Solder Jet Technology Update

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Abstract

Solder Jet Technology (for example, piezoelectric demand-mode ink-jet printing technology used to dispense molten solder droplets) has demonstrated the ability to place 25-125µm diameter bumps onto metallized wafers, circuit boards, and other substrates. Recent developments are discussed in this paper, including test vehicle printing, drop size modulation, microbump printing, and print-on-the-fly.

Key words: Solder Bumps, Wafer Bumping, Chip Scale Packages, and Flip Chip Technology.

1. Introduction

The formation of microdroplets of solder using ink-jet printing technology (Solder Jet technology) has been demonstrated, and MicroFab’s Solder Jet development efforts have been described in detail in previous papers and patents. Recent research efforts have been directed toward demonstrating Solder Jet Technology as a robust wafer bumping method for high volume manufacturing. This paper describes recent results in the areas of test vehicle printing, drop size modulation, microbump printing, and print-on-the-fly (such as dispensing droplets without stopping the translation stages).

2. Background

In demand mode ink-jet printing systems, a volumetric change in the fluid is induced either by the displacement of a piezoelectric material that is coupled to the fluid, or by the formation of a vapor bubble in the ink, caused by heating a resistive element. This volumetric change causes pressure/velocity transients to occur in the fluid and these transients are directed so as to produce a drop that issues from an orifice. A droplet is created only when it is desired in demand mode systems. Demand mode ink-jet printing systems produce droplets that are approximately equal to the orifice diameter of the droplet generator.

The goal of this research work is the development of advanced solder deposition equipment for the electronics manufacturing industry. Solder Jet Technology is based on piezoelectric demand-mode ink-jet printing technology and is capable of producing and placing molten solder droplets, 25-125µm in diameter, at rates up to 2,000 per second. Solder Jet-based deposition will be low in cost (no tooling required), noncontact, flexible, and data-driven technology (no masks or screens are required since the printing information is created directly from CAD information and stored digitally), and it is also an environmentally friendly (it is an additive process with no chemical waste).

3. Test Vehicle Printing

The locations of the pads of an integrated circuit test vehicle with over 1,400 pads were programmed into the initial Solder Jet research platform. This platform is a modified Universal Instruments Corporation hot-bar bonder with the Solder Jet printhead replacing the hot-bar mounted onto the moving gantry. Since this platform moves to each bump location and stops before printing, the net throughput is 4-5 bumps/second.

For these tests, droplets of Sn63/Pb37, 70µm in diameter, were deposited onto several of these test vehicles. Figure 1 shows the results from one test vehicle, and Figure 2 illustrates the details from the same image. The solder bump was deposited onto a nickel pad...
metallization, covered by a flash of gold, which promotes adhesion during the droplet impact and freezing process\textsuperscript{11}.

Figure 1. Illustration of results from one test vehicle (IC test vehicle with 1440 pads, bumped with 63/37 using Solder Jet Technology. Ball size is 70µm).

Figure 2. Details of Figure 1. Files were scanned at 400 dpi from the 5x7 version of attached photograph. Exact location of close-up is not critical.

A scanning electron micrograph (SEM) was obtained of a bump on the substrate and is shown in Figure 3. This bump was imaged in the as deposited state (not reflowed), and the tin and lead rich phases are clearly visible. An SEM micrograph was also obtained from a Free Ion Beam (FIB) cross-section of a bump, and is shown in Figure 4. This bump was also imaged in the as deposited state, and, again, the lead rich and tin rich phases are apparent. The voids seen in the cross-section are most likely an artifact of the cross-sectioning process, since they are not apparent at the surface of the original bump.

Figure 3. SEM Micrograph of a bump on the substrate. (60µm diameter 63/37 bump deposited onto the IC test vehicle).

Figure 4. The JPEG images extracted from a Word file. (Higher resolution).

4. Drop Size Modulation

Solder Jet Technology is inherently flexible since each droplet is dispensed under digital control. To increase the flexibility of the system, the researchers have recently developed novel drive waveform technology that allows the drop size to be modulated over an approximately 2:1 diameter (8:1 volume) range. Figure 5 shows a Solder Jet device producing 62µm diameter droplets at a rate of 120 Hz. The image on the left in this Figure shows the droplet being formed while it is still attached to the orifice of the dispensing device, and the image on the right shows the drop approximately 1 ms later, after it has broken free from the dispenser. The drop velocity is approximately 1.5 m/s.
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Figure 5. Illustration of solder jet device. The drop formation process for a Solder Jet device is shown at two times ($\Delta t \sim 1\text{ms}$) during the process. The drop rate is 120 Hz and drop size is 62µm.

Figure 6 shows the same device operating moments later, again at 120 Hz. In this Figure, a drive waveform that extends the drop formation process over a significantly longer time period is being used. By doing this, a considerably larger droplet is produced. The magnitude of the drive voltage has been altered (increased) to keep the drop velocity at approximately 1.5 m/s. In this case, the diameter is increased to 106µm. Volume modulation using this method is continuous over the entire range of achievable volumes, as illustrated by the results presented in Figure 7.

Figure 6. Illustration of same device operation (captured video image with high resolution). The drop rate is 120 Hz and drop size is 106µm.

This drop volume modulation capability can be used to allow the bump size to be changed under software control, either for product change over, or for the application of variable sized bumps onto a single substrate (wafer or die). With sophisticated drive electronics, volume modulation can be accomplished on a drop-to-drop basis, as has been demonstrated for conventional ink-jet printing at rates up to 3,000 drops per second. This real-time drop volume modulation capability does not currently exist for Solder Jet printheads. Due do the drive waveform used to obtain the larger drop sizes increases the duty cycle of the waveform, the drop formation is limited to rates of up to 1,000 per second.

5. Microbump Printing

Solder bumps currently used in flip chip processes are typically in the 100-125µm diameter range, although some companies are currently evaluating 75µm diameter and smaller bumps. As higher circuit densities and/or greater I/O counts are achieved in integrated circuit devices, there is likely to be a need for smaller bumps for flip chip processes. Initial experiments were conducted to evaluate the suitability of Solder Jet technology for smaller bump sizes. The same printhead and dispensing device design were used for these tests, but the dispensing device diameter was deceased to ~20µm. Figure 8 shows small section of an array of 25µm, 63Sn / Pb37, bumps deposited on a 35µm pitch onto a silicon wafer. Due to of the high surface tension associated with solder (and all liquid metals), it is likely that a 15-20µm diameter is the practical lower size limit for ink-jet based solder bump deposition.

Figure 7. Drop size modulation results.

Figure 8. Polaroid photo is attached. 25µm bumps of 63/37 deposited on 35µm pitch using Solder Jet Technology.
6. High Rate Deposition

The ability to deposit bumps onto substrate at rates of greater than 200 Hz is critical to the commercial viability of Solder Jet technology. The ability to form liquid metal droplets at this rate, and higher rates, was demonstrated several years ago, but platform limitations have prevented the researchers from demonstrating bump rates this high. Two research platforms have been completed that have the ability to deposit bumps, using Solder Jet Technology, while the substrate and/or the Solder Jet printhead are moving. This operating mode is referred to as "print-on-the-fly."

Since the solder droplet travels at a rate of 1m/s or greater, and the velocity of the printhead or substrate would be 5cm/s to place 200 bumps per second on a 250µm pitch, the oblique impact of a drop in print-on-the-fly is not a major concern. However, the locally inert environment near the dispensing device is potentially far more sensitive to translation velocity. Therefore, maintenance of the low oxygen environment was the focus of initial print-on-the-fly experiments. The effectiveness of the inert environment control was measured by an oxygen meter sampling through an empty (of solder) dispensing device and reservoir while the printhead was in printing position above a moving substrate. With substrate velocities up to 10 cm/s, oxygen levels of less than 50 ppm were maintained using nitrogen flow rates of less than 0.14 standard cubic meters per hour (5 scfh).

In addition to measuring oxygen concentration near the dispensing device, initial experiments were conducted with the printhead dispensing at a constant rate over an unpatterned substrate at a rate of 200 drops per second. Bumps were placed using substrate velocities of 2-10 mm/s. The low oxygen level was evidenced by the roundness of the deposited bumps: drops that have significant oxide formation during flight and impact are teardrop shape due to the oblique impact. In addition, microscopic inspection indicated no visible oxide formation.

MPM Corporation has fabricated a Solder Jet research platform that allows for print-on-the-fly operation at rates up to 600 bumps/second. This platform uses a fixed printhead and substrates mount on an x-y stage. In addition to print-on-the-fly capability, some of the features of this platform are: printhead setup, maintenance, and visualization station; substrate temperature control; vision system alignment of the dispensing site to fiducials on the substrate; and substrate pad data file input. Initial print-on-the-fly experiments were conducted on this platform by printing 39x39 arrays on unpatterned copper substrates. Figure 9 shows an example of the results from these experiments. Operating conditions for this experiment were as follows: substrate translation velocity = 12.7 cm/s (5 ips); 304.8µm (12 mil) spacings between bumps; 417 Hz bump rate; bump size ~ 100µm; and bidirectional printing.

Print-on-the-fly performance was quantitatively assessed by measuring the orthogonal distance between successive bumps in both directions. The distance between bumps in the direction of travel (horizontal in the Figure) reflects stage, droplet velocity, and straightness errors, while the distance between bumps normal to the direction of travel (vertical in the Figure) is indicative of stage and straightness errors. The standard deviation of drop-to-drop distance was 0.005µm for the vertical direction and 0.007µm for the horizontal direction. Both values are on the order of the stage accuracy.

Work is currently in progress to assess the accuracy of printing onto pad locations in print-on-the-fly mode. These experiments are also being conducted on the MPM research platform described above. Figures 10 and 11 show a section of an 18x18 array of ~90µm diameter 63/37 bumps printed on-the-fly onto 100µm pads on 250µm centers at 100 bumps/second. The substrate is silicon and the pads are copper. Quantitative assessment of bump-to-pad placement accuracy will be completed in the near future.
7. Summary

The ability to accurately place solder balls, using Solder Jet technology, over a wide range of ball sizes (25-125µm), and at high rates (over 400 bumps/second), onto patterned and unpatterned substrates has been demonstrated in this work. Incorporation of Solder Jet technology into commercial wafer bumping platforms by MPM Corporation is currently underway.

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References


About the authors

Dr. Wallace received his B.S.E. Degree in 1973, and his M.S.M.E. Degree in 1979, both from Southern Methodist University. He was awarded a Ph.D. Degree in Aerospace Engineering from the University of Texas at Arlington in 1987. After spending four years performing defense related research on laminar flow control and turbulence, Dr. Wallace has spent the last 15 years developing ink-jet printing technologies and applications. He has developed experimental and analytical techniques for applications of ink-jet technology to novel areas, including electronics and semiconductor fabrication processes, space based radiators, biomedical applications, and other industrial processes. Dr. Wallace is the inventor and co-inventor on 15 patents related to the development of these systems. He has been principal investigator on research Grants from NSF, DOC, DOD, and NIH. Dr. Wallace has authored over 50 presentations and publications.

Dr. Hayes holds a B.S. Degree and a M.S. Degree in Physics from LSU, and a Ph.D. Degree in Materials Science from Rice University. He has over 20 years experience managing research and development of process driven manufacturing for ink-jet printers, semiconductor devices, and electronic assemblies at MicroFab, Mead Office Systems, Polaroid, and Texas Instruments. He has been awarded 19 patents and has over 20 patent applications outstanding. He is member of the Engineering Counsel, Eric John School of Engineering, University of Texas at Dallas and a member of the Materials Technology Review Board, Texas State Technical Institute.