How to Make Manufacturing of LEDs Truly GREEN

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Overview

- Progression in Lighting Sources
- Typical HBLED Device Structure
- Current HBLED Manufacturing Process
- Precursors – TMG & Ammonia
- Ammonia in LED Manufacturing
- Issues: Ammonia Production & Purification
- Atomic Precision’s Solutions
- Novel Reactor
- Alternative to Ammonia
Lighting Sources

- 60W, 1.5 Yrs, $1.0
- 15W, 3Yrs, $3.0
- 5W, 20Yrs, $15
HBLEDs - Current Applications
HBLED Device Structure

Device Layers

- Buffer GaN (4 to 6 µ)
- n-GaN & p-GaN (2 µ)
- InGaN: In & Ga % varies
- MQW: Quantum Wells
- Total stack: 8 – 10 µ
Current MOCVD Tool Configurations

Vendor - A
- Turbo-Disk; MO + Hydride
- 3-inch x 24 Wafer Capacity

Vendor - B
- Planetary Motion of Wafer
- 3-inch 24 Wafers
- Compact Design
MOCVD: Current Thin Film Process

\[
\text{Ga(CH}_3\text{)}_3 + \text{NH}_3 \rightarrow \text{GaN} + 3 \text{CH}_4
\]

- Process Temp. = 900 – 1,000 °C
- Chamber Pressure = x 100 mT
- Deposition Rate ~ 2 micron/h.
- Rigorous “O” Exclusion Required
- \( \text{H}_2 \) Added to Gas Mixture
- \( \text{GaN} + \text{H}_2 \leftrightarrow \text{Ga} + \text{NH}_3 \)
- Ammonia added to “Reverse” GaN decomposition
- Typical Ammonia Flow Rate ~ 50 slpm
- Typical “Batch” Process Time ~ 5 h.
Volume of Ammonia Required

\[ \text{Volume of Ammonia Required} = 0.6 \times 50 \text{ slpm} \times 60 \text{ min/h} \times 24 \text{ h/day} \times 365 \text{ days/year} \]

\[ = 15,768,000 \text{ Liters/year/Tool} \]

@ 60% Tool Uptime!

Hundreds of Tools Worldwide!
Industrial Ammonia Production

A Flow Scheme of Haber Process

Energy consumed in $N_2$ separation and $H_2$ generation
## HBLED Mfg: Required Ammonia Purity

<table>
<thead>
<tr>
<th>Spec Gas Supplier</th>
<th>Total Purity %</th>
<th>H2O ppb</th>
<th>O2 ppb</th>
<th>CO ppb</th>
<th>CO2 ppb</th>
<th>Total ppb oxygen compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Grade</td>
<td>99.99999</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>71</td>
</tr>
<tr>
<td>B</td>
<td>99.99999</td>
<td>60</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>C</td>
<td>99.99997</td>
<td>5</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>135</td>
</tr>
<tr>
<td>D</td>
<td>99.99995</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

Ammonia Supply in Manufacturing

Issues in Ammonia Supply

- Ammonia is a refrigerant
- During transport cools on expansion
- Couplings, elastomer seals freeze → icing
- Couplings, seals loosen when frozen
- Strong possibility for Re-entry of all “O”s
- Must be “Re-purified” before entry into MOCVD
- Additional cost and energy expended
Solutions by Atomic Precision

1. Novel High-speed Reactor
2. Ammonia Free chemistry
3. Substitute for Ga(CH$_3$)$_3$
1. Novel High-speed Reactor

- Linear Injectors w/ Apertures
- Rapid Uniform Coverage
- ALD & CVD in One Chamber
- Thin & Thick Films
- Chemistry Flexibility

Prasad N. Gadgil, US Patent No. 6,812,157
2. Ammonia FREE Chemistry

\[ \text{Plasma} \rightarrow \text{NH}_x \]

\[ x = 1, 2, 3 \]
Ammonia FREE Chemistry

Low Volume Linear MW Plasma Applicator

\[ \text{N}_2 + \text{H}_2 \]

WR340
Quartz Window
Ceramic Plate

\[ \text{NH}_x \]

\[ \text{N}_2 \]
\[ \text{H}_2 \]
Replace Ga(CH₃)₃ by GaCl₃

<table>
<thead>
<tr>
<th></th>
<th>TMG</th>
<th>GaCl₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>Liquid</td>
<td>Solid</td>
</tr>
<tr>
<td>m. p. (°C)</td>
<td>-15.8</td>
<td>78</td>
</tr>
<tr>
<td>b. p. (°C)</td>
<td>55.7</td>
<td>201.3</td>
</tr>
<tr>
<td>Cost ($/g)</td>
<td>20*</td>
<td>&lt; 1.0 §</td>
</tr>
</tbody>
</table>

• * and §: Estimated bulk cost
• GaCl₃ can be molten and added via a linear injector
C&F GaN System – Atomic Precision
GaN: n&k Analysis

$N_2 = 25$ sccm, $H_2 = 75$ sccm, $500 \, ^\circ C$, $700 \, mT$, $500 \, W$ MW
## Advantage – Atomic Precision

<table>
<thead>
<tr>
<th>HBLED Production Technology - Factors</th>
<th>(MOCVD)</th>
<th>Atomic Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Cost (per g)</td>
<td>10</td>
<td>1x</td>
</tr>
<tr>
<td>Chemical Utilization Efficiency</td>
<td>~ 25 %</td>
<td>&gt; 80%</td>
</tr>
<tr>
<td>Film Deposition Rate</td>
<td>~ 2 μ/h</td>
<td>~20 μ/h</td>
</tr>
<tr>
<td>Undesirable “C” in Film</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Process Automation Potential</td>
<td>Marginal</td>
<td>Full</td>
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<tr>
<td>Product Yield</td>
<td>&lt; 60%</td>
<td>N/A</td>
</tr>
<tr>
<td>Product Cost</td>
<td>10x</td>
<td>1x</td>
</tr>
</tbody>
</table>

†: Estimated.
Summary

✓ Enabling Equipment & Process Technology
✓ HBLED Cost Reduction by approx. 90%
✓ Environmentally Clean and GREEN Process

Thank You!