Direct Writing For Advanced Electronics Packaging

by Dr. Martin Hedges, Neotech Services MTP,
Dr. Bruce King and Dr. Mike Renn, Optomec

The emergence of CAD driven, Direct Write techniques have the potential to significantly impact on many market segments in electronics manufacture and assembly. Direct Writing 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 Direct Writing to create revolutionary designs which offer a wide range of time, cost and quality benefits. We take a look at a specific Direct Write process which is now being scaled up to cope with high volume production.

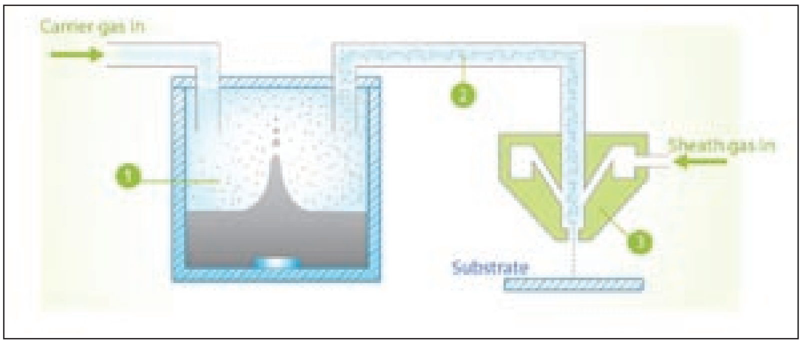


Figure 1 - Schematic diagram of the M³D process

In recent years, a new class of manufacturing techniques has become established which offers significant cost, time and quality benefits across a broad spectrum of industries. These new techniques are collectively known as Direct Writing. During Direct Writing, material is deposited line by line, layer by layer to build system features or even complete parts. Features of Direct Write processes include direct CAD-driven, "Art-to-Part" processing which eliminates expensive tooling and 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 product development and manufacturing, whilst allowing greater flexibility in low-medium volume manufacturing and even mass customisation.
- Lower Costs – This benefit arises because hard tooling costs are eliminated, process costs in terms of operator input, supplier chain complexity and work flows are reduced. Typically, raw material is used more efficiently reducing scrap and waste levels. 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.

Figure 2 - 10 micron Ag lines on glass. Note smooth surface and high edge definition

Features	Screen Print	Ink Jet	M3D	M3D Benefits
Minimum resolution	~100 microns	~30 microns	<10 microns *	Finer feature sizes
Single-pass Layer Thickness	100 microns	~0.1 microns	25nm -10 microns*	Improved process control
Material Viscosity	>10,000 cP	5 to 15 cP	0.7-2500 cP	Wider material choices and control over deposition thickness
Material Formulation Time	Months	Years	Months	Existing materials can be easily adapted
Pattern Generation	Hard Tooling - Screen Template	Digital – Raster	Digital – Direct Vector from CAD	Greater accuracy
Substrate Requirements	Planar - Screen fixed at ~ 1mm above substrate	Planar- Print head fixed at ~ 1mm above substrate	Planar or Non-Planar - Head Variable at 1-5mm above substrate	Not sensitive to surface irregularities, enables conformal deposition
3D Direct Writing	Fixed – planar only	Fixed – planar only	Z-axis option – up to 50mm height	3D capability

*Material Dependent

Table 1 - Comparison of M³D, ink jet and screen printing processes

This article will introduce one of the leading Direct Write techniques for the electronics industry: Maskless Mesoscale Materials Deposition (M³D) from Optomec Inc.

Maskless Mesoscale Materials Deposition

Maskless Mesoscale Materials Deposition (M³D) was originally developed to fill a neglected middle ground in microelectronic fabrication. Current techniques create very small electronic features, for example by mask & etch processes or vapour deposition, and relatively large ones for example by screen printing. No technology was capable of satisfactorily creating crucial mesoscale-sized (1-100µm) 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.

How it works

M³D uses aerodynamic focusing to precisely and accurately deposit liquid inks which contain metal, polymer or ceramic materials. The core technology consists of 3 modules, as shown in Figure 1: atomiser, in flight processing and deposition head.

Aerosol generation from the starting ink is accomplished using an ultrasonic or pneumatic atomiser. This creates a dense aerosol stream of femto-litre (1-5micron diameter) ink droplets. The aerosol is then transported to the deposition head and if required, undergoes in flight processing. On entering the deposition head a secondary gas flow, or sheath gas, is introduced which forms an annular, co-axial flow around the aerosol. The resultant co-axial flow (sheath gas and aerosol) exits the depostion head through a focussing nozzle and is directed at the substrate. The system is driven by standard .DXF CAD data which is converted via proprietary software to make a vector based toolpath. This toolpath alloys patterning of the ink by driving the 2D or 3D motion control system and a shuttering system which interrupts the aerosol stream.

Once deposited the inks generally require post processing to achieve their final properties. For metallic inks, thermal sintering is applied to increase electrical conductivity and mechanical stability. The end result is a high-quality thin film deposit with excellent edge definition, smooth surface profile and near-bulk electronic properties. For applications with low temperature substrate materials, an integrated IR laser is used to locally heat the deposited material without affecting the surrounding substrate. This technique has been applied to metallic and ceramic based deposits on delicate polymer substrates. Polymer based inks can be dried and cured using standard post-processing methods.

During deposition there is no physical contact with the substrate by any portion of the deposition head tool other than the aerosol stream, therefore conformal writing is easily achieved. This allows for the processing of both planar and 3D substrates, opening the way for the development of novel SIP, MID, MEMS and Smart Systems applications. The process also has the ability to add multiple layers of materials to electronic devices such as fuel cells and micro-batteries. The ability to process a wide range of materials combinations in 3D space opens the potential for new and novel device designs.

Features, benefits and applications

Table 1 shows a comparison of the M³D process with traditional screen printing, which is a physical tool based process, and ink jetting, an alternative Direct Write process.

The M³D process can deposit materials with:

Packaging and Assembly	Electronic Devices
High Density Interconnects	Flat Panel Displays
Flip-Chip / Direct Die Attach	Solar Cells & Fuel Cells
Embedded / Integrated Passives	Micro-Sensors
Flex Circuits	MEMS & RFID
Meso-Dispensing	Hybrid Manufacture
Electronic Components	ructure
Resistors, Capacitors and Inductors	BioTech
Micro-Antennae	Bio-Sensors& Implantable Devices
Micro-Batteries	Micro-Arrays

Table 2 - The flexibility of Maskless Mesoscale Materials Deposition opens the way for many different applications using a single process

- Feature sizes down to 10 microns with +/- 10% edge roughness and pitch down to 20 microns,
- Good conductivities,
- Thickness as low as 25nm or as high as 10 microns (single pass deposit),
- Low surface roughness and
- Good adhesion.

M³D reliably produces ultra fine feature circuitry well beyond the capabilities of thick-film and inkjet processes. Most materials can be written with a resolution of down to 20µm. For Ag inks, electronic features below 10µm with a 20µm pitch can be written (Figure 2). Recent developments have allowed sub-5 micron lines to be produced on a lab scale. This capability offers a solution for the production of smaller, 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 M³D technology to create fine features with 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-antennae and micro-batteries. The excellent edge definition and repeatability of the process are particularly relevant to high frequency requirements.

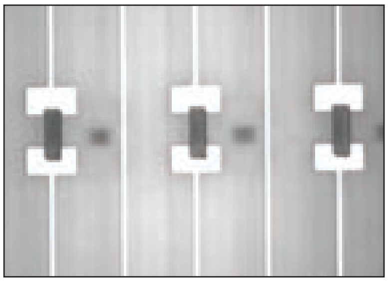


Figure 3 - Carbon PTF (Polymer Thick Film) resistors on FR4

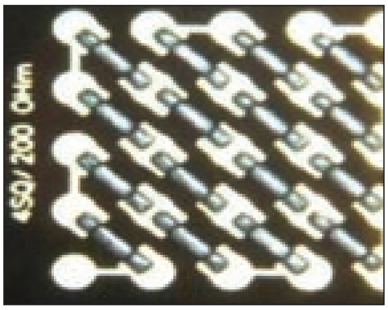


Figure 4 - PTF on a BT substrate. Resistor area approximately 10^{3} mm^{2}

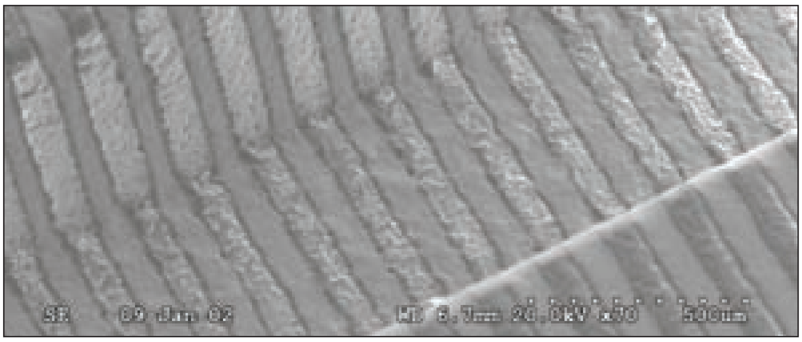


Figure 5 - Ag lines, 50 micron, over a 500 micron deep trench

The conductivity of the deposit depends on the material used and also the ability of the substrate to withstand sintering. Gold and Silver inks generally display conductivities approaching bulk properties when conventional oven sintering (150°C+). If the integrated laser sintering process is used conductivities of 2-3x bulk can be achieved.

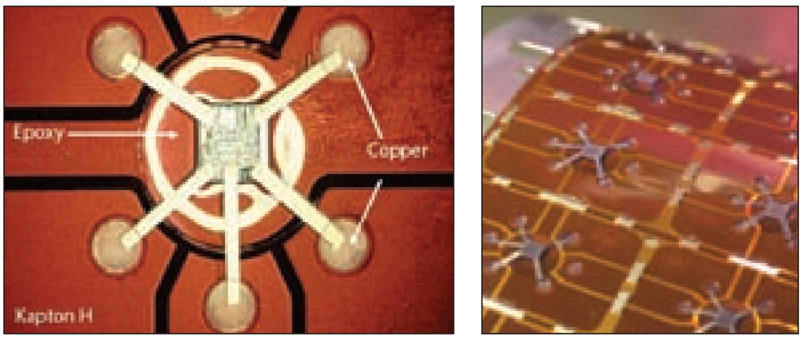
Due to the very fine droplet size of the aerosol (typically 1-5µm) very even surface profiles in the deposit are common. Low viscosity inks can produce mirror-like surfaces whilst thick film inks have micron scale roughness. The ability to process high viscosity inks, relative to ink jet processing, means that higher material loadings are possible in the inks. Consequently, materials processed in this way do not exhibit “coffee staining”, an undesirable feature seen with certain ink jet deposits.

Deposit adhesion is highly dependent on the chemical compatibility between the ink and substrate. For example gold inks adhere to a wide range of substrates including glass, ceramics and various polymers. Silver is more sensitive, but also has good adhesion to a wide range of substrates. For applications where adhesion can be problematic, for example writing Ag in Si wafers, ink formulations contain adhesion promoters are used.

Materials range

M^{3}D can deposit a wide variety of materials, including conductors, insulators, resistors, capacitors, adhesives and biological materials. Deposits can be made on virtually any chemically compatible surface material – for example polymers, silicon, glass, metals and ceramics. This flexibility opens the way for many different applications using a single process (Table 2). The material requirements for the process are much wider than for ink jet printing. M^{3}D can process ink materials with a viscosity range of 0.7-2500cP, compared to a typical range of <20cP for Ink Jet. Thus a wider range of inks can be applied with greater ease and reduced dilution. M^{3}D uses wide range of commercially available inks from a many different of sources. This can be of benefit to the user not being tied to a single proprietary source of material for a given application, as is the case with some ink jet formulations. As the process can accommodate a wide range of ink viscosities, new materials can be quickly developed or existing inks modified successfully for the process. In some cases small modifications to standard screen printing pastes result in inks that can be successfully used.

Figure 6 - Direct die attach. M^{3}D deposited Ag interconnects from the smart card contact pad over epoxy adhesive and connection to the IC. Line width approximately150 microns



Many devices manufactured for electronics products require multi-layer manufacturing techniques. The ability to deposit conductive, insulating, and adhesive materials layer-by-layer within a single system makes the process an attractive solution for the production of novel devices. Examples of multilayer applications include sub-micron layers for fuel cell applications, high density interconnect backplanes (organic and metal) for flat panel displays, and micro-sensors for avionics. Other successes with multilayer deposits have been in the biosciences area, such as the generation of bio-sensor structures. Since many such markets are evolving, M^{3}D can be a powerful product development tool, as well as a viable production solution. The process can also be used as a repair technique for devices such as electronic displays: M^{3}D can precisely place material to fix open circuits on the backplane or coloured inks on the colour mask.

This allows designers to quickly and cost-effectively test new prototypes and products. This eliminates the delays and costs associated with mask sets, screens 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 result is faster time-to-market for new products.

The ability of M³D 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 (Figures 3-4) inductors, capacitors, filters, micro-batteries and micro-antennae.

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 such that no laser-trimming is needed to tune the resistor to the right value. Since M³D can deposit both conductive and insulating materials, one layer at a time, it has the potential to directly embed passive components.

Conformal deposition

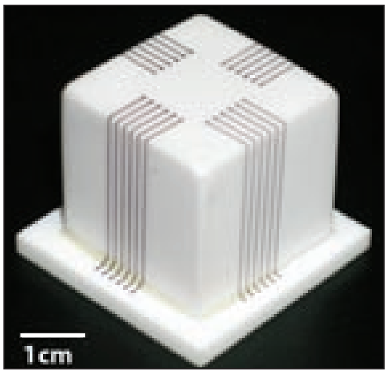
M³D can also precisely deposit materials on non-planar substrates. This is made possible by the relatively high [5mm+] stand off point of the deposition head and the long focal length [2mm+] of the focussed aerosol. With no physical contact with the substrate by any portion of the tool other than the deposition stream, conformal writing is easily achieved. This allows the process to write features or circuits on to 3D structural components, write into trenches (Figure 5) or create MIDs.

This 3D capability can also be used to carry out “direct die attachment”. For example, Figure 6 shows how M³D has been used to replace wire-bonds and directly attach the die to the smart card circuit. This involves directly writing over several different kinds of materials to create the interconnect. The interconnect is written from the Cu pad, over Kapton, and epoxy adhesive (ca. 150 micron height) and over the edge of the IC. This was done using 2D motion control with the height difference accommodated by the aerosol streams long focal length.

For height profiles greater than ca. 3mm up to 50mm an automated 3axis of motion (Z-height) is applied (Figure 7). This 3D capability will further increased by ongoing development of 4th axis automated tilt option on the deposition head which will allow more complex 3D patterns to be written.

To date M³D has been used as a 2 1/2 D process with respect to deposit shape, i.e. complex patterns (X-Y) with limited thickness (Z). Now a EUR 4.5M Framework 6 project funded by the European Union, Multipro (www.multipro-f6.eu), will design and manufacture of novel multifunctional nano-composite materials which will be used to make 3D shaped deposits. The project will produce polymer based materials which will be filled with nano-particles to give increased device efficiency in LED lighting and displays. M³D will be used to deposit these nano-composite materials layer by layer to encapsulate the LED chips and form the shaped lens (Figure 8). Some initial tests have been carried out to test the ability to build 3D shaped deposits (Figure 9). The deposits shown are made from a photopolymerisable Sol Gel and are approximately 200 microns tall.

Figure 7 - Ag circuit with 150 micron line width written on a ceramic substrate (25μm height)



Materials efficiency and reduced environmental impact

M³D provides significant environmental benefits and reduced processing requirements because it is a Direct Write, additive fabrication process. It eliminates the waste associated with traditional subtractive (e.g. mask and etch) processes or consumables such as printing

Figure 8 - Concept of the Multipro project

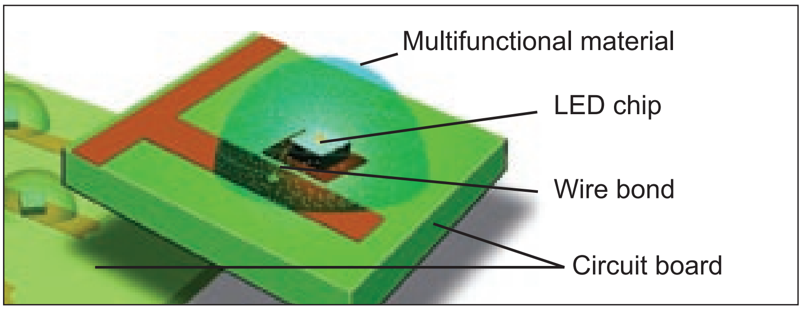
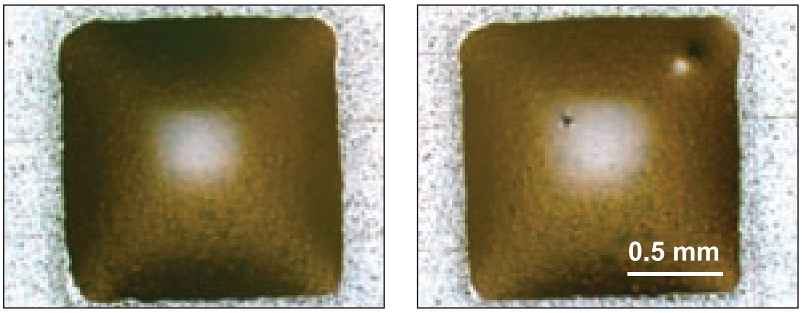


Figure 9 - M³D depsosited Glycidoxypropyltrimethoxysilane



screens. Rather than coating an entire masked surface, manufacturers can deposit exact amounts of material exactly where it needs to be. The tiny droplets created by M^{3}D allow for very thin coatings (i.e. 10s-100s of nanometres thick) which allows for good interaction between differently applied layers. These same femto-litre 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.

Process scalability

To fully exploit their potential, it is necessary for Direct Write techniques can be scaled up to allow high volume production. Currently 25 M^{3}D systems are in operation in product development and R&D in the Europe, Asia and the USA.

The first volume production application, a direct replacement for a screen printing process, will come on stream in 2007. Work is now being undertaken to scale the process for high volume manufacture. This includes the development of multi-nozzle systems with increased atomiser throughput as well as hardware developments to ensure consistent, low maintenance operation over long run times. The exact scaling strategies are dependent on the end applications requirements but typically involve multi nozzle heads, for example 10 x 1 nozzle arrays, multiple deposition heads and atomisers with high throughput capacity.

System Control Software For Micromachining

Micromachining and wafer processing with lasers has reached the sub-micron precision level; to meet these ever-increasing control and programmability challenges, J P Sercel Associates (JPSA) announces the introduction of its new more powerful, more user-friendly JPSAControls32 System Control Software, an engineer-level user interface that provides complete control of all system devices and software components for system setup and programming. JPSAControls32 is Windows-based software offering a number of special features such as a System configuration editor for convenient editing of system software settings and CAD file translation capability (of .dxf files, for easy automated programming of complex designs). JPSAControls32 provides advanced project management utilities that permit system software to 'remember' settings for an unlimited number of different production tasks. The JPSATools32 Module provides setup and control of all stages of motion including linear stages, rotary stages, motorised beam delivery system components (mask changers, rectangular variable apertures, variable attenuators, beam stops, etc.) and laser fire mechanisms.

JP Sercel Associates
5 Woodlands, Freeland OX29 8HD - UK
Tel. +44 870 803 0650, www.jpsalaser.com

Thin Film Photovoltaic Laser Scribing Machines

With the current global shortage and increasing expense associated with manufacture of silicon wafer photovoltaic cells, new thin-film-on-glass solar panel alternatives are gaining popularity. JPSA, a leader in industrial-grade laser systems, announces the introduction of a new family of industrial laser scribing systems to meet the manufacturing requirements of this new technology.

Built on the ChromaDice DPSS laser platform, the PV Series are Class 1 enclosed laser scribing systems for isolation and series interconnection of thin film solar cells. JPSA employs high peak power, short pulsed DPSS laser sources to remove a wide range of thin films from glass, metal or polymer substrates and to produce fine scribed lines with over 30MOhm isolation. A variety of wavelengths suitable for different layer materials are available including 1064nm, 532nm, 355nm and 266nm. The range of applications includes front contact, back contact and semiconductor scribing as well as border deletion. JPSA PV Series workstations accommodate glass sheet sizes up to 1300 x 1300 mm.

JP Sercel Associates
5 Woodlands, Freeland, Oxfordshire, OX29 8HD - UK
Tel. +44 870 803 0650, www.jpsalaser.com