Process Development for 01005 Lead-Free Passive Assembly: Stencil Printing

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ABSTRACT

For some years now, an area ratio of 0.66 or greater has been the criterion for stencil apertures to achieve acceptable volume control in the printed solder paste “brick,” for small apertures Meeting this criterion, in the stencil printing process, has been a constant concern as the volume consistency of the solder paste brick is among the most critical metrics in determining high yields in the assembly process.

With the advent of 0201 and most recently 01005 passives components, meeting the area ratio target of 0.66 is a challenging task; especially with a 5 mil thick stencil and a Type 3 powder solder paste. These tiny passive technologies and minimalist IC packages like 0.4mm CSPs have created a need to re-evaluate the area ratio criterion of 0.66 and other related issues.

In light of this need, we developed a series of designed experiments (DOEs) evaluating Type 3 and Type 4 solder pastes, varying aperture designs for 0201, 01005 and 0.4 mm CSPs, and 3 and 4 mil thick laser cut and E-Fab stencils. In these experiments we determined optimum print parameters for the various combinations of pastes, components, aperture design, and stencil fabrication mentioned above. Our results also suggested new criteria for area ratios.

We believe that with the concurrent implementation of lead-free assembly, this work could not be more timely.

Key words: 01005, passives, passive assembly, lead free passive assembly.

INTRODUCTION

With the advent of 01005 (10 x 5 mil or 0.25 x 0.125 mm) passives and lead-free assembly at the same time, there is a strong need to develop an optimized process for the assembly of these miniscule passives. We hear so much about “01005s” that we can become jaded as to how small they really are. Their width (5 mils is only slightly larger than the thickness of a human hair and their length about the thickness of a sheet of resume paper! Figure 1 shows relative size of different size components. So it should come as no surprise that assembling 01005s with lead-free solder paste is a great challenge.

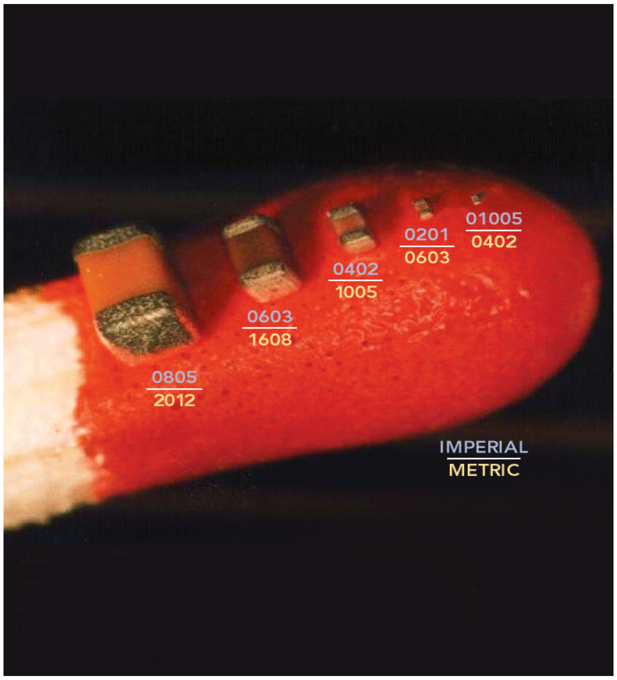

Figure 1. Comparison of 01005 component size with larger size components

In light of this need we planned and executed an experimental protocol to develop an optimized assembly process for 01005 passives. The protocol included Type 3 and 4 lead-free solder pastes, various stencil designs and thicknesses and several stencil printer settings and reflow profiles. This paper discusses the stencil printing process portion of the experimentation.

STENCIL PRINT OPTIMIZATION

A Fractional Factorial 6^{-2} Resolution IV experiment was performed to develop an optimized stencil printing process. Figure 2 is a table of the details. Note that in addition to Type 3 and 4 pastes, 3 and 4 mil stencils thicknesses were used as well as two levels of print speed, separation speed, print pressure and stencil wiping with and without solvent. The response was the volume of the stencil printed "brick'" as measured by an Agilent SP50 laser scanning system.

The stencil design consisted of square, circular and two different shaped "home plate" designs as seen in Figure 3. The stencil had 5 different locations for the 01005 passives with both 0 and 90 degree orientations to the direction of printing. Each location had 200 components. These locations were divided with the 4 different aperture shapes, hence each shape have 50 components at each location. The resulting stencil test vehicle is shown in Figure 4. Larger, 0201, passives were also assembled as a reference.

Phase I: Print Optimization DOE

A two level, Fractional Factorial Design was employed to study the Effects of the following factors.

Fractional Factorial $(2_{IV}\ 6^{-2})$, 2 Levels

		LEVELS		
Factor	Parameter	(-)	(+)	Comments
PT	Paste type	type3	type4	2 vendors
ST	Stencil type	3 mil	4 mil	Laser cut & Electropolished
PS	Print speed	1.5	3	ipm
PP	Print pressure	10	15	psi
SS	Separation Speed	0.05	0.1	ipm
WM	Wiper Method	With Solvent	Without solvent	

Response: Paste volume, Paste height, Paste area

Figure 2. The Stencil Printing Optimization DOE

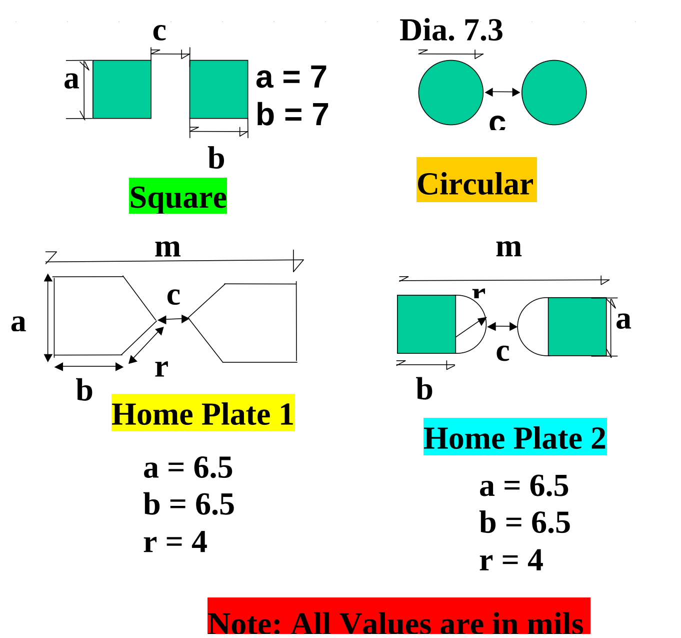

Figure 3. The different stencil designs tested in the printing DOE.

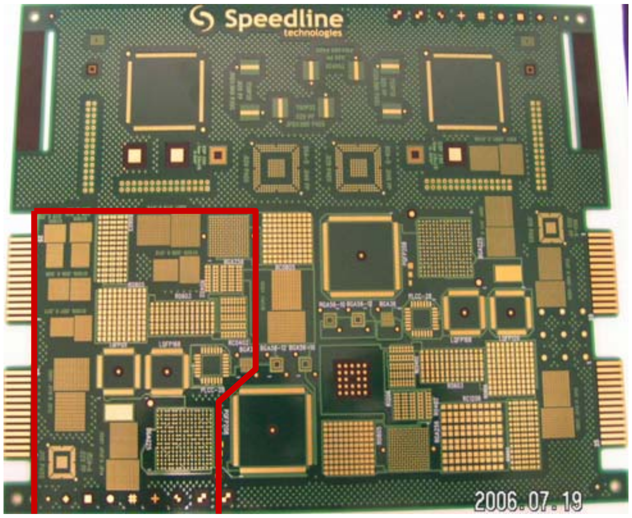

Figure 4. The test vehicle for the DOE. The marked area represents the print inspection location.

Gage Repeatability and Reproducibility Experiment

To ensure minimum experimental variability a Gage R and R (repeatability and reproducibility) analysis was performed to determine the precision of the Agilent SP50 in measuring the volume of the stencil printed bricks. Aperture shapes were evaluated for each treatment combinations. Below is a typical example of the aperture shape evaluated using a 4 mil thick stencil.

An average 6 sigma precision to tolerance ratio (P/T = 6 * St. Dev/(USL-LSL) of 15.8% was achieved. An upper spec limit (USL) of 150% and a lower spec limit of 50% of the nominal aperture were used. We were pleased with the results, as typically a P/T ratio of <30% is considered acceptable for challenging state of the art processes such as these we are attempting.

Printing Experiment & Results

The standard order design table for the printing experiment is shown in figure 5. A "repeat" noise strategy was adopted for this experiment to address run-to-run variations. Four boards per treatment were printed; two boards with 'front to rear' squeegee stroke and two boards with 'rear to front' squeegee stroke. Again, this strategy was adopted to minimize noise effects due to squeegee stroke direction on the print quality. JMP statistical software was used to analyze DOE result.

Standard Order Design Table

Qty	Run Order	Paste Type	Stencil Thicknes	Print Spe	Print Pressure	Seperation Speed	Wipe Method
4	1	1	-1	-1	-1	-1	1
4	2	1	-1	1	1	-1	-1
4	3	1	-1	1	-1	1	1
4	4	1	-1	-1	1	1	-1
4	5	-1	-1	-1	-1	-1	-1
4	6	-1	-1	1	1	-1	1
4	7	-1	-1	1	-1	1	-1
4	8	-1	-1	-1	1	1	1
4	9	1	1	1	-1	-1	-1
4	10	1	1	-1	-1	1	-1
4	11	1	1	1	1	1	1
4	12	1	1	-1	1	-1	1
4	13	-1	1	1	1	1	-1
4	14	-1	1	-1	1	-1	-1
4	15	-1	1	-1	-1	1	1
4	16	-1	1	1	-1	-1	1

Figure 5. Standard order design table for printing DOE.

The main effects plot for the printing data for square apertures is shown in Figure 6. The values plotted are often called the stencil printed "release" values. Release is defined as the volume of the stencil printed deposit divided by the volume of the aperture.

Note that only paste type and stencil type seem to have a significant effect on stencil printed release. This result is not too surprising and is in agreement with several other recent 01005 assembly process studies. One might expect greater relative printed volume from a finer paste (Type 4) and a thinner stencil (higher area ratio).

The data for square and circular apertures showed similar results. However, square apertures provide a slightly higher grand average release of 88.4% (standard deviation = 17.2%) versus 85.9% (standard deviation = 15.9) a relative increase of 2.9 %. This difference is not statistically significant. Data for the "home plate" designs was calculated and will be reported in a later paper. Figures 7-10 shows a series of images representing 'typical' paste deposits for various paste and stencil combination. It is clear from these images that a combination of type 4 solder paste and 3 mil stencil gives a more consistent, higher volume print than type 3 solder paste and 4mil stencil. The average release values for the circle and square aperture print experiments are shown in Figure11. Release is defined as the volume of the stencil printed deposit divided by the nominal volume of the aperture.

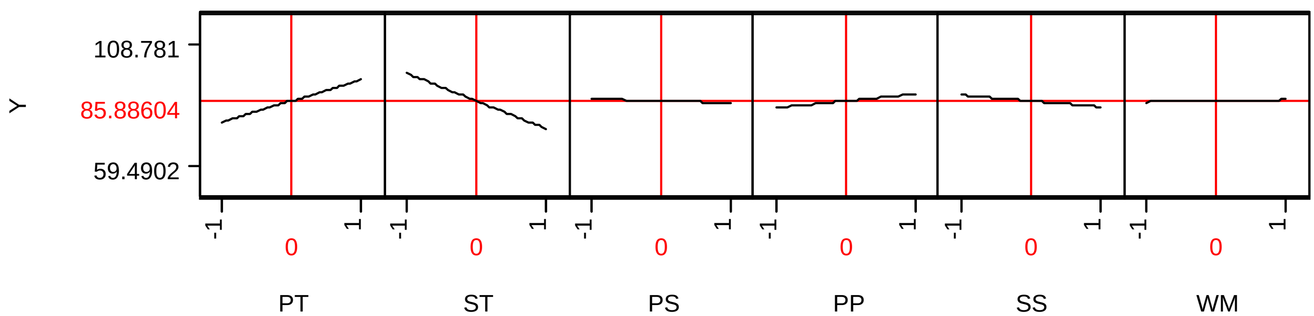

Figure 6. The Main Effects Plot for square apertures, showing that only paste type and stencil type have a strong effect on stencil printed release for square apertures. The data show the percent of the nominal aperture volume filled.

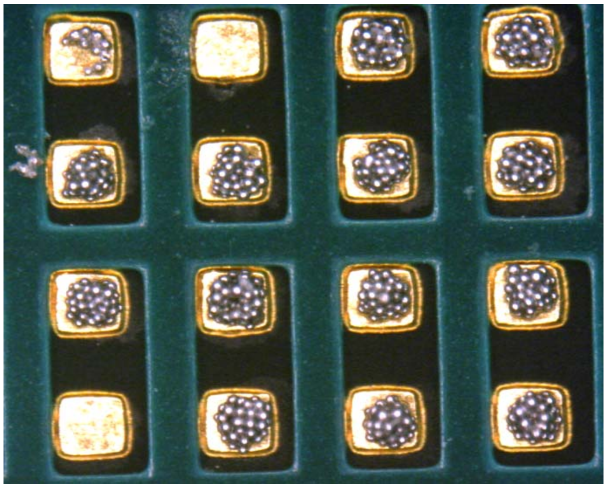

Figure 7. Solder deposition on 01005 pad with Square aperture. Paste type 3 and 3 mil thick

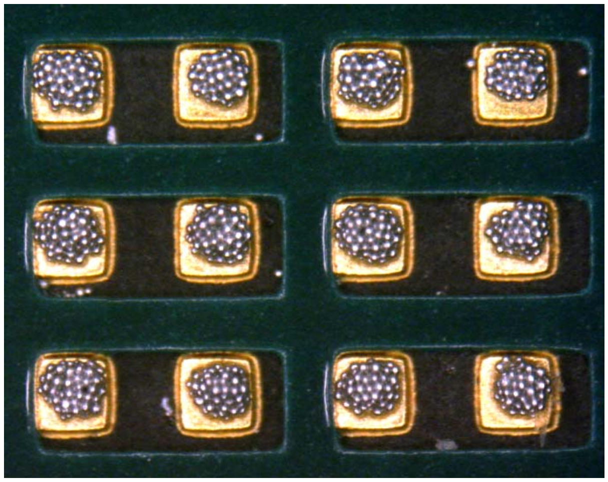

Figure 8. Solder deposition on 1005 pad with square aperture. Paste type 4 and 3mil stencil.

stencil .

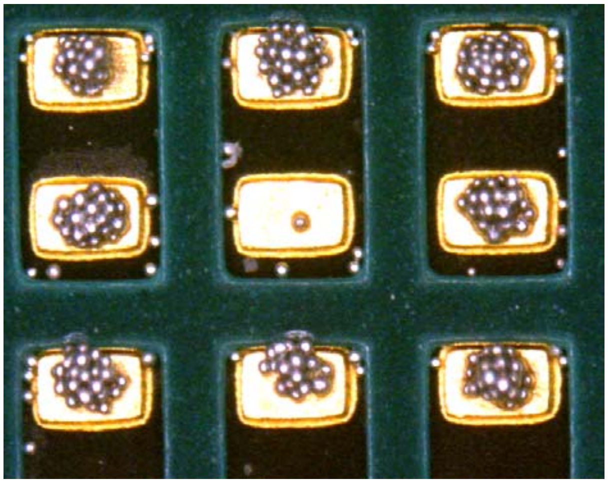

Figure 9. Solder deposition on 01005 pad with Square aperture. Paste type 3 and 4 mil thick

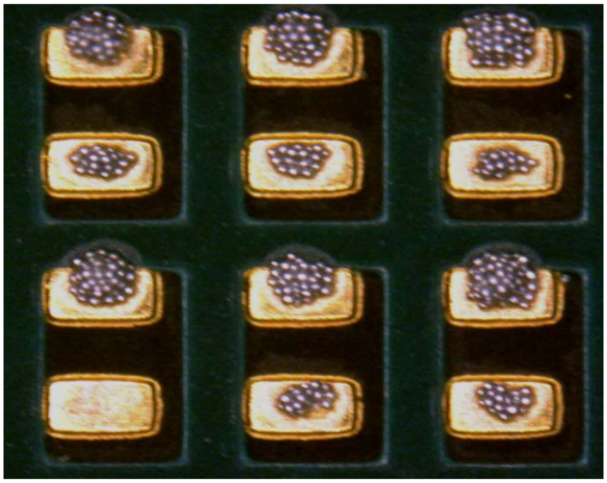

Figure 10. Solder deposition on 1005 pad with square aperture. Paste type 4 and 4mil stencil.

Qty	Run Order	Paste Type	Stencil Tkn	Print Speed	Print Press	Separa. Speed	Wipe Method	Circle Volume	Square Volume	Circle Area ratio	Square Area ratio
4	1	4	3	1.5	10	0.05	No Solvent	108.4	112.3	061	058
4	2	4	3	3	15	0.05	Solvent	102.7	107.7	061	058
4	3	4	3	3	10	0.1	No Solvent	104.6	108.5	061	058
4	4	4	3	1.5	15	0.1	Solvent	108.8	112.6	061	058
4	5	3	3	1.5	10	0.05	Solvent	96.3	102.7	061	058
4	6	3	3	3	15	0.05	No Solvent	97.0	101.3	061	058
4	7	3	3	3	10	0.1	Solvent	68.6	74.4	061	058
4	8	3	3	1.5	15	0.1	No Solvent	89.2	95.7	061	058
4	9	4	4	3	10	0.05	Solvent	84.2	82.6	046	044
4	10	4	4	1.5	10	0.1	Solvent	78.9	76.9	046	044
4	11	4	4	3	15	0.1	No Solvent	85.8	85.3	046	044
4	12	4	4	1.5	15	0.05	No Solvent	81.5	80.7	046	044
4	13	3	4	3	15	0.1	Solvent	73.0	73.8	046	044
4	14	3	4	1.5	15	0.05	Solvent	70.9	69.9	046	044
4	15	3	4	1.5	10	0.1	No Solvent	59.5	60.9	046	044
4	16	3	4	3	10	0.05	No Solvent	64.8	69.6	046	044

Figure 11. Release values for circular and square apertures.

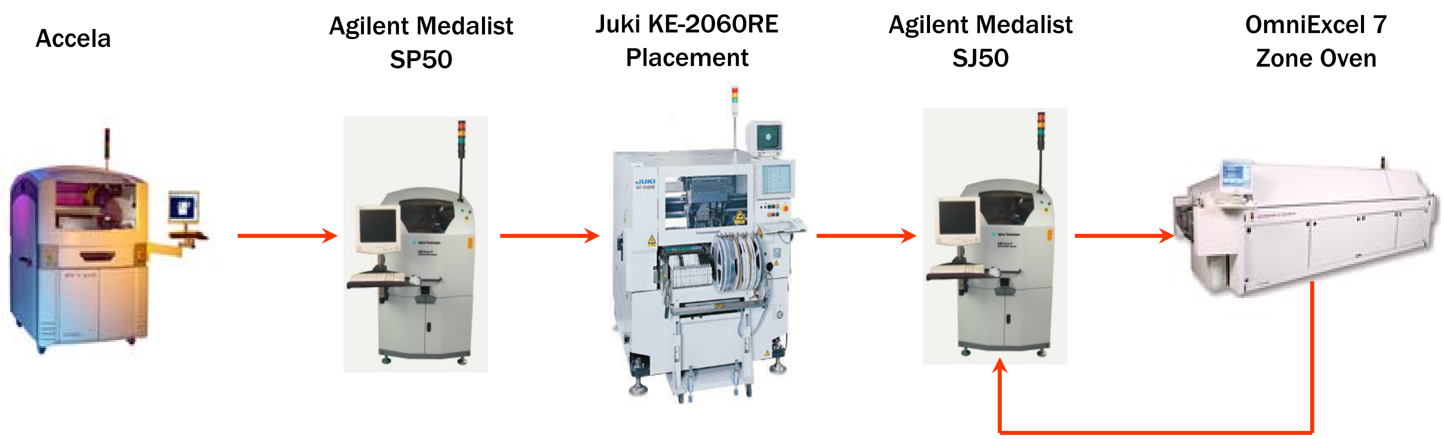

Figure 12. The equipment and product flow used to optimize the 01005 assembly process.

The data in Figure 11 suggest that for 01005 components:

1. With a confidence of greater than 95%, Type 4 paste provides more aperture release than Type 3 paste.
2. With a confidence of greater than 95%, release is improved if a 3 mil stencil thickness is used as opposed to a 4 mil stencil.
3. On average a square aperture provides better release than a circular aperture, but the difference is not statistically significant.
4. Even though the area ratios for the 4 mil thick stencils is < 0.5, by using Type 4 paste release values > 80% are possible.

Preliminary Reflow Results

After stencil printing and optical scanning to measure the printed volume of the solder paste deposit, component placement and reflow was performed to optimize the entire assembly process. Figure 12 shows the process flow and equipment used. Since the Type 4 paste and a 3 mil thick stencil provided better stencil printing solder paste aperture release, these two factors were used in the assembly process. The process optimization variables were the use of nitrogen or air atmosphere in the reflow oven and two types of profiles: Ramp to peak and "soak."

At the time of the writing of this paper only preliminary data have been obtained. These data suggest:

1. Nitrogen appears to maximize fully reflowed solder joints, while not appreciably increasing tombstoning.
2. At this point, the data do not strongly support the use of one reflow oven profile over another.

The detailed results of our reflow soldering experiment will be reported in a subsequent paper.

CONCLUSION

In this preliminary paper on optimizing the entire 01005 assembly process with lead-free solder, we have discussed our initial results in the stencil printing process. This work showed that Type 4 solder paste and a 3 mil thick stencil delivered solder paste aperture release values greater than 100%. It was encouraging to see that Type 3 solder paste worked almost as well with a 3 mil thick stencil, producing releases values around 90%, although Type 3 paste seemed to be more sensitive to stencil printer parameters. With a 4 mil thick stencil, Type 4 paste performed reasonably well achieving release values around 80%, even though the area ratio was less than 0.5. Type 3 paste did not perform well with a 4 mil thick stencil, having release values of less than 70%.

One important question still remains to be answered is what stencil design and stencil fabrication technology will be required to optimize the solder paste printing process for the miniature 01005 components while still providing sufficient solder paste volume for the larger components on the same assembly? The use of multi level (stepped stencils) or a dual thickness stencil solder paste printing processes using two stencils (one thin stencil for the miniature components and one thicker stencil for the larger components with a reversed step down to clear the solder paste printed by the first thin stencil) and two stencil printers may be required to optimize the assembly of products with both miniature and larger components. Future work will include the above mentioned stencil issue to develop a robust process for board with varied size components.

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