

# Development of Transparent Flexible Micro-LED Display with High-Precision Mass-Transfer Technology

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## Abstract

We have developed a high-precision mass transfer technology for Micro-LED displays utilizing self-alignment with wall structure. We achieved high-precision mounting of  $\mu$ LEDs and Micro-ICs without relying on equipment accuracy. This technology facilitates the creation of transparent flexible displays without requiring thin-film transistors (TFTs).

## Author Keywords

Micro LED; Mass transfer; Micro-IC; Wall structure; Spacer

## 1. Introduction

Micro LED displays are characterized by high brightness, high contrast, long lifespan, and lightweight. Because of these features, they are increasingly expected to be applied in AR glasses, wearable information devices used in bright outdoor environments, and large digital signages [1].

Currently, we are developing a transparent  $\mu$ LED display using transparent flexible plastic substrates and micro-ICs for application in automotive displays, as shown in Fig 1. By driving the  $\mu$ LEDs with micro-ICs, low-temperature processing becomes possible, enabling the realization of flexible displays using transparent polyimide substrates.



Figure 1. Transparent  $\mu$ LED display for car windows.

To realize  $\mu$ LED displays, it is necessary to bond  $\mu$ LED chips, which are tens of micrometers in size, from the LED wafer to the backplane quickly and with high precision. Recently, mass transfer technology has been attracting attention for this purpose. In mass transfer technology, wafers or carriers with tethers, PDMS stamps that enable large-scale transfer, and electromagnetic stamps are used. However, these methods depend on the precision of the equipment and the stamps.

Reducing the stamp size to improve transfer accuracy increases the number of repetitions, making it extremely difficult to achieve high-speed and high-precision bonding of  $\mu$ LEDs. Consequently,

technology for high-precision transfer on large screens has not been realized.

In this paper, we report on developing transparent flexible  $\mu$ LED displays by establishing a manufacturing process incorporating a novel wall structure and spacer structure in the bonding method of  $\mu$ LEDs, achieving high-precision transfer technology.

## 2. Fabrication Process

We have developed a novel transfer technology for  $\mu$ LEDs, and Micro-ICs based on Bump Penetration Electric Bonding (BPEB) technology. This process allows for the bonding of  $\mu$ LEDs in a single step. The manufacturing process of the  $\mu$ LED display using TFT in this study is shown in Figure 2.

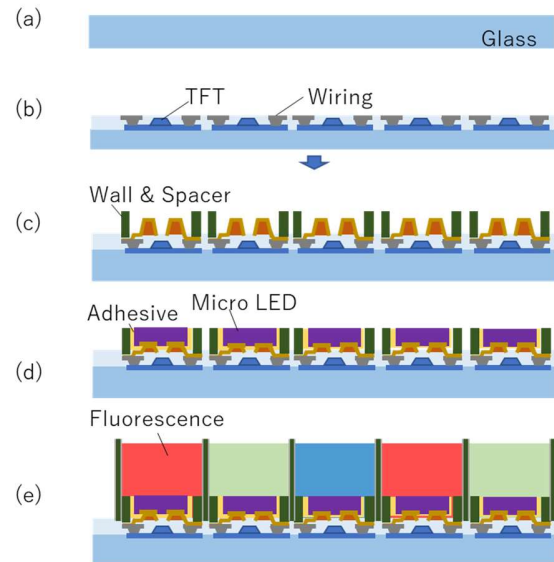


Figure 2. Bonding method of  $\mu$ LEDs using BPEB technology. (a) Backplane Glass, (b) TFT and Wiring formation, (c) Bump Wall Spacer fabrication, (d) LED Bonding, (e) Formation of fluorescence.

First, a thin film transistor is formed on glass. Next, bumps for terminal connections for LEDs are formed. The bumps are created using photosensitive resin materials and photolithography. They are then metal-coated. After this, to ensure chip position accuracy and height precision, walls and spacers are formed using photosensitive resin and photolithography. In the conventional BPEB method, adhesive was applied over the entire wafer, and an electrical connection was achieved by penetrating the bumps on the backplane. However, in this study, to bonding LEDs on the same substrate and ensure more stable electrical connectivity, adhesive was patterned using photolithography in the LED bonding area, and

then the LED chips transferred to the carrier were transferred to the backplane.

Here, to improve the red-light emission efficiency, we used UV-LEDs and formed a color conversion layer by screen printing fluorescence for UV-LED color conversion.

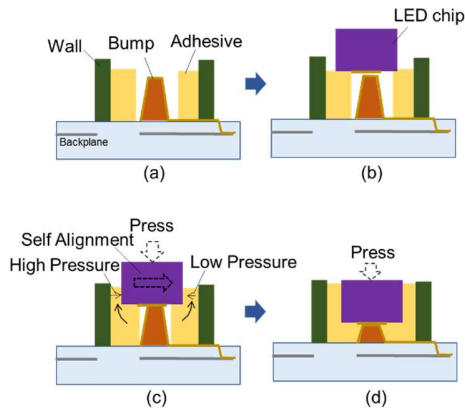
The LED used in this technology is a very small chip measuring  $18 \times 33 \mu\text{m}$ . By adding Wall and fluorescence to this LED and arranging them, it is possible to achieve a display resolution of up to 220ppi. This enables applications in high-definition displays such as televisions and tablets.

### 3. Bonding of $\mu\text{LEDs}$ and Micro-ICs by Mass Transfer Technology

In this method of bonding  $\mu\text{LEDs}$ , after forming the adhesive layer, the chips are pressed to electrically connect the  $\mu\text{LEDs}$  and bumps. Compared to methods like ACF, this method requires less pressure and allows for large-area bonding. However, the precision of the bonding depends on the equipment's accuracy. As a result, as the bonding area increases, the absolute load increases with the number of chips, making it difficult to achieve both precision and high load due to the equipment's play.

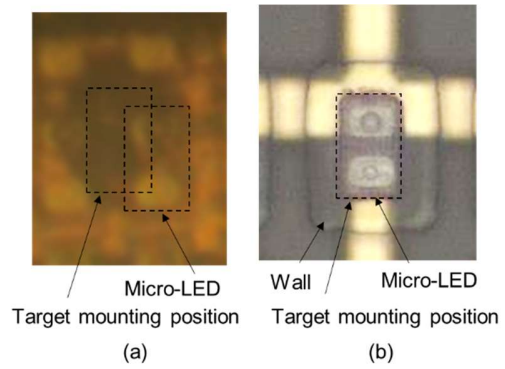
To solve this problem, we developed a self-alignment method by forming a wall structure, which ensures positional accuracy independent of the bonding equipment's precision.

When the adhesive is softened and the chip is bonded (pressed), the adhesive between the wall and the chip flows. Generally, during pressing, misalignment loads occur due to equipment distortion and play, causing chip bonding misalignment. However, as shown in Fig. 3, by forming walls, the pressure generated during the adhesive flow between the chip and the wall corrects the misalignment, resulting in bonding in the corrected direction.



**Figure 3.** Self-alignment of LED chips using wall structures, (a) Bump & Wall formation, (b) Chip bonding, (c) Self-alignment during pressing, (d) After pressing.

The comparison of the post-transfer states of  $\mu\text{LEDs}$  with and without walls is shown in Fig. 4, respectively. We confirmed that positional misalignment was significantly reduced, and this method achieved positional accuracy within  $\pm 2 \mu\text{m}$ .

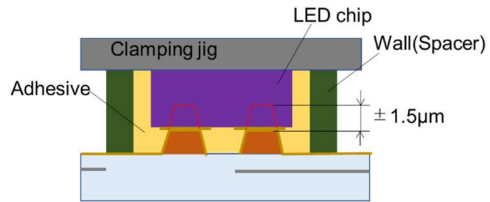


**Figure 4.** Comparison of LED bonding states.

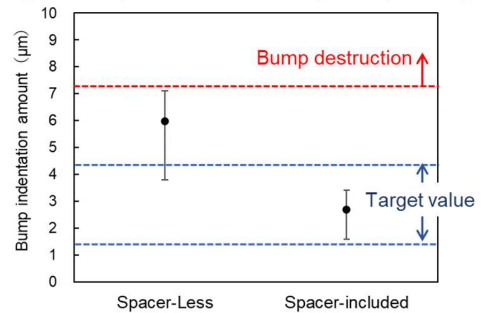
(a) Wall-less, (b) Wall-included.

Next, we developed spacers to control the pressing amount. Generally, in self-alignment using wall structures, bumps are used to connect the backplane and chips. However, if the pressure is insufficient, non-conduction occurs, and if the pressing is excessive, issues such as bump destruction arise. Typically, bonding using bumps requires high-precision control of the pressing amount within  $\pm 1.5 \mu\text{m}$ .

As spacers for the LED chips, we used the walls described in the previous section, as shown in Fig. 5, and optimized their height. The pressing load is about several tens of mN, and to withstand this load, we used an epoxy-based material that is approximately ten times stronger than the bump material to create the walls.



**Figure 5.** Spacer for controlling LED pressing.



**Figure 6.** Comparison of LED pressing amounts with and without spacers.

The comparison of the pressing amount with and without spacers is shown in Fig. 6. We confirmed that using spacers controls the pressing amount and reduces variability.

#### 4. Formation of the color conversion layer

In this method, we use UV-LEDs with an emission wavelength of 385 nm and convert colors using blue, green, and red fluorescence. In this study, we used inorganic fluorescence with excellent durability. We confirmed that inorganic fluorescence has high stability, with a brightness decrease of less than 10% after 1000 hours of continuous irradiation by UV-LEDs.

The cell frame of the fluorescence was formed using a photosensitive resin and a method that employed a metal sputter film for the separation membrane [4].

In this study, the fluorescence was formed by screen printing. The state of the formed fluorescence is shown in Fig. 7. The fluorescence was created by mixing resin, solvent, and fluorescence, and printed in small sizes with cell frame dimensions of  $54 \times 78 \mu\text{m}$  per color. Additionally, it was confirmed that a fluorescence film thickness of approximately  $15 \mu\text{m}$  could be applied.

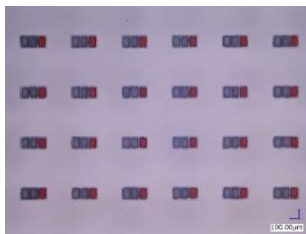


Figure 7. Printing condition of Fluorescence.

#### 5. Development of Transparent Flexible Micro-LED Display using Micro ICs

By applying high-precision mass transfer technology using Wall and spacers to Micro ICs, it is possible to realize transparent flexible Micro LED displays.

The backplane uses transparent polyimide. Since transparent polyimide discolors at high temperatures, TFTs are not used to prevent this, and Micro ICs are used for driving instead. The process flow reflecting this content is shown in Fig. 8. The flow includes forming the transparent polyimide before chip mounting and adding Micro IC mounting after Micro LED mounting.

We confirmed the effect of Micro ICs, similar to the effect of Walls during Micro LED bonding, as shown in Fig. 9. It was confirmed that bonding was achieved with high precision within  $\pm 2 \mu\text{m}$ .

Additionally, the effect of spacers was also confirmed. As shown in Fig. 10, since the Micro ICs have larger chip sizes and greater chip thickness variations compared to LEDs, spacers were placed at the bottom of the chips for bonding. The results are shown in Fig. 11, confirming that control within  $\pm 1.5 \mu\text{m}$  was achieved.

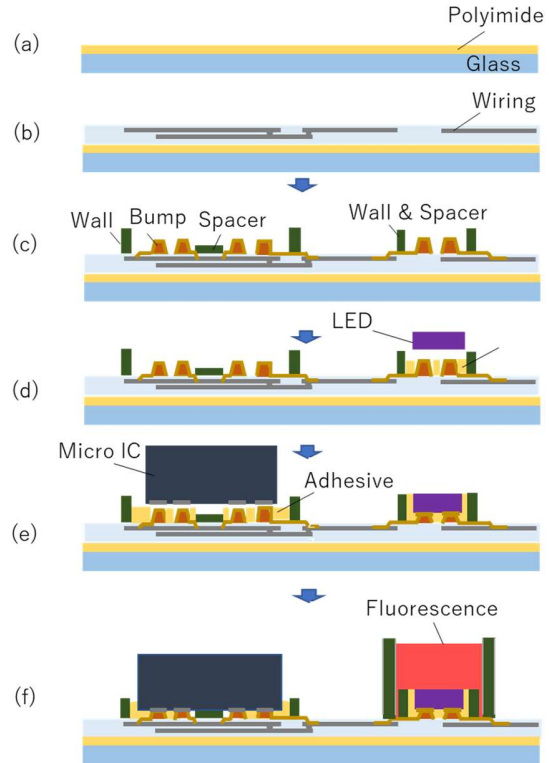


Figure 8. Bonding method of  $\mu\text{LEDs}$  and micro-ICs using BPEB technology. (a)Forming Polyimide, (b) Wiring formation, (c) Bump Wall Spacer fabrication, (d) LED Bonding, (e) Micro-IC bonding, (f) Formation of fluorescence.

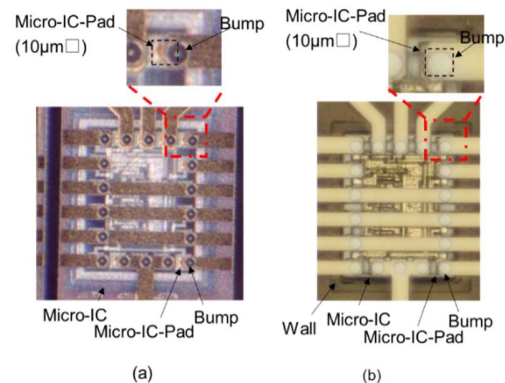


Figure 9. Comparison of Micro-IC bonding states. (a) w/o Wall structure, (b) w/ Wall structure.

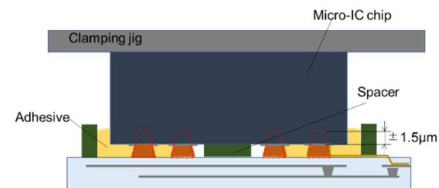
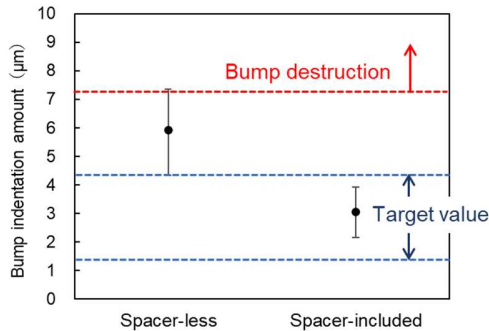


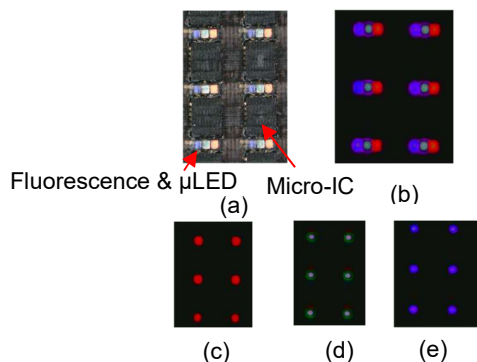
Figure 10. Spacer for controlling Micro-IC pressing.



**Figure 11.** Comparison of Micro-IC pressing amounts with and without spacers.

## 6. Implementation of $\mu$ LED and Micro-IC using Wall Spacer

Fig.12 shows the state where  $\mu$ LED and Micro-IC were bonded, and R, G, and B were individually lit. The lighting is driven by the Micro-IC through control signals, and we confirmed that each color can be controlled to light up through this control. The Micro-IC was designed by Tokai Rika, and a process was developed and manufactured to support ultra-small, thin ICs.

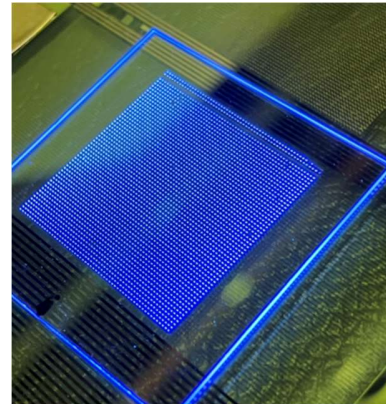


**Figure 12.** Lighting condition of  $\mu$ LED Chips.

(a) Overall view of  $\mu$ LED and Micro-IC, (b) Lighting condition, (c) Red only, (d) Green only, (e) Blue only.

Fig.13 shows the results of bonding  $\mu$ LED with the application of a wall spacer. Here, glass was used as the substrate, the wiring was formed, then the wall spacer and bumps were formed, and subsequently, UV-emitting  $\mu$ LEDs were transferred. A photo of the lit state is shown. The bonding area is 20×20 mm, and the number of LEDs is approximately 9,700.

The lighting rate, excluding line defects caused by short circuits in the backplane, has reached 99.8%. It was confirmed that the non-lighting areas were due to substrate contamination and bump formation defects. The improvement in the lighting rate was achieved through the use of walls and spacers. Therefore, it is believed that further improvement in the lighting rate can be realized by using this manufacturing process and setting the sample production environment to a clean room for display manufacturing.



**Figure 13.**  $\mu$ LED bonding status.

## 7. Conclusion

In this study, a transfer method for  $\mu$ LED and Micro-IC using self-alignment with wall structures and spacers was developed to realize a transparent micro-LED display using a transparent flexible substrate.

By using the manufacturing process developed in this study, the transfer accuracy of  $\mu$ LEDs has dramatically improved. Additionally, by optimizing the structure of the spacers, the variation in the amount of pressing was reduced, achieving improved connection accuracy between the  $\mu$ LEDs and bumps.

Furthermore, using the developed technology, a prototype  $\mu$ LED display was created, and we confirmed to have extremely high transfer accuracy, demonstrating its effectiveness.

## 8. Acknowledgements

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## 9. References

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