Excimer laser technology is fuelling commercialisation of micro-LED displays

POWER AND PRECISION FOR MICROFABRICATION AT HIGH RATE

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Novel displays based on micro-LEDs hold great promise in terms of affording advantages such as high colour saturation, wide viewing angles, short response times, high brightness and low power consumption. However, manufacturing technologies and equipment for micro-LEDs are hindering market expansion because of fabrication issues chiefly relating to throughput, yield and productivity.

Micro-LED displays are envisaged as miniature versions of the large outdoor LED displays. They contain arrays of tiny LEDs that are about a hundred times thinner and smaller than their large-scale counterparts. Furthermore, they are less power-hungry than LCD and OLED displays, consuming only 10 percent and 50 percent of their power, respectively. Therefore, micro-LED displays are proposed for near-term use as wearable displays required for a growing number of smartwatches as well as for large-format TVs with diagonals of 65 in. and more such as Sony's novel ultra-high-definition (UHD) wall-type display.

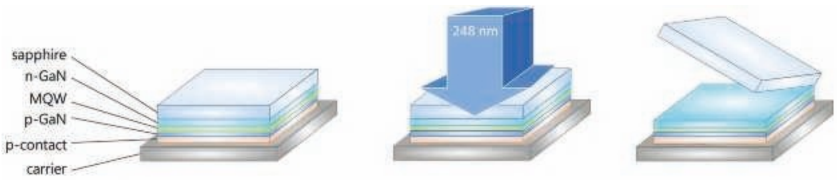
All display manufacturers dominating the LCD and organic LED (OLED) space rely on various laser processes to manufacture paper-thin and lightweight, rigid or flexible displays that deliver exceptional performance and pixel resolution. Among these processes are drilling and cutting of substrates and organic thin films, fine patterning of pixel and touchscreen structures, excimer laser annealing (ELA) for surface modification, excimer laser lift-off (LLO) for substrate separation, welding, and marking.

Excimer lasers are at the forefront of mobile display innovations in the LCD and OLED segments due to their combining the shortest wavelengths and highest output powers. The Coherent LineBeam (LB) excimer laser optical systems with a 308 nm wavelength are used to produce the low temperature polysilicon (LTPS) films required for high-resolution mobile displays as well as gently detach glass substrates from conventional rigid displays in flexible OLED production lines.

Performance enhanced thin film micro-LEDs via excimer LLO

In a similar vein, micro-LED display processing benefits from enabling excimer laser technologies. Like their large counterparts, micro-LEDs are obtained by growing gallium nitride (GaN) films on sapphire wafers. In order to reduce the device height and increase the device efficiency, the GaN-based micro-LED layers are transferred onto a conductive carrier material, and the sapphire wafer of typically 0.8 µm thickness is LLO separated at a short wavelength of 248 nm (figure 1), decomposing the topmost 10 nm of the GaN interlayer.

▶ *Figure 1: The excimer laser lift-off (LLO) principle using a wavelength of 248 nm that is absorbed by the GaN. The sapphire substrate is essentially transparent for the excimer laser beam. At a laser fluence of less than 1 J/cm², the interface layer of GaN decomposes into metallic gallium and nitrogen gas and the sapphire wafer is released.* ▶

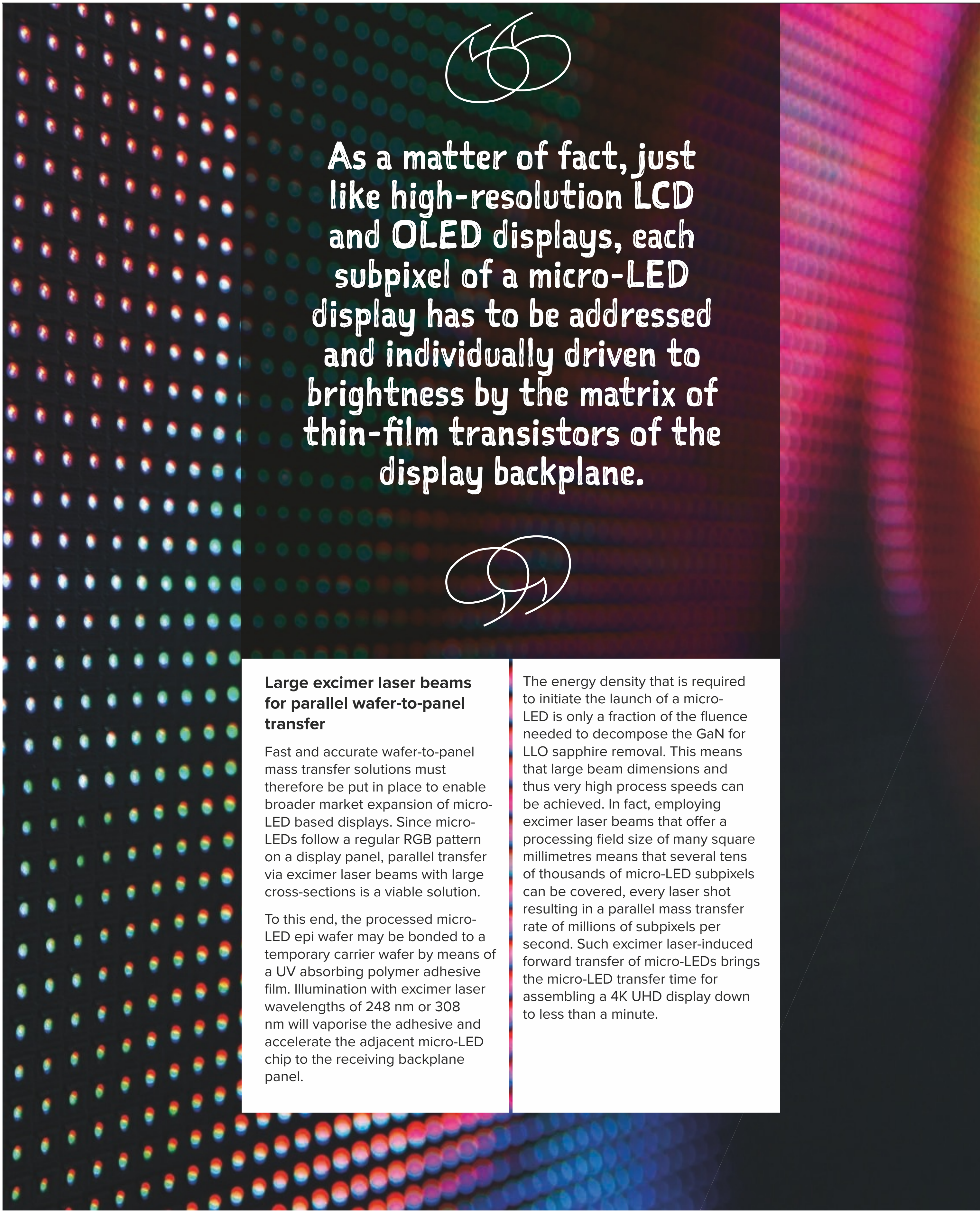


The LLO process commands spatial beam uniformity and fluence stability to prevent side-effects such as crack formation or chipping. The excellent pulse stability of the excimer laser (<1 percent rms), together with beam homogenising optical systems that deliver flat-top beam profiles along both long and short beam axes with some 100 µm depth of field, render a large process window, and a correspondingly high yield is achieved in mass production. In addition, the excimer laser beam geometry on the wafer during the LLO process can be adapted to the actual wafer diameter. Excimer laser optical system configurations support up to 8 in. wafer processing requirements.

The LB 155 system features a 150 W LEAP laser and with a 248 nm wavelength is designed to match a 6 in. sapphire wafer in a single scan. The laser generates a homogeneous line beam of 155 mm long axis length and 0.3 mm short axis width (figure 2). Excimer laser line beam systems enable a throughput of 60 and more wafers per hour and are the preferred solution for force-free LLO release of micro-LED epi wafers from their sapphire substrates.

A 4K UHD display incorporates 3,840 x 2,160 x 3 RGB subpixels. Consequently, this display requires the transferring of nearly 24 mn micro-LEDs onto the display backplane panel with a placement accuracy of just a few microns. Conventional picking and placing applied to such a high number of micro-LEDs would require six weeks per display.

▶ *Figure 2: The Coherent LB 155 system is powered by a 150 W LEAP excimer laser that emits short wavelength photons at 248 nm. A 3D profile of the generated line beam shape (155 mm long axis (LA) length, 0.3 mm short axis (SA) width) is shown in the foreground.* ▶



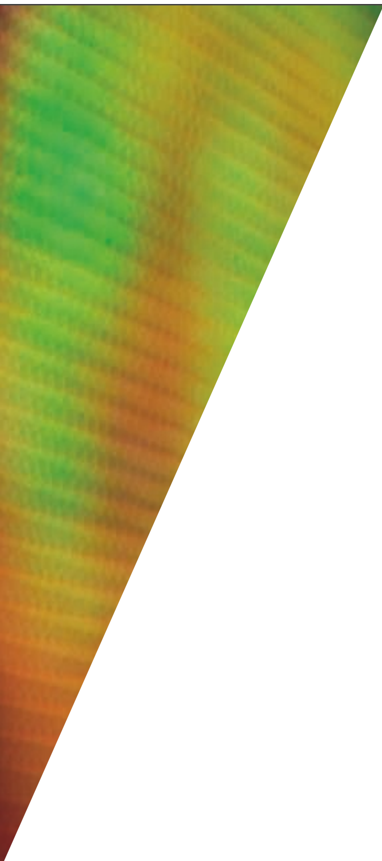
> As a matter of fact, just like high-resolution LCD and OLED displays, each subpixel of a micro-LED display has to be addressed and individually driven to brightness by the matrix of thin-film transistors of the display backplane.

Large excimer laser beams for parallel wafer-to-panel transfer

Fast and accurate wafer-to-panel mass transfer solutions must therefore be put in place to enable broader market expansion of micro-LED based displays. Since micro-LEDs follow a regular RGB pattern on a display panel, parallel transfer via excimer laser beams with large cross-sections is a viable solution.

To this end, the processed micro-LED epi wafer may be bonded to a temporary carrier wafer by means of a UV absorbing polymer adhesive film. Illumination with excimer laser wavelengths of 248 nm or 308 nm will vaporise the adhesive and accelerate the adjacent micro-LED chip to the receiving backplane panel.

The energy density that is required to initiate the launch of a micro-LED is only a fraction of the fluence needed to decompose the GaN for LLO sapphire removal. This means that large beam dimensions and thus very high process speeds can be achieved. In fact, employing excimer laser beams that offer a processing field size of many square millimetres means that several tens of thousands of micro-LED subpixels can be covered, every laser shot resulting in a parallel mass transfer rate of millions of subpixels per second. Such excimer laser-induced forward transfer of micro-LEDs brings the micro-LED transfer time for assembling a 4K UHD display down to less than a minute.



High performance micro-LED pixels necessitate high mobility LTPS backplanes

While the excimer laser optical system lends itself as a one-stop technological solution to LLO wafer release and wafer-to-panel mass transfer processes, it is necessary for the backplane of a high-resolution micro-LED display to also undergo an enabling excimer laser processing step.

As a matter of fact, just like high-resolution LCD and OLED displays, each subpixel of a micro-LED display has to be addressed and individually driven to brightness by the matrix of thin-film transistors of the display backplane. High mobility LTPS backplanes are required for micro-LED displays, and ELA amorphous silicon films at a wavelength of 308 nm is the established industrial laser process. Hence, micro-LED displays gathering market share and eventually forming new display segments are poised to contribute to the ongoing demand for LTPS backplanes. ●

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