Hopes for mini-/micro-LED display market space invasion

Researchers and market analysts suggest that mass production could start in three to five years, or even sooner in niche applications, reports Mike Cooke.

The world is awash with liquid-crystal displays (LCDs) — from tiny indicator panels, through mobile phones, up to giant television screens. Most LCDs, particularly those with color capabilities, incorporate a backlight that now consists of light-emitting diodes (LEDs). In operation, the LCD part of the screen blocks or transmits light to give an image.

While LEDs have reduced power consumption compared with the previous system based on fluorescent technology, much of the light that is produced is wasted — a black screen consumes as much power as white. This is a problem both for the giant TVs and for mobile devices, where energy consumption reduces battery charge.

Table 1. LEDInside's view of advantages and disadvantages of different display technologies.

Display technology	LCD	OLED	Micro-LED
Mechanism	Backlight/LED	Self-emissive	Self-emissive
Contrast ratio	5000:1	∞	∞
Lifespan	Medium	Medium	Long
Response time	ms	μs	ns
Operating temperature	−40ºC to 100ºC	−30ºC to 85ºC	−100ºC to 120ºC
Power consumption	High	Medium	Low
View angle	Low	Medium	High
Pixel per inch	up to 800ppi	500ppi	>2000ppi
Cost	Low	Medium	High

Developers of micro-LEDs plan to give every pixel an independent light-emitting source, cutting the backlight waste — the power consumption of future micro-LED displays is estimated at 10% that of LCDs. Already, this principle is used in large outdoor displays with arrays of regular-size LED devices, but close-range displays — TVs, smartphones, etc — need smaller LEDs.

Regular LEDs are of the order 0.5mm (500μm). Reducing the size to about a fifth gives 100μm mini-LEDs, which find application in ultra-fine pixel-pitch displays for control rooms and indoor advertising.

Micro-LED panels use arrays of individual red-green-blue (RGB) devices of less than 30μm, and even down to 2.5μm. Panels with micro-LEDs should be able to meet resolutions of 2000–6000 pixels-per-inch (ppi), much higher than the 400ppi used in retina LCD panels.

Apart from cutting the backlight waste, LED-based displays are competing with organic LEDs (OLEDs), which have been in development for a couple of decades.

The promise of inorganic LEDs is reduced power consumption along with higher brightness and contrast, even compared with OLEDs. Power consumption of micro-LED displays is expected to be 50% that of OLEDs. Micro-LED development is aimed at improving the quality and uniformity of epitaxial wafers needed for high yield and low cost.

Further hoped-for advantages include ultra-high resolution, high color saturation, quick response and long lifespan (Table 1).

The adoption of micro-LED technology depends on costs being closer to LCD panels than OLED panels — i.e. $12–15 for a 5.8-inch LCD compared with $65–70 for an active-matrix OLED display as used in the iPhone X. Production costs for micro-LED panels are projected to be reduced significantly by 2021. Meanwhile, Japan's Yano Research Institute expects the global micro-LED market to increase from $7m this year to $224m in 2020.

In addition to offering a performance target, OLEDs also stand as a warning to crystal-ball gazers. Many in the industry, including Samsung (2006), expected the technology to replace LCDs as the mainstream display technology. OLEDs were expected to deliver low power consumption, simple structure, wide color gamut, large viewing angles under sunlight, and quick response time, in a compact format.

OLED panels do consume less power, but they have also not realized early expectations in this regard, with savings falling below the original hopes by about 30%. Another problem is that manufacturing processes using organic materials have low yields for the highest performance, increasing costs.

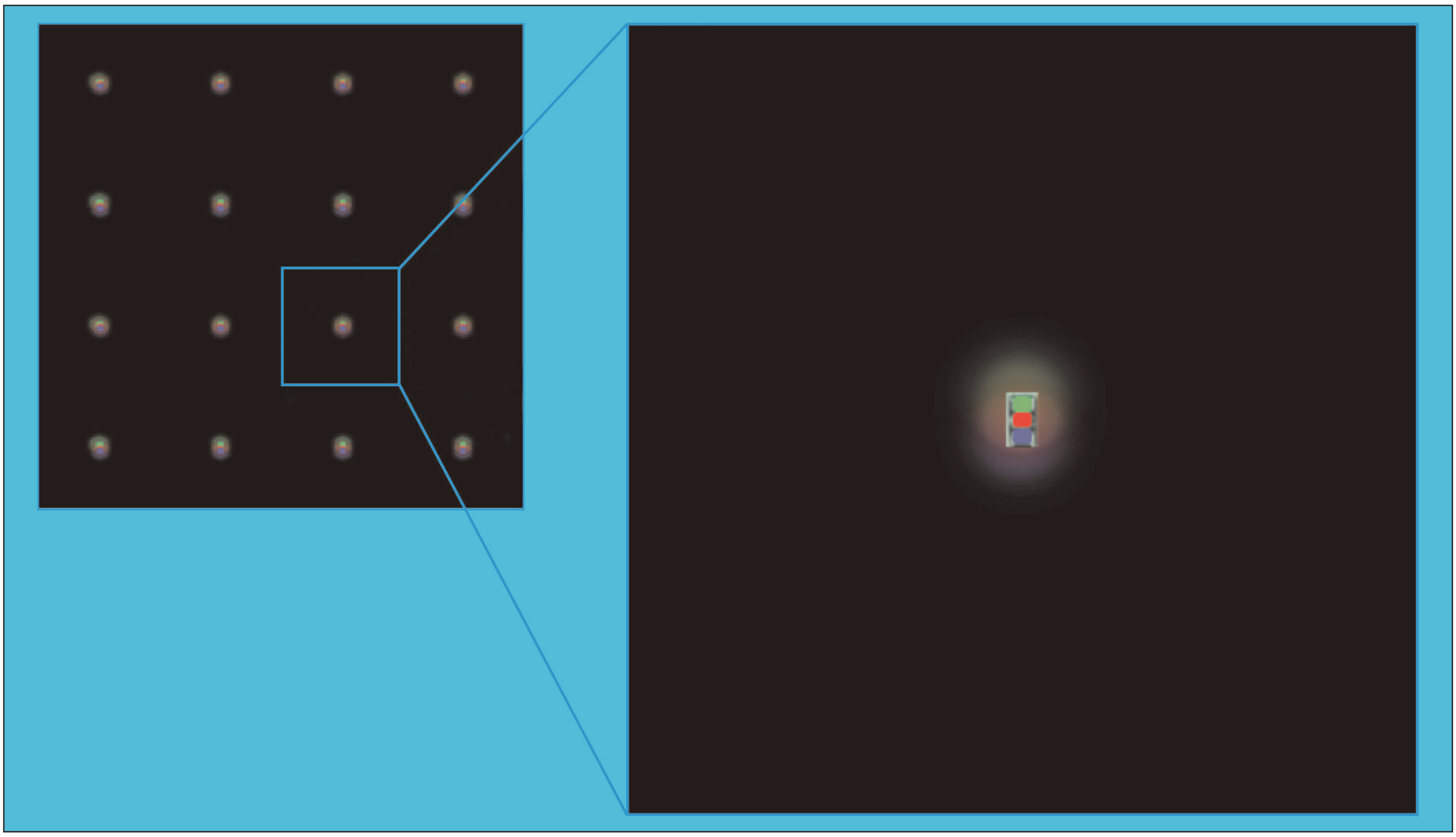

Figure 1. Sony's Crystal LED Integrated Structure giant display uses 0.003mm^2 pixel areas mounted on black display surface.

In many ways, it is not the LED technology that needs improvement — rather production costs and integration into the display production supply chain stand as the present challenges. The micro-LEDs must be accurately transferred and fixed en masse in a way that competes with LCD process speeds (with 10G panels produced in seconds).

Such manufacturing needs to separate epitaxial layers of micron-sized RGB LEDs from their substrates and transfer them onto a receiver substrate that could be glass or some flexible polymer. At the same time, the LEDs need to be connected with the control circuits on the receiver substrate.

Different companies see a variety of routes to mass micro-LED panel adoption, while costs are being reduced. Niche markets employing advanced capabilities could come first for micro-LED panels.

For example, LCDs and OLEDs both perform relatively poorly in competition with bright sunlight. Outdoor activity smart wearable devices could thus benefit from small but high-brightness screens.

Ditto automotive windshield displays, with 80% transparency for micro-LED panels, compared with 40% for OLEDs.

Small indoor screens for virtual/augmented reality (VR/AR) have 20% wider color gamut than OLEDs; and, at the other end, large-scale indoor displays, which could benefit from the variable shapes and areas of flexible panels, are also variously proposed.

Already, end-user companies such as Apple and Sony are developing micro-LED-based products. Sony's Crystal LED Integrated Structure (CLEDIS) giant displays uses 'ultrafine' RGB LED 0.003mm^2 pixel areas mounted on a black display surface (Figure 1).

At the other end of the supply chain, Epistar's president Jou Ming-jiunn commented in a June Digitimes report that US-based companies are inclined to apply micro-LED technology to wearables, VR and AR devices initially and then smartphones, while Asia-based firms, such as Samsung Electronics, are targeting large-size devices such as TVs. Epistar plans to produce 6-inch micro-LED epitaxial wafers, and possibly micro-LED chips, using existing equipment (which presently produces 4-inch LED epitaxial wafers) to meet these demands.

Market forces

Analysis firm Trendforce (through its LEDInside division) has been following micro- and mini-LED developments. LEDinside believes that replacing the entire LCD display chain could open up a market in the range $30–40bn for micro-/mini-LED displays.

LEDInside estimates that manufacturing costs of micro-LED-based products are presently on average 3–4 times as much as products based on traditional display technologies. This analysis puts the possible replacement of LCD technology by micro-LED-based displays at least 3–5 years away.

LEDinside research director Roger Chu believes that it is too early to determine the size of the micro-LED market because of differences among specification standards and manufacturing techniques. He adds: "New specification standards will raise the technology barrier for market entrants. The need for cross-industry collaboration will also prolong the R&D period for developers of micro-LED displays."

Chu also suggests that the developed mass transfer solutions may be used more widely to pick and place LEDs or other electronic components such as sensor chips.

While micro-LED displays are not on the immediate horizon, TrendForce/LEDInside does believe mini-LED-based backlight units will be rolled out in sample demonstrations next year as item 7 of its 'Top 10 Trends in Information and Communication Technology Sector for 2018' analysis. Devices on flexible substrate will allow curved displays. Mini-LED backlight units are also expected in smartphones, TVs, automotive displays and high-end gaming notebooks.

In its third-quarter 2017 results presentation, Epistar reported that it could be shipping products for mini-LED backlight units for large displays in first-half 2018. The company had been hoping for second-half 2017 production, but has had problem with yield rates and process stability.

Meanwhile, MarketsandMarkets Research Private Ltd claims that worldwide demand for micro-LED display and lighting panels could reach $20bn by 2025, growing at a compound annual growth rate (CAGR) of 54.7% between 2019 and 2025. This market researcher suggests commercialization in smartwatches by 2019 and in smartphones and tablets by 2021. Associate director Sachin Garg comments: "Display applications will dominate and drive the growth of the market during the forecast period and are expected to account for more than 95% of the market by 2025."

Initial high-growth-rate applications are expected to be near-to-eye (NTE) devices, smartphones, tablets, laptops and heads-up displays (HUDs). Up to 2025, TV, PC monitor and digital signage applications have relatively low growth rate projections in the study. The researchers suggest that the growth will be mainly driven by consumer electronics.

Samsung Electronics has rolled out its 10.3mx5.4m 4K (4096x2160 pixels) Cinema Screen with brightness of 500nits (candela/cm^2), first at Seoul's Lotte World Tower in July, and has signed up Major Cineplex Group (the largest cinema company in Thailand) to convert a 200-seat cinema at the Paragon Cineplex in Siam Paragon into its Cinema LED venue in October. Of course, at ~4pixels/cm (10ppi), these screens are not likely to be driven by mini-LEDs let alone micro-LEDs, unless they are pre-assembled in large numbers into separate pixels, although there are stringent technical requirements in terms of color and dynamic range.

TV screens with 4K ultra-high-definition (UHD) specs consist of around 24million (3-colorsx4096x2160) separate LED devices which, even with so-called six-sigma production yield (99.99%), would consist of up to 2500 failed pixels. Inspection and repair will inevitably be needed before such products leave the factory.

PlayNitride

Taiwan's Digitimes has been following PlayNitride, which seems to be stepping up work in the area, particularly in the past few months. Epistar is a partial investor in PlayNitride.

Digitimes' "industry sources" say that Electronic and Optoelectronic System Research Laboratories (EOSRL) under the Industrial Technology Research Institute (ITRI) is cooperating with PlayNitride, LED driver IC design house Macroblock and PCB maker Unimicron Technology to develop ultra-fine pixel-pitch micro-LED panels.

Macroblock sources expect samples of large-sized indoor commercial display walls with ultra-fine pixel-pitch panels to be presented in first-half 2018, and trial production to begin in the second half. In this work, PlayNitride is responsible for developing micro-LED wafers without sapphire substrates, and EOSRL is developing related technology for mass transfer of micro-LED chips onto printed circuit boards (PCBs) developed by Unimicron.

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According to Digitimes, PlayNitride has finished one-color micro-LED wafers and expects to have two-color ones by the end of 2017. Macroblock's contribution is a micro-LED display driver IC MBI5359 aimed at a fine pixel pitch of 0.9375mm. The MB15395 chip can detect misplaced micro-LEDs, facilitating early repair to improve the display quality and yields.

Meanwhile, PlayNitride chairman & CEO Charles Li spoke to Digitimes, saying that the company is starting trial production of micro-LED panels for niche markets. Li also reports that PlayNitride has hiked yield rates from

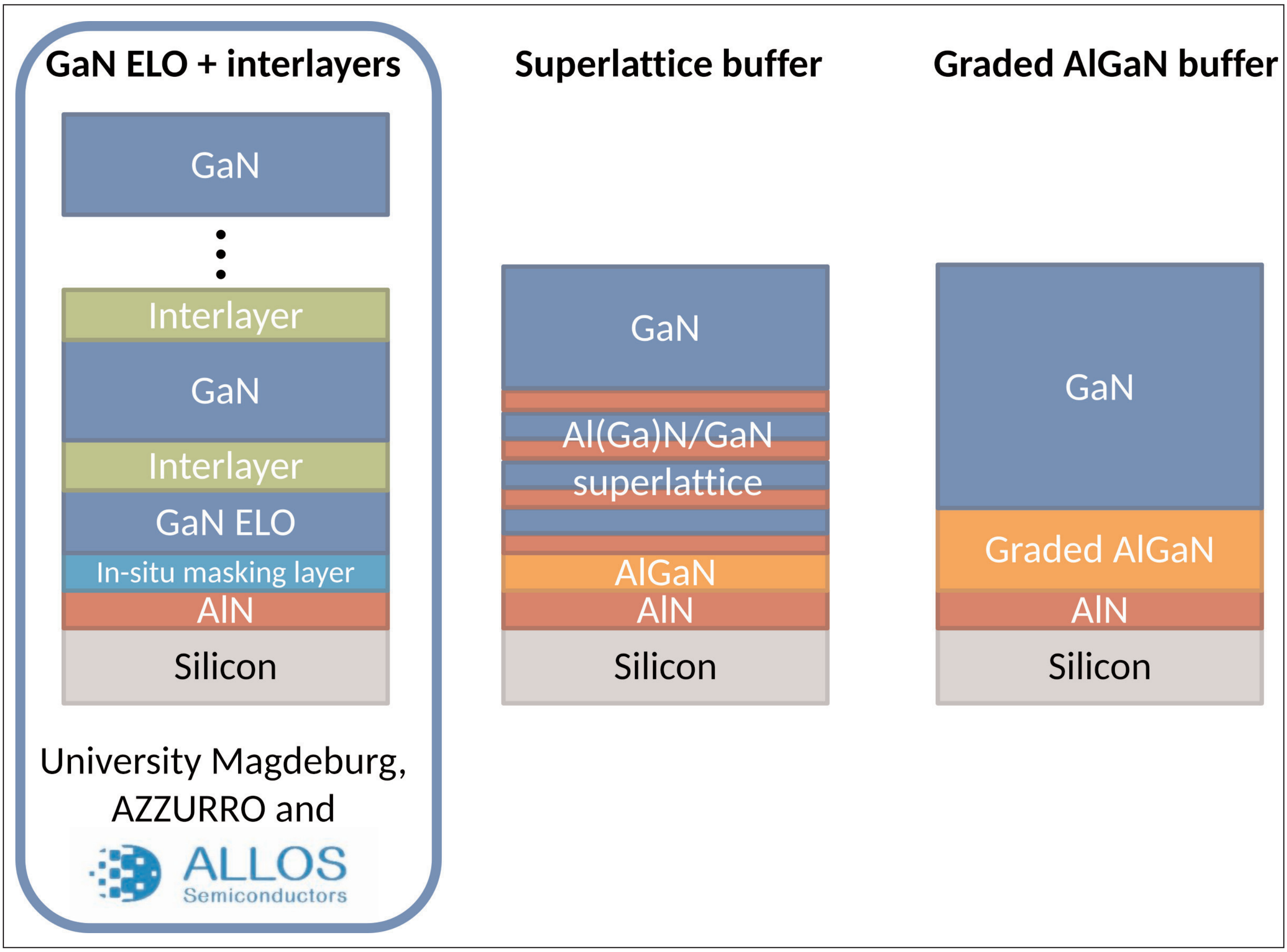

Figure 2. ALLOS approach compared with other often used technologies for GaN-on-Si.

30% initially to more than 99% — still short of the ideal level of 99.9999%. Despite its achievements, PlayNitride is finding it difficult to convince vendors to commit to micro-LED panels. Uniformity of LED epitaxial wafers and mass inspection of micro-LED chips (for which qualified machines are not yet available) are presently challenges, according to Li.

There are other small companies that have been working on micro-LED displays that have been reported over the years. However, the flow of news on their work seems to have been shut off a couple of years ago. For some, this indicates that their mission was accomplished by the sale of venture-capital-backed technology to large, established companies — e.g. Cork-based InfiniLED being taken over by Facebook's Oculus VR, or Luxvue going to Apple Inc. Others presumably have failed, while some have perhaps gone into 'stealth mode'.

GaN-on-silicon

Some parts of the supply chain are already being assembled. Veeco Instruments Inc with ALLOS Semiconductors AG have demonstrated 200mm GaN-on-Si wafers aimed at blue/green micro-LED production. This involved ALLOS demonstrating proprietary epitaxy technology on Veeco's Propel single-wafer metal-organic chemical vapor deposition (MOCVD) system.

ALLOS' CEO Burkhard Slischka reports: "Within one month we established our technology on Propel and have achieved 200mm crack-free, meltback-free wafers with less than 30μm bow, high crystal quality, superior thickness uniformity and wavelength uniformity of less than 1nm."

ALLOS is a fabless intellectual property licensing and technology company, which is the successor of University of Magdeburg spin-off Azzurro Semiconductors AG. The company believes that only GaN-on-Si can deliver the super-uniform, CMOS-compatible large epiwafers needed for micro-LEDs. The ALLOS technique uses interlayers to manage the strain profile between the silicon and GaN lattice and thermal mismatch (Figure 2). ■

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