Solder Materials Science Gets Small as Miniaturization Challenges Old Rules

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History shows that the electronics assembly industry is always up for a good challenge. This was proven with the successful move from through-hole to SMT assembly, the elimination of CFCs from the cleaning process and implementation of lead-free, just to name a few milestones. Now, the industry is arguably at one of the biggest – err, smallest – challenges to date; extreme miniaturization. Though device footprint reduction has been an ongoing process over the last 20+ years, it is safe to say that recent developments are some of the most exigent to date. Though designing much smaller packages presents its own unique set of hurdles (a topic for another article), the ability to incorporate these microscopic components into a high-volume, high-reliability production environment is what's at issue for assembly specialists.

Let's face it; putting down 0201s and 0.4mm CSPs in a lab environment is one thing; achieving this feat reliably in high-volume manufacturing is quite another. There are a plethora of process variables that are impacted by this reality, but none likely as complex as the soldering process. Not only do solder materials have to accommodate for much tighter pitches and smaller geometries, they must also maintain all of the previously established requirements for modern manufacturing including lead-free capability, compatibility with higher reflow temperatures, humidity resistance, wide process windows and much, much more.

These new conditions are placing pressure on tried and true rules for solder materials such as stencil aspect ratios and surface area to volume requirements. Fortunately, ever-ready materials developers have lived up to their perseverant reputation and have responded with some innovative solutions to these emerging challenges. In fact, several developments on the solder materials front – from new powders to activator chemistries to epoxy flux technologies – are meeting miniaturization head-on.

Particles that Pack a Punch

As the use of ultra fine-pitch devices grows and the industry moves from 0201s to 01005s and from 0.4mm CSPs to 0.3mm CSPs, prevailing Type 3 solder pastes will no longer be sufficient to address smaller deposit volume requirements. Simply moving from Type 3 to Type 4, however, will not necessarily deliver the desired result either. It is critical that the Type 4 materials are optimized for today's miniaturization demands.

In this instance, optimizing means tightly controlling not only the particle size but the distribution of those particles within the material as well. While current industry standards tend to be a bit unclear as to allowable particle size in the upper end of the range, the published IPC Standard J-STD-006A (**Figure 1**) is fairly liberal with the distribution range of particle sizes. But, recent testing has suggested that a tighter distribution range and a smaller upper limit particle size may prevent some problems down the line.

Current work has focused on not only condensing the distribution and size range of the Type 4 particles, but also on producing the powder in such a way that the integrity of the surface finish is maintained, as this is also essential to lowering oxidation risk. The smaller particles of Type 4 materials make for a higher surface are to volume ratio which, in turn, introduces more opportunity for oxidation. Left uncontrolled, the oxidation can lead to a variety of performance issues including non-coalescence, poor wetting, and/or graping (more on that later), just to name a few. New powder production technology, however, has delivered consistent, smooth surfaces even on powder spheres less than 35 microns in diameter.

What's more, by tightening the particle size distribution, release of the paste from the stencil is much more complete. Larger particles can easily become trapped in the miniaturized apertures, leading to insufficients and down-the-line defects. By significantly reducing the upper and lower limits on the particle size in newer generation Type 4 materials, high-speed printing through 80 micron-thick stencils with 150 micron apertures becomes a much more robust process. (**Figure 2**)

Lead-Free Solder Paste Advances

Not only is the powder technology critical as the industry moves to much finer dimensions, but the overall capability of the paste and, specifically, the flux system is key. As 0201 integration has increased in production environments – particularly within the handheld sector – the demands on smaller paste deposits have caused new process issues to emerge.

One such problem is graping. This phenomenon, which is partially coalesced solder that resembles a cluster of grapes, is directly attributable to the extreme miniaturization that the industry is experiencing. (**Figure 3**) The cause of graping is easily understood, but not easily remedied without the proper solder materials. With much smaller solder paste volumes, the solder particle surface area to flux ratio is being pushed to a point at which flux exhaustion occurs, the relative level of surface oxidation increases and graping is the result.

Flux's function within the solder paste is to allow the formation of a solder joint by eliminating oxides that are present on metal surfaces -- including the spheres within the paste. In addition, the flux should provide protection of the paste particles during the reflow process so as to prevent re-oxidation. As miniaturization requirements dictate the use of much smaller particle sizes (i.e. Type 4 and, in some cases, Type 5), the total metal surface of the solder increases and, therefore, demands more activity. Most powder oxidation occurs on the particles which are on the surface of the deposit. This puts more demands on the flux as the relative amount of solder surface is increased. Surface oxides generally melt at a higher temperature and, with older-generation formulations, the flux cannot overcome this condition.

By incorporating novel materials development technology, however, there are several ways to help alleviate graping. As mentioned previously, the use of smooth surface powders with a much tighter distribution range and upper/lower particle size limit greatly improves past release from the stencil, delivers more even deposits, provides a reduced metal surface and an ideal deposit surface area to volume ratio .

Next-generation solder paste flux formulations have proven that by providing sufficient activity and re-oxidation mitigation capabilities, graping can literally be resolved as it is occurring. **Figure 4** illustrates this result, as traditional solder materials are compared to newer materials that have been optimized for miniaturization processes.

It is also important to note that while altering the flux and powder to accommodate for new process conditions, materials must also maintain their reliability requirements as well as SIR and ECM performance.

New Approaches for Heterogeneous Component Placement

Another obstacle presented by extremely miniaturized components is the dilemma about how to place the large and small components most efficiently. While previously mentioned new solder pastes are certainly capable on both large and small volume deposits, stencil technologies are often the limiting factor. Designing the stencil capable of printing the large and small deposits in a single sweep is nearly impossible. A second print is out of the question, so the solution becomes dip fluxing.

Traditional dip fluxes certainly deliver the activity required to promote robust solder joint formation; the problem is how to then protect those joints. Capillary flow underfills will only work if there is a gap that is large enough to allow sufficient flow and coverage. Because this is a relatively large "if" considering newer component geometries, an alternative methodology should be considered.

The process is identical, but the material – an epoxy flux – is vastly different. Epoxy flux materials combine the solder joint formation action of a flux and the protection of an underfill into a single material. On a printed circuit board where one might need to place 0.3mm CSPs, other very small types of area array devices or even flip chip on board, epoxy flux is an ideal solution for many reasons.

First, because the material combines the dual-functionality of a flux and an underfill, the secondary underfill dispense process can be eliminated. With epoxy flux, the solder joint is formed and the epoxy surrounds and protects each interconnect during the reflow process. Second, even when capillary underfilling is an option, traditional underfill materials have exhibited problems such as component floating and voiding. A fluxing underfill, however, stays around or near the solder bumps to add an extra level of reliability without inducing floating or void formation.

For manufacturers faced with the heterogeneous – large and small – component conundrum, epoxy flux is an excellent option.

The Nano Future

Despite all of the heretofore mentioned noteworthy solder advances, an article on solder materials science would be sorely lacking without a discussion of what the future may hold. Temperature concerns and development of novel thermal management techniques are, with the advent of very small devices and lead-free processes, more top of mind than ever before. And, while significant progress has been made in relation to temperature control, applying learnings from other markets may provide clues to soldering's future.

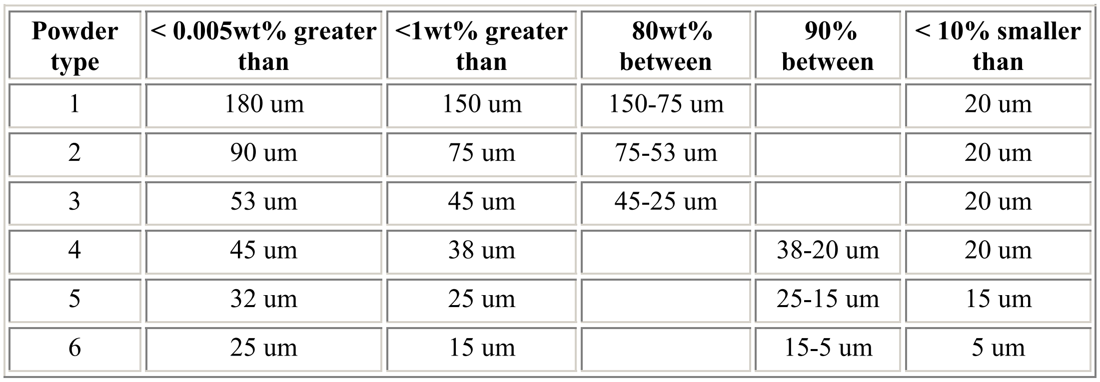
As a case-in-point, transient liquid phase sintering (TLPS) is currently being evaluated as a thermal management solution. Used successfully in ceramic applications, the possibilities for TLPS in electronics manufacture are intriguing. TLPS processes rely on the combination of low temperature melting alloy powders combined with higher melting metal powders which, when processed above the melting point of the lower temperature alloy, fuse together to form a new intermetallic compound that will not re-melt at that same temperature but, rather, a much higher temperature. For electronics, this could conceivably mean that devices could be manufactured at significantly reduced temperatures and be able to withstand higher lead-free processing temperatures with no risk of re-melt or damage. Of course, TLPS for electronics is very much in the infancy stage, but many companies in the soldering industry are currently investigating its potential.

Conclusion

As technology marches on, so does materials innovation. In fact, in many cases materials innovators are far ahead of the parade – developing materials for next-generation applications that are a good three to five years from becoming mainstream. These latest solder materials developments are further evidence of the ingenuity and expertise at the foundation of our industry. Solder solutions such as advanced powder technologies, more capable flux formulations and dual function materials such as epoxy fluxes are all enabling the smaller, faster, cheaper demands of the consumer to be fulfilled.

Solder materials science has, indeed, gotten small – but only because of big ideas and large innovation initiatives from leading materials scientists.

Figures



Powder type	< 0.005wt% greater than	<1wt% greater than	80wt% between	90% between	< 10% smaller than
1	180 um	150 um	150-75 um		20 um
2	90 um	75 um	75-53 um		20 um
3	53 um	45 um	45-25 um		20 um
4	45 um	38 um		38-20 um	20 um
5	32 um	25 um		25-15 um	15 um
6	25 um	15 um		15-5 um	5 um

Figure 1: IPC Standard J-STD-006A, Particle Size Distribution Specifications

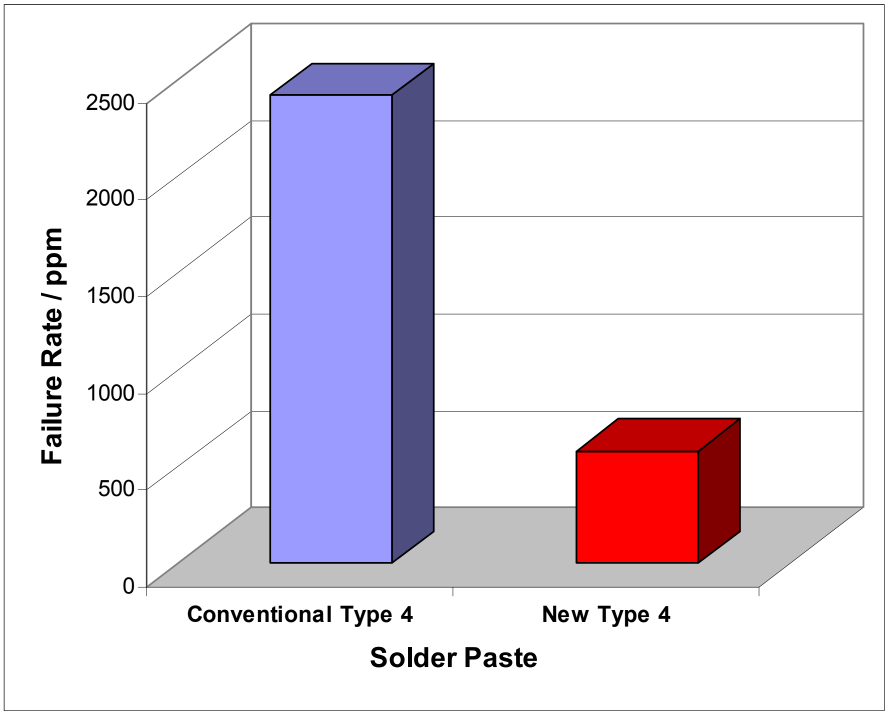


Figure 2: Solder paste formulated with newer Type 4 powder and a tighter particle distribution exhibits significantly lower failure rates as compared to conventional Type 4 solder paste.

Figure 3: Partially coalesced solder on fine deposits appears as a grape-like cluster.

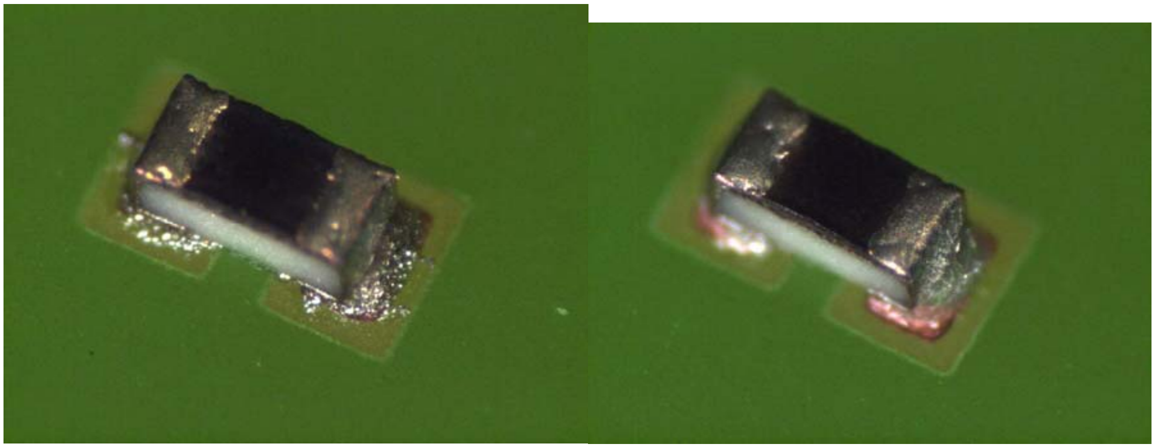


Figure 4: Left side image shows older-generation lead-free solder paste on a 0201 deposit, which exhibits graping. Right side image is a new lead-free solder paste formulation on a 0201 deposit, which shows no graping.