

High Speed Dispensing Solutions for Packaging and Manufacturing

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Abstract

Packaging is one of the key components for manufacturing of compact functional devices. Screen printing has been an important process for patterning a number of electronic devices, however, as the critical dimensions continue to shrink, this technology has been challenged by its accuracy and dimensionality. In order to solve this problem while keeping high productivity, nScript Inc. has developed high speed dispensing technology for packaging and manufacturing finer features such as conductive lines, resistors and dielectric insulators. As a through nozzle dispensing technology, the nozzle (tip) has been optimized to a conical shape, which reduces the pressure that is needed to extrude the material (e.g. paste) through the opening, thus enabling high speed dispensing. This technology can handle material from very low viscosities to high viscosities (several million centipoises). A large number of materials have been dispensed at several hundred mm/second, which qualifies it as high speed dispensing. To further enhance the speed, parallel dispensing has been employed and demonstrated in this paper. A height sensor, normally a laser based sensor, is integrated to acquire the z data for conformal and true 3D surface, which makes it possible to dispense on conformal and even true 3D surface. A novel pumping technology, which employs a special needle valve mechanism to control flow on and off ensures that material is accurately dispensed and placed in an x, y, z map. The needle valve technology enables pico-liter level volumetric control of the dispensed material. Micro resolution x, y and z stages are integrated to the system, which enables the precise placement of dispensed features. In the paper, dispensed micro dots, lines and patterns will be presented. In addition, 3D printing and high speed dispensing will be presented. This technology has various applications, including but not limited to, electronic packaging, manufacturing, solar industry, biomedical applications, electro optical applications and next generation hybrids.

Keywords: nano-particles, low temperature, direct-printing, micro-dispensing, high speed, high viscosity

Introduction

Consumer electronics is rapidly shrinking in packaging size with improved functions. The challenge to put more functional electronics into a physically smaller package durably is creating new manufacturing requirements. Traditional screen printing processes has had the unique position of being simple, proven and cost effective for manufacturing conductive, resistive and dielectric patterns. Screen printing is well suited for flat substrates with large features. Micro dispensing, while not as fast, could aid in unique placement of materials and most specifically adhesives and underfills. These processes have satisfied many steps in the back in process for electronic packaging for many years.^{i,ii}

As the next generation electronic devices are emerging, the limitations of the traditional packaging approach began revealing themselves.^{iii,iv} Screen

printing has become the bottle neck to produce finer lines and dots due to its fundamental issues, such as the limitations of the fine mesh screens for finer line widths and the contact of the screen to the substrate which can damage or break fragile substrate. Screen printing also wastes a significant amount of material, which makes it unfavorable since the price of the base material such as silver has risen dramatically. The screens must be changed and maintained frequently as well thus adding expense to the process. Next generation devices also exposed the limitations of micro dispensing. Micro has been used as a broad term to imply small. Specifically in electronics, micro would typically represent one millionth. In volume that would typically be microliters, in space or size that would typically be micrometers. When applying the term to micro dispensing, this is a bit misleading for state of the art electronic devices. Certainly, micrometer geometries are what are

desired, but traditional micro dispensing has been dispensing on the order of millimeters to few hundreds of micrometers range. Unfortunately, these are too large with respect to current micron devices to be considered as small geometries. To make the point, the term micro dispensing in the past has typically been a nebulous term to describe small as compared to the object being dispensed on.

Next generation devices need a true micro (or so called pico) dispense approach that can achieve the micron regime feature sizes, but doing so with speeds matching screen printing. Either of these is very challenging, while merging them together significantly increases the challenge. nScrypt has developed and demonstrated high speed micro (pico) dispense printing, termed Direct Printing (DP), that rivals screen printing print speeds, but surpasses its geometry limitation. DP has the potential to impact a number of areas such as next generation cell phones, I-Pods, computers, displays, automotive electronics and solar cells.

The challenge to obtain the size of enabling geometries for consumer electronics and solar cells is to flow particles that are suspended in a paste or ink through the micron sized orifice (e.g. 25 microns in diameter). As a practical approach, it is feasible to use materials that are made for screen printing in micro-dispensing tools. The material characteristics of standard screen printable materials are shear thinning in nature. Shear thinning materials will have a viscosity change when shear is applied to the material. The shearing effect is typically present when the material and the screen oppose each other which causes the viscosity drop. Once the material is resting on the substrate, the material will resume the static viscosity. This material characteristic has been optimized for screen printing and is a stable approach for manufacturing.

Inkjet is another possible way to put down materials, specifically inks and lower viscosity materials which are normally less than 30 centipoises. However, ink jet does not work with thick film materials, which are normally highly viscous in nature. Inks are typically jetted with the advantage of finer features. Nano particles are increasingly becoming more popular in electronic devices, which are suspended in inks and then jetted as a pattern onto a surface. The advantage of this approach is its non-contact nature, which allows a gentle approach and reduces the breakage that occurs when using screen printing on fragile devices. The disadvantage of this approach is that the choice of material is limited given the nature of the process; which requires a low viscosity carrier. Nano particles of interest are suspended into a carrier or solvent that will evaporate with temperature and time. Standard loading percentages of nano particles to carrier is about 30% by volume. This implies a 70% shrinkage

after jetting down the pattern and therefore much thinner lines are the result.

The advantages of using standard thick film materials are the extensive choices of materials for this industry, the dramatically wide range of viscosities that can be printed (up to over 1 million cp as compared to 30 cp for ink jetting) and the higher percentage of particle loading in the carrier. Thick film paste can load more than 90% particles by volume.

Direct printing (DP) technology

nScrypt has developed a patented micro valve and pen tip allowing a wider range of materials to be dispensed with exceptional volumetric control.^v One of the critical advancement is the pen tip. A specified conical shape allows a significant reduced pressure in the process, which enables the extrusion of materials through the micro-sized orifice. The size of the openings varies from 12.5 microns to hundreds or even thousands of microns depending on the needs of the application. A side view as well as an upward view of the pen tip I.D./O.D. is shown in the Figure 1 below.

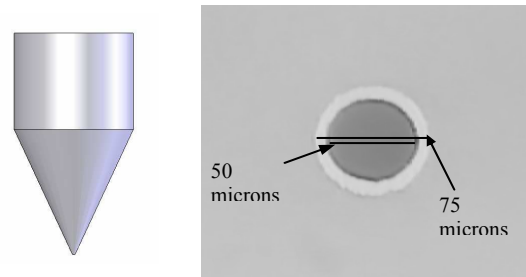


Figure 1. Pen tip shape and end picture for opening.

A number of materials with various particle sizes have been dispensed. The desire for finer features (e.g. less than 100 microns) is driven by adding more functions onto smaller areas or less shadowing in the case of solar cells. For micro-dispensing, this is a challenge given the size of the orifice needed to make finer features. There are a number of limiting factors when considering how fine a feature can be printed or dispensed using a specific orifice diameter. It is not difficult to understand that larger particles on the order of 10's of microns will not flow through a 10 micron orifice. Many screen printable electronic pastes have particles that range from a few microns in diameter to more than 50 or even a hundred microns in diameter.

Material manufactures will rate the particle size using a Particle Size Distribution Data (PSD) sheet. Therefore a D50 of 10 microns means that 50% of the particles are 10 microns or less, which implies the other 50% are larger. A second consideration for understanding the flow of a specific material is the other particles that supplement the other attributes of

the paste. Silver paste with a D95 of 2 micron particles implies 95% of the silver particles are less than 2 microns, but does not mean that the supporting glass particles to help adhesion are less than 2 microns. These still strongly affect the characteristics and flow of the overall material.

Choosing the size of the pen tip to print (dispense) the line has to be carefully considered. The O.D. will typically determine the line width. This is due to the wetting of the bottom surface of the pen tip. Therefore, a 50 micron wide line would have a tip with 50 micron O.D. and a 25 micron I.D. If the particles were 10 microns, then the pen tip would immediately clog and no flow would occur. It might make sense to say that if the particles were 2.5 microns, then this would give 10 times as much room for them to flow out of the orifice. This is indeed true for a short period of time before clogging occurs, and sometimes clogging is immediate.

The next consideration is to move to the nano particles regime and stay literally a thousand times smaller than the orifice diameter. There are two main problems with this as it stands today: 1) most nano based materials are inks and not pastes and 2) nanoparticle agglomeration. Pastes over inks have a serious advantage given the higher percentage of particle loading that can occur which translates to higher quality of electronic performance. While there are a number of new comers that are starting to work on pastes, this still needs a lot of effort to explore. Nanoparticle agglomeration is still a major obstacle and little has been done to remedy this.

Nanoparticle agglomeration occurs for the same reason as low temperature sintering, due to large surface area to volume ratio.^{vi} Surface coatings are standard in nanoparticle inks and pastes to reduce agglomeration; however, the dispensing approach adds pressure to the material and creates shear forces thus inducing the agglomeration. However, nScript Direct Print technology is capable of producing fine lines and dots with the choice of commonly used paste with micron-sized particles. This technology is well developed and demonstrated repeatedly.

To print finer features, materials with micron sized particles (less than 10 microns) are easily obtained. Proper filtering of the particles can insure that no or a very low percentage of larger particles are in the paste. The proper materials will allow a much smaller dispensed line, lines as small as 20 microns wide have been dispensed, but this is still a challenge.^{vii} Continuous research and process development have led to printing 75-micron wide lines without clogging while printing repeatedly and consistently. This was done using a tip of 50 microns I.D. and a 75 microns O.D. Figure 2 is a picture of lines that were printed on a solar cell from Evergreen Solar, Inc. of Marlboro, MA.; the photo shows the pen tip and the printed pattern. Results with

repeatable line geometries have been demonstrated on a number of substrates.



Figure 2 Pen tip printing fine lines on a solar cell.

Innovative high speed dispensing

In order to be accepted by the industry as a manufacturing method, the Direct Print technology has to match the throughput of screen printing, which is currently dominating the market. Our approach is to dramatically increase the printing speed up to several hundreds mm/second as well as using a parallel process which employs multiple heads in the design. As mentioned above, the conical shaped tip helps to reduce the pressure needed to extrude the material, which is one of the enabling factors for high speed printing. High quality stages enable the high speed movement of the tips for dispensing. An innovative dispensing approach is developed for high speed dispensing, where the position of the pen tip is considerably away from the substrate in the range of a few hundred microns.

The challenge of printing narrow lines at speeds high enough to compete with screen printing has a number of variables that must be properly addressed. High speed in micro-dispensing implied 10's of millimeters per second (mm/s) in linear speed. Given the nature of screen printing, large area coverage in a single sweep, 10's of mm/s is not adequate, it will take 100's of mm/s in linear speed. Printing 100's of mm/s in linear speed for lines that are sub 100 microns in width will exaggerate many of the issues that exist in through nozzle printing, such as the balance of material flow versus linear speed. Figure 3 below is a photo of lines printed along the X axis and then lines printed along the Y axis.

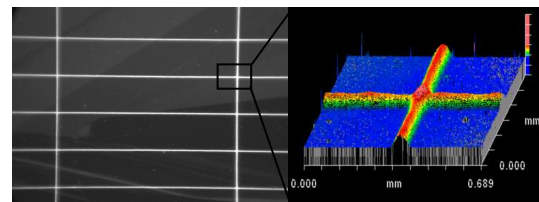


Figure 3. Printed lines in both x and y direction.

The crossing portion of the lines is shown on the right part of the Figure 3, a Zygo (interferometric scope) picture. These lines are 75 microns wide and were printed at 300 mm/s with the nozzle (tip) 300 microns off the deck. To ensure consistency in

printing, the tip is lowered to the surface of the substrate and then lifted up a specific distance in z, in this case 0.3mm or 300 microns.

There is an interrelationship between speed, pressure, height off the deck, and the size of the lines. High speeds allow better efficiency and height off the deck allows a wider variety of substrates to be used, including those that are not uniformly flat.

“Throwing” the material down from a higher distance at higher speeds also relieves some spreading that occurs when the nozzle is much closer to the deck allowing for more consistent and thinner lines. While these advantages are evident, further examination also leads to issues that reside with the high speed, larger working distance approach. Figure 4 below is a photo of the corners of two printed patterns. The pattern on the left is a continuous serpentine pattern, while the pattern on the right are straight lines with starts and stops in the X direction and then straight lines with starts and stops in the Y direction.

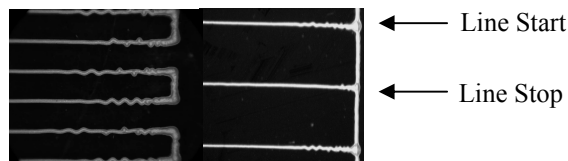


Figure 4. Lines with serpentine and square patterns.

The lines on the left in figure 4 are approximately 100 microns wide and were printed at 300 mm/s with the nozzle 300 microns off the deck. When the tool is programmed to print at 300 mm/s it has to accelerate to that speed and then decelerate when coming to the end of a line or to a sharp turn like that exhibited in Figure 4. With the pressure being held constant and the velocity of the pen tip changing during acceleration and deceleration period, this induces a material build up. In most instances, this build up of material is evident as the line begins to wave. The inconsistency of the corners and start and stop of the lines can be solved by coupling the valve control simultaneously with the motion of the platform. So the flow rate will change at the same rate with the changing of the motion speed of the stages. This is the future work.

The lines on the right in Figure 4 are approximately 75 microns wide and were printed at 300 mm/s with the nozzle 300 microns off the deck. In this picture, the horizontal lines (X direction) were printed first and the vertical line (Y direction) was printed last. There is a distinct difference in the starts and stops of these lines. While they both tend to have the characteristic "wave", the stops tend to have less area affected and a noticeable improvement over the serpentine pattern where excess material can build up on the short turns. Since the velocity of the nozzle is

the same at both acceleration and deceleration, the difference would be attributed to the pause in the valve before the line starts to dispense. This pause allows the nozzle to fill up with the desired material before the next line is printed, allowing the line to begin at its proper xy coordinates. Controlling the valve in an optimized manner would reduce or eliminate the waving in the printed lines; this will be done in future work.

High speed dots

Using micro-dispensing to print dots is different than jetting dots. The main advantage that jetting brings in dotting is the speed or number of dots per second jetted. For low viscosity materials (tens cp or less), ink jetting can jet tens of thousands of dots per second.^{viii} Medium viscosity material (thousands cp) can be jetted at hundreds of dots per second.^{ix} To achieve dotting of higher viscosity materials (tens to hundreds of thousands cp), this is done with micro-dispensing. The consistency of printing dots in this fashion has been shown previously, Li, et al.^x Dispensing dots in this manner, the material must be wetted to the surface or substrate. As mentioned previously, this is close to the surface just as lines have been typically dispensed, but the pen tip still does not touch the surface, therefore making this a non-contact process. Figure 5 shows an array of dots on the left and a Zygo measurement on the right. The dots were dispensed by nScript pumps with high viscous material.

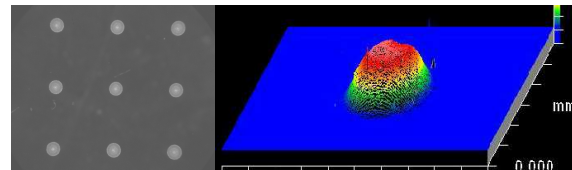


Figure 5. Dots in a matrix and a Zygo pic of a single dot.

The dots in the Figure 5 are approximately 250 microns in diameter and were printed with a distance between pen tip and substrate (gap) of 50 microns. The height of the dots after drying was 35 microns. The specific size of the dots can be controlled by pressure, gap and pen tip diameter. For small particle materials, it is possible to achieve the same dot diameter comparable to the narrow line widths. The dots were printed at 8 hertz (Hz) or 8 dots per second. In comparison to jetting, this is very fast considering the viscosity and the movement of the system. The optimal speed for this is yet to be determined, it is estimated that 20 dots per second is feasible.

Multiple nozzles

Linear speeds of 300 mm/second and dotting speeds of 8 dots per second have been demonstrated. These are fast given the respective nature of the

materials, surfaces, size and process, however this is still not fast enough to compete with the screen printing process. It is however within an order of magnitude. To make up this last portion, multiple nozzles with the patented valving has been designed and tested. There are a two obvious ways to approach multiple nozzles, 1) increase the number of pumps and 2) increase the number of nozzles per pump. Both have been demonstrated. This section will describe the approach to put multiple nozzles on a single pump. Figure 6 below is a picture of a 3-nozzle pump. Notice each nozzle has its own material feed source and separate pressure inlet.



Figure 6 Tri head nozzle pump.

Each nozzle has a fine-tuning knob to set the individual valves, a key attribute for handling the wide range of materials in this pump. This prototype system demonstrates the feasibility to print in a parallel manner. The future work will minimize the individual nozzle and supporting body. The shrinkage will allow a significant increase in the number of nozzles per pump. With the achievement of 10 nozzles per pump and multiple pumps to one machine, it is possible to have 50 or even more nozzles printing in parallel. It also appears practical to print in excess of 500 mm/second. With these coupling together, it brings 25,000mm/second linear speed and 400 or more dots per second for each system.

The advantage of this technology is to print in a non-contact fashion; lines and dots are smaller and more consistent than that screen printing can achieve and do so at speeds that match or exceed screen printing.

Summary

In this paper, a high speed dispensing solution is presented for the packaging and manufacturing of next generation electronics. With the dimension of the electronic device continuously shrinking, it is highly demanded to develop an enabling technology for manufacturing finer features where the traditional approach such as screen printing fails. nScript high speed dispensing technology satisfy this need. Finer

features in the range of less than 100 microns were dispensed at high speeds up to several hundred mm/seconds. Combined with parallel printing, this technology has the capability to match or exceed the throughput of screen printing and other dispensing technologies. This technology has great application potential for both electronics and solar (PV) industry.

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