Current MOCVD Challenges

• Process
  – Capacity is not enough
  – Improved equipment performance is required

• Integration
  – Testing at the device level is most relevant and critical

• Inflection Points
  – Significant interest in GaN-on-Silicon
  – Standardization of PSS
  – Emerging competition
Technology and Cost Curve: Still A Way to Go

• CoO will continue to drive the demand curve for earlier adoption

• The market appears to be focused on 4” production and can benefit greatly from high-capacity, automated equipment with significant floor-space efficiency

• GaN-Si LED manufacturing:
  – Emerging quickly to leverage significant silicon knowledge and capital
  – Can benefit from a high-yield reactor requiring alternate hardware

![5% of World’s Lighting is LED](image)
DOE Funding Complements Industry Investments to Keep Pace with SSL Roadmap Even In Downturns

- 3.0x increase in CapEx Efficiency
- >2.5x lower Cost of Ownership

2013 R&D >$50M

Epi Capex Efficiency (normalized to wpd/SM)

Cost of Ownership (normalized to $/wafer)

K465i  K465i HT  MaxBright C4  Next Gen C1  Next Gen C2  Roadmap

2010

4” and 6” Wafer Production Will Dominate Market

- 4” and 6” will dominate LED production from 2014
- PSS adoption has slowed transition to larger wafers

Notes: Yole and Veeco estimates.
Leveraging MOCVD Performance

- Improvements & advances in epitaxial growth cascade through the manufacturing & R&D supply chains

<table>
<thead>
<tr>
<th>Brightness</th>
<th>Color</th>
<th>Electrical</th>
<th>Process Control</th>
<th>Capital</th>
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</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Wafer-Level Binning</td>
<td>Driver Integration</td>
<td>Wafer-Level Binning</td>
<td>Epi-Specific Metrology</td>
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<tr>
<td>Vertical vs. Horizontal</td>
<td>Blend Binning</td>
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<tr>
<td>Materials</td>
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<td>CoO</td>
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<tr>
<td>Substrates</td>
<td></td>
<td></td>
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<td>Silicon-Based 200mm Reuse</td>
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</tbody>
</table>
MOCVD Enables Aggressive Chip Cost Reduction

<table>
<thead>
<tr>
<th>Description</th>
<th>4” Sapphire Production</th>
<th>Next-Gen GaN:Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Brightness (lm/mm²)</td>
<td>100%</td>
<td>92%</td>
</tr>
<tr>
<td>Chip Yield (lm/mm², V_f)</td>
<td>75%</td>
<td>85%</td>
</tr>
<tr>
<td>Wafer Mean Wavelength Yield (5 nm bin)</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>WiW Wavelength Yield (5 nm bin)</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Relative Chip Cost ($/lm)</td>
<td>100%</td>
<td>76%</td>
</tr>
</tbody>
</table>

Continued DOE funding can accelerate disruptive Next-Gen MOCVD GaN-on-Si technologies for >20% cost reduction of medium power SSL chips to stay ahead of current and emerging Chinese competition.
A Model of DOE-Funded Success

**Fund Key Manufacturing Enablers**
- Leverage EPI CoO
- GaN:Si Capital Reuse

**Encourage Collaboration**
- Close cooperation within SSL food chain
- Materials – OEM
- Analytical – Fab

**Rapid Prototype Pilot Production**
- Reduce barriers to testing new process equipment

Focused strategy to accelerate low-cost commercialization
MOCVD Success Supported by DOE

- Created high-tech U.S. manufacturing jobs
- Increased U.S. competitiveness
- Accelerated the LED roadmap

MaxBright MHP (2012)
- ↑ 20% WiW Uniformity
- ↓ Cost of Ownership

K465i (2010)
- Improved Flow Uniformity
- Improved Serviceability

MaxBright (2011)
- ↑ 5x Productivity
- ↑ Footprint Efficiency

K465

Market Share

2007 2008 2009 2010 2011 2012 .... Long-term

24% 29% 44% 51% 62%