Solder Jet Printing of Micropads and Vertical Interconnects

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Abstract

Solder Jet Technology (e.g., 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, including, microbump printing, and vertical interconnects. The latter includes Chip-Scale Packaging applications.

Key Words: wafer bumping, chip-scale-packages, flip-chip

INTRODUCTION

The adoption of area array attachment as a "packaging" and assembly process is well underway in many areas of the electronics industry. High density area array technologies such as direct chip attach (flip-chip), chip-scale packages, and micro-BGA's are applying pressure to currently available interconnect technologies at the chip, package, and substrate levels.

The methods developed to date for flip-chip assembly have utilized feature sizes (100μm pads and 250μm pitchs) comparable to the wire bonding processes that flip-chip is replacing. This is partly due to standardization of pad sizes during semiconductor fabrication, and partly due to the difficulty of depositing solder onto smaller pad sizes and pitches. As flip-chip becomes a more accepted process, and as semiconductor IO's continue to increase (at constant die size, due to decreasing feature size), there will be pressure to decrease the pad size and pitch in flip-chip processes to less than 100μm and 250μm, respectively, in order to meet the demands of the ever increasing number of small, portable products. Solder Jet Technology is capable of achieving bump features sizes down to 25μm and pitches of less than 50μm, and its application to advanced flip-chip configurations will be discussed.

Chip-scale packages relieve some of the test and handling difficulties with flip-chip assembly, but require vertical interconnect between the integrated circuit pads and the solder bumps on the package. A novel wafer level chip-scale package fabrication method, using Solder Jet Technology to create the vertical interconnects, will be presented.

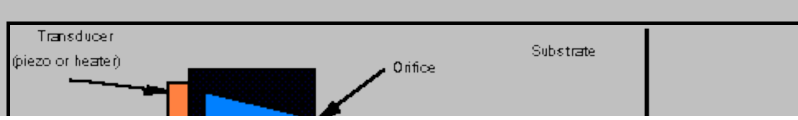
As the density of semiconductor devices, substrates, and packages increases, the size of the vias and vertical interconnects between substrate layers must decrease. Solder Jet Technology can create vertical structures with features sizes down to 25μm, pitches of less than 50μm, and aspect ratios greater than 20. Initial experimental results will be discussed, and several concepts will be presented.

BACKGROUND

The goal of our research 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 cost (no tooling required), noncontact, flexible & data-driven (no masks or screens are required because the printing information is created directly from CAD information and stored digitally), and environmentally friendly (it is an additive process with no chemical waste). MicroFab's Solder Jet development efforts have been described in detail in previous papers and patents. [(1) (2) (3) (4) (5) (6)]

INK JET TECHNOLOGY

In demand mode ink-jet printing systems, a volumetric change in the fluid is induced either by the



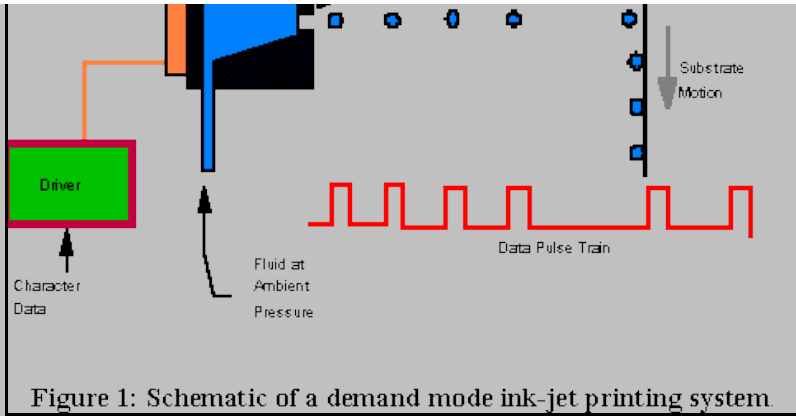


Figure 1: Schematic of a demand mode ink-jet printing system.

displacement of a piezoelectric material that is coupled to the fluid,(7) or by the formation of a vapor bubble in the ink, caused by heating a resistive element.(8) This volumetric change causes pressure/velocity transients to occur in the fluid, and these are directed so as to produce a drop that issues from an orifice.(9) (10) 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. **Figure 1** shows a schematic of a demand mode ink-jet system.

SOLDER JET TECHNOLOGY

Prototype Printhead & Platform

Our initial research efforts demonstrated dispensing of 40-110μm spheres of molten solders at temperatures up to 220C, on-demand, and at rates up to 2,000 per second.(4) Operation was initially demonstrated with Indalloy-58, a low temperature (70C liquidus) eutectic solder. These results have been extended to Sn63/Pb37, indium, In52Sn48, and other solder alloys. **Figure 2** shows a MicroFab demand mode ink-jet device generating 62μm diameter drops of 62/37 from a device with a 58μm orifice at the rate of 120 per second.

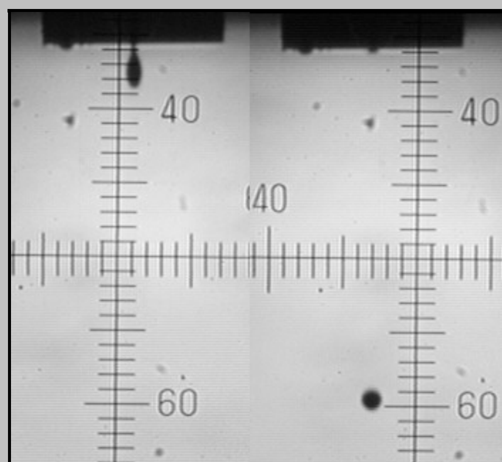


Figure 2: The drop formation process for a Solder Jet device shown at two times during the process; drop rate is 120 Hz and drop size is 62μm.

The droplet generator used in these efforts was incorporated into a printhead design suitable for integration into a prototype platform. Key features of the printhead include: a heated inert environment localized to the tip of the droplet generator and impact area of the substrate; separate heaters for the solder reservoir and droplet generator; vertical dispensing capability; and the ability to deposit solder droplets while the printhead is in motion.

The Solder Jet printhead has been integrated into platforms fabricated by four companies. MicroFab and Universal Instruments have built Solder Jet research platforms, and Motorola and MPM have built prototype production platforms. Some of the features that these platforms incorporate include: printhead setup, maintenance, and visualization station; substrate temperature control, vision system alignment of the dispensing site to fiducials on the substrate; substrate pad data file input; automated dispensing onto the pad locations with an arbitrary number of droplets onto each pad; print-on-the-fly for high throughput operation; vision system assessment of solder droplet placement accuracy, and application of variable sized bumps onto a single substrate. **Figure 3** shows a Solder Jet printhead mounted onto MPM's feasibility demonstration platform.

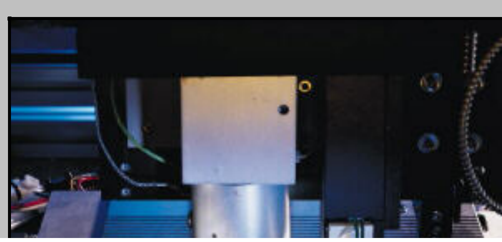
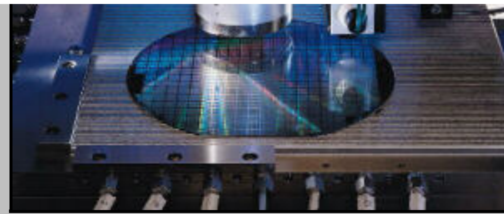


Figure 3: Solder Jet printhead mounted onto MPM's feasibility demonstration platform.



Test Vehicle Printing

The locations of the pads of an integrated circuit test vehicle with more than 1,400 pads were programmed into MicroFab's Solder Jet research platform. Droplets of Sn63 Pb37, 70μm in diameter, were deposited onto several of these test vehicles.. **Figure 4** shows the results from part of one test vehicle. The solder bumps were deposited onto a nickel pad metallization, covered by a flash of gold which promotes adhesion during the droplet impact and freezing process.[(11)]

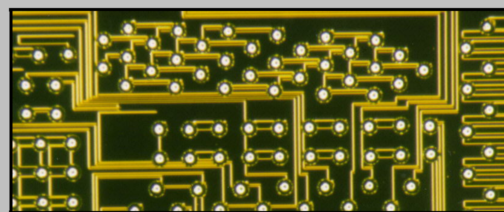


Figure 4: IC test vehicle with 1440 pads, bumped with 63/37 using Solder Jet Technology. Ball size is 70µm.

High Rate Deposition

The ability to deposit bumps onto substrates at rates of greater than 200 Hz is critical to the commercial viability of Solder Jet technology.. To accomplish this, the platform must have the ability to deposit bumps while the substrate and/or the Solder Jet printhead are moving. This operating mode is referred to as "print-on-the-fly"

To qualify the Solder Jet printhead for print-on-the-fly operation, initial experiments were conducted on the MPM platform. A print pattern of 39 x 39 bumps, nominally on 300μm centers, was programmed into the platform control software. The pattern was printed bidirectionally using 60μm diameter droplets of 63/37, at 60mm/sec, for an effective bump rate of 200/sec. A photomicrograph of an area of the print sample is shown in **Figure 5**.

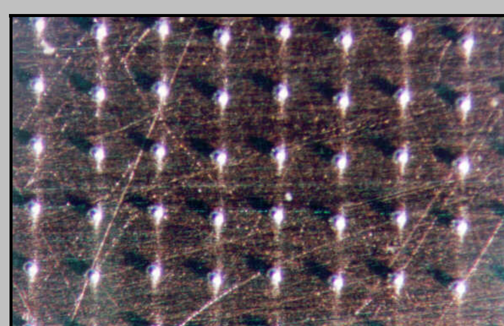
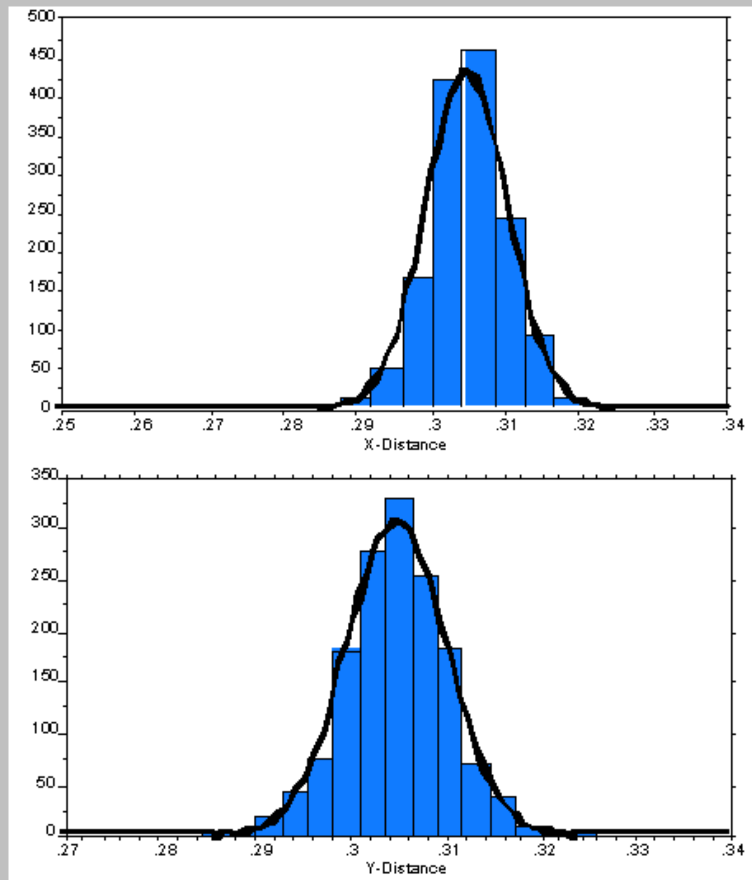


Figure 5: Sample from 39x39 array of 60µm diameter balls of 63/37 printed on-the-fly at 60mm/sec (200 bumps/sec) onto a copper substrate.

The effectiveness of the inert environment is 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. This result was expected because previous experiments with substrate velocities up to 10cm/s (on a rotating surface underneath the printhead) showed no significant degradation in performance.

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 (vertical in the figure) reflects both droplet velocity and straightness errors, while the distance between bumps normal to the direction of travel is indicative of straightness errors only. Note that the rows of bumps in **Figure 5** form a herringbone pattern that results from bidirectional printing. Although the algorithm that corrects for droplet arrival time during print-on-the-fly was enabled during these experiments, the magnitude of the correction used was incorrect and an approximately ±15μm error can be seen in the image.



	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	Variance	Range
X-Distance	.3048	.0056	.0001	1482	.2511	.3328	3.0911E-5	.0817
Y-Distance	.3049	.0053	.0001	1482	.2790	.3339	2.7820E-5	.0549

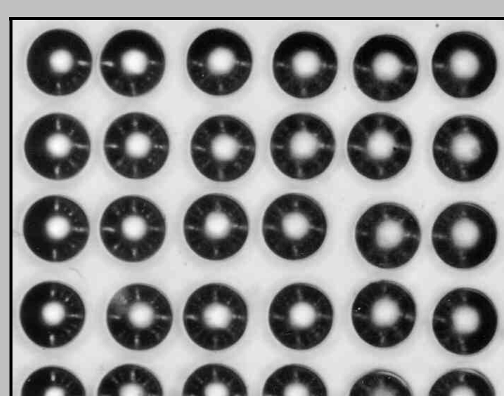
Figure 6: Bump-to-bump spacing for the 39x39 array in the printing direction (Y) and orthogonal to the printing direction (X). Distances in mm.

Figure 6 shows the results for measured bump spacing in both directions. The mean values were 305μm in both directions. The standard deviations were 5μm in the printing direction and 6μm in the direction orthogonal to the printing direction. All of the data fall within ±15μm except for a few outliers. Because of the accuracy of the stages used in this platform, greater accuracy than ±15μm was not anticipated.

In addition to these experiments, satifactory results have been obtained printing at rates of up to 400 per second onto patterned substrates (wafers).

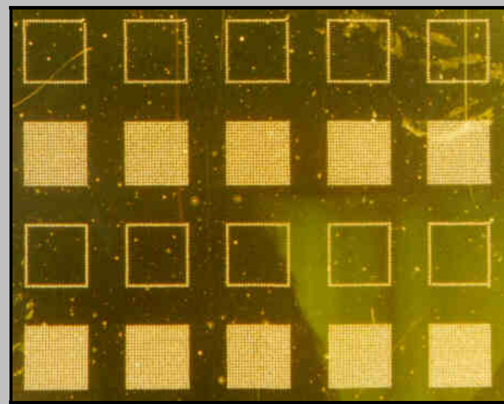
MICROBUMP PRINTING

Figure 7: 25µm bumps of 63/37 deposited on 35µm pitch using Solder Jet Technology.



Solder bumps currently used in flip-chip processes are typically in the 100-125μm range, although some companies are currently evaluating 75μm 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. **Figure 7** shows a small section of an array of 25μm 63/37 bumps deposited on a 35μm pitch onto a metallized silicon wafer. **Figure 8** shows larger section of an array of 35μm 63/37 bumps deposited on a 50μm pitch onto a metallized silicon wafer.

Figure 8: 35µm bumps of 63/37 deposited on 50µm pitch using Solder Jet Technology



VERTICAL INTERCONNECTS

The increase in the number of small, portable products on the market today has put tremendous pressure to reduce the size of the total electronic package. Ultra fine pitch substrates are required to handle the many new packaging alternatives, micro-BGA, chip-scale packages, flip-chip on board, etc. As the density of the boards and packages increases the size of the vertical interconnects between layers must get smaller. In this section we will discuss the use of Solder Jet technology to accurately create these vertical interconnects. Three approaches will be discussed: (1) creating solder columns and building up the dielectric layer around the columns; (2) using the accuracy of Solder Jet Technology to dispense solder directly into the micro-vias (either photolithography or laser ablated vias); and (3) using both Solder Jet and Polymer Jet technologies to print Chip-scale packages directly onto integrated circuit wafers. The first two approaches are illustrated in **Figure 9** and are discussed below.

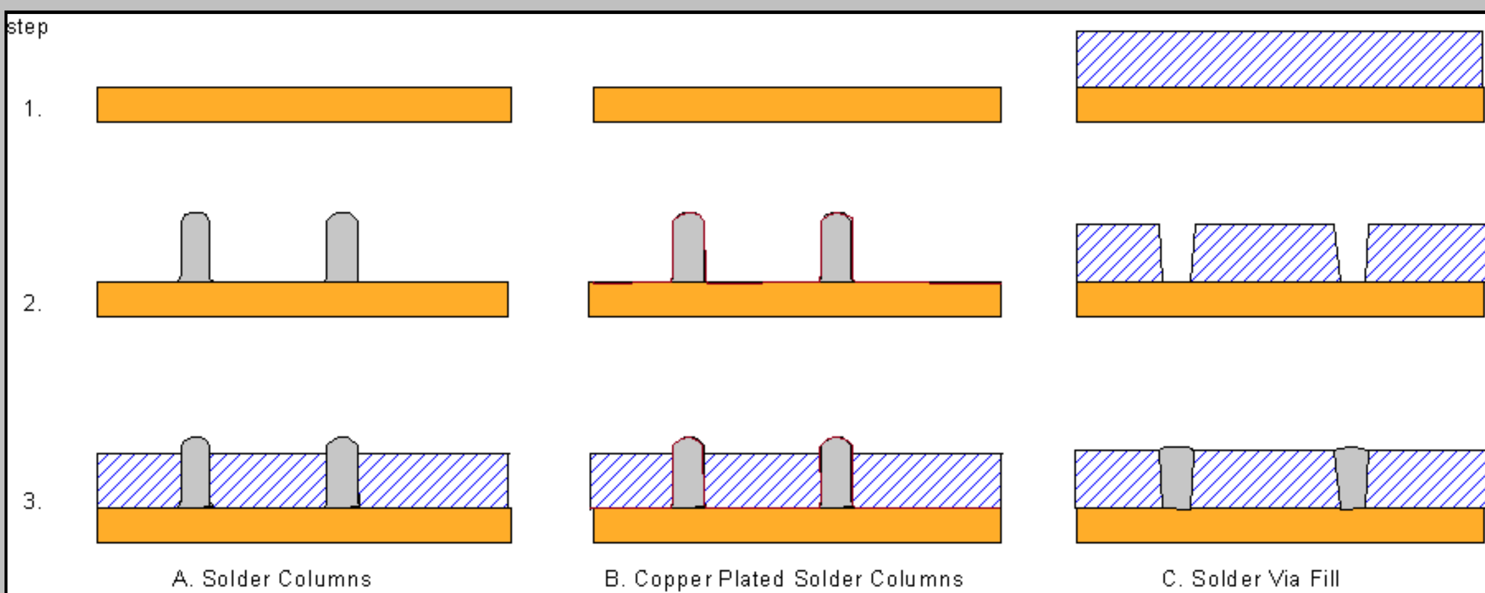
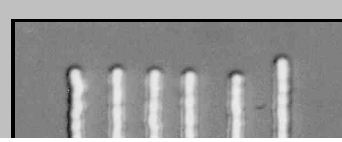
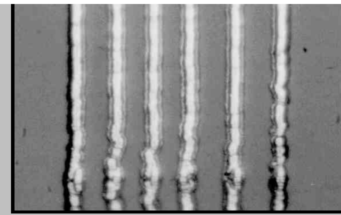


Figure 9: Vertical Interconnect Approaches

A. Solder Columns

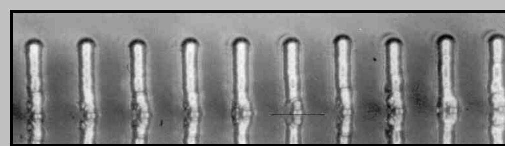
Figure 10: 25µm diameter towers on 50µm centers of 63/37 created using Solder Jet Technology.





On the left side of the figure the solder column approach is shown. Here the solder columns are printed directly onto the copper surface. The copper surface could be either patterned or continuous copper. Columns 25μm in diameter with an aspect ratio of greater than 20:1 have been demonstrated, as shown in **Figure 10**. A two-dimensional array of larger diameter columns is illustrated in **Figure 11** And **Figure 12**. After the solder columns are printed the dielectric layer could be printed with a second jetting head or could be coated by a different method.

Figure 11: Section of two-dimensional array of 50µm diameter towers of 63/37 printed on 200µm centers using Solder Jet Technology.



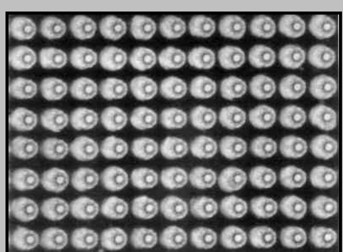


Figure 12: Top view of previous figure.

B. Copper Plated Solder Columns

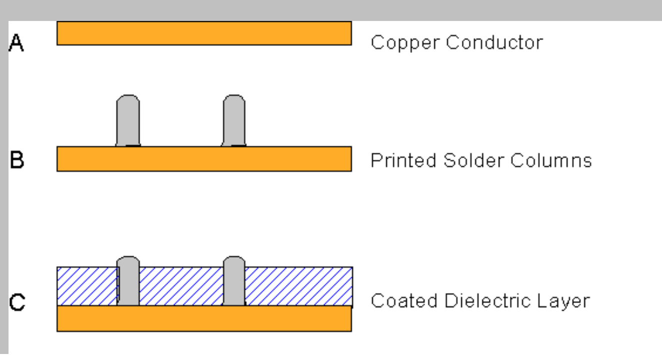
This process is similar to A except that, before the dielectric layer is applied, copper is electroplated onto the solder columns. This would increase both the conductivity and durability of the vertical interconnects. The plating needs (metal, thickness, etc) are determined by the specific application.

C. Solder Via Fill

In this approach, vias are formed into the dielectric layer down to the copper layer. These vias can be formed by photolithography techniques or by laser ablation methods. Once the vias are formed solder can be accurately printed into the vias with Solder Jet Technology. Accurately filling vias down to 75μm could be accomplished using solder droplets on the order of 50μm, and smaller vias could be filled using smaller droplets.

Three Dimensional Interconnects

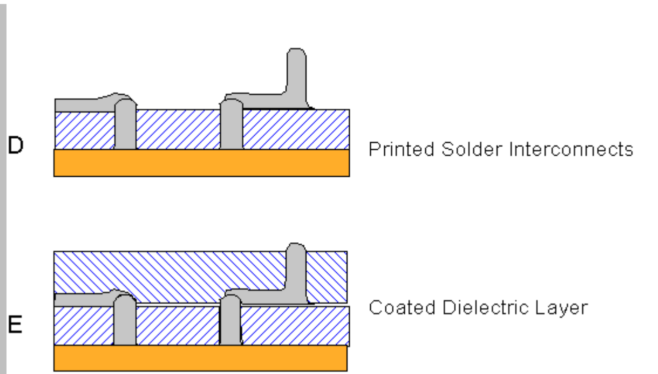
Figure 13 illustrates how three-dimensional interconnect structures can be fabricated using Solder jet technology. Level A, B and C illustrate what was discussed before. Level D illustrates how conductors could be printed onto the surface of the dielectric layer and at the same time columns printed at the end of the conductor. Level E illustrates the coating of the second dielectric layer. Levels D and E could be repeated.



CHIP SCALE PACKAGING

An approach toward wafer-level chip-scale packaging will be discussed in this section. The key elements have been demonstrated but the total concept has not been demonstrated.

The microelectronic package must satisfy various functional requirements: protect the die from the environment, provide direct electrical interconnect, form compliant interconnects to allow for thermal expansion mismatch, and allow for easy assembly to printed circuit boards. The approach discussed here satisfies these requirements. First, a dielectric polymer coating is printed onto the die surface to protect it from the environment. Second, the electrical interconnects are of minimum length. Third, the leads can easily be extended more than 500μm above the die surface to allow for thermal expansion mismatch between the IC surface and the PCB. And fourth, solder spheres 10-12 mils in diameter can be printed for interconnect to the substrate pads. This is the size of sphere used today in microBGA and state-of-the-art CSPs. **Figure 14** illustrates the three major steps in one version of this assembly process. **Figure 15** illustrates this process if both the solder and dielectric polymer coating are printed onto a wafer using ink-jet type dispensing.



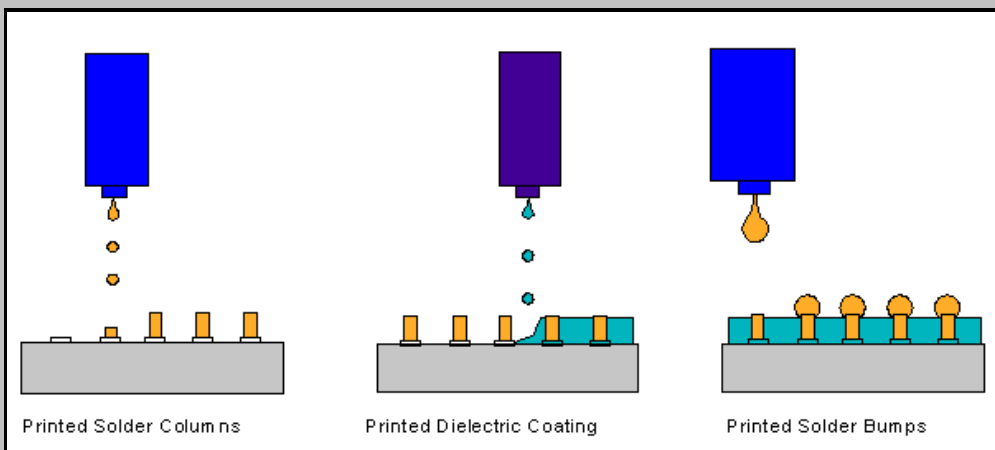
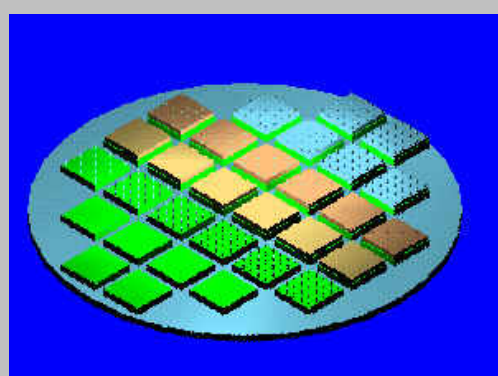


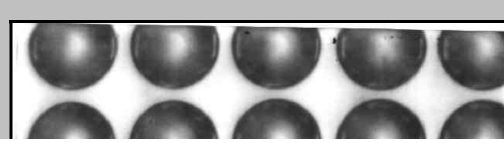
Figure 14: CSP Method of Manufacturing.

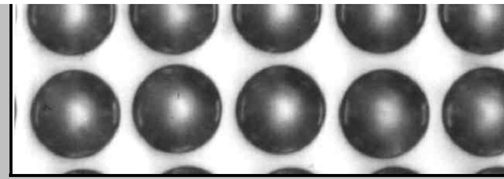
Figure 15: Concept for construction of CSPs on a wafer using ink-jet type dispensing of both solder and polymer dielectric.



The basic components of the process described above, printing of solder columns, dielectric polymers, and solder spheres, have all been demonstrated. **Figure 10** shows 25μm diameter 63/37 solder columns, 250μm high, printed on 50μm centers. **Figure 16** shows 40μm polymer hemispheres printed on 50μm centers. Epoxies, UV curable adhesives, and thermoplastics have all been demonstrated with drop-on-demand jetting technology. At MicroFab, using multi-drop, drop-on-demand Solder Jet Technology, 325μm precision spheres have been printed. MPM has demonstrated printing solder spheres (one drop per spot) using their Continuous Metal Jet Technology.[(12)]

Figure 16: 40µm diameter bumps of polymer dispensed on 50µm centers using ink-jet type dispensing.





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