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JETTING FINE LINES FOR HIGH VISCOSITY FLUIDS ONTO 2D AND 3D ELECTRONIC PACKAGES

Horatio Quinones
Nordson ASYMTEK
Carlsbad, CA, USA
horatio.quinones@nordson.com

ABSTRACT
For many years technologies such as inkjet printing and fine screen printing have been successful in placing dots and lines on mostly flat topographies. However these technologies have required either low viscosity fluid inks with several properties tailored to meet the inkjet hardware operation window, and in the case of the former method, where higher viscosity fluids and pastes are used, a flat and unobstructed topography of the surface is required. We are proposing in this study an alternate method where a hybrid jetting mode is used to dispense small dots and fine lines in which the above restraints are overcome, i.e., the low viscosity fluid requirement and the flatness of surface upon which we place the fluids. The implementation and application process for 2D and 3D packages is described, where nano hybrid jet dispensing is practiced resulting in high conductive lines of 40µm to 160µm in width on 80µm to 200µm pitch. Detailed descriptions will be shared about how traditional issues in jetting are overcome during this work.

Key words: conductive lines, jetting, keep-out-zone, jet streaming, 3D dispense.

INTRODUCTION

The ever increasing demand for smaller dispense doses including fine lines, small dots, edge definition improvement and more accurate dispensing requires examination of available products and technologies. Potential solutions include piezo-driven valves, positive displacement jets, nano-dose dispense valves, multi-nozzle inkjets, and other non-contact valves capable of dispensing high viscosity and doped fluids. Although printing electronics may offer a process solution to some family of fluids and applications, this inkjet technology at present is limited to fluids of single-digit centipoises viscosities and other material properties i.e., thixotropy, magneto-electrical, that may make such fluids incompatible for the electronics industry in other multiple applications. There are some limitations for stenciling or screen printing high viscosity conductive pastes in the form of small dots or thin lines for numerous package formats including multiple components layouts, and accessibility of the printing head. Three dimensional electronic packages, i.e., stacked die, also present major challenges to such processes. An alternative to the traditional processes can be printing or jetting technologies which are non-contact fluid dispensing. Electrical conductive lines are a feasible solution for multiple applications provided that their electrical and physical properties are within well-defined boundaries and ranges. This requirement often requires thin lines and homogeneous lines. In another application where fluid is to be kept from wetting or flowing into Keep-Out-Zones (KOZ), a thin hydrophobic dam can be dispensed with a non-contact technology. Fluid viscosities can vary from a few mPa-s to 5.0E5 mPa-s, therefore dispensing systems capable of operating in those ranges is required.

EXPERIMENTAL WORK

System in package (SiP) and other highly populated boards often require fluid dispensing on well defined areas only, thus avoiding KOZ. Geometries involved, material wetability, osmotic and diffusion of the fluid onto the solid areas violate such zones, and hence a possible solution can be a fluid dam.

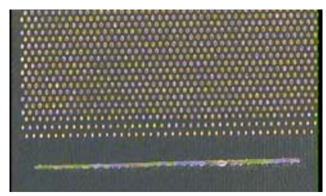

Figure 1. Ink line jetted as a dam to prevent underfill fluid from reaching KOZ.

Such dam can be manufactured as part of the board topology or can also be built by a thin fluid line dispense. A thin line was dispensed using an inkjet print head with a nozzle orifice of 25µm; the line of about 65µm was placed within the allowed zone and near the side of the die where the underfill fluid was jetted. The ink used for this purpose was underfill phobic. Figure 1 depicts the jetted line and part of the footprint of the bump lands (die has not been attached). The property of the fluid as well as the geometry of the dam is expected to stop the underfill from passing over the dam. Figure 2 depicts the efficiency of the dam as underfill ceases to flow. Another application is the writing of conductive lines on substrates, resistors and inductors can be built by simply printing or dispensing conductive lines.

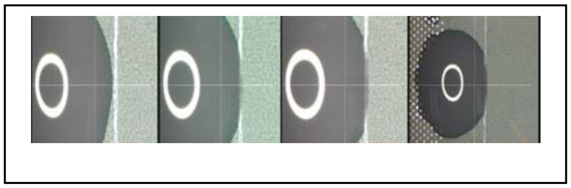

Figure 2. Ink jetted line dispense on die carrier as to stop underfill from reaching KOZ.

A non-contact or jetting process can overcome stencil printing requirements for surface topography and be able to draw conductive lines on 3D topographies and potentially connect multiple 3D layers. Traditionally wire bonding is the connection of choice; we propose here jetted conductive lines to electrically coupled multiple layers of a 3D stacked die. Figure 3 depicts a typical pyramid structure of eight layers.

Figure 3. A multi-level 3D with a pyramid-like geometry, jetted conductive lines at 200µm pitch provide electrical interconnection among the eight layers.

The challenge to meet desired electrical properties, i.e., electrical resistance/conductance, depends on the material properties[1] and the geometry of the line. Highly conductive materials tend to have high viscosity from the fact that the fluid matrix is doped with suspended conductive particles; this rheology state makes dispensing with the non-contact jetting process more difficult. A valve capable of droplet formation in small doses is used[2] ,a hybrid dispense mode where sudden stopping of the fluid stream to form droplets and a fast retrieving motion of the valve from the substrate surface results in a successful dispense. Figure 4 shows conductive lines dispensed in this mode on a 3D package with eight layers, four layers are connected at a time in two opposite sides of the stack, the line pitch is 200µm and the lines are 160µm wide. The cross section of the part shows the fluid migration into the layers, which wets the die pads resulting in a robust connection; line geometry is essential to obtain proper electrical and mechanical attributes. Given the size of the lines and rather complicated geometries and surface wetability, a consistent dispense gap is of most importance to obtain line repeatability.

The jet valve can also be used in a hybrid mode where the pulsing of the piston is used to stop a fluid stream rather than continuously generate droplets at higher frequency of actuations.

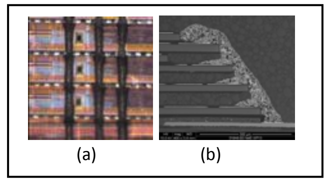

Figure 4. (a) Jetted conductive lines on 3D package. (b) Cross section of an interconnection line.

This "streaming mode of the jet" can generate thin lines at very high rates. The starting and ending of these lines tend to be wider than the bulk of the line as seen in figure 5, a "dogbone effect" for the streaming mode as well as the dot mode. A dynamic dispense control i.e., a dispense rate correlated to the head motion can mitigate this issue. For the present work some modifications to the software i.e., addition of z-motion gave acceptable results. In figure 5b one can notice that for the dot mode the end of the line has no dogbone issue.

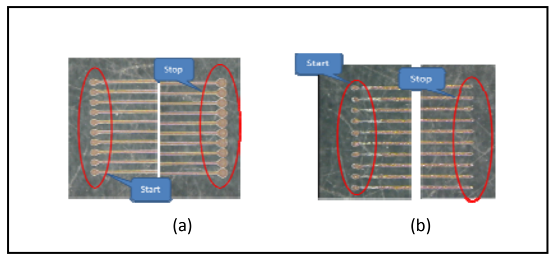

Figure 5. The end of line issues, dogbone effect for: (a) jet in line streaming mode and (b) jet dot mode.

However the beginning has a wider geometry, this is due to the fact that the nozzle orifice has a meniscus from the previous dispensed that get deposited during the jetted first droplet. Figure 6 shows the improvement upon dynamic dispense algorithm implementation and by minimizing the shutoff spike in the fluid delivery. The shutoff spike was minimized by altering hardware geometry like fluid path ducts and by piston driver dynamic deceleration during the jet actuation and just prior to piston to seat impact.

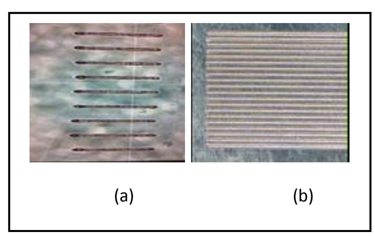

Figure 6. Jetted conductive lines with minimum "dogbone effect for (a) jet streaming and (b) jet dotting.

In some applications, however, the dogbone effect may be advantageous since at those end locations a connection to a pad is needed. Obtaining small conductive lines for long periods of dispensing presented a large clogging problem in the jet ducts. The particle doping needed to make these fluids good electrical conductors have the tendency to segregate upon impact and form a solid powder that eventually causes obstruction of the dispenser ducts; traditionally the smallest diameter of the fluid path is the orifice of the nozzle, and hence it is the location most prone to clogging. For the case of the jet however, the solidification of the particles occurs in the area of high pressure such as where the piston impacts the seat surface and the compacted powder eventually clogs the seat. Figure 7 shows a cross section of the duct and the location of most likelihood for clogging.

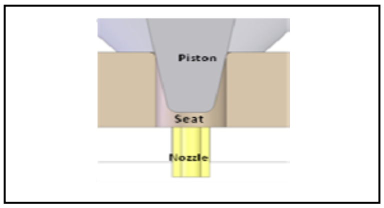

Figure 7. Cross section of the jet valve near the exiting orifice, the seat is the area where material clogs.

This issue becomes apparent after a few hundred actuations of the jet; it has been a common issue for jetting this kind of doped fluid as it is the case for most solder pastes. The valve-on-time was shortened for the pneumatic jet taking advantage of the fact that the impact force to prevent leakage is low and the velocity of the piston does not need to be very high (<1 m/s) since these materials stream well under high pressure differential (>2.5 bars.) Volumetric dispense accuracy and consistency of the line mass density is another issue when dispensing small doses. The jet when used in the streaming mode has a very precise timing in the shutoff (positive shutoff) and opening making it ideal for this type of application. Figure 8 depicts the dispensing accuracy of the jetting process.

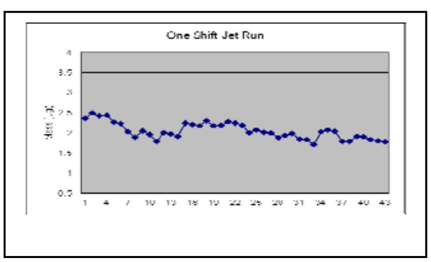

Figure 8. Plot of mass dispense during a simulated shift time frame, accuracy of about +- 0.2µg.

To obtain line widths of less than 160 µm the droplets need to be between 15 to 2.5µg in mass. Lines of <70µm width were dispensed on flat surfaces as depicted in Figure 9 on a 100µm pitch. Similar geometries were accomplished on 3D stacked packages where a vertical device (side of the die) was to be electrically connected to a pad on the substrate to it.

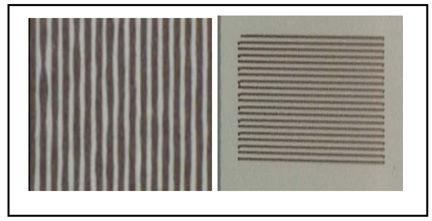

Figure 9. Conductive lines jetted on a flat surface, line width is <65µm.

A similar application process was exercised for solder paste. Thin lines (<230µm width) were jetted. The traditional clogging problem of these materials when jetted was not present in this process. More than 70,000 droplets were jetted without clogging issues.

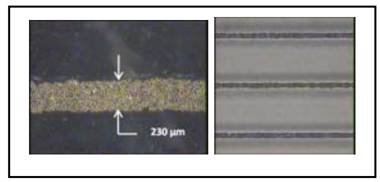

Figure 10. Solder paste line jetted on a flat surface. Line width is 230µm.

Type 500 solder paste was used for this study (a Nordson EFD[3] product). Dispensing was performed during several days without clogging problems with a high rate of consistency.

PROCESS IMPLEMENTATION

The process described above has been implemented in a manufacturing environment. These jetted conductive lines are replacing traditional wire bonding and at the same time providing interlayer interconnection without through silicon vias (TSV.) Figure 11 shows the 3D line jetting process for 125µm jetted lines of conductive silver paste on 3D stacked die with a total of 16 layers, of which eight are connected with the jetted conductive lines on the opposite side of the package; the pitch is 200µm. The ends of the lines exhibit a somewhat wider thickness; this feature was dispensed by design to enhance the conductivity on the connected pads. It was important to not generate debris or satellites that could create electrical connection among lines. The stack was built on steps in a pyramid manner. In another design, the 3D stack was built without the steps with the connected side normal to the die stack carrier.

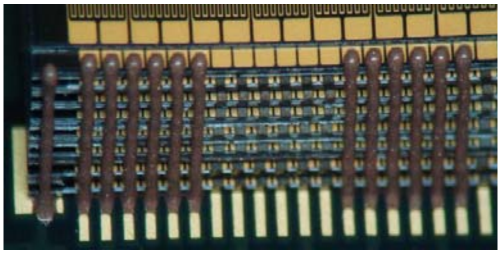

Figure 11. Jetted lines making electrical connection between multiple layers of a 3D package.

Figure 12 depicts the perfectly vertical package and the conductive lines as well.

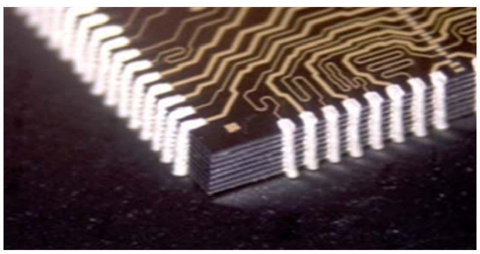

Figure 12. Sixten-layer package with a total height of about 0.8mm.

CONCLUSIONS

Conductive lines with widths of less than 200µm down to 45µm were jetted successfully. These lines were dispensed on flat surfaces as well as in a 3D space. Highly doped fluid with conductive particles was successfully jetted.

RECOMMENDATIONS

Continuous hammering of the material by the motion of the needle needs to be attenuated: Softer elastic modulus of the spring driving the needle motion. Implement needle tip shape change, from spherical to conical to minimize applied pressure on the material. Use a larger seat inner diameter to further minimize likelihood of clogging. Fluid pressure increase to drive (extrude) the material from jet nozzle orifice, i.e., pressure differential jetting. To decrease the shot size and line width, one needs to implement shortening of the valve-on-time, reduce nozzle inner diameter orifice and dispense gap, assure high Z-motion resolution. For lines, apply dog bone geometry elimination software with dynamic line dispense control and minimize the momentum transfer mode from the jetting process.

ACKNOWLEDGEMENTS

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