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Study on increasing durability of wrap around black material for tiled displays

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Tiled display technology, which uses a series of small panels to create a large TV, has gotten a lot of attention for its application of micro LEDs. One of the most important technologies for creating 100-inch or larger TVs by attaching micro LEDs to 10-inch panels is the wrap-around electrodes and black overcoating technology that makes the edges of each panel invisible. This paper describes the material technology and process technology of Ag paste and black overcoating on the glass surface using a pad printing method that can form a film on a curved surface. In particular, the development of a black OC material that is resistant to high temperature and humidity reliability conditions while maintaining black visibility after the process of wrapping the side of the glass using Ag paste to protect it has laid the foundation for the future production of ultra-large TVs using micro LED tile displays. The black overcoating material must not only protect the Ag paste wiring well under external moisture and high temperature conditions, but also adhere well to the substrate. We were able to solve this problem by adding an additive to the black material by applying the mechanism of cement hardening.
Keywords: word; Micro LED, Tiled Display, Durability, Humidity

1. INTRODUCTION

Recently, Samsung Electronics launched a 100-inch or larger extra-large TV created using a tiled display with micro LEDs, positioning it as a new display technology alongside LCD and OLED. As the semiconductor wafer process continues to shrink LED sizes and reduce production costs, various technologies are emerging for aligning LEDs and transferring them to the TFT backplane. Among these, the wrap-around electrode technology plays a crucial role. This technology places the electrode on the side of the glass and applies a signal from the back to drive the front pixel, enabling the creation of tiled displays. Previous methods for constructing wrap-around electrodes involved drilling via holes in the glass to connect the front and back surfaces, as well as experimenting with metal paste formation using inkjet or dispensing nozzles. However, achieving mass production and durability necessitates the development of a novel approach that minimizes working time and maintains consistent resistance in side wiring. In this study, we elucidate the process of developing glass side wiring electrodes and applying black overcoating (OC) using the pad printing method. This technique, commonly employed to print ink on curved surfaces across various industries, is illustrated in Figure 1.

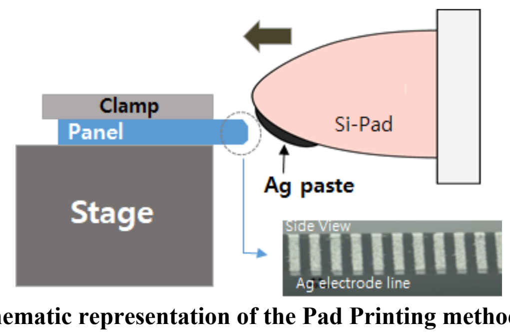

Figure 1. Displays the schematic representation of the Pad Printing method and provides a side view of glass with Ag electrodes.

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Silver paste plays a crucial role in power semiconductor manufacturing, facilitating the attachment of copper plates and chips. The reduction in resistance of silver paste is achieved through the sintering process. Typically, silver paste consists of silver powder with particle sizes ranging from a few nanometres to a few micrometres. It is mixed with polymers and solvents, allowing application via screen printing or pad printing techniques. After application, the initial resistance is high due to the distance between the silver powder particles. Consequently, a sintering process is necessary to agglomerate the particles through heat treatment. During sintering, the solvent volatilizes, and the binder polymerizes, bringing the particles closer together and increasing their size. However, display products face limitations due to the presence of organic films on the glass substrate, which restricts the temperature rise during sintering.

In our study, we experimented with adding an adhesion promoter to enhance the Ag paste's adhesion. Additionally, we explored combinations with modified black overcoating (OC) materials to identify an optimal combination that increases adhesion without delamination under high-temperature and high-humidity conditions. This approach allowed us to overcome the limitations associated with thermal sintering or laser sintering, which typically require heating in a conventional convection oven for more than an hour [7-9].

2. EXPERIMENTALS

To form the side wiring, we fabricated a 12.3-inch panel with wiring on the front and back. The front and back of the panel each had an electrode pad, and we connected these two electrodes with Ag paste to drive the micro LEDs on the front by applying a signal from the back. To check if the two electrodes were broken, we made a test pad next to the electrodes and measured the resistance of the test pads on the front and back, which confirmed that the wires made of Ag paste were broken.

Figure 2(a) shows a cross-sectional schematic structure of the long side end of the micro LED panel. This structure utilizes Ag paste along with glass to connect the electrodes on the top to the electrodes on the back, which are then covered with black OC. The Ag paste consists of about 70-80 wt% nano Ag particles mixed with an epoxy binder and solvent, with a viscosity of about 10,000 cp or more. Black OC, on the other hand, is composed of carbon black pigment, thermosetting resin, and solvent, and has a viscosity of about 3000 cp. To realize these materials in pad printing, the Ag paste and black OC material are put into an imprinted serif and applied to a Si pad for a pickup process. The material on the Si pad is then transferred to the glass side. The Ag paste undergoes a sintering process to reduce resistance after printing, and the Black OC undergoes a curing process to increase adhesion through polymerization. Figure 2(b) shows a microscopic image of Black OC covered with Ag paste wiring on the side of the glass.

In addition, the cross-sectional structure of the materials was investigated using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) to analyse their composition [10].

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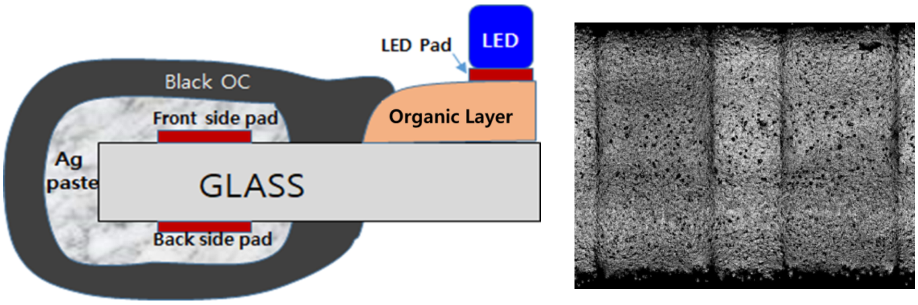

(a) (b)

Figure2. Micro LED panel edge cross-section structure (a) and Black OC overlaid with Ag paste wiring on the glass side(b)

3. RESULTS

3.1. High temperature and humidity reliability evaluation experiments

The role of the side black OC in Micro LEDs is to protect the side wires, prevent wire damage from scratches, and prevent the panel from being visible in tiled displays. Therefore, the black OC should not peel off in high temperature and humidity environments. However, when the panel was subjected to reliability storage tests in a high temperature and humidity environment (85 ℃ /85%), it was found that the adhesion between the OC and the glass was weakened, resulting in peeling. As a result of the hot and humid storage evaluation, Figure 3(a) shows the image before the reliability evaluation, and Figure 3(b) shows the image after the hot and humid evaluation. After the high temperature and humidity evaluation, a significant number of OC materials were peeled or wrinkled, which was assumed to be due to the fact that the conventional black OC material structure analysis showed that only silicon dioxide (SiO_2) was mixed as an additive in the middle of the polymer to support the structure, as shown in Figure 3(c).

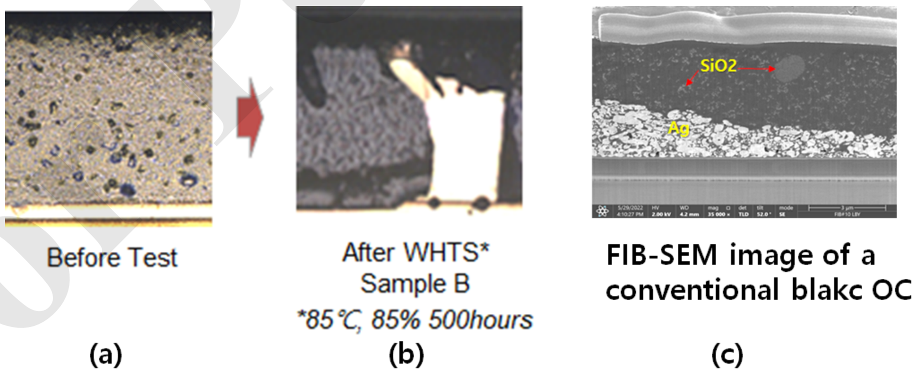

Figure 3. Microscopic image of Black OC before (a) and after (b) high temperature, high humidity reliability and FIB-SEM image of a Black OC cross-section (c).

3.2. Testing for better adhesion by changing material composition

To solve the problem of peeling due to lack of adhesion, we experimented with changing the composition of the black OC to find conditions under which adhesion could be increased. To increase adhesion, we added an amine hardener to the existing

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material, added fillers, or changed the type of binder from epoxy to ester, and evaluated the pencil hardness after hot and humid storage as shown in Table 1. The results showed that the best results were obtained when $CaCO_3$ fillers were added.

Table 1. Scratch test result after evaluation of high temperature and humidity for each sample

No.	Sample	Scratch Test after 85℃, 85% 72hours
1	reference	NG
2	Reference + amine hardener	NG
3	Reference + filler($CaCO_3$)	5B
4	Binder (epoxy -> ester)	4B

As shown in Figure 4, the amount of $CaCO_3$ filler was varied from 5wt% to 30wt%, pad printing on glass was performed, followed by scratch testing. The results showed that the adhesive strength was stronger at 15wt% and above.

Figure 4 presents the scratch test results following the assessment of high-temperature, high-humidity storage conditions based on the quantity of filler.

4. DISCUSSION

A literature study was conducted to investigate why the addition of $CaCO_3$ filler to black OC increased the bond strength. The results suggested that the following pozzolanic reaction occurs in black OC. OC material mixed with $CaCO_3$ turns into CaO as CO_2 escapes during the 180°C curing process. Then, in a hot and humid environment, CaO reacts with water to turn into calcium hydroxide and generate heat. The calcium hydroxide then reacts with other SiO_2 fillers in the OC in a humid environment to turn into an insoluble cement called CSH.

$$Pozzolanic\ Reaction$$
$$CaCO_3\,(s) + heat\ \rightarrow CaO(s) + CO_2(g)$$
$$CaO(s) + H_2O(l)\ \rightarrow Ca(OH)_2\,(aq) + 280\text{Kcal}$$
$$3Ca(OH)_2(aq) + 2SiO2(s) + 3H_2O(l)\ \rightarrow 3CaO, 2SiO_2, 3H_2O\ \text{(s)}$$

The product of this reaction, Calcium Silicate Hydrate (C-S-H), is the main binding phase that provides the concrete with its strength and durability. [11]

When we observed the cross-section of the black OC before and after the reliability evaluation, we noticed a very special phenomenon: Figure 5(a) shows the FIB-SEM

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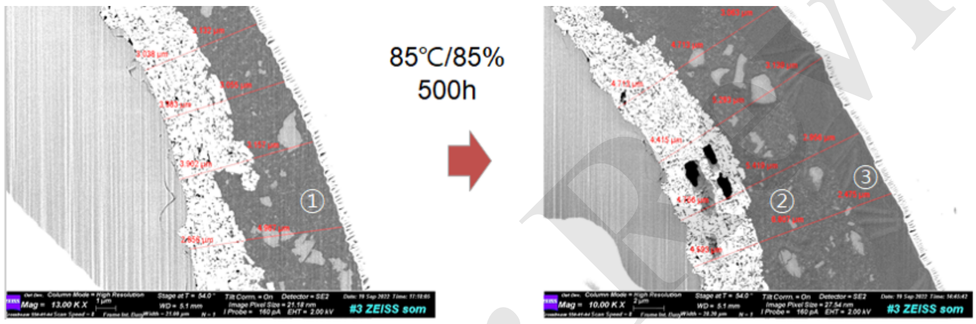
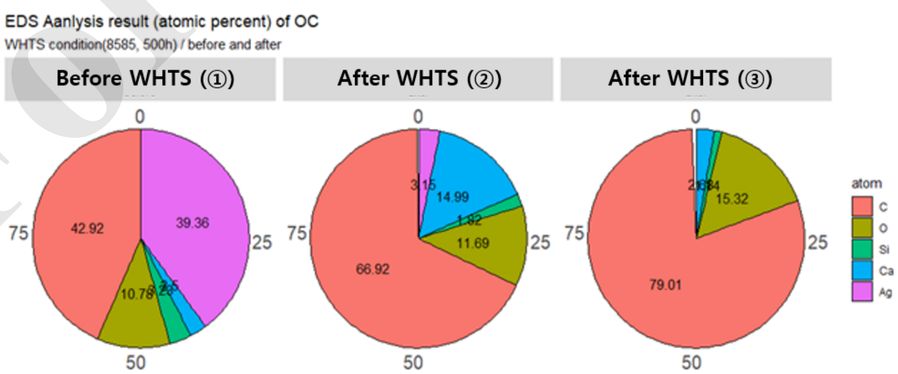
cross-section of the black OCs before reliability evaluation. It can be seen that the polymer with CaCO3 and SiO2 fillers inserted between the black OCs is well cured. However, after the hot and humid reliability evaluation, the black OCs formed a bilayer, as shown in Figure 5(b). The inner layer shows the two fillers similar to the state before reliability evaluation, while the outer layer shows no fillers and only the polymer layer. It is assumed that SiO2 and CaCO3 are formed in black OC in a high temperature and high humidity environment, similar to the formation of a double layer in cement and pozzolanic reactions. The outer layer is mainly composed of newly formed calcium silicate hydrate (C-S-H) and other secondary reaction products, which play an important role in increasing the durability of cement. The inner double layer contains cement particles that have not yet reacted with the initial hydration products, and despite their lack of reactivity, these particles contribute significantly to the internal strength and density of the concrete.



(a) (b)

Figure 5. FIB-SEM image before (a) and after (b) WHTS reliability evaluation

Figure 6 shows the atomic percent of the components of Black OC before and after WHTS in Figure 5 through EDS analysis. Figure 6(a) shows that the composition of Black OC before reliability is comprised of C of the polymer component, Si of SiO2, and Ca of CaCO3, and shows that the Ag component of the Ag paste has migrated. After the WHTS reliability evaluation, it can be seen that Black OC has a double layer, and a large amount of C component of polymer and Ca component of CaCO3 are detected in the inner layer, while almost no Ca component is detected in the outer layer. It is presumed that this double layer is what strengthens the durability of Black OC and increases adhesion.



(a) (b) (c)

Figure 6. EDS analysis data of Black OC before and after WHTS

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4. CONCLUSION

A final verification experiment was conducted to improve the interface adhesion between Ag paste and Black OC to complete the micro LED side wiring process and material method. Ag paste was made with and without silane coupling agent (C.A.), and a total of 4 samples were made by printing Black OC with and without $CaCO_3$ filler on the printed samples. Then, a peeling test was performed with 3M tape after 168 hours after putting the sample in a high-temperature, high-humidity storage of 85°C and 85%. Table 2 shows the types of samples.

Table 2. Scratch test result after evaluation of high temperature and humidity for each sample

No.	Sample	Peeling Result
1	Ag paste + OC	3/3
2	Ag paste with 1.5wt% C.A. + OC	3/3
3	Ag paste + OC with 15wt% CaCO3	1/3
4	Ag paste with 1.5wt% C.A. +OC with 15wt% CaCO3	0/3

In this paper, we described the development of materials and process technology for forming the side wiring of Micro LED using Ag paste and Black OC pad printing method. Ag paste and Black OC were formed on the side of the glass, and in order to have durability in a high-temperature, high-humidity environment, material tuning was required to increase adhesion. Ag paste was improved by adding adhesion promoter, and Black OC was improved by adding $CaCO_3$, which can cause cementation reaction. Through this study, the core technology of micro LED tiled display, wrap-around electrodes and Black OC material and process technology was newly developed. Through this, it is thought that there is a possibility of pioneering the ultra-large premium TV market of 100 inches or more in the future.

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