New Lighting Concepts

Eric Haugaard
Cree Lighting
February 4, 2016
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?)
• Less Electrical Compatibility Conflicts
• Higher Energy Performance Possibilities
• 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…
Light Source Common Categories

Point is the Most Flexible

All Other Forms can be Reasonably Replicated or Improved
The Early Days of LED Solutions

Spots-and-Dots

Giga-Nits???

Glare
  Discomfort Glare
  Disability Glare
  Annoyance Glare???

Efficiency, Control, Comfort… (Pick 2???)

Solutions Should be Comfortable and Attractive as Well as High Performance
Packaged LED Value Evolution

Efficacy (LPW)

$/lm, normalized (Cool White)

Annual Improvement in $/lm @ 100 LPW

<table>
<thead>
<tr>
<th>Year</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>43%</td>
</tr>
<tr>
<td>2006</td>
<td>45%</td>
</tr>
<tr>
<td>2007</td>
<td>35%</td>
</tr>
<tr>
<td>2008</td>
<td>29%</td>
</tr>
<tr>
<td>2009</td>
<td>45%</td>
</tr>
<tr>
<td>2010</td>
<td>40%</td>
</tr>
<tr>
<td>2011</td>
<td>27%</td>
</tr>
<tr>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
</tr>
</tbody>
</table>
Different Die and Package, Same Performance

96% Reduction in Size (volume)
Wave Guides
Optical Coupling and Extraction

- Total Internal Reflection (TIR) Example
Simple Extraction

Roughen / Diffuse to Extract and Distribute Light
Simple Waveguides

Edge Coupled Side Emission

- 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 (Not All Light is Extracted Before Opposite Edge is Reached)
- 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

Recycled

Reflected & Transmitted
Features Can Be Very Small

Feature size required could be 80 microns

\[ 80\mu = \sim 0.003 \text{ in} \]

Maximum allowable surface “roughness”

\[ 0.0000015 \text{ in} \]
Direct / Indirect Lighting
Ceiling Uniformity Improvement Example

High Performance LED Wave Guide

Edge Coupled Side Emission LED

Specification Grade T5 HO

3:1 Max/Min Illuminance

8:1 Max/Min Illuminance

11:1 Max/Min Illuminance
Material Related Challenges Affecting Waveguide Performance

Better Optical Performance Sometimes Requires Longer Optical Path Lengths

Small Changes in Optical Clarity Can Result in Significant Changes in Optical Performance

“Lighting Grade” Acrylics Have Lower Transmissivity Properties Than Many “Non-Lighting Grade” Acrylics (i.e. PMMA used as Fiber Optic Cable)

Many “Lighting Grade” Acrylics are Formulated to Withstand Heat, UV and Other Elements at Levels Well Beyond What LED Systems Will be Exposed to
Thank you for your Kind attention