MESOSCALE DEPOSITION TECHNOLOGY

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Abstract

The continual drive for smaller, more powerful and economic electronic systems, has led to the development of a new manufacturing technology, Maskless Mesoscale Materials Deposition (M^3D). Without masks or resists, features down to 10 microns can be directly written in a wide range of materials, including metals, polymers, ceramics, adhesives, and even bio-materials, on virtually any surface material. For substrates with a low temperature tolerance, M^3D locally processes the deposition through a laser scanning process. The end result is a high-quality thin film with excellent edge definition and near-bulk electronic properties.

As a CAD driven, additive manufacturing process, M^3D provides significant environmental benefits and reduced processing requirements, eliminating the waste associated with traditional subtractive (e.g. mask and etch) processes. M^3D can also precisely deposit materials on non-planar substrates. With no physical contact with the substrate by any portion of the tool other than the deposition stream, conformal writing is easily achieved.

This paper will detail the benefits of M^3D technology in creating mesoscale features for electronics assembly and semiconductor packaging applications and outline some of the current application areas. Repair - M^3D can precisely place material to fix open circuits in service/repair operations for high value electronics.

Key Words: HDI, high density interconnects, microelectronics packaging, direct write, mesoscale deposition.

1. Introduction.

In recent years, a new class of manufacturing techniques has become established which offer manufacturers significant cost, time and quality benefits across a broad spectrum of industries. These new techniques are collectively known as additive manufacture.

During *additive* manufacture, material is deposited layer by layer to build multilayer or 3D parts or features. This is in contrast to traditional manufacturing methods which are mainly *subtractive*, i.e. material is removed from a part to get the final form.

Features of additive manufacturing processes include direct CAD-driven, "Art-to-Part" processing which eliminates expensive tooling, masks and vertical/horizontal integration which leads to fewer overall manufacturing steps. These features combine to offer diverse benefits:

- Time Compression and Increased Manufacturing Agility. CAD driven, tool-less processes speed up the product development and manufacturing, whilst allowing greater flexibility in mass customisation.
- Lower Costs – This benefit arises because tooling and mask costs are eliminated. Process costs in terms of operator input, supplier chain complexity and work flows are reduced. Raw material is used more efficiently reducing waste levels and costs of "manufacturing" scrap. Life-cycle costs are reduced by lower design development costs, increasing product quality and the ability to repair components.
- Better Product Designs. Greater design and manufacturing flexibility offers the potential for revolutionary new end-products with improved performance based on novel size, geometries, materials and material combinations.

This paper will introduce an additive manufacturing technique designed for the electronics industry: Maskless Mesoscale Materials Deposition™ (M^3D). M^3D is aimed at small scale (10-100+ μm) electronic structures and devices as well as biological materials and applications.

2. M^3D - Maskless Mesoscale Materials Deposition.

M^3D was originally developed to fill a neglected middle ground in microelectronic fabrication. Current techniques create very small electronic features, for example by vapour deposition, and relatively large ones for example by screen printing. No technology was capable for satisfactorily creating crucial mesoscale-sized (1-100μm) production of interconnects, components, and devices. As electronic devices continue to shrink, thick-film fabricators are approaching the physical limits of stencil printing. Thin-film technology can deposit mesoscale features, but it requires a highly skilled workforce and a major investment in new manufacturing capability for each new application. It is for these reasons that M^{3}D was developed under the heavily funded Mesoscale Integrated Conformal Electronics (MICE) program supported by the US Defense Advanced Research Projects Agency (DARPA).

2.1 How M^{3}D Works.

M^{3}D is a CAD driven, mask less process. It uses aerodynamic focusing for the high-resolution deposition of chemical precursor solutions and/or colloidal suspensions. An aerosol stream of the deposition material is focused, deposited, and patterned onto a planar or non-planar substrate. The system consists of 3 modules, **Fig. 1**:

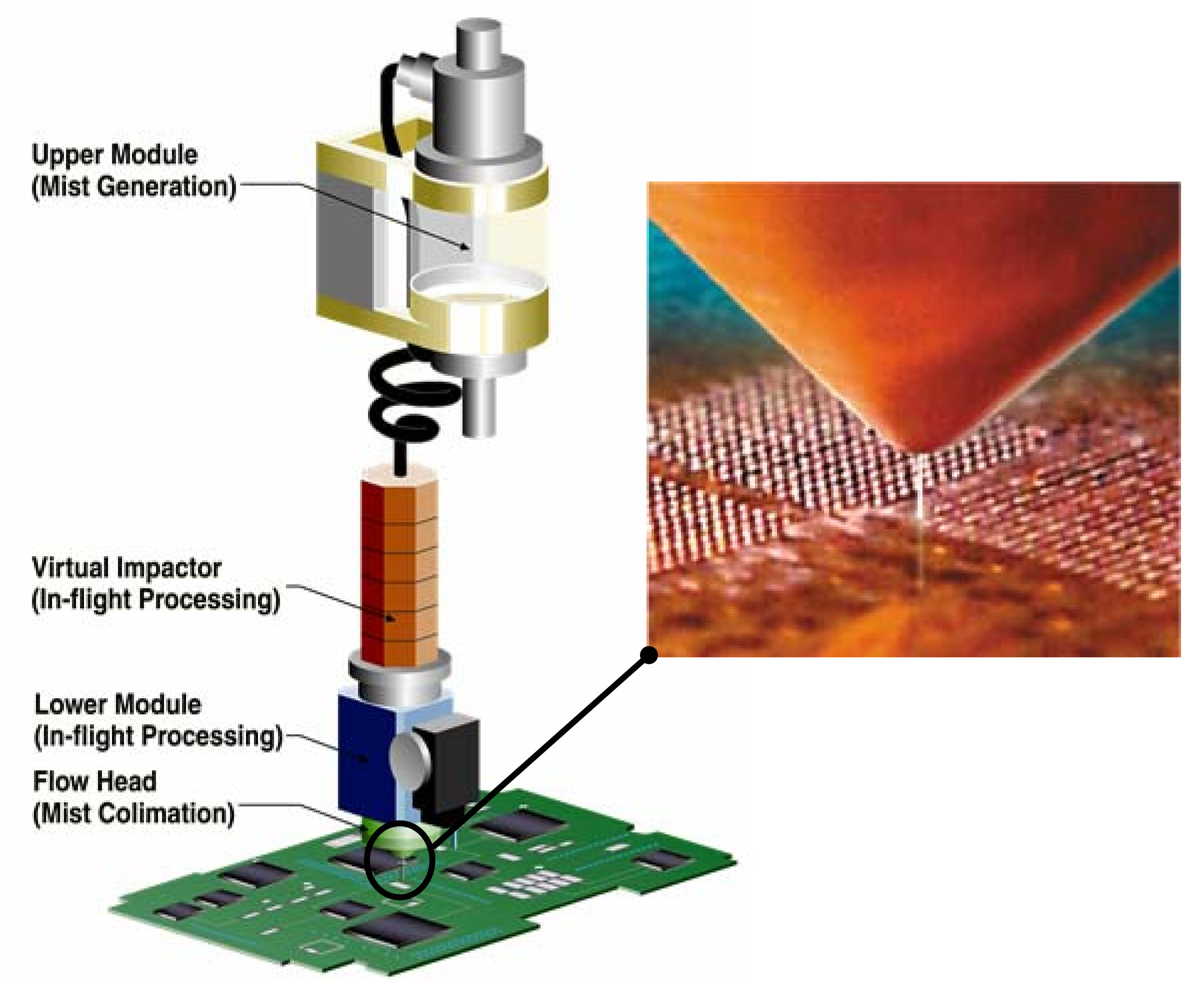

Figure 1: Schematic of the M^{3}D process and photo of the deposition head.

1. A module for atomizing liquid and colloidal suspension raw materials (Mist Generation).

2. A second module for focusing the aerosol and depositing the droplets (In-Flight Processing).
3. The final module is a laser for post treatment sintering of the deposits. This is used where sensitive substrates which cannot be conventionally sintered are present.

Mist Generation is accomplished using an ultrasonic transducer or pneumatic nebuliser. The aerosol stream is then focused using a flow guidance deposition head, which forms an annular, co-axial flow between the aerosol stream and a sheath gas stream. The co-axial flow exits the flow guidance head through a nozzle directed at the substrate. The M^3D flow guidance head is capable of focusing an aerosol stream to as small as a tenth of the size of the nozzle orifice. Patterning is accomplished by attaching the substrate to a computer-controlled platen, or by translating the flow guidance head while the substrate position remains fixed.

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 oven sintering is used, or for low temperature substrate materials a continuous-wave Nd: YAG laser is used to locally heat the deposited material without affecting the surrounding substrate.

The M^3D system can write electronic features at high speeds. Deposition rates are as fast as 100mm per second, allowing the system to meet the requirements of both rapid prototyping and high-volume electronic manufacturing.

2.2 M^3D Features, Benefits and Applications.

Rapid Product Development. The M^3D system is driven by standard .DXF CAD data, which allows designers to quickly and cost-effectively test new prototypes and products. This eliminates the delays and costs associated with mask sets and other upfront capital required by conventional electronics manufacturing techniques. This feature also makes it much easier to implement and validate design changes without the need for “re-tooling”. The elimination of masks and resists also permits on-the-fly changes and rapid design iterations. The result is faster time-to-market for new products.

Materials Range. M^3D can deposit a wide variety of materials, including metals, conductors, insulators, ferrites, polymers, adhesives and biological materials. Deposits can be made on virtually any surface material - silicon, glass, plastics, metals, ceramics, polyimides, and polyesters. This flexibility opens the way for many different applications using a single process, **Table 1**.

Packaging and Assembly

- High Density Interconnects
- Flip-Chip / Direct Die Attach
- Embedded / Integrated Passives
- Flex Circuits
- Meso-Dispensing

Electronic Components

- Resistors, Capacitors and Inductors
- Micro-Antennae
- Micro-Batteries

Electronic Devices

- Flat Panel Displays
- Fuel Cells
- Micro-Sensors
- MEMS & RFID

Hybrid Manufacture

- Smart Structures

BioTech

- Bio-Sensors& Implantable Devices
- Micro-Arrays…

Table 1. Application areas for M^3D.

Many devices manufactured for electronics products require multi-layer manufacturing techniques. M^3D's ability to deposit conductive, insulating, and adhesive materials layer-by-layer within a single system makes it an attractive solution for the partial or complete production of microelectronic devices. M^3D uses in this area include sub-micron layers of Platinum for fuel cell applications, high density interconnect backplanes (organic and metal) for flat panel displays, and micro-sensors for avionics. Since many such markets are evolving, M^3D can be a powerful product development tool, as well as a viable production solution. Potential also exists in electronic Display Manufacture: M^3D can precisely place material to fix open circuits on the backplane or coloured inks on the colour mask.

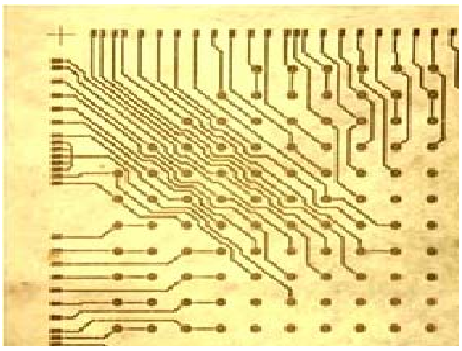

Fig. 2. Bond pad redistribution.

Fine Accurate Features. M^3D reliably produces ultra fine feature circuitry well beyond the capabilities of thick-film and ink-jet processes, making it ideal for next generation packaging and high-density interconnect applications at both the chip and circuit board level. Depending on the material, the technology can even produce electronic features as small as 10 microns with its laser decomposition option. One example where this feature is being applied is in flip chip applications, **Fig. 2**. M^3D produces 25 micron traces with 35 micron bond pads, in order to create bond pad redistribution capable of supporting ever-increasing I/O counts.

The small size of the interconnects allow the use of smaller devices. For example, the current size of an RFID chip is limited to the size of the interconnects created by screen-printing. With the cost of the RFID tag being dependant on the size of the chip, this acts as a barrier to reducing costs. Using

M^{3}D instead of screen printing allows for the use of a smaller chip and less interconnect material, driving the cost down.

M^{3}D offers a solution for the production of smaller (down to 10µm), high performance components critical to size-sensitive applications like those in the wireless and hand-held device markets where component density is increasing dramatically. The ability of M^{3}D technology to create complex geometries from a wide range of materials makes it suitable for the production of both passive and active components, including resistors, inductors, capacitors, filters, micro-batteries and micro-antennae, **Fig. 3**. The excellent edge definition and repeatability of the process are particularly relevant to high frequency requirements. In comparison to screen printing, embedded resistors can be made smaller and more accurately with M^{3}D such that no laser-trimming is needed to tune the resistor to the right value. Since M^{3}D can deposit both conductive and insulating materials, one layer at a time, it has the potential to directly embed passive components.

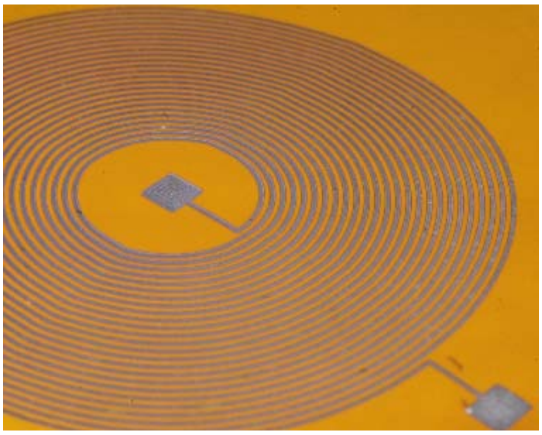

Fig. 3 Ag Inductor on flex substrate.

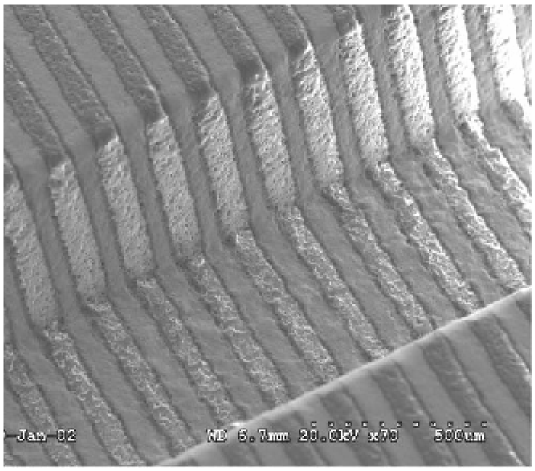

Fig. 4. Ag lines, 50µm, over a 500 µm trench.

Low Temperature Laser Sintering. Once the material has been deposited, conventional approaches require high-temperature treatment. These might include re-flow or cure ovens, or a chemical decomposition process. By contrast, M^{3}D can locally process the deposition on substrates, such as polymers, that have low temperature tolerance (150°C or less) through using the laser module. The end result is a high-quality thin film with excellent edge definition and near-bulk electronic properties.

Conformal Deposition. M^{3}D can also precisely deposit materials on non-planar substrates. This is made possible by the relatively high [5mm+] stand off point of the deposition head. With no physical contact with the substrate by any portion of the tool other than the deposition stream, conformal writing is easily achieved. This allows for the ability to build 3D features on to structural component, write into trenches, **Fig 4**, or fill "vias" with high aspect ratios i.e. 50 micron diameter, 500 microns deep.

Fig. 5 shows an example of conformal packaging or 'zero height, wire-bond replacement' in a Smart Card application. This involves directly writing on several different kinds of materials. The Ag interconnects were written conformally by M^{3}D and laser processed to obtain the required properties.

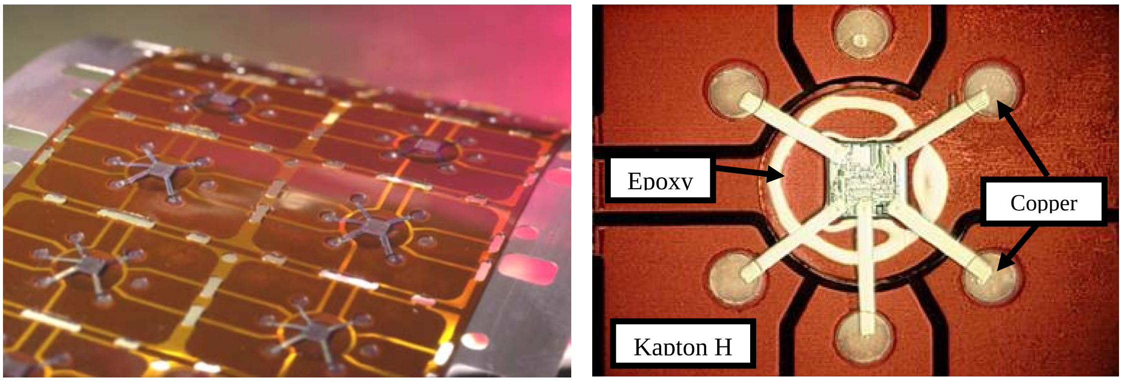

Fig 5. M^{3}D Smart Card Interconnects, conformal Ag lines written from Cu Pad to Chip.

Reduced Processing & Environmental Impact. M^{3}D provides significant environmental benefits and reduced processing requirements because it is an additive fabrication process, which eliminates the waste associated with traditional subtractive (e.g. mask and etch) processes. Rather than coating an entire masked surface, manufacturers can deposit exact amounts of material exactly where it needs to be.

Another application for reducing processing steps and reduced chemical usage is the Catalyst Layer approach for producing interconnects or other features, **Fig. 6**. The standard method consists of dip coating, plating, masking, etching and secondary plating steps. M^{3}D can cut the number of steps by directly depositing the activator solution followed by a standard plating step. In this way the mask and etch steps are removed.

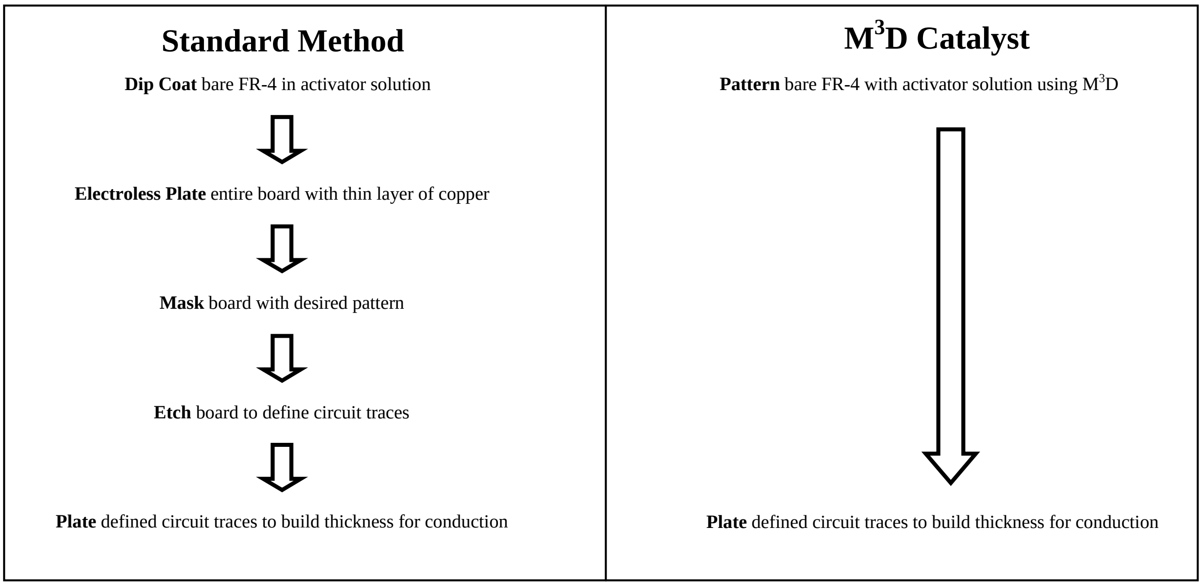

Figure 6. Comparison of Dip/Plate/Etch/Plate vs. M^{3}D Catalyst Technique

Materials Efficiency. The tiny droplets created by M^{3}D allow for very thin coatings (i.e. 10's-100's of nanometers thick) which allows for good interaction between differently applied layers. These same femto-liter sized droplets allow for very careful control of dosages dispensed. Since many electronics materials are expensive to produce, the technology is a key enabler for reducing the cost of each device.

Bio-Materials and Life Science Applications.

The M3D process has the ability to process "off-the-shelf" bio-molecule solutions including buffered saline, protein, and DNA solutions. The process is insensitive to PH value and is compatible with various polymer and overcoat materials and electronic materials. The highly accurate deposition results in very little material waste. Combined with the ability to produce very thin films (down to monolayer thickness) diverse Bio-applications are possible:

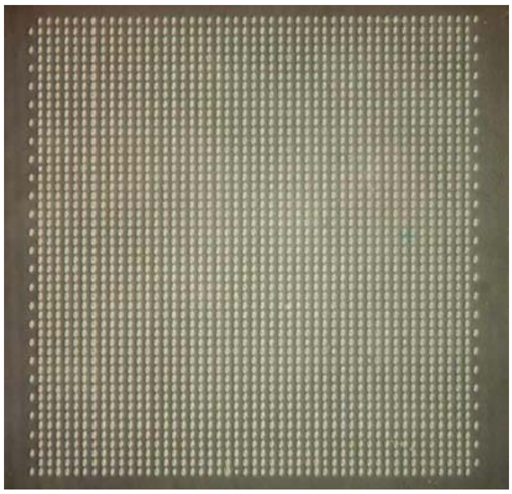

Figure 7. 2500 Spot Oligonucleotide Microarray.
Spot Size: 20micron

- Multi-layer Immunosensor coatings
- Fine Spot Micro-arrays, **Fig. 7**.
- Protein and Cell Patterning
- Biosensing

- Drug discovery
- Drug dispensing
- Lab on a dish/Lab on a chip
- Multiple protein type for multicell culturing
- Graded protein pattering for cell guidance
- Seeding medical devices and
- Combination: electronics with tissue constructs.

SUMMARY.

The emergence of CAD driven, additive manufacturing techniques, such as M^{3}D, are set to significantly impact on many industry segments including electronics, aerospace and bio-sciences.

M^{3}D can economically and rapidly deposit a wide variety of materials on many different substrate types. The process offers the potential to develop advanced packaging solutions and also to reduce the number of processing steps and environmental impact of production operations. Designers can harness the unique features of M^{3}D to create revolutionary designs which offer a wide range of time, cost and quality benefits.