A Novel Bin-Mixing Transfer Technology Based on Die Bonding Equipment for Mini/MicroLED Display

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Abstract

Mini/Micro-LED self-emissive displays have garnered extensive attention due to their superior display performance and broad application prospects. However, one significant challenge faced by Mini/Micro-LED displays is the issue of color blocks and stripes caused by the non-uniformity in wavelength and luminance of LED chips[1]. Addressing this problem traditionally incurs high wafer mixing costs to sort wafers into bin slices, resulting in the decline of display product competitiveness. In this study, we develop an innovative bin-mixing transfer technology based on die bonding equipment to solve this problem. By developing a random pick-and-place algorithm, we successfully achieve the randomization of LED chips, thereby significantly enhancing the brightness, wavelength, and color uniformity of display modules. Compared to traditional technologies that mixing LED chips from LED wafers, this technique improves single-bin wafer utilization from 50% to 90%, and reduces overall costs by approximately 24%, thus significantly enhancing the competitiveness of Mini/Micro-LED products. This novel technology provides a new solution for the mass production of Mini/Micro-LED display products.

Author Keywords

Mixing transfer technology, pick & place die bonding equipment, Mini/Micro-LED display product

1. Introduction

Mini/Micro-LED self-emissive displays have garnered extensive attention due to their high brightness, low operating voltage, high reliability, and high color saturation[2~3]. However, Mini/Micro-LED technology still faces numerous challenges in large-scale commercialization, such as color blocks and stripe issues caused by the non-uniformity in wavelength and luminance of LED chips, which severely affects the visual experience[4~6]. Current solutions typically involve screening and mixing chips from LED wafers. However, such process includes multiple complex sorting steps such as matrix arrangement, multiple loading and unloading process, significantly increasing the total cost of display products and slowing down the market adoption[7~8].

In this study, we develop an innovative bin-mixing transfer technology based on die bonding equipment. By achieving the randomization of LED chips during the pick-and-place process, this technology significantly enhances the brightness, wavelength, and color uniformity of display modules. Compared to traditional methods of mixing chips from LED wafers, this technology eliminates the wafer sorting process and extends the utilization range of wafer RGB bands from 2.5nm/2.5nm/2.5nm to 5nm/10nm/10nm, leading to a improvement of single-bin utilization from 50% to 90% and a reduction of the total cost by approximately 24%. This proposed technology significantly enhances the competitiveness of Mini/Micro-LED products, providing a new solution for the large-scale production.

2. Process Flow

2.1 Process Design

The production process of this novel bin mixing technology primarily follows two kinds of process flow: the first one is no-data mixing, and the other one is data-based bin mixing. The main difference between these two scheme is the picking process. No-data mixing scheme adopts sequential picking process, and data-cased bin mixing scheme adopts bin mixing picking process. In this paper, this novel bin mixing technology main focuses on pick & place die bonding equipment with complex swing arm structure.

The first non-data mixing scheme is shown in Figure 1. After the production of LED wafer, electrical test (ET) process and automatic optical inspection (AOI) process in LED factory, we remove defect chips (NG chips) based on the test data. Then the LED wafer on blue films is produced, which is regarded as supplied material for die bonding process. The LED wafer on blue films is then mounted on the machine for die expansion, and the die bonding equipment only imports the mixing bonding scheme for randomization transfer process. After mixing transfer process, the calibration process is completed as usual.

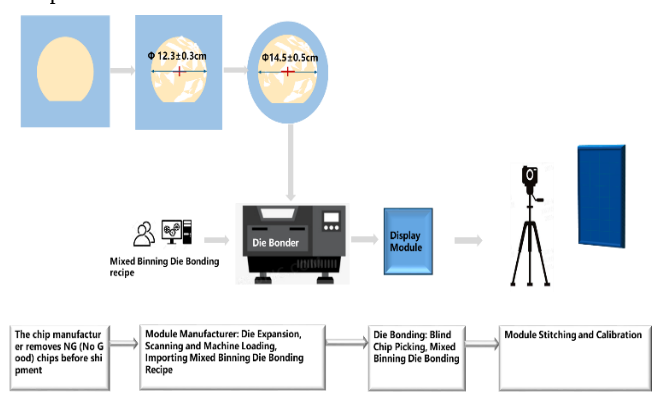

Figure 1. No-data mixing bonding scheme

The advantages of this scheme are that it does not require wafer data planning and is consistent with the existing mass production mode with minimal changes to the subsequent overall process. However, there are still two issues for this scheme listed as follows:

1. Ineffective Sorting: Although the process of removing NG chips is simpler than normal sorting process without binning process, this process is still not efficient enough because of an additional removal process. Therefore, this process does not fundamentally solve the problem of process bottlenecks and costs.
2. Inconsistent Display Quality: Due to the huge number of LED chips on the wafer and the wide range of key optoelectronic

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parameters such as wavelength and brightness, the uniformity of display is not good with traditional sequential chip picking process. Even though the mixing bonding scheme and calibration process are adopted, such wade range of parameters is still difficult to compensate without mixing picking process.

The second data-based bin mixing scheme is illustrated in Figure 2. After the production of LED wafers and the process of electrical and AOI test, the wavelength and brightness data of LED wafer are generated without sorting or re-picking process. Then the corresponding wafer data is adopted by the display module manufacturers for picking route planning. The LED wafer on blue films is then expanded, scanned, and imported into the die bonding machine, acquiring the bin mixing picking and bin mixing bonding file to complete die bonding and calibration process.

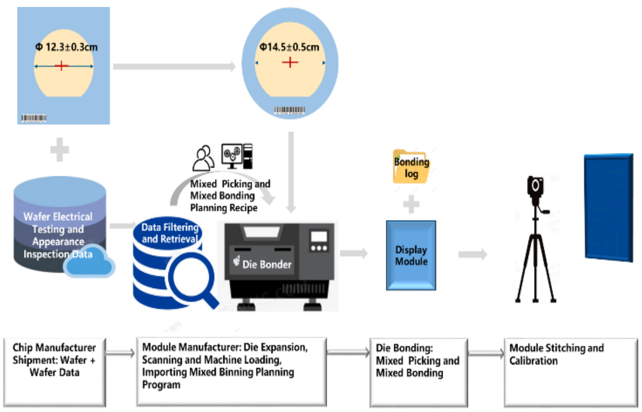


Figure 2. Data-based bin mixing scheme

There are many advantages of this scheme compared to no-data mixing bonding scheme and common transfer scheme. Firstly, the LED wafers no longer need sorting process so that this scheme is simple and cost-effective; Besides, such scheme can realize the pick-and-place mixing bonding function to ensure image quality; Moreover, it can achieve visual effect simulation before and after die bonding, which is able to trace the supplied material based on defective image quality product. The challenges lie in developing a flexible and effective bin mixing algorithm, ensuring the accuracy of incoming material data and the accuracy of equipment scanning and filing, as well as the requirement for a complete set of automated product line.

The primary challenges associated with this process include:

1. Algorithm Development: Developing flexible and effective bin-mixing algorithms to ensure the even distribution of LEDs with wavelength spans of RGB 5nm/10nm/10nm across display modules.
2. Accuracy of Incoming Material Data: Ensuring the accuracy of incoming material data and the precision of equipment scanning and alignment.
3. Automation: Implementing a comprehensive set of automated systems to support the entire process.

Addressing these challenges is crucial for the successful implementation of the proposed technology.

2.2 Process Flow of Die Bonding Technology with Bin Mixing Scheme

Based on the second data-based bin mixing scheme, the new process route designed for the adaptation of robotic arm die bonding technology is illustrated in Figure 3.

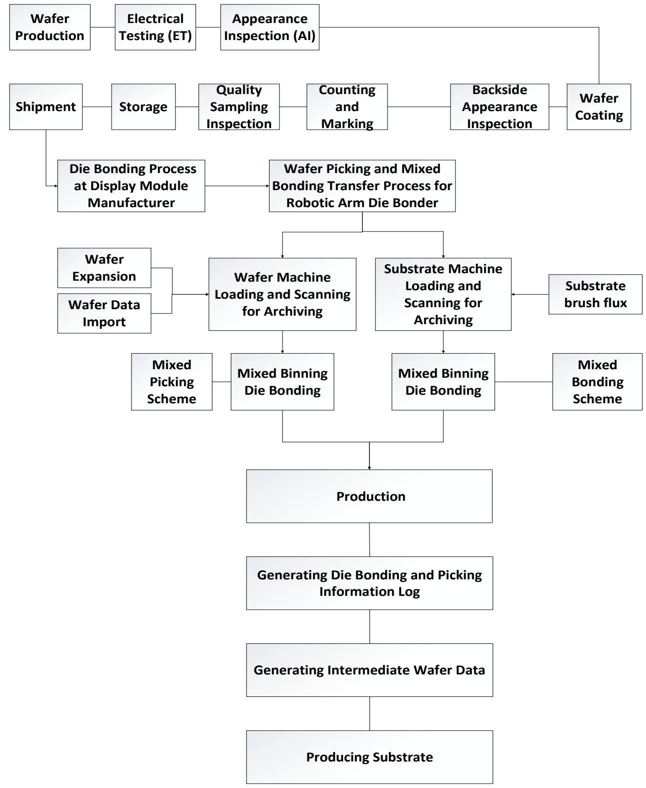


Figure 3. Process route of die bonder equipment for wafer bin mixing technology

The process route for wafer bin mixing technology adapted to pick & place die bonding equipment does not require sorting process or a series of subsequent inspection processes by the chip manufacturer. After completing optoelectronic test and AOI test on the large wafer, all the data are uploaded to the cloud storage after archiving. The developed bin mixing software retrieves remote data and invokes the bin mixing picking planning module for the large wafer. After the display module manufacturer receives the supplied LED chips, the supplied material will undergo die expansion and scanning process, while the corresponding wafer mixing picking plan file is also retrieved. This process completes the scanning and archiving of LED chips and test data. After that, the die bonding equipment imports the required mixing picking and mixing bonding recipes to realize data-based bin mixing scheme.

3. Results and Discussions

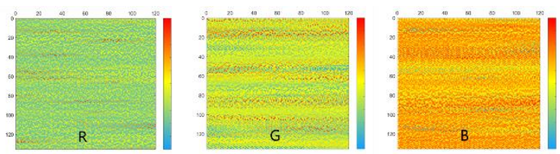
The traditional bin-mixing technology used in chip factories typically devides the LED chips on each wafer into multiple sets ($\geq$ 6) based on wavelength and brightness data. Sorting machines then sort LED chips from the same sets across 6-8 wafers onto a new carrier film, achieving chip mixing process. Subsequently, the module manufacturers use die bonding equipment to transfer the sorted LEDs onto substrates. However, this process will result in regular stripes appearing in the display modules when the mixing process is not sufficient, leading to a bad visual quality (as shown in Figure 4(a)).

In contrast, our developed new bin-mixing transfer technology does not require pre-sorting of LEDs by the chip factory. The module manufacturers can complete the mixing and transferring of LEDs directly on die bonding equipment, such as an arm-type die bonder. This technology relies on innovative pick-and-place algorithms listed as follows.

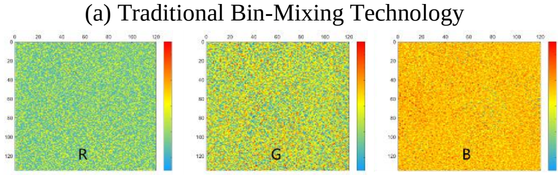
1. Pick Algorithm: Utilizes wafer data (such as coordinates, brightness, wavelength, color coordinates, voltage, current, etc.) to select LED chips that meet production requirements. A random algorithm ensures that each wafer's pick locations and optical parameters differ, achieving randomization in the picking process.

2. Place Algorithm: Plans all the points on the substrate into several random combinations, with each combination having multiple random paths, thus achieving random placement of the LED chips on the target substrate.

The new bin-mixing transfer technology based on die bonding equipment enables direct in-line production of LED wafers without sorting. During the pick-and-place process, random algorithms achieve the random arrangement of LEDs. Even under expanded LED wavelength conditions**,** this technology significantly improves the brightness, wavelength, and color uniformity of display modules because the traditional mixing technology still needs to follow specific paths and such novel mixing transfer technology can realize complete random path. The visual simulation of a single display module (as shown in Figure 4(b)) demonstrates that the display module exhibits no noticeable stripes, clustering, or color block defects with this novel technology, indicating that this novel bin-mixing transfer technology effectively achieves good randomization of LED chips and further enhances the display quality.



(a) Traditional Bin-Mixing Technology



(b) Novel Bin-Mixing Transfer Technology

Figure 4. Visual simulation of a single display module

Then the Mini/Micro-LED display adopting both conventional technology and this novel technology is shown in Figure 5, whe re the upper part is a 2*2 unit splicing module adopting convent ional process, and the lower part is a 2*6 unit adopting bin mixin g bonding process. The image quality uniformity of RGB colors a nd white color with both conventional and novel bin mixing t echnology is great without non-uniformity problem, further sh owing that this novel bin mixing technology can solve the im age quality problem which is comparable and even better to conventional mixing process.

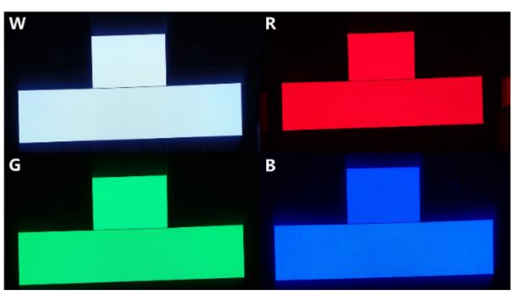


Figure 5. The photos of Mini/Micro-LED modules with both traditional and novel bin-mixing technologies

4. Conclusions

In this paper, we develop a novel mixing transfer technology for Mini/Micro-LED displays based on die bonding equipment. The color block and stripe problem are eliminated after adopting this technology, indicating that this novel data-based bin mixing technology can significantly improve the brightness and color uniformity of the modules through randomization of LED chips. In addition, it is estimated that by adopting this technology, the total cost of the Mini/Micro-LED module could be reduced by approximately 24% compared to conventional bin mixing technology due to the higher utilization of LED chips and simplified process flow. This novel technology will further improve the technological competitiveness and provide a new choice for the mass production of Mini/Micro-LED display product.

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