<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The three-page summary</td>
<td>p04</td>
</tr>
<tr>
<td>Executive summary</td>
<td>p08</td>
</tr>
<tr>
<td>Introduction</td>
<td>p32</td>
</tr>
<tr>
<td>High dynamic range</td>
<td>p50</td>
</tr>
<tr>
<td>LED BLU technologies</td>
<td>p57</td>
</tr>
<tr>
<td>MiniLED backlight units</td>
<td>p80</td>
</tr>
<tr>
<td>MiniLED BLU manufacturing</td>
<td>p108</td>
</tr>
<tr>
<td>MiniLED assembly</td>
<td>p114</td>
</tr>
<tr>
<td>MiniLED BLU applications and forecasts</td>
<td>p127</td>
</tr>
<tr>
<td>• TVs</td>
<td></td>
</tr>
<tr>
<td>• Smartphones</td>
<td></td>
</tr>
<tr>
<td>• Monitors</td>
<td></td>
</tr>
<tr>
<td>• Automotive displays</td>
<td></td>
</tr>
<tr>
<td>• Epiwafer forecasts</td>
<td></td>
</tr>
<tr>
<td>Conclusions on miniLED BLU</td>
<td>p156</td>
</tr>
<tr>
<td>Direct view LED displays</td>
<td>p158</td>
</tr>
<tr>
<td>Overview</td>
<td>p160</td>
</tr>
<tr>
<td>Market</td>
<td>p169</td>
</tr>
<tr>
<td>Narrow pitch displays</td>
<td>p175</td>
</tr>
<tr>
<td>Alternative display technologies</td>
<td>p215</td>
</tr>
<tr>
<td>LED epiwafer forecast</td>
<td>p226</td>
</tr>
<tr>
<td>TVs</td>
<td></td>
</tr>
<tr>
<td>Smartphones</td>
<td></td>
</tr>
<tr>
<td>Monitors</td>
<td></td>
</tr>
<tr>
<td>Automotive displays</td>
<td></td>
</tr>
<tr>
<td>Epiwafer forecasts</td>
<td></td>
</tr>
<tr>
<td>Annex A: LED display driving</td>
<td>p237</td>
</tr>
</tbody>
</table>
ACRONYMS

• AR: Augmented Reality
• BLU: Backlight Unit
• CapEx: Capital Expenditure
• CMOS: Complementary Metal Oxide Semiconductor
• EQE: External Quantum Efficiency
• FALD: Full Array Local Dimming
• FHD: Full High Definition (1920 x 1080)
• FOV: Field of View
• FWHM: Full Width at Half Maximum
• HD: High Definition
• HDR: High Dynamic Range
• HMD: Head-Mounted Display/Device
• HUD: Head-Up Display
• IC: Integrated Circuit
• IQE: Internal Quantum Efficiency
• KBD: Known Bad Die
• KGD: Known Good Die
• LCD: Liquid Crystal Display
• LCOS: Liquid Crystal on Silicon
• LED: Light-Emitting Diode
• LiGP: Light Guide Plate
• LLO: Laser Lift Off
• LTPS: Low-Temperature Polysilicon
• MEMS: Micro Electro-Mechanical Systems
• MOCVD: Metal-Oxide Chemical Vapor Deposition
• MR: Mixed Reality
• ODM: Original Design Manufacturer
• OEE: Optical Extraction Efficiency
• OEM: Original Equipment Manufacturer
• OLED: Organic Light-Emitting Diode
• PDMS: Polydimethylsiloxane (polymer material)
• PECVD: Plasma-Enhanced Chemical Vapor Deposition
• P&P: Pick and Place
• PPD: Pixel Per Degree
• PPI: Pixel Per Inch
• PPM: Parts Per Million
• QD: Quantum Dots
• QHD: Quad High Definition (2560 x 1400 to 3440 x 1440)
• TFT: Thin-Film Transistor
• VR: Virtual Reality
FROM THE LED TO THE MICROLED

• For microLED development, the technological challenges are such that it will be a few years before any products emerge.

• Because processes and applications are wildly different, miniLED development is not really a stepping stone to microLED development.

MiniLED was thought to be a stepping stone to microLED, but its processes and applications are completely different.
REPORT SCOPE

Traditional LEDs

Limit: ~150-200µm

Mini LEDs

Limit: ~50-100µm

MicroLEDs

Packaged: SMD, through hole
(smallest packages: 0.5 x 0.5 mm²)

SMD or chip-on-board assembly

Package-free: “chip-on-board” only

Applications

General and specialty lighting, LCD backlight units, LED videowalls

Low-pitch LED videowalls, LCD and keyboard backlights

Low-pitch LED videowalls, MicroLED displays (TV, smartphones, etc.)

Chips (to scale)

>1 mm

1 mm

200 µm

150 µm

100 µm

50 µm

30 µm

10 µm

2 µm

Packages (Not to scale)

Lumileds

Rohinni

Sony

X-Celeprint

Playnitride

Applications

General and specialty lighting, LCD backlight units, LED videowalls

Low-pitch LED videowalls, LCD and keyboard backlights

Low-pitch LED videowalls, MicroLED displays (TV, smartphones, etc.)
MiniLEDs have two main applications for which they compete against already-mature technologies.

- **Backlight units for LCD panels**
  - Main existing competition: **OLED**
    - (form factor, dynamic range)

- **Low-pitch LED videowalls**
  - Main existing competition: **LCD, Rear Projection Cubes**
    - (dynamic range, pitch)
LCD BACKLIGHT UNITS - EDGE AND DIRECT CONFIGURATIONS

Various LED backlight designs exist, depending on cost and performance targets.

<table>
<thead>
<tr>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge backlight</td>
</tr>
</tbody>
</table>

The choice of an LED BLU design results from the trade-off between cost, performance, and aesthetics (thickness).

<table>
<thead>
<tr>
<th>Description</th>
<th>Edge backlight</th>
<th>Direct backlight</th>
<th>Low-cost direct backlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - 4 LED light bars positioned on the edges. Light is coupled into a light guide-plate.</td>
<td>Dense array of LEDs facing the viewer and coupled into a diffuser sheet</td>
<td>Low-density array of LEDs positioned further away to allow for light spread</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Display thickness</th>
<th>Edge backlight</th>
<th>Direct backlight</th>
<th>Low-cost direct backlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allows very thin TV designs (&lt; 2cm; as low as 5mm with glass light guide-plates)</td>
<td>Thicker design (2 - 5cm)</td>
<td>Much thicker (5 - 10cm)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy efficiency</th>
<th>Edge backlight</th>
<th>Direct backlight</th>
<th>Low-cost direct backlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Medium</td>
<td>Good</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contrast/image quality</th>
<th>Edge backlight</th>
<th>Direct backlight</th>
<th>Low-cost direct backlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate (Lateral dimming possible)</td>
<td>Excellent (Full-array local dimming possible)</td>
<td>Moderate (Full-array local dimming possible, but less precise and usually not implemented for cost reasons)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost</th>
<th>Edge backlight</th>
<th>Direct backlight</th>
<th>Low-cost direct backlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>High</td>
<td>Low / Medium</td>
<td></td>
</tr>
</tbody>
</table>
Quantum dots and narrow band phosphors enabled LCD with wide color gamut. For contrast, FALD was the first step and miniLEDs will be the next one towards reaching contrast levels close to OLED.
PRODUCT ANNOUNCEMENTS AND RUMORS

Number of miniLEDs per dimming zone, per panel size and application

- Analyzing 2017-2018 prototypes and product announcements shows no clear consensus on optimum number of LED per dimming zone as well.
- The number of zone is determined by image performance requirement (contrast) and the number of LED per zones is mostly determined by BLU thickness requirement.
- XXX miniLEDs per dimming zone is usually sufficient.
- The driving architecture is also important to consider: PM driving is not suitable for a higher number of zones.
  - Innolux showed a unique AM driven Automotive panel prototypes at CES and Touch Taiwan 2018. Thanks to the AM driving scheme, each LED correspond to a dimming zone. The technology is branded as “PixinLED.”
  - The highest number of miniLEDs per dimming zone appears to be 225 (TV presented by Nationstar at Touch Taiwan 2018, with 180,000 miniLEDs in 800 zones).
Driving choice is a matter of trade-offs on several parameters.

<table>
<thead>
<tr>
<th>Cost allocation decision for the BLU</th>
<th>Number of dimming zones and/or number of miniLEDs per zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td>XXX</td>
<td>XXX</td>
</tr>
</tbody>
</table>
DIFFUSER SHEETS

Lots of developments left in order to drive miniLED adoption

- Diffuser sheets use polymeric materials that are mechanically and thermally sensitive. Moreover, they must be optically sound in order to avoid “hot spots”, since the individual miniLEDs appear from the front as bright spots behind.

Due to the constraints on the diffuser sheet, reducing BLU thickness is not as easy as reducing the airgap.

Reducing OD, aka BLU thickness, by reducing the air gap may deform the diffuser sheet, thus impacting optics.
**ASSEMBLY: OVERVIEW**

- Cost and throughput vary significantly, depending on the desired placement accuracy and equipment quality.
- Entry-level die bonders for top emission die with ±25 µm accuracy can assemble up to \( XX \) unit per hour (UPH) and cost as little as $\$XXk$. Faster or higher-precision tools can cost up to $\$XXk$.
- Equipment choice depends on the application and process capability (die type, required placement accuracy, and bonding/interconnect type), as well as cost-of-ownership targets.
- For epoxy-based die bonding of top-emitter LEDs, a subsequent wire bonding step is required for electrical interconnect.

<table>
<thead>
<tr>
<th>$</th>
<th>Entry-level: $$XXk$ - $$XXk$</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Epoxy stamping/bonding</td>
<td></td>
</tr>
<tr>
<td>• ±25 µm placement accuracy</td>
<td></td>
</tr>
<tr>
<td>• Up to ( XX )k UPH</td>
<td></td>
</tr>
<tr>
<td>• With top emitters, requires additional wire bonding steps for interconnect</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$$</th>
<th>Mid-range: $$XXk$ - $$XXk$</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Flip-chip</td>
<td></td>
</tr>
<tr>
<td>• Eutectic bonding</td>
<td></td>
</tr>
<tr>
<td>• ±25 µm placement accuracy</td>
<td></td>
</tr>
<tr>
<td>• Up to ( XX )k - ( XX )k UPH</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$$$</th>
<th>High-end: $$XXk$ - $$XXk$</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Flip-chip</td>
<td></td>
</tr>
<tr>
<td>• Eutectic or thermosonic compression bonding</td>
<td></td>
</tr>
<tr>
<td>• ±3 - ±10 µm placement accuracy</td>
<td></td>
</tr>
<tr>
<td>• Up to ( XX )k UPH</td>
<td></td>
</tr>
</tbody>
</table>

Many types of tools, with a wide range of available prices and capabilities.
## MINILED ATTRIBUTES VS. APPLICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Smartphones</th>
<th>Monitors</th>
<th>TVs</th>
<th>Automotive displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Color gamut</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Brightness</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Contrast</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Long lifetime</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Flexible</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Overall attractiveness</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

1 - Not very important or differentiating  
2 - Important  
3 - Very important  
4 - Critical  
5 - Strong differentiator
**MINILED ADOPTION IN TVS**

- MiniLED BLU LCDs TV panels are expected to enter the market in 2019 (e.g.: Innolux).
- Given the price premium added to BLU manufacturing cost, prices will be steeper. The first implementations should appear on large-size panels, for which OLED struggles to compete with LCD.
- As yield and cost improve, miniLEDs could propagate towards smaller sizes, possibly down to 55". But cost-reduction options are limited, so this may not be impactful.
- Moreover, differentiation for the consumer will become unclear and other parameters will come into play, i.e. form factor, for which OLED prevails.
- Beyond 2022, microLED could steal some market share, especially for bigger screens.
Due to the auto industry's long qualification cycles, adoption will be delayed - but then soar.
Some commonly accepted industry jargon is used in this section:

**Pixel pitch:**

PX, where X characterizes the pixel pitch of a direct view LED display. For example, the term “P1.25” refers to a display with a pixel pitch of 1.25 mm (“0909” as well).

**NPP (Narrow pixel pitch):**

We chose to consider as NPP any display with a pixel pitch < 3 mm

**LED package dimensions:**

Surface-mount device (SMD) LED packages are often categorized based on their lateral dimension, rounded down to the nearest value in mm. For example, a “0909” package refers to an LED package with nominal lateral X and Y dimensions of 0.9 x 0.9 mm. However, a package with, say, a 0.98 x 0.98 mm size will also often be referred to as a “0909”.

Miniled for Display Applications: LCD and Digital Signage | Sample | www.yole.fr | ©2018
## MAJOR APPLICATIONS

<table>
<thead>
<tr>
<th>Pitch: 50 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeways</td>
<td></td>
<td>Airports, railway</td>
<td></td>
</tr>
<tr>
<td>Transportation &amp; public information</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch: 5 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadside billboards, media facades</td>
<td></td>
<td>Retail: shopping malls</td>
<td></td>
</tr>
<tr>
<td>Commercial and retail</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch: 0.5 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail: in-store</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial and retail</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch: 5 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concerts, musicals</td>
<td></td>
<td>Cinema</td>
<td></td>
</tr>
<tr>
<td>Sports &amp; Entertainment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch: 0.5 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command &amp; control rooms</td>
<td></td>
<td>Corporate lobbies, hospitality, healthcare</td>
<td></td>
</tr>
<tr>
<td>Institutions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch: 0.5 mm</th>
<th>Outdoor</th>
<th>Overlap Outdoor/Indoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houses of worship</td>
<td></td>
<td>Residential: high-end home theatre systems</td>
<td></td>
</tr>
<tr>
<td>Institutions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[1]: Energy utility, logistic, market exchanges, police/military situation rooms, traffic monitoring, etc.
After peaking at close to 100, there are still more than 30 active LED chip manufacturers. However, the market for display applications is increasingly dominated by strong leaders in China and Taiwan such as San’an, Epistar, Changelight, HC Semitek, ETI, Aucksun etc.

Similarly, there are still 100+ LED packaging companies, but the market for direct-view LED display applications is increasingly dominated by a handful of firms.

Due to low entry barriers for entry-level products, there are hundreds of LED display makers[1]. However, the top 10 hold around XX% of market value.

[1] > XXX in China only!
The narrow pixel-pitch segment is growing much faster than larger pitches.
DIRECT VIEW SMD LED DISPLAYS - COST STRUCTURE

- For an NPP display, LED packages typically represent XX-XX% of the BOM and > XX% of the display’s total cost.
- The number of RGB LED packages per unit display surface increases with the inverse square of the pitch: reduce pitch 2x → increase LED count 4x.
  - A 2 mm-pitch display has 250,000 LED per m²
  - A 1 mm-pitch display has 1,000,000 LED per m²
- The number of drivers increases following the same rule (drivers typically have 16 - 48 channels with 8 - 32 multiplexing capability, allowing for control of up to 512 RGB pixels)

LED packages are the single-largest contributor to a direct view display’s bill of materials (BOM).
DIRECT VIEW LED DISPLAYS - COST DRIVERS

- The cost structure changes for the most extreme pitches (very low or very high), since some of the cost contributors (i.e. cabinets) remain relatively independent of pitch.

- As a result, a full display's per-pixel cost tends to increase for the largest pitches (i.e. small pixel density) as the relative contribution of these “fixed costs” increases. Large-pitch displays also have more stringent requirements in terms of ruggedness, and high-brightness installations require higher-power packages.

For a given pitch, price can vary more than 2x depending on quality, volume, and supplier. The graphs on this slide represent the overall market's average selling price estimates.
LED TECHNOLOGIES FOR DIRECT VIEW DISPLAYS

Pixel pitch

Outdoor

Indoor

0.5 mm

< 1 mm

< 3 mm

10 mm

1997

2006

2016-2018

Through-hole individual R, G, B LED
High pitch

SMD[1] LED
R,G,B chips on a single surface-mount package. Shifted the color balance responsibility to the LED packagers and opened the door to smaller pitch and lower cost (use of fast P&P and SMD soldering machines)

COB[2] LED
Package-free LED chips mounted directly on the electric board substrate. Theoretically enables smaller pitch than SMD (<0.7 mm) and reduces LED cost.

“Four-in-One” COB SMD packages
Compact SMD packages featuring 4x RGB LEDs

Package-free, very small LED chips mounted directly on the electric board substrate. Could further reduce the pitch (<0.5 mm) and bring other benefits (cost, contrast, etc.)

Small and smaller packages: 0505 enables 0.7 mm pitch

[1]: Surface-mount device (SMD)
[2]: SMD LED types are often described by four digits, corresponding to their lateral dimensions: i.e. a “0606” LED package is typically 0.6 x 0.6 mm in size
[3]: Chip-on-board LED
• Standard InGaAlP chips are typically XX - XX% more expensive than green or blue GaN-based chips

• For flip-chip, the gap increases dramatically with red FC die: up to XX - XXXx more expensive than blue or green FC. However, this gap has slimmmed down from XX - XXXx only a few years back.

• For this reason, Sony's Crystal LED display XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXX

• Due to strong demand and the market potential driven by NPP LED displays and microLED displays, chip manufacturers are continuously improving their red FC design and investing in equipment to ramp-up production

• Red FC cost is therefore decreasing rapidly, although it is expected that, due to the intrinsically more complex manufacturing process, a cost gap with GaN-based FC LED will remain

Flip Chip structures are emerging for red die but remain expensive (typically about XX to XXXx more than blue or green).

COB POTENTIAL BENEFITS

Lower pitch:
No package → enables higher packing density

Better performance:
Contrast: Low LED emitter occupancy limits ambient light reflection on chips/package (example next slide)
Viewing angle: wider emission angle of chips vs. package

Reliability/ruggedness /reduced maintenance:
Improved thermal management, easy encapsulation (SMD easily knocked off the board)
Some players claim ½ to 1/10 pixel defect rates on COB NPP, compared to SMD

Transparent displays:
Alternative to assembly on a black-coated PCB, the chips can be mounted on a transparent substrate (i.e. glass).
The low chip occupancy then enables display with high transparency.

Flexible displays:
Small size/low occupancy. Can also increase flexibility and robustness if assembled on a flexible substrate
(thin glass, polymer, etc.).

Lower cost:
Eliminating the package could potentially reduce LED cost by half
MINILED AND MICROLED

- MiniLED and microLED are usually distinguished by their size (< 50 µm) and structure:
  - miniLED are small-size FC LED structures with a native sapphire substrate (blue and green LED) thinned down but remaining in the structure
  - microLED are much smaller vertical or horizontal chips from which the native substrate has been removed

<table>
<thead>
<tr>
<th></th>
<th>MiniLED</th>
<th>MicroLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>50 - 200 µm</td>
<td>2 - 50 µm</td>
</tr>
<tr>
<td>Die structure</td>
<td>FC, native epitaxial substrate remains on structure</td>
<td>Vertical or horizontal FC. Growth substrate is removed.</td>
</tr>
<tr>
<td>Die singulation methods</td>
<td>Laser scribing (typical street width: XX µm)</td>
<td>Plasma etching (typical street width: XX - X µm)</td>
</tr>
<tr>
<td>Die assembly method</td>
<td>Can be handled by standard pick-and-place die bonders, high semi-continuous printing (flexographic, R2R), self-assembly</td>
<td>Requires innovative technologies and equipment not yet commercially available (massively parallel P&amp;P, semi-continuous printing, laser transfer)</td>
</tr>
</tbody>
</table>

Major characteristics of mini and microLED

picture: ITRI at SID 2018
NARROW PIXEL-PITCH LED DISPLAY - TECHNOLOGY ROADMAP
EMERGING APPLICATIONS: LED DIGITAL CINEMA

- Our forecast exclude a potentially significant opportunity for direct view display: in 2017, Samsung unveiled the first LED cinema screen under the brand “Onyx”. As of Q3-2018, the displays have been installed at a dozen theatre multiplexes in Korea, Thailand, Malaysia, Hong Kong, China, India, Switzerland, Germany, Austria, Mexico and the US.

- The screens are built from P2.5 mm modules of 256 × 360 pixels to satisfy both flat (1.85:1 aspect ratio) 3,996x2,160 pixel and and cinemascope (2.35:1 aspect ratio) 4,096 × 1,716 pixels delivering up to 500 nits brightness.

- Sony followed suit in 2018 and started pitching its CLED technology for cinema applications.

![Samsung’s “Onyx” LED Cinema Display](source: Samsung)  
![Samsung’s “Onyx” LED Cinema Display module](source: Samsung)

The typical pixel pitch in traditional digital cinema is in the P2 to P5 mm range: well within the realm of LED displays.
We remain conservative on the LED cinema opportunity at this stage and see it more as a high end niche similar to Dolby Cinema or Imax.
The excitement about microLEDs has grown exponentially since Apple acquired technology startup Luxvue in 2014. All major display makers have now invested in the technology and other semiconductor or hardware companies such as Intel, Facebook Oculus or Google have joined the pool.

Amidst this flurry of news and activity, a new term emerged in early 2017: miniLED. The technology is often described as a stepping stone, bridging the technology and application gap between traditional LEDs and microLEDs. However, there is no commonly accepted definition of either term. As the names suggest, size is a critical aspect. Building on a consensus from the many companies surveyed, microLEDs are typical below 50µm along their sides, although the bulk of the activity is skewed toward the smaller dimensions, typically in the 3-15µm range. By default, miniLEDs fill the size gap between microLEDs and traditional LEDs. But more than size, the technology and manufacturing infrastructure requirements and the applications differentiate the two. While microLEDs require major technology breakthroughs in assembly and die structure, as well as a significant overhaul of the manufacturing infrastructure, miniLED chips are just scaled-down traditional LEDs. They can be manufactured in existing fabs with no or little additional investment.

On the application side, microLEDs’ promise lays in the realization of disruptive, high pixel density self-emissive displays, while miniLEDs can be used to upgrade existing Liquid Crystal Displays (LCDs) with ultra-thin, multi-zone local dimming backlight units (BLU) that enable form factors and contrast performance close to or better than Organic Light Emitting Diodes (OLEDs). On the business-to-business side, miniLEDs are promising for the realization of cost-effective, narrow pixel pitch LED direct view displays used in digital signage applications such as in retail, corporate and control room applications.

The report discusses the different chip structures considered for the various applications.

MINILED ADOPTION IS FIRST DRIVEN BY HIGH-END LCD DISPLAYS

For smartphone applications, miniLEDs are facing a strong incumbent in OLEDs, as their cost to performance ratio has already gained the technology a strong position in high-end/flagship segments. OLED is expected to further increase its share and become dominant as the number of suppliers and global capacity increase dramatically over the next five years and cost continues to drop.
MiniLEDs, however, have a card to play in various small to mid-size high added-value display segments, where OLEDs have been less efficient at overcoming its weaknesses such as cost, lack of availability and longevity issues such as burn-in or image retention. In tablets, laptops and high-end monitors for gaming applications, miniLEDs could bring excellent contrast, high brightness and thin form factors at lower cost than OLEDs. The automotive segment is especially compelling, first because of its strong growth potential in terms of volume and revenue, and also because miniLEDs can deliver on every aspect auto-makers are aspiring to: very high contrast and brightness, lifetime, conformability to curved surfaces and ruggedness. Regarding the last point on ruggedness, miniLED offers significant benefits over OLEDs since they only use proven technologies, LED backlights and liquid crystal cells, not much different from already established LCDs. Automakers therefore don’t have to make a leap of faith and hope the new technology will meet the demanding lifetime, environmental and operating temperature specifications they require.

On the TV side, miniLEDs could help LCDs bridge the gap and regain market share against OLEDs on the high-end, large sizes above 65”, and most profitable segments. This opportunity is all the more enticing to panel and display makers that have not invested in OLED technologies and see the potential to extend the lifetime and profitability of their LCD fabs and technologies.

For direct view LED displays, miniLEDs used in conjunction with Chip On Board (COB) architecture could enable higher penetration of narrow pixel pitch LED displays in multiple applications, hence increasing the serviceable market. Die size will evolve continuously toward smaller dimensions, possibly down to 30-50µm in order to reduce cost. Adoption in cinema is still highly uncertain but even modest adoption rates would generate very significant upsides.

The report provides detailed adoption and volume forecasts for each application.
Harvatek or Nationstar’s new “4-in-1” Surface Mount Device (SMD) packages allow LED direct view display makers to alleviate a critical obstacle for miniLED adoption: the need to retool and transition from an SMD to a direct die bonding assembly philosophy.

MiniLEDs should benefit chip makers by increasing their available market. Some are trying to cash in on the opportunity and move up the supply chain by offering miniLED packages and/or BLU modules. For example, Epistar is spinning off but keeping control of its miniLED activities.

A remaining question is how fast equipment makers will develop new generation of miniLED-specific assembly tools that will help speed up adoption by reducing manufacturing costs. Key attributes for such tools are much higher throughput and the ability to handle smaller dies, 100µm or smaller. Various routes are investigated, including upgrade of traditional die assembly technology or more disruptive processes inspired from the vast body of work and technologies being developed for microLEDs. The first to market is Kulicke & Soffa which recently introduced a tool co-developed with startup Rohinni.

The availability of tools capable of efficiently handling smaller dies will in turn enable LCD and LED direct view display makers to further reduce cost by reducing the die size to the smallest level required for each individual applications.

Ultimately, for most of the targeted segments, miniLEDs offer performance close to the incumbent technologies like OLED for high-end consumer displays and SMD LEDs for narrow pitch digital signage. Cost will therefore be a major driver or showstopper for adoption.

The report discusses the major cost contributors and cost-down paths.

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TABLE OF CONTENTS (complete content on i-Micronews.com)
The three-page summary 04
Executive summary 08
Introduction 32
High dynamic range 50
LED BLU technologies 57
MiniLED backlight units 80
MiniLED BLU manufacturing 108
MiniLED assembly 114
MiniLED BLU applications and forecasts 127
> TVs
> Smartphones
> Monitors
> Automotive displays
> Epitaxial forecasts
Conclusions on miniLED BLU 156
Direct view LED displays 158
Overview 160
Market 169
Narrow pitch displays 175
Alternative display technologies 215
LED epitaxial forecast 226
Annex A: LED display driving 237
Annex B: LED for digital cinema 243

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