Direct Printing/Micro-dispensing Solution for 3D Coating Applications

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Abstract

Material deposition utilizing a dispensing approach has been widely used in microelectronics for decades. The trend towards more compact and complicated electronic devices at a lower cost has challenged traditional manufacturing and packaging processes, including dispensing. Dispensed coatings for applications such as EMI/RFI shielding, encapsulating, heat transfer, enhanced structural support, and shock protection bring additional benefits. Unfortunately there are challenges due to the component's increased density, the interconnects in a limited foot print, and the three dimensional nature of the components. Technologies and tools are greatly needed to provide not only accuracy, repeatability, and flexibility, but also a wide range of material choices, dimensionality and the ability for in-line integration. The high speed micro-dispensing/direct printing technology of nScrypt provides such a solution with pico-liter level volume control, advanced computerized motion platform, high resolution vision system and the ability of printing on 3D conformal surfaces. The materials that can be processed include but not limited to: conductive, dielectric, adhesive, epoxy, rubberized polymer and encapsulate.

Keywords: micro-dispensing, direct-printing, high speed, selective coating, conformal, EMI/RF shielding

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Introduction

The trend of modern electronic products to become more compact and complicated has put increasing pressure on traditional manufacturing and packaging technologies. Miniaturization improvements use higher density and the ability to build 3D structures; this adds more functions to the device in a limited footprint, and has drawn a lot of interest. As the number of components continues to increase and the pitch between them decreases, new solutions are being sought for EMI/RFI shielding, encapsulating, heat transfer, enhanced structural support and shock protection. The challenges to this include: expanding material choices, shrinking the resolution, and allowing large feature coverage with flexibility at a low cost.

Material deposition as a bottom-up approach has been utilized for decades in the electronics industry. A number of technologies can be utilized for directly depositing materials; each has its own specific advantages and disadvantages, given the nature of the technology. Screen and stencil printing is well understood as high throughput processes but are limited to non curved surfaces and have limited resolution. Ink jetting is valuable for many applications and has the strength of obtaining small feature sizes; however, it has limitations with regard to material choices. These limitations are primarily induced given the nature of the viscosity required for ink jetting (a few hundred centipoise). Aerosol jetting is one emerging technology for dispensing fluid using a focused aerosol beam [1], yet it is also limited to material choices and not able to process the materials (10,000 to more than 100,000cps) usually used in electronics assembly.

Micro-dispensing is one of the options for material deposition and is particularly useful given the wide range of materials that can be dispensed. This applies to viscosity and also to the particle size that is loaded in the material. nScrypt technology has demonstrated pico-liter level volume control, material viscosities handling range from 1 centipoise to several million centipoises, nanometer to 10's of micrometer particle sizes and print speeds reaching half meter per second. This brings a number of contributions to very small or large area selective coating for electronic applications. The materials that can be directly printed include, but are not limited to: conductive, dielectric, adhesive, epoxy, rubberized polymer and encapsulate materials.

Direct Printing by Micro-Dispensing Technology

Micro-dispensing is typically done using positive pressure on the material and pressing the material through a small orifice. nScrypt direct printing technology is based on micro-dispensing and uses a patented valve near the dispensing orifice to control the start and stop of the material. The shape of the patented pen tip was specially designed to reduce the pressure when enabling dispensing from very small holes, such as 100 microns or less. ***Figure 1*** shows a drawing of the current generation nScrypt SmartPump^{TM}. It is capable of handling materials with viscosities ranging from 1cps to several million cps. The material is typically transferred from a syringe or other customized cartridge by a positive pressure through the material flow inlet into the valve. When dispensing is initialized, the valve opens, which allows the material to flow through the pen tip onto the substrate. The removable print head assembly is easily taken off when changing the material or cleaning. ***Figure 2*** shows a view of the cross section of the wetted parts. The valve rod is driven by a motor and travels up and down in the channel of the valve body with a resolution of 0.1µm. ***Figure 3*** illustrates the valve operation of the SmartPump^{TM} in a dispensing process.

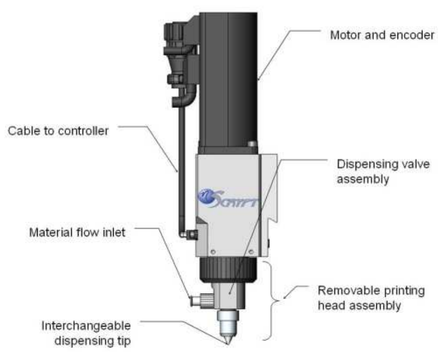

Figure 1 - Schematic view of nScrypt Smart Pump^{TM}

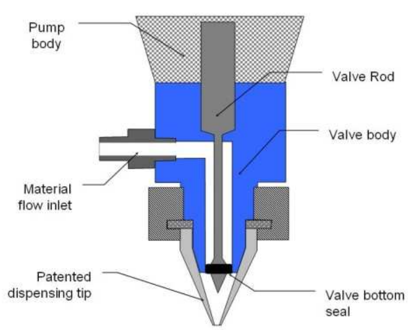

Figure 2 - Schematic view of nScrypt Smart Pump^{TM} valve assembly

At a close position before dispensing starts, the bottom of the valve rod is used to seal the channel by either a fitted o-ring or the matched mechanical surface between the rod and the inside channel of the valve body. At an open position, the valve rod moves downward and releases the material under the positive pressure, which will prime the pen tip and flow through the pen tip for deposition. To stop the dispensing, the valve rod moves back to the close position that not only keeps a seal to the channel, but also maintains a negative pressure in the dispensing tip chamber to induce a reverse of the material flow. ***Figure 4*** [2] shows the pressure distribution inside the pen tip when the valve is open and closed respectively. It can be seen that a positive pressure is maintained inside the tip chamber to push the material through the tip orifice. A negative pressure is created in the closing process which collects the material back into the tip for a clean stop. This unique feature allows the orifice to be left clean and delivers a consistent start when dispensing commences. Moving the valve into the closed position induces two important features: 1) closes the material flow pathway and 2) pulls material back as shown in ***Figure 3***. This pulling action pulls both material and air back into the tip chamber. Priming is done by cycling through the open close process and establishing a proper valve close position which is typically done before dispensing.

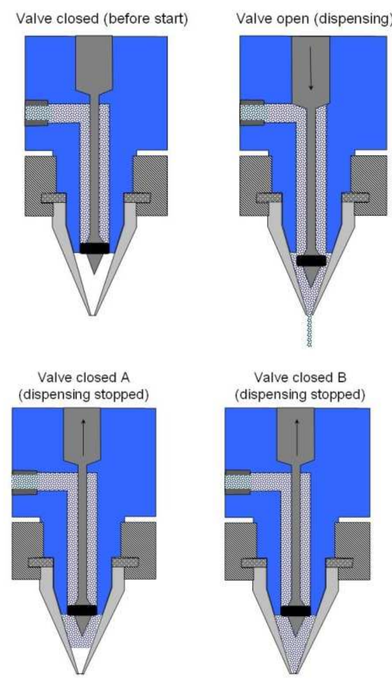

Figure 3 - Schematic view of nScrypt Smart Pump^{TM} operation

The valve will open and close in a synchronized manner with the X and Y motion control. This allows any pattern to be printed in an X, Y plane and, if necessary, conformally in the Z plane. The impression of traditional micro-dispensing is

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always slow and lacks resolution and accuracy. However, the nScrypt technology controls the material volume flow at pico-liter levels and the control valve enables clean starts and stops of the dispensing/printing path. Integrating this into a high precision motion platform enables high speed direct printing with fine features. The linear print speed of X and Y can be as fast as 500mm/second and the resolution and repeatability of motion in all directions is within a few micrometers. ***Figure 5*** shows a picture of nScrypt 3Dn-450 direct printing system. In addition to the SmartPump™ and the motion platform, a high resolution vision/camera system is also integrated for substrate alignment and a real time processing view.

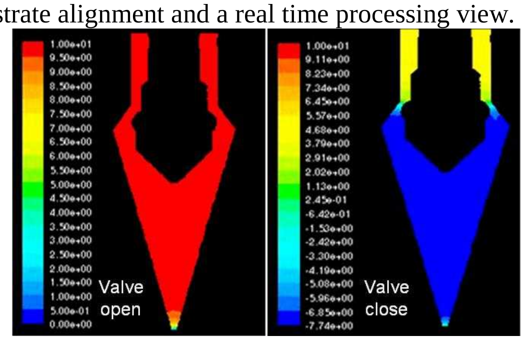

Figure 4 - Pressure distribution in the tip chamber

Figure 5 - nScrypt 3Dn-450 direct printing equipment

The printing pattern can be generated by a number of CAD software packages. The output of the CAD is transferred into a script file using nScrypt software; this provides integrated, synchronous commands for the machine. There is no need for a screen mask or other complicated setup in the process, which enables rapid prototyping. Higher speeds enable rapid manufacturing. The combination can reduce the cost and maintenance on the production floor. Additional benefits include a reduction in material waste because the material resides in a syringe or a customized reservoir. Also, there is only a fraction of a milliliter dead volume in the entire pump/valve setup. Another benefit of direct printing is that any pattern that can be generated in a computer can now be printed on any curved surface; therefore patterning on electronic devices with a wide variety of surfaces is much more feasible.

For large volume printing applications, a multi-nozzle pump and its array can be integrated to meet the throughput demand. ***Figure 6*** shows a picture of the multi-nozzle pump assembly, which includes 12 pen tips. The spacing of the pitch between each printing nozzle can be customized based on the requirement of the application.

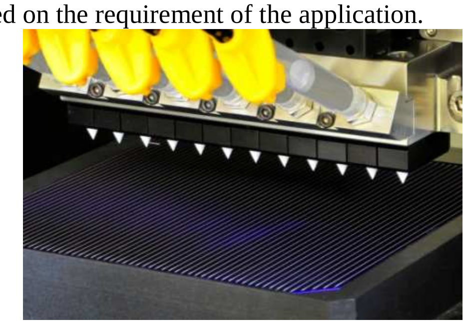

Figure 6 - nScrypt multi-nozzle printing head

Large Area 3D Coating by Direct Printing

Printing gap is one of the critical parameters of most printing/dispensing technologies. It usually refers to the distance between the dispensing nozzle and the surface of the substrate or object. Most dispensing is utilized by maintaining a relatively small dispensing distance so that the material can be continuously transferred from the nozzle to the substrate in order to obtain the desired feature size. ***Figure 7a*** shows the "close-deck printing" as the case. The flow rate of the material depends on the pressure, valve opening, and the size of the tip orifice. A previous study [2] showed that it is critical to control the printing gap in order to obtain desired printing feature size and resolution; the material flow rate is sensitive to variances of this gap.

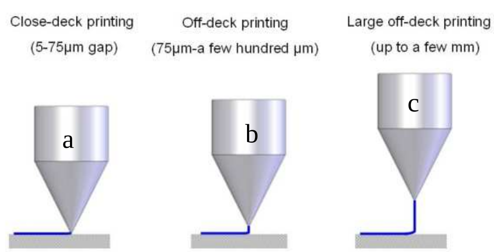

Figure 7 - Schematic view of different printing gaps

When the printing gap increases to a certain point, the material flow rate is mainly affected by pressure, valve opening, the size of the orifice and the material rheology and surface tension. A successful "off-deck printing" process (shown in ***Figure 7b***) has been developed to print high aspect ratio finger lines for front side metallization of silicon solar cells [3]. The material used in this specific case is a thixotropic

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conductive paste with a viscosity of more than 200,000cps and the printing gap is more than 75µm. The printed line width and height have a standard deviation smaller than 1.5. In addition, the line quality is much better than screen printed lines.

Increasing the printing gap further would turn the process into “large off-deck printing” (shown in ***Figure7c***). With proper control of the pump setup and printing parameters, the material can be directed downward in a controlled “beam” with desired line width and pitch, while maintaining control over the start/stop. The SmartPump™, the pen tip design, the rheology, surface tension of the material, and the printing setup (to maintain the printed resolution) all contribute to this process. The large off-deck printing has good control but a reduction in control and increased line width does occur. The following are two case studies of utilizing “large off-deck printing” to perform conformal coating.

1. Conformal coating with fixed Z

In many applications, the coating has to be restricted to a certain footprint and cannot contact adjacent wire bonds or components; this requires the material to be placed in a controlled manner. This exceeds traditional dispensing capabilities that have less volume control. In addition, a small but long needle is typically used in tight spaces, which slows the dispense process. Also, the needle cannot be so small that it does not allow the material to flow thorough the capillary. The large off-deck printing process using the nScrypt SmartPump™ will overcome these challenges and enables assembly designers to meet compact requirements. ***Figure 8*** shows a view of printing with a fixed Z position. The material is “beamed” down to the board and there is no Z motion for printing on surfaces with different height.

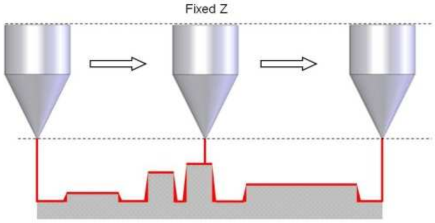

Figure 8 - Schematic view of large off-deck printing for 3D conformal coating with fixed Z

The tight spaces and the sharp edges of some large SMT components can be well coated by the process setup and material rheology. ***Figure 9*** shows an actual coating on top of a 1.1mm tall IC chip. The material is a UV curable dielectric and has a viscosity of 20,000cps. The printing gap between the orifice and the PWB board was more than 2mm. The coating thickness can vary from 50µm to the scale of millimeter, depending on the material and application.

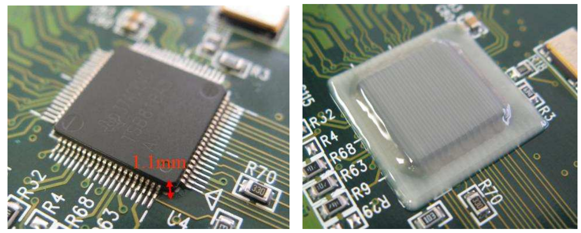

Figure 9 - Conformal coating of an IC chip with fixed Z

2. Conformal coating on a curved surface with conformal mapping and Z tracking

Some assembly design requires the circuits on a curved surface or other specific profile to meet certain requirements. With the aid of a laser based height sensor, the nScrypt printing equipment is able to scan the surface of the substrate or object and integrate the obtained conformal map with the printing process; the pen tip can follow the surface profile for a desired distance. The large off-deck printing process makes it feasible to print on a curved surface filled with components of varying height tolerances; ***Figure 10*** shows a schematic view of such a process. The pen tip follows the profile of the object with a large gap, which allows the freedom to print on SMT components or any surface with severe changes in Z.

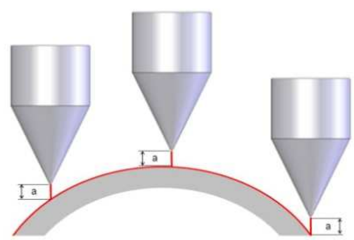

Figure 10 - Schematic view of large off-deck printing on curved surface using Z tracking

Figure 11 shows an object with a curved surface used in this study, as well as the conformal map obtained by the laser height sensor. ***Figure 12*** shows the coating on this object. The material is a UV curable dielectric and has a viscosity of 15,000 cps. The printing gap was maintained at 3mm during the process, and the coating is smooth and uniform in terms of thickness.

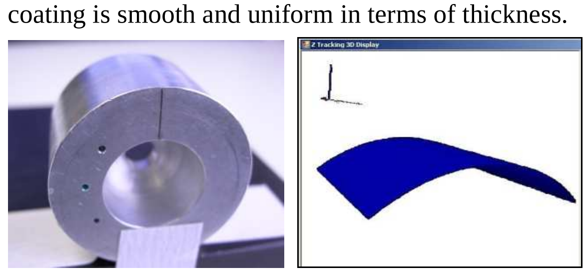

Figure 11 - Conformal Z map of a curved surface scanned by a laser device

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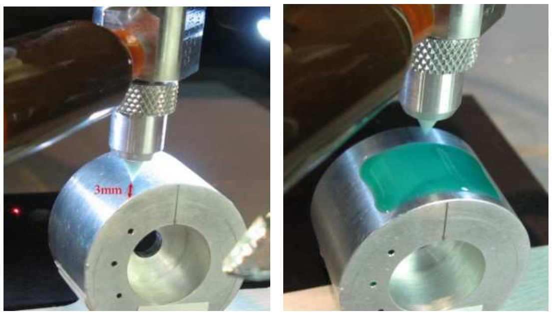

Figure 12 - Large off-deck printing on a curved surface using Z tracking

Summary

This paper presents the nScrypt direct printing/micro-dispensing technology and the tool system that provides enabling techniques and solutions for manufacturing and packaging. It demonstrated the large off-deck printing process with and without conformal mapping. It is able to transfer material in a well controlled manner onto any 3D conformal surface with a relatively large dispensing gap. The materials that can be processed include but are not limited to: conductive, dielectric, adhesive, epoxy, rubberized polymer and encapsulate materials. This process can be used for coating applications such as EMI/RFI shielding, encapsulating, heat transfer, enhanced structural support and shock protection.

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