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Laser technologies for the production of microLEDs

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Abstract

MicroLEDs have a tremendous potential for future displays. However, there are several technical challenges to overcome prior to widespread deployment of MicroLEDs. One key hurdle is developing a process to release the dies from the sapphire growth wafer. Another is a process to transfer these to the display substrate with micron level precision and reliability.
Laser processing offers several opportunities for MicroLED display production, such as Laser Lift-Off (LLO) to separate the finished MicroLEDs from the sapphire growth wafer and Laser Induced Forward Transfer (LIFT) to move the devices from a donor to the substrate.
In this presentation, laser-based system solutions for the different manufacturing steps for MicroLEDs, will be presented. Integrated process control and monitoring is used to assure stable and reliable operation to ensure high throughput and low yield losses.

Keywords: microLED; Laser Lift-Off (LLO); Laser Induced Forward Transfer (LIFT); display; laser processing

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1. Introduction

MicroLED, also called mLED or µLED, is a new display technology based on light-emitting diodes (LEDs). As the name suggests, the technology relies on light-emitting diodes with dimensions in the micrometer range. Manufacturers such as PlayNitride and Sony define microLED screens by light-emitting diodes with dimensions smaller than 50 µm or a luminous area smaller than 0.003 mm^2.

MicroLEDs are self-luminous, dimmable and completely switchable, and have enormous potential for future display technologies. They score particularly well with their brightness, higher contrasts and high production density, but are currently very cost-intensive to manufacture in mass production. Potential applications include very large displays for indoor and outdoor use – just think of the microLED display "The

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Wall", which Samsung impressively presented at CES 2018 – but also high-resolution displays for augmented reality (AR) and virtual reality (VR) applications.

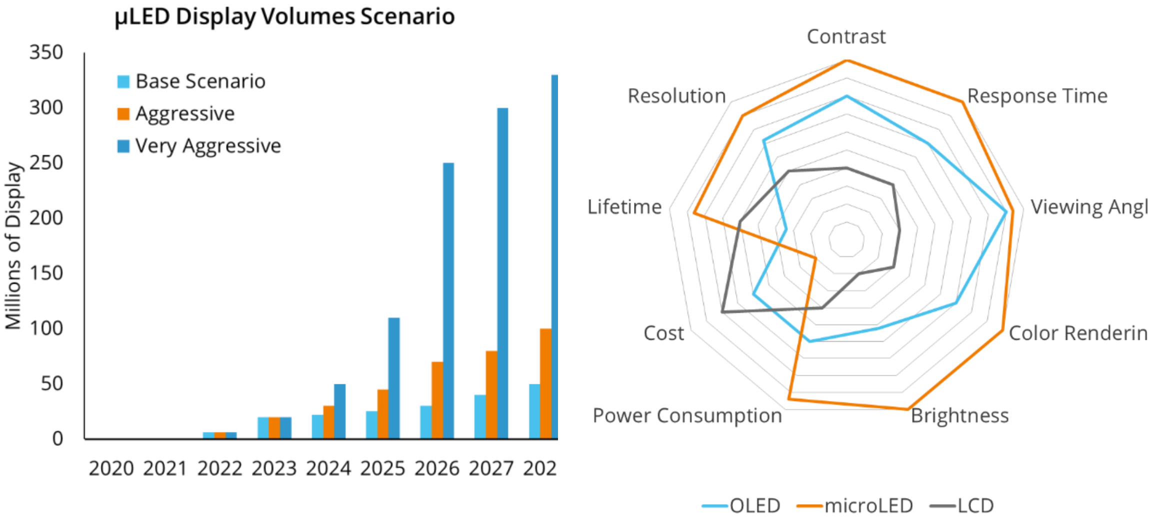

Fig. 1. (a) Market potential and (b) benefits of microLED applications

Typically, microLEDs are based on gallium nitride (GaN) and currently have dimensions in the range of 20 to 50 µm. However, future generations of displays are expected to have significantly smaller dimensions down to below 10 µm. Using existing GaN fabrication technology on sapphire wafer growth substrates, microLEDs can be produced in very high numbers and with linewidths of a few micrometers due to their small size.

However, before microLEDs can be used in the mass market, there are some technical challenges that need to be overcome in the fabrication process. One of these is detaching the chips from the growth wafer. Another hurdle lies in developing a suitable process to precisely transfer the chips to the display substrate. With Laser Lift-Off (LLO) and Laser Induced Forward Transfer (LIFT), two laser-based processes are available to address precisely these challenges. Further potential is offered by so-called "repair" processes, i.e. technologies that are able to detect and repair/replace defective microLEDs during the manufacturing process.

2. The microLED manufacturing process

The manufacturing of a microLED panel is – in contrast to conventional OLED or LCD displays – a complex task. The process steps typically do not take place on a substrate. The production of the backplane, the target substrate, and the fabrication of the microLED take place on separate production lines that include several process steps. These include the production of the LED chips, the preparation of the substrate, the production of the backplane, and the transfer and application of the LED chips.

A wafer with an epitaxially grown gallium nitride layer and a glass backplane serve as the basis. Chips are built up on these using processes that are standard in the semiconductor industry. Using laser lift-off technology, the microLEDs are released from the wafer and their functionality is tested by photo- and electroluminescence. Due to the thermal effects of laser processing, the detached microLEDs move towards the glass intermediate substrate and latch onto it. In the course of bonding, the microLED is connected to the glass backplane under the influence of heat and then inspected again using a camera. Defective microLEDs are removed during the laser trimming/repair process step. The process is then repeated with new microLEDs in order to replace the removed microLEDs until the desired yield is achieved.

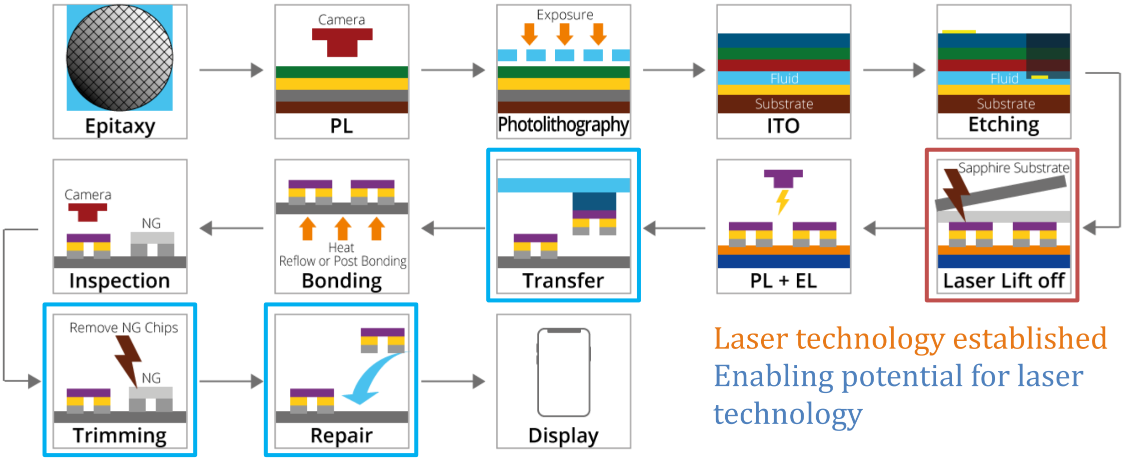

Fig. 2. The microLED manufacturing process

3. Laser Lift-Off (LLO)

Laser Lift-Off, or LLO, is a process for selectively detaching one material from another. It involves a laser beam, which penetrates a transparent base material that is coupled to a second material. LLO is commonly used in the fabrication of LEDs and microLEDs, where the light-emitting layer stacks are separated from the sapphire base substrates for reuse. Other applications can be found in the separation of transparent and absorbing flexible substrates from glass substrates, such as those used in the manufacture of flexible displays, OLED or AMOLED. In addition, further applications can be found in the semiconductor industry or sensor manufacturing. The underlying concept of the LLO process is the varied absorption of the laser light in the different layers that need to be separated from each other. Short-wavelength laser light in the UV wavelength range from 193 nm to 355 nm and pulse lengths in the nanosecond range are ideal for the LLO process.

The laser beam penetrates the sapphire wafer and strikes the impermeable GaN layer. This heats the interface between GaN and sapphire up to 900°C. The two materials are then separated. The receiver substrate is provided with an appropriate adhesive layer. In the process, the UV laser lifts off the GaN layer from the sapphire base material over the entire surface – without damaging the underlying material. Essential for a successful lift-off process are the beam quality of the laser as well as the process control in order to realize high-performance production processes with high process speeds.

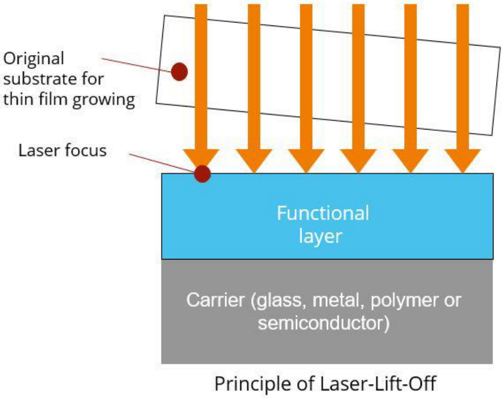

Fig. 3. Schematic representation of the laser lift-off process

For this process step, 3D-Micromac AG relies on the laser lift-off system microMIRA, which enables a very uniform, force-free lift-off of flexible layers on large areas and at high speeds. The system is capable of processing different materials and sizes and has been successfully used in mass production by leading electronics manufacturers worldwide for years.

4. Laser-Induced Forward Transfer (LIFT)

Laser-Induced Forward Transfer (LIFT) is a process in which laser radiation is used to selectively transfer material from a starting carrier (donor) to a target substrate (acceptor) by means of laser radiation. The laser does not process any material in the classical sense, but is used as a tool that triggers the material transfer via a controlled energy input. Similar to LLO, the interface between the substrate and the microLED is heated, and the microLED detaches from the substrate. By positioning the source material upside down to the target substrate, the LED is transferred by gravity. The laser is so selective that single or multiple LEDs can be detached and transferred.

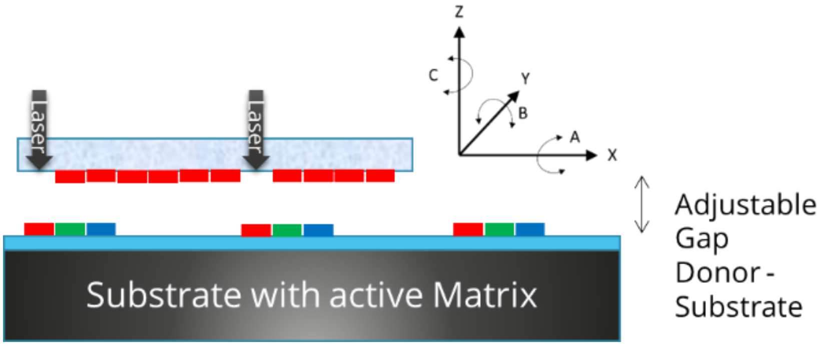

Fig. 4. Schematic diagram of the LIFT process

The transfer of microLEDs is subject to special requirements in terms of accuracy, transfer rates and reliability. In contrast to LIFT, conventional transfer methods do not deliver the required throughput. Mechanical placement methods are limited in terms of speed and positioning/placement accuracy. Flip-chip bonders, on the other hand, are capable of high-precision placement, but can only handle one microLED chip at a time.

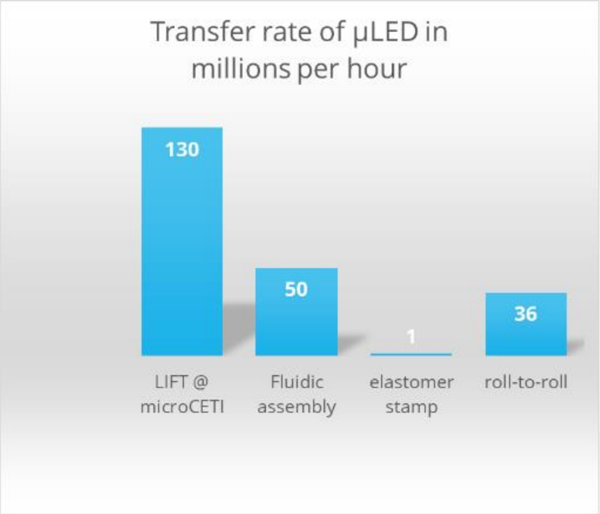

Fig. 5. Comparison of transfer rates of different transfer approaches.

The LIFT technology used at 3D-Micromac currently offers the highest transfer rate of approximately 130 million microLEDs per hour and is integrated into the new microCETI platform. The system is characterized by positioning accuracies of less than 2 µm and is therefore perfectly suited for the transfer of microLEDs.

Fig. 6. 3D-Micromac's new microCETI platform serves all laser processes in microLED display manufacturing.

5. Laser processes are perfectly suited for the production of microLEDs

MicroLEDs represent a promising development for future display applications. However, there are still several manufacturing hurdles to overcome before these displays can be manufactured in high volumes using mass production processes. Despite the technological advances discussed above, there are still some critical bottlenecks that need to be overcome for mass production of microLED displays.

An important issue is the pixel yield of the display. A dead pixel can occur at various stages of manufacturing, such as epitaxy, LED chip processing or the transfer process. To produce a full-color 1920 × 1080 full-HD (high-definition) display with less than five dead pixels, the yield must be 99.9999%. This yield is too high for the technical level achievable today with conventional manufacturing methods.

3D-Micromac's laser systems with UV lasers have enormous potential to establish themselves in the field of LLO and chip transfer to drive mass production of microLED displays. Above all, the high transfer rates enable a cost-efficient process and thus a reduction in the overall costs of display production.