APPLICATION NOTE

HXP HEXAPOD BASED SOLUTIONS FOR MASS TRANSFER AND DIE REPAIR IN MICRO-LED MANUFACTURING EQUIPMENT

PROBLEM

The micro-LED (Light Emitting Diode) is the latest in the LED evolution. A standard LED is approximately 250 microns, a mini-LED is approximately 100 microns, and the term micro-LED (also known as μ-LED) is generally reserved for LEDs whose dimensions are less than 50x50 μm or whose maximum diameter is 55 μm for circular ones. The first experimental "micro-LEDs" appeared in 2000 (Figure 1). Soon, the idea came to use them in a network to create very high-resolution color screens with pitches down to less than 50 μm (Figure 2). At the beginning of the 2000s, the first screens were designed on passive-matrix devices. This limited the image quality with regards to resolution and brightness because each pixel must maintain its state passively while other pixels are being addressed, without being driven by circuitry (transistor and capacitor). The first active-matrix screens with pixel state maintained by circuitry, each sub-pixel of which is composed of 3 micro-RGB LEDs, appeared after 2008.

Figure 1: Advanced Display Technology

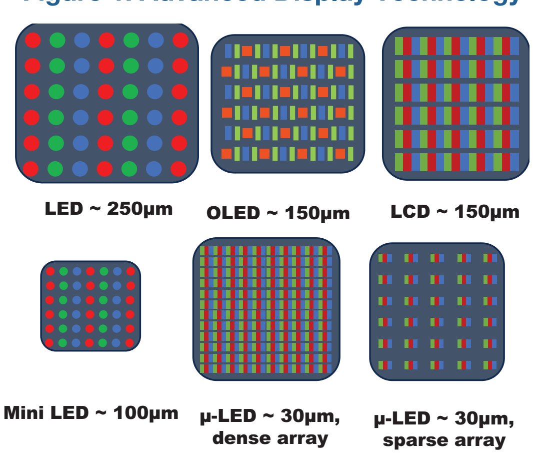


Figure 2: High Resolution Display

The most important change in existing display technologies is LEDs now require high processing temperatures of over 1000°C and therefore can not be "grown" and patterned directly on top of the transistor matrix. The process to obtain micro-LEDs is similar to that of LEDs, but requires more accuracy and may need additional mask levels and different process steps due to the very small size of components. Typically, a 6" sapphire epitaxial wafer is used and receives operations of lithography, etching (GaN etchers), passivation and metallization. Unlike other proven technologies manufactured in large quantities, such as LCD or OLED panels, each micro-LED is an independent component that must be positioned very precisely and then connected to the transistor matrix. In addition to increased resolution and brightness, the benefits include reduced power consumption and dramatically longer lifetime.

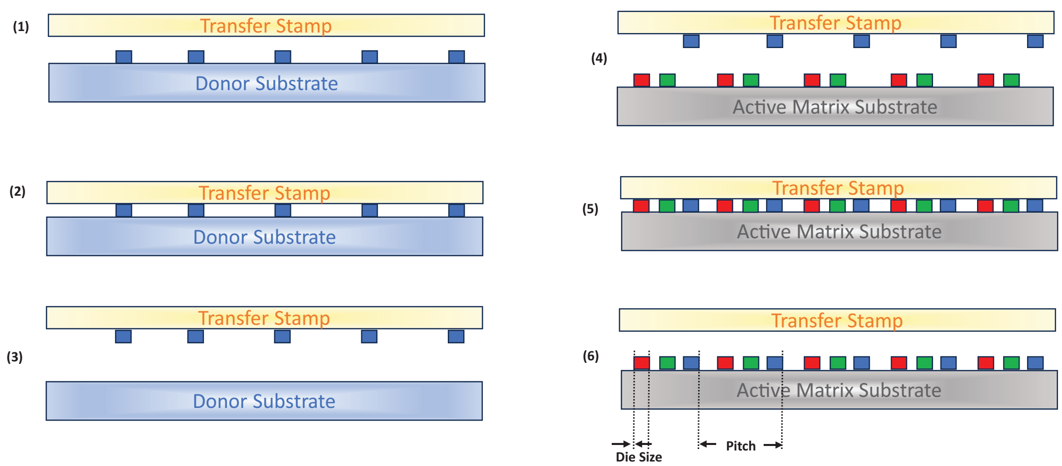
There are significant difficulties inherent in this approach. Several million micro-LEDs (over 25 million for a 4K television) must be handled and precisely assembled within an acceptable time frame. It is also mandatory to identify and replace defective micro-LEDs. It is therefore necessary to develop a manufacturing technique that allows many components to be handled and assembled simultaneously. Most of these industrial techniques and processes for implementing and assembling micro-LEDs on a large scale were still under development in 2023.

The process of transferring and placing micro-LEDs on the matrix is a crucial step in the production of micro-LED displays. For the reasons mentioned above, this is the most technical and complicated phase of the manufacturing process.

Currently, there are 3 different technical approaches for the handling and assembly of micro-LEDs:

1. **Massively parallel pick and place: Mechanical Stamp-Figure 3**
   A transfer stamp shuttles between a donor wafer and a receiver wafer transporting thousands of micro-LEDs simultaneously and with high precision for placement on the TFT matrix substrate.

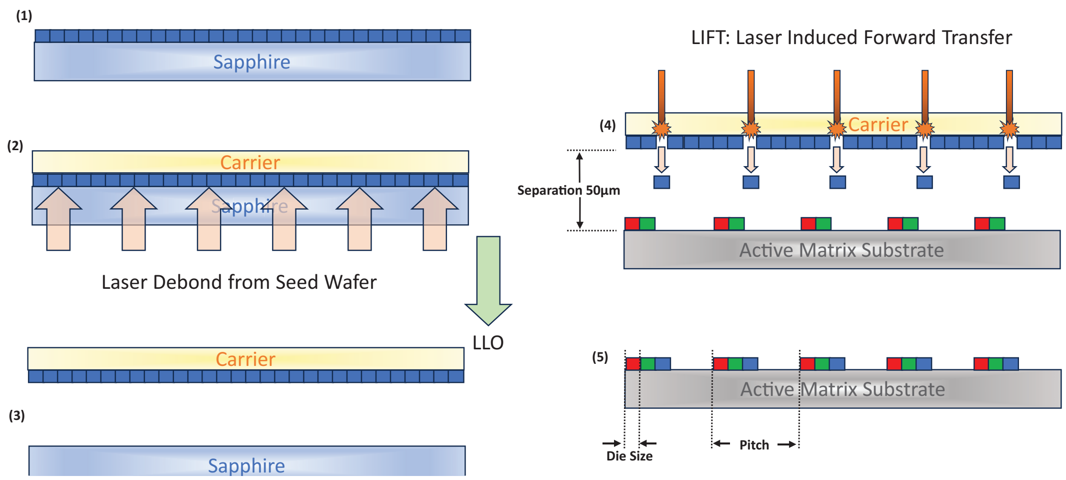
Figure 3: micro-LED Transfer Shuttle (stamp)



Position and parallelism is critical during Transfer Stamping

2. **Sequential/Semi-continuous**
   A large quantity of micro-LED chips are placed in a cartridge and "printed" sequentially at high speed and precisely, individually or in small groups. An evolution of this approach is a direct transfer that takes place from the epitaxial wafer where micro-LEDs have been grown to a laser-transparent glass carrier: the "donor substrate". Then, the micro-LEDs are released from the donor substrate by a Laser Lift Off (LLO) process and moved to the display panel. This alternative seems to be the preferred process today because combined with laser technology, it provides a high positioning accuracy and higher yields.

Figure 4: Illustration of LLO & LIFT principles



Position and parallelism is critical during LLO & LIFT Processes

3. Self-assembly

The chips are stored in a "tank" and kept in suspension or brought close to the receiving substrate where they self-assemble at specific sites guided by purely mechanical or electromagnetic forces. Specific shapes on dies and on receivers may exist to facilitate the positioning and improve its accuracy. The fluidic mass transfer provides the advantage of randomization of the micro-LEDs positioning because the dies come from "different wafers". This randomization provides a better quality display.

Currently, the mechanical stamp process is the mainstream method because it reduces the amount of travel between the print head and the donor wafer. Laser based technologies (Figure 4), such as LLO (Laser Lift Off) and LIFT (Laser-Induced Forward Transfer), are expected to gradually replace the stamp process. These techniques are for many industrial manufacturers the most promising technique for transferring micro-LEDs in an industrial process.

Regardless of the micro-LEDs transfer principle, the positioning and assembly of micro-LEDs will experience a defect rate. For optimal image quality, it is essential to replace defective components by having the ability to identify and separate them from their support, and replace them with new components. Given the millions of micro-LEDs required to create a screen, we intuitively understand that the ppm rate of defective components or defective assembly is a crucial issue for making quality screens at a controlled and acceptable cost for the consumer. Extremely precise alignment and positioning of the components are essential elements for a high-quality image.

Compared to existing high-performance technologies such as OLED, micro-LEDs are much more complicated to implement as individual components, due to their quantity and size. However, they have many advantages in terms of brightness, power consumption and lifespan when compared to OLEDs. Due to their extremely small size, they make it possible to produce screens with a pixel density previously unknown with high brightness and exceptional color depth. This is why screen manufacturers are very interested in the development of this technology and are looking for industrial ways to position and connect micro-LEDs. Today, the four main applications are Smart Watch, Automotive, AR/VR, & Luxury TV. They are under development in parallel and each have different requirements in micro-LED size, pitch and resolution.

Performance comparison: LCD vs OLED vs μ-LED

Display Technology	LCD	OLED	μ-LED
Luminous Efficiency	Low	Medium	**High**
Luminance cd/m²	>3000	>500	**>100,000**
Contrast	Medium	High	**High**
Response Time	ms	μs	**ns**
Power Consumption	Medium	Medium	**Low**
Operating Temperature	-20 to 80°C	-30 to 70°C	**-100 to 120°C**
Flexibilty	Low	High	**Medium**
Lifetime	Long	Medium	**Long**

The main challenges of implementing millions of micro-LEDs on a TFT receiver are as follows:

- Percentage of defects: poor alignment, defective micro-LED. Manufacturers have achieved 99.98% yield and now target 99.999% in order to manufacture large panels with an acceptable effectiveness. The micro-LED screen industry is currently more focused on sizes smaller than 300 mm x 300 mm (AR/VR devices, smart phone, tablet, car display). Due to the challenge of transferring dies in quantity with a high level of quality, it is easier for manufacturers to demonstrate industrial feasibility on small screens first and then to enlarge, step by step, on wider ones.
- The cost of finished goods remains high despite years of past research. There is still a long way to go to make it affordable for a consumer market.
- The emerging micro-LED technology is in competition with efficient and proven technologies, such as OLED, AMOLED and LCD, which already make it possible to have high quality displays delivering a high-definition image at a reasonable price. The yield is already very high in LCD and OLED panel displays. Producing a much higher yield is a challenge for micro-LEDs.
- Throughput is the most direct contributor to the operating cost, and yield is the current bottleneck.
- The transfer process can also suffer from various problems. Some of the LEDs could be damaged (especially when they are physically handled during the transfer) or could be placed in the wrong location. Unlike standard LED production, which is a mature process, micro-LED transfer process development is still at an early stage, and standard LED placement and bonding processes are not yet fully adequate. The most popular micro-LED mass transfer processes are based on stamp transfer, which uses a print head to pick up several LEDs from the wafer, transfer them to a donor substrate, and place them on the TFT matrix. This mechanical handling of LEDs is relatively straightforward but could potentially harm the LEDs/dies.
- Laser Lift-Off, or LLO, combines with the z-tip tilt of a hexapod to separate the micro-LEDs from the donor wafer. The micro-LEDs are produced using a succession of metalorganic chemical vapor depositions (MOCVD) to grow different epitaxial layers. Micro-LEDs are directly grown on a sapphire substrate. The LLO process employs a high energy pulsed laser which is transparent in sapphire but is strongly absorbed by GaN. The GaN is decomposed, so that delamination occurs. Then, the diode is released from the sapphire substrate to the donor wafer.
- Laser Induced Forward Transfer technology (LIFT) allows the LED to be simultaneously separated from the donor wafer and propelled onto the receiving substrate placed nearby, which constitutes the TFT display. The transfer is induced by focusing the

laser pulses on the support-adhesive film interface, where heating and phase change of the film provide the propulsion necessary to propel the LED towards the TFT receiver placed nearby at an accuracy of a few tens of microns. The LIFT operation also enables changing the pitch of the donor to fit the enlarged pitch of the receiver.

- Die repair: Even with a tremendously high yield of 99.999%, there are still a significant number of defective micro-LEDs that need to be repaired (about 40 for a 4M die display). In that case, the technique differs from mass transfer. You do not have dozens of micro-LEDs to manipulate but you need to check the health of each micro-LED on your flat panel display and identify precisely where the defective dies are located. Then, with a miniaturized tool, you can heat and remove one single defective micro-LED and replace it with a new one of the same color (using the LIFT process). Finally, you affix it with a conductive ink on the transistor matrix. To realize this operation with a precise alignment of the tools and the matrix, a hexapod is often used because the 6 degrees of freedom allows the process to precisely position and mount a single micro-LED, replacing the defective one.

BACKGROUND

Manufacturers require a solution that delivers a high throughput and high yield to transfer the (LED) die from the donor wafer to the TFT matrix (or another temporary carrier, depending on the process design). Today, Hexapods manufactured by Newport, with 6 degrees of freedom, are ideal compact tools used to develop LLO and LIFT techniques. They enable the alignment and constant spacing between (Figure 5) two wafers with high precision to transfer dies. Typically, the values are about 50 µm between the 2 wafers with a flatness tolerance of 1 to 5 µm, depending on the application.

SOLUTION

During the LLO and mass transfer processes, it is important to obtain high precision positioning so the donor wafer and the carrier wafer are precisely aligned and parallel.

During the mass transfer solution LIFT process, the distance between the surfaces must be a few dozen microns with little variation over the entire surface (typically 50 µm between carrier wafer and recipient (TFT matrix) with a variability of 5µm).

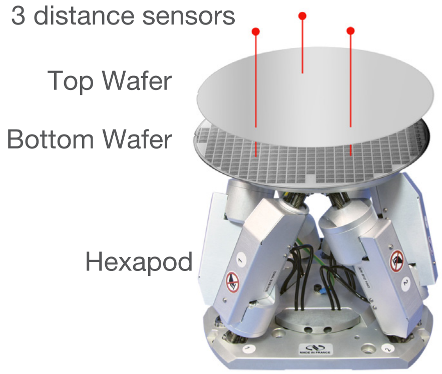
For the LIFT process, the transfer from the carrier wafer to the substrate with active matrix or another carrier wafer, the pitch changes but the requests for accuracy of alignment remains the same between the wafer and the matrix.

The Newport Hexapod is ideally suited to meet the stringent requirements of this solution and realize a near-perfect parallelism between the carrier wafer and the TFT matrix.

- Compared to traditional assemblies of stages, the hexapod offers high stiffness, is compact, and easy to use and configure. The performance in Accuracy/Repeatability of Tip/Tilt is improved, which is important to realize high parallelism between bottom and top wafers.
- A high straightness of the Z-axis is crucial to ensure the position alignment between top and bottom wafers during the movement of the z-axis. Standard and Hysteresis modes are available to help meet this requirement.
- A customized algorithm developed for the customer's application controls the parallelism of the wafer from the distance sensor output, thus allowing the hexapod to fit precisely and maintain accuracy between wafers.

Current customers' profiles for these mass transfer applications are system integrators of laser tool equipment working for display manufacturing companies.

Figure 5. Illustration of our solutions with a hexapod



The system is composed of one hexapod supporting a single wafer precisely aligned to a fixed wafer. Linear stages can be added under the hexapod for the purpose of loading and unloading wafers when the system is integrated in industrial equipment.

To realize the alignment, three distance sensors are used to measure the average distance between the wafers and to command the hexapod carrying the bottom wafer/substrate to approach the upper wafer at certain separation and keep parallel between both. High speed and short settling time in tip-tilt and z-axis movement (<10s for whole cycle) are required. The throughput is generally limited by the time needed to perform the mechanical alignment.

Micro-LED transfer requires the donor and the receiver to align precisely in order to avoid damaging the micro-LEDs in one area, or leaving others behind due to insufficient contact. Newport hexapods excel at moving two planar surfaces parallel to each other and controlling the separation, making them ideal for bonding or transfer.

Hexapods can also provide precision alignment, utilizing 6 degrees of freedom required to position and precisely mount the new single micro-LED that replaces a defective LED during die pick & place repairs.

The welding process is another critical process for micro-LED manufacturing. After LIFT or mass transfer is complete, a welding (either thermal or laser welding) process follows to create an electric connection between LED dies and TFT substrate. During this process, several tens of Newtons force (typically 20-30 N) is applied to push the carrier wafer onto the receiving substrate, while laser or thermal treatment is conducted. During this process, rigidity of the hexapod is crucial so that drift of receiving substrate is minimal. The outstanding performance and rigidity of Newport hexapods play a crucial role during this process.

CONCLUSION

Today, micro-LED technology is very promising because of the unrivaled performance it provides in luminous efficiency, brightness, power consumption and lifetime, compared to OLED technology & other current technologies. Nevertheless, due to the small individual size of the micro-LEDs, manufacturers are still looking for transfer solutions capable of moving a very high quantity of dies quickly and with a very low rate of failure. This will offer production level volume at a competitive price.

Combining techniques of laser transfer with high precision motion solutions, such as Newport hexapods, offers OEMs an efficient industrial solution for mass production of micro-LED displays.

NEWPORT PRODUCTS

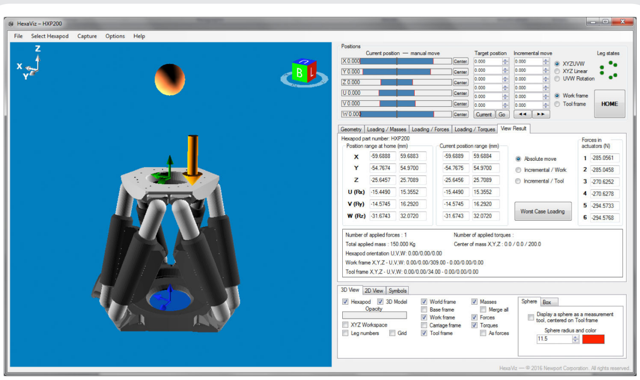
HXP100-MECA: Hexapod, High Precision, 200 mm Diameter Platform, 20 kg Load

The HXP100-MECA High Precision 6-Axis Hexapod is a parallel kinematic motion device with a 200 mm diameter platform and 20 kg load capacity. It provides six degrees of freedom: X, Y, Z, pitch, roll, and yaw for an effective solution to complex motion applications that demand high load capacity and accuracy in up to six independent axes. The HXP100-MECA hexapod is compatible with our HXP100-ELEC-D controller. Hexapods, in general, are high priced and complex devices that are difficult to implement. The HXP100-MECA, on the contrary, is not only affordable but easy to use and re-configure.

The quality of actuators has a critical impact on the overall motion performance of a hexapod. Drawing on over 55 years of Newport's expertise in actuators, the top plate of HXP hexapods is driven by 6 industry-proven, high-performance actuators with encoder feedback at the leadscrew nut to provide precise minimum incremental motion, low backlash and fast speed.

HXP100 Hexapod

Of equal importance to overall motion performance as the actuators are the 12 joints that connect these actuators to the base plate and moving top plate. Rather than using ordinary universal joints, HXP hexapods utilize ceramic spherical joints to ensure constant preload over full travel, enhancing rigidity that reduces material stress, while improving performance and avoiding corrosion. The result is a hexapod that is more rigid with higher load capacity compared to similarly sized hexapods.
The HXP100-ELEC-D controller to be purchased separately to drive the HXP100-MECA.



HexaViz Software

Our HexaViz™ hexapod simulator allows you to discover which Newport hexapod model best fits your application needs before ordering. Newport's FREE HexaViz Hexapod Simulation Software provides an easy-to-use virtual hexapod interface to evaluate travel range, load capacity, force, and torque characteristics.

HXP200-MECA: High Load Hexapod, 50 kg Centered Load Capacity

The HXP200-MECA High Load 6-Axis Hexapod is a parallel kinematic motion device that provides six degrees of freedom: X, Y, Z, pitch, roll, and yaw. The HXP200 is an effective solution to complex motion applications that demand a high load capacity of up to 50 kg, centered and offset loads of at least 5 kg. The HXP200 also features long travel ranges (up to ±59 mm), fast speeds (up to 81 mm/s), high stiffness and stability. The HXP200 is driven by six DC servo motor actuators which provide precise MIM (0.2 µm). A brake on the actuator eliminates drift at power-off conditions. A critical design feature that enhances the overall motion performance is the joints with which the actuators are attached to the base and the moving top plate. The preloaded and backlash-free, cardan joints enhance not only the repeatability and positioning performance of the HXP200 but are also key to its position stability and stiffness. Determine if the HXP200-MECA is the right hexapod for your application by using Newport's free HexaViz Simulation Software.

The HXP200-ELEC-D controller to be purchased separately to drive the HXP200-MECA.

Hexapod Motion Controller

Hexapod Motion Controllers/Drivers

The HXP-ELEC-D is a high-performance motion controller, dedicated for use with Newport hexapods, with the ability to control an additional two single-axis motion systems. The HXP-ELEC-D is based on the same hardware as the Newport XPS-D Universal High Performance Motion Controller/Driver, but it is preconfigured with special firmware to command the Hexapod mechanics. The firmware features are designed for simplified programming and integration.

- Controller and driver for hexapod positioners
- HXP+2 feature enables use of two additional axes of motion
- RightPath™ Trajectory Control for ultra-low runout at constant velocity