MicroLED Displays 2019

Status for the consumer display industry

Market and Technology Report 2019
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ACRONYMS

- µLED: microLED
- 3D: three dimensions
- 4K: 3840x2160 resolution
- 4N: Four Nines – meaning 99.99%
- 5N: Five Nines – meaning 99.999%
- 8K: 7680x4320 resolution
- ACLED: Alternating Current Light Emitting Diode
- AI: Artificial Intelligence
- ALD: Atomic Layer Deposition
- AMOLED: Active Matrix OLED
- AR: Augmented Reality
- ASP: Average Selling Price
- a-Si: Amorphous Silicon
- ASP: Average Selling Price
- BLU: Backlight Unit
- CAGR: Compound Annual Growth Rate
- Capex: Capital Expenditure
- CF: Color Filter
- CMOS: Complementary Metal Oxide Semiconductor
- CMP: Chemical Mechanical Planarization
- CR: Contrast Ratio
- CRT: Cathodic Ray Tube
- CSP: Chip Scale Packaging
- DLP: Digital Light Projection
- EL: ElectroLuminescence
- EL-QD: Electroluminescent QD
- EQE: External Quantum Efficiency
- FALD: Full Array Local Dimming
- FHD: Full High Definition (1920x1080)
- FMM: Fine Metal Mask
- FOV: Field Of View
- FWHM: Full Width at Half Maximum
- GDP: Gross Domestic Product
- GOA: Gate on Array
- GX, GenX: fab of Xth generation
- HDR: High Dynamic Range
- HMD: Head Mounted Display/Device
- HUD: Head Up Display
- IC: Integrated Circuit
- IJP: Inkjet Printing
- IP: Intellectual Property
- IQE: Internal Quantum Efficiency
- IR: Infrared
- KBD: Known Bad Die
- KGD: Known Good Die
- KSF: K2SiF6 PFS phosphor
- LC: Liquid Crystal
- LCD: Liquid Crystal Display
- LCOS: Liquid Crystal on Silicon
- LED: Light Emitting Diode
- LLO: Laser Lift-Off
- LTPS: Low Temperature Poly Silicon
- mLED: miniLED
- MMG: Multi Mother Glass
- MOCVD: Metal Organic Chemical Vapor Deposition
- MR: Mixed Reality
- NBP: Narrow Band Phosphor
- NTSC: National Television System Committee
- OEM: Original Equipment Manufacturer
- OLEO: Organic Light Emitting Diode
- OSAT: Outsourced Semiconductor Assembly and Testing
- PCB: Printed Circuit Board
- PDMS: Polydimethylsiloxane (polymer material)
- PECVD: Plasma-Enhanced Chemical Vapor Deposition
- PFS: Potassium Fluoro Silicate
- PL: PhotoLuminescence
- PL-QD: Photoluminescent QD
- PPI: Pixel per Inch
- PVD: Physical Vapor Deposition
- PWM: Pulse Width Modulation
- QD: Quantum Dot
- QDFF: Quantum Dot Color Filter
- QDEF: Quantum Dot Enhancement Filter
- QD-OLED: Quantum Dot OLED
- QWP: Quarter Wave Plate
- RCLED: Resonant Cavity Light Emitting Diode
- RGB: Red, Green and Blue
- RIE: Reactive Ion Etching
- RoHS: Restriction of Hazardous Substances
- SID: Society for Information Display
- TADF: Thermally Activated Delayed Fluorescence
- TFT: Thin Film Transistor
- UHD: Ultra High Definition
- UV: Ultra Violet
- VR: Virtual Reality
- VTE: Vacuum Thermal Evaporation
- WCG: Wide Color Gamut
- WOLED: White OLED
- YAG: Yttrium Aluminum Garnet
**METHODOLOGIES & DEFINITIONS**

Yole’s market forecast model is based on the matching of several sources:

**Comparison with existing data**
- Monitoring of corporate communication
- Using other market research data
- Yole analysis (consensus or not)

**Comparison with prior Yole reports**
- Recursive improvement of dataset
- Customer feedback

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**Top-to-bottom approach**
- Aggregate of market forecasts
  - @ System level

**Bottom-up approach**
- Ecosystem analysis
  - Aggregate of all players’ revenue
  - @ System level

**Market**
- Volume (in Munits)
- ASP (in $)
- Revenue (in $M)

---

**Top-to-bottom approach**
- Aggregate of market forecast
  - @ Semiconductor device level

**Bottom-up approach**
- Ecosystem analysis
  - Aggregate of key players’ revenues
  - @ Semiconductor device level

**Semiconductor foundry activity**
- Capacity investments and equipment needs

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**Preexisting information**

**Primary data**
- Reverse costing
- Patent analysis
- Annual reports
- Direct interviews

**Secondary data**
- Press releases
- Industry organization reports
- Conferences

**Information Aggregation**
MicroLED technology is progressing on all front.

As anticipated, many companies have been showing prototypes since the beginning of 2019.

Interest keep increasing and panels makers are accelerating effort and catching up.

Our estimates of die size required for each applications as well as yield targets have been validated by most players in the industry.

Smartphone was identified as the most challenging application.

Some of the overlooked challenges identified in 2018 such as driving or light extraction are now gathering more attention.

Some of the remaining challenges in term of both technology development (overall efficiency for very small die sizes) and supply chain ramp up were still underestimated.

As a result, our adoption timeline was still too optimistic.

We are now very cautious regarding smartphones: our forecast scenario still consider that adoption in smartphone is possible but the probability is lower than it was are more challenges are identified and OLED keep improving.
MICROLED AND MINILED

There are no strict and commonly accepted definition of mini and microLEDs. Size is the primary criteria but the technologies are better distinguished by a combination of chips size, architecture, manufacturing and assembly requirements:

**Traditional LEDs**
- LCD Backlight
- Direct view LED videowalls

**MiniLED**
- Improved LCD backlight and Direct view LED videowalls
- 120 to 1000 µm on sapphire
- Side up, Flip Chip, Vertical
- 50 to 200 µm on sapphire
- Flip Chip preferred

**MicroLED**
- Self-emissive displays for consumer applications.
- < 5-15 µm edge\(^1\), < 8 µm thick
- Epitaxial substrate removed
- New challenges, architectures

**Chip size and design**
- Traditional LEDs: 120 to 1000 µm on sapphire, Side up, Flip Chip, Vertical
- MiniLED: 50 to 200 µm on sapphire, Flip Chip preferred
- MicroLED: < 5-15 µm edge, < 8 µm thick
- Epitaxial substrate removed
- New challenges, architectures

**Chip Manufacturing**
- Traditional LEDs: Class 10,000 or worse, Mask aligners, PVD…, Laser dicing: 15-25 µm kerf loss
- MiniLED: Same fab + incremental improvement (reduce dicing kerf loss etc.)
- MicroLED: New / significantly upgraded fab, Class 100 with class 10 cells, steppers, ALD, lift off, wafer bonders…, Plasma dicing: 1-3 µm kerf

**Assembly**
- Traditional LEDs: Standard die bonders: 1000 to 50,000 UPH, 25 µm accuracy
- MiniLED: Improved die bonders being developed: target 500,000 UPH or more.
- MicroLED: Need >> 100 million Die Per Hour: orders of magnitude faster than miniLED or traditional LEDs

\(^1\): \(<15 \text{ µm} \) for most applications
MICROLED INDUSTRY DASHBOARD

Technology
- Technology is progressing at a quick rate.
- Progress is being driven by strong interest.
- Costs are increasing at an alarming rate.

Interest
- A large number of major companies have announced plans to enter the space.
- Large ecosystem is emerging as a result of increasing interest.

Supply Chain - Manufacturing
- Equipment vendors are starting to reveal new equipment.
- Major suppliers are evaluating and planning to enter the space.
- More and more companies are disclosing their roadmaps and timelines.

Other
- The industry is focusing on 2D and 3D microLEDs for various applications.
- Flexible microLED displays are gaining momentum for unique applications.
- The industry is developing new materials and processes for enhanced performance.
- The market is looking for new business models and revenue streams.
- The industry is exploring new applications and use cases for microLEDs.
TECHNOLOGY: RECENT PROGRESS AND REMAINING ROADBLOCKS

1. Early stage
   - Epitaxy
   - Chip manufacturing
   - Chip efficiency
   - Testing & yield management
   - Transfer
   - Color conversion
   - Light management
   - Driving

2. Feasibility
3. Technology development
4. Technology demonstration
5. System/equipment development
6. Manufacturing

[1] Average trends: some companies may be significantly more advanced than others in some areas.
Pending incremental capex, some tier-1 LED fabs would be able to manufacture die sizes down to \(~10-20 \, \mu m\). Those are suitable for first generations of products such as smartwatches, low volumes of luxury TVs and, possibly automotive applications.

For microdisplays, the application drives the die size: high pixel density requirements imply small LED pitch and emitter size.

For all other applications, economics drive die size: to address higher volume TV markets as well as tablets, laptops and smartphones at cost compatible with the applications, much smaller dies size \(\leq 5 \, \mu m\) are required [1].

[1]: see discussion in the cost modeling section of this report.

- Needs significantly upgraded capabilities.
- Maintaining high EQE is challenging.
- Transfer and assembly is more challenging.
The microLED industry might be facing an 80/20 conundrum: 20% of the effort solves 80% of the problems but going the last mile to produce consumer-grade displays requires much more time and money than anticipated.

Encouraged by the rapid progress and return on experience gained from the first prototypes, many might underestimate the challenges and efforts required to iron out the final kinks and be ready to cost-efficiently mass produce consumer grade displays with performance matching or exceeded that of OLED. Significant efforts are still required in term of yields as well as display efficiency.

**Prototypes:**
- Just needs to work: most pixels light up, some defects OK.
- Produced at any cost and any yield.
- Lab-scale production
- Sony presented the 1st ever µLED TV prototype in January 2012. Why aren’t there any on the market yet?
- Luxvue was already making prototypes prior to its acquisition by Apple in 2014. Since then, the company has been spending >$200m/year on µLEDs

**Consumer Grade:**
- Zero defects.
- High performance and efficiency >LCD and OLED.
- Impeccable color and brightness homogeneity at any angle.
- No visible stitching or placement errors at any angle.
- Off-state aspects.
- High consistency and Stability (>1000 Hrs).
- High volume supply chain ready.
- Cost efficient manufacturing.
TENTATIVE ROADMAP: WHERE ARE WE?

Technology development

Supply chain and manufacturing

Most of the industry is here

Apple is somewhere here (?)

T0

+18-24 months

+24-30 months

+30-42 months

Multiple iterations
WHY IS SMARTPHONE SO HARD?

Smartphone is by far the most difficult market for microLED. The major reasons are summarized below and discussed extensively throughout this report:

**Strong incumbent technology**

**Challenges**

**Consequences**

Smartphone is the most challenging consumer display application to address. Whether the remaining technical and supply chain roadblocks can be lifted remains a major question!
MICROLED EPIWAFER FORECAST

• In the aggressive scenario, Epiwafer volume could climb to close to XX million 6" a scale similar to the existing LED industry in term of volumes.

• If successful in its initial years, the market would be far from saturated in 2027 and growth could accelerate further beyond that point.

• The base and conservative scenario leading to a much lower scale adoption, the industry backbone would be applications where microLED have very clear elements of differentiation and/or lower barrier of entrance in term of cost or performance.

• Those markets are: automotive, smartwatches, AR, very large TVs.

• Multiple high added value niche applications not factored-in in our scenario could also help support a variety of small and specialized µLED companies (e.g.: HUD for military, various industrial applications etc.)
More than 240 organizations have filed for microLED display-related patents.

The top 35 organizations represent 948 families out of 1219: 78% of the total.

Top ten and top five companies: 41% and 25% respectively, led by Apple and Sony.

When adding up Innolux, Sharp and eLux patents, Foxconn group portfolio is the second largest with 69 unique families.
MICROLED EFFICIENCY

- The External Quantum Efficiency (EQE) of traditional LEDs (> 100 µm) far exceeds that of OLED, however, it decreases significantly when size goes below X µm for GaN based LEDs (blue and green) and below X µm for GaAs based red LEDs.
- The respective contribution of power to generate white color is typically <15% Blue / >60% Green / >30% red\([1]\). As a result, despite significant improvement over the last 18 months (more than 2x) large µLED barely match total OLED efficiency and smaller die (≤ X µm) still falls significantly behind.
- This is compounded by the fact that OLED use resonant cavity effects that concentrate more light into a direction perpendicular to the plane of the display whereas µLED naturally have a “batwing” emission pattern where a lot of the photons are emitted toward the sides at high angles and wasted to the viewer (when not absorbed by the display structure).

[1]: this varies depending on which color gamut / white points are targeted
Typical yield workflow as of 2019:

1. **Wavelength Binning**
   - 95% (Assumes ~1x1 cm² transfer fields, out of spec areas are binned out)

2. **Epitaxial Defect**
   - Epitaxial defects are not binned out; carried downstream in workflow as part of the “functional yield” failure

3. **LED Functional yield**
   - Epitaxial Defect: 99.485%
   - Chip manufacturing: 99.5%

4. **Transfer to Interposer (Optional)**
   - 99.995%

5. **Transfer and Assembly**
   - Transfer: 99.99%

→ ~ 0.5% of the pixels on the panel are defective!

### Yields

<table>
<thead>
<tr>
<th></th>
<th>8K TV</th>
<th>QHD Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td># of LED die per panel</td>
<td>99,532,800</td>
<td>11,059,200</td>
</tr>
<tr>
<td>Number of repair required</td>
<td>519,519</td>
<td>56,947</td>
</tr>
<tr>
<td>Repair cost per panel [1]</td>
<td>$XXX</td>
<td>$XXX</td>
</tr>
</tbody>
</table>

[1]: repair tool depreciation cost only, assuming Xs cycle time per die and $X tool cost. To this, one should add ~X% for overhead, clean room, maintenance, labor etc…
The industry is still in an “Cambrian explosion” phase, with a multiplicity of companies and competing technologies still emerging on a regular basis to offer new solutions to the multiple challenges posed by µLED display manufacturing.

This proliferation offers multiple possible technology paths for the different applications.

At the current stage of the industry, many of these paths are still credible: none as yet emerged as clear winners.

Ultimately, it is probable that different processes and display architectures will co-exist depending on the type of applications, required display performance, supply chain and IP constrains of the different players.

<table>
<thead>
<tr>
<th>Company / Organization</th>
<th>Technology</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXX</td>
<td>Transfer and assembly equipment</td>
<td>Collaboration with X and X. Target 1.5 µm placement accuracy</td>
</tr>
<tr>
<td>XXX</td>
<td>Transfer and assembly equipment</td>
<td>Achieved 2 µm placement accuracy, target 1 µm</td>
</tr>
<tr>
<td>XXX</td>
<td>MicroLED Inspection</td>
<td>Collaboration with X. Both companies part of the X group</td>
</tr>
<tr>
<td>XXX</td>
<td>Mass transfer and Assembly</td>
<td>Fluidic self assembly</td>
</tr>
<tr>
<td>XXX</td>
<td>Transfer and assembly equipment</td>
<td>Part of X, collaboration with X</td>
</tr>
<tr>
<td>XXX</td>
<td>UV microLED</td>
<td>Collaboration with X</td>
</tr>
<tr>
<td>XXX</td>
<td>RGB nanowires on single wafers</td>
<td>Technology from X, former X co-founder</td>
</tr>
<tr>
<td>XXX</td>
<td>Mass transfer</td>
<td>Vacuum flow in anodized aluminum nano-pores</td>
</tr>
<tr>
<td>XXX</td>
<td>Display Inspection (mura)</td>
<td></td>
</tr>
<tr>
<td>XXX</td>
<td>Inspection and laser repair, mass transfer</td>
<td>AOI and photoluminescence</td>
</tr>
<tr>
<td>XXX</td>
<td>Mass Transfer</td>
<td>Collaboration with X</td>
</tr>
<tr>
<td>XXX</td>
<td>Mass transfer</td>
<td>Leveraging Inkjet Technology</td>
</tr>
<tr>
<td>XXX</td>
<td>Laser Lift Off, exposure system, transfer &amp; assembly, color conversion</td>
<td>Collaboration with X, X, X and X</td>
</tr>
<tr>
<td>XXX</td>
<td>Mass transfer</td>
<td>Addressable (deterministic) fluidic assembly</td>
</tr>
</tbody>
</table>

Companies that have emerged on the µLED technology landscape over the last 18 months.
MicroLED are taking baby steps away from the labs into pilot lines but there are no signs of significant volume manufacturing ramp up yet.

**PROGRESS TOWARD MANUFACTURING**

**Front End: Epi and LED fabrication**
- Moving into larger building with 1200 m² clean room for pilot scale fabrication (epi) and R&D.
- No volume manufacturing activity yet but could benefit from X µLED ecosystem: X investor in X+ renting it fab space. X part of X group.
- Most mature supply chain for microdisplay: already owns epi + GaN-on-Si fab with low/mid volume capacity.
- Currently setting up class 100 µLED fab capable of producing 4 µm chips. Planning US$ 1.8 billion investment for Mini LED µLED development and production.
- Pilot line to start H2 2019: epi + chip manufacturing + assembly.
- All operate high quality traditional LED fabs. Some lines could be rapidly upgraded for Gen 1 µLED (>10 µm die).
- Shipping low volumes of microdisplays for evaluation.

**Backplane**
- Established capacity for OLED (LTPS, Oxide) can be used.
- Some panel makers started presenting TFT based prototypes in collaboration with various µLED companies:
  - CSOT
  - SAMSUNG
  - PLANITRIDE
  - TIANMA
  - KYOCERA
  - glo
  - AUO
  - LG

**Assembly, testing, repair**
- Various equipment makers have started developing transfer, testing and repair tools.

- Transfer
- Testing, metrology, repair
  - Tesoro Scientific
This scenario considers only applications where microLED have a clear, strong element of differentiation against incumbent technology AND for which the remaining technological and supply chain roadblocks appear relatively easily removable.
### SELF-EMISSIVE TECHNOLOGIES SCORECARD FOR TVS

#### Emissive technology scorecard

<table>
<thead>
<tr>
<th></th>
<th>Color</th>
<th>Brightness</th>
<th>Efficiency</th>
<th>Long term cost</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Need color filter</td>
<td>Color filters</td>
<td>Complex stack</td>
<td></td>
<td>In production since 2014</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>QD = narrow band</td>
<td>+ : no filter - : conversion</td>
<td>No color filter</td>
<td>Complex stack + QD deposition</td>
<td>Ramp up 2021?</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Broadband unless hyperfluorescent materials (?)</td>
<td>Need color filters to narrow bands</td>
<td>Need color filters to narrow bands</td>
<td>Simpler stack</td>
<td>Ramp up 2023+?</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>QD= Narrow band</td>
<td>No filters, high EQE</td>
<td>No filters, high EQE</td>
<td>Simple stack, cheaper materials</td>
<td>Blue material still a science project</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>LED = narrowband</td>
<td>No filter, highest EQE (?)</td>
<td>No filter, highest EQE (?)</td>
<td>Complex mfg. Costly LEDs</td>
<td>Still a massive engineering project</td>
</tr>
</tbody>
</table>
**MICROLED OPPORTUNITY**

- The automotive display market is expected to grow at a X% CAGR between X and X in term of unit. Revenue grow will be higher due to increasing panel sizes.

- Automakers are already showing interest for µLED. Panel makers and most startup involved in µLED development have made automotive an important, if not a cornerstone market in their strategy. MicroLED companies are already appearing at automotive display trade shows and conferences.

- Due to higher price elasticity, larger die (>X μm could be used, at least initially) and redundancy could be acceptable or even required for the quality-conscious automotive industry.

- Adoption however will take time:
  - µLED development is not mature enough
  - Conservative and long development and qualification cycles of the automotive industry: unlike miniLED LCD backlight, µLED is an entirely new technology.

![MicroLED Displays 2019 | Sample | www.yole.fr | ©2019](image-url)
### MAJOR PLAYERS BY TECHNOLOGY NODE (NON EXHAUSTIVE)

<table>
<thead>
<tr>
<th>Epitaxy</th>
<th>MicroLED structure</th>
<th>Transfer and interconnect</th>
<th>Hybridization</th>
<th>Testing and repair/defect management</th>
<th>Color conversion</th>
<th>Light extraction and shaping</th>
<th>Display driving and architecture</th>
</tr>
</thead>
</table>

- Epitaxy
- MicroLED structure
- Transfer and interconnect
- Hybridization
- Testing and repair/defect management
- Color conversion
- Light extraction and shaping
- Display driving and architecture
## OVERVIEW OF LARGE COMPANIES AND THEIR MICROLED ECOSYSTEMS

### LED Chips (design or manufacturing)

<table>
<thead>
<tr>
<th>Company</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
</tr>
</thead>
</table>

### TFT & panel makers

<table>
<thead>
<tr>
<th>Company</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
</tr>
</thead>
</table>

### Device makers & OEMs

<table>
<thead>
<tr>
<th>Company</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
<th>Sample</th>
</tr>
</thead>
</table>
CHINA MICROLED ECOSYSTEM

Epitaxy & chip manufacturing
Monolithic
Backplane
Assembly and testing
Final panel e.g. drivers etc.
OEMs & consumer brands

[Diagram with various components and logos]
**THROUGHPUT**

Throughput (die per hour = DPH) is driven by stamp size, cycle time and pixel pitch.

<table>
<thead>
<tr>
<th>4K 55&quot; TV</th>
<th>Smartwatches</th>
<th>Smartphones</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="4K_55_TV.png" alt="Image" /></td>
<td><img src="Smartwatch.png" alt="Image" /></td>
<td><img src="Smartphone.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Display PPI</th>
<th>80</th>
<th>325</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel pitch (X,Y)</td>
<td>(318µm, 318µm)</td>
<td>(78µm, 78µm)</td>
<td>(42µm, 42µm)</td>
</tr>
<tr>
<td>Max # of pick-up heads on a Xcm² array</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

**Throughput with X s cycle time and Xcm² array**

*(Die Per Hour = DPH)*

- **Throughputs**
  - Increases with higher pixel density
  - Increases with larger stamp size
  - Decreases with longer cycle time

| Throughputs | × million | × million | × million |
MICRODRIVER COST: REALITY CHECK

Note: for TV, LTPS would have to be assembled from multiple modules since effective production of large panel on G6 substrates is not possible.
• With µLED die performance, transfer processes capabilities and throughput getting closer to targets for volume manufacturing, yield management and repair might become the major roadblock still standing between the lab and commercial production. This section focuses on the major µLED yield contributors:
  o Epitaxial wavelength homogeneity.
  o LED functional yield (epitaxy and chip fabrication defects).
  o Transfer and from epitaxial to interposer (if used).
  o Transfer and assembly from interposer to backplane.
WAVELENGTH UNIFORMITY

- Yields related to wavelength uniformity across wafers depend on:
  - Maximum acceptable spread within a display (defined by the display maker)
  - Capabilities of the epitaxial process.
  - Size of the transfer fields.

- As discussed in the epitaxy section of this report, 95% wavelength binning yield appears to be a reasonable and achievable target, i.e.: 95% of the surface of wafer (minus the edge exclusion zone) can be binned into 10x10 to 20x20 mm transfer fields that each have a maximum wavelength spread of 1 to 2 nm.
INCREASE LED FUNCTIONAL YIELD

The industry doesn’t yet have experience manufacturing µLED with the appropriate equipment and clean room. Players therefore still disagree regarding the outcome of the interplay of two driving:

For a fixed amount of defects on a wafer, the proportion of bad LED declines as die size decreases. In that case, functional yields could increase to >5N for die 10 µm and smaller (illustration on the right).

As size of the die and its smallest features[1] decrease, the size of killer defects decreases as well[2]. This increases the number of defects and drives the need for better clean rooms, tools that generates less particles, better cleaning processes etc.

Most companies however have roadmap with functional yields improving from X to X once pilot fabs are ready, and then to X or X at maturity in dedicated high volume fabs.

<table>
<thead>
<tr>
<th>Defect density</th>
<th>3 µm die</th>
<th>5 µm die</th>
<th>10 µm die</th>
<th>20 µm die</th>
<th>50 µm die</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>0.2 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>0.3 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>0.4 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>0.5 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>1 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10 #/cm²</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Functional yield estimates for different defect densities and die size derived from a Murphy defect model. Defect densities = epi + chip manufacturing defects.
# Conclusions on Yield Management and Repair Strategies

<table>
<thead>
<tr>
<th>Improve µLED Functional Yield</th>
<th>Multi Die Repair</th>
<th>Redundancy[1]</th>
<th>KGD Binning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>• Most natural path, doesn’t require additional process</td>
<td>• Leverage on know-how and equipment developed for transfer</td>
<td>• Easy to implement.</td>
<td>• Potentially best cost position (on par with multidie repair)</td>
</tr>
<tr>
<td><strong>Challenges</strong></td>
<td><strong>Challenges</strong></td>
<td><strong>Challenges</strong></td>
<td><strong>Challenges</strong></td>
</tr>
<tr>
<td>• No agreements on realistic target but most target 4N, some 4N5.</td>
<td>• Random depopulation of donor wafer: will need some good algorithms to optimize</td>
<td>• Doubles die cost: requires use of smaller die than other methods</td>
<td>• Needs tools for on-wafer µLED testing + actionable transfer process</td>
</tr>
<tr>
<td><strong>Maturity</strong></td>
<td><strong>Maturity</strong></td>
<td><strong>Maturity</strong></td>
<td><strong>Maturity</strong></td>
</tr>
<tr>
<td>• Low: will have more visibility when the first dedicated µLED fabs (better clean room and tools) go live.</td>
<td>• Medium: some companies making good progress but little information on actual outcomes, challenges etc.</td>
<td>• As mature as transfer processes</td>
<td>• Low: functional led testing tools in development. • Actionable transfer process: self assembly OK. Can deterministic methods be developed?</td>
</tr>
<tr>
<td><strong>Proponents</strong></td>
<td><strong>Proponents</strong></td>
<td><strong>Proponents</strong></td>
<td><strong>Proponents</strong></td>
</tr>
<tr>
<td>• Sample</td>
<td>• Sample</td>
<td>• Sample</td>
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<tr>
<td>• Sample</td>
<td>• Sample</td>
<td>• Sample</td>
<td>• Sample</td>
</tr>
</tbody>
</table>

[1]: Redundancy is discussed extensively in Luxvue and Apple patents + a partner at KPCB, a Luxvue investor publically disclosed in 2013 that the company was using redundancy. Obviously, the information could very well be obsolete by now, but it shows that redundancy was at least initially considered as the path of least resistance.
HYBRIDIZATION: EXAMPLES OF BONDING PROCESSES

Hybrid bonding: Copper and oxide

- Copper deposition
- Oxide deposition
- Planarization & Copper reveal
- Alignment
- Plasma Activation
- Bonding (polymer fully cured & bonding of copper interface)

Hybrid bonding: Copper and polymer

- Copper deposition
- Polymer deposition
- Polymer 50% cured
- Activation with formic acid gas
- Bonding (polymer 100% cured & bonding of copper interface)
- Alignment
- Polymer removal
- Copper removal & planarization

Microtube bonding

- Patterning
- Flip Chip
- Microtube bonding
- Hybridisation

Hybridized active-matrix GaN 873x500 pixel microdisplay at 10μm pitch using microtube bonding

Source: LETI
Contact our Sales Team for more information.

Yole Développement


MiniLED for Display Applications: LCD and Digital Signage

Next-Generation Human Machine Interaction in Displays 2019

Displays & Optical Vision Systems for VR, AR & MR 2018

MicroLED Displays: Intellectual Property Landscape
Yole Développement

From Technologies to Market
**Life Sciences & Healthcare**
- Microfluidics
- BioMEMS & Medical Microsystems
- Inkjet and accurate dispensing
- Solid-State Medical Imaging & BioPhotonics
- BioTechnologies

**Power & Wireless**
- RF Devices & Technologies
- Compound Semiconductors & Emerging Materials
- Power Electronics
- Batteries & Energy Management

**Semiconductor & Software**
- Package, Assembly & Substrates
- Semiconductor Manufacturing
- Memory
- Software & Computing

**Photonics, Sensing & Display**
- Solid-State Lighting
- Display
- MEMS, Sensors & Actuators
- Imaging
- Photonics & Optoelectronics
4 BUSINESS MODELS

- **Consulting and Analysis**
  - Market data & research, marketing analysis
  - Technology analysis
  - Strategy consulting
  - Reverse engineering & costing
  - Patent analysis
  - Design and characterization of innovative optical systems
  - Financial services (due diligence, M&A with our partner)

- **Syndicated reports**
  - Market & technology reports
  - Patent investigation and patent infringement risk analysis
  - Teardowns & reverse costing analysis
  - Cost simulation tool
    - [www.i-Micronews.com/reports](http://www.i-Micronews.com/reports)

- **Monitors**
  - Monthly and quarterly update
  - Excel database covering supply, demand, and technology
  - Price, market, demand and production forecasts
  - Supplier market shares

- **Media**
  - i-Micronews.com website and application
  - i-Micronews e-newsletter
  - Communication & webcast services
  - Events: TechDays, forums,…

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- Market, technology and strategy consulting
- www.yole.fr

**SystemPlus Consulting**
- Manufacturing costs analysis
- Teardown and reverse engineering
- Cost simulation tools
- www.systemplus.fr

**KnowMade**
- IP analysis
- Patent assessment
- www.knowmade.fr

**Piseo**
- Design and characterization of innovative optical systems
- www.piseo.fr

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- Due diligence
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OUR GLOBAL ACTIVITY

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  - Yole Deutschland
    - Frankfurt
  - Nantes
  - Vénissieux

- **30%**
  - of our business
  - Yole Korea
    - Seoul
  - Tokyo
  - Greater China office
    - Hsinchu

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    - Cornelius
  - Palo Alto
  - Hsinchu
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Device manufacturers

Suppliers: material, equipment, OSAT, foundries...

Financial investors, R&D centers
SERVING MULTIPLE INDUSTRIAL FIELDS

We work across multiples industries to understand the impact of More-than-Moore technologies from device to system.

From A to Z…

Industrial and defense

Medical systems

Energy management

Automotive

Transportation makers

Mobile phone and consumer electronics
Over the course of more than 20 years, Yole Développement has grown to become a group of companies. Together with System Plus Consulting and KnowMade, we now provide marketing, technology and strategy consulting, media and corporate finance services, reverse costing, structure, process and cost analysis services and well as intellectual property (IP) and patent analysis. Together, our group of companies is collaborating ever closer and therefore will offer, in 2019, a collection of over 125 reports, 10 new monitors and 120 teardowns. Combining respective expertise and methodologies from the three companies, they cover:

- MEMS & Sensors
- RF devices & technologies
- Medical technologies
- Semiconductor Manufacturing
- Advanced packaging
- Memory
- Batteries and energy management
- Power electronics
- Compound semiconductors
- Solid state lighting
- Displays
- Software
- Imaging
- Photonics

If you are looking for:
- An analysis of your product market and technology
- A review of how your competitors are evolving
- An understanding of your manufacturing and production costs
- An understanding of your industry’s technology roadmap and related IPs
- A clear view supply chain evolution

Our reports and monitors are for you!

Our team of over 70 analysts, including PhD and MBA qualified industry veterans from Yole Développement, System Plus Consulting and KnowMade, collect information, identify trends, challenges, emerging markets, and competitive environments. They turn that information into results and give you a complete picture of your industry’s landscape. In the past 20 years, we have worked on more than 2,000 projects, interacting with technology professionals and high-level opinion makers from the main players of their industries and realized more than 5,000 interviews per year.

WHAT TO EXPECT IN 2019?
In 2019 we will extend our offering with a new ‘monitor’ product which provides more updates on your industry during the year. The Yole Group of Companies is also building on and expanding its investigations of the memory industry. Moreover, in parallel, the Yole Group reaffirms its commitment to a new collection of reports mixing software and hardware and is increasing its involvement in displays, radio-frequency (RF) technology, advanced substrates, batteries and compound semiconductors. Last but not least, System Plus Consulting is developing its teardowns service providing 120+ offers related to phones, smart home, wearables and connected devices. Discover our 2019 program right now, and ensure you get a true vision of the industry. Stay tuned!
18 fields of excellence combined with six markets to provide a complete picture of your industry landscape

**Market – Technology – Strategy – by Yole Développement**
Yole Développement (Yole) offers market reports including quantitative market forecasts, technology trends, company strategy evaluation and indepth application analyses. Yole will publish more than 55 reports in 2019, with our partner PISEO contributing to some of the lighting reports.

The Reverse Costing® report developed by System Plus Consulting provides full teardowns, including detailed photos, precise measurements, material analyses, manufacturing process flows, supply chain evaluations, manufacturing cost analyses and selling price estimations. The reports listed below are comparisons of several analyzed components from System Plus Consulting. More reports are however available, and over 60 reports will be released in 2019. The complete list is available at www.systemplus.fr.

**Patent Reports – by KnowMade**
More than describing the status of the IP situation, these analyses provide a missing link between patented technologies and market, technological and business trends. They offer an understanding of the competitive landscape and technology developments from a patent perspective. They include key insights into key IP players, key patents and future technology trends. For 2019 KnowMade will release over 15 reports.

**The markets targeted are:**
- Mobile & Consumer
- Automotive & Transportation
- Medical
- Industrial
- Telecom & Infrastructure
- Defense & Aerospace

Linked reports are dealing with the same topic to provide a more detailed analysis.
### OUR 2019 REPORTS COLLECTION (1/5)

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#### MEMS & SENSORS

- **MARKET AND TECHNOLOGY REPORT**
  - Status of the MEMS Industry 2019 - Update
  - Status of the Audio Industry 2019 - New
  - Uncooled Infrared Imagers and Detectors 2019 – Update
  - Consumer Biometrics: Technologies and Market Trends 2018
  - MEMS Pressure Sensor Market and Technologies 2018
  - Gas & Particle Sensors 2018

- **STRUCTURE, PROCESS & COST REPORT**
  - MEMS & Sensors Comparison 2019
  - MEMS Pressure Sensor Comparison 2018
  - Particle Sensors Comparison 2019
  - Miniaturized Gas Sensors Comparison 2018

- **PATTERN REPORT**
  - MEMS Foundry Business Portfolio 2019 - New
  - Miniaturized Gas Sensors 2019 - New

#### PHOTONIC AND OPTOELECTRONICS

- **MARKET AND TECHNOLOGY REPORT**
  - Silicon Photonics and Photonic Integrated Circuits 2019
  - LiDARs for Automotive and Industrial Applications 2019 - Update

- **PATTERN REPORT**
  - Silicon Photonics for Data Centers: Optical Transceiver 2019 - New
  - LiDAR for Automotive 2018

#### RF DEVICES AND TECHNOLOGIES

- **MARKET AND TECHNOLOGY REPORT**
  - 5G’s Impact on RF Front-End Module and Connectivity for Cell Phones 2019 – Update
  - 5G Impact on Telecom Infrastructure 2019 - New
  - Radar and Wireless for Automotive: Market and Technology Trends 2019 - Update
  - Passive & Active Antenna Systems for Telecom Infrastructure 2019 - New
  - RF Standards and Technologies for Connected Objects 2018

- **STRUCTURE, PROCESS & COST REPORT**
  - RF Front-End Module Comparison 2019 - Update
  - Automotive Radar RF Chipset Comparison 2018

- **PATTERN REPORT**
  - Antenna for 5G Wireless Communications 2019 - New
  - RF Front End Modules for Cellphones 2018
  - RF Filter for 5G Wireless Communications: Materials and Technologies 2019
  - RF GaN 2019 – Patent Landscape Analysis

Update : 2018 version still available

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**IMAGING**
- **MARKET AND TECHNOLOGY REPORT**
  - Status of the CIS Industry 2019: Technology and Foundry Business - Update
  - Imaging for Automotive 2019 - Update
  - Neuromorphic Technologies for Sensing 2019 - Update
  - Status of the CCM and WLO Industry 2019 – Update
  - 3D Imaging & Sensing 2018
  - Machine Vision for Industry and Automation 2018
  - Sensors for Robotic Vehicles 2018
- **STRUCTURE, PROCESS & COST REPORT**
  - Compact Camera Modules Comparison 2019
  - CMOS Image Sensors Comparison 2019
- **PATENT REPORT**
  - Facial & Gesture Recognition Technologies in Mobile Devices 2019 - New
  - Apple iPhone X Proximity Sensor & Flood Illuminator 2018

**MEDICAL IMAGING AND BIOPHOTONICS**
- **MARKET AND TECHNOLOGY REPORT**
  - X-Ray Detectors for Medical, Industrial and Security Applications 2019- New
  - Microscopy Life Science Cameras: Market and Technology Analysis 2019
  - Ultrasound technologies for Medical, Industrial and Consumer Applications 2018
- **PATENT REPORT**
  - Optical Coherence Tomography Medical Imaging 2018

**MICROFLUIDICS**
- **MARKET AND TECHNOLOGY REPORT**
  - Status of the Microfluidics Industry 2019 - Update
  - Organ-on-a-Chip Market & Technology Landscape 2019 - Update
  - Point-of-Need Testing Application of Microfluidic Technologies 2018
  - Liquid Biopsy: from Isolation to Downstream Applications 2018
  - Chinese Microfluidics Industry 2018
- **PATENT REPORT**
  - Microfluidic Manufacturing Technologies 2019 – New
  - Nanopore Sequencing 2019 - New

**INKJET AND ACCURATE DISPENSING**
- **MARKET AND TECHNOLOGY REPORT**
  - Inkjet Printheads - Dispensing Technologies & Market Landscape 2019 - Update
  - Emerging Printing Technologies for Microsystem Manufacturing 2019 - New
  - Inkjet Functional and Additive Manufacturing for Electronics 2018
- **STRUCTURE, PROCESS & COST REPORT**
  - Piezoelectric Devices from Bulk to Thin Film 2019 - New
  - Piezoelectric Materials from Bulk to Thin Film Comparison 2019

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BIOMEMS & MEDICAL MICROSYSTEMS

- MARKET AND TECHNOLOGY REPORT
  - Medical Wearables: Market & Technology Analysis 2019 - New 📈
  - Neurotechnologies and Brain Computer Interface 2018 📈
  - BioMEMS & Non-Invasive Sensors: Microsystems for Life Sciences & Healthcare 2018 📈

- PATENT REPORT
  - 3D Cell Printing 2019 - New 📈
  - Circulating Tumor Cells Isolation 2019 - New 📈

SOFTWARE AND COMPUTING

- MARKET AND TECHNOLOGY REPORT
  - Artificial Intelligence Computing For Automotive 2019 - New 📈
  - Hardware and Software for Artificial Intelligence (AI) in Consumer Applications 2019 - Update 📈
  - Image Signal Processor and Vision Processor Market and Technology Trends 2019 📈
  - xPU (Processing Units) for Cryptocurrency, Blockchain, HPC and Gaming 2019 – New 📈
  - Artificial Intelligence for Medical Imaging 2019 - New 📈

- PATENT REPORT
  - Artificial Intelligence for Medical Diagnostics - New 📈

MEMORY

- MARKET AND TECHNOLOGY REPORT
  - Status of the Memory Industry 2019 - New 📈
  - MRAM Technology and Business 2019 - New 📈
  - Emerging Non-Volatile Memory 2018 📈

- STRUCTURE, PROCESS & COST REPORT
  - Memory Comparison 2019 📈

- PATENT REPORT
  - Magnetoresistive Random-Access Memory (MRAM) 2019 - New 📈
  - 3D Non-Volatile Memory 2018 📈

ADVANCED PACKAGING

- MARKET AND TECHNOLOGY REPORT
  - Fan Out Packaging Technologies and Market Trends 2019 - Update 📈
  - 3D TSV Integration and Monolithic Business Update 2019 - Update 📈
  - Advanced RF SiP for Cellphones 2019 - Update 📈
  - Status of the Advanced Packaging Industry 2019 - Update 📈
  - Status of the Advanced Substrates 2019 - Update 📈
  - Panel Level Packaging Trends 2019 - Update 📈
  - Automotive Packaging Market & Technology Trends 2019 - New 📈
  - Trends in Automotive Packaging 📈
  - Thin-Film Integrated Passive Devices 2018 📈

- STRUCTURE, PROCESS & COST REPORT
  - Advanced RF SiP for Cellphones Comparison 2019 📈
OUR 2019 REPORTS COLLECTION (4/5)

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**SOLID STATE LIGHTING**

**MARKET AND TECHNOLOGY REPORT**
- Status of the Solid State Light Source Industry 2019 - New
- Edge Emitting Lasers (EELS) 2019 - New
- Light Shaping Technologies 2019 - New
- Automotive Advanced Front Lighting Systems 2019 - New
- VCSELs – Market and Technology Trends 2019 - Update
- IR LEDs and Laser Diodes – Technology, Applications, and Industry Trends 2018
- UV LEDs - Technology, Manufacturing and Application Trends 2018
- LiFi: Technology, Industry and Market Trends 2018

**STRUCTURE, PROCESS & COST REPORT**
- VCSEL Comparison 2019

**PATENT REPORT**
- VCSELs 2018

**DISPLAY**

**MARKET AND TECHNOLOGY REPORT**
- Next Generation 3D Displays 2019 - New
- Next Generation Human Machine Interaction (HMI) in Displays 2019 - New
- Micro-and Mini-LED Displays 2019 - Update
- Displays & Optical Vision Systems for VR, AR & MR 2018

**PATENT REPORT**
- MicroLED Displays: Intellectual Property Landscape 2018

**BIOTECHNOLOGIES**

**MARKET AND TECHNOLOGY REPORT**
- CRISPR-Cas9 Technology: From Lab to Industries 2018

**PATENT REPORT**
- Personalized Medicine 2019 – New

**SEMICONDUCTOR MANUFACTURING**

**MARKET AND TECHNOLOGY REPORT**
- Nano-Imprint Technology Trends for Semiconductor Applications 2019 - New
- Equipment and Materials for Fan Out Packaging 2019 - Update
- Equipment for More than Moore: Thin Film Deposition & Etching 2019 - New
- Wafer Starts for More Than Moore Applications 2018
- Polymeric Materials at Wafer-Level for Advanced Packaging 2018
- Bonding and Lithography Equipment Market for More than Moore Devices 2018

**STRUCTURE, PROCESS & COST REPORT**
- Wafer Bonding Comparison 2018

**PATENT REPORT**
- Hybrid Bonding for 3D Stack 2019 – New

**UPDATE**

- Version still available

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OUR 2019 REPORTS COLLECTION (5/5)

18 fields of excellence combined with six markets to provide a complete picture of your industry landscape

POWER ELECTRONICS

- MARKET AND TECHNOLOGY REPORT
  - Power SiC: Materials, Devices and Applications 2019 - Update
  - Power Electronics for EV/HEV and e-mobility: Market, Innovations and Trends 2019 - Update
  - Status of the Power Electronics Industry 2019 - Update
  - Discrete Power Packaging: Material Market and Technology Trends 2019 - New
  - Status of the Power ICs Industry 2019 - Update
  - Status of the Passive Components for the Power Electronics Industry 2019 - Update
  - Status of the Inverter Industry 2019 - Update
  - Status of the Power Module Packaging Industry 2019 - Update
  - Wireless Charging Market Expectations and Technology Trends 2018
  - Power GaN 2018: Epitaxy, Devices, Applications and Technology Trends

- STRUCTURE, PROCESS & COST REPORT
  - Automotive Power Module Packaging Comparison 2018
  - GaN-on-Silicon Transistor Comparison 2019
  - SiC Transistor Comparison 2019

- PATENT REPORT
  - Power SiC: Materials, Devices and Modules 2019 - New
  - Power GaN: Materials, Devices and Modules 2019 – Update

BATTERY & ENERGY MANAGEMENT

- MARKET AND TECHNOLOGY REPORT
  - Status of the Rechargeable Li-ion Battery Industry 2019 - New
  - Li-ion Battery Packs for Automotive and Stationary Storage Applications 2019 - Update

- PATENT REPORT
  - Battery Energy Density Increase: Materials and Emerging Technologies 2019 - New
  - Solid-State Batteries 2019 - New
  - Status of the Battery Patents 2018

COMPOUND SEMI.

- MARKET AND TECHNOLOGY REPORT
  - Emerging Semiconductor Substrates: Market & Technology Trends 2019 - New
  - Status of the Compound Semiconductor Industry 2019 - New
  - InP Materials, Devices and Applications 2019 - New
  - GaAs Wafer and Epiwafer Market: RF, Photonics, LED and PV Applications 2018

- PATENT REPORT
  - GaN-on-Silicon Substrate: Materials, Devices and Applications 2019 - Update

Update: 2018 version still available
Get the most updated overview of your market to monitor your strategy

Yole Développement, System Plus Consulting and KnowMade, all part of the Yole Group of Companies, are launching a collection of 10 monitors in 2019. The monitors aim to provide updated market, technology and patent data as well dedicated quarterly analyses of the evolution in your industry over the previous 12 months. Furthermore, you can benefit from direct access to the analyst for an on-demand Q&A and discussion session regarding trend analyses, forecasts and breaking news.

Topics covered will be compact camera modules (CCMs), advanced packaging, compound semiconductors, microfluidics, batteries, RF and memory.

**MARKET MONITOR** by Yole Développement

**A FULL PACKAGE:**
The monitors will provide the evolution of the market in units, wafer area and revenues. They will also offer insights into what is driving the business and a close look at what is happening will also be covered in it.

The following deliverables will be included in the monitors:

- An Excel database with all historical and forecast data
- A PDF slide deck with graphs and comments/analyses covering the expected evolutions

**ADVANCED PACKAGING – NEW**
This monitor will provide the evolution of the advanced packaging platforms. It will cover Fan-Out Wafer Level Packaging (WLP), Fan-Out Panel Level Packaging (PLP), Wafer-Level Chip Scale Packaging (WLCSP), Flip Chip packaging platforms, and 2.5D and 3D Through Silicon Via (TSV) integration. **Frequency:** Quarterly, starting from Q3 2019

**COMPOUND SEMI. – NEW**
This monitor will describe how the compound semiconductor industry is evolving. It will offer a close look at GaAs, InP, SiC, GaN and other compounds of interest providing wafer volumes, revenues, application breakdowns and momentum. **Frequency:** Quarterly, starting from Q3 2019

**CAMERA MODULE – NEW**
This monitor will provide the evolution of the imaging industry, with a close look at image sensor, camera module, lens and VCM. Volumes, revenues and momentum of companies like Sony, Samsung, Omnivision and OnSem will thus be analysed. **Frequency:** Quarterly, starting from Q3 2019

**MEMORY – UPDATE**
For the memory industry you can have access to a quarterly monitor, as well as an additional service, a monthly pricing. Both services can be bought separately:

- DRAM Service: Including a quarterly monitor and monthly pricing.
- NAND Service: Including a quarterly monitor and monthly pricing.

**REVERSE TECHNOLOGY MONITOR** by System Plus Consulting

**SMARTPHONES – NEW**
To stay updated on the latest components, packaging and silicon chip choices of the smartphone makers, System Plus Consulting has created its first Smartphone Reverse Technology monitor. This year, get access to the packaging and silicon content database of at least 20 different flagship smartphones – more than five per quarter. Starting at the beginning of 2019, the monitor will include an Excel database report for each phone and a quarterly comparison.
OUR 2019 MONITORS COLLECTION (2/2)

Get the most updated overview of your market to monitor your strategy

PATENT MONITOR by KnowMade

A FULL PACKAGE:
Starting at the beginning of the year, the KnowMade monitors include the following deliverables:

• An Excel file including the monthly IP database of:
  • New patent applications
  • Newly granted patents
  • Expired or abandoned patents
  • Transfer of IP rights through re-assignment and licensing
  • Patent litigation and opposition

• Quarterly report including a PDF slide deck with the key facts & figures of the quarter: IP trends over the three last months, with a close look to key IP players and key patented technologies.

○ GaN for Power & RF Electronics
  Wafers and epiwafers, GaN-on-SiC, silicon, sapphire or diamond, semiconductor devices such as transistors, and diodes, devices and applications including converters, rectifiers, switches, amplifiers, filters, and Monolithic Microwave Integrated Circuits (MMICs), packaging, modules and systems.

○ GaN for Optoelectronics & Photonics
  Wafers and epiwafers, GaN-on-sapphire, SiC or silicon; semiconductor devices such as LEDs and lasers; and applications including lighting, display, visible communication, photonics, packaging, modules and systems.

○ Li-ion Batteries
  Anodes made of lithium metal, silicon, and lithium titanate (LTO); cathodes made of Lithium Iron Phosphate (LFP), Nickel-Manganese-Cobalt (NMC), Lithium Nickel Cobalt Aluminium Oxide (NCA), Lithium Nickel Metal Dioxide (LiNiMo2), Lithium Metal Phosphate (LiMPO4), and Lithium Metal Tetroxide (LiMO4); electrolytes including liquid, polymer/gel, and solid inorganics; ceramic and other separators; battery cells including thin film/microbattery, flexible, cylindrical and prismatic; and battery packs and systems.

○ Post Li-ion Batteries
  Battery technologies including redox-flow batteries, sodium-ion, lithiurnsulfur, lithium-air, and magnesium-ion, and their supply chains, including electrodes, electrolytes, battery cells and battery packs/systems.

○ Solid-State Batteries
  Supply chain including electrodes, battery cells, battery packs/systems and electrolytes, including polymer, inorganic and inorganic/polymer, inorganic materials, including argyrodites, Lithium Super Ionic CONductor, (LISICONs), Thio-LISICONs, sulfide glasses, oxide glasses, perovskites, anti-perovskites and garnets.

○ RF Acoustic Wave Filters
  Including Surface Acoustic Wave (SAW), Temperature Compensated (TC)- SAW, Bulk Acoustic Wave- Free-standing Bulk Acoustic Resonator (BAWFBAR), BAW-Solidly-Mounted Resonator (BAW-SMR), and Packaging.

○ RF Power Amplifiers
  Including Low Noise Amplifiers, Doherty Amplifiers, Packaging, and Millimeter-Wave technology.

○ RF Front-End Modules

○ Microfluidics
  From components to chips and systems, including all applications.
To meet the growing demand for market, technological and business information, i-Micronews Media integrates several tools able to reach each individual contact within its network.

We will ensure your company benefits from this

### ONLINE

- i-Micronews e-newsletter
- i-Micronews.com
- FreeFullPDF.com

**Unique, cost-effective ways to reach global audiences.**

Online display advertising campaigns are great strategies for improving your product/brand visibility. They are also an efficient way to adapt with the demands of the times and to evolve an effective marketing plan and strategy.

#15,800+ monthly unique visitors on i-Micronews.com
#10,900+ weekly readers of i-Micronews e-newsletter

### ONSITE

- Events

**Brand visibility, networking opportunities**

Today’s technology makes it easy for us to communicate regularly, quickly, and inexpensively – but when understanding each other is critical, there is no substitute for meeting in-person. Events are the best way to exchange ideas with your customers, partners, prospects while increasing your brand/product visibility.

#110 attendees on average
#7+ key events planned for 2019 on different topics

### IN PERSON

- Webcasts

**Targeted audience involvement equals clear, concise perception of your company’s message.**

Webcasts are a smart, innovative way of communicating to a wider targeted audience. Webcasts create very useful, dynamic reference material for attendees and also for absentees, thanks to the recording technology.

#380 registrants per webcast on average to gain new leads for your business

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