Fluxless Reflow Technology for Combination Fine-Pitch and SMT-Level Component Attach

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ABSTRACT

Miniaturization continues to be a challenge for the electronics industry. One of the challenges in assembling ultra-fine pitch devices is the challenge of remaining flux residue after reflow; the decreasing standoff height of flip-chip devices makes residue cleaning difficult which can result in dendritic growth and poor compatibility with underfill materials.

One solution to the residue cleaning problem is the removal of flux from the soldering process, referred to as fluxless soldering. Fluxless soldering alleviates many of the problems caused by using flux as a soldering agent, such as the residue problems, as well as eliminating voids caused by outgassing. There are a few common reducing agents which can be used in place of flux for oxide removal, one of these is formic acid vapor (CH_2O_2). While formic acid can act as a reducing agent in this process, there still exists a material need to hold devices in place during the reflow process. This paper will introduce a novel fine-pitch soldering material compatible with the formic acid reflow process. Fine-pitch device soldering in a formic acid environment is possible with the combination of reflow equipment and soldering materials.

The objective of this study to be discussed in this paper is to determine a solution for component attach in a formic acid environment with the appropriate combination of soldering material and equipment. A particular focus will be placed on a material and equipment combination which will provide acceptable soldering using a low-residue solder paste for large components and a novel formic acid adhesive for fine-pitch flip chip components. Post-reflow residue, SIR performance, and solder joint cross sections will be discussed. In addition, the performance of the novel material will be discussed as a solution for the BGA ball attach process.

Key words: Formic Acid, Adhesive

INTRODUCTION

The need for Heterogeneous Integration stems from the observed abating of Moore's Law. With both physical and economic constraints having become more evident with respect to process nodes, several innovations have been developed to keep up with the pace Moore's Law has set since the invention of the integrated circuit.

Embedded Multi-die Interconnect Bridge (EMIB) technology is one of these advancements; an advanced, cost-effective approach to in-package high density interconnect of heterogeneous chips, providing high density I/O, and controlled electrical interconnect paths between multiple dice in a package. System-in-Package (SiP) is another of these innovations; a version of the package on a package (PoP) packaging method where components such as logic and memory chips are stacked on top of each other in one package. SiPs can be compared to System on a chip (SoC) solution, the contrast being that SiPs are not constrained to a single semiconductor die.

As the package performance demand goes higher and the yield in the advanced node transistors becomes more challenging, the heterogeneous integration with high bandwidth is crucial in packaging technology [1]. With the trend of requiring more functions and performance, bump pitch scaling poses significant challenges in the plated solder bump reflow process, e.g., solder wicking control, bump height / coplanarity control, and bump void control. It's crucial to ensure a high-quality solder bump reflow process to meet the final product reliability requirements. Process advancements of high-quality reflow techniques with vacuum and formic acid have proven effective to meet these package performance demands [2]. There is another rising trend in the industry where the removal of cleaning altogether may be required, especially for applications where bump pitches become so small (~30-40 microns), where cleaning becomes impossible. A combination of formic acid reflow, and an appropriate material set will be explored in this paper to meet these needs.

PROCESS OVERVIEW

Formic acid reflow has been developed for use in the advanced packaging industry, among others, as a fluxless reflow technology. During the reflow process, formic acid vapor in a nitrogen atmosphere is introduced into the oven as an oxide removal agent. The formic acid vapor reduces tin oxides on the surfaces of the bumps to its elemental state. This differs from traditional mass reflow as the formic acid vapor acts as the fluxing agent to assist solder reflow. In addition to acting as a carrier gas for formic acid vapor, the nitrogen atmosphere significantly reduces the presence of atmospheric oxygen within the oven that could lead to reoxidation of metal surfaces prior to reflow.

During oxide reduction, carbon monoxide, carbon dioxide, hydrogen gas, and water are generated as by-products. To remove the toxic and environmental hazardous byproducts, all gases leaving the oven are first passed into burn boxes located at the entrance and exit tunnels of the oven, as well as at the exhaust of the vacuum pump. These burn boxes contain a heated metal catalyst that converts most of the residual formic acid and byproducts into carbon dioxide and water vapor. Catalyst conversion efficiency is a function of formic acid load, catalyst temperature, catalyst age, and measurement technique and is subject to variation with each application. These gases are then passed to the facility exhaust system [3].

The introduction of formic acid as a fluxless reflow technique has benefits, but there is a need for a complementary material to avoid defects in this new process. The most obvious need is for the material to act as a tacking agent to ensure chips are held in place during the reflow process. Some manufacturers have developed tooling to ensure die location consistency, however these can be cumbersome to use and costly.

MATERIAL OVERVIEW

To overcome this manufacturing constraint, a novel material technology has been developed for fine-pitch assembly to enable precise placement without dedicated tooling and fixturing equipment. This material, when dispensed during the assembly sequence, provides robust tackiness to maintain consistent alignment of the semiconductor chip and assembly components, thus preventing die shift non-wet open defects. The tacking material used in this application contains no fluxing properties; instead, it is completely consumed during the reflow process with no remaining residue, avoiding the need for post-process cleaning steps and making it an ideal solution for flux-free formic acid reflow techniques that are a strong solution for fine-pitch assembly or processes which would act as a true no-clean assembly process.

The rheological and tacking properties will be analyzed first. The robustness of the attachment properties for this novel material was analyzed using a conventional tack testing method commonly used for fluxes:

- Circular deposits of material printed
- Measurements every 2h over 24h period
- 50% relative humidity, constant

The novel tacking material was tested against a conventional tacky flux, as well as isopropyl alcohol (IPA) variants as a baseline.

As demonstrated in Figure 1, this novel tacking material, shows high tack strength, even when compared to a typical solder paste. In addition, this high tack is maintained over time, demonstrating consistent properties over a long working time. The IPA solutions tested in this setup exhibited a relatively low tack strength and significant degradation over a short period of time, thus reducing the viability of IPA as a similar alternative to a tacking material.

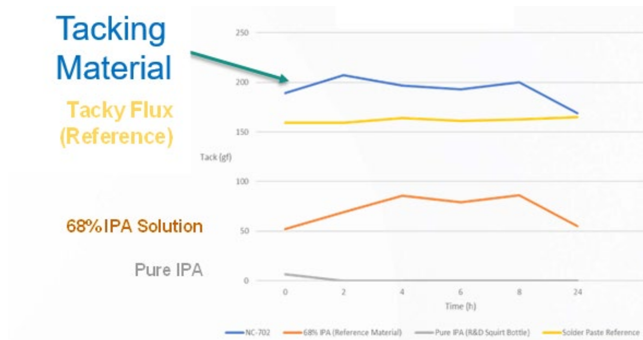

Figure 1: Tack Testing Results

The novel material was also tested to ensure minimal residue would be present post-reflow. A series of tests were performed to simulate a typical reflow process leveraging vacuum and formic acid. First, a thermogravimetric analysis (TGA) was performed to analyze the potential residual components after the material had reached the target processing temperature. The material was constantly heated to 300°C at a rate of 10°C/min. As shown in Figure 2, this tacking material was completely consumed with zero weight % after exposure to a temperature of approximately 230°C, below a typical reflow peak of SAC305 or other Sn-rich alloys. The risk of contamination from residue during a flux-free soldering process is low as the processing temperatures for these alloys are generally much higher than the curve captured from the TGA.

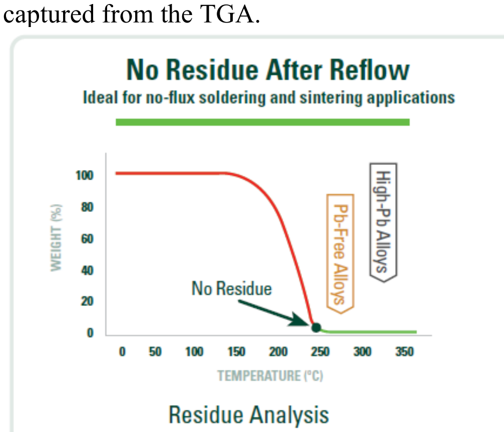

Figure 2. TGA Analysis

EQUIPMENT OVERVIEW

With a novel tacky material for fine-pitch semiconductor materials presented, further experiments were conducted to determine a combination of materials and process equipment to utilize formic acid for fine-pitch chip assembly. Certain assemblies may need one fine-pitch component, with multiple other large footprint SMT components together. In a standard reflow process using flux, a fine-powder solder paste paste in combination with a water-soluble flip-chip assembly flux may be used. However, for applications where cleaning is not desired or is impossible, the novel material presented earlier in this study may be used in combination with a similarly low-residue solder paste to achieve a true no-clean, fluxless reflow process.

The reflow equipment used will be described below. An inline convection reflow oven with combined formic acid and vacuum capability has been developed to deliver maximum process flexibility. The formic acid injection ports in the convection heating zones are adjustable, enabling the formic acid distribution as well as concentration to be fine-tuned to meet different process requirements. The vacuum chamber in this system has two stations, a heating station with an IR panel, and a cooling station with a water-cooling chill plate. This configuration allows the entire reflow process to be performed under vacuum, which would induce any entrapped void in the molten solder to expand, and expulsion from the solder bump by buoyancy forces. The pump down rate, set point pressure, and vacuum dwell time are all programmable for achieving the optimum void reduction results. The oven configuration diagram is shown in Figure 3.

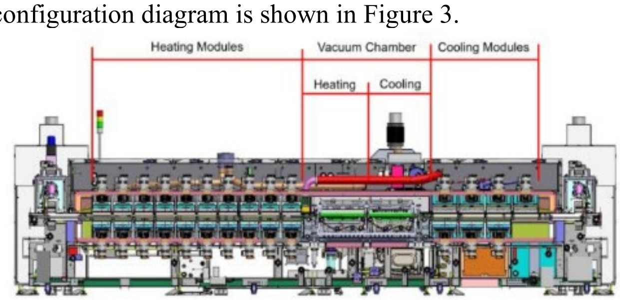

Figure 3: Oven Configuration Diagram

In a typical process, the board would heat up and soak in formic acid environment to remove oxidation. It would reach and maintain about liquidous as it enters the vacuum state. It would dwell under vacuum to allow for the void to escape, and solidify under vacuum, forming void-free bumps. Figure 4 is a typical vacuum formic acid reflow profile.

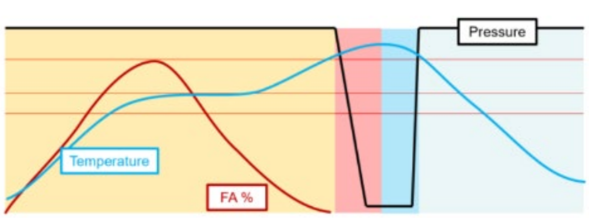

Figure 4: Typical formic acid reflow profile

EXPERIMENT RESULTS AND DISCUSSION

An experiment was conducted to determine the validity of using the novel tacking material presented earlier in combination with a low-residue solder paste to use in a fluxless reflow process with the equipment described earlier. In order to test the validity of formic acid as a process step, the experiment would compare results with only nitrogen in the atmosphere compared to a nitrogen atmosphere with formic acid. Any differences in results will be noted. The solder paste which was used is a readily available low-residue solder paste meant to leave minimal residue after reflow. The material in question was had a SAC305 alloy and Type 4 powder size. The formic acid concentration was kept constant for that leg of the experiment at 10%.

For the following experiment, a readily available test vehicle from Magnalytix was used. This test vehicle allows for a combination of component placement and SIR testing. The test vehicle is shown in Figure X. Notably, the Magnaltix test vehicle does not include components which have a fine enough pitch to reflow only with formic acid. To simulate this, four drops of the novel tacking material were dispensed on a component pad to simulate a flip chip component being placed. The resulting residue analysis will be conducted with that material in mind. Previous studies have shown that minimal amounts of the tacky material are needed to ensure adequate soldering with large, soldered components [4].

RESIDUE ANALYSIS

Firstly, a visual inspection was conducted between boards reflowed in solely nitrogen and in a formic environment. These boards were also weighed pre- and post- reflow to determine the effect that formic acid had on the amount of residue which remained. As shown in Figures X and X, using the same solder paste, the formic acid had the effect of removing the ring of residue which would be typically left behind in a nitrogen process. The second figure shows the same effect, with the added benefit of removing solder balls in the same reflow profile.

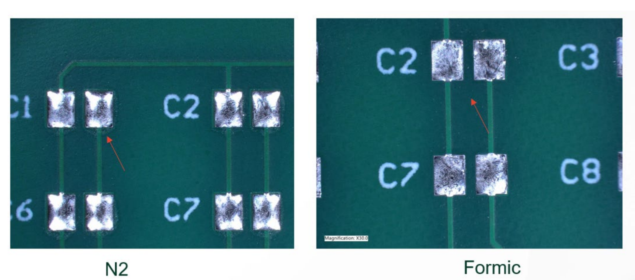

Figure 5a: Residue removal with formic acid reflow

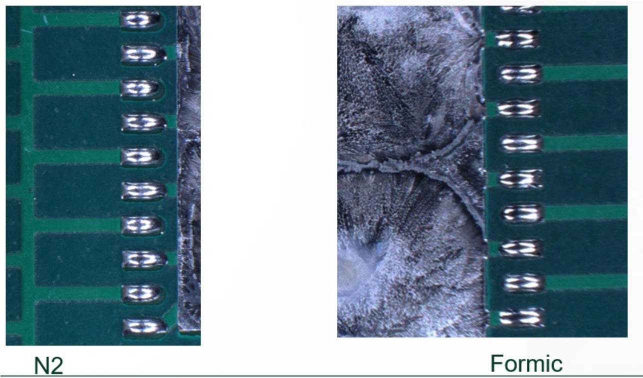

Figure 5b: Solder ball removal with formic acid reflow

SIR PERFORMANCE

The Magnalytix test vehicles also underwent an SIR test with the populated boards, to see if there were any major differences which the formic acid caused with respect to SIR performance. The results of the N2 SIR board and the Formic SIR board are shown in Figures 6 and 7. Both boards pass SIR testing, above 8 Ohms of resistance, meaning there is little risk of formic acid causing SIR related failures.

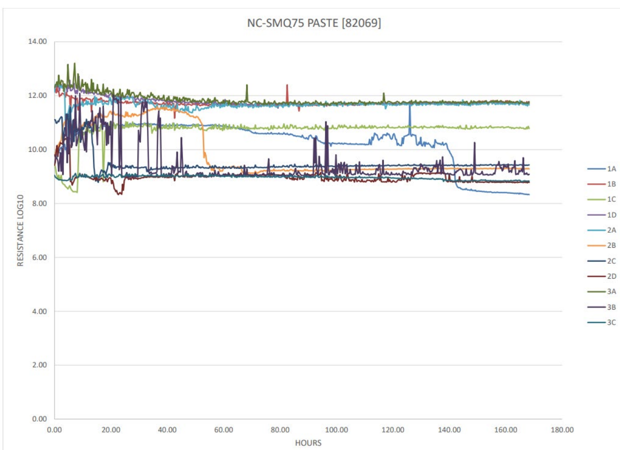

Figure 6: Formic Reflow SIR

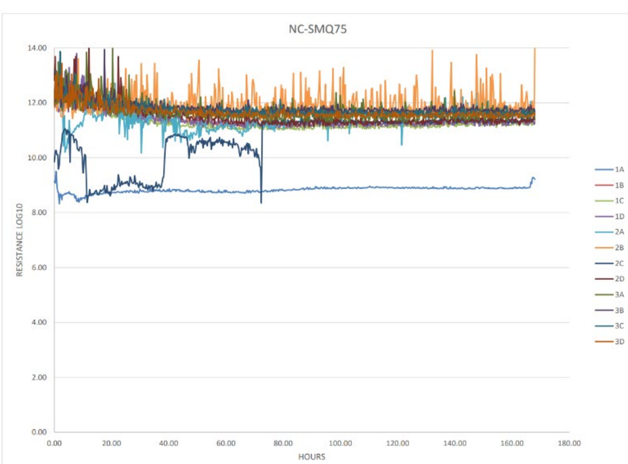

Figure 7: Nitrogen SIR

IONIC CONTAMINATION TESTING

To further evaluate the risk of residue contamination, the tacking material was evaluated against a typical analysis suite for electronics assembly cleanliness, focusing on Ion Chromatography. Previous work has been conducted with purely the tacking agent in collaboration with Zestron, shown here in Figure 8. These results show that levels of typical contaminants were well within control limits for all samples and demonstrated no contamination. In addition, there was no significant difference in levels measured with the tacking material samples compared to the baseline samples [4].

Contamination in µg / cm²						
Anions	#1	#2	#3	#4	#5	Reference values
Bromide	ND	ND	ND	ND	ND	1.55
Chloride	0.07	0.03	0.07	0.02	ND	0.93
Fluoride	ND	ND	ND	ND	ND	0.47
Nitrate	0.05	0.01	0.03	0.01	ND	0.47
Nitrite	ND	ND	ND	0.01	ND	0.47
Phosphate	0.01	ND	ND	ND	ND	1.09
Sulfate	ND	0.01	0.03	0.02	0.02	0.47
Weak org. acids						
Acetate	0.03	0.02	0.04	0.03	0.02	
Adipate	ND	ND	ND	ND	ND	
Formate	0.06	0.02	0.05	ND	ND	
Glutarate	ND	ND	ND	ND	ND	∑ 3.88
Malate	0.01	ND	ND	ND	ND	
Methanesulfonate	ND	ND	ND	ND	ND	
Succinate	ND	ND	ND	ND	ND	
Total	0.10	0.04	0.09	0.03	0.02	
Cations						
Ammonium	0.01	0.01	0.01	0.01	0.01	0.47
Calcium	0.05	ND	ND	ND	ND	0.16
Potassium	0.09	ND	0.02	ND	ND	0.47
Lithium	ND	ND	ND	ND	ND	0.47
Magnesium	0.02	ND	0.02	ND	ND	0.16
Sodium	0.03	ND	0.02	ND	ND	0.47

Figure 8: Tacking Material IC Study

Following up on this, two of the reflowed magnalytix board underwent a similar Ion Chromatography analysis, to determine if either the presence of solder paste affected the ionic contamination results or if the presence of formic acid affected the results. The results shown in Table 1 show that once again, any ionic contaminants are well below generally accepted limits.

Table 1: Internal IC study on combination paste/tacky agent

Element	Contamination (ppm)
Fluorine	ND
Chlorine	1 ppm
Bromine	1 ppm
NO2	ND
NO3	ND
PO4	1ppm
SO4	3ppm
Iodine	ND

CROSS SECTION IMAGES

It was further validated that cross-sectional images be taken to show there is minimal difference with the intermetallic formation when comparing formic acid reflow to pure N2. Figure 9 shows cross section images of the BGA component from the Magnalytix test vehicle. As shown, there is no significant difference in intermetallic growth between formic acid reflow and pure nitrogen.

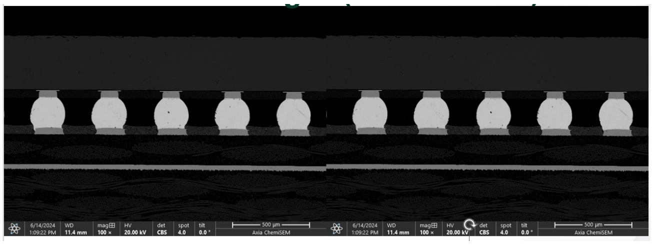

Figure 9: Formic (left) vs. Nitrogen (right) cross-sections.

BALL-ATTACH APPLICATION

In addition to being used for chip-attach, the novel tacking agent has potential for BGA sphere attach applications as well. This will be useful for manufacturers needing to integrate more steps of the full board assembly process with formic acid.

For this experiment, SAC305, 0.76mm solder spheres were placed using the tacky agent on an LGA chip and reflowed with the same in-line formic acid oven and a similar formic acid concentration. The LGA had gold plated pads. Approximately 26 spheres were hand placed by this method. The results are shown in Figure 10. While the surface morphology is a bit rough, this is more of an indication of needing the reflow profile optimized, particularly in the cooling zone. Good wetting did occur.

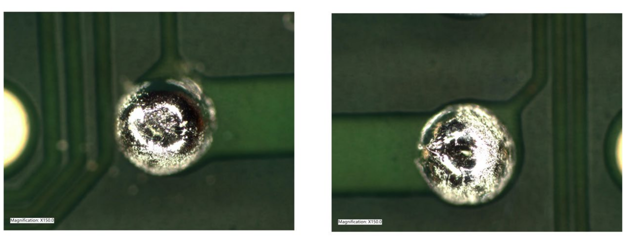

Figure 10: BGA sphere reflow in formic acid.

CONCLUSION

In this paper, a novel tacking agent for fine-pitch chip attach was introduced, and a combination of material and in-line formic acid reflow equipment was presented, showing equivalent performance when compared to a similar performance in pure nitrogen. A BGA sphere attach application was also presented. This combination of low-residue solder paste and tacky agent can prove a promising solution to customers wishing to assemble fine-pitch components or achieve a true no-clean build. Further development work is planned on a one-step fluxless solder paste solution for formic acid reflow, as well as a tacky agent with an activation temperature below SAC305 and other mid-temperature alloy reflow peaks.

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