Light Emitting Diodes for Solid State Lighting

Klaus Streubel

Outline

Osram at a Glance

Motivation

Advances in LED Technology

Solid State Lighting

OLED: next generation LED
OSRAM at a Glance

- OSRAM: one of the world’s two leading lighting manufacturers (headquarters: Munich)
- Trademark registration: on April 17, 1906 at the then Imperial Patent Office in Berlin
- Founded on July 1, 1919 by the merger of the incandescent lamp manufacturing activities of AEG, Siemens & Halske AG and Deutsche Gasglühlicht-Anstalt (Auer-Gesellschaft)

![Image](Image)

Employees: More than 43,500
Production: 46 factories in 17 countries
Turnover: EUR 4.6 billion
Group profit: EUR 401 million
R&D: 6% of sales

FY 2008

The art project SEVEN SCREENS at OSRAM headquarters in Munich – a project developed in cooperation with OSRAM Light Consulting - shows that the OSRAM brand is 102 years young. 700,000 high-power RGB LEDs (16 mio different colours possible) have been installed on the masts and can be controlled via fiber optic cable from a central computer room.

OSRAM - Part of the Industry Sector of Siemens

Siemens is a global powerhouse in electronics and electrical engineering, operating in the industry, energy and healthcare sectors.

### Industry
- Drive Technologies
- Industry Automation
- Building Technologies
- Mobility
- Lighting (OSRAM)
- Industry Solutions

### Energy
- Fossil Power Generation
- Renewable Energy
- Oil & Gas
- Energy Service
- Power Transmission
- Power Distribution

### Healthcare
- Imaging & IT
- Workflow & Solutions
- Diagnostics

For full list of Siemens Divisions, see page 4.
OSRAM Activities

**PL** Professional Lighting
- High Pressure Discharge (HPD)
- LED Systems
- Electronics & Controls (EC)
- Luminaires

**SP** Special Lighting
- Automotive Lighting (AM)
- Display / Optic (DO)

**CL** Consumer Lighting
- Halogen, CFL LED Retrofit
- Low Pressure Discharge (LPD)

**OS** Opto Semiconductors
- LEDs, OLEDs, Laser, IR

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Osram: Driving Innovation

- "Oscar" Academy Award 1983, 1986
- Emmy Award 2007
- German "President's Prize for Technology and Innovation" 2007
- German Sustainability Prize 2008
- red dot design award 2008
- red dot design award winner 2008
LEDs for General Lighting

Many rational arguments:

- Highly efficient
- Long lifetime
- Small & Rugged
- Mercury free
- Instant on, dimmable
- Directional emission
- All colors available
- ….  

LEDs for General Lighting

Emotion
**LED is driver for future growth of the lighting market**

- **Conventional light sources**: stable, slightly decreasing market
- **LED components**: strong market growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Total market for light sources (Billion €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>9''</td>
</tr>
<tr>
<td>2010</td>
<td>10''7</td>
</tr>
<tr>
<td>2015</td>
<td>12''9</td>
</tr>
<tr>
<td>2020</td>
<td>15''9</td>
</tr>
</tbody>
</table>

* OSRAM estimation, only general lighting

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**Efficiency**

- Lighting accounts for 19% of global electricity consumption
- 2651 TWh were used for lighting in 2005 (=consumption of Japan and China)
- It would be technically feasible to save about 50% of this energy
- Then, 460 Million Tons of CO₂ would not be emitted into the atmosphere
Efficiency of High Brightness LEDs

![Efficiency Graph](image1)

Auger Loss in Visible LEDs

![Auger Loss Graph](image2)

- Non-radiative losses proportional to \( n^3 \) → Signature of Auger
- Auger model with coefficient from literature fits experimental data

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Thin-Film Process Flow

**AlGaInP**
- GaAs
- GaAs
- GaAs
- Epitaxy
- dry etching
- metalization
- soldering
- substrate removal

**InGaN**
- Sapphire
- Epitaxy
- metalization
- soldering
- laser lift-off
- surface roughening

Thin-Film – A new LED Platform

- **InGaAlP**, **InGaN**, **AlGaAs**
- High efficiency
- Scalable area
- Ideal for 2D chip arrays
- Novel possibilities for chip designs
- Surface emission
**Advanced Thin-Film Chip Designs**

**Standard ThinGaN**

- **Cross sectional view**
  - **n-contact**
  - Absorption vs. Series resistance

**ThinGaN UX:3**

- **Cross sectional view**
  - **Conductive carrier**

**Luminance**

Luminance @ 1.4 A

**Linearity**

Luminance @ 2.8 A

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**R&D 1mm Power ThinGaN blue and green**

- **1mm² chip @440 nm, Golden Dragon+**
  - Advanced Package: 643 mW
  - 3199 mW @ 3 A
  - 1966 mW @ 1.4 A
  - 601.4 mW @ 350 mA

- **1mm² chip @532 nm, Golden Dragon+**
  - Advanced Package Blue: 643 mW; Vf= 3.24 V, WPE = 57%
R&D 1mm² Power ThinGaN white

- 1mm² chip, CLC Ultra White, Golden Dragon+ (CCT = 5000K)
- 1mm² chip, CLC, Golden Dragon+ (CCT=3000K, Ra=80)

Advanced Package White: 155 lm; 136 lm/W; 3.24 V; 5000 K

Generation of Light and Heat

Chip: 1 x 1 mm²
Operation: 1 A @ 3.2 V
Efficiency: 40%
Total power: 3.2 W
Emitted: 1.3 W
Heat: 1.9 W

Power Density: 1.9 x 10⁶ W/m²
Innovative Package Development

TOPLED®
- 2 lm @20mA single chip white
- 90mW

OSTAR®
- 100-1000lm
- 10 - 50W
- multi chip

Golden Dragon®
- 30 lm @350mA single chip white
- 250mW

Increasing drive current / output improved thermal performance

Electrical and Optical Power Flow
Current Status and Optimization limit

R&D status:
- El. loss: 1134mW
- IQE 80%
- LEC 86%
- Chip out

P_{opt} = 677mW; 60%
P_{heat} = 457mW; 40%

Chip optimization limit:
- El. loss: 1020mW
- IQE 95%
- LEC 95%
- Chip out

P_{opt} = 853mW; 84%
P_{heat} = 167mW; 16%

Limit for 1mm chip at about 180-190lm at 350mA
White Light by Phosphor Conversion

Blue emitting LED → Yellow phosphor

400 500 600 700nm

CIE (x,y)-Chromaticity-Diagram

Phosphor concentration
Color coordinate
Chip wavelength

Blue Pumped Phosphors

• High quality white light requires more than one phosphor
• Each phosphor system has specific strong and weak properties
• Intensive research and development activities
The Phosphor System is the Key Parameter…

<table>
<thead>
<tr>
<th>phosphor property</th>
<th>parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectral emission</td>
<td>$\lambda_{\text{pe}}$, FWHM</td>
</tr>
<tr>
<td></td>
<td>$C_x, C_y$</td>
</tr>
<tr>
<td>spectral absorption</td>
<td>$\lambda_{\text{abs}}$, R_{\text{abs}}</td>
</tr>
<tr>
<td>phosphor efficiency</td>
<td>QE, LE</td>
</tr>
<tr>
<td>grain characteristics</td>
<td>$d_{50}$, ($d_{10}$, $d_{90}$), shape</td>
</tr>
<tr>
<td>phosphor stability</td>
<td>$T$, $T_{\text{stability}}$, $h_{\nu}$-stability, chemical stability</td>
</tr>
</tbody>
</table>

relevant LED property

LED color, color gamut

CRI = 90
CRI > 80

Efficacy and Color Rendering of PC-LEDs
Simulations for Various Down Conversion Approaches

constant opt. Power of blue chip

Cx & Cy = 0.33

CRI Effciency

- Daylight 100
- standard phosphor 79 100%
- red & green phosphor 89 85%
- narrow yellow phosphor 59 119%

- CRI and Efficiency strongly depend on chosen phosphor solution
- Estimation of max. 150 lm/W @ CRI 80 and 180 lm/W @ CRI 60
Color Rendering and Color Preferences of White LEDs

- Many options to tune color impression:
  - Enhancement of color saturation for more vividness by spiky spectrum
  - Smoothening of color contrasts for more “natural” appearance
- LED light sources show often higher people preference ratings than suggested by their CRI
- CRI likely not the most suitable metrics…

White LEDs
Color Quality is Key for Success in General Lighting

Our biological clock has a strong influence on
- nocturnal sleep quality
- body core temperature and heart rate
- mood and well being
- alertness, cognition and reaction time
- performance and vigilance
**LEDs Can Play their Benefits Everywhere!**

**USPs per Field of Application**

<table>
<thead>
<tr>
<th><strong>Architainment</strong></th>
<th><strong>Light@home</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Design freedom</td>
<td>• Light quality and comfort</td>
</tr>
<tr>
<td>• Infinite color change possibilities</td>
<td>• Energy saving</td>
</tr>
<tr>
<td></td>
<td>• Additional features</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Shop lighting</strong></th>
<th><strong>Street, Tunnel, Parking</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Light quality</td>
<td>• Safety feeling (homogeneity, no glare)</td>
</tr>
<tr>
<td>• Changeable light (colour)</td>
<td>• Energy saving</td>
</tr>
<tr>
<td>• Energy saving (freezers)</td>
<td>• Instant on, dimming</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Office lighting</strong></th>
<th><strong>Hospitality</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Energy saving</td>
<td>• Design freedom</td>
</tr>
<tr>
<td>• Direct and indirect light</td>
<td>• Infinite color change possibilities</td>
</tr>
<tr>
<td>• Variable scene settings</td>
<td></td>
</tr>
</tbody>
</table>

Energy Savings and TCO is important, but...  
...there is as well emotion, amazing new designs & smart features

**Street- & Tunnel-Lighting**

**Yantzi River Tunnel**
LED = Light where it should be!

LEDs need less lumens to reach the brightness target: lower energy consumption and environmental protection by better directionability

- Conventional system
  - 30% of light is wasted
  - Light pollution disturbing residents
  - Birds and animals breeding can be disrupted with unwanted light

- LED System
  - perfect use of the lumen packages
  - Homogeneous light distribution → increased safety, less fatigue for drivers
  - Animals and birds can live undisturbed

The Optical Concepts for Technical Street Lighting

1. Oval Optics
   - PCB
   - LED
   - Oval lens

2. Tilted focusing optics
   - PCB
   - LED with focusing lenses

3. Combination of wide beam spread optics and reflector
   - PCB
   - LED
   - Reflector
   - Lens with wide beam spread

4. Combinations
   - PCB
   - LED with lens
   - Reflector

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LED Module STREETlight Advanced

- Technical illumination of service and trunk roads, in future main roads, as well as illumination of paths and places

Special benefits
- Efficient and most uniform illumination of street & pavement with the reflector concept
- Illumination of street according to street lighting standard EN 13201 (glare limitation fulfilled)
- Fast and tool less module swap for easy maintenance
- Small & constant (standardized) module size enables individual luminaire designs
- Long module life time: up to 50 k hours

Product Highlights / Benefits

STREETlight Protect

A high power modular light source which can be stacked and configured to meet all types of applications; street lighting, warehouse, freezer, factory, task lighting, etc.

Benefits / USP
- No light wastage with oval light distribution focusing light on targeted areas
- Modular concept, stackable, easily configurable
- Uniform heat dissipation (Long life maintenance)
- IP66 rated
- Wide operating temperature -25 to 55°C enables wide range of applications
- Rotational bracket (optional)
Modular concept advantage
One standard module for all different pole heights

Flexible Array – scalable to meet different street height application

8-module lamp

HPML Module in Korea
Standardization in Solid State Lighting
Efforts are Going on all over the Globe

- The innovative LED technology is on the way to revolutionize General Illumination.
- SSL is leaving its niche to broaden manifold applications in various market segments.
- Standardization, driven by Governments and Lighting Industries, is essential to pave the road to a successful market entry.
- The key drivers are:
  - Energy Efficiency  
  - Lifetime  
  - Labeling  
  - Environment Protection  
  - Safety  
  - Retrofits
- Worldwide consistent standards will be the success factor for midterm push in SSL.

The Key Issues to Make LEDs Ready for Prime Time

- Play the unique technology advantages
  - Color & dynamic light
  - Small size
  - Unique forms
  - Light patterns and intensity distributions
- Make SSL easy to control
- Provide high quality white light at highest efficiency
- Control cost - cut back the payback times
  - go for high maintenance & high energy cost applications
  - Secure the investment by getting the “-abilities” in place:
    - upgrade-ability
    - reorder-ability
    - compatibility
- Focus on excellent system reliability

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The Next Wave in SSL…The Organic LED

OLED – The Aesthetics of Light

OLED positioning will be centered on the emotional perception:
- OLED – is just light - not loaded with lot’s of luminaire materials
- OLED – is ultimately reduced & pure aesthetics
- OLED – delivers harmony of form and light
Some application examples (I)

Source: PPML design contest 2009, Osram OS
for SSL – Romme, Sweden 12.3.2010 | Page 39

Decorative & Mood lighting

Some application examples (II)

Source: PPML design contest 2009
Some application examples (III)

Room Separator
Desktop Illumination

Source: Osram OS

Outstanding Features

- High energy efficiency:
  - 62 lm/W on R&D level
  - >100 lm/W in future
- High quality white light: CRI > 80
- Diffuse non glaring area light source
- Instant on/off
- Mercury-free
- Low voltage DC driven
- Functionality
  - Various colors
  - Different color temperatures
- Design & aesthetics
  - Thin, flat, lightweight
  - Diffuse – transparent – mirror
  - Flexibility

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Transparent OLEDs open up completely new opportunities regarding design and applications!

**Technology facts:**
- 210 cm² active lighting area
- 55% transparency
- Highly conductive electrodes
- No busbars required
- 2 contact pads (lighting conform)

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**OLED Lighting - Market Development**

**OLED market will develop from high end to high volume applications**

I. **Luxury Designs “Light Art”**  
"The birth of a light revolution"  
Emotional factors overweigh the price  
Market Entry

II. **Functional Designs “Design & Illumination”**  
"Great value propositions by (e.g.) transparency"  
Amazing features will enable impressive, new applications.  
Transition to Volume

III. **General Lighting “White Volume Flatlight”**  
"A key segment in the world’s volume lighting portfolio"  
Volume fit per cost, performance & capacity.  
Volume Business
The Application Categories Lead to Challenging Requirements...

...to be fulfilled without sacrificing the aesthetic appeal and the lighting essentials: lumen maintenance, sustainability, low cost and efficiency

<table>
<thead>
<tr>
<th>Mood Lighting</th>
<th>Object Illumination</th>
<th>General Illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Decorative light</td>
<td>- Windows</td>
<td>- Task light</td>
</tr>
<tr>
<td>- Accent light</td>
<td>- Shop</td>
<td>- Integrated ceiling &amp; wall light</td>
</tr>
<tr>
<td>Requirements:</td>
<td>- Specially</td>
<td>Requirements:</td>
</tr>
<tr>
<td>- Diffuse emission at moderate luminance level (&lt;500 Cd/m²)</td>
<td>- Large area &amp; transparency and/or aesthetic tiling concepts</td>
<td>- High luminance level (up to 4000 Cd/m²) &amp; directional beam shaping</td>
</tr>
</tbody>
</table>

Note: Automotive applications are currently not in focus due to high required temperatures

OLED Beyond Glass Substrates

- First proof of principle on bendable substrates successful (top emitter on metal substrate).
- Flexible OLEDs on e.g. plastic foils will be available in 3-5 years.
- At OSRAM OS bendable and flexible substrates are part of the activities regarding R&D as well as potential applications.
Thank You For Your Attention