FLIP CHIP LED SOLDER ASSEMBLY

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ABSTRACT
Flip-Chip and Chip Scale Package (CSP) Light Emitting Diodes (LEDs) are being increasingly adopted for applications in TV backlight and mobile flash. Lately they are also being used for automotive interior, street lighting and even and general lighting applications. The advantages of very small form factor, easier optics, improved thermal dissipation and no wire-bond result in unrivaled high lumen density at lower cost.

Eutectic gold tin (AuSn 80/20) is the die attach material of choice for flip-chip LEDS. Lately, there has been a significant effort to make these devices compatible with SMT. However, SMT assembly of these small packages is challenging. Package float and tilt can result in sub-par assembly yields.

In this study, a pin transfer (also called stamping) process was adapted to assemble flip-chip CSP LEDs with fine pitch solder paste. Pin transfer or stamping is a popular method to assemble small lateral and vertical LEDs on flat substrates. However flip-chip LEDs are tricky because of their rectangular interconnect pads with small gaps (that are increasingly getting smaller).

In this presentation we will present the findings of this flip-chip assembly process development by the pin transfer process. Solder reservoir height and die attach conditions were varied to optimize solder spread, voiding and die shear for commercial flip-chip CSPs. Also preliminary results on the effect of cleaning of LEDs (after assembly) on light output and color are also presented.

This study is relevant for LED packaging and LED module assembly makers who use flip chip for automotive, backlight and general lighting applications.

Key words: LED, Die Packaging, Die Attach, Flip chip, Solder, SMT, Pin Transfer, Cleaning

LED CHIP STRUCTURES
There are three main LED chip structures (Figure 1). The **Lateral structure** consists of laterally spaced electrodes (with one wire-bond for each electrode) and is used in low power applications. The **Vertical structure**, used for most of the high and super-high power applications, consists of a conductive substrate at the bottom which forms the bottom electrode with the current flowing vertically. The **Flip-Chip structure** has both electrodes on one side and is put face down on the substrate. It provides the highest lumen density at cost lower than vertical structure. Any of these three structures can also be mounted directly on a board, next to each other, to form **Chip-on-Board** (CoB) modules.

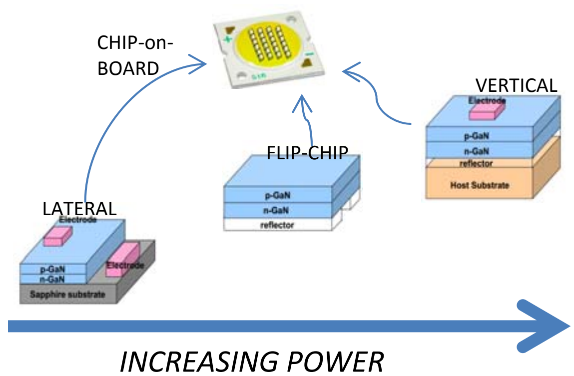


Figure 1: Common LED structures

FLIP CHIP and CHIP SCALE PACKAGE LEDS
The high lumen density (and low lumen/$) advantage of the Flip-Chip LED structure (as mentioned above) essentially stems from replacement of the wire-bonds by relatively large area contacts that serve as both electrical and thermal pads. The improvement in heat dissipation allows the chip to be driven at high currents without the need for expensive highly conductive substrate (like CuW) – which, along with reduced defects from the absence of the wire-bonds, extends the lifetime. The small form factor (and flat wire-bond free surface) also makes optical design much easier – thereby reducing the cost even further.

Lately there has been a concerted effort by most LED makers to use the flip-chip structure to make a chip-scale package (CSP) with the foot print very close to the flip-chip pads compatible with solder (and SMT process) – especially for COB applications. The idea is to put the solder compatible pads (and sometimes even interconnects) at the wafer-level. The chips can then be picked and placed by either a high precision die bonder (with solder printed on substrate pads), or preferably, by a regular pick-place machine (also sometimes called a chip shooter) on the SMT line.

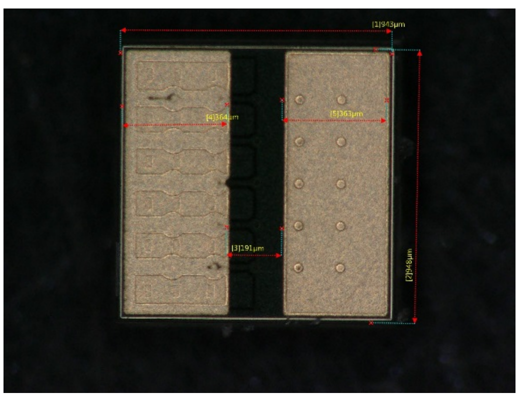
The SMT option is very attractive for several reasons. While it adds one step at the back-end (solder pads), it skips the traditional packaging (die attach on a sub-mount substrate and wire-bonding) step completely. As a result the module makers can buy the CSPs and assemble them directly on SMT lines (cheaper equipment with higher throughput).

EXPERIMENTAL

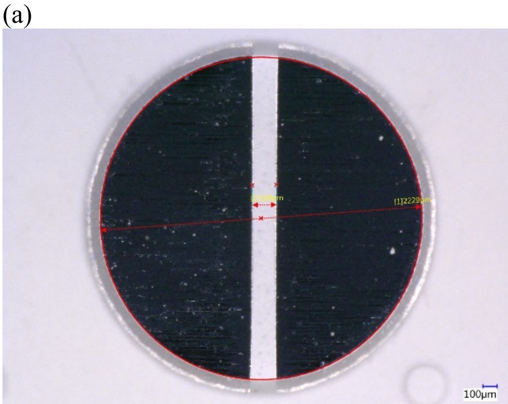
In this study, a pin transfer process was adapted to assemble commercially available flip-chip LEDs with solder.

Pin transfer (also called stamping) consists of using a pin (or a set of pins configured to match the foot print of the die) to stamp the solder off a reservoir on to the substrate. The die is then aligned and placed on the substrate (with the solder stamp) and then reflowed. Pin transfer is very popular for both lateral (mesa) and vertical LED die attach since it is a very high throughput process (up to 15K units per hour) and is SMT compatible. The thin bond line (5-10 um typically) ensures lower thermal resistance compared to conventional printing. Finally it also allows assembly with cavity packages which normally require use of a 3-D stencil.

An ASM pin transfer die bonder ASMD838L was used for the pin transfer with a no-clean solder paste. Commercially available UV flip-chip dies (from Lumileds) were assembled on custom designed silver finish lead frames. A Heller 7-stage reflow oven was used to reflow the assemblies. The flip-chip die pads and the substrate pad are shown in Figure 2, while the reflow profile used is shown in Figure 3.



(a)



(b)

Figure 2: (a) Flip-chip die pad and (b) Gap between substrate pads

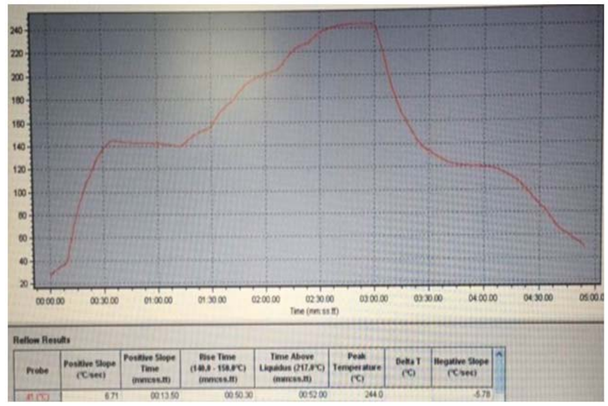


Figure 3: Reflow profile used

First the pin transfer stability of solder paste was studied over a typical 8-hour work shift with 1x1 mm dummy silicon dies (Cr/Ni/Au finish) on FR4 substrate. The Paste volume transfer (which translates into bond line thickness control), die shear and die shear failure mode were recorded over 8 hours.

Next the flip-chip dies were assembled on the substrate. Pin transfer reservoir height was varied and fillet size, voiding and die shear were recorded.

The assembled parts were cleaned via in-line and ultrasonic batch cleaning stations at 60C by Zestron Inc. with different cleaning chemistries. The cleaned and un-cleaned parts were characterized for radiant flux before and after aging (at 150C for 1000 hours). Preliminary, pre-aging results are discussed in this paper.

Flip-chip parts were also assembled by printing solder paste on substrates and placing flip-chip dies (from Lumileds) by Datacon bonder (model EVO220). Both water soluble and no-clean solder pastes were used. This print-place process is essentially identical to the traditional SMT process (with the exception of the use of the more accurate bonder instead of the pick-place / chip-shooter) and its results are not included or discussed in this paper.

RESULTS

The pin transfer volume stability for solder paste shown in Figure 4. As can be the seen the variation in the volume over 8 hours is maximum 15% (difference between maximum and minimum volumes deposited at 1 hour intervals over 8 hours). This translates into ~2 micron variation in bond-line-thickness (BLT) over 8 hours – which meets the spec for almost all applications (see Figure 5 for the measured BLT variation).

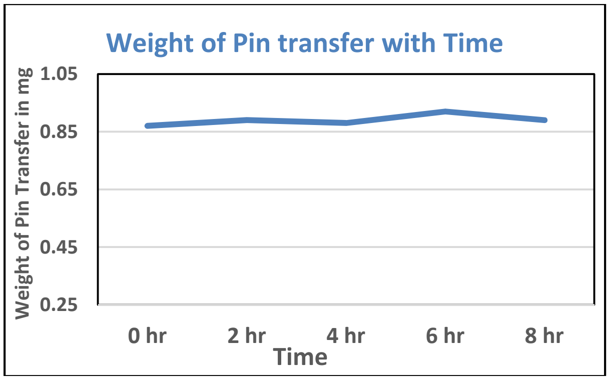


Figure 4: Solder weight variation over time during 8-hour pin transfer over 8-hours

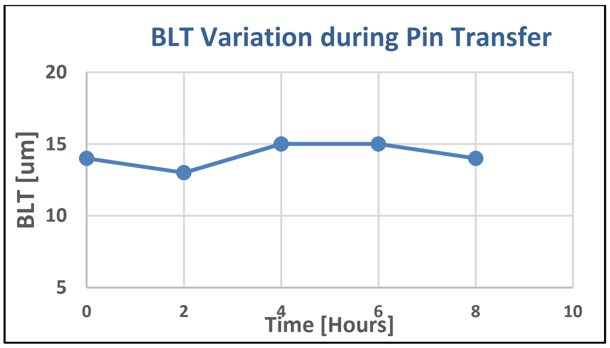


Figure 5: Bond line thickness variation over 8 hours

The reservoir thickness optimization results are discussed next. The bond force had to be kept at the lower end of the bonder range (30-50 grams) to prevent excess squeeze out while the bonding time was kept as short as possible to ensure high throughput as well as to minimize the paste squeeze out. Hence, the reservoir thickness optimization becomes a key to ensure that there is no bridging between the p & n pads while at the same time there is enough solder volume for adequate die shear strength. Flip-chip LED's active light emitting areas are close to the bottom of the die and it is important to ensure that the interconnect material (solder in this case) does not block the light from these active regions. For this reason the interconnect material and any residue associated with this material should not spread beyond the solder pads.

Figure 6 shows the transferred solder paste squeeze out after die placement and x-ray of the die-substrate assemblies at different reservoir heights before solder reflow. The assemblies after reflow are shown in Figure 7. It is important to note that for all reservoir heights the solder squeeze out in-between the die pads was contained and there was absolutely no bridging (as clearly seen in x-ray shots).

At the lowest reservoir height (200 um), the volume of solder transferred was inadequate to cover the entire pad area and did not coalesce to form a uniform interconnect layer between the die and the substrate. The distinct circular deposits of wet solder can be seen both before and after reflow. For 300 um height setting, the paste did coalesce, however, the spread around the pad was non-uniform.

On the other end, higher reservoir heights (600-700 um), resulted in excessive volume transfer and excessive spread around the pad that may block edge light emitting regions (or block the reflective pad on the substrate thereby indirectly reducing the light extracted).

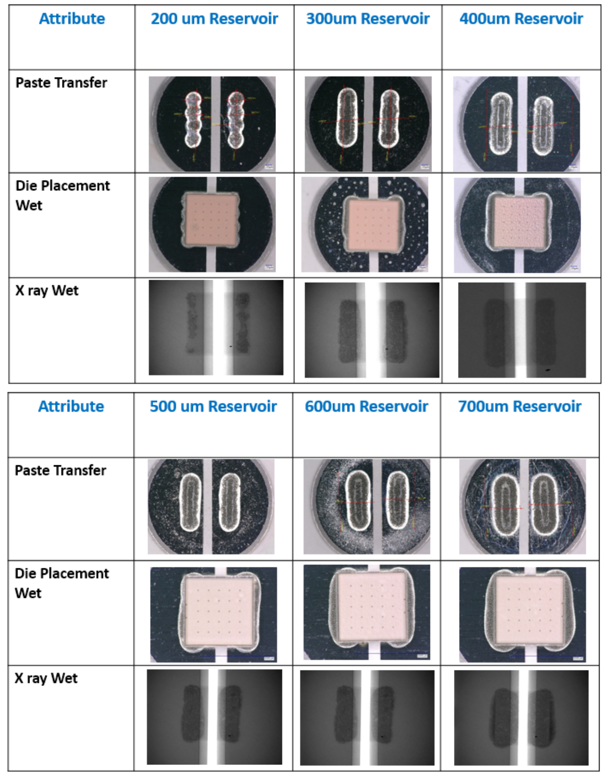


Figure 6: Pin transferred solder and squeeze out after die placement (wet) before reflow

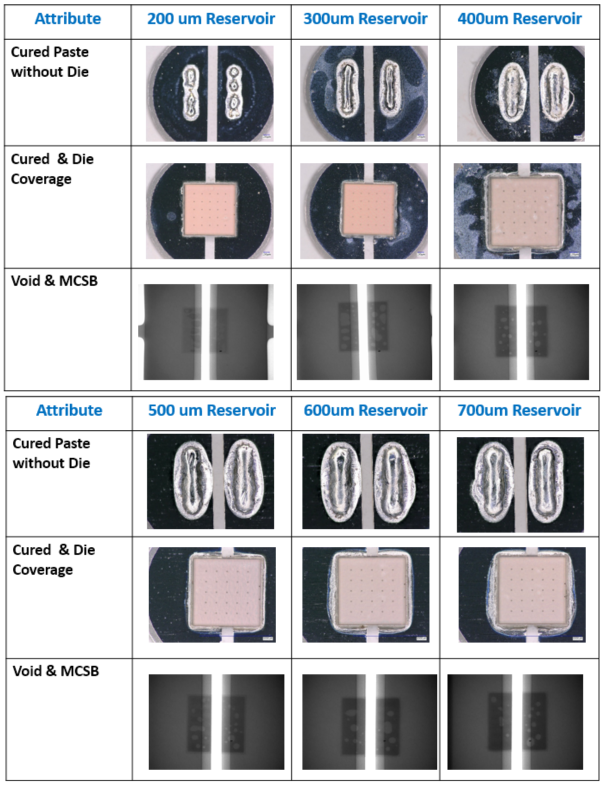


Figure 7: Solder coalescence and fillet at different reservoir heights

The volume of transferred solder also results in different levels of die shear and voiding. Excessive solder (from a thick reservoir height), although not desirable for active light emission, does help reduce the voiding and increase the die shear strength. The low volume transfer (off the lower reservoir heights, especially 200-300 um) resulted in higher voiding and lowest die shear.

Table 1 summarizes the process outputs like die shear, voiding, fillet, coalescence, mid-chip solder balling etc. as a function of reservoir height. Figure 8 shows a plot of the die shear as a function of the reservoir height.

Table 1: Process output variation versus paste reservoir height.

Attribute	200 um Reservoir	300um Reservoir	400um Reservoir
Die Placement Wet	No squeeze out	Little / inconsistent Squeeze out	Minor squeeze out
Cured Paste without Die	No proper Coalescence	Good coalescence	Good coalescence. Optimal paste volume
MCSB	No	No	No
Coverage	90%	100%	100%
Cured Die	No Fillets	Inconsistent Fillet	Uniform Fillet
Void	Very High	~ 20%	10-20%
Die Shear	1.5 kg	2.5 kg	4 kg

Attribute	500 um Reservoir	600um Reservoir	700um Reservoir
Die Placement Wet	~ 60 um squeeze out	80 – 120 um squeeze out	80 – 120 um squeeze out
Cured Paste without Die	Good coalescence Optimal paste volume	Good coalescence Excess paste volume	Good coalescence Excess paste volume
MCSB	No	No	No
Coverage	100%	100%	100%
Cured Die	Fillets ~ 60 um	Fillets ~ 80-120 um	Fillets ~ 80-120um
Void	8 to 15%	5 to 12%	5 to 12%
Die Shear	> 4 kg	> 4 kg	> 4 kg

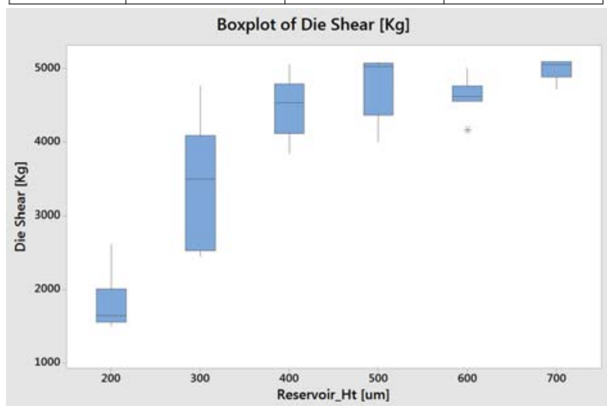


Figure 8: Die shear variation as a function of Reservoir Height

It is important to note that the intermediate reservoir height settings (at 400-500 um) gave the optimal balance between coverage (which impacts die shear and voiding), coalescence and fillet spread.

The effect of cleaning the assemblies on radiant flux is shown in Figure 9. The measurements clearly indicate that radiant flux output is significantly higher for the cleaned assemblies irrespective of the chemistries used. The radiant flux for the best-cleaned assemblies is on the order of 15% higher than the un-cleaned ones.

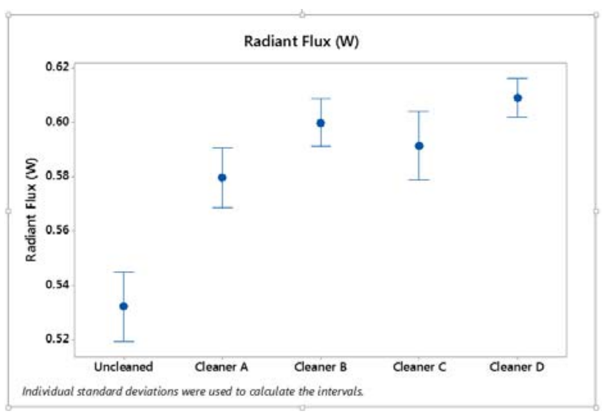


Figure 9: Effect of cleaning (and different chemistries) on radiant flux output

It would be interesting to track the change in radiant flux for these assemblies following high temperature aging at 150°C. Those results will be presented elsewhere.

SUMMARY / CONCLUSION

A pin transfer / stamping process was successfully adapted for high throughput assembly of flip-chip LEDs. The paste volume was optimized to achieve high die-shear, low voiding and minimal spread-out for highest light extraction. Solder paste stability over 8 hours of the stamping / pin transfer process was also demonstrated.

Preliminary functional performance testing of the assembled UV LEDs suggest that cleaning after assembly can have significant positive impact on the radiant flux output.

ACKNOWLEDGEMENTS

The authors appreciate the help of Ravi Parthasarathy and Christine Anderson of Zestron Inc. (located in Manassas, Virginia, USA) towards cleaning of the flip-chip assemblies with different cleaning chemistries on Zestron cleaning equipment.