

Substrate Printing for Micro BGA

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Abstract

As the demand for faster, smaller, cheaper and smarter electronic products such as cell phones, pagers and PDAs increases, the demand on packaging footprint also increases. Flip chip and micro BGA are the ideal responses to the demand for more functionality and compact packaging. But the assembly of flip chip and micro BGA comes with its own challenges. The primary challenge is to provide reliable mechanical and electrical interconnection. The most cost effective way to provide both mechanical and electrical interconnection is the application of solder paste via stencil printing process.

Stencil printing is a common process in surface mount and other packaging process. The guidelines for stencil design, paste formulation and printing equipment are well developed for mainstream SMT process. When it comes to ultra fine pitch application, some of the previously developed guidelines may no longer hold. New guidelines may need to be developed to address the requirements of ultra fine pitch printing. Most assemblers believe that 50-70% of the end of the line defects contribute to the stencil printing process. Controlling the amount of solder paste deposit to meet the ultra fine pitch application is critical to the process.

This paper will describe work done in the area of micro BGA assembly using various stencil designs, materials and process factors through a series of design of experiment. Bump size of 65 microns to 150 microns will be the focus of this discussion.

Key words: Substrate bumping, solder paste printing, SPI inspection, Print DOE, Transfer efficiency

Introduction:

The flip chip technology has been one of the key enablers in the advancement of smaller, cheaper and faster packaging design. It provides excellent electrical performance and high I/O's handling capability compared to traditional wire bonding technology. Flip chip technology was originally developed for computer and notebook PC to improve miniaturization and performance. Here, performance took priority over cost. As we start to apply this technology to consumer products, cost becomes as important as the performance. There are two distinct ways to address the second level electrical connection need - bumping the wafer or bumping the substrate. Traditionally, wafer bumping has been the mainstream approach. As the pressure for cost reduction has increased for the semiconductor packaging industry, people have investigated bumping lower cost organic substrate as an alternative.

There are several solder bumping technologies for substrate bumping. These are evaporation, electroplating, solder paste deposition and others. Evaporation is well-documented and highly reliable, with extremely fine pitch capability. Yet, it is considerably expensive, relatively slow and capital-intensive. The more common processes implemented today are electroplating and solder paste deposition. Electroplating is a complex process that involves several steps that can be considered environmentally unfriendly. The solder paste deposition is a simpler, faster, cheaper and environmentally friendly process. In this process, a metal mask with an opening for the pad area is used to deposit solder paste. Solder paste is printed onto the substrate and reflowed once. Because of overall faster throughput, solder paste printing is lower in cost compared to electroplating. While electroplating offers finer pitch capability, solder paste printing offers material flexibility, which presents advantages when considering Pb-free packages. Because of the

varying plating rates required for the Pb-free solders that are typically ternary alloys, electroplating has difficulty controlling compositions. In general, ternary alloys are a greater challenge because they require more complex equipment and photo-resist processing. Solder paste printing, on the other hand, offers greater composition control and material flexibility to support Pb-free alloys.

Background:

Though there are several advantages to the solder paste printing process, there are also challenges and limitations associated with printing. Namely, these are printing solder paste deposits that are large enough to produce bumps with the required height and co-planarity within the constraints of the pitches. The difficulty lies with the stencil manufacturing technologies and solder paste limitations. When printing full area array designs, the slumping of the overprinted solder paste results in solder robbing during reflow process. Therefore, it is very important to use a paste and stencil technology which promotes easy release of the paste and has adequate slump resistance during print and reflow. In this study, performance of two different paste chemistries is evaluated.

The following factors are critical to achieve successful bumping using solder paste printing:

- Printing technique
- Stencil design
- Paste formulation
- Reflow process
- Substrate flatness

The current study focuses on the printing part of the bumping process. Printing is a highly complex process and is considered to be “black magic” by many experts. The goal here is to demystify the printing process through a series of well designed experiment. Results from the evaluation of the printing technique and paste chemistries are presented in this paper.

Test Vehicle:

The test vehicle used for the study was a two layer FR4 substrate. The thickness of the substrate was 0.012” with 0.5oz copper and Immersion Nickel Gold (ING) pad finish. The substrate was designed to include extreme cases, (extremely small pad size and web size) to understand the limitation of the stencil printing capability. The pad size varied from 200 μ to 65 μ , as shown in figure 1. In addition to various pad sizes, the pitch/web was also varied to understand the effects of the above factors on the printing capability. The details of the pad size, pitch and web dimension are shown in table 1. Figure 2 shows an expanded view of an 200 μ (8mil) pad design. For better data management, each group of pads was assigned a location number., the top left group being LN1 and the bottom right being LN36.

Each location contained an array of 25X25 pads. Some arrays were repeated on the board to understand the printing characteristic as a function of location. To keep the scope of the initial experiment manageable, only the areas shaded in white (10X10) were inspected for transfer efficiency data.

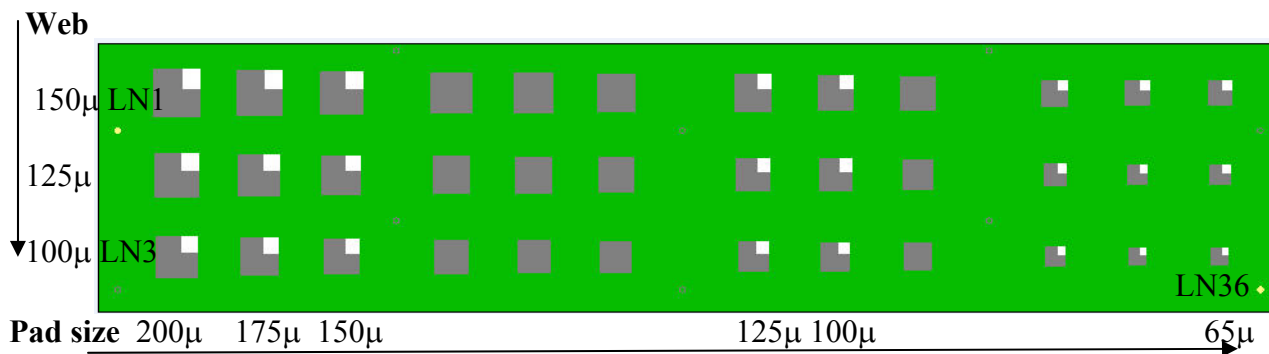
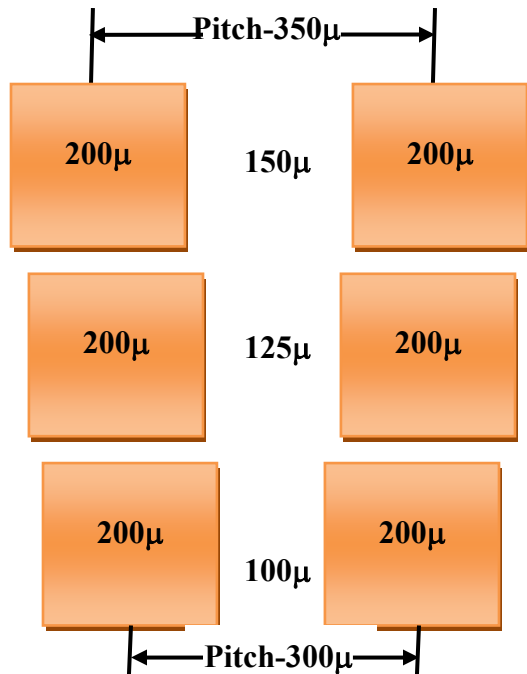


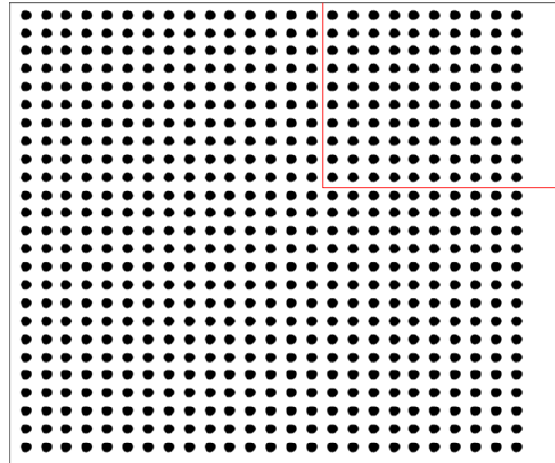
Figure 1. Test Vehicle showing pad locations used in the SPI inspection scheme.

Table 1. Pad design

Pad size, Microns	Web, Microns	Pitch, Microns	Area Ratio
200 (LN1-3)	150, 125, 100	350, 325, 300	0.70
175 (LN4-6)	150, 125, 100	325, 300, 275	0.80
150 (LN7-9)	150, 125, 100	300, 275, 250	0.93
125 (LN10-12)	150, 125, 100	275, 250, 225	1.12
100	150, 125, 100	250, 225, 200	1.40
75	100, 75, 50	175, 150, 125	1.87
50	100, 75, 50	150, 125, 100	2.80

**Figure 2. An example of the pad layout showing 200μ pad size and corresponding pitch/web.****Stencil Design:**

It is well known that the stencil design is a critical factor affecting the transfer efficiency of any printing process. Print volume and consistency for small deposit could be maximized by carefully choosing the stencil design parameters. Keeping this in mind, the stencil for this study was chosen to be a 35 micron thick electroform stencil. The aperture size and pitch was in 1:1 ratio with the land pattern. The stencil apertures were designed as squares to maximize the amount of paste deposited per site. Figure 3 and 4 shows the layout of the stencil.

**Figure 3. Stencil design****Figure 4. Expanded view of the stencil layout.****Paste type:**

The pastes used in this study consisted of type 6 powder with both water base and no clean chemistry.

Experimental:

A MPM Accela printer with Rheopump was used in this study. Due to the thin nature of the substrate, a dedicated tool with an external venture pump was used to hold the substrate flat for the printing experiment. During the experiment, the Rheopump chamber pressure was held constant at 1.0 psi. Several boards were printed to stabilize the chamber pressure before the actual DOE was run. To eliminate paste simmering, the stencil was cleaned with solvent and vacuum after each print.

Print DOE

The factors and level setting for the print DOE is shown in table 2. As it can be seen from this table, the experiment consisted of three factors, two levels, and full factorial design. The response for the print experiment was wet paste volume and height. A Kho Young (KY300) Solder Paste Inspection (SPI) system was used to characterize the print quality, paste volume and paste height. In addition, optical images of the printed board were also collected to obtain qualitative data.

Table 2: Factors and level for print DOE

Purpose of test: To establish guideline for substrate bumping using stencil printer						
Date: XXX			Engineer:			
Experimentation Type: Screening			Full Factorial (3^3 , 2 Levels)			
Factor	Parameter	LEVELS		Comments		
		(-)	(+)			
PS	Print speed	1	2	ips		
PP	Print pressure	18	22	psi		
SM	Separation method	P1	P2			

P1 – Distance = 0.1mm
 Speed = 0.02mm
 Step Size = 0.001mm

P2 – Distance = 0.1
 Speed = 0.1
 Step Size = 0.01mm

Response: Paste volume, pad height							
Qty	Treatment order	Run order	PS	PP	SM	Volume	Height
4	5	1	1	-1	-1		
4	3	2	-1	1	-1		
4	6	3	1	-1	1		
4	1	4	-1	1	1		
4	8	5	1	1	-1		
4	7	6	-1	-1	-1		
4	4	7	-1	1	1		
4	2	8	1	-1	1		

Note: KY300 SPI for paste volume, height and area measurement.

To minimize noise, the experiment was fully randomized with 4 repeats (4 boards per run order). The noise was further controlled by printing all 4 boards with one print stroke only; front to rear squeegee direction.

There were several challenges encountered during the experimental stage: the biggest one being the limitation of KY 300 to inspect deposit size below 100 microns. Therefore, data from pads under 100 microns were excluded from the analysis process.

Gage R&R

To ensure minimum experimental variability a Gage R&R study was conducted on the KY300 SPI by inspecting one printed board 20 times. Results from the gage study are shown in table 3. Both volume and height repeatability are well within the acceptable range. Based on this result, the gage was considered to be adequate.

Table 3. Gage R&R from KY300

Volume Repeatability = 15.198 % (3 Sigma)						
Height Repeatability = 4.843 um (3 Sigma)						
Pad	#of Pad	Size X	Size Y	Solder shape	Vol GRR	Ht GRR
0	1875	0.198	0.198	1	8.929	1.827
1	525	0.178	0.178	1	6.052	1.278

Results and Discussion:

The standard order design table for the printing experiment is shown in figure 2. A “repeat” noise strategy was adopted for this experiment to address run-to-run variations. The board was designed to understand the effect of various pad size, web size and pad location. Figure 5 shows the sampling strategy for the study presented here. To make the discussion simple, results from two locations are presented here. Figures 6 & 7 shows the main effect plot and pareto chart for no-clean paste for location 4 (pad size 200 μ) and location 12 (pad size 125 μ) respectively.

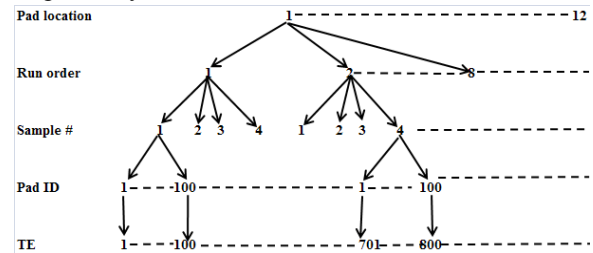
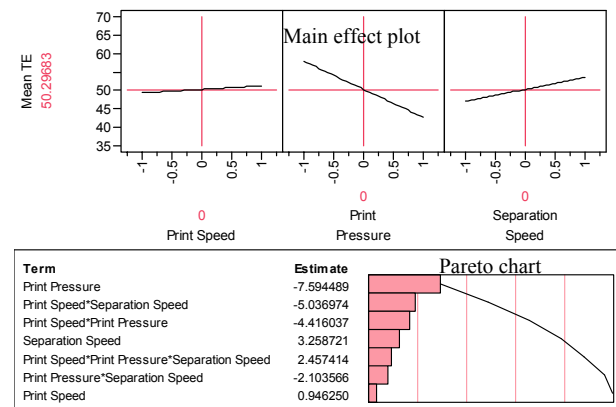
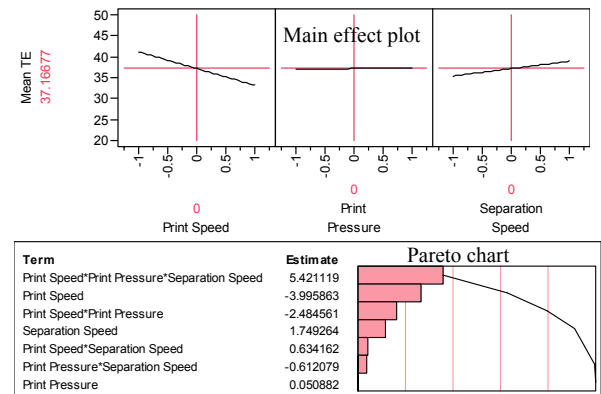
**Figure 5. DOE sampling strategy****Figure 6. Result for no-clean paste, location 4.****Figure 7. Result for no-clean paste, location 12.**

Figure 7 and 8 shows the two locations behave very differently. Specially as the pad size decreases, complex interactions becomes very important for the printing process. This is evidenced by the three way interaction for the 125 μ pad size.

Result for the water base paste for location 4 (175 μ pad) is shown in figure 8. We see here the main effect is different from no clean paste and interaction do play an important role in the TE.

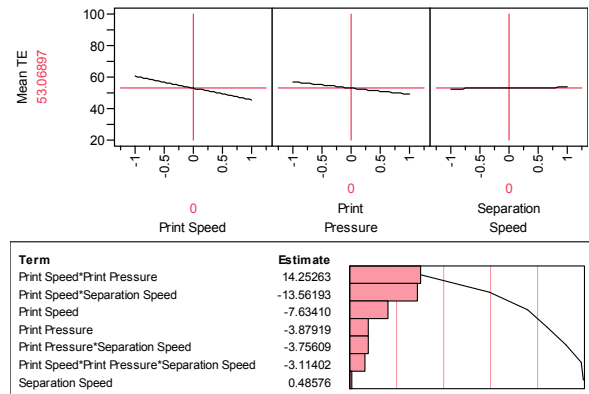


Figure 8. Result for water base paste, location 4.

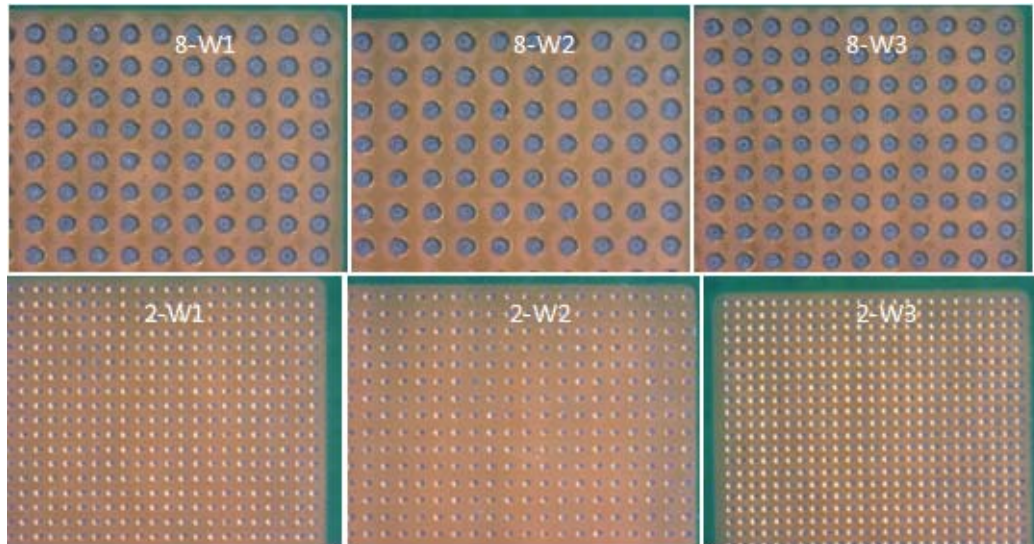


Figure 9. No clean "Paste on pad" images of various pad and web size. 8 and 2 refers to pad size in mils and W1-3 refers to web size of 6,5 and 4 mil

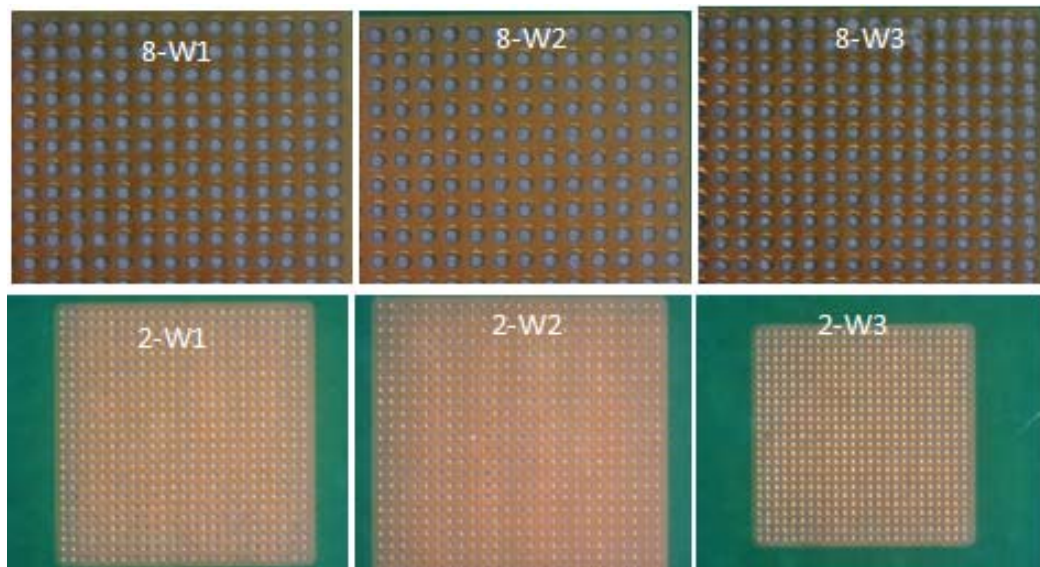


Figure 10. Water soluble "Paste on pad" images of various pad and web size. 8 and 2 refers to pad size in mils and W1-3 refers to web size of 6,5 and 4 mil

Based on the DOE analysis, an optimum factor combination was determined for each type of paste and the result is presented below.

Optical micrographs for both types of pastes are shown in figures 9 and 10. Pad sizes smaller than 100 microns (4mil) showed acceptable paste transfer (qualitatively) but the registration was very poor (paste was printed off the pads) due to board stretch. In addition, the SPI machine used in this study was not able to inspect deposit below 100 microns size.

Hence the result and discussion is restricted to pad size above 100 microns.

As it can be seen from the above figures, the deposits were well formed without any bridging or insufficient for 200 μ pad size. As the pad size decreased, even with higher area ratio, the paste transfer deteriorated due to extremely small aperture opening.

Figure 11 shows the effect of pad size and web on the overall transfer efficiency for both no-clean and water base paste.

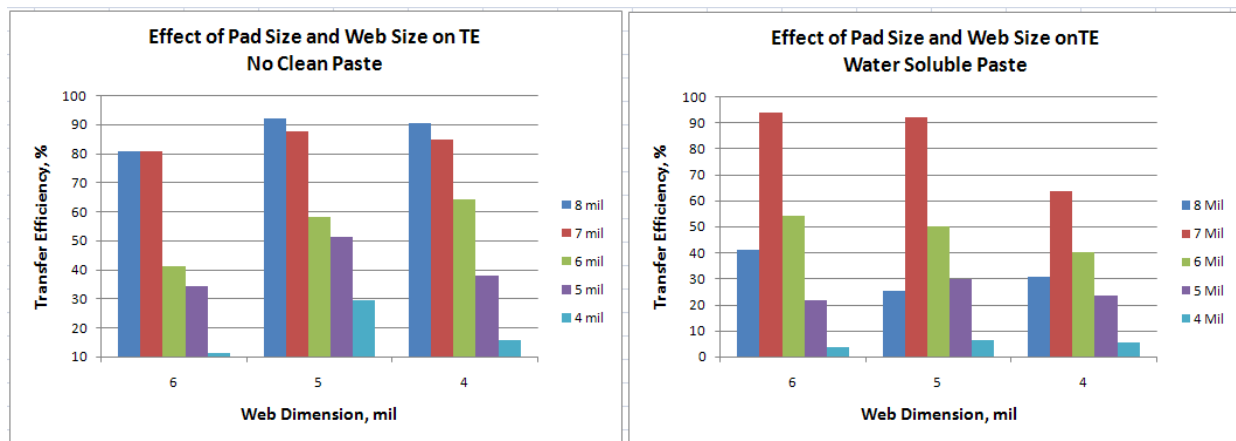


Figure 11. Effect of pad and web size on paste transfer efficiency

Effect of paste chemistry:

Paste chemistry appears to have a significant effect on the paste transfer characteristic. No clean paste provides a more consistent paste transfer as would be predicted by the aperture size. However, water soluble paste shows inconsistent paste transfer for 200 μ and 175 μ pad size. Further investigation is necessary to fully understand the phenomena exhibited here.

Effect of pad/aperture size:

As one would expect, larger pad size provides better transfer efficiency regardless of the area ratio. As it was mentioned above, the inconsistency of water base paste for the 200 μ pad will require further investigation to confirm the finding.

Effect of web size:

Web size shows no effect on the paste transfer efficiency. The critical factor to watch here

would be the stencil life span. As the web size becomes smaller and smaller, the potential for stencil damage becomes higher.

Summary

As this work was an initial attempt at understanding the complex printing process associated with fine pitch printing, the experiment raised more questions than answers. It is clear that the paste chemistry plays an important role in the overall printing performance when it comes to bumping application. It is also clear that pad size below 150 μ becomes a challenge for stencil printing.

Another important observation from this experiment is that strong interactions exist between various factors. The factors include both printing parameters, board design and paste type.

Further investigation is necessary to fully understand the interaction between various factors and set guideline for substrate bumping process using stencil printing process.

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