MicroLED Displays:
Hype and Reality, Hopes and Challenges.

Webcast – March 29th 2017
Yole Développement

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DISPLAY ACTIVITIES: COST MODELING, TEAR DOWN ANALYSIS AND REVERSE COSTING

Display Price+

Cost & Price Tool for Display Devices

The most complete and powerful costing tool

From a short data input list, with no need for technical expertise, to a detailed data input list and fine tuning of technical parameters, Display Price+ will help you to calculate your manufacturing cost and estimate your selling price.

System Plus Consulting has used its expertise to develop an efficient and easy-to-use cost simulation tool able to simulate most display technologies in production.

How does it work?

1. Describe your device
   Select LCD or OLED display, touch screen, backlight, additional films, adherence, etc.

2. Enter physical parameters
   Technology description and process parameters, as well as options and sub-descriptions.

3. Enter the manufacturing location
   Technology description: mother glass substrate size and generation, clean room and equipment parameters.

4. Get the manufacturing cost
   Existing direct selling price, and cost for display on how factors like backlight, display modules, assembly and manufacturing.

Find more information here
What Are MicroLED Displays?
**LCD**

Light is generated by an LED backlight and goes through a matrix of liquid crystal “light switches” and colour filters constituting the individual subpixel.

**Emissive**

Each sub-pixel is a tiny light emitter which brightness can be individually controlled.
WHAT IS A MicroLED DISPLAY?

Self emitting displays (just like OLED) that use individual, small LED chips as the emitters.
POTENTIAL MICROLED BENEFITS

- Low power consumption.
- Perfect black + high brightness = High Dynamic Range (contrast).
- Wide color gamut.
- Long lifetime, environmental stability.
- High Resolution/Pixel density.
- Fast refresh rates.
- Wide viewing angles.
- Curved/flexible backplanes.
- Integration of sensors within the display front-plane.
Do we have the best display technology ever?
Challenges
• LEDs are commonly used in large direct emissive video billboards (stadium, advertising…)
• **Discrete packaged LED** containing red, green and blue chips to form the individual pixels
• Pitch: 1 to 40 mm depending on display size and resolution.
MICROLED DISPLAY PITCH

Evolution of Sub-pixel pitch with increasing PPI

Pixel Density - PPI

Subpixel Lowest Pitch (µm)

4K 55” TV

Samsung

Smart Watch

Oppo

Smartphone

Apple

Consumer VR

Oculus

AR/MR Microdisplays

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MICROLED DISPLAY ASSEMBLY

4K Display (TV, smartphone…): 24.9 million µLED chips

• Traditional pick and place equipment
  ~ 1000 hours → 41 days…
• Small chip handling (<10 µm)?
• Accuracy?

Need for technologies to handle 1000’s chips simultaneously!
• 1000’s to 100,000’s chips per cycle.
• Electrostatic, magnetic, electromagnetic, adhesive… MEMS or passive.
MICROLED EFFICIENCY

Problem compounded by the low current driving regime in most applications. Need to improve to > 50% to deliver on power consumption promises:

Chip architecture + Manufacturing processes
## DEFECT MANAGEMENT

### µLED Yield

Epitaxy + chip manufacturing: dead or dim µLED pixel.

### Transfer Yield

Die not properly picked or placed, or faulty connection to the TFT: missing, dead, or “always-on” pixels.

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<table>
<thead>
<tr>
<th>µLED Yield</th>
<th>Transfer Yield</th>
<th>Combined Defect Rate (in ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.9%</td>
<td>99.9%</td>
<td>20 ppm</td>
</tr>
<tr>
<td>99.99%</td>
<td>99.99%</td>
<td>2 ppm</td>
</tr>
<tr>
<td>99.999%</td>
<td>99.999%</td>
<td>0.2 ppm</td>
</tr>
</tbody>
</table>

Most high-end displays are guaranteed zero defects.
The choice for the best defect management strategy is application dependent:

<table>
<thead>
<tr>
<th></th>
<th>Smartwatch</th>
<th>2K Smartphone</th>
<th>4K TV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel density</td>
<td>325 PPI</td>
<td>577 PPI</td>
<td>80 PPI</td>
</tr>
<tr>
<td>Total # of emitters</td>
<td>0.365 Million</td>
<td>11.1 Million</td>
<td>24.9 Million</td>
</tr>
<tr>
<td># of transfer cycles to populate the full display without redundancy with a 2 x 2 cm² stamp</td>
<td>2</td>
<td>18</td>
<td>2,135 (High # of pixels + low PPI)</td>
</tr>
<tr>
<td># of additional repair cycles assuming 100 ppm defect</td>
<td>37</td>
<td>1106</td>
<td>2488</td>
</tr>
</tbody>
</table>
While very promising in terms of performance, there are still multiple manufacturing challenges that need to be addressed to enable cost effective, high volume manufacturing of µLED Displays.

Multiple challenges need to be tackled to enable the µLED display opportunity.

**LED µDisplays**
SUPPLY CHAIN

Large scale µLED displays manufacturing?
Bringing together disparate technologies and industries.

LED Makers

- LED epitaxy.
- Small diameter wafers 4” to 6”
- Cleanroom class 10,000 at best
- Produce components / chips
- Fab CapEx <$500M

Display Makers

- TFT backplanes + LCD/OLED frontplanes
- Large substrates (1 to 10 m²)
- Clean room class 100 -1000
- Semi-finished products (panels)
- Typical fab CapEx for large players: $5 to $10 Billions.

Mass transfer, assembly, test technologies

Not established yet!

- No commercially available equipment.
- No supply chain.
EXAMPLE OF POSSIBLE SUPPLY CHAIN

OEM: Supply chain management (e.g.: Apple)

Joint Venture or supply agreement

- LED Makers
- Foundries

Display Maker

- TFT Backplane
- uLED Chips

Assembly (Massively Parallel P&P)

Or OSAT?

Display panel
Competitive Landscape
WHO’S WORKING ON IT: IP LANDSCAPE

Phase I

Keywords and term-set definition

Search equations / Search strategy

Phase II

Manual screening of the results

Patent classification

Refine search using IPC classes and citations analysis

Phase III

Patent Segmentation

Relevant
Non relevant

Segmentation improved during patent analysis

Patent Analysis

Landscape Overview
In-depth analysis of Key Technology Segments and Key Players
Ranking of key players, analysis of key patents...

Final search equation has more than 100 terms and booleans
MICROLED PLAYERS

Increasing activity from all types of companies: display makers, LED makers, semiconductor companies, start ups...

Patent activity in the field of MicroLED

1,570+ patents (500+ patent families*), including 680+ granted patents and 690+ pending patent applications

Note: Due to the delay between the filing of patents and the publications by patent offices, usually 18 months, the data corresponding to the year 2015 and 2016 may not be complete since most patents filed during these years are not published yet.

* A patent family is a set of patents filed in multiple countries by a common inventor(s) to protect a single invention.

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Sony “Crystal LED TV” at CES 2012

- 55”
- 1920 x 1080 resolution
- 6.2m individually addressable chips
- Never seen again…

*Sony 55” Crystal LED prototype (presented at the 2012 CES)*
FIRST COMMERCIAL PRODUCT

Sony small pitch video display – InfoComm 2016

- 403 x 453 mm modules of 320 x 360 x RGB resolution
- 1.26 mm pitch.
- 1,000 Cd/m² brightness
- Pixel size (estimate): 30 x 30 µm
HOW DO WE FORECAST?

• Performance, features
• Technology requirements
• Cost requirements
• Incumbent technologies

For each application: SWOT analysis → applications roadmap → adoptions rates → forecast
SMARTWATCHES: THE LOW HANGING FRUIT?

**Cost**

Small amount of pixels + high PPI = low cost

**Technology**

Getting there

**Performance**

Differentiating improvement in power consumption.

**Supply Chain**

~low volumes / low capex
AUGMENTED / MIXED REALITY: A POTENTIAL KILLER APP

Performance
Only technology that could deliver the high brightness required for outdoor applications.

Technology
CMOS integration / hybridization
Color conversions issues

Cost
Need <= $100 per microdisplay for consumer.

Supply Chain
Reduced capex, can be addressed by smaller company, well funded startup

Most AR/VR HMDs feature a darkened shield to reduce the amount of ambient light.
WHAT’S HAPPENING IN THE SHORT TERM?

- **2017**
  - Finalize technology development

- **2018**
  - Set up supply chain. Manufacturing of dedicated equipment

- **2019**
  - Test and ramp up

- **2020**
  - First high volume consumer products

- **2021**
  - More high volume consumer products?

Remaining technical and manufacturing challenges prove to difficult to overcome.

µLED remain too expensive & difficult to manufacture for high volume consumer applications, and or incumbent technology keep improving too fast.

Niche product only (where µLED performance are highly differentiating)

Crash and burn: no µLEDs displays?

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CONCLUSIONS

• MicroLED is inherently more complex than OLED and LCD.
• MicroLED won’t completely displace OLED and LCD.
• MicroLED could end up dominating a few niches: wearable, AR/MR/HUD
• MicroLED could compete with OLED on the very high end of the market in various other applications…
• …or not.
Thanks!
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