

Development of Particle-Arrayed ACF for MicroLED

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Abstract

Anisotropic Conductive Film (ACF) is an adhesive film that provides three functions: adhesion, conduction, and insulation. It is used in many applications, including flat panel displays.

Recently, we developed a new particle-arrayed ACF specifically for Micro-LED applications. This product ensures excellent contact resistance and high shear strength when bonding to small pads of the Micro-LED. We also investigated the laser bonding process to improve production efficiency and pre-cut ACF technology for transparent displays.

Author Keywords

ArrayFIX; ACF; Anisotropic Conductive Film; Particle-arrayed ACF; Micro-LED; Bonding process; contact resistance; shear strength; conductive particle; laser bonding

1. Basics of Anisotropic Conductive Films

Anisotropic Conductive Film (ACF) is an adhesive film composed of thermosetting resin and conductive particles. It provides an adhesion, electric conductivity between the facing pads, and insulation between the adjacent pads. Conductive particles are made of Ni-plated polymer and covered with an insulation layer. Under the influence of heat and pressure, the particles between the facing pads shed the insulation layer, establishing an electrical connection. Meanwhile, the insulation is maintained between adjacent pads, preventing short-circuits. ACF is a thermosetting adhesive that provides high reliability while electrically connecting multiple circuits simultaneously (Figure 1).

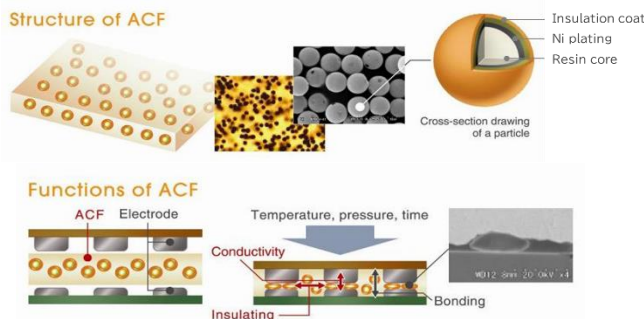


Figure 1. Basics of Anisotropic Conductive Film

Currently, ACF is widely used for flat panel displays and IC chip bonding, and its usage is expanding in camera modules and IC card assemblies. [1,2,3,4]

2. Manufacturing challenges for Micro-LED

Though Micro-LED Displays have exceptional brightness, high contrast ratio and design flexibility, they have not yet expanded in the market due to very high pricing. For this business to grow, a reduction of module manufacturing costs as well as a more efficient manufacturing process are necessary.

There are many challenges, especially related to the mounting process of Micro-LED. The mounting process involves three major processes: chip arraying, chip transfer, and bonding process.

(Figure 2)



Figure 2. Micro-LED mounting process

In particular, the bonding process is associated with many challenges. For conventional Mini-LED bonding, solder bonding is a general method in which solder paste is applied to a specified pad by screen printing or forming a solder bump. However, for Micro-LED bonding, solder needs to be applied on pads with an area of 1000 μm^2 or less, which is difficult to achieve by normal screen printing. Therefore, it has become necessary to consider new bonding methods such as ACF and eutectic bonding.

Unlike the soldering method, eutectic bonding is well-suited for creating reliable connections on extremely small pads. However, it requires forming thin layers of AuSn or AuIn on both the backplane and the LED by electrolytic plating or vapor deposition, which involves several preprocessing steps. The bonding temperature, generally 250°C or higher, may damage the backplane during bonding. In addition, the bonding interface becomes unstable depending on the condition of the metal surface, which makes the process management challenging. Even if bonding is successful, there is a disadvantage that the process takt time is very long. During the eutectic bonding, the LED is initially mounted on a heated backplane using a stamp approximately 3 x 3 cm in size. After cooling, the backplane is reheated and another set up LED is mounted.

The ACF method has a relatively simple bonding process compared to solder and eutectic bonding and is expected to improve the process takt time by reducing the number of bonding steps. However, conventional ACFs with randomly dispersed particles cannot meet requirements for small pads of 500 μm^2 in size or less. Therefore, we developed a new particle-arrayed ACF for Micro-LED, "ArrayFIX", which can bond very small pad areas in Micro-LED. [5]

Bonding method	ArrayFIX	Conventional ACF	Eutectic	Solder	Conductive paste	
Pre-processing <small>*Electrode bonding material formation</small>	Not required	Not required	· Electrolytic plating · Vapor deposition	· Screen printing · Inkjet	· Screen printing · Inkjet	
Conductive material <small>Reliability performance</small>	Ni plated polymer <small>Elastic property</small>	Ni plated polymer <small>Elastic property</small>	AuSn, AuIn <small>Metal Bonding</small>	SAC series <small>Metal Bonding</small>	SnBi, SnIn <small>Metal Bonding</small>	Carbon, Nano-Ag <small>Contact only</small>
Bonding temperature	140°C~	140°C~	250°C~	250°C~	180°C~	150°C~
Bonding time <small>*15 × 15cm area Bonding</small>	0.5min <small>1time x 30sec for whole area</small>	0.5min <small>1time x 30sec for whole area</small>	75min <small>25times x 3min for 3x3cm stamp size each</small>	3~10min <small>Reflow & Flux Removal</small>	0.5min <small>1time x 30sec for whole area</small>	
Bonding strength	Good <small>Resin covers around the LED</small>	Good <small>Resin covers around the LED</small>	Unknown <small>interface strength may weak</small>	Good	Poor <small>Known as brittle</small>	Poor <small>Contact pad area only</small>
Min. required pad size	30µm ² ~	500µm ² ~	10µm ² ~	1000µm ² ~	10µm ² ~	

Figure 3. Types and features of Micro LED bonding technologies

3. Particle-arrayed ACF for Micro-LED

ArrayFIX is a particle-arrayed ACF, where particles are uniformly arrayed. This allows Micro-LEDs with small pad areas to achieve stable electrical connections while reducing the possibility of short circuits between the pads. Furthermore, the particle size and density have been optimized, with 2.2 µm being the smallest size in the history of ACF, and 58,000 pcs/mm² representing the highest density achieved to date. As a result, conductive particles were captured with certainty on the Micro-LED, even with pad sizes of 10×10 µm (area size 100 µm²).

1.7 µm /100,000 pcs/mm² ArrayFIX has also been developed with sample offerings recently made available. Theoretically, more than two conductive particles can be captured on a pad with the size of 30 µm² using this ACF.

The benefit of ArrayFIX, in contrast to the solder or eutectic bonding, is that it eliminates the need to prepare bumps for bonding on the backplane. Additionally, the low temperature bonding (around 140°C) is possible, reducing the risk of substrate damage and misalignments caused by backplane expansion when exposed to heat during bonding. (Figure 4)

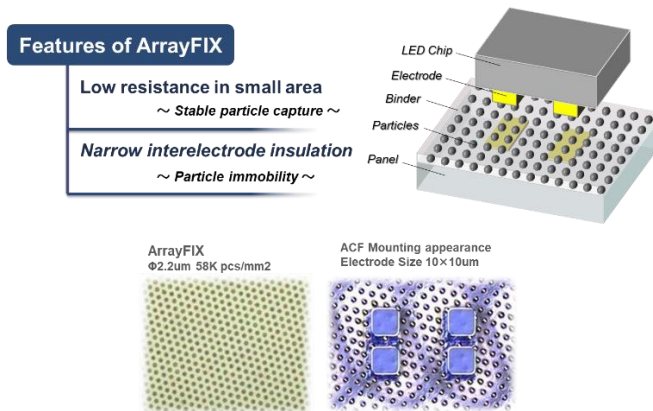


Figure 4. Features of ArrayFIX

4. Usage Instructions

Step 1. ACF lamination onto the backplane: laminate ACF on backplane using a roll laminator or vacuum laminator.

Step 2. LED Pick & place: Mount LED onto the ACF laminated backplane.

Step 3. LED main bonding: Using the Heat tool, apply heat above 140°C and pressure over 10 MPa. (Figure 5)

Using ACF for the Micro LED mount process is straightforward. It involves laminating ACF onto the backplane, placing LED, and bonding. Unlike eutectic or solder bonding processes, it is not necessary to create bumps between the board and LED pads.

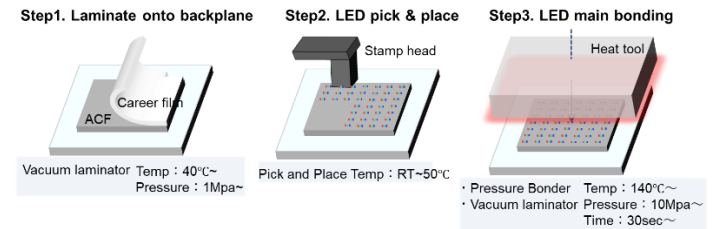


Figure 5. ACF bonding process

5. Performance and feature

To evaluate ArrayFIX for Micro-LED, the contact resistance, shear strength, and lighting tests were conducted. For verification, 2.2 µm conductive particles with Ni coated resin core and 58 Kpcs/mm² 5 µm thick ArrayFIX were prepared.

Contact resistance. Firstly, the ACF was laminated onto a glass substrate with Ti/Al/Ti contact pads. Then, a chip with a bump size of 10 µm x 10 µm was placed on it, and the chip was bonded at a temperature of 150°C under pressure of 5 to 60 MPa, respectively. No increase in contact resistance was observed even after 500 hours in an environment at 85°C and 85% humidity. This indicates excellent reliability of the ACF.

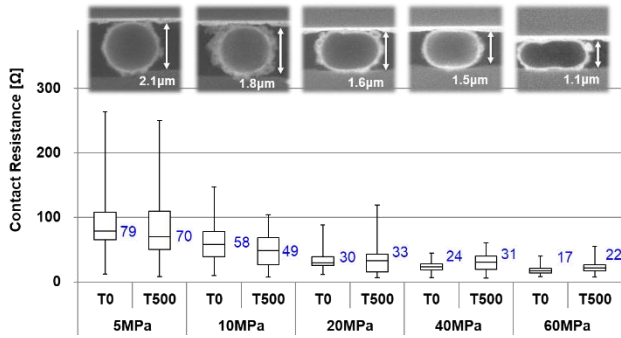


Figure 6. Contact resistance

Shear strength: Micro-LEDs sized 18 x 36 μm were prepared and bonded onto a glass substrate under conditions of 150°C, 60 MPa, and 30 seconds. Shear strength was measured using a die shear tester. The ACF demonstrated a shear strength exceeding 100 MPa, which is higher than that of SnAg bonding. The epoxy resin used in the ACF encapsulated the LED, resulting in strong adhesive strength (Figure 7).

[Verification support by Toray Engineering Co., Ltd.]

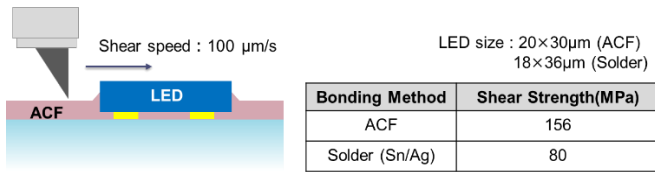


Figure 7. Micro-LED Shear Strength

Lighting test: To demonstrate that ArrayFIX can illuminate small Micro-LEDs, lighting tests were conducted using a 15 x 30 μm Micro-LED, one of the smallest in the industry for a flip-chip type. After laminating the ACF onto the backplane, a 15 x 30 μm Micro-LED (RGB, 3 colors) was placed and bonded to create a Micro-LED lighting substrate. A voltage of 3 to 5 V was applied to confirm the lighting test. As shown in Figure 8, ACF can be used without any issues in Micro-LED applications.

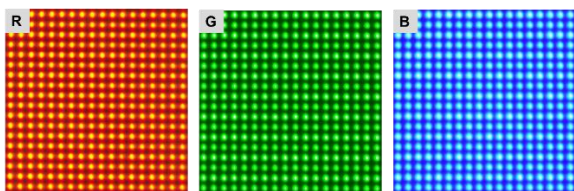


Figure 8. Lighting image

6. Laser-assisted ACF bonding

Laser-assisted ACF bonding was examined to reduce the bonding time using an 18 x 36 μm LED. The ACF was successfully cured by applying a laser at 190°C for 1 second while applying a pressure of 60 MPa (Figure 9). The curing rate of the ACF bonding sample exceeded 95%, with shear strength over 100 MPa, comparable to that of 150°C for 30 seconds heat bonding. As shown in Figure 10, the lighting performance was excellent.

[Verification support by Toray Engineering Co., Ltd.]

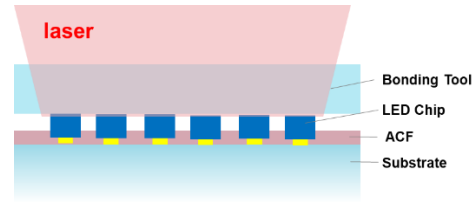


Figure 9. Schematic diagram of laser-assisted bonding

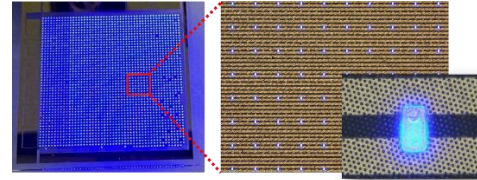


Figure 10. Lighting test after laser-assist bonding

7. Pre-cut ACF for Stretchable and Transparent Micro-LED Display

Stretchable and transparent MicroLED displays hold significant potential for next-generation electronics, including wearable devices, augmented reality (AR), and IoT/smart devices

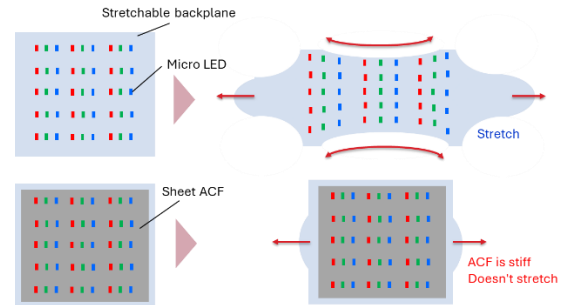


Figure 11. Micro-LED Stretchable Display

ACF's low-temperature bonding process is suitable for resin-based stretchable backplanes. However, if ACF is attached to the entire surface of the stretchable backplane, it cannot stretch because the ACF sheet cures and becomes stiff after thermal bonding (Figure 11).

Additionally, due to the coloration of sheet ACF, the background of the transparent backplane will not be visible (Figure 12).

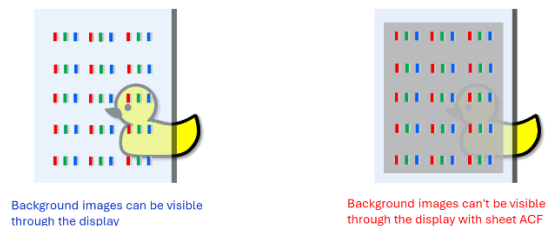


Figure 12. Micro-LED Transparent Display

Pre-cut ACF was developed to overcome these challenges in stretchable and transparent Micro-LED displays (Figure 13).

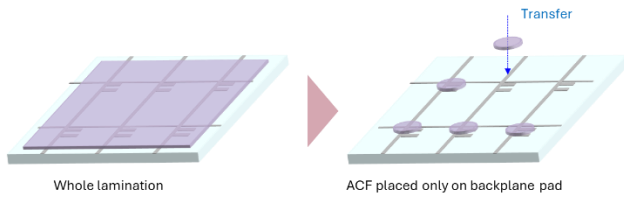


Figure 13. Pre-cut ACF for Stretchable/Transparent Display

Pre-cut ACF preparation and transfer: Pre-cut ACF, with an 80um diameter with 160um pitch, was prepared on glass substrate by removing the unnecessary part from the ACF sheet. Then, laser light was irradiated through the glass surface to transfer the Pre-cut ACF to the designated position on the backplane using the excimer laser high-speed trimming/repair device (Shin-Etsu Chemical). The pre-cut ACF interface facing the glass was slightly ablated by laser irradiation and ejected from the glass (Figure 14).

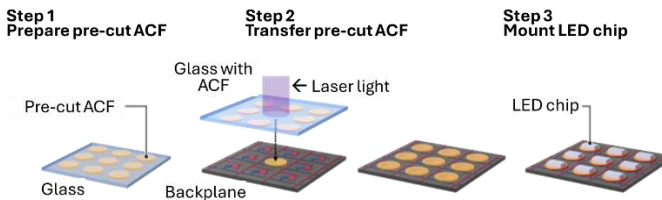


Figure 14. Pre-Cut ACF transfer method

The transferred pre-cut ACF functioned properly, similar to laminated ACF sheet (Figure 15).

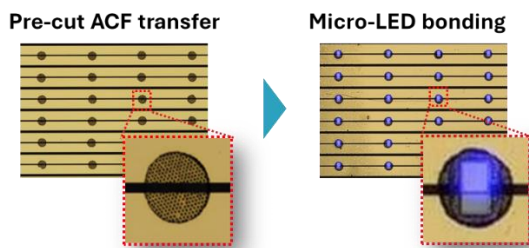


Figure 15. Lighting test of Pre-cut ACF

Application for Transparent Display: The visible light transmission of pre-cut ACF applied to glass has been evaluated. The company logo under the ACF sheet is opaque with a transmittance of 70%. Meanwhile, when the pre-cut ACF is applied with a 500 μm pitch, the transmittance increases to 99%, allowing the company logo to be seen clearly (Figure 16).
[Verification support by Shin-Etsu Chemical Co., Ltd.]

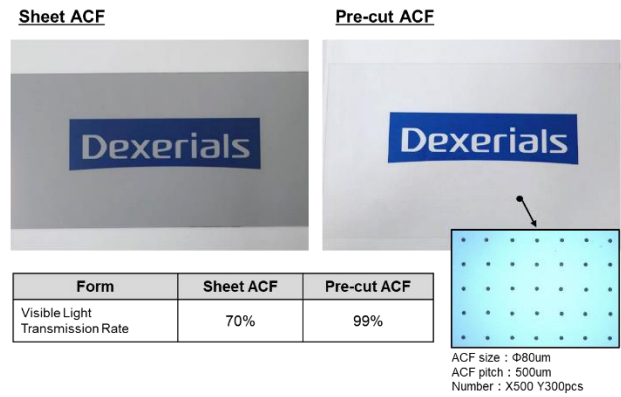


Figure 16. Transmittance of ACF

8. Conclusion

Driven by the growing market demand and advances in display technology, Micro-LED displays are expected to transform the display industry.

However, challenges remain, such as the complexity of the manufacturing process, low yields, and meeting future technical requirements. Despite these obstacles, Dexerials is committed to developing innovative “Particle-arrayed ACF” products and improving manufacturing technologies “Pre-cut ACF transfer” to accelerate the adoption of Micro-LED displays. Through these efforts, we aim to help shape the future of display technology and realize its great potential.

9. Acknowledgements

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10. References

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