Improved Organics for Power Electronics and Electric Motors

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2011 Vehicle Technologies Annual Merit Review
and Peer Evaluation Meeting
Arlington, VA
11 May 2011

Project ID #: PM037

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Overview

Timeline
• Project start: October 2010
• Project end: September 2013
• Percent complete: 16%

Budget
• Total project funding
  – DOE 100%
• FY11: $250k
• FY12: $250k
• FY13: $250k

Barriers*
• Barriers Addressed
  – Reliability and lifetime of power electronic devices (PEDs) degrade rapidly with temperature increase.
  – PEDs need improved thermal management to operate at higher temperatures.
  – New paradigms in cooling would enable achievement of higher power densities without compromise to device reliability.
• Targets:
  – DOE VTP* 2020 target: 105°C Coolant
  – DOE VTP* 2020 target: 4 kW/liter power density

Partners
• NTRC – ORNL
• Mossey Creek Enterprises

* VTP Multi-Year Program Plan 2011-2015
Objectives

- Identify and develop lower-cost and better-performing organic compounds for dielectric and thermal management applications in power electronics, electric motors, and film capacitors.

- Reduce volume and improve thermal reliability of power electronics, electric motors, and film capacitors through improved thermal management strategies.
Milestones

- FY11 - 1: Establish baselines by measuring thermal properties of unused and serviced organic molding compounds from power electronic devices, electric motors, and film capacitors.

- FY11 - 2: Develop test methods that representatively thermal cycle organics for laboratory tests and subsequent characterization.
Technical Approach

- Harvest *unused* organic dielectric materials from power electronic devices, electric motors, and film capacitors for thermal property testing (thermal diffusivity, thermal conductivity, and heat capacity).

- Harvest *used* organic dielectric materials from power electronic devices, electric motors, and film capacitors for thermal property testing. Compare with thermal responses of unused materials.

- Develop test fixtures for in-situ thermal property testing.

- Develop organic materials (e.g., epoxy molding compounds) with improved thermal properties, ease of processing, and sustained low cost.
Technical Accomplishments (1 of 3)

- Literature survey (particle size distribution, percolation limit)
- Surveyed candidate ceramic fillers (electrical insulators) having high thermal conductivities.
- Attrition mill undergoing refurbishment
- Molds procured for casting organic or epoxy molded compounds (EMCs)
- Particle size distribution measurement system procured
- Transient finite element model developed for use analyzing thermal conductivity of EMCs
- Electrical resistivity and dielectric breakdown test systems undergoing development
Technical Accomplishments (2 of 3)

Epoxy molding compound with a ceramic filler used in a power electronic module from a hybrid vehicle’s inverter

Traditional fillers are electrically insulative, have a low thermal conductivity, and are cheap.

Particle size distribution and volume fraction solids must be controlled.

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## Technical Accomplishments (3 of 3)

### Potential ceramic fillers for EMCs

<table>
<thead>
<tr>
<th>Material</th>
<th>Electrical Resistivity at 25°C (Ω•cm)</th>
<th>Thermal Conductivity at 25°C - κ - (W/m•K)</th>
<th>Heat Capacity - Cp - (J/kg•K)</th>
<th>Density - ρ - (kg/m³)</th>
<th>Coefficient of Thermal Expansion - CTE - (x 10⁻⁶/°C)</th>
<th>Estimated Cost ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica silicon dioxide (SiO₂)</td>
<td>&gt; 10¹⁴</td>
<td>2</td>
<td>700</td>
<td>2600</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Alumina aluminum oxide (Al₂O₃)</td>
<td>&gt; 10¹⁴</td>
<td>30</td>
<td>900</td>
<td>3900</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Magnesia magnesium oxide (MgO)</td>
<td>&gt; 10¹⁴</td>
<td>40</td>
<td>900</td>
<td>3600</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Silicon carbide (SiC)</td>
<td>&gt; 10¹⁴</td>
<td>120</td>
<td>800</td>
<td>3100</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Aluminum nitride (AlN)</td>
<td>&gt; 10¹⁴</td>
<td>250</td>
<td>700</td>
<td>3200</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>Beryllia beryllium oxide (BeO)</td>
<td>&gt; 10¹⁴</td>
<td>280</td>
<td>600</td>
<td>2900</td>
<td>9</td>
<td>800</td>
</tr>
<tr>
<td>Epoxy</td>
<td>&gt; 10¹²</td>
<td>0.05 - 0.1</td>
<td>1500</td>
<td>1200</td>
<td>30-60</td>
<td>5</td>
</tr>
</tbody>
</table>
Future Work

- Thermally and microstructurally characterize unused and used molding compounds from power electronic devices, electric motors, and film capacitors.
- Model thermal conductivity of EMCs with fillers as a function of volume fraction, particle size distribution, and percolation limit.
- Relate attrition milling conditions to produced particle size distribution.
- Complete electrical resistivity and dielectric breakdown test setups.
Summary

- Identifying and developing lower-cost and better-performing organic compounds for dielectric and thermal management applications in power electronics, electric motors, and film capacitors.

- Comparing epoxy molding compounds (EMCs) of unused and used components through thermal and microstructural characterization.

- Developing new EMCs with high thermal conductivity, that have predictable and simple processing characteristics, and are inexpensive.