Innovative Materials for Advanced Ball-Attach Processes for Advanced Packages

Evan Griffith
Indium Corporation
NY, USA
egriffith@indium.com

Sam Lytwynec
Indium Corporation
NY, USA
slytwynec@indium.com

ABSTRACT

In the advanced packaging space, fan-out wafer level packaging (FOWLP) and fan-out panel level packaging (FOPLP) has become a popular packaging technology used in the semiconductor industry due to its many potential advantages (such as cost reduction) when compared to conventional flip-chip packages and other heterogeneously integrated packages. Typically, the last stage of the FOWLP manufacturing flow is the ball-attach or bumping process before package singulation. For the ball-attach process, flux is usually printed, and spheres are dropped onto the flux, then reflowed and cleaned. Due to the warpage of the reconstituted carrier, choosing a flux with appropriate properties is important for improved yields. Different aspects of flux properties will be explored in this paper.

This paper will discuss advantages of advanced ball-attach materials developed to meet the challenges of advanced packaging. First, the compatibility of these ball-attach materials with passivation materials will be discussed, with advanced materials overcoming the inherent CTE mismatch causing warpage. Next, advancements in printability of ball-attach fluxes will be discussed, with long working time being a key attribute in the assembly process. Finally, the wetting of these materials will be discussed, with a particular emphasis on consistent wetting with minimal ball movement on all areas of the package.

Key words: Ball-Attach; flux.

INTRODUCTION

Semiconductor packaging, or semiconductor assembly, in the most basic sense is the assembly process which allows a semiconductor chip to communicate with the outside world and protects that chip from the harmful elements of that outside world. The semiconductor packaging process comprises a variety of assembly technologies that allow an I/O to be electrically connected to the system.

Wire bonding of chips continues to predominate as the lower cost, known reliability, assembly method of choice for legacy devices such as engine control modules for cars. However, since the 1990s, the miniaturization trends in chips and the desire for chips to not only take up less space, but have more connections as well, have led to innovations in design, shifting from QFNs to BGAs and then to more advanced technologies.

These technologies, such as flip-chip, chip scale packaging, and wafer level packaging (both fan-in and, increasingly, fanout) have grown over the years, as the need for higher functionality in smaller spaces continues to push for smaller package sizes, with the silicon die shrinking and thinning, yet increasing as a fraction of the volume of the overall rapidly shrinking package. Packaging solutions like 2.5D and 3D stacking technology are well in development.

BALL-ATTACH FLUX BACKGROUND

Fan-out wafer level packaging (FOWLP) or panel-level packaging is one of the focused areas for ball-attach assembly in heterogeneous integration. Usually, the last process for these packages is the ball-attach, or bumping, process to prepare the package for the next solder interconnection assembly.

Even with different variations of FOWLP process flows, typically flux is printed on the wafer or panel, followed by a ball drop process, reflow, and cleaning, to form the solder bump on the package. Then the wafer will be singulated to form an individual package, and the solder bump will be the solder interconnect to the board or substrate in the subsequent process.

While there are many technical advantages of the FOWLP packaging technology, there are several process challenges with FOWLP as well. One of the key challenges is the warpage of the reconstituted wafer due to the different materials being used causing CTE mismatch. The degree of warpage may affect the subsequent ball-attach or bumping process; hence, an appropriate flux needs to be chosen in order to minimize defects such as missing ball and bridging. Also, many passivation materials have been tested for compatibility with the ball-attach process. If the chosen flux is not compatible with the passivation material, it may cause swelling and delamination on the passivation layer. The passivation layer also influences the residue cleanability. If the passivation is not fully cured or has a rough texture on the surface, it could entrap flux residues and could be harder to clean as well.

A study was conducted in order to simulate the compatibility between the passivation material and flux. Selected ball-attach fluxes were printed on two different types of substrates; both had the same passivation layer, but one had pad openings and the other had no pad openings. The substrates were then reflowed three times using standard reflow conditions to simulate a worst-case scenario. Incompatibility between fluxes and passivation are easier to detect with more flux and multiple reflow cycles. Figure 1 shows an example of incompatibility between the flux and passivation layer. No abnormality was observed during the first reflow. However, after the second reflow onwards, a white ring was observed on the substrate after residue cleaning. The white ring was etched into the substrate; hence, it couldn't be removed with the residue cleaning process.

Figure 1. Compatibility of Fluxes with Passivation Layers

Ball-attach fluxes, in theory, can be formulated with water-wash or no-clean formulations. However, water-wash formulations are the most common since the absence of residue is critical for this process, and the high tackiness provided by water-wash formulations. To achieve a good yield for ball-attach fluxes, typically these formulations need to be halogen-free, achieving minimal leakage under stencil during printing, having a high enough tackiness to hold spheres or die in place without shift or excessive warpage, compatibility with passivation material, no excessive wetting of solder, good joint shear strength, cleanable residue with DI water, and the absence of white residue after cleaning. Certain no-clean fluxes, however, may be an attractive solution for ball-attach applications for a few reasons. First, a no-clean flux would eliminate the cleaning step during the assembly process. However, this is only possible with a flux which naturally leaves minimal and benign residue after the reflow process.

PROJECT STATEMENT

In this paper, several different ball attach fluxes were tested side by side to each other. All of these water-soluble fluxes were evaluated to determine a suitable replacement for a ball-attach flux which had poor wetting at the edges of certain die and occasionally poor cleaning in DI water. Flux printability, slump resistance, transfer efficiency, wetting, and cleanability will be discussed.

A novel no-clean ball attach flux will also be discussed with the same tests being done to simulate this flux as a potential solution for applications where the elimination of the cleaning process may be desired.

BALL-ATTACH FLUX RHEOLOGY

Viscosity

The rheology of the flux is important in several different aspects of how the flux behaves, such as promoting low flux bleed-out underneath the stencil during printing; flux definition after printing; slump behavior; and the ability to hold the sphere in place during placement and reflow ("MDR"—movement during reflow). If the viscosity is too low, the flux will tend to bleed underneath the stencil, causing smearing of the flux outside of the intended print area/pad and less flux volume. If the layer of flux deposited is too thin and smeared, it may not hold the sphere properly during the process, hence causing "missing ball" failures.

It is important to note that viscosity is only one of the rheological characteristics of a flux, and only for a Newtonian material is the viscosity independent of the shear rate; fluxes are mostly non-Newtonian. Therefore, the use of this single point measurement, although common, is not recommended for complete characterization, and may be used as a "shorthand" for many different rheological parameters.

A Brookfield Cone and Plate Viscometer was used to measure the viscosity of the flux as a function of time. The spindle used was a CP-51 and measurements were taken at 25°C at 10rpm. The results are shown in Figure 2. Each flux in this case showed a consistent viscosity after a normal short period of thixotropic breakdown. Typically, after each production shift (8–10 hours), the user is advised to discard the flux and replenish with fresh flux, to ensure consistent flux printing performance. All the fluxes tested here exhibited a stable viscosity, hence there is no problem using the flux in a standard operation. What is interesting to note is that the flux highlighted in yellow exhibited a much quicker thixotropic breakdown than the other two materials, indicating consistent material performance with less kneading time. The rheology of a flux can be fine-tuned to suit specific applications, such as applications with varied solder ball diameters and package configurations.

Figure 2. Flux Viscosity as a Function of Time

Tackiness

To measure tackiness flux was printed on a ceramic substrate and the tackiness was checked from 0 hours up to 24 hours after printing. The test was conducted in an ambient atmosphere, with relative humidity 50% ± 3% and room temperature of 21.5°C ± 2°C. Results are shown in Figure 3. Tackiness is one of the characteristics of the fluxes that are checked to ensure the flux will not lose its ability to hold the sphere in place. From the testing results above, it was noticed during the tests that the tackiness of some fluxes showed an increase trend, while some had a decrease over time. This is determined by the flux chemistry and how it reacts with the atmosphere when exposed for an extended period. Some solvents in the flux may slowly evaporate once exposed to an ambient condition, while some fluxes may absorb more moisture from the atmosphere.

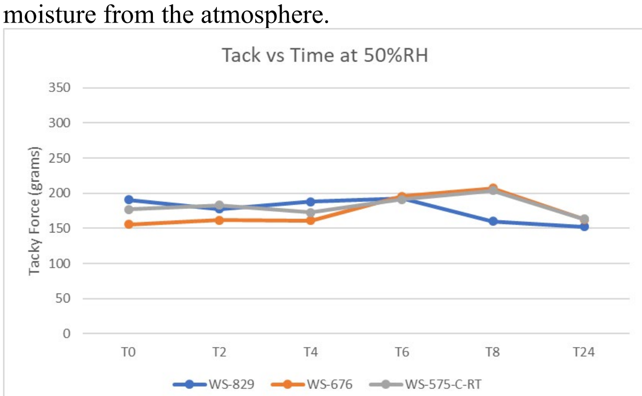

Figure 3. Flux Tackiness over Time

Wetting

One of the key functions of flux is to clean oxides from the pad to be soldered and the solder sphere, and to promote good wetting and solderability between the solder sphere and the pad. If the solderability of flux is insufficient, it will lead to weak joint formation or voiding. In some cases, controlled wetting is needed for specific applications, which have special designs, and sometimes different sized spheres are used. Typically, the request for controlled wetting is to ensure the solder sphere stays where it is during reflow, and to control the collapse of the solder sphere and ensure the coplanarity of the bump after reflowing; hence, in such cases, the wetting of the flux needs to be optimized according to the application and its requirements.

Testing for solderability was done by printing flux onto a OSP-coated copper coupon. Next, SAC305 solder spheres were placed onto the flux using an automated pick and place machine. The coupon with the printed flux and spheres was then reflowed in a nitrogen-purged environment at <500ppm O2. After reflow, solder wetting was calculated from the height of the solder bump; the solder spread ratio (%) was calculated using the following equation:

$$S = [(D-H)/H] * 100$$

Where:
S = Spread factor
D = Initial sphere diameter
H = Post-reflow solder height

The results of the solderability test are shown in Figure 4. When controlled wetting is desired, fluxes with a lower spread factor are appropriate. If a more activated flux with better wetting is needed, especially on oxidized or contaminated pads, then fluxes with a higher spread factor should be chosen.

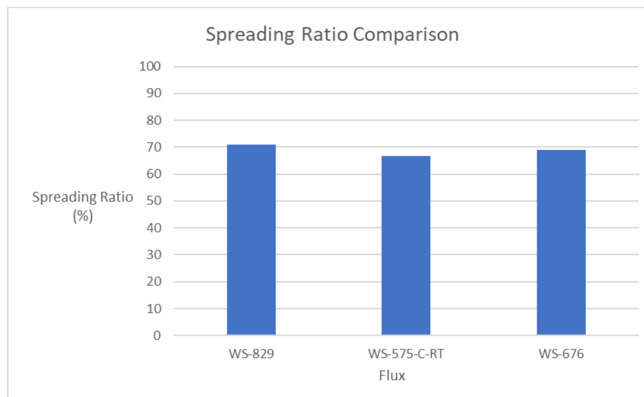

Figure 4. Flux wetting on Copper Substrates

PRINTING

For this test, the two flux vehicles were printed using an SMT printer on a commercially available test PCB. The stencil was an 80 µm laser cut stencil with imbedded nano-coating. The boards were OSP metallization and supported by dedicated vacuum fixturing. The printer was set to the following parameters:

- Print pressure - 3 kgs
- Print speed - 50 mm/s
- Blade length - 250 mm
- Printer temperature - 23.8 ˚C
- Printer humidity - 40 %RH

The print procedure was to knead the flux 30 strokes before a "Wet, Wet, Vac, Vac" under stencil cleaning procedure. After the wipe, the "time zero" board was printed and then inspected. After this there was an hour abandon time for the flux on the stencil. After this pause there were 80 knead strokes, wipe and then the "time one hour" board was printed. This was done for both fluxes.

The flux deposits were inspected under an optical microscope at 0.7x & 3x magnification, with particular focus given to deposits with a width of 300 µm. The images for the three tested fluxes are shown below in Figures 5, 6, and 7.

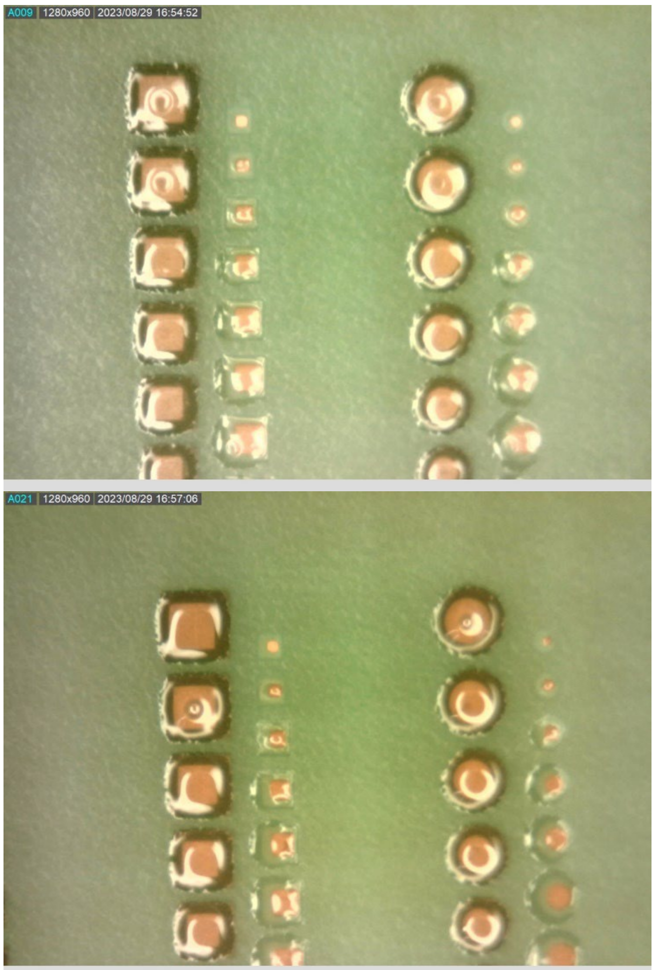

Figure 5. Flux A at T=0 and T=1 hour

Figure 6. Flux B at T=0 and T=1 hour

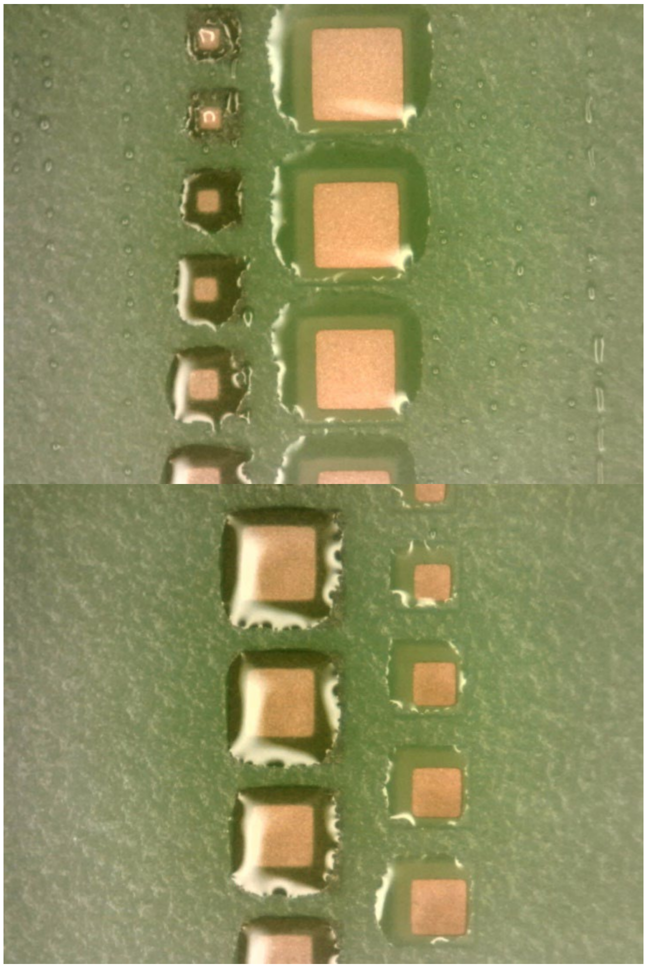

Figure 7. Flux C at T=0 and T=1 hour

The stencil apertures were 1:1 with the PCB pads. With this knowledge, the flux slumped on all pads. Flux A showed the best slump resistance over an hour hour of rest, with fluxes B and C seeming to slump more. Both fluxes had similar printing performance. The hour abandon time had minimal impact on the deposit of the flux.

NO-CLEAN BALL-ATTACH FLUX SOLUTION

There has been some interest in a no-clean solution for the ball-attach process. The benefits of a no-clean material for this process include reduced cost from eliminating the cleaning step, sustainability incentive from the removal of waste water, and reduced risk of package warpage from the elimination of the cleaning step.

There are a few caveats to the success of a no-clean ball-attach flux solution. First, the flux naturally needs to leave behind minimal and benign residue after reflow to ensure there is no electrochemical migration risk. Figure 8 shows a Thermogravimetric Analysis on this flux. The novel no-clean flux (in red) exhibits roughly 7% residue by weight at the standard SAC305 reflow peak. The minimal residue which remains after reflow removes much of the risk of contamination in future assembly steps.

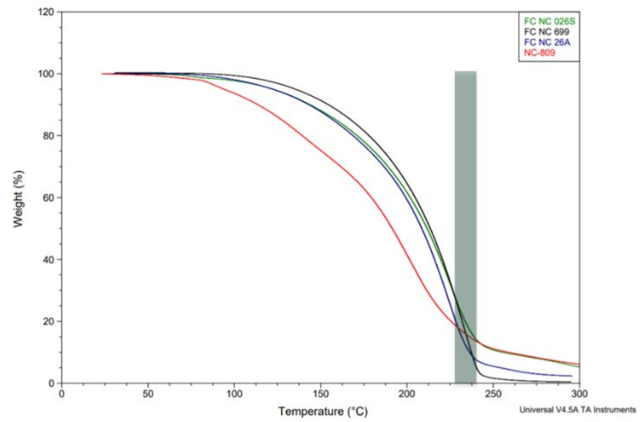

Figure 8. Residue Analysis of No-Clean Ball-Attach Flux (Red)

NO-CLEAN FLUX RHEOLOGY

The following charts highlight the same tests as described in the previous section to show similar rheological performances of the no-clean ball attach flux to their water-wash counterparts.

Figure 9 shows the viscosity of the material. The chart shows a similar thixotropic breakdown as the water-soluble materials, highlighting comparable workability.

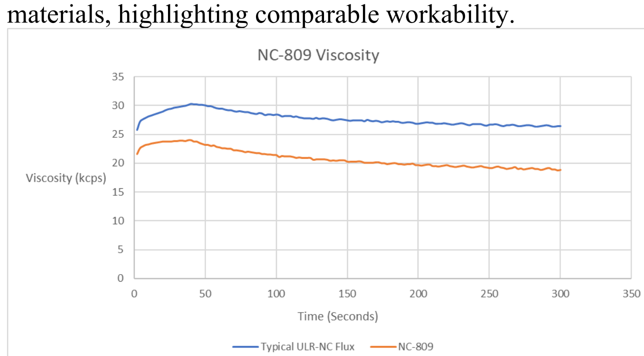

Figure 9. NC Flux viscosity over time.

Figure 10 shows the tackiness of the material, which is much higher than that of the water-soluble materials. This is especially useful to hold smaller spheres in place, key to meeting miniaturization trends.

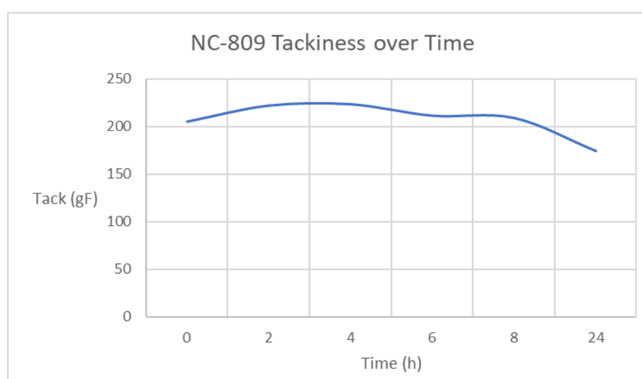

Figure 10. NC Flux Tackiness over Time

Figure 11 shows the wetting of this material on Cu pads. This material wets on par with the WS materials. This is key for ball-attach applications because typically NC fluxes do not have as strong wetting power as NC fluxes.

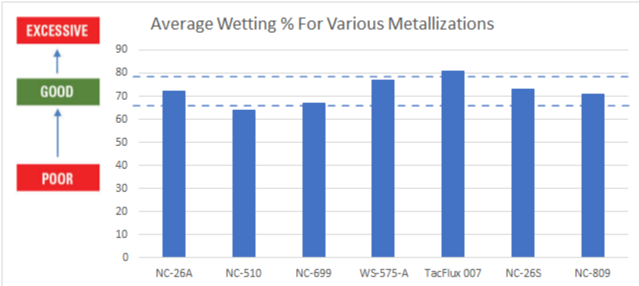

Figure 11. NC Flux Wetting

CONCLUSION

In this paper, novel ball-attach fluxes were discussed with the parameters which are important to the assembly of advanced packages. Three ball-attach fluxes were tested side-by-side with each other, with each having mostly similar results. A novel no-clean ball-attach flux was also discussed and its relevant parameters were tested. The benefits of this material as an alternative ball-attach assembly solution were highlighted. Future work will be conducted on the printability of the NC ball attach flux solution to ensure applicability is not a problem