Manufacturing MicroLED Display by PixeLED Solution

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ABSTRACT

MicroLED display is an emerging technology which can be used for all current display applications and new scenarios, such as transparent, seamless tiling, and AR glasses for metaverse. Based on our novel R/G/B novel R/G/B Chip-on-Carrier step, we could improve the transfer yield and process time.

1 Introduction

MicroLED display is believed to be the ultimate display which fulfills all display feature requirements. There are already many MicroLED demonstrations in different applications, such as large-size TV/signage, automotive transparent display, flexible display, wearable device, and AR/HUD display picture generation unit. MicroLED is already proved its high brightness, high contrast ratio, wide color gamut, good reliability, flexible, and high transparency.

A MicroLED is an LED chip removed substrate, and its size typically is thinner than 10 microns and narrower than 50 microns. MicroLED display is using such tiny LED chips as emitting source of each pixel. Within each pixel, MicroLED chips typically composed by red, green, and blue three-color chips, and it can also be composed by blue color or UV chips with color conversion material, such as quantum dot or phosphors, on top of each MicroLED chip to generate full color.

The most important advantages of MicroLED display are lower energy consumption and better reliability. Current LCD is a light absorbing device, which means most of light from backlight unit is wasted and transformed to heat. This will be a big energy crisis while we use more and more displays. OLED seems able to reduce some energy consumption as an emissive display, but it is limited by material lifetime and weak environmental reliability. MicroLED could be a good solution by higher efficient and inorganic LED chips.

Because of different requirements of each application, we have demonstrated several solutions to support each need, such as seamless modular displays, transparent displays, wearable devices, and flexible displays, and micro-displays. To realize such high performance MicroLED display, we have established solutions including wafer epitaxy, MicroLED chip process, mass transfer, mass repair, and correlated module design technologies. In this paper, we are going to explain manufacturing MicroLED display by our proprietary PixeLED solution.

2 MicroLED Display Manufacture

To realize such high performance MicroLED display, we have established a solution including LED wafer epitaxy, MicroLED chip process, massive process technology, including PixeLED display and SMAR·Tech repair technology. In Fig.1, we briefly showed the ecosystem of building a MicroLED display. Although most of technology is available in the market, we still need to develop unique process to fulfill display spec requirements. Most of the technology is owned by us, and it helped the technology realized faster.

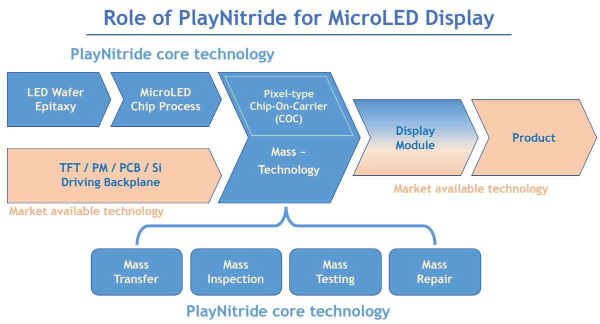

Fig. 1 Brief ecosystem of building a MicroLED display

2.1 Mass Transfer Process

Most people focused on mass transfer since it needs a newly developed technology. It is recognized that very low cost and very high yield are both required for mass transfer technology. And we also proposed that mass repair technology is as important as transfer technology.

We have been working on MicroLED mass transfer for some time and using not only one technology but many different mass transfer technologies for different applications. Some technologies are good for some specific applications while the other technologies are good for some other specific applications. Several mass transfer solutions are discussed as following.

The first solution is stamp transfer technology. We believe this could be the most popular one. Generally speaking, this is a pick-and-place technology by area instead of single chip. However, only small area like 30 mm by 30 mm can be transferred each time due to the flatness and parallelism of stamp and backplane.

Because of this small transfer head size, normally shot mura can be observed and de-mura process is required. Precision level is medium and can be used for many applications. We also developed selective repair solution, SMAR·Tech, for this technology.

The second solution is fluid transfer technology. This technology can be used for large area and mild to not-observable shot mura. The disadvantage is that the precision level is quite low and not easy for selective repair.

The third solution is laser induced forward transfer technology. This technology has been developed for more than twenty years and is good for transfer small items to a substrate. Both the transfer speed and precision level are reasonable. However, for MicroLED applications, there is a chance to damage LED or backplane if the laser power is inappropriate.

There are also laser bonding technology and direct bonding technology for very specific applications.

2.2 Stamping Mass Transfer Process

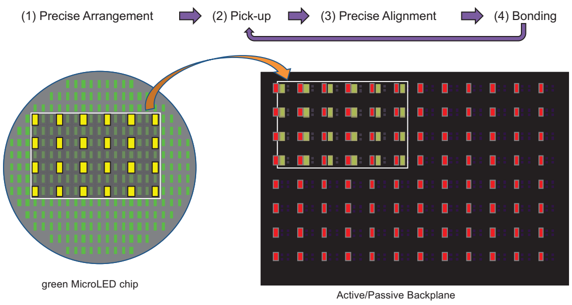

Fig. 2 Stamping Mass Transfer Process Flow

We used the stamping pick-and-place process to build samples demonstrated since 2018. As shown in Fig. 2, the stamp picked up from a wafer with precise arranged MicroLED chips. Then, moved to backplane and precisely aligned the bonding position. Final step was bonding MicroLED chips onto the backplane. Continued and repeated these steps to transfer red, green, and blue MicroLED chips onto the backplane.

2.3 Selective Mass Addressable Repair Technology

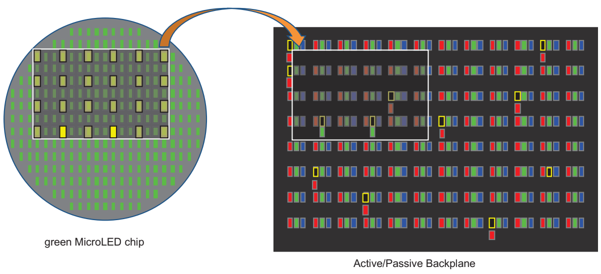

Fig. 3 SMAR·Tech

PixeLED display technology ensured MicroLED display can be realized. Then, we needed a repair technology to step into production on defect free panel. PlayNitride developed a new "Selective Mass Addressable Repair Technology", which is named as SMAR·Tech. With this technology, we can repair the defect dots by area which is much faster than single dot repair solution.

In the MicroLED display manufacturing process, defects might come from LED wafer or imperfect mass transfer. If we can achieve total 99.5% yield after transfer process, there are still more than 120,000 defect dots in one 4K panel. This is unlikely to repair one-by-one as traditional process. For our SMAR·Tech, it has similar process as mass transfer. We can only pick up the addressed MicroLED chips mapping to defect positions from LED wafer, then selectively mass transfer to the backplane as shown in Fig. 3. SMAR·Tech can reduce the repair process from 120,000 steps to tens of steps depending on display size.

2.4 Novel R/G/B Chip-on-Carrier Step

High yield and highly efficient mass transfer process is very important to build a MicroLED display. Normally, mass transfer process includes transferring from Chip-on-Wafer to Chip-on-Carrier then to display backplane, which means we need at least three times transfers to backplane. This process is very strait forward and should be lower cost. However, we found the transfer yield improvement has limitation.

The stamp transfer process requires flat surface for fast and reliable MicroLED chip bonding. However, display backplane design highly influenced the flatness. Since the thin film layers are patterning on glass, there is stress to make the glass bending. The deposition process also has thickness variation, which results the bonding pads on backplane have different height from glass surface. While we transfer lots MicroLED chips by stamp, these variations result low flatness of bonding pads height. Some of chips have higher pressure by relative higher bonding pads on backplane and is easily crack. Some of chips are missing due to no contact on relative lower bonding pads on backplane. We could improve this process by a better precision control equipment and take more time on bonding process to avoid chip crack or missing.

To achieve better transferring yield and shorter process time, we have introduced R/G/B chip-on-carrier by transferring R/G/B three colors to a temporary carrier, then transfer to driving backplane only one time, as shown in Fig. 4. This temporary carrier is a flat substrate without patterning.

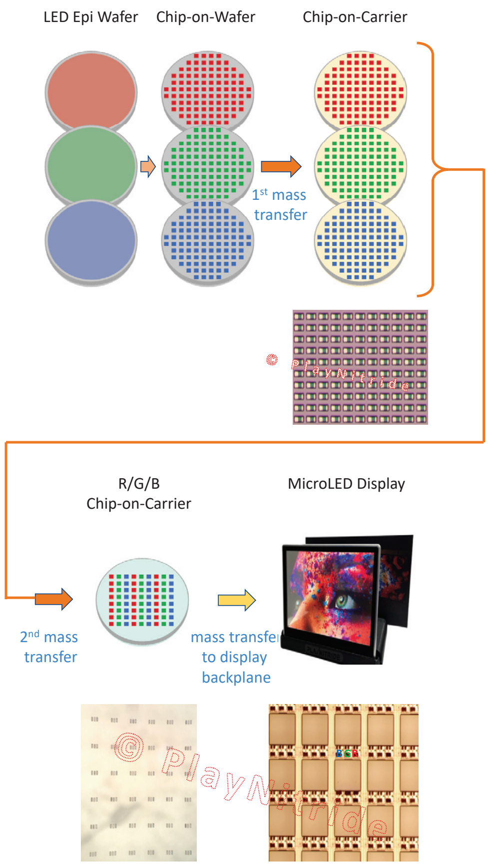

Fig. 4 Mass transfer process with novel R/G/B Chip-on-Carrier step

Although one more transfer step is introduced, the merit of transferring onto a flat surface can save more cost. There is no bonding process while transferring onto carrier and one-time bonding process onto backplane, which can save time comparing to three times bonding process directly onto backplane. The lower process temperature can improve alignment accuracy comparing to heating and cooling for three cycles of directly transfer.

This novel R/G/B chip-on-carrier requires MicroLED chips to be arranged very precisely on the temporary carrier without local alignment key. We can make the spacing less than 2μm. At the same time, the transfer yield is higher than 99.9% and transfer cost is very low, which is around 10% of the chip cost.

With high precision transfer capability, mass repair becomes feasible. First, we confirmed the defect address and prepare for the repair chips with the correct arrangement. Then we could do the repair only one time, as shown in Fig. 5. With mass repair technology, high yield MicroLED display panel can be manufactured.

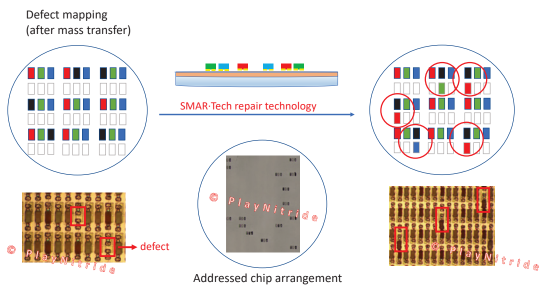

Fig. 5 SMAR·Tech mass repair process with novel R/G/B Chip-on-Carrier step

3 Conclusion

MicroLED can be used in a variety of different application scenarios, and it provides the ultimate visual experience. We developed a novel R/G/B Chip-on-Carrier step to improve the transfer yield and process time. This helps the MicroLED display technology solve the challenges on transferring to non-flat surface and move to a production phase. Our solution opened a new path for transferring micro-components onto driving backplane for emerging display applications.

References

[1] Y. Liu and Y. Li, "Invited Paper: Development of MicroLED Display Technology and Applications", SID Symposium Digest of Technical Papers, 53: 654-657 (2022)

[2] Y. Liu and Y. Li, "Invited Paper: 89-inch 5K Curved PixeLED Matrix MicroLED Display", IDW 2021 Symposium Digest

[3] Liu Y and Li Y, "Borderless Tiling MicroLED PixeLED Matrix Display", SID Symposium Digest of Technical Papers, 52: 857-859 (2021)

[4] Liu Y, Liao K, and Li Y, "Development of MicroLED Display by PixeLED Display Technology", SID Symposium Digest of Technical Papers, 51: 429-431 (2020)

[5] Liu Y, Liao K, and Li Y, "Toward for Ultimate Displays with MicroLED by PixeLED Display Technology", IDW 2019 Symposium Digest

[6] Liu Y, Liao K, Lai Y, and Li Y, "High Transparency Borderless Active-Matrix MicroLED Display", Vehicle Display Symposium 2019

[7] Liu Y, Lai Y, and Li Y, "Heading to Ultimate Display with MicroLED", ICDT 2019 Symposium Digest

[8] Liu Y, Liao K, Lin C, and Li Y, "PixeLED Display for Transparent Applications", SID Symposium Digest of Technical Papers, 49: 874-875 (2018)