Innovative Film Type Backplane with Super-Fine and Ultra-Low Resistance Wiring for Transparent Display

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Abstract

We have created the film-type transparent backplane using the transparent conductive film composed of metal mesh with our unique manufacturing process. By forming super-fine and ultra-low resistance wirings with a line width of 2µm and a thickness of 2µm on a flexible film, and mounting LEDs with optimized material and process, transparent and highly visible LED displays can be realized. Additionally, by employing unique via formation and high aspect ratio metal wiring, we are looking into making a matrix display that shows more varied images.

Author Keywords

Transparent Display; Flexible Display; Backplane; Micro LED; Mini LED; AR

1. Introduction

With the advent of the highly information-oriented society, the introduction of AR (Augmented Reality) is being explored in various situations. In order to further promote the widespread use of AR, the practical application of transparent displays is necessary to display a large amount of information without obstructing the field of view.

Transparent displays are being developed in various ways, but there are challenges in terms of transparency, brightness, and flexibility, making it difficult to apply them into transportation equipment such as automobiles.

Thus, we researched the film type backplane for transparent display that can be applied to curved cover panel and achieve both high transmittance and high brightness by utilizing a transparent conductive film produced by our unique manufacturing method.

In this paper, we describe the transparent conductive film and its application to the LED display backplanes.

2. Backplanes for Transparent LED display

The backplane of a transparent LED display needs high transparency, low resistance wiring, and LED-mountable features. The frequently used ITO (Indium Tin Oxide) for transparent electrodes has high resistance, causing uneven current distribution in the plane and resulting in brightness variations. Therefore, metal mesh is considered a good alternative.

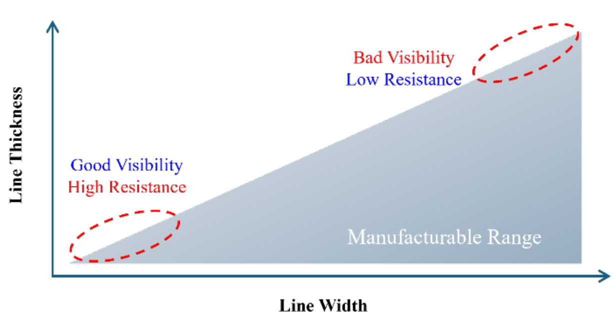

Figure 1. Manufacturable Range of the Etching Method

For metal mesh transparent conductive films, the etching method is commonly used. In the case of the etching method, wiring is formed on the base film, making it very difficult to maintain a thick wiring thickness with a narrow line width. Consequently, to reduce resistance, it is necessary to increase the width of the wiring, which results in decreased transparency. (Fig. 1)

To address this issue, we have examined the possibility of applying groove-forming metal wiring conductive film, which offers low resistance and high transparency, as a backplane for transparent LED displays.

2.1 Groove-forming metal wiring conductive film

In the etching method, wiring is formed on the base film, but in our new method, as shown in Fig. 2, grooves are formed on the base film, and metal is filled into the groove.

As a result, this allowed for obtaining a high aspect ratio of 1.5µm wiring thickness with a narrow 2µm wiring line width (Fig. 3 (b)).

The following is a detailed explanation of the manufacturing process. A visible light-transparent PET is used as the base film(substrate), with a thin transparent resin layer on top, and grooves are formed on the top of this layer using a mold. Metal is filled in the grooves to work as the wiring. Copper, which has low electrical resistance and is flexible, is used as the wiring material.

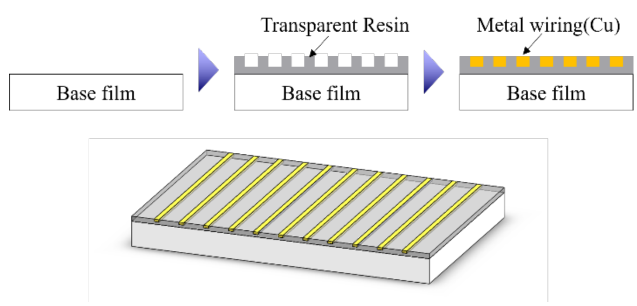

Figure 2. Process of the groove-forming metal wiring

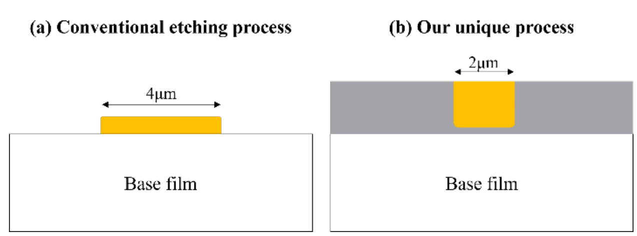

Figure 3. Aspect Ratio Comparison by Process

The groove-forming method is particularly helpful for transparency. Since the metal used to form the wiring obstructs light, narrower wiring line widths result in a larger aperture ratio. This increase in aperture ratio is helpful for achieving a transparent display. As the aperture ratio is proportional to the transmittance, finer line patterning can achieve high transmissivity, based on the principles illustrated in Fig. 4.

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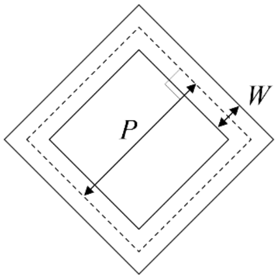


$$AR = (P - W)^2 / P^2$$

AR : Aperture ratio
P : Mesh pitch
W : Wire width

Figure 4. Wiring width and aperture ratio

2.2 Characteristics

The characteristics for each manufacturing method are shown in the table below.

Table 1. Aperture Ratio of Each Metal Mesh Method

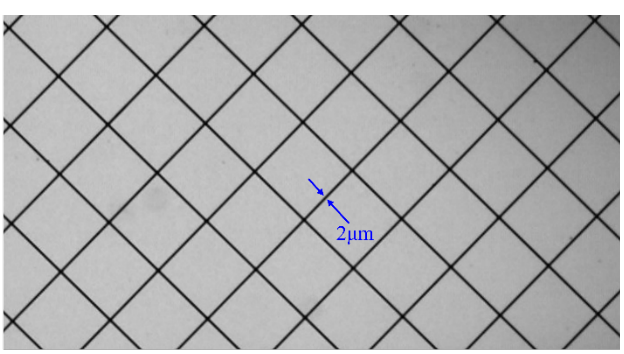
Items	Etching Type Metal mesh	Groove-forming Type Metal mesh
Wiring Line Width (Visibility)	4µm	2µm
Aperture ratio without LEDs (Sheet resistance =2Ω/□)	92%	96%

※Comparison between our own prototypes

3. Study on application possibility to transparent LED displays

3.1 The required specifications for backplanes

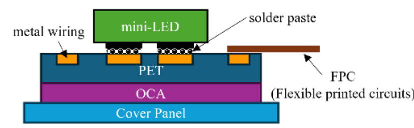
To create the backplane for transparent displays that can be adhered to a curved surface, it needs low resistance, high visibility, flexibility, and the ability to mount LEDs. We have investigated the use of a grooving type of transparent conductive film to achieve low resistance, high visibility, and flexibility. The wiring takes the form of mesh, as shown in Fig. 5, and a pad pattern is provided for LED mounting, which is then joined by solder paste. As the base film is PET and cannot withstand reflow at high temperatures, a low temperature solder paste that can be used at 200° C below was selected. The specifications of this study are shown in Table 2. For LED control, a segment method was employed(32LEDs per segment).



※The above figure is for example.

Figure 5. Wiring design of mesh

Table 2. Specifications and stack-up for the study

Items	Material
Base film	PET
Metal wiring	Copper
LED	mini-LED（□0.4mm）
LED mounting	low-temperature solder paste + N2 reflow
Lamination	OCA（Optical Clear Adhesive）
Stack-up image	

3.2 LED mounting flow charts

The LED mounting process is shown in Fig 6.

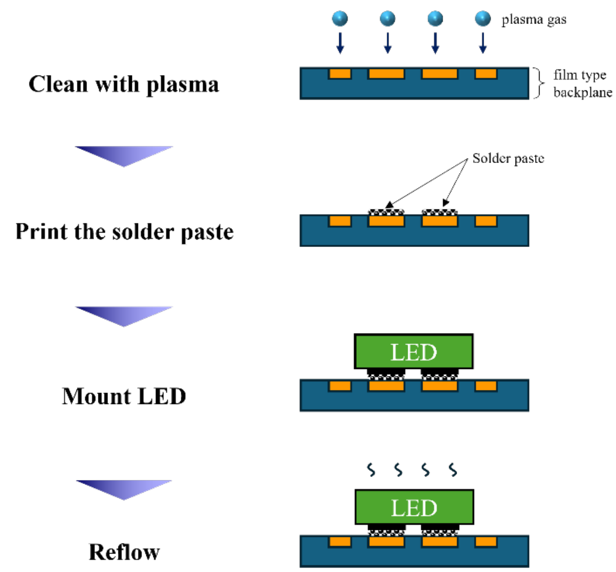


Figure 6. LED mounting flow on transparent film

The wiring surface has been treated with blackening to prevent reflection, but it negatively impacted solder wettability. Therefore, before printing of solder paste, plasma treatment was performed on the surface to improve wettability. It enhances the bonding strength with the LEDs (Fig. 7). Then, solder paste was printed to the pad on the film, and after mounting the LEDs, heat treatment was carried out using N2 reflow to complete the LED mounting process.

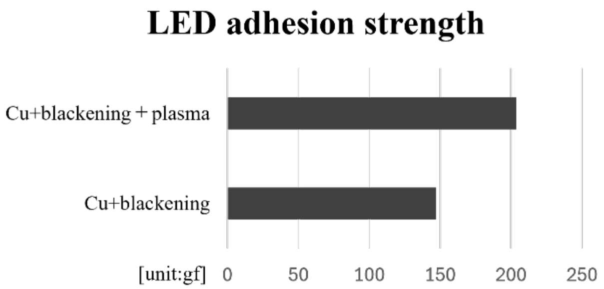


Figure 7. LED Adhesion Strength by Surface Condition

Furthermore, by improving the wettability of the conductive film surface, the LEDs were arranged without rotation, as shown in the Figure 8 below, and any tilt in the vertical direction was also removed.

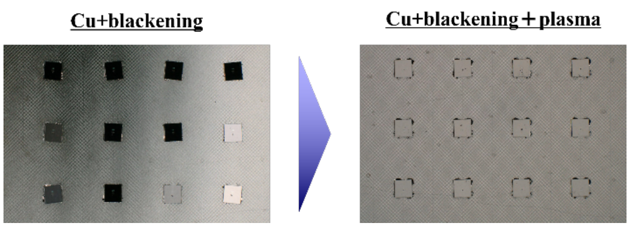


Figure 8. LED mounting status by the surface condition

3.3 Adhesion method

The film type backplane was adhered to curved cover lens using OCA(Optical Clear Adhesive).

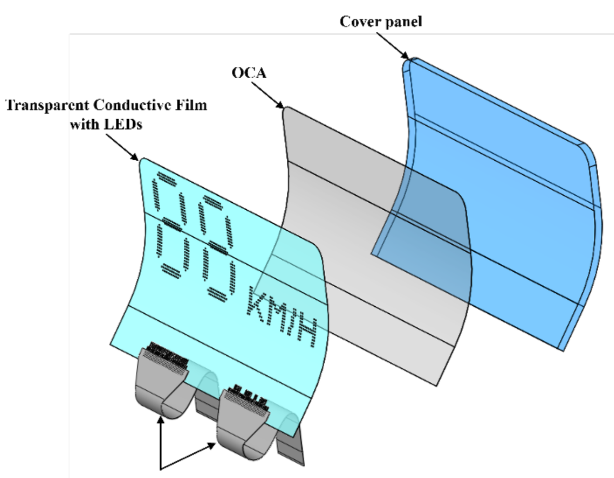


Figure 9. How to adhere to curved cover panel

3.4 Turning on the LED

Figure 10 shows that the mini-LED （0.4mm x 0.4mm） mounted on the film-type backplane is lighting up.

Wiring line width: 3µm

Aperture ratio: 90% (only mesh line area)

Sheet Resistance: 0.5Ω/□

Mounted LED: mini-LED （0.4mm x 0.4mm）

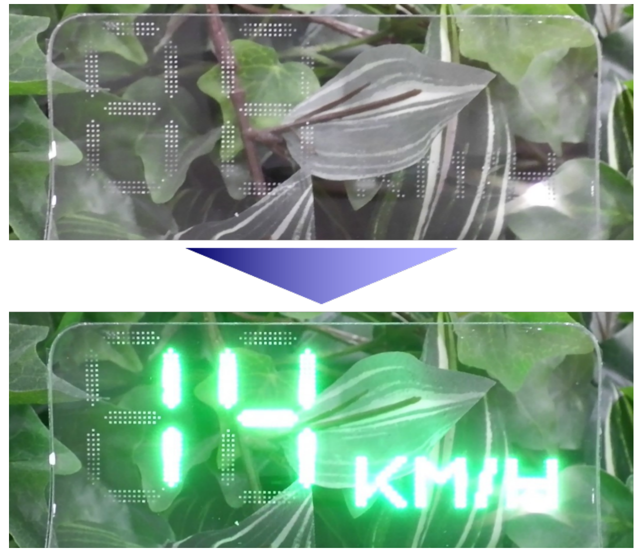


Figure 10. mini-LED mounting sample

4. Future works

4.1 Higher Transparency with micro-LED

To further improve transparency, we tried to switch from mini-LED to micro-LED and confirmed that the micro-LED was working on the film backplanes. Through improvements in the compatibility between the film-type backplane and the LED mounting materials, we were able to produce samples with uniform light without defects (Fig. 11).

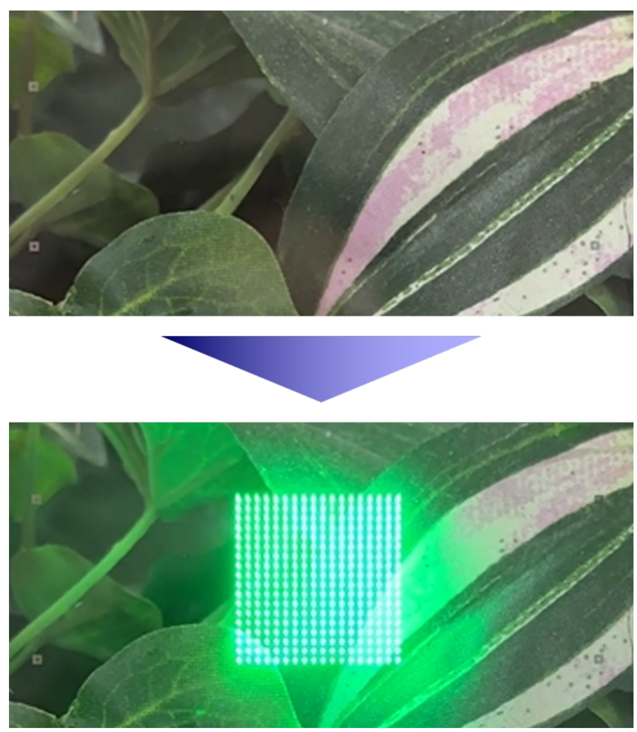
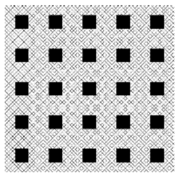
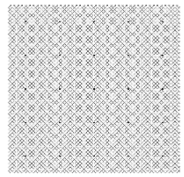


Figure 11. Micro-LED mounting Sample

Table 3 shows the aperture ratio comparison of using mini-LED and micro-LED under the same wiring condition. Reducing LED size helps improve the aperture ratio.

Table 3. Aperture Ratio by LED Size

	Mini-LED	Micro-LED
Product design		
LED size	400μm x 400μm	30μm x 20μm
LED mounting pitch	1mm	
Wiring design	Line width 2μm, pitch 80μm	
Aperture ratio	80%	95%

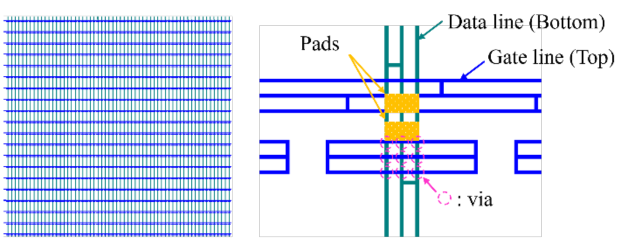
4.2 Future works

In this report, we studied the segment display method for transparent displays in transportation equipment such as automotive use. After this study, process improvements in the groove-forming method allowed us to enhance the aspect ratio to 1, resulting in lower-resistance metal wiring with a width of 2μm and a thickness of 2μm.

Looking ahead, we aim to achieve a matrix display using this improved groove-forming type backplane and demonstrate its applicability not only in transportation equipment like automobiles but also in a wide range of other fields.

4.2.1 Wiring design for matrix display

Figure 12 shows the wiring design diagram for achieving a matrix display. In this design, the line width is 3μm, and the overall aperture ratio is 90%. Vias with the same line width as the wiring can be formed by connecting the top and bottom wiring only at the crossing points. This unique design is advantageous for achieving a high aperture ratio in the display.



<Top view> **<Detail view>**

Figure 12. Wiring design diagram for matrix display

5. Conclusions

By applying our groove-forming metal wiring conductive film technology to the essential component of the display, the backplane, we have developed a attachable transparent display that maintains high transparency while enabling clear visibility.

6. Impact of Research

The innovative groove-forming type transparent conductive film is an excellent electronic substrate characterized by high visibility and low resistance, making it ideal for backplanes in flexible transparent displays. A backplane with lower resistance and higher transparency is expected to contribute to the widespread adoption of flexible transparent displays across various fields. Furthermore, beyond displays, this technology holds the potential to lead to new products such as transparent indicators, transparent lighting, and transparent sensors that are not yet available in the market. The development of transparent devices could also accelerate the adoption of AR(augmented reality) technologies.

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  CONNECTEC JAPAN Corporation

- **Micro-LED:**

  Toray Industries, Inc.

  Toray Engineering Co., Ltd.

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