MicroLED Displays: Hype and Reality, Hopes and Challenges

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Abstract

MicroLED is a new, self-emissive display technology. It offers unique features that could disrupt the display market as well as trigger significant changes in the supply chain. The authors have thoroughly analyzed the MicroLED industry landscape, including MicroLED's technological status and its strengths and weaknesses for all major display applications.

INTRODUCTION

There are two major routes to realize a displays from MicroLED. The microchips can be singulated and picked up and transferred individually or in groups onto a Thin Film Transistor (TFT) driving matrix similar to the ones already used in OLED displays (Fig. 1).

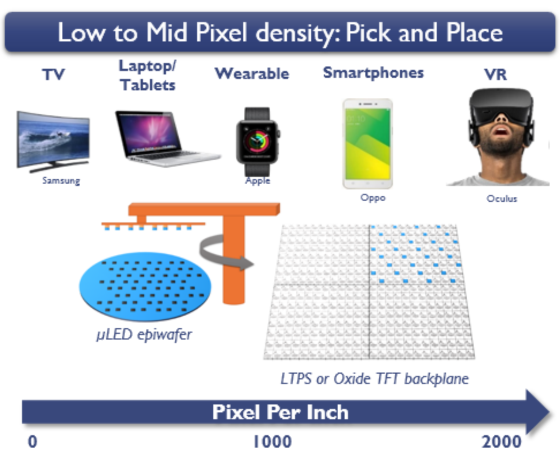

Fig. 1 The Pick & Place approach to handling MicroLEDs.

Alternatively, a full monolithic array of 100,000's of MicroLEDs that can be hybridized on a CMOS driving circuit. The former approach is the one towards which many people are working. Indeed circumventing the technological bottlenecks and work on the overall yield will allow for a mass consumer market address. Challenges exist on every level of the product development chain and every step of it impacts the performance (Fig. 2).

As the target is a "zero-defect" display, the focus of this discussion will be on the transfer yield, a technological field that is the main difficulty of today's technology development, as proven by the intense intellectual property activity of the main actors [1], see for example Apple's patenting activity (Fig. 3).

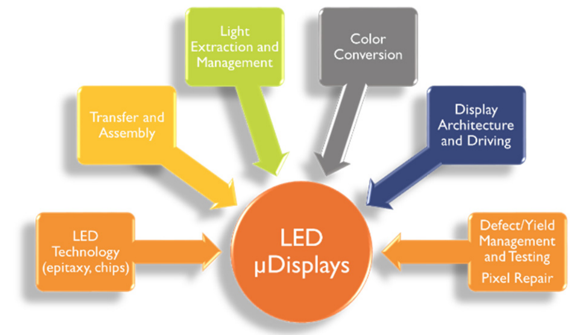

Fig. 2 The numerous challenges to overcome to enable MicroLED display opportunities.

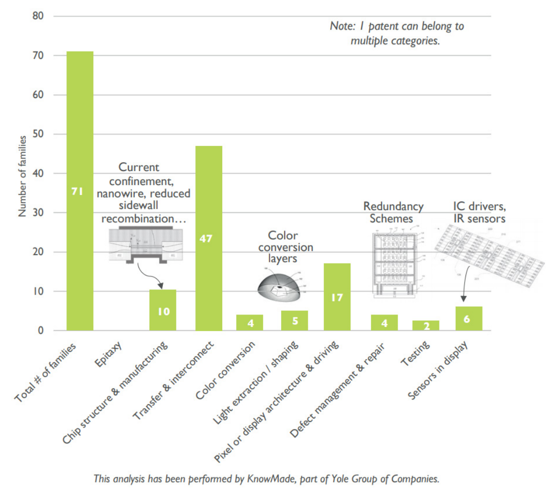

Fig. 3 Apple MicroLED patent portfolio as of December 2017.

YIELD DEFINITION FOR MICROLED DISPLAYS

The yield of the complete MicroLED display process could be defined as the product of several yield elements (Fig. 4):

- Epitaxy;
- Chip processing;
- Transfer;
- Assembly and interconnect;
- Others (color conversion, panel assembly, etc.).

Of course processing a chip on an epitaxy defect (pit, scratch, particle, etc.) would be deleterious. So would be the transfer of a defective chip (because of lithography, etching, or other process step issues), and so on down the value chain. Yield and defect management strategies must be implemented to minimize the cost of yield and pixel repair.

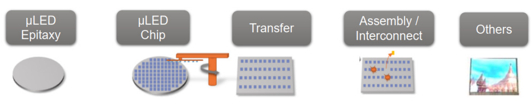

Fig. 4 The total MicroLED process yield.

YIELD AND PIXEL REPAIR

Consideration is taken for the three major kinds of consumer products that could make the MicroLED technology relevant for the industry: smartwatches, which we believe would be the first proper product target to introduce the technology to the market; smartphones; televisions. Tab. 1 shows the numbers of anticipated defective pixels for various manufacturing process yield hypotheses.

TABLE 1 NUMBER OF PIXELS TO REPAIR FOR MAJOR CONSUMER PRODUCTS, DEPENDING ON MICROLED PROCESS YIELD.

MicroLED process yield		Watch	QHD phone	4K panel	8K panel
99%	2N	3,650	87k	248k	995k
99.99%	4N	37	876	2,488	9,953
99.999999%	6N	0.4	8.8	24.9	99.5

For a 4K panel at a 4N MicroLED process yield, the number of defective pixels being 2,488, the repair time would probably be over 2 hours, which would not be efficient for mass manufacturing.

Ensuring about 90% manufacturing yield for a 4K display would require a full MicroLED manufacturing yield in excess of 8N [2]. For a smartwatch, the threshold is still above 6N. Using pixel redundancy dramatically eases the requirement to about 4N (Fig. 5).

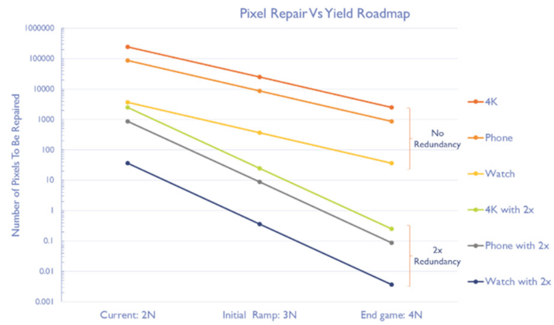

Fig. 5 The impact of redundancy on yields.

The opportunity to use pixel redundancy can be analyzed for each application by looking at the additional chip and transfer & assembly cost vs repair cost. Some level of pixel repair will therefore be required. Pixel repair is complex and expensive. Most therefore see an incentive to manage yield upstream and eliminate bad die prior to printing. This way, the pixel repair requirement are driven only by yields at the transfer/assembly process.

Upstream yield management strategies can be classified in 2 major groups:

- Individual Known Good Die (KGD) binning and printing: it ensures the highest yields and lowest repair costs but requires individual die testing plus the ability to selectively print only good die.

- Transfer field binning: define wafer areas with acceptable wavelength spread and level of defects, then create interposers with those binned areas or print directly from the wafer.

Both strategies would benefit from the ability to perform functional testing on individual die and create KGD maps. Otherwise, determination of KGD will depend on photoluminescence mapping and surface inspection after epi and chip processing (detection of compromised pads, contacts, particles etc.), which we know are not reliable enough as there is little correlation between both photoluminescence and electroluminescence performances.

Between the print and repair strategy (with possible redundancy) and the upstream elimination strategy (with individual die binning or field binning), there could be an intermediate alternative based on the two other ones (Fig. 6). After an individual die testing and/or optical inspection, a binning could be performed on an intermediate carrier (like an interposer). Performing the final printing from this one would provide a simplified pixel repair with fewer defects, and could help mitigate the complexity and cost. The optimum strategy depends on the application, the types of transfer processes at hand, the availability of individual die testing, the capabilities of each process and so on.

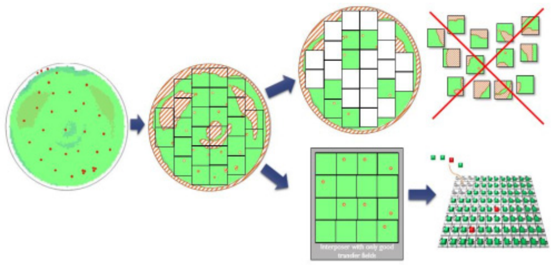

Fig. 6 Intermediate defect and yield management strategy.

Dedicated repair tools and process (different from the mass transfer tools) can improve repair efficiency and decrease cost of ownership. In most cases, repairing will also require the ability to cut or restore electrode paths to contact the repaired pixel or disconnect the defective one.

MICROLED DISPLAY PROCESS AND COST-DOWN PATHS

Cost is the major challenge for MicroLEDs. As the design and process capabilities progress, three major thrust areas can be worked on to reach a more acceptable display cost:

- The die size: going from a 10µm die size towards a 5um die size for a potential 4x reduction;
- Redundancy: eliminating it for a potential 2x reduction for the die cost, and 0x to 2x reduction of transfer cost;
- Transfer/assembly: working with interposers for a potential 10x to more than 40x reduction of transfer cost.

If one considers the example of a 75” 8K TV, it can be shown that given a certain number of process development enhancements (small dies) and the choices made in terms of defect management and transfer strategy (interposers), then the die and assembly costs would be close to an acceptable target compared to the competition. Most notably, transfer cost could become essentially negligible. This would make MicroLED displays competitive with respect to OLED displays on the high-end segment.

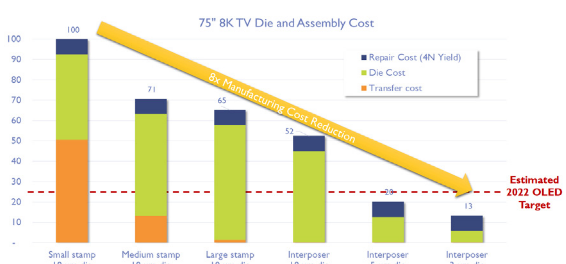

Fig. 7 Cost-down path for large TV: small dies and interposers.

Transfer process however is only one of numerous challenges to be overcome. The science is here, but MicroLED is an inherently complex technology with cost drivers different from those OLED and LCD. Referring to the high-level challenges illustrated on Fig. 2, significant progresses have been made these past eighteen months. However, much more is still needed to conquer the display world. The upstream steps of the technology seem advanced enough but many others are at an early stage, with the holy grail being around the transfer technology.

CONCLUSIONS

Based on the current status of the developments and the maturity level of the supply chain, it will not be before a few years that a high volume MicroLED application could hit the market, with augmented reality microdisplays or wearables as the first candidates. High added value displays such as automotive applications could come next, but large volume consumer products such as TVs or smartwatches will likely require more time. In the meantime, various companies will likely introduce various low-volume, high-end products built with little concern for costs in an almost artisanal fashion, with the sole purpose of showing the company’s presence in this hot and promising field.

There are reasonable expectations that MicroLEDs will succeed in various segments, but it is still a bit early in the technology development cycle to assert whether they will take the industry by storm or crash and burn like many other “promising” technologies in the past.

Finally, the vast amount of ongoing research and development on the MicroLED topic will likely bear fruits and cross pollinate into other applications, leading to better and more efficient LEDs, high speed Li-Fi communication, lithography application and micro-device transfer technologies that could benefit many other industries.

REFERENCES

[1] E. Virey, N. Baron, “MicroLED Displays: Intellectual Property Landscape,” Yole Développement, Jan. 2018.

[2] E. Virey, Z. Bouhamri, “MicroLED Displays 2018,” Yole Développement, Jul. 2018.