The Impact of China’s Rising LED Industry on Global LED Manufacturing and SSL Adoption

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2016 DOE R&D Workshop
• Overview of China LED industry

• Impact of China’s rising LED industry on global SSL industry and LED adoption

• Sanan and its global reach strategy
Status of China LED Industry

- China LED industry is going through a technology upgrade similar to other high tech industries
- The technology gap between Chinese LED companies and the rest of the world has shrunk dramatically
- Strong companies in SSL supply chain have emerged
- Adoption of SSL in China is faster than the rest of the world
- The rise of Chinese LED industry has impacted global SSL industry in a profound way
  - Supplying LEDs and driving volume growth for general lighting
  - Driving cost down faster than experts have predicted
  - Causing profit margin erosion in the industry
  - Forcing some players to change business models or exit
  - Benefiting end users
  - Accelerating adoption of SSL
Advantages of Chinese LED Companies

• Innovation in scale (full vertical integration)
• Entire ecosystem for rapid and low cost prototyping
• Government Support (both central and local) even in difficult times
• Scaling in manufacturing
• Creative in cost reduction
• Inflow of talents from outside
• Aggressive, pragmatic and risk taking
• Huge domestic market
Characteristics of China LED Industry

- More emphasis on lm/$ in consumer and retrofit market. Willing to trade off with lifetime and quality of light.

- Lm/W, quality of light and aesthetic design are becoming more important in the commercial lighting marketing.

- Brand name is very important in commercial and government projects.
China vs. Global Market Size

China LED market is growing faster than the rest of the world

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>13.552</td>
<td>0.81</td>
</tr>
<tr>
<td>2013</td>
<td>18.559</td>
<td>1.986</td>
</tr>
<tr>
<td>2014</td>
<td>23.957</td>
<td>3.119</td>
</tr>
<tr>
<td>2015</td>
<td>29.908</td>
<td>4.57</td>
</tr>
</tbody>
</table>

5.9% x 5.6 = 10.7% x 2.2 = 13% x 1.5 = 15.3%
# GaN LED Chip Technology Overview

<table>
<thead>
<tr>
<th>Chip Structure</th>
<th>LED Package</th>
<th>Application</th>
<th>Cost advantage</th>
<th>Technology Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral die</td>
<td>- Mid Power</td>
<td>- Backlight</td>
<td>Yes</td>
<td>Asian companies</td>
</tr>
<tr>
<td></td>
<td>- COB</td>
<td>- Interior</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Ceramic 3535</td>
<td>- Outdoor</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Street light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VTF</td>
<td>- High Power</td>
<td>- Outdoor</td>
<td>No</td>
<td>US/European companies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Specialty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flip Chip</td>
<td>- High Power</td>
<td>- Outdoor</td>
<td>No</td>
<td>US/European companies</td>
</tr>
<tr>
<td></td>
<td>- CSP</td>
<td>- Specialty</td>
<td></td>
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</tr>
</tbody>
</table>
Illumination Market Today

Application Lumen Density

Diffuse/Linear
- T8
- Panel
- A19
- Downlight
- MR/PAR

Directional/Point
- Outdoor
  &
- Industrial

Typical use

Not typical use

Depends on objectives

Typical use

Platform Lumen Density

High

Low

COBs

Die on Ceramic (now too expensive for illumination)

Midpower
Is Haitz’s Law Still Relevant?

- Haitz’s law served as the roadmap to inspire the SSL revolution
- \$/lumen (or lumens/\$) has exceeded the prediction due to aggressive cost down by Asian companies
- Lumens/package has also exceeded the prediction, but lost relevance as big chips and big packages have only niche applications
Midpower LED Value and Performance

Haitz law at work: mid power LED example

Drive at higher current for more lm/$

Drive at lower current for higher lm/W

Lumens per Dollar

Lumens per Watt

(3000K, 80CRI)
Efficacy & Flux vs. Current
3000K, 80 CRI

- Flux vs. Current
- Efficacy vs. Current
MP-3030 Delivers World Class Performance

Efficacy & Flux vs. Current
5700K, 70 CRI

Efficacy & Flux vs. Current
5700K, 70 CRI

Efficacy (LPW) vs. Current (mA)

Flux (Lumens) vs. Current (mA)
Sanan Opto: Overview

- Established in Nov, 2000
- IPO in July, 2008
- 6000+ employees worldwide
- Acquired Luminus Devices in June 2013
Sanan Opto: Largest Chip Manufacturer

- Number one LED chip manufacturer in the world
- ODM/OEM with global customer base
- Strong R&D capability

2015 Global LED chip sales
(Data from LEDinside)
Sanan Opto: Core Technology
Sanan Opto: Full Spectrum LED Products

- **AlInGaN**
  - 365~380nm
  - 380~400nm
  - 447~452nm
  - 450~460nm
  - 465~475nm
  - 515~535nm

- **AlGaInP**
  - 447~452nm
  - 450~460nm
  - 465~475nm
  - 515~535nm
  - 564~580nm
  - 580~597nm
  - 595~618nm

- **AllInGaAs**
  - 564~580nm
  - 580~597nm
  - 595~618nm
  - 610~650nm
  - 640~660nm
  - 840~870nm
  - ~940nm
Sanan Opto: Lateral Chip Roadmap

- Higher reflectivity
- Lower absorption
- Higher transparency
- Higher refraction index

2016 Chip Process Technical Plan for Lateral GaN LED
Sanan Opto: Flip Chip Roadmap

* 3535 Ceramic @350mA, 4700~5300K, Ra=70

Lm/W

160
155
150
145
140
135
130
125
120
115

2013 2014 2015 2016 2017

45x45

Gen-I

+5.1%

Gen-II

+5.6%

Gen-III

+5.3%

Gen-IV (40x40)

+6.5%

+7.5%

+8.5%

Sapphire sub.

GaN LED

PKG Sub-mount

45x45

145x193

145x242

145x286

145x334

145x378

145x421

145x467

145x512
Sanan Opto: VTF Chip Roadmap

* K1 PKG @350mA, 5700k, Ra=70

Lm/W

2013  2014  2015  2016  2017

45x45

Pro-VTF  40x40

VTF

GaN LED

Permanent sub.

PKG Sub-mount

+5%

+4.5%

+19%

+15%

+6.5%

+6.5%

Sanan Opto: VTF Chip Roadmap
Sanan has built a robust IP portfolio through

- Internal technology investment and patent filing
- IP acquisition
  - Over 100 patents in high power chip and packaging through acquisition of Luminus Devices in 2013
  - 139 patents covering epitaxy and chip from a global LED company in 2014
  - More acquisition in progress
Sanan Global Reach Strategy:

Key Partners throughout the entire SSL supply chain

ODE/OEM, Joint Venture and Direct Investment

Sanan

Global Partners and Customers
Sanan Global Reach Strategy

Luminus Devices Acquisition in 2013

Luminus: pioneer of Photonic Lattice and HB LED technologies and innovator in specialty and general lighting

- **2002**: Luminus founded to commercialize MIT technology
  - Revolutionized front projector market by powering the first high brightness LED projectors

- **2008**: Create first “high power” >10W, white products. operation.

- **2009**: Introduced UV, RGBW and first “round” die for spot light and entertainment
  - Tactical and Transportation
  - Fiber Coupled and 3D Printing

- **2012**: Lightera design
  - Entertainment and Stage Lighting

- **2014**: Introduces UV, RGBW and first “round” die for spot light and entertainment
  - Specialty Lighting Business Unit

- **2015**: Introduced Xnova Cube Innovation and Midpower
  - Illumination Business Unit

Luminus Devices Acquisition in 2013

Luminus: pioneer of Photonic Lattice and HB LED technologies and innovator in specialty and general lighting
Luminus COB Performance Leadership

• Generation 1 (2014)
  – Wide product selection, leading performance
  – >115/130 LPW typical (3000/5000K, 80/70 CRI, 85° C)

• Generation 2 (2015)
  – Targeted to shop, industrial, residential, outdoor, hospitality markets - ceramic metal halide replacement
    • >130/150 LPW typical (3000/5000K, 80/70 CRI, 85° C)

• Generation 3 (2016)
  – Available Q1 2016, Industry leading performance
    • >150/170 LPW typical (3000/5000K, 80/70 CRI, 85° C)

Luminus COBs are aligned with Haitz’s law and DOE roadmap

- lumens/package
- $/lumen
- lumens/W
• **AccuWhite™ High CRI**
  – 98 CRI 2700K, 3000K, and 3500K
  – GAI > 105 typical

• **Sensus™ Below the Blackbody Locus “Pure White” LEDs**
  – 80 and 90 CRI, 3000K and 3500K
  – GAI ~20% better than on the BBL

• **High Lumen Density (XH00)**
  – CDM “killers”
  – >40,000 cd in a narrow, 10° beam
  – Replace ceramic metal halide spots

**Building on High Power and Specialty Heritage**
High lm/mm², Performance-oriented Solutions

Luminus Specialty LEDs can operate at powers up to 100W and are typically used in applications requiring high optical output.
Thank you!