

# Anisotropic Solder Paste (ASP) Material Solution for Laser Assisted Bonding (LAB) Process

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**Abstract**—Anisotropic conductive paste (ACP) or anisotropic conductive film (ACF) consisting of a polymer matrix and a metal-coated polymer bead are introduced as interconnection materials in mini-LED display panel packaging through a thermal compression bonding process. However, this packaging solution has been leading to important problems such as alignment difficulties due to high bonding temperature and pressure, and its repair issues for bad LED devices after the bonding process. Recently, laser-assisted bonding (LAB) process for mini-LED display packaging has been introduced to solve these problems[Ref. 1-2]. This study introduces, an anisotropic solder paste (ASP) using conductive solder particles and applies it to the mini-LED packaging through the LAB process.

**Keywords**— Anisotropic Solder Paste (ASP), Anisotropic Conductive Film (ACF), Laser Assisted Bonding (LAB), mini LED

## I. INTRODUCTION

Recently, there has been a growing demand for chips and high-resolution packages such as Mini and Micro LED displays. Therefore, the number of I/O(Input/Output) is increasing and the pattern pitch needs to decrease. Anisotropic conductive paste (ACP) or anisotropic conductive film (ACF) are generally used for electrical interconnection between metal pads of the upper and bottom substrates, as the high density interconnection materials, and the conductive adhesives have many advantages such as fine pitch. There are generally used for chip on glass (COG) and chip on flex (COF) packaging technologies[Ref. 3-8].

However, the transfer method and bonding technology of Mini & Micro LED devices to substrates still has many challenges like lack of productivity, high bonding force and high electrical resistance by ACP interconnection. Anisotropic Solder Paste (ASP) material for Laser Assisted Bonding (LAB) technology may be an excellent solution to

high bonding pressure and electrical resistance. Also, a LAB process using ASP material can prevent electrical short by controlling solder volume and polymer bead size.

This study newly introduced ASP using conductive solder particles and applied it to the mini-LED packaging through the LAB process which was developed for good electrical interconnection and low bonding pressure.

## II. MATERIALS AND EXPERIMENT

### A. Anisotropic Solder Paste (ASP)

The resin of Anisotropic Solder Paste (ASP) consists of an epoxy-based solvent free resin, solder particles for electrical interconnection, and non-conductive polymer beads(spacer) for the standoff height of solder joints between the device and the substrate. The base resin was composed of an epoxy, a reductant to remove oxide from the metal surfaces, curing agent and catalyst for controlling the chemical reaction. A residue removal process of thermosetting based resin was not necessary because unreacted chemical components did not remain after the bonding process[Ref. 9]. We developed a novel ASP material for fine pattern pitch using solder particles with a Sn/58Bi type6 size and 2vol.% of polymer beads with a 10 $\mu$ m diameter. ASP material was placed between the metal pads of the device and the substrate, and the bond process was performed. The viscosity of the ASP with a 6%vol. of solder particles was 130,000 cPs@10rpm at Room Temperature in a Brookfield viscometer. Since it did not depend on the ASP pattern size and pitch, both dispensing and screen printing processes had the advantage of being easy.

### B. Laser Assisted Bonding (LAB) Process

The traditional flip chip bonding thermal compression bonding (TCB) technology with a long process time and a substrate fully heat path process can warpage of flexible substrates. The Laser-Assisted Bonding (LAB) is next

generation flip chip bonding technology that can avoid warpage of flexible substrates by controlling the temperature

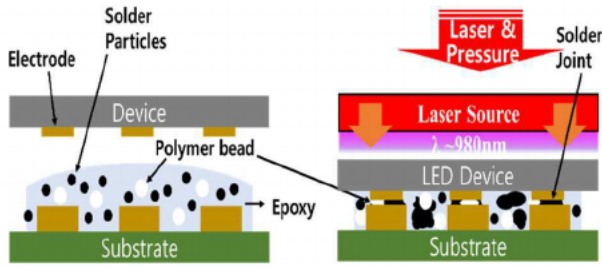


Figure 1. Schematics diagram of ASP material solution for LAB Process

and time of the bonding process.

Figure 1 shows a schematics diagram of the LAB process with ASP. ASP printing on substrate was applied by a dispensing method. The device of the upper and bottom substrates were aligned, pressured with a quartz head, and laser irradiated. The heating mechanism of the LAB process was based on the laser absorption of a device with in 980nm wavelength homogenized laser beam. The ASP consisted of a solvent-free resin, solder particles for electrical interconnection, and non-conductive polymer beads for the stand-off height of the solder joints between the device and the substrate. After the LAB process, we observed that the interconnection was completely achieved by the solder wetting between the device and the bottom metal pads. The post curing process was 120°C for two hours in a convection oven after the LAB process.

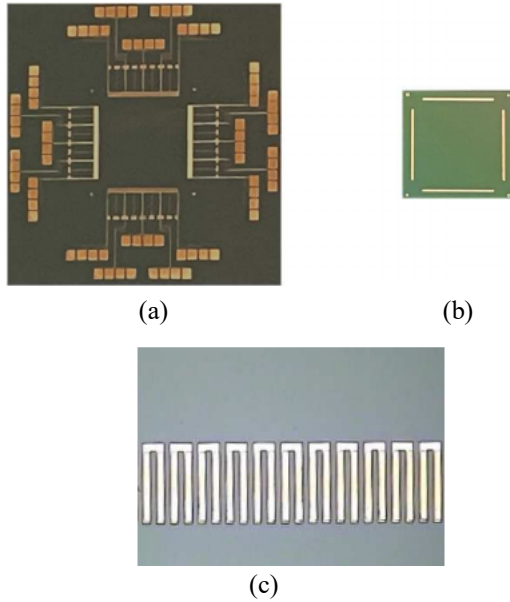


Figure 2. Pictures of Si test vehicles (a) Si substrate and (b) Si device of a 40μm PAD pitch

### III. RESULTS AND DISCUSSION

The chemo-rheological properties of ASP were measured using rheometer and differential scanning calorimetry (DSC).

For the rheometer measurement, the ASP material was placed between parallel plates with a 20mm diameter gap into and 1 mm thickness. The applied frequency and heating rate were 1 Hz and 10°C/min, respectively.

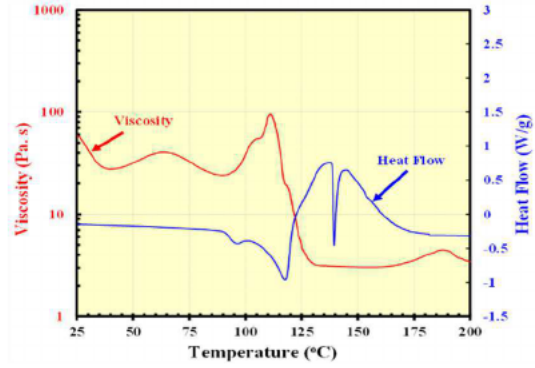


Figure 3. Viscosity and heat flow of ASP with a heating rate up 10°C/min

The measured viscosity and heat flow by DSC and Rheometer are shown in Figure 3, where the red line indicates the viscosity and the blue line indicates the heat flow as the temperature increases. An exothermic peak is observed around 135°C, indicating an exothermic reaction caused by chemical reaction. The endothermic peak observed at around 139°C refers to the melting of Sn/58Bi solder. The viscosity was maintained while the chemical reaction was in progress and the viscosity gradually increased from 170°C near the end point of the chemical reaction. As a result of the viscosity and heat flow, it was observed that the processability characteristics were retained because enough low-viscosity of ASP viscosity with 3Pa.s at the process temperature (melting point of solder).

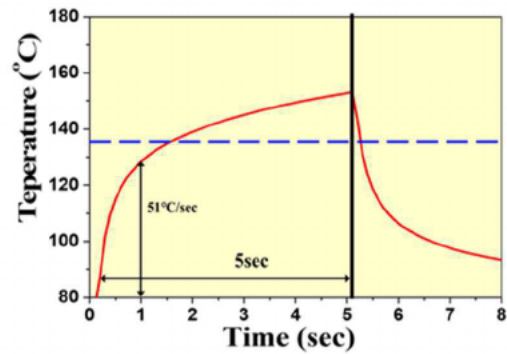


Figure 4. Temperature vs. Laser Irradiation time Curve

The LAB process was performed by a demonstrated with a homogenized laser power of 200W for 5 seconds irradiation to the chip using a wavelength of 980nm at a stage temperature of 80°C. To measure the process temperature during the laser irradiation, a thermo-couple was placed between the device to the substrate. Figure 4 shows the process temperature profile measured using the thermo-couple which was over the melting temperature of the solder when laser irradiation at 200W for 5sec. At this time, the measured heating rate maximum, that is 51°C/sec.

The Scanning electron microscope (SEM) image in figure 5 is of a conductive polymer bead trapped between the electrodes, and the remainder of the gap is filled with resin. A

sample for cross-section observation was produced by polishing process the bonded sample. The interconnection, polymer bead shape and solder joint analysis of the polished cross-section of the composite was observed using SEM.

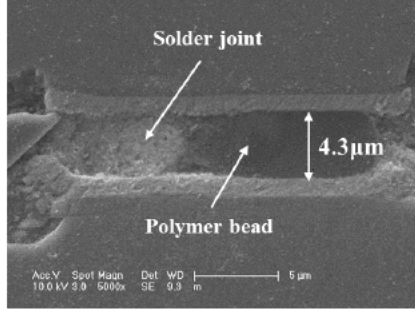


Figure 5. Cross-Sectional SEM image of the device on a bonded substrate

The solder joint area in this case refers to an electrical contact area that forms an electrical path from the device to the substrate electrode pads. The interconnections were partially contacted by melted volume content 6% of Type-6 solder particles. In this study, the optimized composition was 6 vol.% of solder type-6 particle size and 2 vol.% of polymer beads with a diameter of 10  $\mu\text{m}$ . If there is a difference in volume ratio or size of the solder particles and polymer beads, the electrical interconnection to open or short expected. After the LAB process, we observed that the interconnection was completely achieved by the solder wetting between the device and bottom metal pads. A Bonding Line Thickness(BLT) of 4.3 $\mu\text{m}$  was observed after the LAB process with 5sec at 200W with a bonding force of 0.41 Mpa. Since the 10 $\mu\text{m}$  diameter polymer bead was compressed by pressure, it became a constant gap of 4.3 $\mu\text{m}$ . The ASP material composition for LAB optimized the non-conductive polymer bead and solder particle size and LAB process pressure. The electrical interconnections were also optimized by size and volume of polymer beads and solder particles. The solder particles formed electrical connections, while the polymer beads achieved uniform dispersion of the solder particles and prevented electrical shorts.

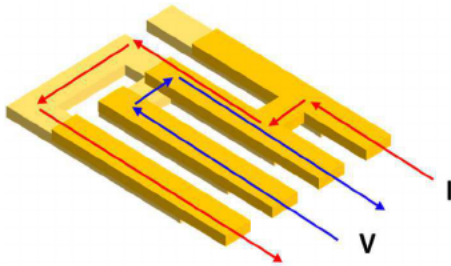


Figure 6. Schematic circuit to measure the electrical resistance by ASP interconnection using the four-point probe method

The electrical resistance by ASP interconnection was measured by employing the four-point probe method and configuring the circuit according to the schematic shown in Figure 6.

ACF is metal-coated conductive particles form mechanical contacts, which creates a relatively small electrical path compared to solder joints, so it has a higher electrical

resistance. As shown in Table 1, the ASP and ACF process bonding force was 0.18MPa and 3.27MPa, and ASP was about 18 times less than the ACF. The ASP needed a low bonding force because lowering the viscosity and forming electrical contact while the solder particles melt. On the other hand, ACF requires a high bonding force as it contacts the metal-coated conductive beads.

| Material                                                                      | ASP                    | ACF                  |
|-------------------------------------------------------------------------------|------------------------|----------------------|
| Conductive particle                                                           | SnBi Solder Type-6     | Au/Ni coated polymer |
| Polymer bead size [ $\mu\text{m}$ ]                                           | 10                     | 10                   |
| Electrode pattern (W x L) [mm]                                                | 0.02 x 0.2             | 0.125 x 3.0          |
| Bonding force [MPa]                                                           | 0.18 (~ 18 times less) | 3.27                 |
| Gap between device and sub. [ $\mu\text{m}$ ]                                 | 4.3                    | 5.91                 |
| Electrical resistance by ASP interconnection [ $\text{m}\Omega/\text{mm}^2$ ] | 62.5 (~ 4 times less)  | 289                  |

Table 1. Comparison of bonding process conditions and results of ASP and ACF [Ref. 10].

After the bonding process of the ASP and ACF test vehicles, the electrical resistance of each test vehicle was measured by a four-point probe method. The electrical resistances of the ASP and ACF were each 62.5  $\text{m}\Omega/\text{mm}^2$  and 289  $\text{m}\Omega/\text{mm}^2$ , respectively. The electrical resistance of the ACF is about 4-times higher than that of the ASP because of the small electrical path.

#### IV. CONCLUSION

The chemical reaction during processing was analyzed using Differential Scanning Calorimetry (DSC). A novel Anisotropic Solder Paste (ASP) consists of a solvent-free resin, solder particles for the electrical interconnection, and non-conductive polymer beads for the stand-off height of the solder joints between the device and the substrate. The Laser Assisted Bonding Compression (LABC) process was successfully demonstrated with a laser power of 200W for 5 seconds applied to a chip using a wavelength of 980nm with a homogenized laser beam. The post curing process for the ASP was carried out at 120°C for 120min and was optimized by controlling the isothermal processing temperature. Moreover, ASP can be observed that the array patterns are interconnected without electrical shorts. The epoxy-based resin in the ASP is expected to be an underfill between the device and the substrate to improve the bonding shear strength. Also, since the solder joint forms the electrical connection, it has a lower electrical resistance by the interconnection and the advantage of a low bonding pressure. According to our experimental results, we believe that ASP for LAB will greatly influence the commercialization of Micro/Mini LED display packaging.

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