MicroLED Mass Transfer - A Future Proof UV Laser Based Process

Oliver Haupt[1], Jan Brune[1]

Oliver.Haupt@coherent.com
[1]COHERENT LaserSystems GmbH&Co.KG, Hans-Boeckler-Str. 12, 37079 Göttingen/Germany
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ABSTRACT

A large scale MicroLED display consist of millions micron sized LED´s. One of the main challenges is the transfer step where the MicroLED´s need to be transferred in one or the other way from the growth wafer (EPI wafer) to the substrate.

Concurrently, the pitch must be increased. In order to reduce costs per part the target is to produce as much MicroLED´s with smallest street width on the growth wafer followed by a selective transfer to achieve a larger pitch on the substrate. Thus, a flexible, high precision mass transfer technology is required. In this paper the UVtransfer technology will be described which offers such high precision combined with the high throughput needed.

1 Introduction

The step from MiniLED to MicroLED is enormous and existing technologies reach their limits due to the smaller sizes of the individual dies that are economically required. With shrinking sizes beyond the 10µm range and corresponding smaller street widths, mechanical transfer solutions reach their physical limits when considering precision and throughput at the same time. Over the last years different approaches were developed and tested. The different technologies are based on electrostatic, or electromagnetic, van der Waals forces, or fluidic forces, and the promising laser-based approach [1]. The published transfer rates are in the million parts per hour regime where the lowest rates are listed with >1m per hour and as fastest the laser transfer with up to 100m per hour, as listed in Table 1.

Methode	Force	Transfer Rate
Laser Transfer	Laser	> 100m per hour
Fluidic Assembly	Gravity and Capillary	>50m per hour
Electro Static	Electrostatic	nn
Elastomere Stamp	van der Waals	> 1m per hour
Roll-to-Roll	Roll Stamp	> 30m per hour

Table. 1 Transfer rates for different transfer methods [2]

Another challenge for high throughput mass transfer of MicroLED´s is the placement accuracy. The stamp/ pick and place is the most common and known technology for MiniLED´s in the 100 µm range. With die sizes in the ≤10µm range the technique is facing serious challenges due to the smaller area to pick the individual dies.The placement accuracy of MicroLED´s needs to be in the range of <± 1.5µm. However, currently, the accuracy of existing transfer equipment (Pick & Place) is significantly higher (Multi-chip per Transfer), while flip chip bonders reaches an accuracy of ±1.5µm (single chip per transfer), which are failed to meet the throughput requirements of Micro LED mass transfer. Laser technologies are the most promising approach to reach the required accuracies along with the necessary throughput.

1.1 Laser Wavelength

The common material combination for single MicroLED´s is GaN as buffer layer on sapphire for green and blue, while for red die´s Silicon is the wafer material. For the Laser Lift-Off step it´s well known that a short UV wavelength 248nm or 266nm is required to release the die´s from the EPI wafer and keep the laser interaction zone in the first nanometers of the GaN layer. The bandgap of GaN with 3.3 eV needs to be exceeded. UV Excimer laser give the wavelength (photon energy) to find direct linear absorption in the GaN. 248nm or 5 eV is a good match.

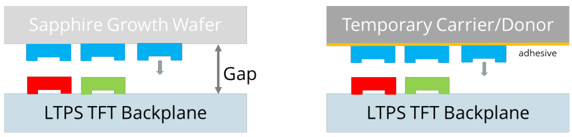


Fig. 1 Transfer directly from the growth wafer vs. transfer from a temporary carrier

Mass transfer can either be used to transfer MicroLED´s directly from the EPI wafer and for this direct transfer the short UV wavelength of 248nm or 266nm is mandatory. This direct transfer method has some advantages due to the reduced number of process steps. On the other hand the energy density needed for a direct transfer is higher with a fluence of up to 1200mJ/cm² compared to the method where a temporary carrier is used and the die´s are temporarily fixed by PI or other adhesives. Here the energy densities were determined between fluence up to 300mJ/cm² for 248nm Excimer wavelength and are the preferred technology to enable a large field size.

1.2 Laser Beam Profile

Mass transfer means transfer of multiple die´s within the same process step or better: with the same pulse of the laser. The larger amount the better as this drastically increases the throughput. All die´s need to be transferred precisely and without damages to the right landing position. Therefore, it is essential that the laser beam is highly homogeneous over the entire field – a top-hat beam is mandatory. Excimer based processing systems are known to be capable of providing the best beam homogeneity. In figure 2 a simple system schematic is shown.

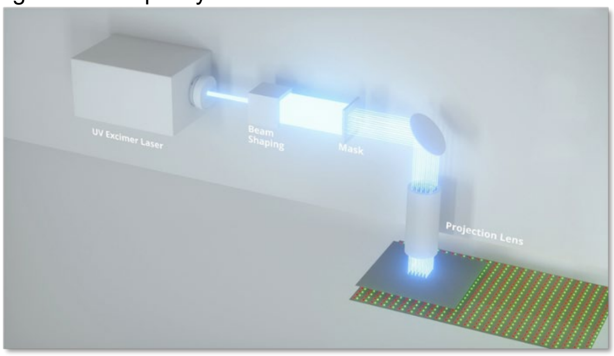


Fig. 2. Excimer laser based mask imaging system – homogenized Top-Hat beam enables mass transfer

The optical systems are designed to reduce the energy densities to a reasonable regime so that a chrome on quartz (fused silica) mask can be used. The advantage that these masks are widely used and readily available is given. On the mask any pattern could be designed and according to the later pitch on the substrate., This mask pattern is imaged through a high-resolution imaging lens onto the wafer plane where the die´s are located to be transferred. Depending on the energy densities needed the typical demagnification of the high-resolution imaging lenses is 2.5x or 5x with a corresponding field of view to enable the required throughput.

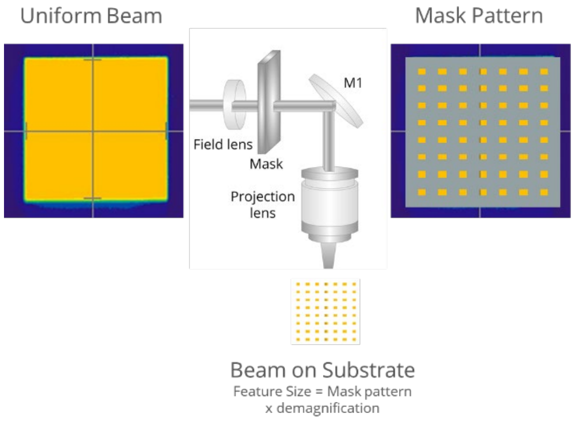


Fig. 3 High resolution mask imaging - Laser Mass Transfer

As sketched in Fig. 3 the large homogenized field is transferred into multiple single features, each with the same properties as the large field in each specific location. Homogeneity and energy density are the same from left upper corner down to the right lower corner. This is the basis for a high-throughput and high yield mass transfer process.

A beam profiler is used to measure the beam properties of an individual feature. Here, the homogeneity and the “edge steepness” of the beam can be measured. The steepness is important in regard of precision and resolution of the entire transfer process.

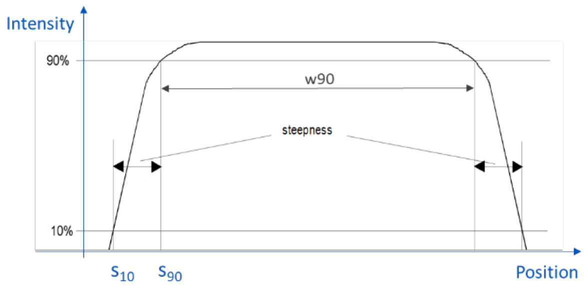


Fig. 4. Edge steepness of a Top-Hat beam profile

Laser Induced Forward Transfer is an established process that is already used in the production of this display type today. This laser-based process can work with smallest LED die sizes such as 5µm and has the potential to meet the cycle time demands for mass production.

The (edge) steepness S10/90 is defined as the lateral distance between the intensity positions s10 (10% of full flat-top-ED) and s90 (90% of full flat-top-ED):

$$S10/90 = |s90 – s10| \qquad (1)$$

The steepness is separately evaluated for left (ascending or S10/90) and right (descending or S90/10) edge. Usually is:

$$w50 = w90 + S10/90 \quad (2)$$

The edge steepness can be measured and can be in the range of a few micrometer. The example of a measured single beam on the wafer level (Fig. 5) illustrates the precision reachable with an Excimer laser based optical system.

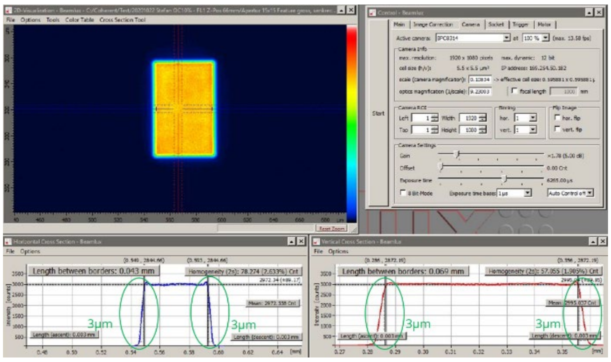


Fig. 5. Feature sized beam profile measurement in the wafer-level – homogeneity and edge steepness are measured values

The measurement result of this single feature where obtained using a 2.5X demagnification high precision projection:

Beam Dimension (x,y)	43μm x 69μm
Homogeneity in short axis (SA; 1σ)	2.6%
Homogeneity in long axis (LA; 1σ)	1.9%
Edge Steepness left (10/90)	3μm
Edge Steepness right (90/10)	3μm

This 3μm edge steepness is one of the keys to a precise process with high yield.

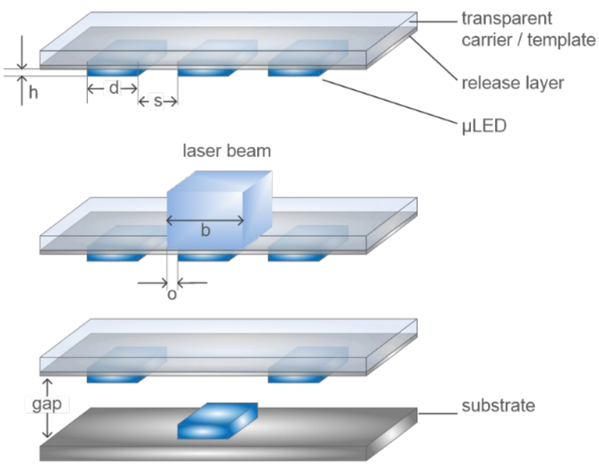


Fig. 6. Basic conditions for selective MicroLED Mass Transfer

Roadmaps are predicting MicroLED sizes down to 5μm or even less with corresponding smaller street widths in the same range. Therefore, it is obvious for a future proof transfer technology that it needs to be capable to address a single die on the high packaging density of the EPI wafer designs to be expected.

Fig. 6 shows how the individual laser beam as applied to the EPI wafer or temporary carrier is looking To address a single die with a certain tolerance given by the mechanics of the machine, an optical overshoot must be considered. At the same time the street width defines the limitation for the optical beam for the neighboring die which should not be affected in any way by the laser shot onto the selected die. Assuming, that the street widths are decreasing in the near future to 10μm and less the optical precision is a key to success. An edge steepness of S10/90 ≤ 3μm allows to calculate, when considering the process window, that for an ED ≤ 50% of the process ED effects on the neighboring die can be neglected. Consequently, a calculation with S10/90 (at w50) of approx. 1.5μm can be assumed. With a typical mechanical accuracy of 1.5μm and an edge steepness S10/90(w50) = 1.5μm the highest value will be 3 μm today. There is a further margin for the overexposure. It also can be demonstrated that the top-hat profile has the advantage of giving a constant force to the addressed die. This allows the die to fly straight from the carrier to the target. It´s obvious that a Top-Hat vs. a gaussian laser beam profile ensures a higher placement accuracy and transfer yield and therefore is the preferred solution for an industrial process.

1.3 Laser Beam size

The throughput of a mass transfer machine is mainly determined by the numbers of die´s per laser shot, the pulse repletion rate in conjunction with the addressable stage speed. With a 1 Joule per pulse 248nm Excimer laser beam sizes of up to 20 mm and larger can be realized in one dimension. Optimization needs to be done according to the customers preferences and can be either square / rectangular or a line beam approach. Both approaches ensure a high throughput potential with the described precision of the highly homogeneous beam properties.

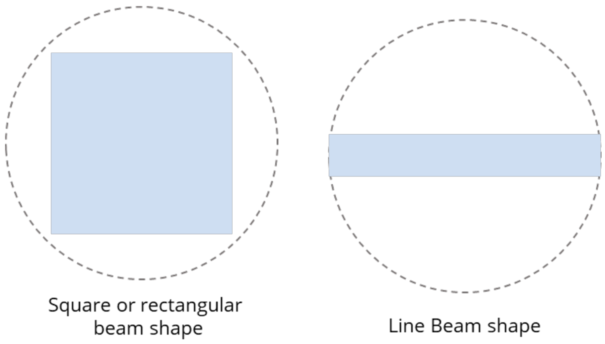
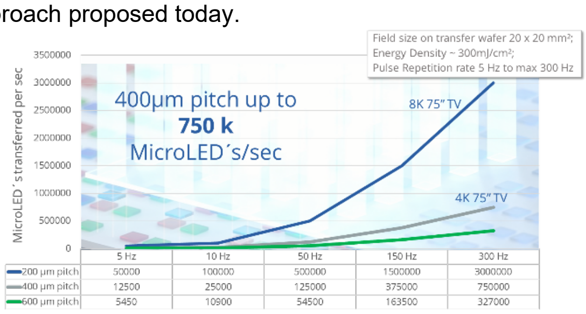


Fig. 7. Beam Geometry for Mass Transfer

2 Mass Transfer Throughput

Optical systems are available and can be designed to the max. beam geometry. The optimized system using the laser in an efficient mode and yielding a maximized throughput.

Assuming that the pixel pitch for a 4K 75" TV is approx. 400µm. Then within a field of 20 x 20 mm² 50 MicroLED's can be addressed in x and y direction which results in 2500 dies per laser shot. A low laser repletion rate of only 10Hz could transfer 25k MicroLED's per second or 90 million per hour which exceeds already the number of pixels for one TV. 248nm Excimer lasers with enough pulse energy for described field sizes are available today with repetition rates of up to 300 Hz. The 300Hz are exceeding the stage speed if a rectangular beam is applied today. Further, assuming that a repetition rate of 50Hz can be used, the throughput for the LLO step can be calculated with 450million dies per hour already which is by far the fasted approach proposed today.



	5 Hz	10 Hz	50 Hz	150 Hz	300 Hz
200 µm pitch	50000	100000	500000	1500000	3000000
400 µm pitch	12500	25000	125000	375000	750000
600 µm pitch	5450	10900	54500	163500	327000

Fig.8. Throughput Estimation for 4K and 8K TV based on Excimer Laser Mass Transfer

3 Conclusions

The UVtransfer system can provide the highest throughput in combination with superior precision compared to other technologies. The future prove mass transfer has several advantages, but the most valuable advantage is the selective transfer directly from the sapphire wafer where 248nm is required. Excimer lasers are well known in the display industry for 24/7 production with the highest throughput in the market. Now, as higher precision will be needed for selective MicroLED transfer, Excimer 248nm lasers are the first choice and already used in the MicroLED processing chain in production environments.

References

[1] Ding, K.; Avrutin, V.; Izyumskaya, N.; Özgür, Ü.; Morkoç, H. Micro-LEDs, a Manufacturability Perspective. Appl. Sci. 2019, 9, 1206.

[2] Su, P.; et al, Full-Color Realization of Micro-LED Displays. Nanomaterials 2020, 10, 2482