MicroLED Displays Continuous Progress

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Keywords: microLED, market, intellectual property, supply chain, cost.

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).

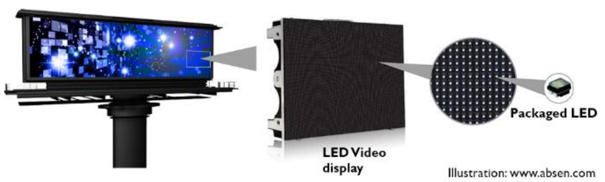

Fig. 1: Traditional LED video walls

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.

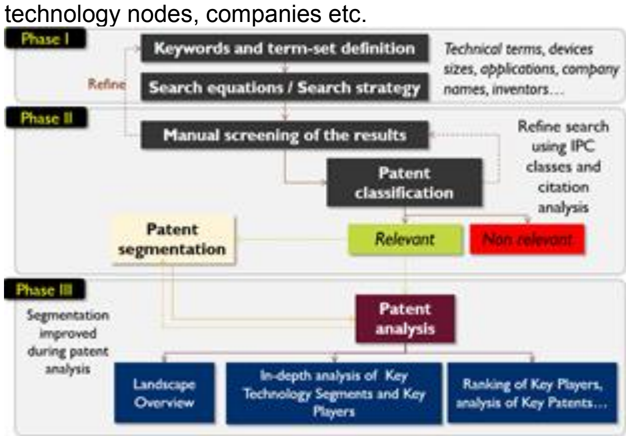

Fig. 2: Patent search and analysis methodology

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 February 2021, updated from last year with over 1,640 new patent families. This brings the analysis about microLED display IP to around 4,100 patent families overall. Out of everything, more than 3,100 have already been granted, 4,700 are pending and the balance abandoned, denied, or expired [2]. This represents a total of 4,093 patent families. As seen in Fig. 3, the activity has increased dramatically over the past few years: close to 40% of the patents in our corpus have been filed in 2020 alone.

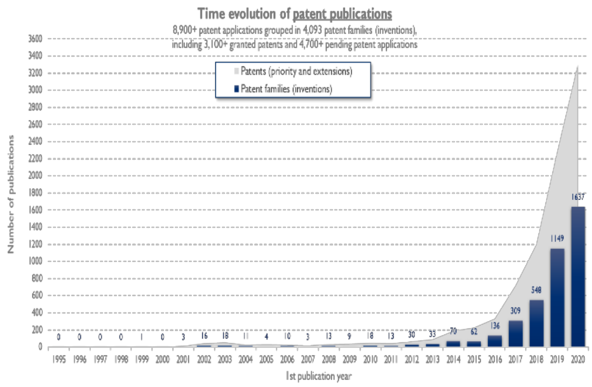

Fig. 3: Time evolution of microLED patent publications as of mid-January 2021

Activity is strongly dominated by Chinese companies, followed by Korea. LG and Samsung made strong showings in 2019 and kept up the pace in 2020 in terms of new applications. Samsung made a remarkable push with more than 130 new patent families, revolving for the most around its Display division's self-assembled nanorod LED technology, often referred to as Quantum Nanorod Emitting Devices (QNED). The patents show the technology maturing, and a commitment to tackle the challenges associated with moving QNED from the lab to the fab.

CSOT and BOE led patenting activity in 2019 and remained close to the top in 2020. With similar levels startup PlayNitride, which raised another $50M in 2020 to expand capacity, plays in the same league as leading panel makers and OEMs. Aledia, which moved into a new R&D facility in 2019 and raised close to US$95M in 2020 to build a fab, is also accelerating its IP effort, inching closer to historical leaders such as XDisplay. Panel makers that were missing have now entered our patent corpus including Japan Display, CEC Panda, HKC and Sakai Display.

The field is getting crowded but there is still time for ambitious newcomers to build credible portfolios. In late 2019 and early 2020, Konka and Visionox announced plans to invest $365M and $175M respectively in mini and microLED development and production ramp ups. Konka only filed its first microLED patent in 2019 and Visionox in 2017, but both already have sizable portfolios of pending applications, some showing a surprising level of maturity.

Activity at Apple peaked in 2017. However, the quality and details of new applications shows how far the company's technology has advanced. The acquisition of Tesoro indicates a focus that is shift or expansion toward enabling volume production rather than fundamental technology development. TSMC, which is expected to be one of Apple's key partners, appears for the first time in our corpus. And as we can see, all in the meantime, Chinese companies continue their strong push towards microLED IP, maintaining the strong push they had been undergoing in 2019 as seen in Fig. 4.

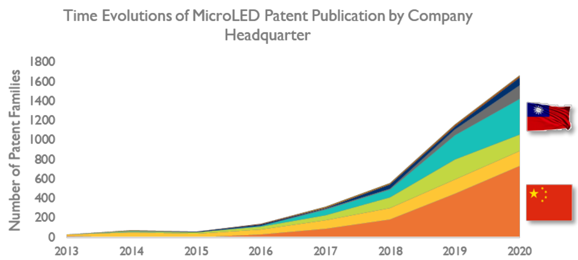

Fig. 4: Time evolutions of microLED display patent publication by company headquarter

We sum all the major trends in Fig. 5 and some highlights are worth being explicated.

Many recent patents feel "closer to reality", going deep into details of pixel bank structures and backplanes, or aiming at improving manufacturing efficiency. Detailed analysis shows that most of the IP leaders are moving beyond concepts and lab prototypes and tackling the challenges of bringing microLEDs to mass production. Inventors never seem to run short of new ideas to improve capabilities, cost of ownership, and enable freedom of operation in an increasingly crowded IP landscape.

Growing numbers of applications describe backplanes with testing functionalities, redundancies, and repair management. Efforts to improve small chip efficiency are accelerating on all fronts, including passivation, current confinement, tunnel junctions and plasmon resonance.

New transfer processes keep emerging, exploiting materials' contraction, expansion phase changes or surface tension. Polymer stamps still lead, but laser-based transfer dominated activity over the last two to three years. The 2019 comeback of self-assembly was sustained in 2020. Notably, many of LG's recent applications revolve around a technology ecosystem to enable its fluidic self-assembly process. Transfer is only the first step. With bonding pad sizes and gaps shrinking below 5 µm, die interconnects are challenging at microLED scale. Effort on this issue is therefore accelerating.

Growing the three emitter colors on the same wafer is also a hot area. Pixel chiplets that integrate emitters and driving circuits into a microsystem with redistribution layers are on the rise. For AR or light field, optical multiplexing is an intriguing option worth monitoring.

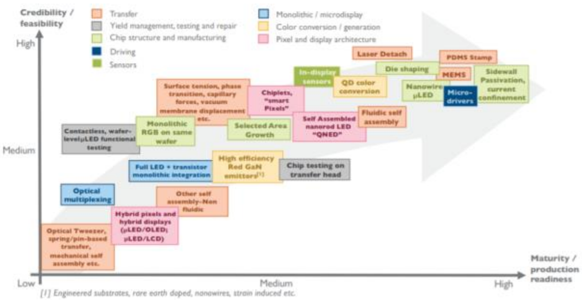

Fig. 5: Tentative microLED IP technology mapping

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 FOCUSING ON PRODUCT ROADMAPS AND SUPPLY CHAIN BUILD-UP

Many companies have some pieces of the microLED puzzle, but none has all of them. It is unlikely that any player will fully integrate all elements. Each will remain mostly focused on its core expertise: panel makers will source Chips-on-Wafer or binned, Chips-on-Carrier from LED makers. This leads to more margin stacking.

Collaborations are increasingly falling along nationalist lines: Chinese companies BOE, CSOT, Visionox, Huawei, etc., are collaborating with the major domestic LED makers Sanan, HC-Semitek, Nationstar, etc. At the same time, Taiwan leverages its strong LED, Display, and Semi ecosystem with AUO, Ennostar, and Playnitride increasing collaborations.

Is the trend driven by the Covid crisis what prevents teams from crossing borders? There are no major technology or equipment access restrictions that would prevent fully national supply chains: microLED could become a supply-chain-decoupling poster child.

The traditional, vertically integrated display panel business model requires multi-billion-dollar fabs that few can afford. With microLED, the capital expenditure is distributed among different industries. This leads to a more complex but potentially more agile supply chain, opening the door to new entrants. If it desires, Apple could ultimately control a fabless microLED display supply chain, independent of traditional panel makers and with multiple suppliers at each critical step.

For most applications, we are struggling to deliver a cost model scenario where microLED is significantly cheaper than OLED, let alone LCD, but we exhibit a tentative adoption scenario in Fig. 6. Strong differentiation is therefore essential. This is easier in segments with no strong incumbents. Adoption in Augmented Reality (AR) will take off from 2023, but AR is still searching for a strong use case for high-volume consumer adoption. Automotive is compelling for microLED, but long design and qualification cycles are pushing initial adoption beyond 2025. If Apple's current pilot effort succeeds, smartwatch will be the first high-volume consumer application with a product introduction anticipated for 2024. TV and smartphone are more difficult nuts to crack as OLED is a moving target, improving continually in both cost and performance. Samsung's commitment to TV is encouraging. The first real consumer products could emerge from 2025. Smartphone remains the most challenging application, but Apple's ambitious microLED technology choices bring new hope.

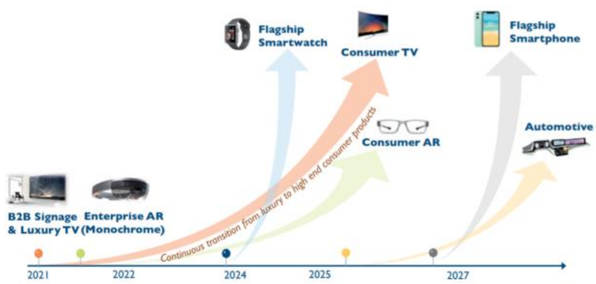

Fig. 6: 2021-2027+ microLED display application timelines

5 HAVE MICROLED DISPLAYS REACHED ESCAPE VELOCITY?

The display industry is favorable to microLED: China won the LCD war, and the industry is turning its focus to technologies that deliver differentiation and high margins. Helped by a Covid-driven demand boost, it has swung back to profit and is generating cash to fund new technologies. While the LCD business model needs high-volume commodity products to absorb huge fab costs and make money on premium products, microLED could seed CapEx-light operations focused on serving premium markets [3].

Apple put microLED on the map when it acquired Luxvue. Display makers were initially skeptical but now believe that, while challenging, microLED displays might be credible contenders in some applications. As a result, money and resources are flowing into microLED, fueling a virtuous circle with faster developments, and improving prospects that are attracting further investments as can be seen in Fig. 7.

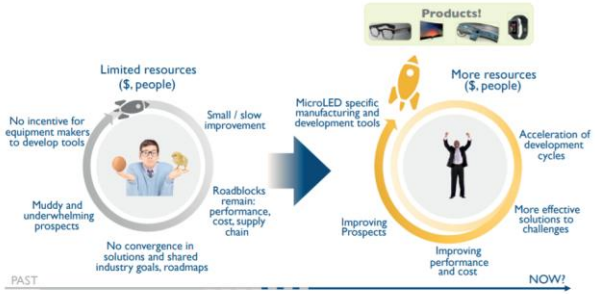

Fig. 7: The question of reaching escape velocity for microLED displays

LCD or OLED did not take off until HVM equipment became available. Equipment makers are now offering microLED-dedicated tools, and, although hindered by a lack of standardization in processes, some are developing one-stop solutions, including transfer, inspection, and repair.

Mass transfer is no longer considered a fundamental roadblock by most players. Many issues remain, but the industry now sees a clearer runway. Commercial tools from ASMPT, Toray, Coherent/3D Micromac using different processes are accelerating development. More are coming from TDK, V-Technology, Besi, Bolite/Contrel, etc.

Samsung and Vuzix (with JB Display) are introducing the 1st commercial microLED products in 2021 [4]. They will not yet move the needle of the display industry but are positive developments.

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