Economical High Performance Thermoplastic Composite Bipolar Plates

2006 DOE Hydrogen Program Merit Review

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NanoSonic, Inc.
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This presentation does not contain any proprietary or confidential information
Overview

Timeline
Start – May 2005
End – March 2006 (Phase II submitted)
Phase I 100% complete

Budget
Total project funding
- Fuel cell stack components $32.5M
- Total H₂ & FC $169.5M
Phase I funding - $100k

Barriers Addressed
- Bipolar plate/fuel cell cost
- Durability
  - Operating temperature range
  - Mechanical strength
  - High electrical conductivity
  - Low permeability

Bipolar Plate Targets:
$10/kW, >59 MPa, >100 S/cm

Partners
STTR partner: Virginia Tech
Corporate: Lockheed Martin
Objectives

OVERALL: Develop materials and processes to fabricate high performance bipolar plates that meet DoE performance metrics with a cost below $10/kW (below $6/kW by 2010)

Phase I (2005-2006)
- Fabricate bipolar plates using novel wet-lay materials
- Demonstrate superior performance metrics
- Preliminary process modeling for processing time/cost estimates

Phase II (Proposed 2006-2008)
- Downselect best material compositions
- Semi-continuous bipolar plate fabrication
- Full scale bipolar plate production cost analysis
- Fuel cell device integration, including hybrid system development
Approach

**APPROACH: Novel wet-lay composite material suitable for compression molding**

Wet-lay processing facilitates material integration unlike any other process:
- Superior mechanical properties with high filler loading levels
- Reinforcement/matrix orientation
- Low-cost, environmentally friendly, fast processing times

**Phase I Technical Feasibility Assessment**

- Wet-lay material fabrication
- Multiple compositions
- Batch bipolar plate fabrication
- Performance characterization
- Process modeling
- Time/cost estimates
Technical Accomplishments
Phase I Results

Novel wet-lay composites and associated bipolar plate processing have shown superior performance compared to other technologies:

[DoE targets in brackets]

- High flexural strength 96 MPa [target 59 MPa]
- High tensile strength 57 MPa [target 41 MPa]
- Low gas permeability, estimated \(\sim 10^{-8} \text{ cm}^3/\text{cm}^2/\text{s} \) [\(<2\times10^{-6}\)]
- High conductivity, up to 271 S/cm [\(>100 \text{ S/cm}\)]
- Rapidly moldable, no machining required
- Short processing times, projected <2 minutes/plate (TBD Phase II) – current state of the art thermoset at 8 minutes/plate
- Low materials cost (Cost/plate area TBD Phase II)
## Comparison of NanoSonic/Virginia Tech Bipolar Plates to Other Technologies

<table>
<thead>
<tr>
<th></th>
<th>Carbon composite</th>
<th>POCO graphite</th>
<th>Vinyl Ester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>chemical vapor infusion</td>
<td>poor mechanical properties</td>
<td>require endplates, cannot handle clamping pressures</td>
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<tr>
<td></td>
<td>expensive processing</td>
<td>high machining costs</td>
<td>current state-of-the-art</td>
</tr>
<tr>
<td></td>
<td></td>
<td>subject to corrosion</td>
<td>~8 minutes to fabricate plate</td>
</tr>
<tr>
<td>Ticona LCP</td>
<td>no reported properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LCP materials are generally brittle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;85% filled = questionable mechanical properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NanoSonic/VT Thermoplastic Composite</td>
<td><strong>advantages</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>high mechanical strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>no endplates required .. can be directly clamped</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>lightweight</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>no machining required</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>inexpensive manufacturing method</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>&lt; 5 minutes per plate, with potential for ~1-2 minutes</td>
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<tr>
<td></td>
<td>high chemical &amp; corrosion resistance</td>
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</tbody>
</table>
Comparison of NanoSonic/Virginia Tech Bipolar Plates to Other Technologies

Polymer matrix composite bipolar plate comparisons

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Polymer</th>
<th>% Graphite + Fibers</th>
<th>Conductivity (S/cm)</th>
<th>Mechanical Strength</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>In-plane</td>
<td>Through-plane</td>
<td>Tensile (MPa)</td>
<td>Flexural (MPa)</td>
<td>Impact (ft-lb/in)</td>
</tr>
<tr>
<td>GE</td>
<td>PVDF</td>
<td>74</td>
<td>119</td>
<td></td>
<td>36.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>PVDF</td>
<td>64 + 16 CF</td>
<td>109</td>
<td></td>
<td>42.7</td>
<td></td>
<td></td>
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<tr>
<td>LANL</td>
<td>Vinyl Ester</td>
<td>68</td>
<td>60</td>
<td></td>
<td>23.4</td>
<td>29.6</td>
<td></td>
</tr>
<tr>
<td>Premix</td>
<td>Vinyl Ester</td>
<td>68</td>
<td>85</td>
<td></td>
<td>24.1</td>
<td>28.2</td>
<td></td>
</tr>
<tr>
<td>BMC</td>
<td>Vinyl Ester</td>
<td>69</td>
<td>30</td>
<td></td>
<td>26.2</td>
<td>37.9</td>
<td></td>
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<tr>
<td>Commercial</td>
<td></td>
<td>105</td>
<td></td>
<td></td>
<td>19.3</td>
<td>20.7</td>
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<tr>
<td>BMC 940</td>
<td>Vinyl Ester</td>
<td>100</td>
<td>50</td>
<td></td>
<td>30.3</td>
<td>40.0</td>
<td>0.30</td>
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<tr>
<td>Plug Power</td>
<td>Vinyl Ester</td>
<td>68</td>
<td>55</td>
<td>20</td>
<td>26.2</td>
<td>40.0</td>
<td>0.30</td>
</tr>
<tr>
<td>DuPont</td>
<td>Vinyl Ester</td>
<td>100</td>
<td>25-33</td>
<td></td>
<td>25.1</td>
<td>53.1</td>
<td>0.14</td>
</tr>
<tr>
<td>SGL</td>
<td></td>
<td>100</td>
<td>20</td>
<td></td>
<td>40.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂Economy</td>
<td></td>
<td>67</td>
<td></td>
<td></td>
<td>29.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia Tech</td>
<td>PET</td>
<td>65 + 7 GF</td>
<td>230</td>
<td>18-25</td>
<td>36.5</td>
<td>53.0</td>
<td></td>
</tr>
<tr>
<td>This work(VT)</td>
<td>PPS</td>
<td>70 + 6 CF</td>
<td>271</td>
<td>19</td>
<td>57.5</td>
<td>95.8</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Note: Process modifications have resulted in through-plane conductivities up to 209 S/cm on NanoSonic/VT materials
Technical Accomplishments
Wet-lay Composite Continuous Fabrication

Demonstrated continuous manufacturing capability of wet-lay composites
Polyphenylenesulfide, polyethylene terephthalate, polyvinylidene fluoride
Technical Accomplishments
Batch Bipolar/Monopolar Plate Fabrication

Specially designed molds
Plus wet-lay materials

Compression mold (stamping)
Well-defined heat/cool cycle

Molded bipolar plate
High feature resolution
Technical Accomplishments

Mechanical Strength Evaluation

Flexural and Tensile Strength

Impact Strength

<table>
<thead>
<tr>
<th>Strength (MPa)</th>
<th>Modulus (GPa)</th>
<th>Maximum Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>Std Deviation</td>
<td>Average</td>
</tr>
<tr>
<td>95.84</td>
<td>4.24</td>
<td>12.65</td>
</tr>
</tbody>
</table>

Tensile Strength : 57.5 MPa

Mechanical strength far exceeds DoE targets
Technical Accomplishments
Electrical Conductivity/Resistivity Performance

Through-plane conductivity

- In plane conductivity 271 S/cm far exceeds DoE target (100 S/cm)
- Modified processing has resulted in through plane cond. of 209 S/cm
Technical Accomplishments
Permeability Estimates

Van Krevelen Permeability Analysis

\[ P = D S \]

\[ D = D_o \exp \left( -\frac{E_D}{R g T} \right) \]
\[ \log D_o = \frac{E_D \times 10^{-3}}{R g} - 5.0 \]
\[ 10^{-3} \frac{E_D}{R g} = \left( \frac{\sigma_s}{\sigma_{N_2}} \right)^2 \left[ 7.5 - 2.5 \times 10^{-4} \left( T_g - 298 \right)^{3/2} \right] \]
\[ S = S_o \exp \left( -\frac{\Delta H_s}{R g T} \right) \]
\[ \log S_o = -6.65 - 0.005 \frac{\varepsilon}{k} \]
\[ 10^{-3} \frac{\Delta H_s}{R g} = 0.5 - 0.01 \frac{\varepsilon}{k} \]

For \( H_2 @ 3\text{atm}, 80^\circ\text{C}, P \approx 1.2-2.5 \times 10^{-8} \text{ cm}^3/\text{cm}^2\text{s} \)
Far exceeding DoE target of \( 2 \times 10^{-6} \text{ cm}^3/\text{cm}^2\text{s} \)
Polyphenylenesulfide based plates developed here performed comparably to POCO graphite plates.
Technical Accomplishments
Cost/Process Model Development

Bipolar plate cost primarily dictated by processing time
Heating/cooling cycle of the stamping process

Two heating mechanisms modeled during Phase I for continuous mfg.

Radiation Heating

- 47 second heating cycled
- Total estimated process time <2 min.

Induction Heating

- 10 second heating time for 7 kW heater
- Total estimated process time 30-60 s
Future Work
Phase II Work Plan (FY06 - FY08)

• Downselect most appropriate material composition
  - Investigate PVDF/PPS skin/core bipolar plates
• Semi-continuous bipolar plate fabrication
  - Experimentally compare radiation and induction heating to Phase I model estimates
  - Cost analysis
• Fuel cell integration
  - Performance comparison to current “baseline” bipolar plates
  - Hybrid fuel cell system development
  - Test platform integration, both in-house and with corporate collaborators, to practically evaluate:
    - Durability
    - Weight savings
    - Performance
Project Summary

Relevance: Identification of low cost, high-performance bipolar plate materials and fabrication processes.

Approach: Compression molding, or stamping, of wet-lay thermoplastic composite material mats.

Technical Progress and Accomplishments: Proposed bipolar plate technology has exceeded DoE performance requirements, and requires significantly lower estimated processing energy and time compared to current state-of-the-art, corresponding to significantly reduced total cost.

Collaborations: NanoSonic and Virginia Tech have teamed to develop the technology. NanoSonic has active collaboration with Lockheed Martin and other Fortune 500 collaborators for design input, platform insertion, marketing, and commercialization.

Proposed Future Work: Continuous bipolar plate manufacturing for cost analysis. Fuel cell integration for performance characterization compared to “baseline” and current state-of-the-art bipolar plate technologies.