HB-LEDs and Solid State Lighting: Challenges and Opportunities

Tom Morrow
Executive Vice President
SEMI
Agenda

• About SEMI
• LEDs and Solid State Lighting
  – Why the excitement?
• Current Market Outlook for LEDs and SSL
• Focus 2020
  – Manufacturing Cost Reduction
  – The Role of Manufacturing Standards in Long-Term Cost Reduction
• Focus 2020
  – Accelerating Consumer Acceptance
About SEMI

• Global industry association
• ~2000 members
• Established in 1970 to serve the semiconductor supply chain
• Today serves members interests in the following industries:
  – Semiconductor
  – Flat Panel Display
  – Photovoltaic/Tech-Energy
  – LEDs
  – MEMS
Current SEMI LED Activities

- **Major Events:**
  - 6th Annual LED Korea, co-located with SEMICON Korea (Feb. 7-9, 2012)
  - China HB LED Manufacturing Forum and Pavilion, SEMICON China (March 20-22)
  - LED/SSL Market Forum, SEMICON Russia, Moscow, (May 15-16, 2012)
  - LED Manufacturing Forum, SEMICON West (July 11, 2002)
  - LED Pavilion and Manufacturing Forum, SEMICON Taiwan (Sept 5-7, 2012)
  - Japan New Technologies Pavilion, LED Symposium, SEMICON Japan (Dec 5-7, 2012)
  - SSL Summit, India (Sept 3-5, 2012)
- Industry Research-Opto/LED Fab Watch and Forecast
- Manufacturing Standards development
- Public Policy
SEMI LED Advisory Committees

North American and Europe
China
India
Korea

Participating Companies (partial list)

- CREE
- EPISTAR
- invenLux
- LG
- LITEON
- Lextar
- PHILIPS
- SAMSUNG
- SEOUL
- AIXTRON
- Veeco
- Applied Materials
- Synopsys
- KLA-Tencor
- EVG
- Ultratech
- Kulicke & Soffa
- M+W Group
- SUSS MicroTec
- mks
- Air Products
- Brewer Science
- GE
- Matheson Tri-Gas
- Dow
- Silian
- Silian Sapphire Corporation
Solid State Lighting: Why the Excitement
Solid State Lighting (SSL)

- Over 1/3 of the electricity for lighting could realistically be saved: nearly 900 billion kWh (OSRAM)
- Japan IEE report estimates Japan electricity consumption can be reduced 9% with LED lighting
- SSL can save by 2025*:
  - 1 billion barrels of oil
  - Reduce the need for 250 nuclear power plants
  - Annual energy savings in US alone of 1.5 Peta ($10^{15}$)W/h
  - Reduce CO$_2$ emissions by 952 metric tons

*Rensselaer Polytechnic Institute, Smart Lighting Center, SSL Summit, 2011*
LED/Solar Lighting Systems

“Renewable Energy based Solid State Lighting is arguably the most important Agent of Change available to the Developing World in the past 100 years!”

Light Up the World

Source: Light Up the World
More Illumination and More Than Illumination

In analogy to “More Moore and more than Moore”

- Efficiency
- Cost reduction
- Miniaturization
- Retrofit
- Form & fixture revolution

Interacting with other systems, people and environment
Non-illumination function
System-in-package (SiP)

More than Illumination: Function Enrichment

Source: Guo Qi Zhang, Philips Lighting
Revolution in Smart Lighting

- Fully integrated systems with sensors and controls
- Any color, any time
- Data with illumination
- Illumination with video
- Pollution and health monitoring
- Biochemical sensing and mitigation
- Circadian corrected lighting
- Adaptive lighting
LEDs and SSL: Where we are today
LED Market Size and Growth

Revenue in Billions

- Strategies Un.
- IMS Research
- GaN LED Only

2009: 5.6
2010: 10.3 (108% growth)
2011: 11.2 (-6% growth)
2012: 13.3

2010: 8.2
2011: 8
2012: 10
LED Market Sizing – Lighting as the Key Driver

Source: DOE, Goldman Sachs
LED Dedicated Fabs
Changing LED Landscape

<table>
<thead>
<tr>
<th>Year (begin operation)</th>
<th>2001</th>
<th>2006</th>
<th>2011 (est)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total count of LED fabs</td>
<td>36</td>
<td>64</td>
<td>142</td>
</tr>
<tr>
<td>Capacity in 4-inch EQs w/m</td>
<td>127,124</td>
<td>376,400</td>
<td>~1,570,000</td>
</tr>
</tbody>
</table>

Source: SEMI Opto/LED Fab Forecast, Nov. 2011
LED Fab Capacity by Region, 2012

Worldwide LED Capacity
2.33M in 2012 (4” equivalent per month)

- Korea 20%
- Japan 20%
- Taiwan 22%
- China 24%
- SE Asia 4%
- Americas 7%
- Europe & ME 3%

Top 10 Pkg LED Suppliers
1. Nichia
2. Samsung LED
3. Osram
4. LG Innotek
5. Seoul Semiconductor
6= Cree*
6= Philips Lumileds*
8. Sharp
9. Toyoda Gosei
10. Everlight

Source: Strategies Unlimited

Source: SEMI Opto/LED Fab Watch Nov. 2011
LED Equipment Spending

In $US Millions

<table>
<thead>
<tr>
<th>Region</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU and Mideast</td>
<td>21</td>
<td>99</td>
<td>60</td>
</tr>
<tr>
<td>SE Asia</td>
<td>31</td>
<td>132</td>
<td>0</td>
</tr>
<tr>
<td>Americas</td>
<td>0</td>
<td>138</td>
<td>167</td>
</tr>
<tr>
<td>China</td>
<td>108</td>
<td>437</td>
<td>719</td>
</tr>
<tr>
<td>Taiwan</td>
<td>110</td>
<td>321</td>
<td>423</td>
</tr>
<tr>
<td>Japan</td>
<td>260</td>
<td>300</td>
<td>482</td>
</tr>
<tr>
<td>Korea</td>
<td>179</td>
<td>2,415</td>
<td>1,969</td>
</tr>
</tbody>
</table>

Source: SEMI Opto/LED Fab Watch Nov. 2011
Market Situation Summary

- Recent market slowdown due to weaker demand for LCD panels and less LEDs per panel:
  - New TV models, and purchasing schedules expected to drive demand pick up from 1Q12 onwards
- 2011 LED ASP decline ~25-40%
- Rapid capacity increase followed by low fab utilization (~50-80%)
- Solid state lighting to become key market driver in 2012 and beyond
- MOCVD shipment is expected to slow down significantly next year after two years of aggressive investment
- Opportunities increasing for larger wafers and non-MOCVD equipment
Challenges to 2020

Manufacturing Cost Reduction

Consumer Acceptance
Cost/Performance History

Typical High Performance 1W Cool White LED Package

Source: Strategies Unlimited, SiL 2012
LED Cost Reduction Roadmap

Manufacturing standards are essential to meet the industry’s long term cost reduction needs
Importance of Manufacturing Standards

**LED Manufacturers**
- Effective global standards allow manufacturers to buy equipment and materials from multiple vendors with minimal adaption

**LED Suppliers**
- Effective global standards allows suppliers to focus on innovation and critical price and performance variables
SEMI Standards

• Standards Development for over 35 years
  • ~1800 standards, 4000 volunteers, 20 Technical Committees and 200 Task Forces
  • Formed HB-LED Standards Committee in November 2010
    • 150 participants
• Current Status
  • Wafer Task Force- 6” Sapphire Wafer Standard in Ballot
  • Factory Automation Task Force
  • Environmental Health & Safety Task Force
  • Sapphire Defects and Impurities Task Force
# Why 6” Wafer Standards?

## Wafer Size and CoO

<table>
<thead>
<tr>
<th>56x2” → 14x4”</th>
<th>56x2” → 8x6”</th>
<th>56x2” → 5x8”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Investment</strong></td>
<td><strong>1. Investment</strong></td>
<td><strong>1. Investment</strong></td>
</tr>
<tr>
<td>♦ Capacity</td>
<td>♦ Capacity</td>
<td>♦ Capacity</td>
</tr>
<tr>
<td>$A = n \cdot \pi \cdot r^2$</td>
<td>$A = n \cdot \pi \cdot r^2$</td>
<td>$A = n \cdot \pi \cdot r^2$</td>
</tr>
<tr>
<td>$A(4”)/A(2”) = 1$</td>
<td>$A(6”)/A(2”) = 1.29$</td>
<td>$A(8”)/A(2”) = 1.43$</td>
</tr>
<tr>
<td>=&gt; same capacity</td>
<td>=&gt; +29% capacity</td>
<td>=&gt; +43% capacity</td>
</tr>
<tr>
<td>♦ with 3mm edge exclusion</td>
<td>♦ with 3mm edge exclusion</td>
<td>♦ with 3mm edge exclusion</td>
</tr>
<tr>
<td>$A = n \cdot \pi \cdot (r-e)^2$</td>
<td>$A = n \cdot \pi \cdot (r-e)^2$</td>
<td>$A = n \cdot \pi \cdot (r-e)^2$</td>
</tr>
<tr>
<td>$A(4”)/A(2”) = 1.14$</td>
<td>$A(6”)/A(2”) = 1.53$</td>
<td>$A(8”)/A(2”) = 1.74$</td>
</tr>
<tr>
<td>=&gt; +14% capacity</td>
<td>=&gt; +53% capacity</td>
<td>=&gt; +74% capacity</td>
</tr>
<tr>
<td>♦ System investment</td>
<td>♦ System investment</td>
<td>♦ System investment</td>
</tr>
<tr>
<td>$$/1.14 = 0.88$</td>
<td>$$/1.53 = 0.65$</td>
<td>$$/1.74 = 0.58$</td>
</tr>
<tr>
<td>=&gt; 88%</td>
<td>=&gt; 65%</td>
<td>=&gt; 58%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>2. Running Cost</strong></th>
<th><strong>2. Running Cost</strong></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$$/1.14 =&gt; 88%</td>
<td>$$/1.53 =&gt; 65%</td>
<td>$$/1.74 =&gt; 58%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assume 150% processing time of 4” compared to 2”:</td>
<td>Assume 200% processing time of 6” compared to 2”:</td>
<td>Assume 250% processing time of 8” compared to 2”:</td>
</tr>
<tr>
<td>$(4^2/1.5)/(2^2/1) = 2.7x$ Throughput</td>
<td>$(6^2/2)/(2^2/1) = 4.5x$ Throughput</td>
<td>$(8^2/2.5)/(2^2/1) = 6.4x$ Throughput</td>
</tr>
</tbody>
</table>

Source: AIXTRON
Substrate Trends

Sapphire Substrates for LEDs: Diameter trends

- % of total surface processed
- 6"
- 4"
- 3"
- 2"

Year: 2008 to 2015

Source: Yole Development
150 mm Wafer Standards

- Critical for factory automation and other standards
- Currently in ballot
- Covers 4 150 mm wafer geometry options
  - Flat and Notched
  - 2 thickness options
- 17 Key Parameters
  - Total Impurity Content
  - Wafer ID Marking
  - Front Surface Condition
  - Edge Surface Condition
  - Back Surface Condition
  - Diameter
  - Fiducial Type
  - Fiducial Dimensions
  - Flat Length
  - Fiducial Notch Depth & Notch Angle
  - Fiducial Orientation
  - Edge Profile Template
  - Thickness, Center Point
  - Total Thickness Variation, Max.
  - Bow and Warp, Max.
  - Inclusions or Bubbles
  - Dislocations
  - Thermal Conductivity Uniformity
Factory Automation Interfaces

- **Critical Requirements:**
  - **Cassette**
    - Open cassette
    - Process tray cassette
  - **Load Port**
  - **Automated tracking**
    - Cassette/wafer
    - Process Tray
  - **Shipping Carrier**

- Ballot Expected Mid Year 2012

- **Cassette Specifications Identified for Industry Standard**
  - Pitch
  - Capacity
  - Loadport coupling
  - Material
  - ID type and location (for automated tracking)
  - Wafer support
  - End effector exclusion
  - First wafer height
  - Pocket volume
  - Windows / open sidewalls
  - Wafer plane
  - Overall dimensions
  - Manual grips
  - Electrical continuity
  - Automated gripping features
  - Wafer orientation features
  - Mapping
Challenges to Market Acceptance

- SSL Lamps are complex systems
- Quality of light is subjective
- Quality of products will vary
- Cost competitiveness in many segments will remain a challenge
- Consumers resist change/complexity
Compact Fluorescent Lighting: Lessons Learned

• Introduced in 1970’s—Market Share 2000: 0.6%
• Early consumer experience generated bad reputation:
  – Too big
  – Buzz and flicker
  – High cost
  – Poor color quality (high CCT, low CRI)
• Marketing Mistakes by fractionated industry
  – Exaggerated life expectancy claims
  – Inconsistent incandescent equivalency claims
  – Inconsistent specifications and terminology
Challenges in Consumer Acceptance

US Department of Energy, Lighting Facts 2011

- 67% of current A4 replacement lamps on market fall below 450 lumens (40W equivalency), 56% fall below acceptable color quality
- Only 2 commercially available LED reflector lamps offer comparable light output than 75W PAR 30 lamp
- LED replacements for 4-ft linear fluorescents produce on average one-half the light output and use more energy
Complex Regulatory/Standards Environment

International Standards Organizations

- IEC
- CSA International
- NEMA
- CIE
- NIST
- Zhaga
- ANSI
- Underwriters Laboratories Inc.
- IEEE

Certifications/Labeling

- CQC
- Lighting Facts
- PSE
- CE
- ENERGY STAR
Summary

• SSL is a new industry with enormous economic potential and environmental benefit

• A 10X improvement in $/klm at the packaged LED level is required to support widespread adoption of solid state lighting

• The majority of this cost reduction will occur through yield, throughput, productivity, and materials cost reduction

• Manufacturing Standards will accelerate cost reduction in packaged LEDs and will become the platform for advanced, automated LED manufacturing in the future

• Consumer labeling, quality certifications, and consumer education just beginning.