ADVANCED MATERIALS FOR LED LIGHTING

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What Will the Products of the Future Look Like?

• New Form Factors
• Smaller Volumetrically / Lighter Weight
  – With Illumination Performance Improvements; Brightness Control, etc.
• Less LED Material at Higher Power???
• More LED Material at Lower Power???
  – Cheaper and Better LEDs
  – Less Heat…
• More Housing Material Options
  – Plastics… Low Environmental Impact Options
• As Close to One Highly Reliable Circuit Board as Possible
  – Fully Populated for all Possible Functionality (Less SKUs)
    • Programed at Factory or During Installation (Commissioning)
  – Populated as Needed (More SKUs, More Inventory Challenges)
Component and Process Consolidation for Greater Overall Value

- Fewer Electronic Components and Circuit Boards
- Fewer Manufacturing Process Steps and Associated Risk (Higher Reliability)
- Full Function Solutions With Flexibility to Configure/Reconfigure as Needed (programmable?)
- Higher Energy Performance Possibilities
- Less Electrical Compatibility Conflicts
- Lowest Average Product Cost
- Greater Possibilities for Highly Reliable Solutions

Do they need to be "serviceable"???
Overcoming Resistance to the “Non-Serviceable” Solution

- High Reliability
- Long Warranty Periods
- Acceptance of Non-traditional Form-factors
- Acceptance of Non-traditional Materials and Manufacturing Processes
- Etc…
Cost Breakdown for Various LED Solutions

- Outdoor Area: 5% Overhead, 40% Mech/Thermal, 20% LED Package, 20% Optics
- Interior 6” Downlight: 30% Overhead, 33% Assembly, 5% Driver, 5% Optics
- A19 Replacement: 30% Overhead, 35% Assembly, 10% Driver, 5% Optics

We Need to Shrink All Remaining Costs

Cost Per Delivered Performance Continues to Shrink

Data source: DOE R&D Manufacturing Roadmap, September 2013
Luminaire Housing Materials
Challenges and Opportunities

What would the ultimate material look like?

- Manufacturability
- Durability
- Safety / Compliance
- Cost
- Etc…

- All of the Good Properties and None of the Bad
  - Aluminum
  - Engineered Plastic Composites
  - Steel
  - ABS
  - Etc…

We Need to Shrink All Remaining Costs

- Overhead
- Assembly
- Driver
- Mech/Thermal
- Optics
- LED Package
Optical Materials
Challenges and Opportunities

What would the ultimate material look like?

• Manufacturability
• Durability
• Optical Properties
• Safety Compliance
• Cost
• Etc…

• All of the Good Properties and None of the Bad
  – Acrylic
  – Polycarbonate
  – Glass
  – Silicone
  – ABS
  – Etc…
  • “Printable” optics?

We Need to Shrink All Remaining Costs

- Overhead
- Assembly
- Driver
- Mech/Thermal
- Optics
- LED Package
Packaged LED Value Evolution

Annual Improvement in $/lm @ 100 LPW

<table>
<thead>
<tr>
<th>Year</th>
<th>Improvement</th>
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<tbody>
<tr>
<td>2005</td>
<td>43%</td>
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<tr>
<td>2006</td>
<td>45%</td>
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<td>2007</td>
<td>35%</td>
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<tr>
<td>2008</td>
<td>29%</td>
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<td>2009</td>
<td>45%</td>
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<td>2010</td>
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<tr>
<td>2011</td>
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<tr>
<td>2013</td>
<td></td>
</tr>
<tr>
<td>2014</td>
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Different Die and Package, Same Performance

96% Reduction in Size (volume)
Example of the Cost Impact of Increasing LED Performance

2007
- 42 LEDs
- 650 lm
- 12W

$>100 Commercial Wholesale

2011
- 8 LEDs
- 650 lm
- 9.5W

$19.97 Retail
$39.97

The same thing is happening in other segments of LED lighting
Material Use Optimization

Aluminum Heat-sink/Housing

Plastic Housing

Aluminum Trim

Aluminum Heat-sink/Trim
Thermal Management Value Opportunities Have Changed

Extruded Aluminum
Thermal Conductivity = ~250 W/m-K
Thermal Management

More LEDs With Same Total Power…

More Light…

Less Heat…

Less Energy…

More Cost???
Multi-Die Packages
Die Cast Aluminum
Thermal Conductivity = ~125 W/m-K
Metals to Engineered Composites

Automotive Examples
Automotive Application Examples

- ECU Enclosures
  - Electric Motor Brush Holders, Armatures, Housings
- Engine Heat Shield/Beauty Covers
- Cylinder Head Covers
- Electronic Throttle Bodies
- Thermostat Housings
- Head Lamp Reflectors
- Vacuum Pump Housing
- Engine Front/Rear Covers
- Cooling Pump Housing
  - Oil Pump Housing
  - Oil Filter Housing
- Turbo Systems
- Spoilers, Air Vents
- Capless Fuel Filler
- Fuel Pumps
- Under Body Heat Shields
- Body Structural Inserts
- Transmission Sump Pan
- Transmission Thrust Washers
- Transmission Valve Body
- Transmission Linkage
- Starter End Cap
- Oil Sump/Pan

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Environmental Impact

*Energy Content*

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<th>Material</th>
<th>MJ/Kg of Material</th>
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<tr>
<td>BMC</td>
<td>40</td>
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<tr>
<td>Polyethylene</td>
<td>70</td>
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<td>Polypropylene</td>
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<tr>
<td>Copper</td>
<td>450</td>
</tr>
<tr>
<td>Aluminum</td>
<td>600</td>
</tr>
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1 Megajoule (MJ) = ~1/4 Kilowatt-hour (kWh)

*Engineered Composite Bulk Molding Compound (BMC) Example*

- Inherently Low Energy Content
  - Requires Less Energy to Produce / Process Than Other Materials
- Recyclable as Filler into Virgin BMC or Other Applications

*Embedded Energy*

Aluminum = 15X BMC

*The non-renewable energy required to produce a unit of finished material.*
Hybrid Luminaire Housing

Heat Sink
Thermal Conductivity = ~250 W/m-K

Housing
(Engineered Composite)
Thermal Conductivity = ~25 W/m-K
Non-Metallic Engineered Composites

- **Possible Advantages**
  - Durability
    - Corrosion Resistance
    - UV Resistance
    - Mechanical Vibration and Shock
  
  Molded in Color (no secondary painting required)
  - Long Life Color Retention

  High Strength-to-Weight Ratio
  - Comparably Lighter Weight Products
    - Installation Benefits
    - Lower Shipping Costs
  - Generally Higher Resistance to Brittle Fractures Compared to Aluminum and Other Materials

Non-Metallic
- Electrical Insulating Properties (safety… ground fault protection, etc…)

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Optics
Optical Coupling and Extraction

• Total Internal Reflection (TIR) Example
Simple Extraction

Roughen / Diffuse to Extract and Distribute Light
Simple Waveguides

• Core Technology from Display Backlighting
• Optical Coupling Losses
• Often Requires Addition of Reflectors, Etc…, to Recycle Light Not Efficiently Extracted
• Usually Around 80% Optical Efficiency
• Typically Limited Optical Control Possibilities

Typical “Simple” Waveguide:

1) Room-Side Diffuser
2) Side Reflectors
3) Waveguide
4) Back Reflector
Maximizing Optical Coupling

The coupling surface is designed to maximize the amount of light entering the wave guide from the source.
Precise Light Extraction Features

Transmitted

Reflected
&
Transmitted
Features Can Be Very Small

Minimum feature size required is approximately 80 microns

$$80\mu \approx 0.003 \text{ in}$$

Maximum allowable surface "roughness"

$$0.0000015 \text{ in}$$
Molding Challenges

Precision, Repeatability, Processing Cost
THANK YOU FOR YOUR KIND ATTENTION

Eric Haugaard
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