Celgard and Entek
Battery Separator Development

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USABC

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Project ID # es_08_tataria

HIGHLY FILLED AND/OR CROSSLINKED LI-ION BATTERY SEPARATORS FOR HEV/PHEV APPLICATIONS

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May 19, 2009

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Project ID # es_08_tataria

Overview

Timeline

- Start – October 2008
- Finish – December 2009
- Percent complete – 30 %

Barriers

- High temperature (200 °C) mechanical integrity
- Stability in Li-ion battery environment
- Low cost (goal - $1/m^2)
- Thickness target – 20 micron

Budget

- Total project funding
  - DOE share - $ 208,260
  - Entek share - $ 208,260
- Funding received in FY2008 - $ 36,274
- Funding for FY 2009 - $ 380,246

Partners

- Portland State University – Electron microscopy
- EMI, Oregon – Equipment and materials processing

Objectives

- Separator performance under abuse is vital for HEV/PHEV battery safety. Requirements different from typical consumer devices
- Thermal protection of the large scale battery packs are expected to be handled at a system level. Reduces need for single cell shutdown.

Mechanical integrity of the separator at elevated temperatures is the key to HEV/PHEV Li-ion cell safety

Objectives of the study (FY 2009)

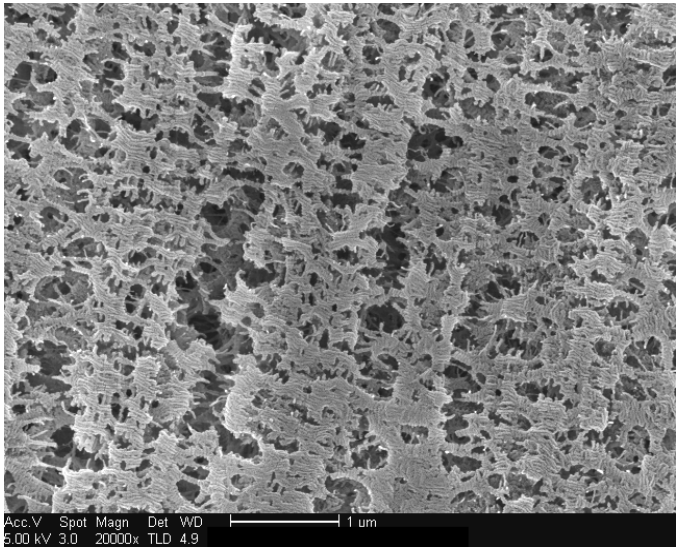
- **Materials selection (polymers, inorganic fillers)**
- **Develop process parameters and technology to achieve highly filled, thin film separators**
- **Demonstrate good mechanical integrity and low thermal shrinkage at 200 °C**

Milestones

	Action	Purpose	Milestone	Time frame				
				Oct	Nov	Dec	Jan	Feb
1	Separators made with different fillers and polymers	To identify compatibility issues	No-go on certain fillers due to incompatibility at higher loading levels					
2	Development of processing technology to produce highly filled membranes	Demonstrate processing capabilities	Produced initial samples in roll form. Various filler combinations were attempted successfully					
3	Conduct physical, morphological, and electrochemical characterization	To understand structure, properties, and stability in Li-ion battery environment	Significant improvement in high temperature (200 °C) stability achieved. No-go on certain fillers due to inadequate properties					

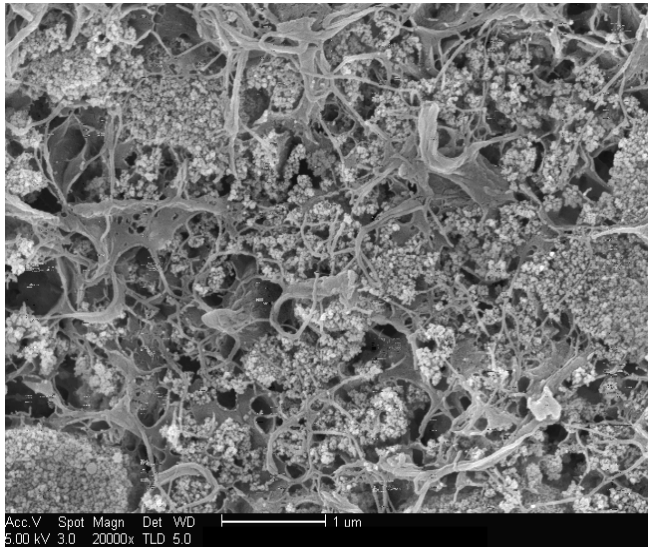
Approach

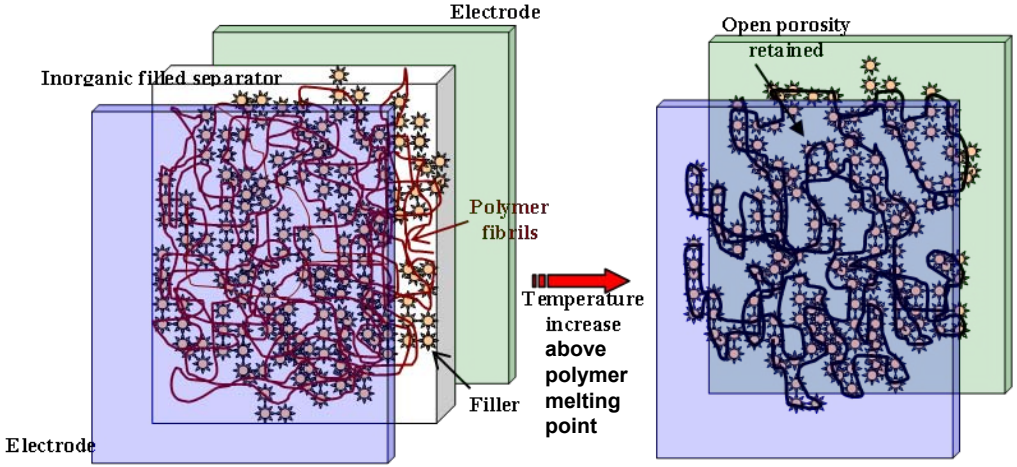
Teklon® standard Li-ion separator (40 % porosity): Unfilled



Incorporation of filler into UHMWPE matrix

Entek's new experimental Li-ion separator (> 65 % porosity): Filled

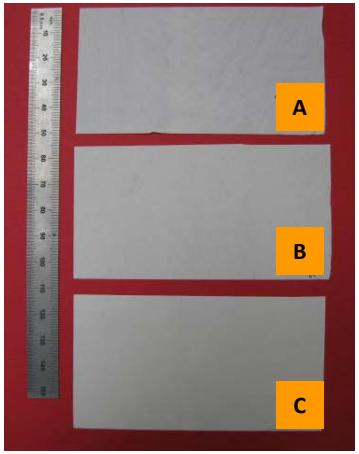




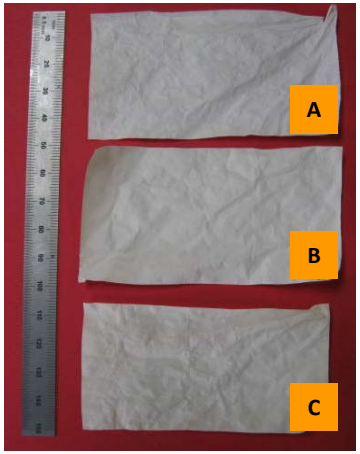
At elevated temperatures – Electrodes are still separated with inorganic filler

Technical accomplishments

- High (> 50 wt %) filler loading levels achieved in pilot plant trials
  - Entek's material and process technology was able to produce highly filled separators with various inorganic fillers
  - Filled separators had good handling characteristics – flexible and strong. No shedding or cracking observed.
- High temperature mechanical integrity achieved
  - Samples kept in Argon filled oven at 200 °C / 15 min. Highly filled separators displayed excellent integrity at these conditions
  - Low separator shrinkage achieved at 200 °C



Before 200 °C test



After 200 °C test

Filler loading
A>B>C

Thermal shrinkage
C>B>A

Future work

- Continue pilot plant investigation of fillers that are identified as stable in Li-ion environment
  - Achieve optimum separator properties through material(s) selection
  - Characterization of separator properties
- Scale up to commercial production line
  - Define material and processing parameters
  - Target thickness of 20 microns
  - Complete physical, microstructural, and electrochemical characterization of separators
  - Provide samples to USABC battery partners
  - Improve formulation based on performance feedback from battery manufacturers

Summary

- Separators containing > 50 wt % inorganic filler were produced in pilot plant studies
- Samples had excellent flexibility and strength. No particle shedding observed even at higher filler loading levels
- Initial characterization of separator physical, mechanical, and electrochemical properties completed
- Entek's new experimental separators exhibited good mechanical integrity after 200 °C oven test

DEVELOPMENT OF A HIGH-TEMPERATURE BATTERY SEPARATOR

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Project ID # es_08_tataria

Lead Acid Batteries	Lithium Batteries	Medical Membranes	Liquid Degassing
Industrial	Derma Patches	Dialysis	O2 Removal
Specialty	Gas diffusion	Oxygenation	CO2 Removal
	Food packaging	Plasma Separation	Semiconductors
	Specialty	Food & Beverage	Power generation
		Industrial	Pharmaceutical
			Photographic
			Food & Beverage
			Ink Processing

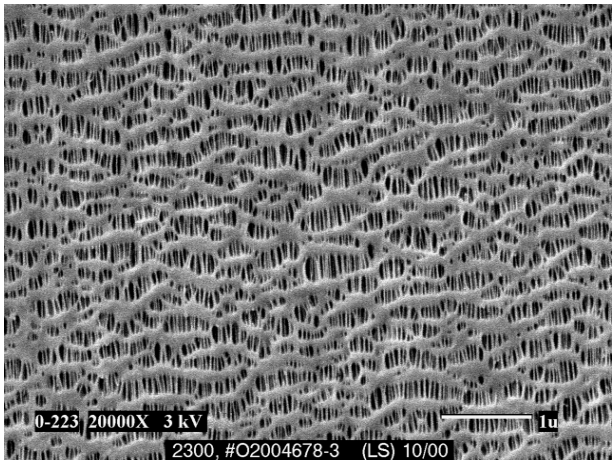
World-class Microporous Membrane Processing Technologies

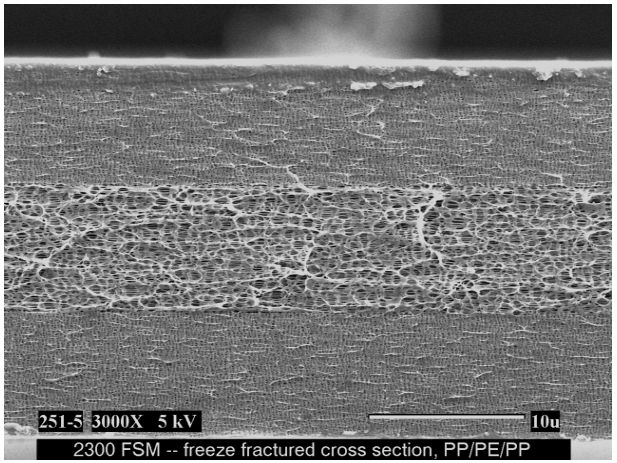
POLYPORE INTERNATIONAL, INC.

Strategically located facilities and service offices throughout the world

*** Indicates technical center in addition to manufacturing facility**

Functions of a battery separator





Battery separators are microporous membranes that:

- Provide separation of the anode and cathode
- Allow for ionic conductivity
- Are a reservoir for electrolytes

Overview

Timeline

- Start – September 2008
- Finish – March 2010
- Percent complete – 20 %

Barriers

- Meeting (HTMI) High temperature Melt Integrity 220 °C
- Lack of testing standards

Budget

- Total project funding
  - DOE share - $ 1.03 mil
  - Celgard share - $ 1.27 mil
- Funding received in FY2008 - $370,921
- Funding for FY 2009 - $1,425,659

Objectives

- **Develop a standard for evaluating HTMI in lithium battery separators**
- **Design and develop a product that meets the criteria of HTMI at 220 C.**

Milestones

- **Hand samples with HTMI of 220 °C**
- **Internal cell testing**
- **Establishment of correlation between performance tests and film properties**

Approach
Developing a Standard

Develop a standard For HTMI

- Industry Standardized Testing
- Product Characteristics

Correlate film tests to battery performance

- **High Temperature Stability**
- **Mechanical Integrity**

Film tests for properties of HTMI

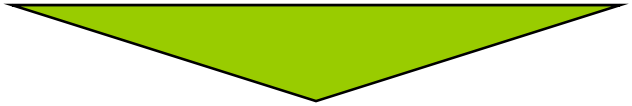
- Shrinkage
- Z Direction Strength
- High Temperature Stability

Baseline of existing products

- Array of Technologies
- Commercially available

Technical Accomplishment

Characteristic	Leading Performance
Shrinkage (MD/TD)	(Dry Stretch Trilayer)/(Dry Stretch Trilayer)
Z Direction Stability	*Dry Stretch Trilayer
High Temperature Stability	Dry Stretch PP



Results to date have reflected the advantages of polypropylene

*Normalizing for design characteristics levels the performance between the sampled population

Future Work

- Analysis:
  - Cell testing
    - Mechanical Tests
    - High Temperature Tests
  - Correlation study of film characteristics vs. battery performance
- Material Development
  - Several Approaches under review

Summary

- The battery industry is seeing a shift toward high standards and design requirements for battery separators.
- Driven mainly by the requirements of large format batteries.
  - High Rate Capability
  - High Temperature Capability
  - Long Term Stability
- Numerous solutions have been presented in the market place.
  - No consistent measurement requirements have been determined by the industry
  - No consistent approach has been determined to meet the customer goals of HTMI
- Celgard is evaluating several methods for HTMI
- Development efforts are in early stages
- More to come at next year's meeting