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Solder Paste Printing of High Density Substrates using Enhanced Print Technology

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Abstract
The research discussed in this paper uses an innovative enhancement technique for printing High Density substrates. The technique takes advantage of high frequency low amplitude vibrations applied to the stencil at the time of the stencil/substrate separation. Similar work has been performed in a previous study for the bumping of wafers,[1] however the range of pitches and bump heights addressed in the present work is different. The pitches and bump heights of interest are of the order of 200 and 40 microns respectively. The study shows that enhanced printing produces taller bumps and more uniform bump heights than can be achieved with conventional printing without vibrations. The study concludes that the vibratory enhanced printing technology represents an economical and attractive alternative for the mass bumping of High Density substrates.

Introduction
The downward migration of device pitches has brought the Surface Mount industry past the limits of the conventional stencil printing process. Direct Chip Attach (DCA) and Chip Scale Packages (CSP) are a few examples. New technologies, such as solder jetting or sphere printing are being investigated to deal with these smaller component requirements. However, another approach has been to investigate techniques that extend the range of conventional solder paste printing. Extending the range of stencil printing to the smaller pitch arena is driven by the obvious benefits of mass imaging techniques: higher throughputs, shorter cycle times and typically, lower cost.

As package sizes decrease, the demands on the conventional stencil printing process have increased. When the stencil aperture opening becomes small (area ratio < 0.66), low and inconsistent solder paste transfer is observed when conventional stencil printing is used[2, 3]. In the research presented here, a novel approach to improve the solder paste transfer effiencies and assembly yields is discussed. The technique consists of applying vibrations to the stencil, during the stencil/substrate separation. The vibration applied to the stencil helps produce more uniform and higher bump height when compared to the conventional stencil printing process. As a result, vibratory printing pushes the limits of conventional printing. As this paper demonstrates it, acceptable prints can be obtained down to area ratios of 0.57. The effects of the enhancement technique on solder bump heights and bump uniformity are quantified in the following sections of the paper.

Test Vehicle Design
The test vehicle was an FR4 substrate with Au plated Cu foil pads 8 microns thick (1/4 oz Cu). The substrate contained both full area and perimeter array patterns (see Figure 1).

The area array contained 3016 pads in a 58 x 52 matrix (12.5 mm x 12.5 mm). Only the full area array pattern was used for evaluating High Density printing. The perimeter array offered no challenge, easily being accomplished by overprinting. The dimension of the UBM was 127 microns x 127 microns and the pitch between the UBM was 190 and 254 microns (Figure 2). Each board was visually inspected for defective UBM before printing. The only defects found were damaged or missing gold plated sites. These defects resulted in poor adhesion of the solder to the pad and subsequent removal of the solder bump during ultra-sonic cleaning.

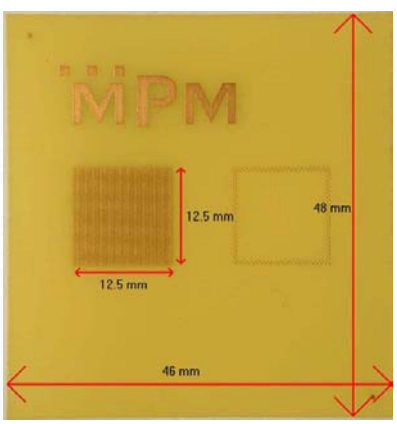


Figure 1 - High Density Substrate – Test Vehicle

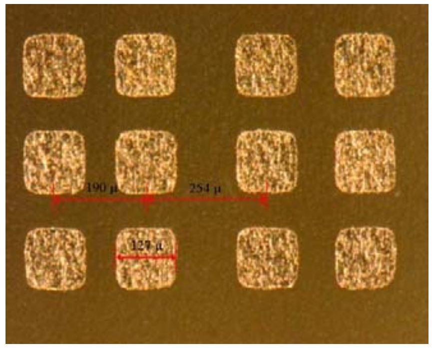


Figure 2: High Density Substrate - UBM

Stencil Design
A 50.8 micron thick laser cut stencil was used in the study. Since the image of the printing area was small, two different sets of aperture openings could be placed on the same stencil. This allowed for two conditions to be evaluated for the cost of one stencil. The stencil apertures were designed as square, in order to maximize the amount of paste deposited per site, given the high density of the device. Figure 3 shows the stencil layout. The stencil image on the top half of the stencil (Location 'A') had an opening of 114 microns (area ratio of 0.57) and the image on the bottom half of the stencil (Location 'B') had an opening of 140 microns (area ratio of 0.69). Aperture dimensions were designed using a truncated sphere model for the bump height.

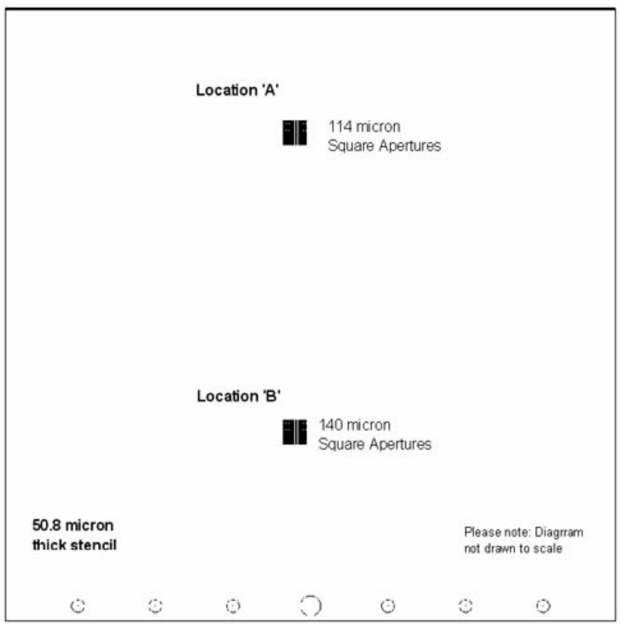


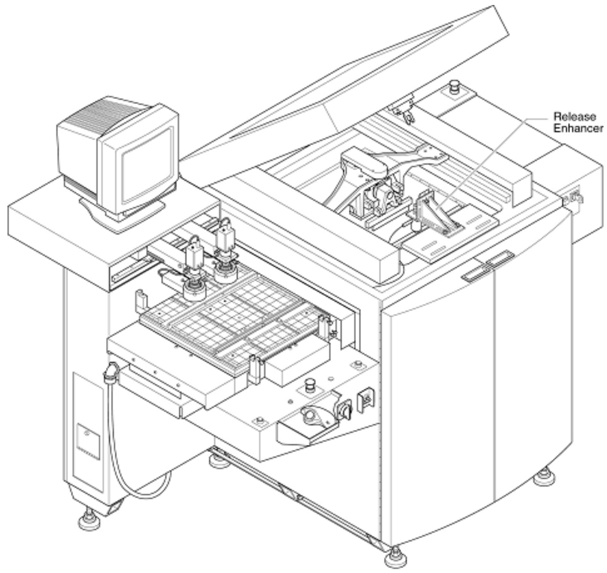
Figure 3 - Stencil Design for HDS

Process Parameters
Printing was carried out using a modified MPM printer with a patent pending enhanced release system. The vibrating unit was coupled directly to the stencil as shown in Figure 4. The boards were printed at a speed of 17.78 mm/sec with a blade pressure of 14 lbs on a 203 mm long blade. Polyurethane blades (90 durometer) were used for printing.

The paste used for printing was a no-clean 63Sn/37Pb Type 5 powder. Hot and cold slump of the paste is a contributor to bridging and solder robbing. The metal loading of the paste was increased to 90.5 wt% in order to minimize slump induced defects.

The reflow of the boards was performed in an Omniflow 7 zone convection oven with nitrogen. Figure 5 shows the profile used for reflowing the boards. An oxygen level of less than 20 ppm was maintained in the oven during reflow. A longer low temperature soak time was provided during the reflow to drive off the lower boiling point volatiles. This procedure was used to reduce the hot slump of the paste during reflow and hence reduce and or eliminate bridging.

Figure 6 show images of printed and reflowed board. The images were taken on a same substrate using a 3x magnification.



Standard SPM Printer

Figure 4 - SPM Printer with Release Enhancement

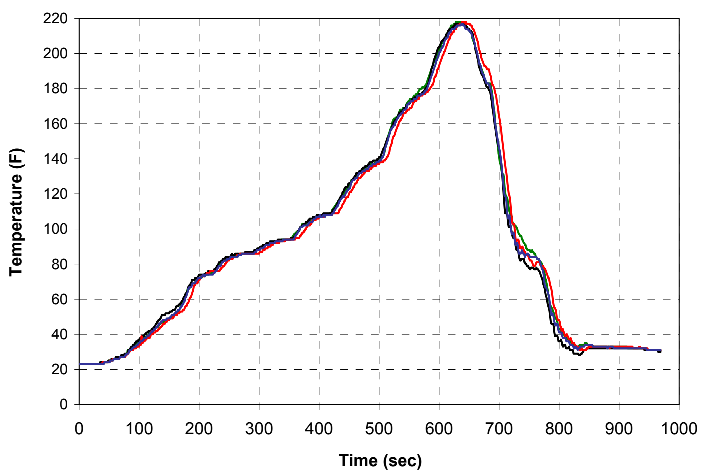


Figure 5 - Reflow Profile

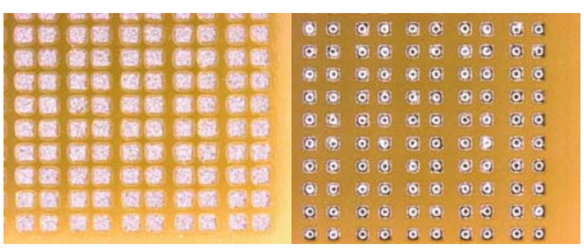


Figure 6 - Images of Printed and Reflowed HDS

Screening Experiment

A simple screening experiment was used to evaluate the performance of each set of apertures. Two boards were printed with enhancement for each aperture size. All four boards were printed using the same print stroke direction. After reflow, the boards were cleaned with IPA in an ultrasonic bath for two minutes. They were then sputtered with Au and measured on the WYKO solder bump height measurement system.

The bump height measurements showed a normal distribution for each set of apertures (Figure 7). The average bump heights for the 140 and 114 micron aperture openings were 52.2 and 37.9 microns respectively. The 114 micron aperture openings were used for further experimentation because they were closer to the 40 micron target bump height. A simple adjustment in aperture size dimension would shift the distribution of the bump heights to the targeted 40 microns without too much difficulty.

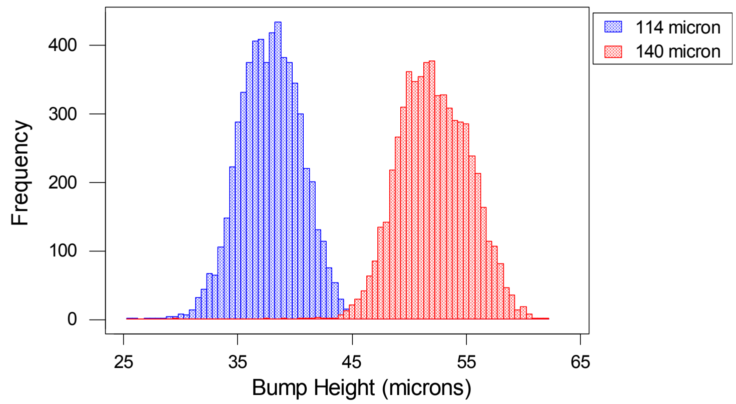
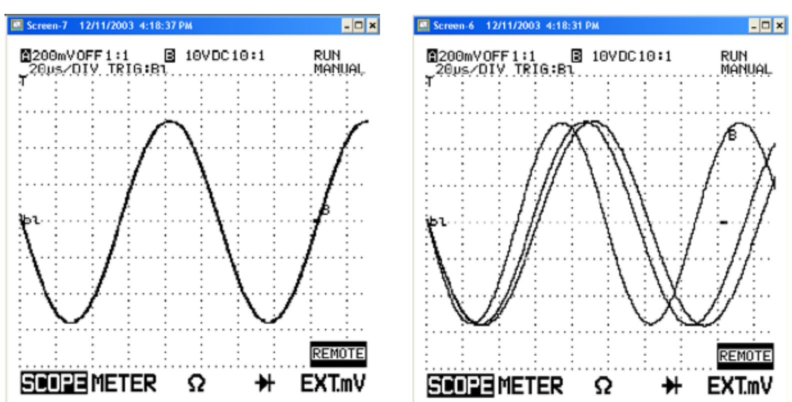


Figure 7 - Bump Height Distribution for 114 and 140 micron Square Opening

Ultrasonic Frequency Optimization

An Etrema Terfenol-D magneto-strictive actuator was used to induce a mechanical wave into the stencil. The actuator was coupled directly to the stencil as shown in Figure 4. Attempts have been made to optimize the frequency by observing release videos of the paste from the stencil apertures at various frequencies[1]. In this study, the previously optimized frequency of 9.2 KHz was used as a baseline frequency. Alternately, it was decided to modulate the baseline frequency in case the 9.2 KHz was not optimal.

The two waveforms used to enhance the release of the solder from the stencil are specified as follows. One was a pure sine wave of 9.2 KHz and the other was a frequency modulated sine wave centered at 9.2 KHz. The span of the modulation was 2 KHz. The modulation frequency was 500 Hz. Figure 8a shows the trace of the 9.2 KHz sine wave. Figure 8b is a trace of the FM 9.2 KHz sine wave.



a b

Figure 8(a) - Waveform of 9.2 KHz and 8(b): Waveform of 9.2 KHz with FM

Experiment

Three print conditions were used to evaluate the print performance of conventional printing and enhanced stencil printing. Table 1 below summarizes the three print conditions and the number of boards used in each condition.

Table 1 - Experiment Matrix

Exp #	Print Condition	# of Board Printed	Stencil Opening
1	Enhancement with 9.2 KHz/FM	9	114 micron
2	Without Enhancement	9	114 micron
3	Enhancement with 9.2 KHz	6	114 micron

All the boards were printed using the same print stroke direction. The printing conditions were maintained constant for all the prints. After print and reflow, the boards were cleaned in an ultrasonic bath with IPA for 2 minutes to remove the flux residue. The substrates where then sputtered with Au. The sputtering process was necessary for the WYKO bump measurement system to operate.

Results

After cleaning/sputtering, the bump heights were measured using the WYKO solder bump height measurement system. The response variables used to measure the performance of the printing process are:

1. Bump Height Distribution
2. Bump Height Range
3. Process Capability Index (Cp analysis)

The results from each of these response variables are discussed below.

Bump Height Distribution

Figure 9 below shows the box plot of height distribution for all the boards printed at three different print conditions. The bottom and top of the box plot represents the first and third quartile. The solid line across the box is the median. The whiskers extend beyond the box to the highest and lowest data point that are within 1.5 times the box height. The asterisks represent all outliers.

The figure shows a target height of 40 microns can be achieved with and without the enhancement. However, the prints without the enhancement have a significant number of outliers on both sides of the distribution. Clearly, the bump height range tolerance cannot be met without the enhancement. The prints with enhancement (i.e., condition 9.2 KHz and 9.2 KHz/FM) have a tighter bump height distribution. To achieve a successful bumping process, the bump heights should be close to the target with a tighter distribution.

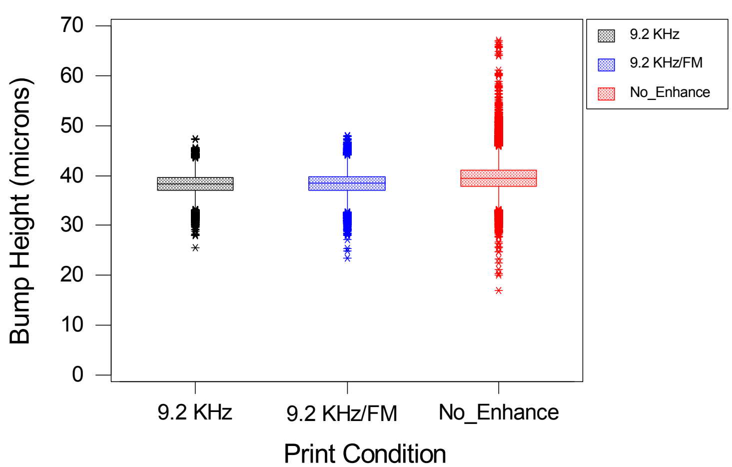


Figure 9 - Box Plot of Bump Height Distribution

Bump Height Range

In addition to the bump height, the uniformity of the bump height is critical to the component attach process. A bump that fails to connect to a substrate will produce a defective package. Figure 10 shows a noticeable decrease in the bump height range for the prints with enhancement when compared to the prints without enhancement. The smaller bump height range reflects a more uniform and consistent release of the paste from the stencil apertures.

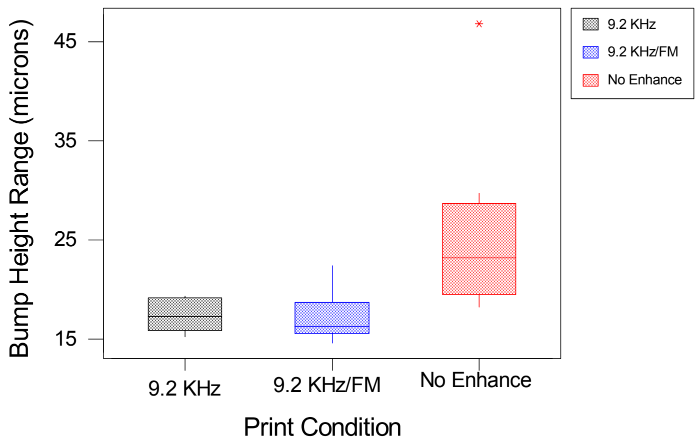


Figure 10 - Box Plot of Bump Height Range

Process Capability Index

Process capability index shows how close a process is running to its specification limits, relative to the natural variability of the process. The larger the index, the less likely it is that the package will be outside the specification limit. Cp is calculated using a specification of 40 +/- 10 microns. Figure 11 below shows the Cp index for the three different print conditions. The prints with enhancement (condition 9.2 KHz and 9.2 KHz/FM) clearly show a better process capability (highest Cp) when compared to the prints without enhancement.

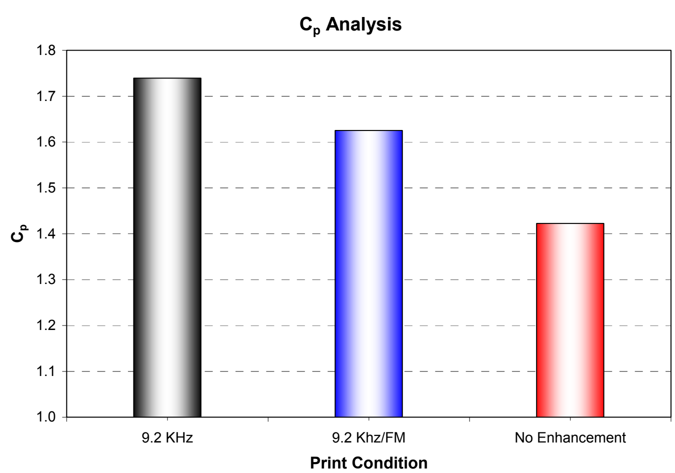


Figure 11 - Plot of Process Capability Index

Conclusions

An analysis of the bump height measurements produced in this study shows that the prints with enhanced release yield tighter bump height distributions and less bump height range when compared to conventional printing without enhancement. The current study clearly shows that vibrating the stencil at the time of stencil/substrate separation extends conventional stencil printing capabilities by improving material transfer efficiencies. The study suggests that the enhanced vibratory printing technique could potentially be an attractive, cost effective process for the mass bumping of High Density substrates.

References

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