MicroLED Display Technology Trends and Intellectual Property Landscape

Zine Bouhamri[1], Eric Virey[1]

zine.bouhamri@yole.fr
[1]Yole Développement, 75 cours Emile Zola, 69100 Villeurbanne, FRANCE
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ABSTRACT

Having analyzed the most recent trends in microLED display technologies and their intellectual property landscapes, which have been growing exponentially since 2014, we want to exhibit here the key technologies, highlight the unusual solutions, and provide insights on the status of microLED developments.

1 INTRODUCTION

Traditionally packaged or Chip Scale Package (CSP) LEDs have been used for more than a decade as the illumination source in LCD panel backlights. Packaged LEDs are also used in the large video billboards used in stadiums, malls, and video facades. In those large displays, discrete packaged LEDs containing red, green, and blue chips form the individual pixels with pitches typically ranging from 0.7 to 40 mm depending on display size and resolution (Fig.1).

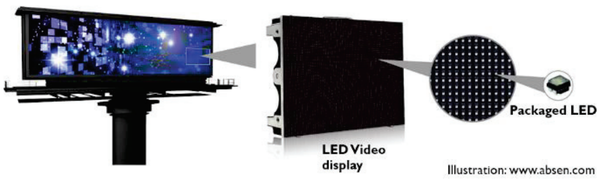

Fig. 1: Traditional LED Video Walls

As of today, LEDs have never been used as the direct emissive element (pixel) in small pitch, consumer displays. The reasons are cost and manufacturability. Nevertheless, the idea of using microLED at sub-millimetric pixel pitches to realize a display is almost as old as the invention and commercialization of LEDs themselves [1]. Over the last five years, interest in this concept has increased dramatically.

Micro-light emitting diodes (microLED) are an emissive display technology in which each individual red, green, and blue sub-pixel is an independently controllable light source. Just like Organic Light Emitting Diodes (OLED), they therefore offer high-contrast, high-speed, and wide viewing angles. In addition, they could also deliver a wider color gamut, orders of magnitude higher brightness, significantly reduced power consumption, improved lifetime, ruggedness, and environmental stability. Finally, microLEDs could allow the integration of sensors and circuits, enabling thin displays with embedded sensing capabilities, such as fingerprint identification, in-display camera, touch function, and gesture control.

2 METHODOLOGY

For emerging technologies that have yet to find their way into mass manufacturing, a good proxy to gauge the level of activity and identify the major technological roadblocks is to study the intellectual property (IP) landscape. In collaboration with IP expert Knowmade, we conduct annual analysis of the microLED display field.

The process starts with a complex (>150 Booleans) search equation used to extract a raw corpus from the FamPat worldwide database (Questel-ORBIT), which provides 100+ million patent documents from 95 offices. The returned results (1000's of patents) are then screened manually to eliminate non relevant documents (Fig. 2). The final corpus is analyzed and categorized by technology nodes, companies etc.

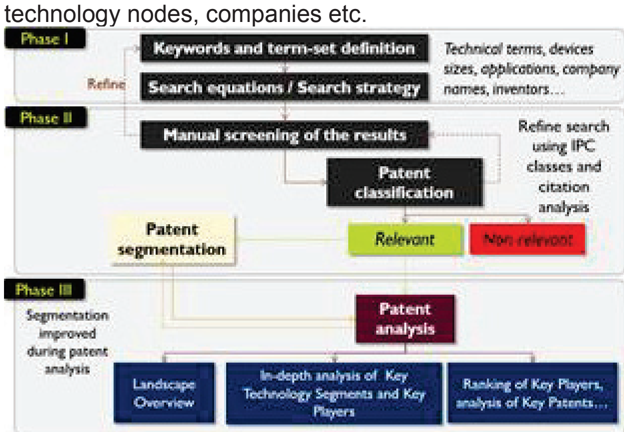

Fig. 2: Patent Search and Analysis Methodology

A patent is considered relevant to the field of "MicroLED Display" only if it meets all 3 of the following conditions: 1) the led chips are < 50 µm in size, 2) each chip is independently controlled/addressed by a transistor-based circuit, and 3) the application to self-emissive display is clearly stated or least reasonably obvious. Some generic LED or display inventions developed without microLED displays in mind are therefore excluded even if they could be applied and benefit microLED display performance and manufacturing processes (e.g. certain LED structures). This restrictive criterion can lead to some companies being under-represented in our corpus, for example LED makers with many epitaxy or led structure patents not specific to microLED but that could still be beneficial to microLEDs. Those sometime strict and restrictive criteria are however necessary to better extract from the noise inventions that are specifically aimed at solving microLED display performance and manufacturing issues.

3 INTELLECTUAL PROPERTY TRENDS

This recent study shows that as of January 10, 2020, about 350 companies or research organizations had filed close to 5,500 patents. Out of those, 2,068 have already been granted, 2,997 are pending and the balance abandoned, denied, or expired [2]. This represents a total of 2,453 patent families. As seen in Fig. 3, the activity has increased dramatically over the past few years: more than 40% of the patents in our corpus have been filed in 2019 alone.

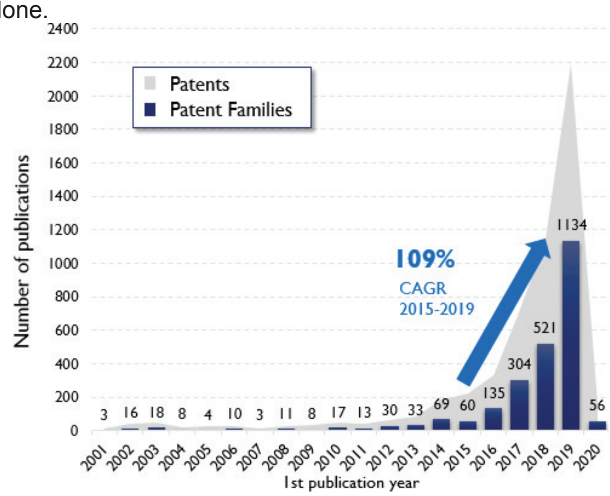

Fig. 3: Time Evolution of microLED Patent Publications as of mid-January 2020.

While historic leaders such as Apple/Luxvue, X-Celeprint, Sony, and a few others are still very active, this dramatic increase since 2018 has been driven essentially by Chinese companies and by display makers. The growth in China (Fig. 4) mirrors a more general trend in the country as it transitions from a manufacturing- to an innovation-driven economy. This also reflects the situation in the display industry, where Chinese companies now hold more than 50% of the worldwide display capacity in 2020 [3].

Display makers dominated IP activity in 2019. Most were initially dismissive of microLEDs, but all are now accelerating their efforts. Among panel makers, BOE strongly dominated IP activity in 2019, followed by LG, AUO, Samsung, CSOT, Tianma, Innolux, CEC Panda, OLED specialist Visionox, etc. BOE now ranks first with almost double the amount of patent families (195 granted + pending) compared to LG, which ranks second. Apple, however, still leads in terms of granted patents and total amount of citations accumulated by its portfolio. Large numbers of citations give a portfolio more strength in possible litigations and helps identifying seminal patents. Sony and X-Celeprint also have strong portfolios in terms of granted patents and number of citations.

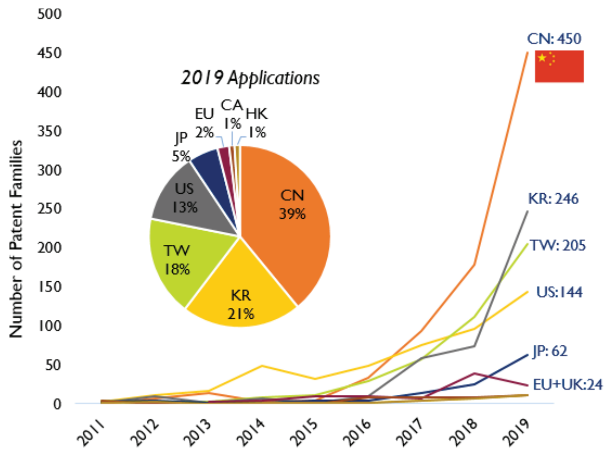

Fig. 4: Time Evolutions of microLED Display Patent Publication by Company Headquarter

Overall, panel makers now hold 29% of the total number of patent families, up from 19% in our January 2018 study (Fig. 5). Early players, such as X-Celeprint, and more recently, PlayNitride, also remain very active. Just like other leaders, such as Apple, they have developed broad portfolios covering a wide range of microLED technology nodes. Start-ups Glo and VueReal have also significantly increased their IP portfolio size.

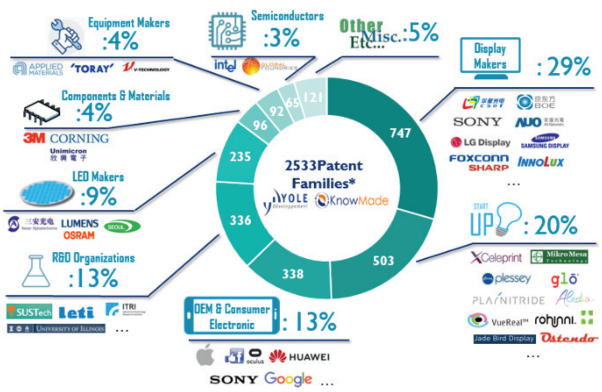

Fig. 5: MicroLED IP Breakdown per Company Type

Activity at Sony has stalled even though the company is commercializing a microLED based Public Information Display. More surprisingly, activity at Apple has also slowed down significantly since 2017. The patents it has since published, however, show the high level of maturity and development reached by the company in microLED display technologies. The reduced activity could also be a sign of confidence in its already robust portfolio. In addition, the company is also starting to have some patenting activity explicitly aimed at addressing challenges for high pixel density microLED microdisplay for AR applications on CMOS backplanes.

4 ENABLING TECHNOLOGIES & BOTTLENECKS

The art of making microLED displays consists of processing a bulk LED substrate into an array of microLEDs that are poised for pick up and transfer to a receiving backplane substrate for integration into heterogeneously integrated system incorporating LEDs, pixel driving transistors, optics, etc. An 8K display (7680 × 4320) requires close to 100 million individual microLED. To ensure proper interconnection and eliminate certain image artifacts (bright or dim lines due to inconsistent spacing between groups of microLEDs), the required placement accuracy is typically ± 1µm. Today's best die bonders can't manipulate the very small die (3 to 15 µm) required to enable high volume consumer applications. In addition, they typically have throughput in the range of 1,000 dies per hour. At this pace, it would take more than 11 years for such equipment to manufacture a single 8K TV. There is therefore a need for a paradigm change: the development of mass transfer technologies that can manipulate and assemble much smaller die than the current industry standards, and do so with a throughput at least 5 orders of magnitude faster (Tab. 1)

	Standard die Bonder *(LED, others)*	**MicroLED Display Mass Transfer Requirements**
Die size	> 70 µm	3 to 15 µm
Placement accuracy	± 1 µm	± 1 µm
Throughput	< 1000 die / hour	> 300 m die /hour

Tab. 1: Requirement for microLED Consumer Display Assembly

With such requirements in mind, it is no surprise that mass transfer and assembly are still seen as key enablers and remain the major thrust area in microLED display R&D and patenting activity (Fig. 6). Although they built up on previous work from companies such as Alien Technology, IMT MEMS, or the University of Illinois, among others, Sony, Sharp/eLux, Apple, and X-Celeprint are considered pioneers in microLED mass transfer and assembly for display applications. However, more than 150 companies now have some IP describing mass transfer processes.

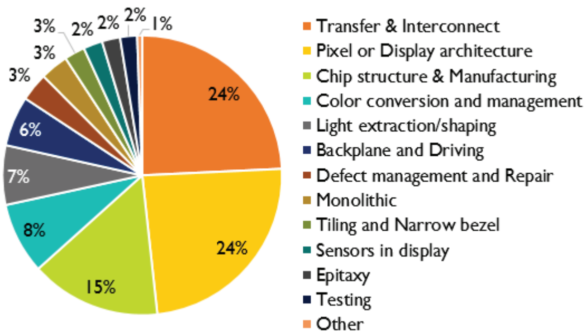

Fig. 6: Breakdown of Patent Families per Technology Node (Note: One patent family can belong to multiple technology nodes)

The level of creativity in transfer and assembly is impressive. Some patents plagiarize and others build upon established methods, such as elastomeric microprinting stamps or electrostatic MEMS; but new concepts are being introduced on a regular basis. An increasing number use laser detach mechanisms. Lasers enable die selectivity, potentially useful in some yield management strategies. There is also a renewed interest in self-assembly processes. Those have potential for high throughput and cost efficiency. They could also enable yield management strategies impossible with deterministic transfer processes. Processes based on vacuum or micro displacement of membranes activated by fluid or gas contraction/expansion are also on the rise. Finally, new concepts are emerging such as the use of optical tweezers.

Initially overlooked, the challenge of bonding the microLED die and delivering proper interconnects to the backplane with very small bonding pads is now getting more attention with companies such as Facebook, Vuereal, Mikro Mesa, and others coming up with improved low-pressure and low-temperature solutions involving for example interlocking nanoporous materials.

Another major thrust area is microLED chip structures. Major axes of research revolve around improving efficiency, devising structures suitable for mass transfer, or creating RGB monolithic chips which could simplify display assembly. The dramatic drop in LED efficiency at small sizes is now well documented and its causes are better understood [4], [5]. Many patents describe improved manufacturing technologies and structures such as current confinement layers to reduce non-radiative carrier recombination due to sidewall damages. Initially overlooked but equally important are light extraction and beam shaping, which are critical to ensuring that the highest possible number of photons created at the diode junctions actually escape the structure and is directed toward the viewer. Multiple technologies are presented from die shaping (e.g. hexagonal [6]), mirrors and more complex structures such as photonic crystals [7] and Distributed Bragg Reflectors used as spectral and/or angular filters [8].

On the display architecture front, many patents describe TFT structures, compensation, and driving schemes adapted to the specificities of microLED, such as EQE variations and wavelength shift with current density. But some companies are looking at more disruptive architectures based on µdrivers, or so-called "smart pixels," where transistors and capacitors are integrated directly with a single LED die or a full RGB pixel before singulation and assembly on a simplified backplane [9].

Innovative concepts are emerging, such as hybrid OLED + microLED displays, as well as pixel-level antennas for wireless data transfer between pixels and drivers, or even RF coupling to energize the microLED dies.

While many patents focus on specific process steps or technology nodes, some describe more transversal innovations and full paradigm incorporating specific die structures, mass transfer and interconnect, and pixel and/or display architecture. This reflects the complex interplay between technology bricks that can't be looked at in isolation: often a die structure is developed for a specific transfer process and/or display architecture. In that regard, Samsung Display's nanorod microLED "ink", AKA QNED, while still at an early stage, could be disruptive and bring the full benefits of microLED to its emerging QD-OLED technology and manufacturing infrastructure (Fig. 7).

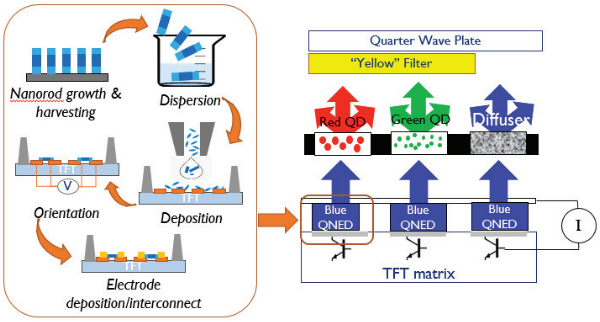

Fig. 7: Samsung Display's "QNED" process and integration into a QD-OLED-like architecture, where the blue OLED emitters are replaced by nanorod microLED "ink"

Many companies are also looking at taking advantage of unique and distinctive microLED features such as high aperture (transparent displays, sensor in displays) as well as the ability to design borderless modules which open the door for arbitrarily large displays assembled from individual tiles.

5 CONCLUSIONS

Quantity doesn't always mean quality, and not all patents present realistic solutions. Many appear to have been devised in a brainstorming room rather than in a lab. Nevertheless, the overall level of creativity and the diversity of approaches being deployed to address microLED display technology and manufacturing roadblocks is impressive and keeps expanding. Especially, while their patent portfolio might be of inconsistent quality, established players shouldn't underestimate the threat posed by Chinese competitors: Some of their patents show world class innovation and demonstrate a strong resolve to close the gap with established rivals. In addition, in high volumes, even low-quality patents can be used as bargaining tools to fend off infringement lawsuits, negotiate cross licensing agreements, etc.

The proliferation of subpar patents may, however, hinder innovation as it increases barriers to entry: increasing resources are required to conduct freedom-to-operate analysis, monitor patent activities, try to invalidate wrongly granted patents, and respond to infringement lawsuits.

Many companies now have portfolios addressing multiple technology nodes. Licensing and legal battles will likely arise if microLED displays enter volume manufacturing. Except in the field of microdisplays, where the most capex-intensive manufacturing steps can easily be outsourced, startups and small companies are not planning to become display makers. Rather, most will focus on their core expertise and attempt to license their technology to established display makers and OEMs.

From a technology standpoint, more than 20 companies have now publicly demonstrated microLED display prototypes. However, more effort is needed to reach the quality and manufacturability required for consumer displays. As confidence increases that the mass transfer and chip efficiency conundrums could be resolved, the effort is accelerating on topics that were previously seen as "second order" issues: light extraction and shaping, driving, display designs, as well as any concepts that would increase manufacturability and yield and reduce cost. Efficient yield management and repair strategies are as critical as mass transfer to enable microLED displays. Yet, efforts in those areas are still limited and appear insufficient; although, in many cases, companies are advancing on the topic but not filing IP in order to protect trade secrets.

Overall, microLED technologies are progressing at a fast pace. Nevertheless, multiple manufacturing and technology issues still need to be resolved before volume production of consumer products display can start. There is still a risk that microLED might never materialize or remain confined into various higher added value markets (e.g. automotive) or applications where they are highly differentiating or enabling (e.g. Augmented Reality). The road to commercial products could still be long. However, there is a proliferation of new players, especially display makers with large resources who could shop around in order to acquire licenses for the most suitable technologies developed by various pioneering startup companies to fill in the blanks within their own technology and patent portfolios. This could create an exciting environment and brighter prospect for microLED.

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