Cookson Electronics
A Division of Cookson Group plc

A Technique for Improving the Yields of Fine Feature Prints

Dr. Gerald Pham-Van-Diep and Frank Andres
Cookson Electronics Equipment
16 Forge Park
Franklin, MA 02038

Abstract
A technique that enhances the release of solder paste from stencils during the print process has been developed. The technique is based on applying variable high frequency and low amplitude vibrations to the stencil during the stencil/substrate separation sequence. The effects of the technique are demonstrated in the context of bumping wafers. It is shown that the enhanced print technique produces wafers with less defects, greater bump heights and better height uniformity than when conventional stencil printing is used without the enhancement technique.

Introduction

Conventional solder paste stencil printing is increasingly being proposed as a cost effective process solution for the packaging of electronic components that appear to be continuously shrinking in scale. In the SMT market, a few examples are the packaging of 0201's, □BGA's, and CSP's. In the semiconductor industry, stencil printing has been proposed as an attractive process to deposit minute and controlled amounts of solder pastes on wafers to produce solder bumps.[1]

While print scales decrease, the demands on yields are becoming more stringent. This is particularly true in the SMT industry where the solder paste deposition operation is already recognized as a major contributor to end-of-line defects. As print features decrease in scale, it is expected that print yields will decrease as well, thereby making the solder deposition operation even more critical. In the wafer-level packaging arena, solder paste printing has to produce yields that are comparable to those of currently used bumping technologies in order to compete.

Much work has been performed on designing new solder paste systems to improve print yields.[1] A typical approach has been to design pastes with superior release, minimal slump characteristics, and higher metal content. Other studies have focused on improving transfer efficiencies by modifying stencil aperture geometries.[2] This paper presents a complementary approach to improving transfer efficiencies and print yields. The technique is based on applying vibrations with a characteristic frequency and amplitude to the stencil during the stencil/substrate separation phase. Since print yields are a critical issue for smaller print features, the technique is demonstrated in the context of producing bumps on wafers. The effects of the enhancement technique on release efficiencies, bump heights and uniformity are quantified.

Bumping Technologies

Numerous technologies are presently available as bumping processes: solder evaporation, electro-plating, paste printing on photomasks (also known as the Flip Chip Technologies (FCT) process), stud bumping, robotic ball placement and conventional paste printing on stencils. While the solder evaporation and electro-plating processes produce high quality small pitch solder bumps[3], these techniques suffer from being relatively expensive, complex and rigid in terms of bump alloys. Other bumping processes such as stud bumping and sphere placement typically address regimes of bump size and count against which stencil printing can hardly compete. The FCT process, although very similar to stencil printing, presents the drawbacks of requiring multiple print strokes, multiple reflow sequences, and chemical handling for stripping the photomask. Conventional stencil printing has traditionally been limited in pitch capability, yields and achievable bump heights. The market segment that presents the greatest opportunity for conventional stencil printing is for bumps that are 80 to 100□m high on

Cookson Electronics
A Division of Cookson Group plc

pitches ranging from 200 to 250 □m. This market segment represents the bulk of today's wafer bumping business and appears addressable by conventional stencil printing combined with the enhancement technique presented in this study.

Various analyses place the cost of electroplating solder bumps between 0.02 to 0.1 cent per bump for a 10mil pitch die.[1,4] By contrast the cost of bumping the same die using conventional printing is estimated to be below 0.01 cent per bump. In addition to being less expensive, stencil printing would have the advantages of requiring lower capital investments and deliver higher throughputs. Naturally, this is all contingent on conventional stencil printing being capable of achieving yields that are competitive with those of plating.

Background

A real-time visualization platform capable of simultaneously imaging the substrate and the stencil while the stencil/substrate separation occurs was used to demonstrate and optimize the effects of vibrations on transfer efficiencies. This platform was originally conceived to better understand paste release mechanisms and has been used in other studies for the rapid evaluation of stencil and paste release performances.[5]

The transfer efficiency of a particular print is defined as the ratio of the volume of paste deposited on the substrate to the volume of the stencil aperture. Of particular interest in this study is the difference in transfer efficiency between the case where the stencil is subjected to vibrations and the case where the release occurs without the application of vibrations. Two test stencils were used in the visualization tests, a 2 and a 3mil thick laser cut stainless steel foil. The test stencils had 10, 8, 6, 4 and 3mil circular and square apertures. The test stencils were populated with 106 apertures. Only 53 apertures were printed at a time but as can be seen from Figs.1 through 4, only but a few apertures could be monitored at one particular time. The substrate was copper clad FR4 and the stencil/substrate separation speed was set at 0.1 in/sec.

The physical basis for using vibration to enhance the release of pastes from stencils is to induce enough shear/thinning at the stencil/paste interface to reduce the viscosity of the solder paste at the wall of the aperture. Given the thixotropic nature of solder paste and the shear imparted by the vibrating aperture walls, it is reasonable to expect that a thin layer of paste located near the aperture walls experiences a shear thinning effect ultimately resulting in a better release of the paste from the stencil.

Figures 1 through 4 show a succession of video frames illustrating the transfer of paste from the stencil for various print conditions. Figures 1 and 2 show the release sequences for five 6mil square apertures with a stencil thickness of 3mils. Similarly, Figs.3 and 4 show the release sequences for six 4mil circular apertures for a stencil foil 2mil thick. Figures 1 and 3 correspond to the no-vibration case while in Figs.2 and 4 the stencil is subjected to vibrations. As a reference, the dashed red line indicates the stencil lower surface while the solid blue line indicates the substrate. Note that a reflection of the paste transferred to the substrate can be seen in the stencil.

A comparison of Figs.1 and 3 to Figs.2 and 4 shows that vibrations produce not only a noticeable increase in transfer efficiency but also an improvement in print yields. For example, while some deposits are missing in Fig.1, all of them are present in Fig.2. In the case of the 4mil apertures of Fig.3 it can be noted that virtually no paste is transferred when no vibrations are applied while a noticeable amount of paste is transferred for all apertures when vibrations are applied as indicated in Fig.4. It is also interesting to note that the area ratio for either of these print conditions is 0.5. The area ratio is conventionally defined as the ratio of the area of the substrate wetted by the paste to the aperture wall area. It is common practice in the stencil printing business to avoid using stencil apertures with area ratio that are less than 0.66. Figures 1 through 4 indicate that when vibrations are applied to the stencil, apertures that have area ratio less than 0.66 can be used to reliably produce small solder paste deposits. However, the question of whether the effects of vibrations shown for a small number of apertures could be implemented in an industrial context for a full wafer typically requiring hundreds of thousands of deposits still remains to be addressed.

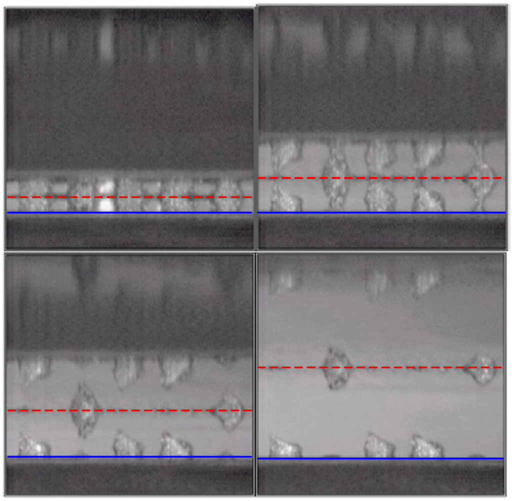

Figure 1: Release of 6mil square apertures, 3mil thick stencil without enhancement

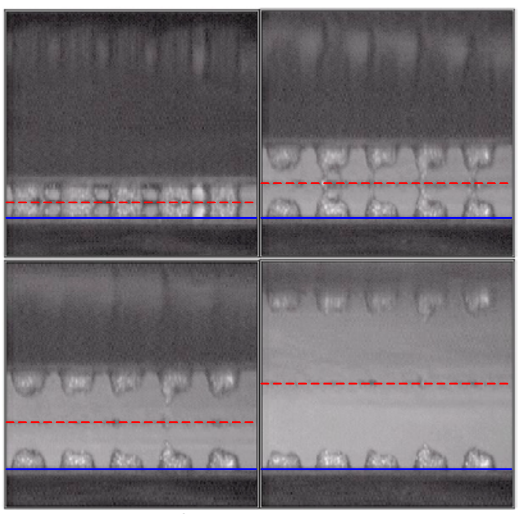

Figure 2: Release of 6mil square apertures, 3mil thick stencil with enhancement

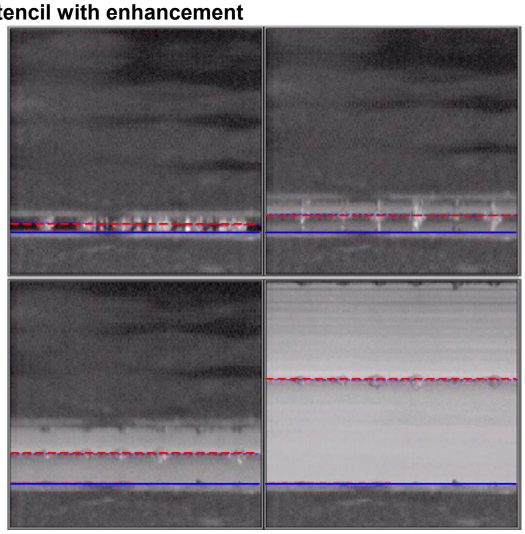

Figure 3: Release of 4mil circular apertures, 2mil thick stencil without enhancement

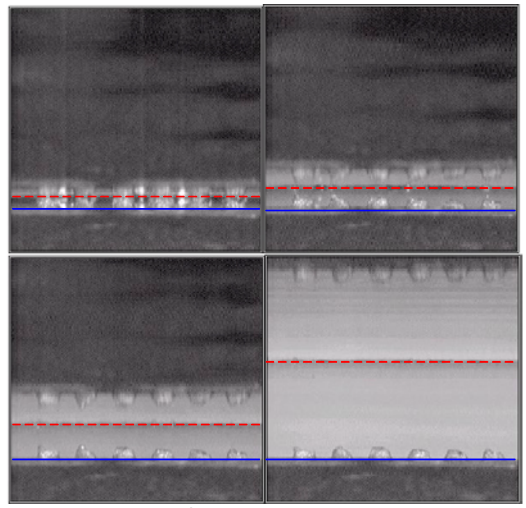

Figure 4: Release of 4mil circular apertures, 2mil thick stencil with enhancement

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 foil. The frequency and amplitude of the wave were controlled with a function generator. Frequency optimization was done using the real time visualization platform.[5] Videos of releases with different frequency vibrations were taken. The stencil release speed was 0.1 inches per second and the print speed was 12.7 mm/s. A 90 durometer polyurethane blade with a pressure of 0.5 lb per cm of blade was used. The videos were then compared to each other in order to determine which frequency produced the best paste transfer. A frequency of 9.2 KHz appeared to work the best for both the 6mil square apertures and the 4mil circular apertures. Typical displacements of the stencil were on the order of one quarter of a micron. The displacement of the stencil was measured with a Bruel and Kjaer accelerometer.

Wafer Bumping Experiment

A standard FA10 wafer (125mm dia.) was used as a test vehicle. The pitch was 254 μm with a full area array. There are 109,048 bumps per wafer. The Ni/Au under bump metalization was 102 microns in diameter.

A no clean type 5 powder paste was used. The solder was Sn63/Pb37 composition with a weight percent of 87.7%. An electroformed

76μm thick stencil was used for printing. The apertures were 152μm squares. This left a 102μm web thickness. Bump height measurements were made using a WYKO NT-2000 bump measurement machine.

Printing was performed with a modified SPM printer (see Fig.5). The actuator was coupled directly to the stencil foil. A 90 durometer Polyurethane blades, 203mm long was used. The squeegee speed was 12.7 mm/s. The blade pressure was 18lbs. The stencil/wafer separation velocity was 14 mm/s.

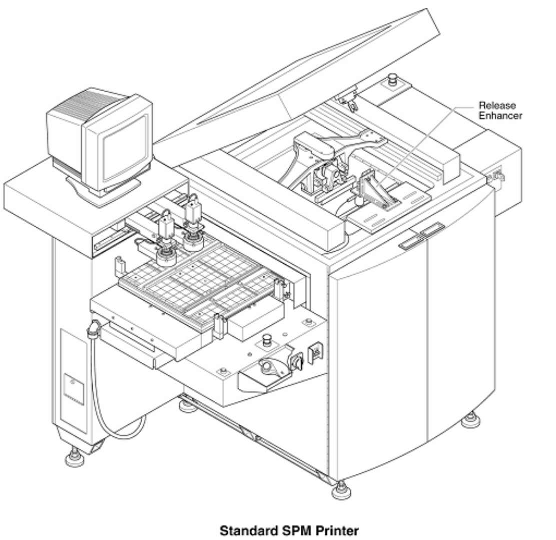

Figure 5: SPM Printer with enhanced release system

Results

A total of three wafers were printed and subsequently reflowed in a Nitrogen environment. Three different print conditions were tested: 1) contact printing without stencil vibration, 2) contact printing with vibrating stencil at the time of release and 3) snap-off printing (70mil). For contact printing the entire wafer is in contact with the stencil when the squeegee performs a print stroke. By contrast, snap-off printing implies that the stencil is in contact with the substrate only along the line where the squeegee contacts the stencil. Figure 6 shows distributions of average bump heights for the three print and release conditions. Figures 7 and 8 show box plots of the average co-planarity per die and the height range within a die for the three print conditions described above. The plots represent measurements taken over the entire wafer, so each plot represents a bump sample population of 109,048 elements.

The average bump height per die is the mean value for all bumps measured within a die. The measurement device defines the average co-planarity. It is specific to a die not a wafer. The three highest bumps within a die that are significantly far enough apart are used to define a plane. The distance a bump is from this plane is the reported co-planarity value. It follows that at least three bumps within a die will have a co-planarity of zero. The height range within a die is the maximum bump height minus the minimum bump height.

The bottom and top of the box plot represents the first and third quartile. The solid line across the box is the median and the dot is the mean. The whiskers extend beyond the box to the highest and lowest data point that is within 1.5 times the box height. The asterisks represent all outliers.

The print parameters were optimized in a qualitative manner by varying the print speed and blade pressure while observing the resulting print under a light microscope. The quality of the print, least slump and best brick like definition were used to judge the prints. The same print conditions were then used for the three sets of print tests.

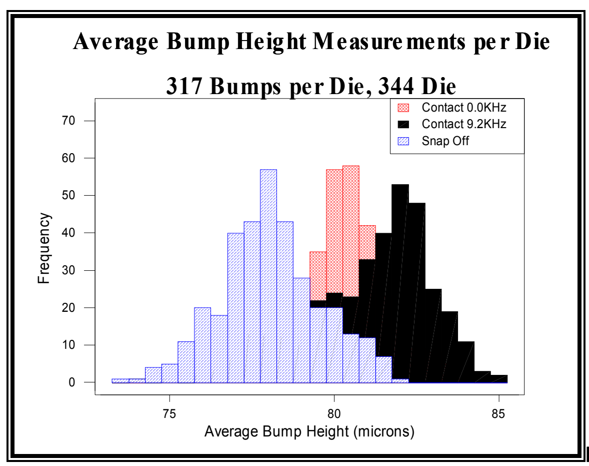

Figure 6: Distributions of average bump heights for three print/release techniques

Figure 6 indicates that a significant increase in bump height is achieved when the stencil is subjected to vibration at the time of the stencil/substrate separation. A bump height gain of about 4μm can be noted when the "Snap-off" distribution is compared to the "Contact with vibration" distribution. This gain in average bump height corresponds to a volume or transfer efficiency increase of about 15.3%, which represents an appreciable improvement in print performance. An increase in transfer efficiency typically results in more consistent deposits, which would in the context of this study produce better bump height uniformity.

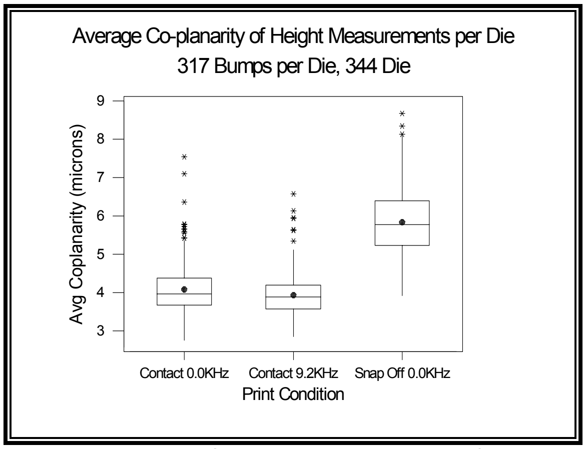

Figure 7: Box plot of the average co-planarity for each die

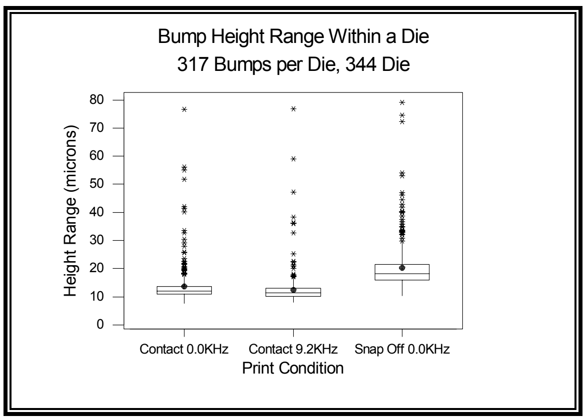

Figure 8: Box plot of the bump height range within a die

In addition to bump height, bump height uniformity is critical to the die-attach process. A bump that fails to connect a die to a substrate will produce a defective package. Moreover, a die whose bump heights fall within too broad of a range may cause premature failure of the device even though the package may originally function. Figure 7 and 8 show a noticeable decrease in both co-planarity and bump height range within a die for contact printing with enhancement in particular when compared to the "Snap-off "printing case.

Each wafer was visually inspected for print defects after reflow. Two types of defects were recorded: skips and extra bumps. Table 1 shows the yield for each wafer. The yield is based on the number of bad die and only takes into account print-related defects.

	Snap off 0.0KHz	Contact 0.0KHz	Contact 9.2KHz
Bad die due to print defects	10	5	3
Die Yield	97.1%	98.5%	99.1%

Table 1: Die Yield after Reflow

Conclusions

Preliminary print tests have demonstrated that an appreciable gain in solder paste transfer efficiency can be achieved if specific vibrations are applied to the stencil at the time of the stencil/substrate separation. Bump height measurements also indicate that the enhanced release technique produces improvements in bump co-planarity performance. A visual inspection of the wafers for print defects indicates the enhanced printing process results in a reduction in skips. Although only a limited number of wafers were tested, die yield figures based on print-related defects are acceptable. The bump heights achieved in this study are lower than those required by the current wafer bumping industry. Future work will focus on producing similar results but for larger bumps.

References:

1. Dr. Benlih Huang and Dr. Ning-Cheng Lee, "Low Cost Solder Bumping via Paste Reflow", Journal of SMT, Volume 15, Issue 1, 2002.
2. Dr. Gerald Pham-Van-Diep et al., "A Study of Small and Tapered Aperture Transfer Efficiency", Proceedings of Nepcon West, San Jose, CA, 2002.
3. John Franka et al, "Solder Bump Technology: Present and Future", SemiconductorFabtech.com.
4. Jack Bodanski,"The Economics of Flip Chip Wafer Bumping Assembly", Procedings of Nepcon West, Anaheim, CA, 1998.
5. Dr. Gerald Pham-Van-Diep et al., "Visualizing and Predicting Solder Paste Flow", Circuit Assembly, February 2003.