Major LED manufacturing trends and challenges to support the general lighting application

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Director Product Management Aligner
1. SUSS MicroTec Introduction

2. LED application and main manufacturing trends

3. Cost and Yield considerations
   Case study: Photo Lithography
SUSS MicroTec: At a Glance

- SUSS MicroTec is one of the worldwide leading suppliers of equipment and process solutions for microstructuring in semiconductor and related industries.
- Our focus lies on growth markets such as 3D Integration/Advanced Packaging, MEMS, III-V Semiconductors/LEDs.

At a Glance

- Founded 1949 by Karl Süß in Munich
- Went public in 1999 (listed in Deutsche Börse AG’s Prime Standard)
- Revenue of the SUSS MicroTec group in 2010: ~140 Mil.
- Global footprint with more than 8,000 systems installed worldwide

1949 – 2009: Sixty Years of Engineering Spirit
**SUSS Solutions for HB LED Manufacturing**

**Equipment & Process Innovations**

**Lithography**
- Coating, exposure and developing solutions for all relevant litho layer

**Permanent Wafer Bonding**
- Eutectic bonding (i.e. AuSn)
- Diffusion bonding (i.e. Au-Au)

**Nano Imprinting**
- Substrate conformal imprint lithography for nm scale production of photonic crystals
- Lens molding and replication

**Thin Wafer Handling**
- Supported temporary wafer bonding processes: 3M, Brewer Science, TMAT

**HB LED top contacts**
[Exposed on a MA100e Gen2, Coat/Dev on SUSS Gamma 2010]

**Multi wafer bond tooling**
High throughput bonding process through multi wafer processing

**Full wafer scale nano imprinting**
Photonic Crystal Structures etched in Si-Wafer Ø 250 nm

**Temporary wafer bonding**
Temporary carrier technology to support manufacturing of thin-film LEDs with LLO

**MA200 Compact Mask Aligner**

**Gamma Coater/Developer**

**SB6/8e Wafer Bonder**

SUSS MicroTec
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Let's go for General Lighting – so what?

+ Device requirements to enter the market:

- High Lifetime
- High Output
- Low Costs

Manufacturing Trends:

- Chip design optimization
- New materials
- Light efficiency improvements (PSS, PhC, etc.)
- Wafer size transition
- Higher productivity
- Wafer Level Packaging
Lumen per Dollar Gap

**Incandescent Light Bulb**

- 60W
- 800lm

**LED Light Bulb**

- Actual cost level: 300lm/$
- Cost target for general lighting: 500lm/$

*Source: Epistar*
HB LED Device Structures and Trends

Conventional LED device with patterned sapphire substrate (PSS) (essentially all LED chip makers)

- Relatively inexpensive
- Up to 30% active surface lost to the Mesa
- Transparent or small contact needed on the p-side
- Current crowding due to poor conductivity of n-GaN increase total resistance

Thin-film vertical LED device with n-GaN texturing with substrate removal (Osram, Lumileds, Semileds, Cree, Luminus)

- Complexity and Cost
- Good thermal properties
- Larger active area (no MESA)
- n-GaN can be thinned down to bring active layer close to the surface and improve light extraction (surface emitter)
- Lower resistance
Typical manufacturing flow:

**Substrates**
- Patterned Sapphire Substrate (PSS)

**Epitaxy**
- Chip patterning
- Thin wafer handling
- Reflective layer
- Photonic Crystals

**Device Manufacturing**
- Advanced Lithography
- Photo mask supply
- Permanent wafer bonding (Temporary wafer bonding)
- Nano Imprinting

**Singulation**
- Advanced Lithography
- Photo mask supply
- Permanent wafer Bonding (Temporary wafer bonding)
- Wafer level packaging

**Packaging**
- Wafer level packaging
- TSV
- Phosphor coating
- Lens molding

**SUSS Solutions**
- SUSS MicroTec
General HB LED Equipment Trends

- Large wafer size support:
  - 2” and 4” substrates are state of the art, first moves into 6”, firm plans for 200mm

- Cost of Ownership improvements:
  - increase throughput
  - multi-wafer processing
  - higher yield
  - lower CapEx

SUSS multi wafer bonding solution
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Today's LED have up to seven lithography layers:

- **General layers:**
  - MESA etch,
  - passivation
  - N contact (lift-off)
  - P contact (lift-off)

- **Additional lithography layers:**
  - Anti-current crowding
  - Surface texturing (not always litho)
  - Light guiding
  - Bond / Bump layer patterning

Source: Epistar
Productivity Improvements
Case Study: Lithography

+ Low CapEx / High throughput lithography solution: Proximity printing

<table>
<thead>
<tr>
<th>Technology</th>
<th>CapEx</th>
<th>Throughput (4“)</th>
<th>Cost / Wafer</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projection (Stepper)</td>
<td>1.000.000$</td>
<td>75 W/h</td>
<td>92 c/wafer</td>
<td></td>
</tr>
<tr>
<td>Proximity Printing (SUSS LED Mask Aligner)</td>
<td>400.000$</td>
<td>150 W/h</td>
<td>18 c/wafer</td>
<td>-80% (!)</td>
</tr>
</tbody>
</table>

+ High Yield Proximity Printing:

Advanced Mask Aligner Lithography

Exposure Optics with:
- High light intensity
- Excellent light uniformity
- Telecentric illumination
- Customized illumination

SUSS MA100e Gen2
Micro-Optics in Front-End Lithography

Micro-Optics is **Key Enabling Technology** in Front-End Lithography

- Customized Illumination
  - Pupil Shaping (DOE)
  - Now: FlexRay™
  - programmable illumination technology from ASML
- Excimer Laser (193nm)
- Laser Beam Shaping
- Laser Beam Homogenizing

- Diffractive Optical Elements (DOE)
- MEMS Mirror Arrays (FlexRay™)
- Microlens Köhler Homogenizer
Macroscopic lenses in a fixed configuration:

Micro lens array coupled with a separated filter plate:

Micro Optics

Illumination Filter Plate
LED Yield Enhancements with Exposure Optics Tuning

**Equipment Setup**
- IFP-HR "High Resolution"
- IFP-LGO "Large Gap"
- IFP- "Talbot"

**Process Result**
- 2.5µm L/S in proximity printing (20µm)
- 3D TSV lithography
- Talbot lithography (<5µm in 100µm gap)

**HB LED Application**
- PowerThinGaN top view
- Sapphire substrate
  - GaN epi-layer

- Front side
  - TSV
Summary

1. Continued cost and light efficiency improvements are key enabler to enter the general lighting market place for LED

2. Photolithography is a significant cost contributor

3. New SUSS MicroTec technologies in proximity printing enable high yield and low resolution lithography on a cost effective equipment platform
Thank You!