Aerosol Jet® Printing of High Density, 3-D Interconnects for Multi-Chip Packaging

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Optomec's patented Aerosol Jet technology is a maskless, non-contact material deposition system used to enable 3-dimensional semiconductor packaging. This paper highlights results of collaborative work done by Optomec and Vertical Circuits (VCI) on printing of high density 3-D interconnects on stacked die modules which incorporate video, communication and memory chips. Such packages are critical for meeting the increasing functional requirements of SmartPhones, portable media players, handheld game consoles, and other mobile devices.

Aerosol Jet Technology:
The Aerosol Jet process is being used to deposit a wide variety of materials onto a wide variety of substrates without conventional masks or thin-film equipment. The process is non-contact, enabling traces to be printed over steps or curved surfaces. Features as small as 10 microns have been printed.

The process utilizes low viscosity inks in the range of 1-2500 cP. Typical materials that can be printed include nanoparticle metal suspensions, polymers and adhesives. Conductor traces can be printed using gold, silver or other nanoparticle inks. Conductors can also be formed by printing a seed layer, followed by electroless plating. Polymer thick film pastes can be printed to form embedded resistors. Polyimide and various epoxies can be printed for adhesives, overcoat dielectrics, etc. Substrates include silicon, polyimide, glass, FR-4 and aluminum oxide. In principle, virtually any substrate can be used provided the ink is compatible with it.

Aerosol Jet Process:
The Aerosol Jet process uses aerodynamic focusing for the high-resolution deposition of colloidal suspensions and/or chemical precursor solutions. An aerosol stream of the deposition material is focused, deposited, and patterned onto a planar or 3D substrate. The basic system consists of two key components, Figure 1:

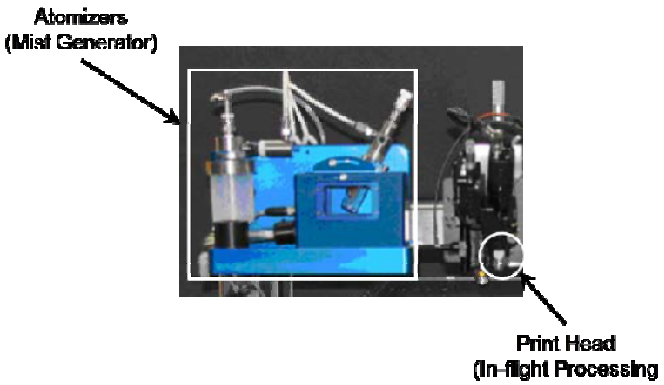

Figure 1. Schematic of the Aerosol Jet hardware and photo of the deposition head.

1. A module for atomizing liquid raw materials (Mist Generation).
2. A second module for focusing the aerosol and depositing the droplets (In-Flight Processing).

Mist Generation is accomplished using a pneumatic atomizer (an ultrasonic atomizer is optional). The aerosol stream is then focused using a flow deposition head, which forms an annular, co-axial flow between the aerosol stream and a sheath gas stream (Figure 2). The co-axial flow exits the print head through a nozzle directed at the substrate. The Aerosol Jet print head is capable of focusing an aerosol stream to as small as a tenth of the size of the nozzle orifice.

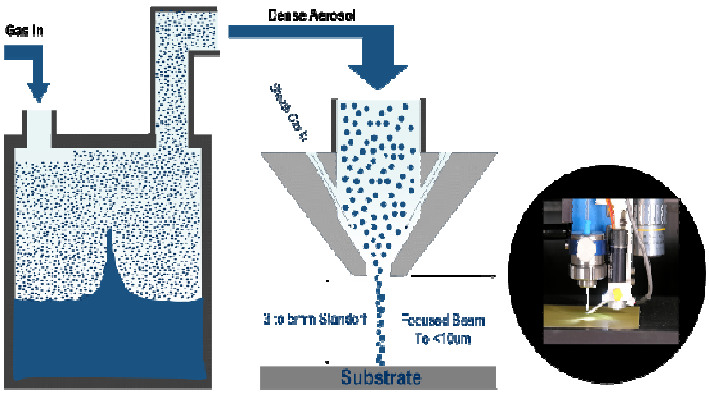

Figure 2. Schematic of the Aerosol Jet process and photo of the deposition head.

Thermal post processing of the deposited material is often needed to cure the material or increase properties such as electrical conductivity. Depending on the application, either conventional sintering or curing is used for low temperature substrate materials.

Aerosol Jet and its Application for 3-D Interconnects:

While the functionality of application specific handheld mobile devices converge into single multipurpose products, consumers continue to demand ever decreasing product footprints and lighter weight devices. Manufacturers of mobile devices are addressing these seemingly contradictory challenges by implementing new 3D package on package (PoP) techniques that can increase product performance within a smaller device footprint. Traditional wire bond technology has been used for interconnecting vertically stacked die system in package (SIP) components (See Figure 3). However with ever increasing functionality demands, wire bonding is challenged to meet both physical packaging and electrical performance requirements of next generation products. Revolutionary process technology such as through-silicon-via (TSV) is being developed as an alternative solution to address these challenges, however implementation is years away and is expected to be costly. Vertical Circuits, Inc. (VCI) is a pioneer in the vertical stacking and interconnection of integrated circuit die for high density and high performance applications, and holds a number of patents on vertically integrated semiconductor components. VCI has been working in close collaboration with Optomec to integrate Optomec's Aerosol Jet technology into VCI's manufacturing methods.

Optomec's Aerosol Jet print solution is an excellent tool for implementing VCI's technology, an evolutionary alternative to both wire bond and TSV technology, which provides a high density 3-dimensional interconnect solution that enables multi-functional integrated circuits to be stacked and vertically interconnected in high performance Multi-Chip Packages (MCP's).

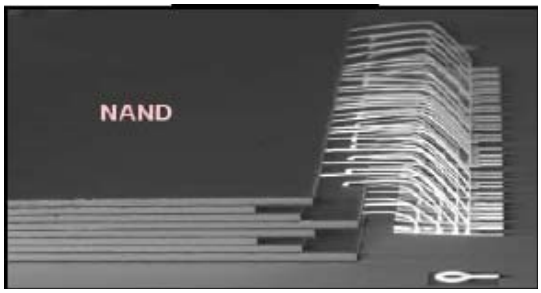

Figure 3. Traditional Wire Bond Stacked Die

Optomec's Aerosol Jet system is used to deposit silver nanoparticle ink connections of staggered multi-chip die stacks (Figure 4). High aspect ratio interconnects with 30-micron line width and greater than 10-micron line height (Figure 5) have been demonstrated at sub 75-micronpitches (Figure 6).

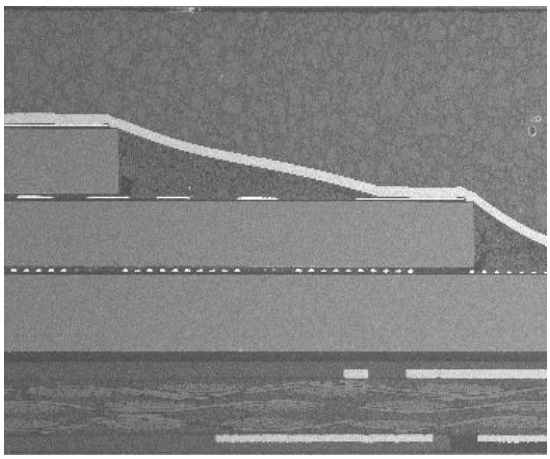

Figure 4. Aerosol Jet Printed Die to Die Interconnects

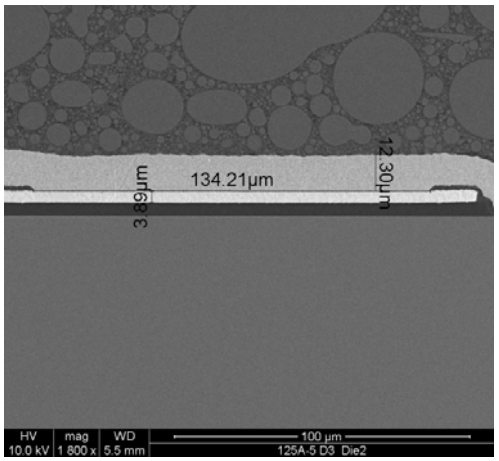

Figure 5. Aerosol Jet Printed >10µm Thick Traces

Figure 6: Sub-75 micron pitch Silver interconnects

The stacks can include up to 8 die, with a total stack height below 1 mm. The printing system has a working distance of several mm which means that no Z-height adjustments are required for the interconnect printing. Closely coupled pneumatic atomizers with multiplexed print nozzles (Figure 7) are used to achieve production throughputs of greater than two interconnects per second per nozzle.

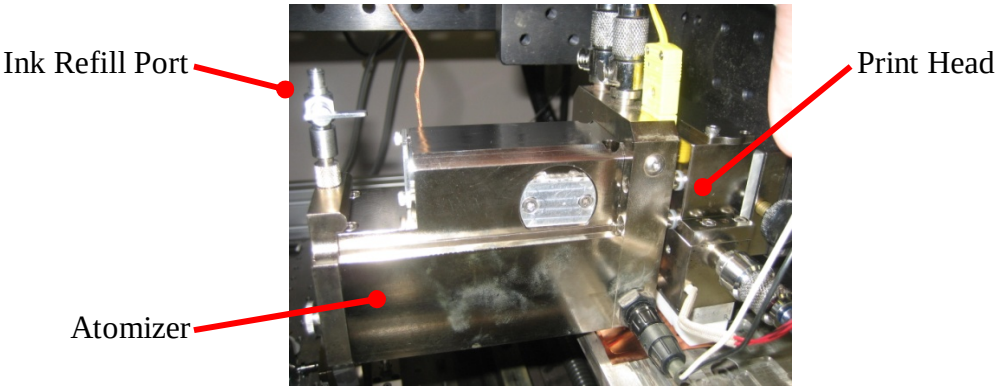

Figure 7: Closely Couple Pneumatic Atomizer with Multiplexed Nozzles

After printing, the silver inks are submitted to a low temperature cure, which results in interconnect resistances below one-Ohm.

Based on cost and functional advantages, the Aerosol Jet print process is emerging as an effective evolutionary alternative to traditional wire bond and disruptive, revolutionary through-silicon-via (TSV) technologies.