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PROCESS OPTIMIZATION TO PREVENT THE GRAPING EFFECT

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INTRODUCTION

The explosive growth of personal electronic devices, such as mobile phones and personal music devices, has driven the need for smaller and smaller active and passive electrical components. Not too long ago, 0401 (40 x 10 mils) passives were seen as the ultimate in miniaturization, yet the introduction of 0201's and most recently 01005 passives has occurred. For active components, area array packages with 0.4mm lead spacing have become virtually a requirement for enabling the many features in modern portable electronic devices, with 0.3mm packages already on the way.

This miniaturization trend, occurring at the same time as the conversion to RoHS compliant lead-free assembly, has put a considerable strain on the electronic assembly industry. This paper will discuss the specific challenge of the *Graping Effect* and the work that has been performed to mitigate this phenomenon. Discussed are the effects of the solder paste material attributes, consistent stencil printing of the small solder paste deposits required, and minimizing oxidation of the small solder paste deposit during reflow. All of these steps are necessary to assure a good finished solder joint.

Graping Phenomenon

As the solder paste deposit decreases in size, the relative surface area of exposed solder particles increases and the amount of available flux to remove surface oxide decreases. Add to this, the added heat necessary to reflow most lead-free solders and you have a formula conducive to producing the graping phenomenon. During the heating process, the flux viscosity decreases and the flux begins to spread downward and outward, exposing the solder particles at the top of the paste deposit. If there is no flux in proximity, these solder particles may become oxidized as the paste enters into the actual solder reflow stage. These oxides will inhibit the full coalescence of the particles into the solder joint. The unreflowed particles often exhibit the appearance of a cluster of grapes.

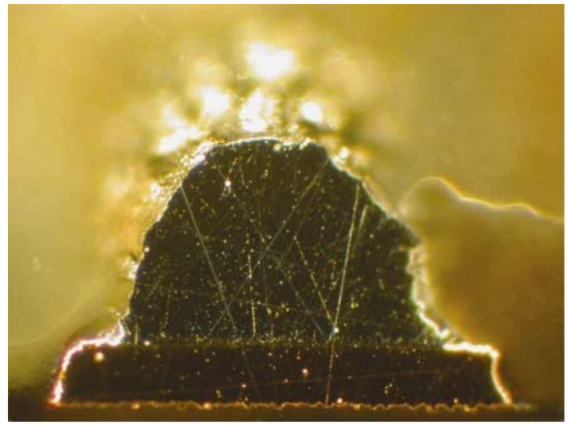

Figure 1. Graping effect.

STENCIL PRINTING

Area Ratio

The area ratio (AR) is a critical metric in successful stencil printing. It is the area of the stencil aperture opening divided by the area of the aperture side walls. Figure 1 shows a schematic for a circular aperture. A simple calculation shows that the area ratio (AR) is simplified to the diameter (D) of the circle divided by 4 times the stencil thickness (t): AR = D/4t. Somewhat surprisingly, the result is the same for square apertures, with D now equal to the sides of the square. For the AR of a rectangular aperture, the formula is a little more complicated: ab/2(a+b)t, where a and b are the sides of the rectangle.

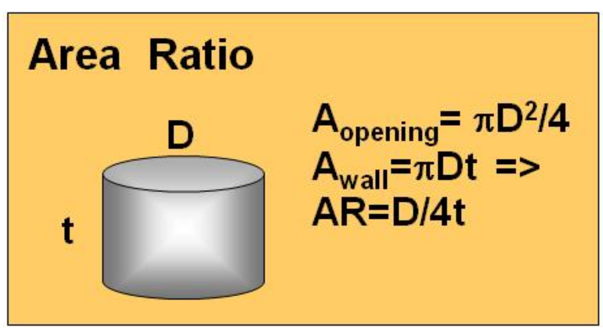

Figure 2. A schematic showing the definition of the area ratio for a circular stencil.

It is widely accepted in the industry that in order to get good stencil printing, the AR must be greater than 0.66. Experience has shown that if AR < 0.66, the transfer efficiency will be low and erratic. Transfer efficiency, another important stencil printing metric, is defined as the volume of the solder paste deposit divided by the volume of the aperture.

The previous section on stencil printing was taken from "Fine Feature Stencil Printing in a Lead-free SMT Process" presented International Conference on Soldering & Reliability May 2008.

The Experimental Design

To investigate ways to minimize graping we performed some experiments. The design of these experiments was to assure the previous guidelines with respect to area ratio and transfer efficiency have been followed. In addition, we wanted to observe the effect of solder paste material attributes, specifically particle size and flux chemistry, in both water-soluble and no-clean solder pastes, as well as the effect of the reflow profile on the graping phenomenon. Therefore, in an effort to reduce the number of variables, the same stencil, squeegee blades, printer parameters, and PWB surface were utilized.

Powder Size		
	Diameter Range	
TYPE	***microns***	
3	**25**	**45**
4	**20**	**38**
5	**15**	**25**
6	**5**	**15**

Figure 3. Types 3, 4, 5, and 6 particle size powders were utilized in both water-soluble and no-clean chemistries.

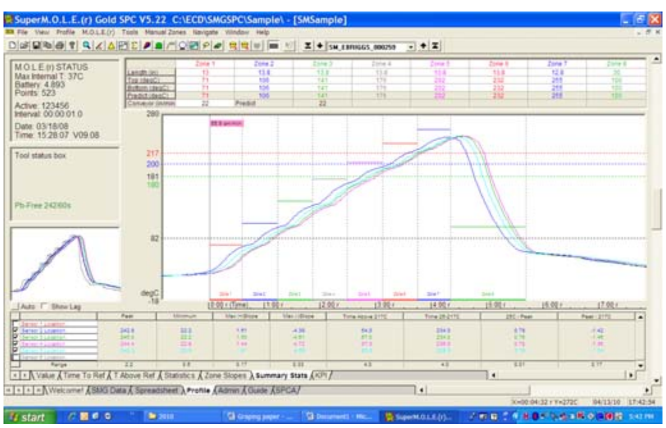

Table 1. Table Ramp-to-peak profile (242°C peak and 60 seconds time-above-liquidus).

Table 2. Soak profile (110 second soak @ 190-210°C, 242°C peak, and 60 seconds time-above-liquidus).

A 3mil laser cut/electropolish stencil, 200mm squeegee with edge guards, foiless clamps, and landscape vacuum support blocks were optimized on the stencil printer. Each solder paste was printed at 50mm/second with a blade pressure of 4kg.

A test board including 6mil circles and squares in both solder mask defined (SMD) and non solder mask defined (NSMD) pads on a Cu OSP surface finish were the focus of observation.

RESULTS

Particle size

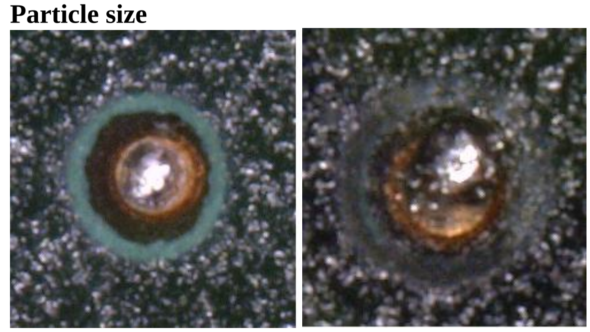

Figure 4. Typical results - Type 3 (left) vs. Type 6 (right) using the same no-clean flux chemistry and reflow profile (RTP).

To accommodate fine feature stencil printing it is not uncommon to look at finer powder solder pastes to optimize the printing process. However, as the size of the powder particles within the solder paste decreases, the relative amount of surface area exposed increases. With this increase in surface area, an increase in total surface oxides is also introduced. This increase in surface oxides requires the flux chemicals to work even harder at removing the oxides and protecting the surfaces during the rest of the reflow process, as seen above.

For the same profile, the graping phenomenon increases as the particle size decreases.

Water-soluble vs. no-clean

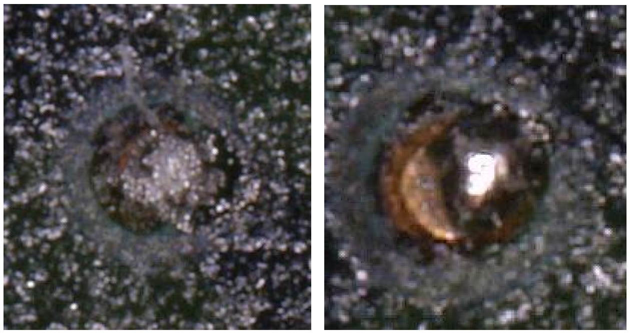

Figure 5. Typical results - Water-soluble (left) vs. no-clean (right) using the same Type 6 powder size and reflow profile (RTP).

No-clean flux chemistries are generally rosin/resin-based (hereafter referred to only as resin) formulas. Because resins are not very soluble in the solvents used in water-soluble flux chemistries, they are typically replaced with large molecular compounds such as polymers in water-soluble fluxes. The activator(s) within the flux chemistry removes the current oxides on the joining surfaces as well as the solder paste particles within the solder paste itself. Further oxidation/re-oxidation does occur during the heating stage. Whereas, in no-clean fluxes the resins are excellent oxidation barriers and protect against re-oxidation, the lack of resins in water-soluble chemistries cause them to fall short in providing that same oxidation resistance.

Hence, for the same reflow profiles, though water-soluble chemistries are generally more active, the lower oxidation resistance of water-soluble chemistries makes them more sensitive in long and/or hot profiles, increasing the graping defect.

Ramp-to-peak (RTP) vs. soak

Figure 6. Typical results - RTP profile (left), soak profile (right) using the same Type 6 powder size and flux chemistry (no-clean).

In years past, the “soak type” reflow profile was very prevalent, but focus has shifted somewhat to RTP as the preferred reflow profile. Contributing to this shift is the introduction of higher reflow process temperatures associated with lead-free solders and the need to diminish the total heat exposure of the smaller paste deposits and temperature sensitive components. Another benefit of the soak profile was its utilization to reduce voiding; however, it is not as effective with lead-free solders due to the increased surface tension of lead-free solders and the higher temperature used to reflow them.

To minimize graping, the shorter the time in the oven the better, provided you use the same time-above-liquidus and peak temperature. The soak profile typically produces more of the graping phenomenon than RTP profile. The graping effect is exacerbated as the total time in the oven increases. Decreasing the total heat dramatically decreases the graping affect. A ramp rate (from ambient to peak) of 1°C/second is recommended, which equates to about 3 minutes 40 seconds to a peak temperature of 245°C.

SMD vs. NSMD

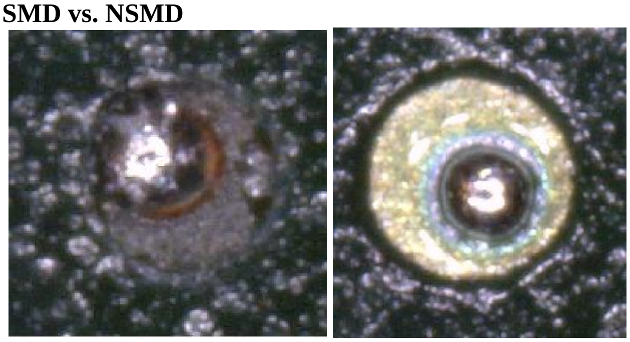

Figure 7. Typical results - Non-solder mask defined pad (left), solder mask defined pad (right) using the same Type 6 powder size, flux chemistry (no-clean), and reflow profile (RTP).

Results of the experiments using solder masking show that for the solder mask defined pads the graping effect was less prevalent. It is believed that the solder mask provides a barrier (dam), which restricts the spread of the flux during the heating process so that it does not “run away” as easily, increases the potential availability of the flux to remove oxides.

Square aperture vs. round aperture

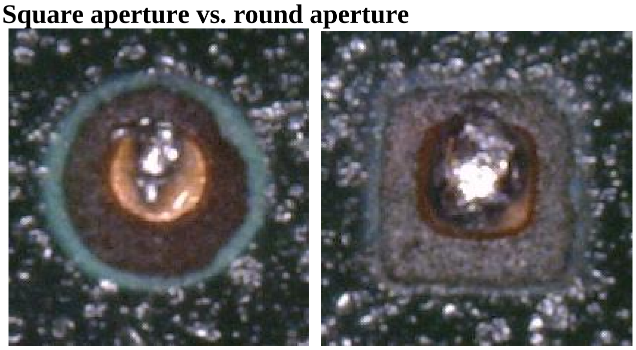

Figure 8. Typical results - Circular aperture/pad (left), square aperture/pad (right) using the same Type 3 powder size, area ratio, flux chemistry (no-clean), and reflow profile (RTP).

Component ID	A.R.	T3-88.75%	T4-88.50%	T5-88.75%	T3-89.00%	T4-88.75%	T5-88.50%
C6 SMD	0.50	39	38	47	44	43	51
S6 SMD	0.50	50	50	56	53	53	58
C6 NSMD	0.50	24	31	34	33	30	47
S6 NSMD	0.50	41	45	50	49	46	58

Transfer efficiency comparing 8mil circle vs. 8mil square aperture design

The area ratio for a 6mil square and 6mil circular apertures on a 3mil thick stencil equals 0.50. In comparing the two, however, the volume for the square solder paste deposit is greater (~108 cubic mils) than the circular deposit (85 cubic mils). The additional paste volume provided by the square aperture may help reduce the graping phenomenon. Of greater importance though, is the increased transfer efficiency provided by the square aperture. As shown above for both solder mask defined and non solder mask defined pads of the same area ratio, the square aperture design provides more consistent transfer efficiency, reducing the potential for the graping phenomenon.

CONCLUSION

To reduce the graping effect, it is vital to ensure an optimal printing and reflow process. Using the guidelines provided for the area ratio and good process/equipment set-up will ensure good transfer efficiency. From a reflow standpoint, decreasing the total heat input will decrease the likelihood of the effect. Using a RTP type profile with a ramp rate of ~1°C/second is suggested.

Material factors also influence the outcome, with an increase in the observance of graping as the solder paste particle size decreases and the area of surface oxides increase. Water-soluble solder paste chemistries do not provide the oxidation barrier that resins do for no-clean chemistries and are more prone to the graping effect.

Though the area ratio for circular and square aperture designs may be equal, the potential for the graping phenomenon increases with circular aperture designs due to decreased paste volume and decreased transfer efficiency.

Though not performed in this experiment, but observed with customer evaluations, the use of nitrogen does diminish or eliminate this effect.