, D.T., Jr.; Elabd, Y.A. Transport of Water in Nafion<sup>®</sup> using Time-Resolved FTIR-ATR Spectroscopy. Annual Meeting of the North American Membrane Society, Orlando, FL, May 2007.
6. Elabd, Y.A. Methanol Crossover: New Insights and Experimental Techniques. Fuel Cells 2007 Meeting, sponsored by The Division of Polymer Chemistry (POLY) of the American Chemical Society, Asilomar, CA, February 2007. **Invited Speaker**
7. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Plasma-Radiation Enhanced Nanofiber-Thermoplastic Composites. Materials Research Society Fall Meeting, Boston, MA, November 2006.
8. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Structure, Property and Cure Kinetics of Thermosetting Copolymers. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006.
9. Hallinan, D.T., Jr.; Elabd, Y.A. Multicomponent Transport of Water and Methanol in Nafion<sup>®</sup>. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006. **Received Schering-Plough Research Institute Travel Award (\$2,000)**
10. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains. Fall National Meeting of the American Chemical Society, San Francisco, CA, September 2006.
11. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Polyelectrolyte Nanocomposite Membranes as Breathable and Responsive Barriers. Annual Meeting of the American Institute of Chemical Engineers, Cincinnati, OH, November 2005.
12. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Synthesis and Characterization of Thermosetting Copolymers as PEMs. Annual Meeting of the American Institute of Chemical Engineers, Cincinnati, OH, November 2005.
13. Chen, H.; Palmese, G.R.; Elabd, Y.A. Polyester-Poly(methacrylic acid) Nanocomposite Membranes as Breathable Barriers. Fall National Meeting of the American Chemical Society, Washington, DC, August 2005.

**Presentations** (*Poster Presentations at Meetings and Conferences, presenter underlined*)

14. Throckmorton, J.A.; Hallinan, D.T., Jr.; Elabd, Y.A. Diffusion of Water and Methanol in Nafion: In Situ Infrared Experiments and Multicomponent Models. Annual Meeting of the American Institute of Chemical Engineers, Philadelphia, PA, November 2008. **Received 2<sup>nd</sup> Place Award in the Materials Science and Engineering Poster Competition**
15. Chen, H.; Elabd, Y.A. Ionic Liquid Polymers: Electrospinning and Solution Properties. Fall National Meeting of the American Chemical Society, Philadelphia, PA, August 2008.
16. Schaeffer, H.; Elabd Y.A. Transport in Polymer-Polymer Nanocomposite Membranes. Annual Meeting of the American Institute of Chemical Engineers, Salt Lake City, UT, November 2007.
17. Chen, H.; Palmese, G.R.; Elabd, Y.A. Membranes with Oriented Polyelectrolyte Nanodomains as Breathable Barriers for Protective Clothing. 25<sup>th</sup> Army Science Conference, Orlando, FL, November 2006.
18. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Plasma-Radiation Enhanced Nanofiber-Thermoplastic Composites. Annual Meeting of the American Institute of Chemical Engineers, San Francisco, CA, November 2006.
19. Hallinan, D.T., Jr.; Elabd, Y.A. Multicomponent Transport of Water and Methanol in Nafion<sup>®</sup>. Annual Meeting of the North American Membrane Society, Chicago, IL, May 2006. **Received NAMS Poster Award (\$500) and NAMS Annual Meeting Student Travel Award (\$1,000)**
20. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymer Membranes: Synthesis and Characterization. Annual Meeting of the North American Membrane Society, Chicago, IL, May 2006. **Received Elias Klein Founders' Travel Award (\$500)**
21. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymers. American Chemical Society Local Section 6<sup>th</sup> Annual Poster Session, Villanova University, Philadelphia, PA, January 2006. **Received the EssTech Polymers and Materials Science Award**
22. Chen, H.; Rahmathullah, A.M.; Hallinan, D.T., Jr.; Napadensky, E.; Palmese, G.R.; Elabd, Y.A. Polymer-Polymer Nanocomposite Membranes as Breathable and Responsive Barriers. 2005 Scientific Conference on Chemical and Biological Defense Research, Timonium, MD, November 2005.
23. Rahmathullah, A.M.; Elabd, Y.A.; Palmese, G.R. Multifunctional Nanoporous Thermosetting Copolymer Matrices. American Society of Composites Annual Meeting, Philadelphia, PA, September 2005.

24. Rahmathullah, A.M.; Palmese, G.R.; Elabd, Y.A. Proton Conductive Nanoporous Thermosetting Copolymers, Fall National Meeting of the American Chemical Society, Washington, DC, August 2005.