Process Window of Mini-LED Display Panel Packaging using Laser Assisted Bonding Technology

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Abstract

For high-resolution display panels using mini-LEDs, high alignment accuracy and high yield of LED transfer and bonding technology are very important parameters of packaging technologies. These parameters of packaging technologies are highly dependent on the interconnection material and bonding process. The use of laser assisted bonding (LAB) technology and epoxy-based interconnection materials has been introduced in mini-LED display panel packaging to improve bonding accuracy and yield. The bonding process of the entire display panel was performed by a tiling SITRAB process because the laser irradiation area is smaller than the LED bonding area on the substrate. For the SITRAB process, an epoxy-based SITRAB material to remove oxide on the surface of solder bump has been developed as a solvent free material. For good wetting of the solder bump during the SITRAB process, the temperature of the solder bumps must be higher than the melting temperature of solder. In general, the stage temperature of the laser process is determined to be around 100 °C in order to minimize the laser power. However, if the stage temperature is high, the initial properties of the SITRAB material (such as low viscosity and deoxidation function) may be lost due to the high temperature. In this study, the process window of the SITRAB material was determined for a stable SITRAB process. The process window was identified according to three different pot lifes: room temperature pot life (RPL), stage pot life (SPL), and laser pot life (LPL).

Key words: simultaneous transfer and bonding, process window, room temperature pot life (RPL), stage pot life I(SPL), laser pot life (LPL), mini LED

Introduction

For high-resolution and high-brightness displays, mini- and micro-LEDs are attracting attention for large-area TV, laptop notebooks, smartphones, automotive head-up displays, virtual reality and augmented reality. The world's first micro-LED display was introduced by Sony at 2012 Consummer Electonics Show (CES), and Samsung demonstrated the world's first spliced 146-inch micro-LED TV, called "the Wall" in 2018 [1]. A 4K full color TV display is known to include 24,883,200 (3840 x 2160 x 3) LEDs. If the device bonding yield of a 4K display panel is 99.99%, there will still be 2,488 damaged pixels to be repaired. The yield and manufacturing cost are meanwhile highly dependent on the LED transfer and bonding technology. For high yield of mini- and micro-LED transfer and bonding, a new technology called "SITRAB" was introduced in SID 2021 [2]. Figure 1 shows a schematic of the simultaneous transfer and bonding (SITRAB) process. First, SITRAB paste or film is deposited on the display panel substrate through screen printing or dispensing or film lamination processes at room temperature. The SITRAB paste and film consist of epoxy as a base resin, a reductant to remove oxide on the surface of solder bumps, a curing agent, a catalyst to control the rate of chemical reaction, and some addictives to optimize processability. The top surface of the mini- or micro- LED is aligned to the sticky PDMS on the glass interposer with a constant area in the form of an n x n matrix as shown in Figure 1(b). The glass interposer with LEDs held by a quartz chuck is aligned with the display panel substrate. After alignment between the LEDs and the display panel substrate, the solder bumps under the LEDs move down and contact the display panel substrate. An areal laser is then irradiated for a few seconds through a transparent quartz and glass interposer with PDMS, as shown in Figure 1(c). After penetrating the quartz and glass interposer with PDMS, the laser reaches the nontranspaent metal pad and solder bumps below the LEDs, and solder bumps and adjacent SITRAB material are heated to the melting temperature of the solder bumps. When the temperagture reachs the melting temperature of solder, the oxide on the solder surface is removed by the activated SITRAB material, and solder bumps are wetted to the metal pads on the display panel substrate. The LEDs are then separated from the PDMS of the glass interposer because the bonding strength of solder between the LEDs and the metal pads of the display panel substrate is greater than the sticky bonding strength between the LEDs and PDMS, as shown in Figure 1(d).

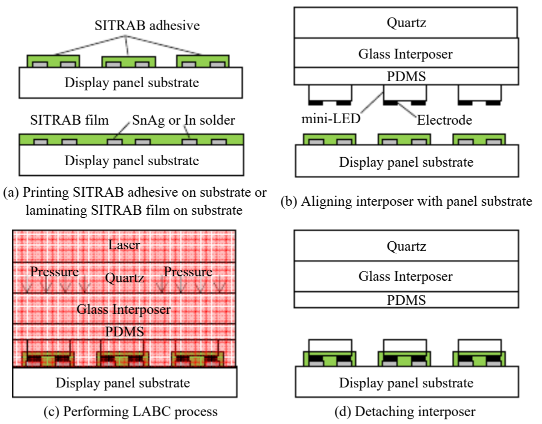


Figure 1: Schematic of SITRAB process [2]

In Figure 1(c), the display panel substrate is placed on a metal stage for the SITRAB process. The temperature of the metal stage is maintained at 80 ~ 100 °C to minimize laser power during the SITRAB process. Therefore, the epoxy-based SITRAB material must remain in a stable state without chemical reaction at a given stage temperature during the alignment process between the LEDs and the substrate. If the total area of the display panel is larger than the laser irradiation area, the SITRAB process for LED bonding must be repeatedly performed through tiling or laser line scanning processes. As shown in Figure 2, if there are three kinds of glass interposers performed with red, green, and blue LEDs, respectively, the SITRAB material is exposed three times in three SITRAB processes. Therefore, the SITRAB material can be exposed a maimum of six times by the SITRAB process due to the three different interposer applications and the tiling SITRAB process.

Table 1 shows three pot life definitions of SITRAB materials for the SITRAB process. Room temperature pot life (RPL) is determined by the time it takes for the SITRAB paste to reach 1.2 times its initial viscosity at 25 °C. Stage pot life (SPL) is defined as the time that the SITRAB paste can remain without undergoing a chemical reaction at a given stage temperature, such as 80, 90, and 100 °C. After the SPL time, the chemical performance of SITRAB paste is demonstrated by solder wetting tests. As illustrated in Figure 2, the SITRAB paste placed on a substrate with a given temperature of stage allows up to six laser irradiations due to the three interposers and the tiling process. Therefore, laser pot fife (LPL) is defined as the number of times that laser is irradiated to the SITRAB paste at a given temperature of stage. After LPL, the SITRAB material is evaluated with solder wetting tests. In the current research, the RPL, SPL, and LPL of SITRAB paste are studied according to chemo-rheologically properties.

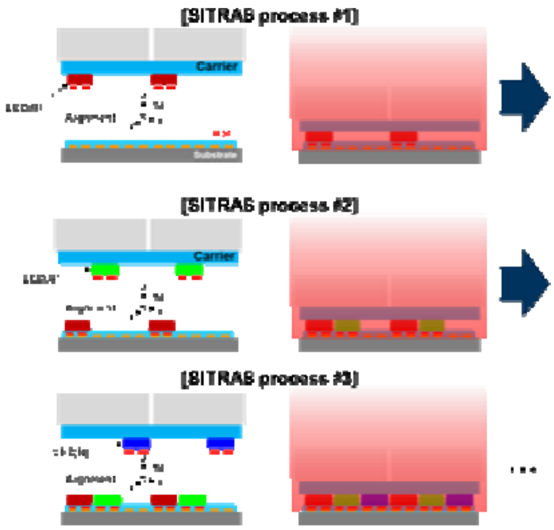


Figure 2: Schematic diagram of SITRAB process with three types of interposers [3]

Table 1: Definition of three different pot lifes of SITRAB material for SITRAB process

Items	Abbre viation	Environmental Temperature	Requirement
Room Temp. Pot Life	RPL	25°C	1.2 x Initial viscosity
Stage Pot Life	SPL	80, 90, 100°C	Solder wetting
Laser Pot Life	LPL	Laser Irradiations on 25, 80, 100°C Stage	Solder wetting

Materials and Experiment

Two types of SITRAB paste are prepared. One is the SITRAB paste with a viscosity of 37,000 cPs at 25 ℃ and 10 rpm. In Figure 1, if the solder bump is fabricated on the substrate, the SITRAB paste can chemically react by the catalytic activity of SAC305 solder [4]. The other material is SITRAB paste mixed with 1 wt.% SAC305 type 7 powder. When the solder bump is fabricated on the display panel, the surface area of the solder bumps of one pixel including three types of LEDs is similar to that of 1 wt.% type 7 solder.

The viscosity of SITRAB paste was measured at 25 °C and 10 rpm using high viscometer (BrookField Ltd.) for RPL. For SPL, the SITRAB paste was installed between a circular parlllel plate with a diameter of 20 mm. Its viscosity was measured at 1 Hz and a given temperature of stage, such as 80, 90, and 100 °C, using a rheometer (HAAKE, Mars 3). To evaluate solder wetting performance, after the SPL, a solder ball with a diameter of 0.5 mm was put into the SITRAB paste on a Cu plate, heated to 240 °C at a heating rate of 120 °C/min, and held for 10 minutes. To simulate the LPL, the SITRAB pastes placed on a silicon substrate was irradiated with an areal laser up to six times at 5-minute intervals at a given temperature of stage. After laser irradiations (LPL), the uncured glass transition temperature, conversion, and solder wetting performance were observed.

Results and Discussion

The viscosity and thixotropy index changes of the SITRAB paste were measured for six days at 25 °C, 10 rpm as shown in Figure 3. The initial viscosity and thixotropy index ere 37,000 cPs and 1.4, respectively, and the room temperature pot life (RPL) was six days, because the viscosity was increased to 1.2 times of its initial viscosity after six days.

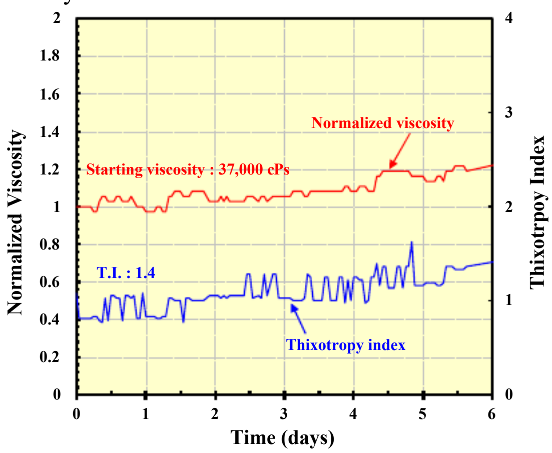


Figure 3: Measured room temperature pot life (RPL) of SITRAB paste.

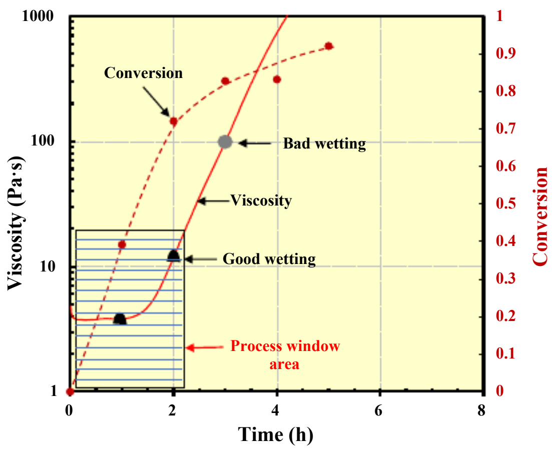


Figure 4: Satge pot life (SPL) of SITRAB paste at the stage temperature of 100 °C.

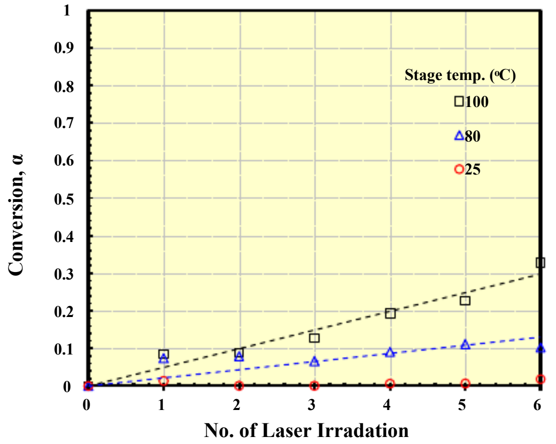
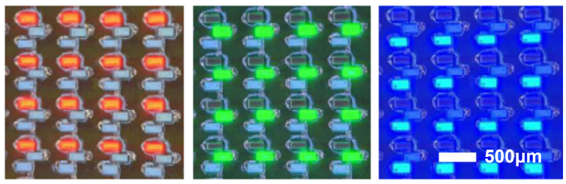


Figure 5: Laser pot life (LPL) of SITRAB paste at given stage temperatures.

(a)



(b)

Figure 6: Fabricated full-color mini-LED display on flexible panel: (a) 64 x 64 color, and pixel pitch 0.576 mm display with mini-LED, (b) bonded red, green and blue LED by process window of SITRAB paste.

For stage pot life (SPL) of the SITRAB paste at a stage temperature of 100 °C, the viscosity, conversion, and solder wetting were measured. Good solder wetting was observed up to 2 hours, the conversion and viscosity of the SITRAB paste were approximately 0.7 and 20 Pa·s after two hours at 100 ℃ stage temperature, as shown in Figure 4. Thus, it was clearly shown that the process window for 100 °C SPL was two hours. Figure 5 shows the conversion changes with anincreasing number of laser irradiations at the stage temperature of 80, 90, 100 °C. After six iterations of laser irradiation at a stage temperature of 100 °C, the conversion of the

SITRAB paste was about 0.33, which was lower than the conversion after two hours at SPL in Figure 4. Therefore, it was observed that the process window of 100 ºC LPL was higher than six iterations of laser irradiations.

Figure 6(a) shows a full-color mini-LED display fabricated with a 64 x 64 pixel array with 0.576 mm pixel pitch. The SITRAB bonding process using red, green and blue interposers are performed sequentially in the process window of SITRAB paste. In addition, the tiling SITRAB process was applied because the laser irradiation area was smaller than that of the display panel.

Conclusion

For mini- and micro-LED display panel packaging applications, a new SITRAB paste and process were introduced. An epoxy based SITRAB paste was developed for adoption in the SITRAB process using area laser irradiation at high stage temperatures. The process window of the SITRAB material was defined according to room temperarture pot life (RPL), stage pot life (SPL), and laser pot life (LPL). A full-color mini LED 64 x 64 pixel array display panel was successfully fabricated according to the process window of the tiling SITRAB process.

Acknowledgements

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