Research on LED Sorting, LED Mixing, and Image Quality

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Abstract

To optimize the interplay among LED material cost, die bonding efficiency, and image quality, this paper presents a comprehensive analysis of three LED sorting schemes—mixed compilation, mixed platoon, and conventional sorting—as well as die bonding solutions and strategies for backlight module image processing. This research proposes targeted strategies designed to enhance the cost-effectiveness of Mini LED products, which have substantial implications for reducing manufacturing expense.

Author Keywords

Mini LED; Sorting; Die Bonding; Image Quality;

1. Introduction

Mini LED technology exhibits superior performance in image display and power consumption when compared to OLED. It effectively mitigates challenges associated with high refresh rates, brightness, and screen burn-in. By integrating LCD technology with precise backlight control and enhanced refresh rate capabilities[1], Mini LED products can achieve improved motion blur performance, rendering them highly competitive in the backlight markets. To enhance cost-effectiveness and further expand market share, it is essential for Mini LED products to optimize their manufacturing processes for greater cost efficiency.

Mini LED manufacturing solutions can be classified into three categories: POB, COB and COG. The POB solution employs LED packaging in conjunction with the SMT process route. This method is well-established and facilitates rapid scaling in the short term, providing a cost advantage overall; however, it is only suitable for products with an OD (Optical Density) greater than 3 mm. Both COB and COG solutions utilize an LED chip along with SMT processing. These processes are relatively straightforward but necessitate initial investment in specialized equipment. They are applicable to a wide range of products starting from OD 0 mm and above, thereby encompassing broader application fields including AR, NB, MNT, TV, and commercial displays. At this juncture, as Mini LED technology continues to innovate and evolve—coupled with the swift implementation of new technologies and cost-reduction strategies—the trend in Mini LED manufacturing solutions is gradually shifting from POB towards COB/COG methodologies.

In the production process of Mini LED products, the primary factors influencing costs include raw material expense, manufacturing efficiency, product specifications and yield. Among these, the quantity of LEDs utilized is the most significant determinant concerning raw materials. In terms of manufacturing efficiency, die bonding efficiency plays a critical role. Furthermore, with respect to performance specifications, the image quality must adhere to established standards.

To develop more cost-effective Mini LED products, this paper researchs the interplay among LED material cost, die bonding efficiency, and image quality. It presents a comprehensive study of LED sorting schemes, die bonding methods, and module image processing solutions. The primary focus is on three types of LED sorting methodologies: mixed compilation, mixed platoon, and conventional sorting.The corresponding die bonding pathways required for these sorting schemes are analyzed alongside their efficiencies. Additionally, we explore the Demura processing solution that enhances image quality.

2. Methodologies for LED sorting

In Mini LED products, the quantity of LEDs utilized is considerable. For example, in a 27-inch product featuring 1152 zones, if a configuration of four LEDs per zone is employed, the cost of raw LED materials can constitute up to 20% of the overall BOM cost for the backlight. Consequently, the expense associated with LED materials significantly influences the total BOM cost of the Mini LED[2].

Mini LEDs are made from the COW state by grinding and cutting them into individual chips. After testing and sorting, these chips can be readied for shipment as LED components, as illustrated in Figure 1. In the cost structure of LED material production, expenses related to the sorting process typically account for about 15% to 20%. Furthermore, due to variations in wavelength, brightness, and voltage acceptance specifications, the yield rate of LEDs may fluctuate significantly, which can result in an even larger portion of costs being linked to the sorting process.

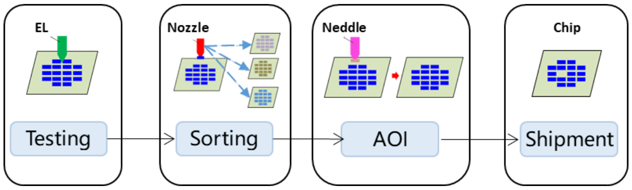


Figure 1. LED fabrication process

We have established three sorting methodologies for Mini LEDs: mixed compilation, mixed platoon, and conventional sorting. Each methodology features specific specifications related to bin classification, sorting logic, yield rate, and associated costs.

LED Sorting Scheme 1: The mixed compilation LED sorting methodology utilizes a wavelength parameter binning scheme with a range of 2.5nm to 3nm, and its brightness range is 12% to 15%. Prior to the sorting process, wavelength and brightness parameters are meticulously refined, followed by random arrangement based on the corresponding parameter ratios. This approach facilitates an overall acceptance criterion of 7.5 nm[3] while maintaining no more than four distinct LED bin levels. The integration of finely detailed parameters with random arrangements enhances uniformity within individual bins. Utilizing this scheme, the average wavelength of LEDs across different films and batches can achieve a tolerance of ±0.5 nm, with no aggregation in the LED raw materials. However, the sorting process for mixed compilation LEDs is intricate; redundant bins occur during this procedure, leading to a shipment rate of only 50%. As a result, the production cost for mixed compilation LEDs is the highest among the available options.

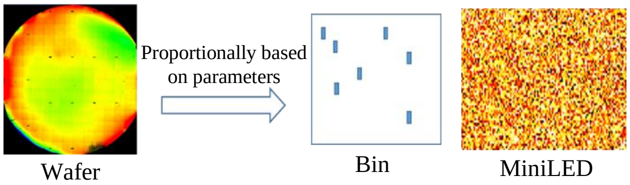


Figure 2. Mixed compilation LED sorting methodology

LED Sorting Scheme 2: The mixed platoon LED sorting methodology employs a wavelength parameter binning scheme with a range of 1.5 nm to 2 nm, and its brightness range is 3% to 6%. Prior to the sorting process, it is essential to select multiple COW wafers that conform to the same BIN specifications for the LEDs. Subsequently, random arrangement techniques are utilized to enhance uniformity within each individual-bin wafer. For LEDs utilizing the mixed platoon approach, the average brightness across different films and batches is comparable to the brightness dispersion observed within the mixed compilation; however, the average wavelength can only achieve ±0.8 nm, which exceeds the wavelength dispersion in the mixed compilation and results in inferior performance. Moreover, under an overall acceptance criterion of 7.5 nm for this strategy,
the number of LED bin will reach 20 to 40. Additionally, there exists a certain degree of material aggregation among LED raw materials. Despite these factors, the sorting process for mixed platoon LEDs is simpler than that of mixed compilation methods; there are no redundant bin issues involved—only approximately 10% rework and rearrangement required—resulting in an impressive shipping rate of up to 75%. Consequently, this renders the costs associated with mixed platoon LEDs relatively moderate.

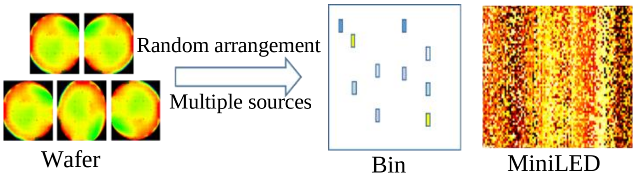


Figure 3. Mixed platoon LED sorting methodology

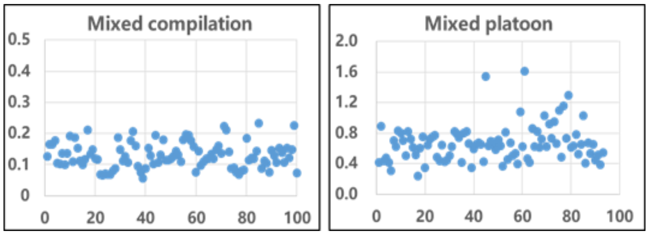


Figure 4. Comparison of Wavelength Discrepancy

LED Sorting Scheme 3: The conventional sorting LED scheme employs a bin classification based on wavelength parameters ranging from 0.5nm to 1 nm, and its brightness range is 3% to 6%. Prior to the sorting process, there is no requirement for parameter refinement or control over the number of COW wafers; it merely necessitates selecting LEDs corresponding to the designated bin level from the wafers and placing them sequentially onto square substrates. Compared to mixed platoon LEDs, conventional sorting LEDs exhibit only a 3% rework rate due to issues such as chip misalignment and contamination. The sorting efficiency is 1.2 times greater than that of mixed platoon, with a shipping yield for chips reaching up to 80%, resulting in cost approximately 10% lower than those associated with mixed platoon solutions. However, one notable drawback of the conventional sorting LED approach is its extensive bin count; under an overall acceptance criterion of 7.5 nm, the number of LED bin will reach 40 to 60. Additionally, because this scheme lacks parameter control and path management, it struggles to effectively regulate wavelength and brightness across films and batches. Moreover, LEDs produced using the conventional sorting method show a notable tendency to aggregate.

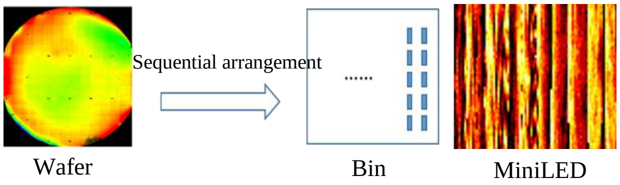


Figure 5. Conventional sorting LED sorting methodology

3. LED Bonding Techniques

Based on the principles of die bonding equipment, existing die bonding methods can be classified into three categories: traditional pick-and-place, high-speed needle-piercing, and the still-evolving full-surface binding method. The pick-and-place approach consists of two steps—extraction and placement of the chip—which results in a significant speed disadvantage compared to the needle-piercing method. Until the full-surface binding technique reaches maturity, needle-piercing remains the preferred option among current die-bonding methodologies.

Under the needle-piercing scheme for backlight fabrication, our company has developed five types of die bonding solutions: fast bonding, standard smooth bonding, three-mixing, six-mixing and multi-wafer mixing.

Bonding Method 1: Fast bonding employs a wafer jump mode, pad sequential consolidation, and X-line replacement, achieving the highest consolidation efficiency, quantified here as 100%.

Bonding Method 2: Standard smooth bonding method employs a wafer sequential and pad sequential solidification mode, resulting in a solidification efficiency of 79%.

Bonding Method 3: The three-mixing scheme employs a mode of sequential wafer removal, three random pad solidifications, and regular random mixing, resulting in a solidification efficiency of 60%.

Bonding Method 4: The six-mixing scheme employs a mode of sequential wafer removal, six random pad solidifications, and regular random mixing, resulting in a solidification efficiency of 32%.

Bonding Method 5: The multi-wafer mixing scheme necessitates multiple LED square pieces, employing a consolidation mode that includes wafer jump, pad sequential consolidation, and X-line replacement, resulting in a consolidation efficiency of 62%.

4. Module Image Processing Solution

Within the same LED sorting methodologies, the visual effects produced by employing different die bonding methods can vary significantly. This variation is crucial as it directly impacts the overall performance and aesthetic quality of the final product. For instance, in mixed platoon LEDs, the application of the standard smooth bonding method results in pronounced boundaries at the LED splicing film positions on the backlight. Conversely, when employing a three-mixing bonding approach, these boundaries are significantly softened, as illustrated in Figure 6.

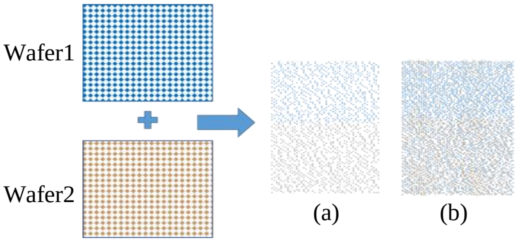
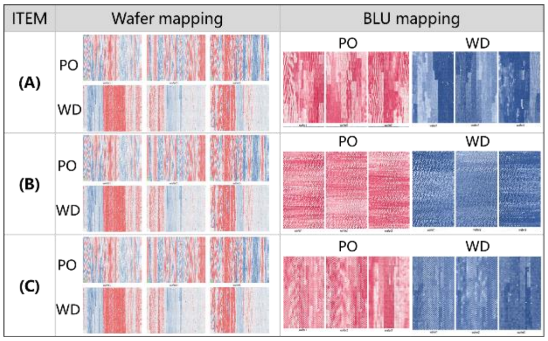
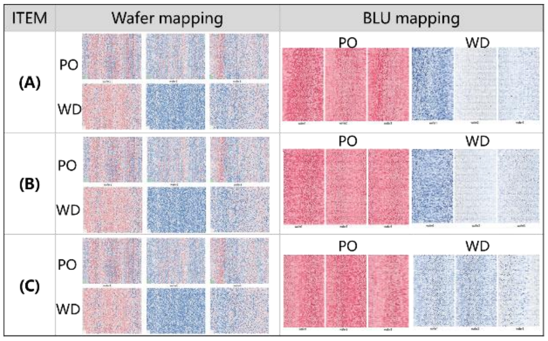


Figure 6. Impact of Die Bonding on Visual Presentation

In various LED sorting schemes, the visual effects produced by different die bonding methods can vary significantly. As illustrated in Figure 7, a comparison is made between the mapping of LED chips and backlight under three bonding modes:(A) fast bonding, (B) three-mixing scheme, and (C) multi-wafer mixing for both the conventional sorting scheme and mixed platoon scheme. In Figure 7-1, the LED raw materials exhibit distinct aggregation patterns; thus, different bonding methods exert a pronounced influence on visual output. Conversely, in Figure 7-2, where the aggregation patterns of the LED raw materials are less evident, the impact of varying bonding methods on image quality is comparatively minimal.



7-1 Conventional sorting scheme



7-2 Mixed platoon scheme

Figure 7. Comparative of Die Bonding Solutions

Based on the module's blue light display and the evaluation system developed utilizing CCD technology alongside visual inspection, the image quality of the module can be categorized into four levels: L0, L0.5, L1, and L2, as illustrated in Figure 8. The L0 level represents an almost flawless image devoid of visually detectable mura issues, resulting in optimal performance. The L0.5 level image displays minor defects, with the module output exhibiting slight mura issues that are perceptible to the naked eye, along with medium image quality. The L1 level screen presents moderate non-invasive defects, with the module display revealing medium-level mura issues that are clearly visible, they remain acceptable for lower-end products.Finally, the L2 level module display shows pronounced penetration defects, with its visual output indicating significant mura problems. The graphics are poor and unacceptable.

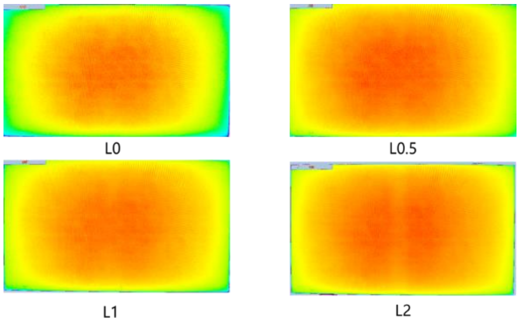


Figure 8. Module Display Classification

For products exhibiting suboptimal module display quality, the Demura algorithm can be utilized to enhance visual output. This algorithm functions based on the state of the BLU and optimizes peripheral compensation coefficients by addressing differences of 6% to 10% in adjacent partition coefficients while ensuring a total reduction in compensation coefficients of 5% to 15%. This methodology guarantees a smooth transition of overall data, resulting in a module display effect that closely approximates an ideal surface.

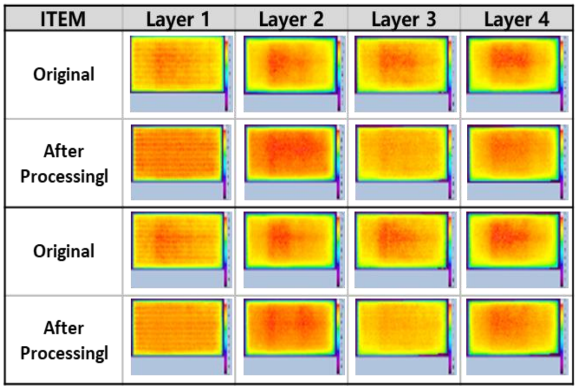


Figure 9. Image Processing Effect

Through thorough validation, we have found that an integrated approach combining the LED sorting scheme, die bonding method, and module image processing solution is crucial for achieving Mini LED products with an optimal cost-performance ratio. Below are three combination schemes developed by our team.

Solution 1: The mixed compilation LED can be paired with the standard smooth bonding method. During the wafer die extraction process, no special requirements are imposed; a standard extraction approach is employed. Similarly, during the die bonding of the backlight, there are no specific demands, allowing for a sequential bonding procedure. Under this combination scheme, the module display achieves L0.5 or higher levels without necessitating any additional processing. This scheme features the fewest bin quantities and facilitates straightforward production control for backlighting, resulting in high production efficiency(79%) and optimal visual effects; however, it incurs the highest cost(150%) for LED raw material. This solution is suitable for upscale products with strict optical quality requirements.

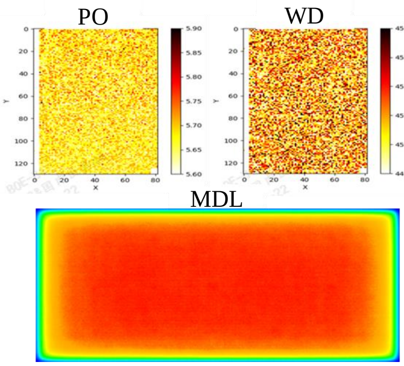


Figure 10. Mixed Compilation LED and Standard Smooth Bonding

Solution 2: The mixed platoon LED can be paired with the three-mixing method. During the wafer die extraction process, it is crucial to align the extraction direction vertically along the stripe pattern of the LED chip. The die bonding should be conducted in three random passes. Under this die bonding mode, no additional processing is required for the module image, achieving a quality level between L0.5 and L1. This scheme incurs moderate costs(110%) for LEDs and involves an average number of bins; however, it results in lower efficiency(60%) in die bonding and presents more complex challenges in production management. This solution is suitable for products with fewer LEDs.

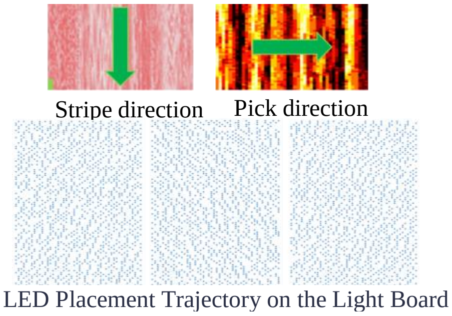


Figure 11. Mixed Platoon LED Pickup Directions and Die Bonding Pathways

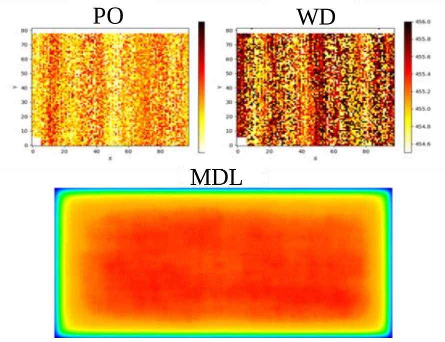


Figure 12. Mixed platoon LED and Three-Mixing Bonding

Solution 3: This scheme utilizes conventional sorting LED components in conjunction with the fast onding method. During the wafer extraction process, it is crucial to execute LED selection perpendicular to the stripe pattern on the LED chip. The bonding procedure should adhere to an X-scan line sequence. Under this bonding configuration, if no specialized treatment is applied to the module display, image quality can only attain levels L1 to L2. However, subsequent application of specialized Demura processing enables it to achieve levels between L0.5 and L1. This approach yield the highest number of LED bins but also introduces more intricate production management challenges; furthermore, specific treatments are essential for attaining moderate image quality. Despite these obstacles, this scheme provides the most economical option for LEDs while optimizing bonding efficiency for Mini LED products. When fully automated production lines become feasible, this combination scheme emerges as the most cost-effective solution concerning production expenses. This solution is suitable for all product models and is the most recommended solution.

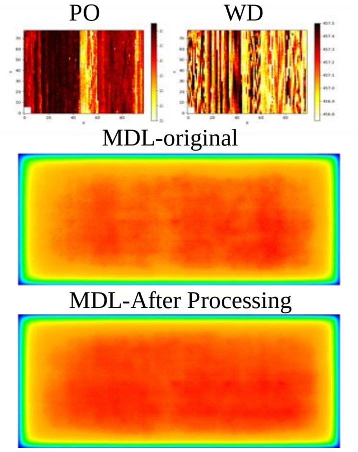


Figure 13. Combination of Conventional Sorting LED and Fast Bonding

In pursuit of more cost-effective Mini LED products, this paper delves into the intricate interplay among LED material cost, die bonding efficiency, and display quality. It presents relevant research on LED sorting scheme, die-bonding solution, and module image processing strategie. The primary emphasis is placed on three types of LED sorting methods and five distinct die bonding solutions, along with the corresponding die bonding paths required for each of the three LED sorting schemes and their respective advantages and disadvantages. Additionally, it introduces a Demura processing solution designed to enhance image quality. Currently, the aforementioned scheme has been successfully mass-produced in a multitude of Mini LED products, while a complementary solution is proposed to facilitate the advancement of more cost-effective Mini LED offerings.

5. References

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