Impressive Technologies for MicroLED Displays

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ABSTRACT

MicroLED is a promising display technology. There are however still many technical challenges that need to be tackled before it is ready for consumer products. Mass transfer of the microLED chips is the elephant in the room, but many others could prove as challenging and possibly derail the microLED roadmap.

1 INTRODUCTION

MicroLEDs present a whole gamut of technical challenges that are often not commonly addressed by the traditional display industry. The elephant in the room is of course the transfer and assembly of dozens of millions of microLED chips, but as research groups and companies progress with that task and are able to assemble their first fully functioning prototypes, a whole new range of other challenges appear, that were initially masked by the daunting transfer and assembly task. Those need to be addressed to bring the industry from the prototype stage to the cost efficient, high yield manufacturing of flawless, consumer-grade display. That is displays that are affordable, perfect under any angle and maintain their performance through the lifetime of the device.

MicroLED displays are still in the development phase and no consumer products are available yet. However, the number of companies working on the technology and, as a result, patent activity have increased dramatically over the last 5 years as illustrated in figure 1 [1].

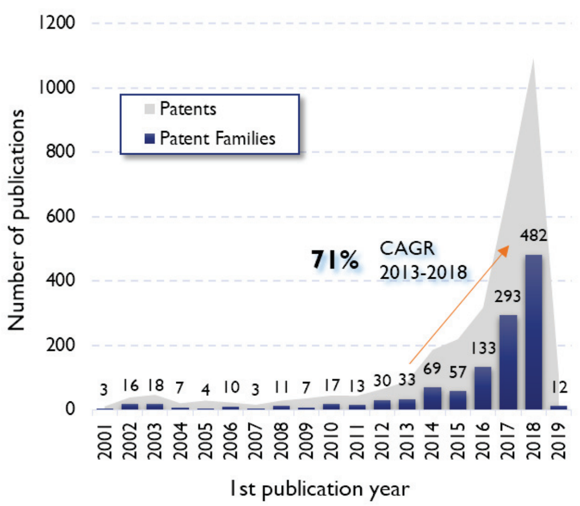

Fig. 1 Time evolution of microLED patent publications as of early 2019

Patent filings are growing exponentially and technology is progressing on all fronts. The external quantum efficiency of blue and green microLED chips has more than doubled over the past 18 months. Some transfer and assembly processes are reaching performance close to what is required to enable some microLED consumer applications.

Progress is also visible in the proliferations of prototypes presented over the last 18 months by close to 20 companies. The demos cover a broad range of display types, sizes and technologies. Native RGB or color converted displays on Thin Film Transistor (TFT) backplanes are offered by many companies, with some examples including Playnitride, CSOT, Samsung, LG, Glo, AUO, eLux, and Kyocera. Lumiode has developed native RGB or color converted displays on monolithicaly integrated Low-Temperature Polysilicon (LTPS). Meanwhile such displays on CMOS backplanes are on offer from companies including Plessey, Glo, Lumens, JB Display, Sharp and Ostendo. Finally, discrete microdriver ICs have been developed by X-Display. The multiple prototypes based on TFT backplanes give credence to the idea that microLED displays can leverage existing panel maker capacity, thereby simplifying and streamlining the supply chain.

Equipment makers have taken notice and are starting to develop microLED-specific tools for assembly, bonding, inspection, testing and repair. LED makers are also showing interest, with San'an planning to invest $1.8B to set up a mini and micro-LED manufacturing base. Osram, Seoul Semiconductor, Nichia or Lumileds are also increasing their activity and Playnitride is completing its first microLED pilot line.

2 SIGNIFICANT ROADBLOCKS

For many applications, economics is pushing die size requirements below 10µm. This compounds efficiency, transfer and manufacturability challenges and despite significant improvement, small die efficiency remains low. Display efficiency based on this technology still can't match OLED. Significant effort is therefore needed to further improve the internal quantum efficiency, light extraction and beam shaping of green and red microLED chips.

Epitaxy and chip fabrication are no longer seen as roadblocks, but solid yield management and repair strategies must be implemented. Transfer and assembly processes need to evolve from table-top experiments to robust high-volume production tools. The proliferation of technology paths creates some confusion and delays. Equipment makers can be reluctant to commit. A piece of equipment developed for certain processes or architectures therefore often won't work with others. Developing process-agnostic tools is challenging. Choosing a technology today is risky, but so is waiting too long to get in the game with an increasingly crowded intellectual property (IP) landscape

For microLED companies, the first few prototypes provide strong returns in terms of experience, but maturing toward consumer-grade displays could require thousands more. Startups are entering the 'valley of death'. Many might fail to raise enough money to successfully go through this more capital- and resource-intensive phase. Support and partnership with large display makers or original equipment manufacturers (OEMs), either as strategic investors or development partners is critical.

The situation is less challenging for microdisplays. Many prototypes can be built from a wafer run, and setting up the supply chain is easier as a lot of steps can be outsourced. Small foundry runs are expensive, however, and non-recurring engineering costs can be significant.

All the progresses over the past 18 months regarding epitaxy, chip manufacturing and so on, added to the remaining roadblocks to clear, are summarized in figure 2.

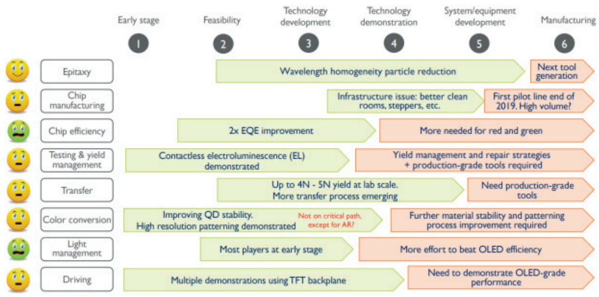

Fig. 2 Last 18 months technology progress and remaining roadblocks

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3 MICROLED TRANSFER AND ASSEMBLY

Unlike OLED, inorganic LEDs can't be deposited and processed over very large areas. LEDs are grown on 4" to 8" wafers and the art of making microLED displays therefore consists in singulating individual emitters and transferring and assembling them onto a backplane substrate.

For most consumer displays such as TV or smartphones, microLED with die size ranging from 3 to 10 μm are required to ensure cost compatibility with the applications. For an 8K display, close to 100 million of those must be assembled without a single error with a 1 to 2 μm placement accuracy at a throughput exceeding 100 million units per hour. Transfer and assembly are therefore often seen as the single largest technical challenges to overcome to enable microLED manufacturing.

Multiple companies and research organizations are tackling the challenge and making very encouraging progresses. Transfer and assembly yields in the 99.99% (4N) to 99.999% (5N) range are being reported. We anticipate that in the mid-term, transfer could become a marginal contributor to the cost structure of a microLED panel compare to the die cost [2].

However, it is still quite the challenge to anticipate the technology that would prevail. Proliferation of technology options as can be seen in figure 3, and lack of convergence and visibility on the paths for volume manufacturing make investment decisions risky and premature. It is for exemple difficult for equipment makers to choose which technology to develop and implement in their tools. The conclusion of this is that there are no off-the-shelf equipment available for microLED testing, transfer, assembly, repair etc.

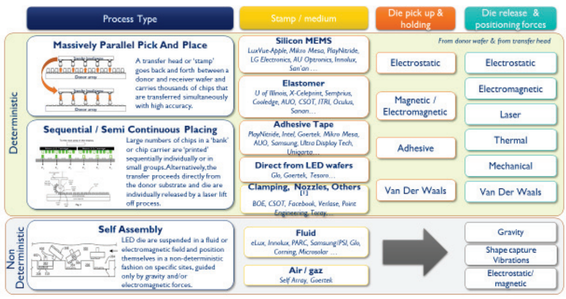

Fig. 3 Classification of transfer processes

When looking at the patent filings for transfer and assembly, as shown in figure 4, one can hardly be sure to have a complete freedom to operate. IP is distributed over many companies, making the investment decisions for equipment manufacturers even more difficult.

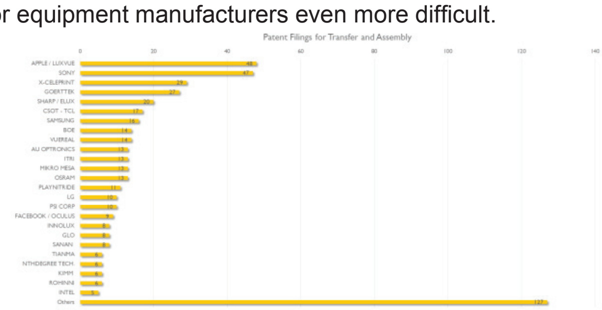

Fig. 4 Patent filings for transfer and assembly

The current capabilities of the tools are encouraging but still insufficient for cost effective production of consumer μLED displays. Transfer tools for massively parallel pick-and-place or semi-continuous processes are more complex than single die tools due to additional requirements such as more stringent rotational accuracy, higher sensitivity to temperature fluctuations etc.

Throughput is driven by stamp size, cycle time and display pitch. While the transfer stamp could conceptually be made arbitrarily large to increase throughput, there is actually some trade offs in term yields and placement accuracy. The typical combinations of cycle times and stamp, transfer field or self assembly module sizes for the various display prototypes shown over the past 18 months lead to throughput in the 10 to 40 million DPH .

Our estimate and commonly accepted target is that to be economically viable, assembly equipment must be able to assemble a TV in less than 10-15 minutes, which, for an 8K TV, translates into a throughput of > 250m DPH.

For most applications, the solution will therefore lie in tools featuring multiple assembly head/units.

4 CONCLUSIONS: WILL EVERYTHING EVER MATERIALIZE?

Smartwatches are a perfect ‘beach-head’. Low volumes, small displays with high price elasticity make it possible to use larger dies and more redundancy. Apple could push high volume manufacturing and make smartwatches a stepping stone to overcoming supply chain obstacles and improve technology toward other applications. Other companies could enter the market sooner with lower volume, lower specification devices. Glo is partnering with Kyocera to set up its supply chain and Playnitride expects to ship passive-matrix wearable displays with its partner RiTdisplay by the end of 2020.

There is also a strong case for augmented reality (AR) and head-up display (HUD) microdisplays where microLEDs could be the only technology delivering the right combination of brightness, efficiency and form factor [3]. More work however is needed to deliver full-color displays and efficient coupling to waveguide optics. For automotive, microLEDs offer a unique and compelling combination of high brightness, contrast, ruggedness and environmental stability, while enabling freeform, conformable displays. Higher price elasticity means microLED could be technology-ready rapidly, but lengthy qualification cycles will delay adoption past 2023.

The TV market is more challenging. OLEDs are progressing and might leave little room for differentiation by the time microLEDs are ready. TV sizes up to 75” will be commoditized by then, but larger panels with modular builds present an opportunity. Companies like Samsung could test the water as early as 2020-2021 with low volume “luxury” models aimed at “mansion” home theatres or high-end retail. Smaller dies, below 5µm, are needed to address consumer markets, which will require at least two more years.

For smartphones, OLED will be a mature, high-performance, cost-effective solution by the time microLED is ready. MicroLED can’t match OLED’s cost. Differentiating performance and features still to be invented are required to compete. Die sizes below 5µm are needed to remain within an acceptable cost bracket, and high volumes require massive investments in the supply chain

Overall, this leads to think of a tentative roadmap looking like the one in figure 5. And given the case scenarios discussed, this would lead to different adoption forecasts, as presented in figure 6.

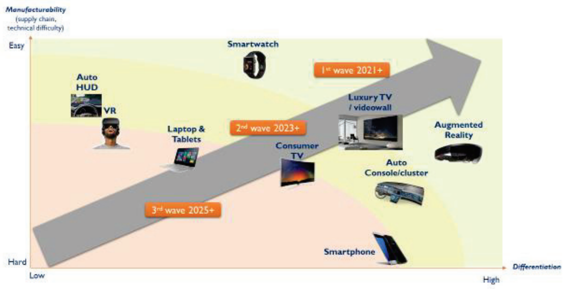

Fig. 5 MicroLED application roadmap

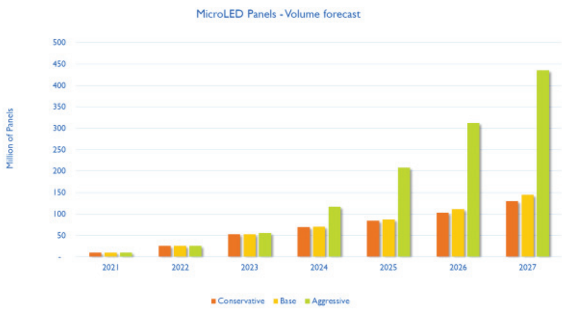

Fig. 6 MicroLED forecast scenarios in millions of panels

Apple still appears the best positioned to enable high volume microLED smartphones. This could happen 2-3 years after introduction in smartwatches but also raises an existential question for the industry. What happens if Apple pulls the plug on microLEDs?

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