MicroJet Printing of Solder and Polymers for Multi-Chip Modules and Chip-Scale Packages

by
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Abstract

High temperature ink-jet based printing processes (MicroJet) have been developed for the fabrication of high-density microelectronic and optoelectronic packages, including MCMs and CSPs. The enabling technology for this work has been the development of a printhead that accurately dispenses picoliter volumes of solders to polymeric formulations at operating temperatures up to 300EC. The inherently data-driven nature of MicroJet processes leads to a higher level of process integration, lower cost, and increased flexibility. Potential applications of MicroJet processes include: integrated circuit packaging, chip scale packaging, optoelectronic interconnect fabrication, and printed circuit board manufacturing. Using commercial, print-on-the-fly printing platforms, balls of Sn63/Pb37 solder have been dispensed and placed onto pads, at rates of over 400 bumps/sec. Solder interconnects and vertical vias have also been printed. Similarly, polymer formulations have been utilized in the printing of micro-optics, dielectric coatings, and electronic adhesives. Printing stations having multiple print heads for solder and dielectric material dispensing may be utilized to fabricate, in-situ, high-density and chip-scale packages on wafers.

Key words: Chip-Scale Package, Multi-Chip Module, MicroJet, Packaging

Introduction

MicroJet Technology is an emerging technology developed to address next generation electronic and optoelectronic packaging needs in a data-driven manner. It is based on piezoelectric demand-mode ink-jet printing technology and is capable of producing and placing droplets of solders, polymers, particle-laden fluids, etc., 25-125µm in diameter, at rates up to 1,000 per second. MicroJet based deposition is 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).

Ink Jet Technology

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,[1] or by the formation of a vapor bubble in the ink, caused by heating a resistive element.[2] 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.[3,4] 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 single channel MicroJet device generating 50µm diameter drops of ethylene glycol from a device with a 50µm orifice at 2,000 per second.

Operation of piezoelectric demand mode ink-jet devices at temperatures above 200EC has been one of the principle challenges in developing MicroJet technology. In addition to selecting materials, designs, and assembly processes that are compatible with these operating temperatures, MicroFab has developed patented drive waveforms for piezoelectric devices at elevated temperatures.[5] Operating characteristics for solders that have been demonstrated include: formation of spheres with diameters of 25-125µm; drop formation rates (on-demand) up to 1,000 per second; deposition onto pads at up to 600 per second; and operating temperatures to 320EC.[6]

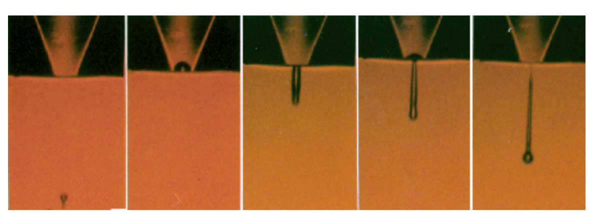

Figure 1: Demand mode ink-jet device generating 50µm diameter drops at 2kHz.

Polymer solutions usually require lower operating temperatures (<200EC), but represent a much broader class of materials in terms of printhead design requirements. UV curing, thermoplastic, and filled polymer solutions have all been successfully dispensed using MicroJet Technology.[7]

Prototype Printhead

The piezoelectric demand mode droplet generator described above was incorporated into a printhead design suitable for integration into a printing 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 fluid reservoir and droplet generator; and vertical dispensing capability. The inert environment is required for solder dispensing, and may be useful for some polymer solutions, or other materials. A MicroJet printhead is shown in Figure 2 mounted on a platform.

Drop Size Modulation

MicroJet Technology is inherently flexible because each droplet is dispensed under digital control. To increase the flexibility of the system, we have developed a novel drive waveform technology that allows drop size to be modulated over an approximately 2:1 diameter (8:1 volume) range. Figure 3 shows a MicroJet device producing 62µm diameter droplets of solder 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 1ms later, after it has broken free from the dispenser.

Figure 4 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. In this case, the diameter is increased to 106µm. The volume modulation using this method is continuous over the entire range of achievable volumes. This capability could be used to allow bump size to be changed under software control, either for product change over, or for application of variable sized bumps onto a single substrate. Drop volume modulation has been demonstrated with solders, but should be applicable to other materials as well.

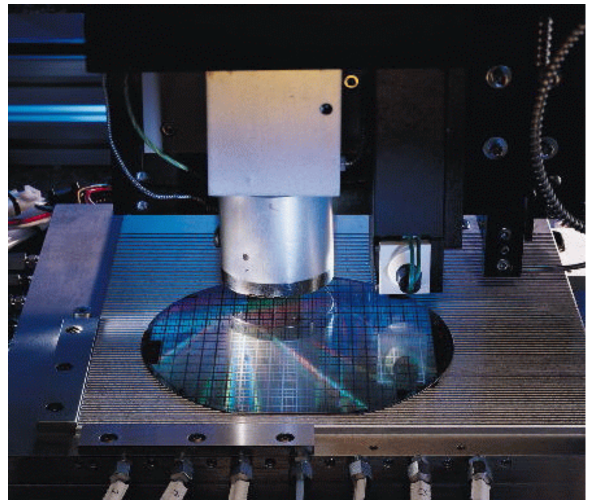

Figure 2: MicroJet printhead mounted on a platform.

Print-on-the-fly

Given droplet creation rates of up to 1000 per second, the printing platform must be able to deposit droplets onto pads while the printhead is in motion. To accomplish this, the printing platform must integrate and synchronize the image data (pad locations), drop generator controller, and substrate motion controller. Figure 5 shows results from printing onto an 18x18 test coupon with 100µm diameter pads on 250µm centers. The deposited solder volume is equivalent to a drop diameter of 100µm. Note that the drop shape shown in Figure 5 is a consequence of rapid (<100µs) solidification.[8] The instantaneous droplet rate for these tests was 400 per second and the pattern was printed by rastering the substrate in the horizontal direction of the figures. An average placement error of 10µm was achieved in

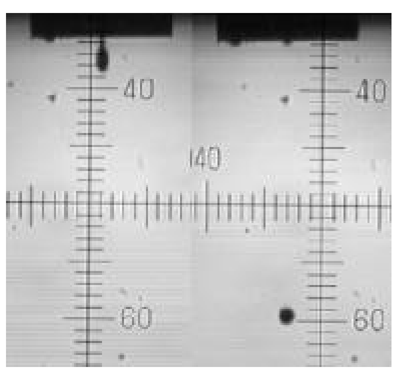

Figure 3: Drop formation process for a solder at two times during the process. Drop rate is 120 Hz and drop size is 62µm.

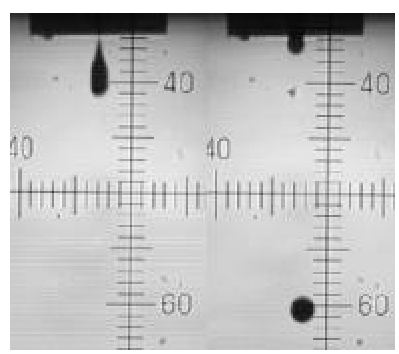

*Figure 4**: Drop formation process for same device shown in the previous figure, but using a different drive waveform. Drop rate is 120 Hz and drop size is 106µm.***

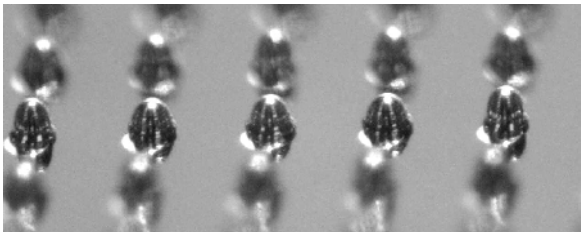

*Figure 5**: 100µm diameter solder bumps placed onto 100µm pads on 250µm centers at 400 per second on the MPM Solder Jet feasibility platform.***

these tests, which is close to the accuracy limitations imposed by the positioning and alignment systems of the platform. Operation at 600 bumps per second has been demonstrated, but this is at the limits of the platform current being used.

Wafer Bumping - Test Vehicle Printing

To illustrate the use of MicroJet Technology in a wafer bumping applications, the locations of the pads of an integrated circuit test vehicle with more than 1,400 pads were programmed into the platform. Droplets of Sn63 / Pb37, 70µm in diameter, were deposited onto several of these test vehicles. Figure 6 shows the results from one test vehicle, and Figure 7 is a detail 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.[9]

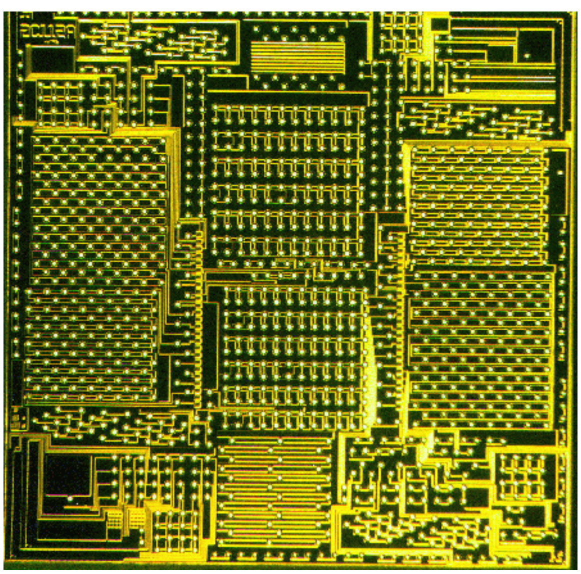

*Figure 6**: IC test vehicle with 1440 pads, bumped with 63/37 using MicroJet Technology. Ball size is 70µm.***

Chip Scale Packaging

A microelectronic package must satisfy various functional requirements: support the die, 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. A direct-write wafer-level chip-scale packaging concept satisfying these requirements is presented in this section.[10] The key elements have been demonstrated but the total concept has not yet been proven.

Figure 8 illustrates the three major steps in one version of the proposed direct-write wafer-level chip-scale package assembly process. First, solder columns with an aspect ratio of 2 or greater and approximately the same width as the pads are printed onto each pad using one Solder Jet device. Second, a dielectric polymer coating is printed onto the die surface and cured (UV or thermal). Third, solder spheres 0.25-0.30mm in diameter (the size of sphere used today in µBGA and state-of-the-art CSP's), are printed for interconnect to the substrate pads using a second Solder Jet device. The solder for the bumps would have a lower melting point than that of the columns so that the columns would not reflow when the CSP is attached to a substrate

This type of chip-scale package would have electrical interconnects that are of minimum length, and the leads could extend to more than 500µm above the die surface to allow for thermal expansion mismatch between the IC surface and the PWB. In volume manufacturing, three printheads (solder columns, polymer, solder balls) could be mounted onto a sigle machine, or the wafers could be processed in series through three

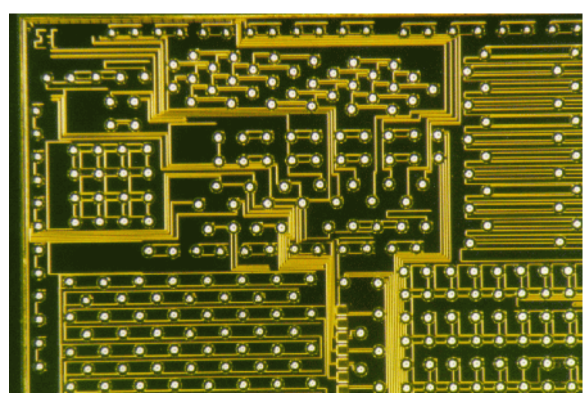

*Figure 7**: Detail of previous figure.***

separate machines dedicated to a single process.

Figure 9 illustrates how the concept of Figure 8 could be extended to a three-dimensional interconnect structures for redistributing leads. The first layer would be printed as discussed above. Horizontal and vertical solder interconnects would be printed in the next process step, followed by another polymer layer. This process could then be repeated.

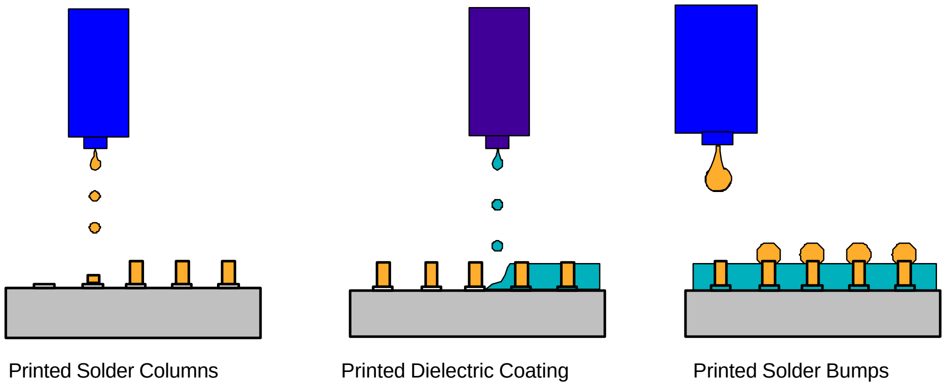

*Figure 8: **CSP Method of Manufacturing.***

The basic components of the process described above, printing of solder columns, dielectric polymers, and solder spheres, have been demonstrated. Figure 10 shows 25µm diameter 63/37 solder columns, 250µm high, printed on 50µm centers. Figure 11 shows 100µm polymer waveguides printed into a splitter. Epoxies, UV curable adhesives, and thermoplastics have all been demonstrated with drop-on-demand jetting technology. Using multiple drops per bump, 325µm bumps have been printed using demand mode Solder Jet technology. MicroFab is currently developing solder (electrical interconnect) and polymer (micro-lenses) dispensing processes for use in vertical cavity surface emitting laser (VCSEL) package assembly.

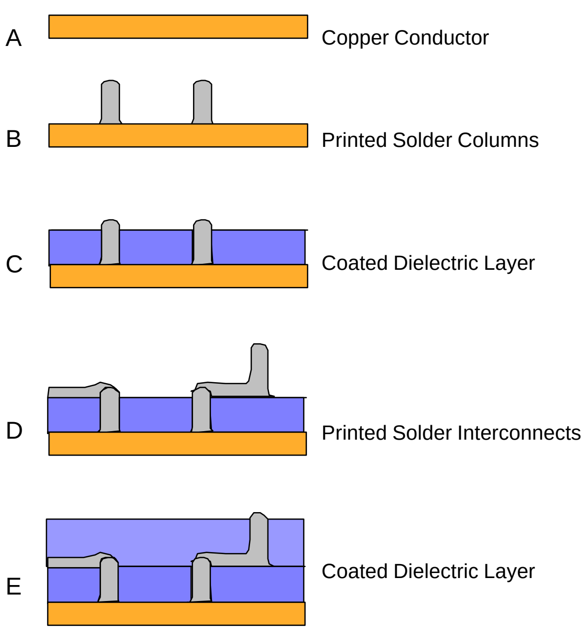

*Figure 9: **Printed Solder Interconnect Concepts***

Multi-Chip Modules

MicroJet-based direct write of metals, polymers, and other materials has application to Multi-Chip Module (MCM) fabrication for the interconnect and dielectric layers, embedded passives, sealing and bonding of components, and other processes. Specific processes and applications include:

Solder for Flip-Chip Assembly
Dielectric Layers and Coatings
Fluxes for Reflow
Epoxy Adhesives - for chip attach
- for sealing

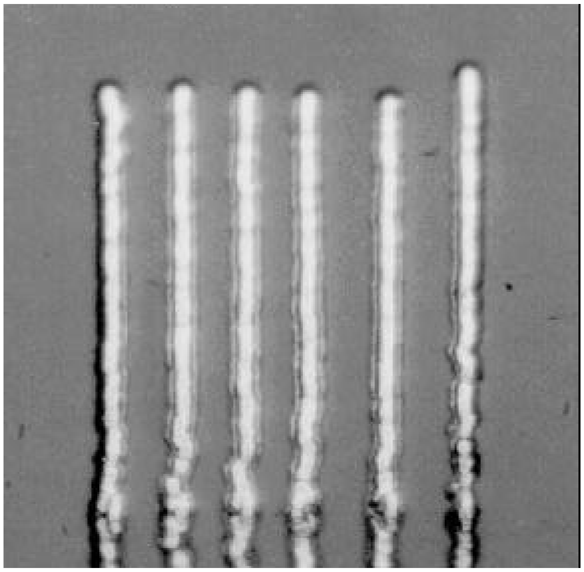

*Figure 10: **25µm diameter towers on 50µm centers of 63/37 created using MicroJet Technology.***

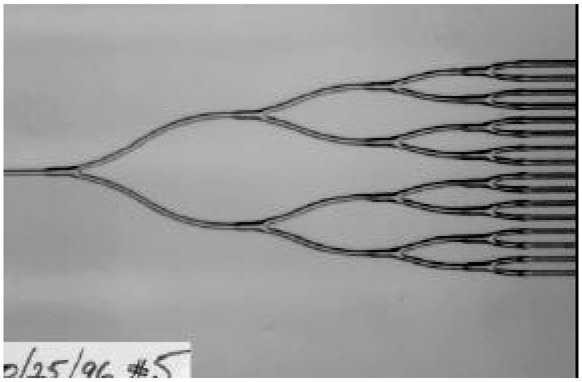

*Figure 11: **100µm** polymer waveguide / splitter created using MicroJet Technology.*

Embedded Passives - filled epoxies for resistors
- dielectrics for capacitors
- nanoparticle dielectrics
- ferrite filled polymers for inductors
- organo-metallics
- conductors using nanoparticles

All of the above process and application have been demonstrated to some extent, including: printing of conductive traces utilizing nanoparticle filled polymers and organo-metallic polymers; resistors printed using filled polymers (micron sized particles); capacitor dielectrics printed with nanoparticle fillers; and both micron and nanoparticle ferrites. Figures 12-14 illustrate some of these results.

Conclusions

The feasibility of dispensing solders and polymers using MicroJet Technology has been demonstrated. Rates up to 600 bumps per second have been achieved. Assembled packages using this technology have been verified.[11] The key elements to a new approach to wafer scale chip-scale packaging have been demonstrated. Application of the direct-write material dispensing capabilities of MicroJet Technology to MCMs has been shown to be viable for a number of materials and processes.

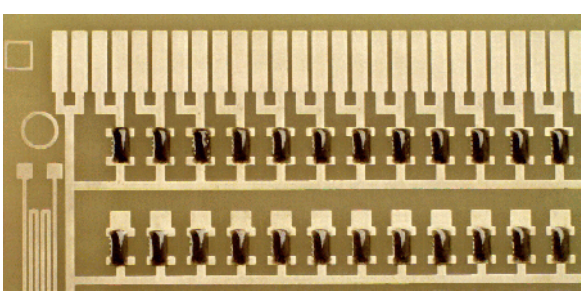

Figure 12: 0402 resistors printed using MicroJet Technology; filled, UV curing epoxy.

Acknowledgments

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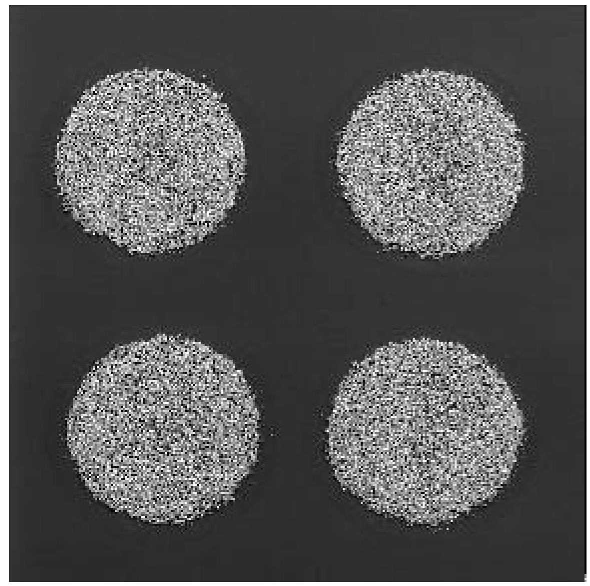

Figure 13: 150µm spots of ferrite particles; MicroJet printed.

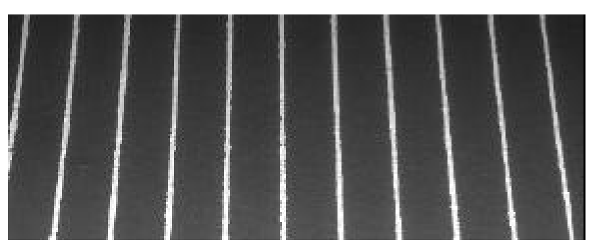

Figure 14: Gold lines printed on FR-4 ; <200EC cure.

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