ENABLING HIGH DENSITY SYSTEM IN PACKAGE (SiP) MANUFACTURING AND CONSUMER ELECTRONIC DEVICES THROUGH THE USE OF JETTING TECHNOLOGY TO MINIMIZE SUBSTRATE AREA FOR UNDERFILL

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ABSTRACT

Hard Disk Drives (HDD) and products using System In Packages, (SiPs), like all other forms of consumer electronic (CE) devices, have to be small, lightweight and portable for convenience of the user. At the same time, new features and functions are being added to designs of HDD and SiPs that put tremendous pressure on the use of the substrate area. Flip chip (FC) devices and micro-BGA devices are being used as preamplifiers on flex circuits and substrates for these markets. Underfilling these devices on flex circuit and PCB substrate presents some fundamental problems for needles that Jet dispensing can eliminate.

Jetting overcomes the difficulties incurred on designs which are otherwise impractical to dispense with using a needle. An example of this is found in HDD Flex circuits and SiP packages, which have very high component density and little room to position a dispensing needle. Along with density concerns, flex circuits must be kept flat so as to support the design of receiving a FC. Stiffening layers are added to give the flex compliant system structure where an FC can be mounted. This rigid surface is also a requirement for establishing a known height from the substrate to needle tip, which is a critical control parameter in conventional dispensing. Jet dispensing on flex surfaces or on tightly designed SiP packages eliminates the need to precisely control the substrate to dispensing tip distance. As a result, Jetting can significantly increase throughput.

A process requirement of underfill is that it must be dispensed adjacent to the component edge, flip chip or micro-BGA, so that capillary forces pull the fluid under the device. At risk are other components near or in direct path of the dispense needle transfer pattern, which may become wetted with underfill and become contaminated with underfill. This creates concerns of wasting expensive underfill fluids or can lead to solder connections that do not meet proper IPC 610A criteria. A worse case is FC devices, which cannot be completely underfilled due to design densities and thus may be at risk of being starved of underfill at one corner of the device. In looking for solutions to these manufacturing challenges with dense packaging, Jet dispensing has proven very effective in being able to control the deposition of the underfill fluids and lower the risks associated with needle dispense transfer patterns. With the increased precision of dispensing position and jetting's ability to take advantage of smaller substrate layout footprints, high layout densities are able to be achieved. Jetting is also able to significantly increase throughput as the need to slow down needle transfer speeds is no longer required with a jet.

The authors of this paper will discuss the merits of jetting verses needle dispensing. They will show how it has been possible to save board space while improving throughput in real life applications.

Typical Applications

The following two applications demonstrate flip chip on flex circuit and system in a package on PCB. In figure 1 a flip chip is soldered on to a flex circuit and it has been underfilled to give the device higher reliability than would be obtained without underfill (Ref 1). Flex circuits present and interesting problem when trying to set a needle gap between the substrate and a needle tip, because flex materials are not flat.

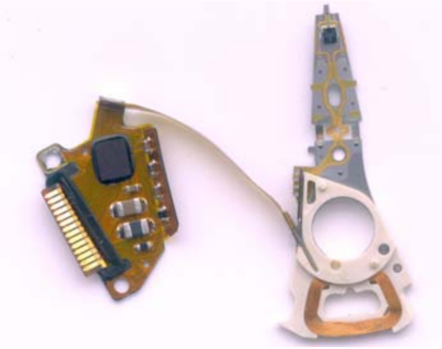


Figure 1

Figure 2 is a photograph of a compact flash hard drive. The PCB under the drive is a system in a package, with multiple flip chips and CSP devices that have been underfilled (Ref 1). In this photograph, a large space between the array packages and the adjacent components has been left vacant to give access to component for needle dispensing and allow space for the fluid to flow without coating the adjacent components. This is wasteful of board space and could force the designers to use more layers on the board if this space was not available. With modern dispensing tools such as jet dispensers, it is not necessary.

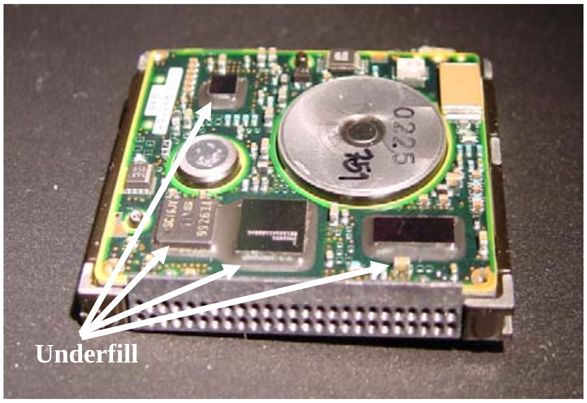


Figure 2

Figure 3 illustrates what can go wrong if a dispensing / underfill process and the board layout design are not optimized. In this case, fluid has flowed onto adjacent passive components on two sides of the component being underfilled. While this will not cause a device failure, it is wasteful of underfill fluid. It also makes repairing passive components virtually impossible after dispensing. More important is status of the corner (of the… chip, component, etc.) marked with an arrow. If fluid has flowed onto passives in an uncontrolled manner it is possible that the amount of fluid at this corner is less than desired and could be a potential reliability problem area.

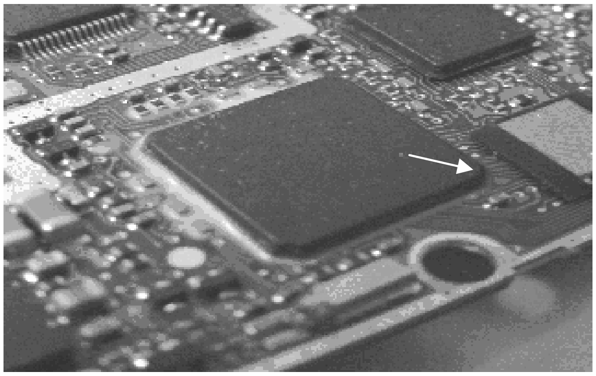


Figure 3

Dispensing Technology Review

The chart in figure 4 highlights the technologies for depositing fluids onto an assembly and shows how they relate to each other and their inherent limitations and capabilities (Ref 2).

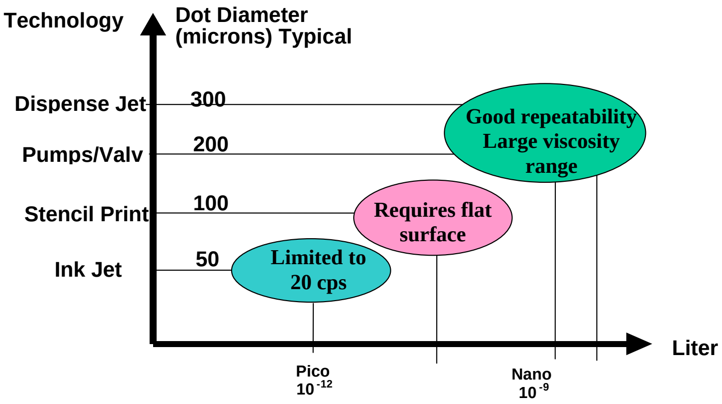


Figure 4

Inkjets

It has long been realized that employing ink jet technology to dispense fluids used in electronic assembly would provide a very flexible tool. Unfortunately, ink jets used in printing cannot dispense the typical underfill fluids used in electronics assembly, with viscosities from 1000 to over 100,000 centipoise, and in many cases highly filled with abrasive particles. It is also difficult to characterize an ink jet dot of fluid as thin viscosity fluids tend to flow out very rapidly. So far, piezo and thermal ink jets have only found limited applications in electronics assembly.

Stencil Printing

Stencil printing is a popular method of depositing materials onto surfaces. Stencils have a great advantage in that the material only has to move through the thickness of the stencil, instead of being pushed through a length of needle. Additionally, stencil printing is very fast. However, stencils require a flat surface, and assembled PCBs are not flat. One company in Japan has developed a screen printer in a vacuum box for underfill deposition.

So far this does not appear to have gained wide acceptance for the underfill process.

Auger pumps have been used in the dispensing industry for many years. The smallest dots of electronic assembly fluids, such as silver epoxies, are still made today using auger pumps.

Augers need to be adjusted periodically as fluid viscosities change over time and the components wear. Plus, the needle tip has to be held at a precise distance from the PCB surface to get a consistent dispensing.

DispenseJet®

The Dispense Jet (Figure 5) uses a pneumatic piston with a ball tip end to push fluid through a narrow orifice at the jet nozzle tip. Air pressure raises the piston, which allows a fluid to flow (shown in red) around the piston and into the nozzle. Spring pressure returns the piston to the nozzle tip when the air pressure is removed. As the ball tip on the end of the piston engages in a seat at the nozzle, the fluid is energized and shoots a droplet from the end of the jet. The nozzle orifice and several other factors control the size of the droplet.

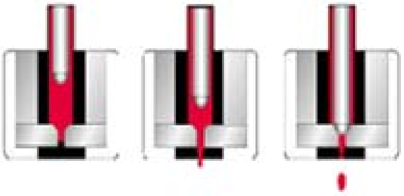


Figure 5

Because the typical fluids change viscosity with temperature, it is necessary to control the tip temperature to ensure consistent operation. Several drops of fluid can be deposited in the same location to get a larger dot. The DispenseJet can deposit over two hundred drops per second. By moving while dispensing, lines are formed.

Jetting Modes

There are several modes of operation for jetting fluids onto a part. The simplest method, to move into position and fire a dot, which is typically used for materials such as surface mount adhesives (SMA). SMA dispensing requires accurately placed consistent round dots so that when a component is placed on the dot, the adhesive does not spread onto the adjacent component terminals, and interfere with the electrical connection.

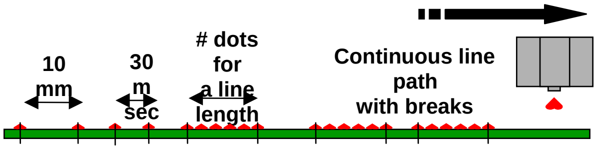


Figure 6

Underfill dispensing does not require precise round dots, and oblong shapes can be tolerated. In this case, the head moves as dots of adhesive are fired from the Jet. This requires the system software to be able to make predetermined, precise moves timed to the firing the Jet, in order to place a line of dots at an exact position. Figure 6 shows the four different modes of Jet dispensing “on the fly.” The four modes are distance, time based, fixed number of dots in a line and the fastest mode which is a continuous line with breaks. In this mode, the head does not stop moving between the end of the first line to the start of the second line. This is the fastest mode of jet dispensing.

Underfill

Being able to dispense fluid from above the surface of a flip chip or array package significantly simplifies the underfill process. Common problems associated with needle dispensing such as setting the gap between the board and the needle tip are eliminated. Figure 7 demonstrates a number of problems associated with needle dispensing: fluid on top of the part caused by build on the tip, too small a gap to get a needle into, varying fluid dispensing changes to lines or dots as the gap between board and needle changes.

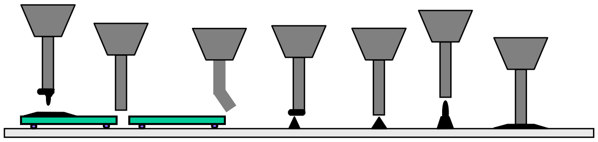


Figure 7

A catastrophic problem which can occur at high speed is die clipping. This is where the dispenser does not make a sharp right angle corner and cuts across the corner of the die. This tends to happen at higher speeds and the usual method of curing this problem is to create a large gap between the edge of the die and needle. However this uses more valuable space on the board or substrate as this will increase the size of the wetted area. Figure 8 shows the damage that can occur when a needle makes contact with a silicon die. The dotted line shows the likely path of the needle.

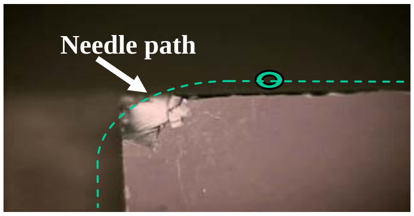


Figure 8

Jet Dispensing of Underfills

In Jet dispensing, a nozzle tip is brought into position alongside and above the die. This eliminates any chance of clipping the die with the needle. Z movement of the dispense head is eliminated, which speeds up the process particularly with many small die on an array assembly.

When using a needle to dispense, it is often necessary at the end of a line to stroke the needle back over the line to break an epoxy string. Discrete dot dispensing of underfill with a Jet does not have tail-off problems, which makes programming the end of a line much easier and saving time in production.

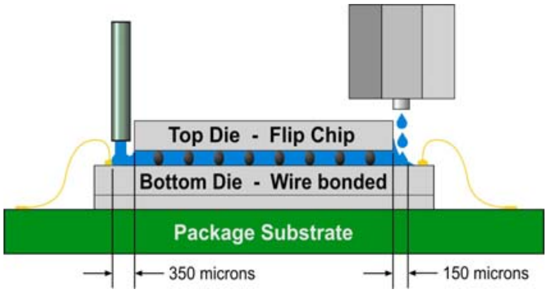


Figure 9

Figure 9 shows a cross sectional view of stacked dies. It can be seen that the needle is no longer required to be positioned halfway up the die edge. In addition, because the nozzle tip of the jet is above the surface of die and much less sensitive to height variations, the robot positioning the jet can move between die without having any Z movement to set the needle to board gap.

When two die or a die and passive components are in close proximity, it can become difficult to underfill a die without coating these other components. In figure 10 (Ref 3) two squares represent a die to be underfilled and an adjacent component. It can be seen that in tight spaces the needle size needs to be small to fit into a gap between the die. With a 100 micron diameter fluid flow stream from the jet (see figure 11), the fluid can be shot between the die with very compact spaces between them. Only the smallest needles can get into some of these situations. However, small needles offer a large resistance to fluid flow and require greater positional accuracy, which tends to slow the operation.

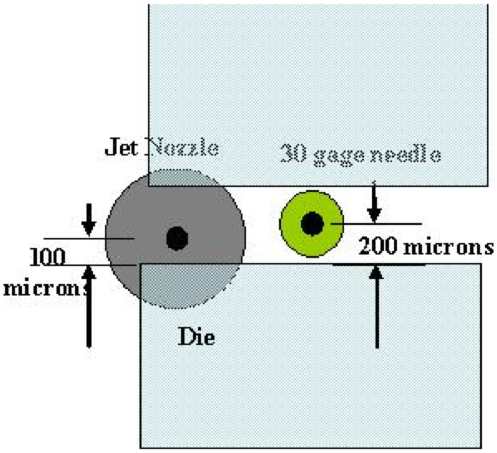


Figure 10

Figure 11 is a still picture from a high speed video camera. In this picture, the nozzle tip is shown at the top of the picture. In this picture, one drop of fluid has just emerged from the nozzle and is elongated. As it flies from the nozzle tip to the board, the droplet becomes spherical and measures approximately 100 microns in diameter, depending on nozzle size. Once the fluid droplet has formed into a sphere, it does not change shape on it flight between die and passive components and therefore that it can pass through gaps slightly larger than 100 microns.

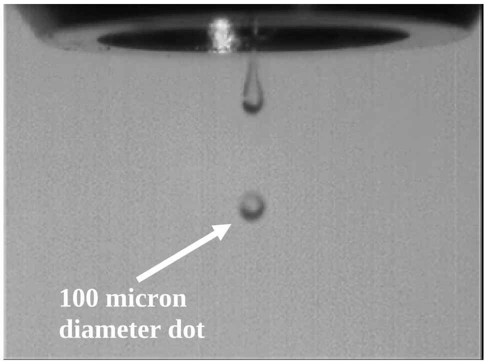


Figure 11

Figure 12 shows two 5mm square glass die with a 1mm space between the die, the stand off height of the die to the board is 125 microns. Both of these die have been underfilled using a jet dispenser. It can be seen that the underfill fluid has not bridged between the two die. In fact, when measured, the wetted area is approximately 0.25mm. The wetted area is usually greater than the fillet area, as this is where the underfill fluid is staged prior to capillary forces pulling the fluid under the die. Note this demonstration of how small a wetted area is possible. For reliability reasons, a larger fillet area may be required.

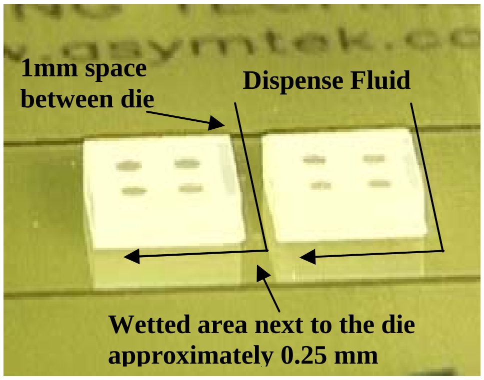


Figure 12

With the ability to precisely control the amount of underfill fluid on a substrate, the savings in board area can be significant. As an example, if a 7mm square die is going to be underfilled, a footprint for the device (assuming standard 1.5mm keep out zones between the device and adjacent passive components) would take an area of a board of 100mm square. By reducing the keep out zones to 0.5mm, the board area for the same device size is reduced to 64mm square, almost a 40% saving in board area, which becomes significant in small SIP devices, where the overall size is only 10mm square. Figure 13 shows a comparison of the area required for both needle and jet keep out zones when underfilling a device.

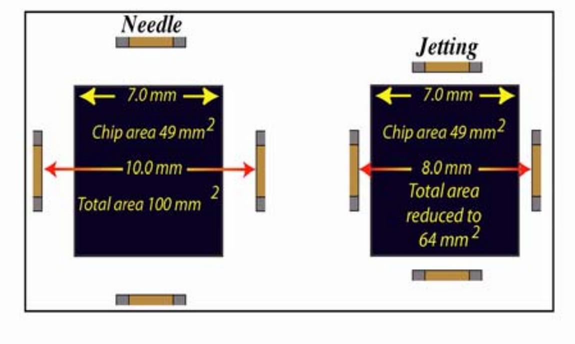


Figure 13

Practical Technology Demonstration

Building a SiP on a conventional surface-mount assembly line can be challenging and demands a wide range of knowledge and competencies. Materials such as solder pastes, underfills and conductive adhesives must be selected not only to perform the task required of them, but also to be compatible with all other materials as well as with downstream assembly processes.

Micro Modular Technologies Ltd. (MMT) and Belton Technology created a complete GPS receiver module with 12-channel GPS receiver in a 10 by 10 by 1.8 mm, 36-pin SiP. Power consumption is less than 75 mW. A power supply and an antenna are the only external components required (Ref 4).

The assembly presented complex challenge, because the SiP called for multiple die with dissimilar ball pitches to be located in close proximity. The processes necessary to assemble the SiP included screen printing lead-free solder paste, component placement, reflow, underfilling, conductive adhesive deposition, deposition of non-conductive structural adhesive and attachment of an RF shield, followed by final curing of both types of adhesives.

Selecting the materials involved evaluating a number of aspects, including manufacturability, compatibility between materials, processes and surface treatments, and long-term reliability. Among the manufacturability challenges, the very close spacing of the three die included in the SiP presented a tough challenge when it came to applying the underfill to each die.

Figure 14 is a picture of the GPS SiP before an RF shield is placed over the device. The red arrows are on top of the devices that are underfilled, and the direction of the arrows indicate flow path of the underfill. The underfill fluid is dispensed in a line between the two larger die and along the short side of the smaller die. An exact amount of underfill has to be dispensed under the die because a metal trace for attaching an RF shield to is around the perimeter of the GPS device. Clearly this has to be free of any epoxy underfill fluid contamination.

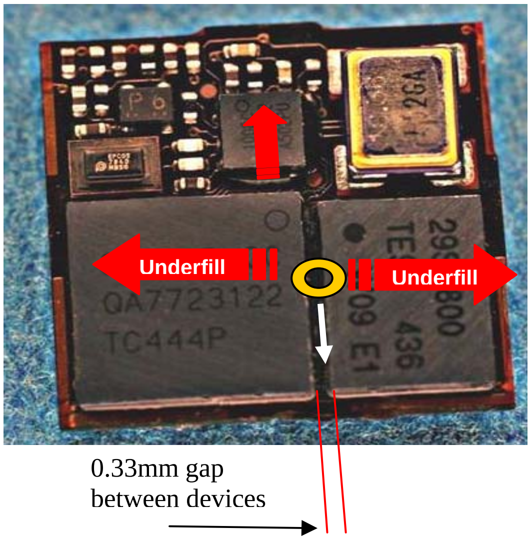
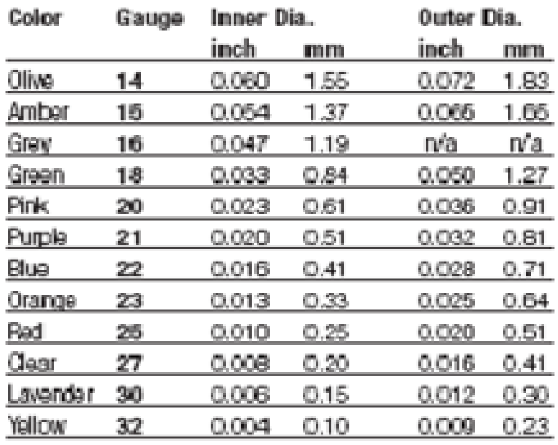


Figure 14



Color	Gauge	Inner Dia. inch	mm	Outer Dia. inch	mm
Olive	14	0.060	1.55	0.072	1.83
Amber	15	0.054	1.37	0.066	1.66
Grey	16	0.047	1.19	n/a	n/a
Green	18	0.033	0.84	0.050	1.27
Pink	20	0.023	0.61	0.036	0.91
Purple	21	0.020	0.51	0.032	0.81
Blue	22	0.016	0.41	0.028	0.71
Orange	23	0.013	0.33	0.025	0.64
Red	25	0.010	0.25	0.020	0.51
Clear	27	0.008	0.20	0.016	0.41
Lavender	30	0.006	0.15	0.012	0.30
Yellow	32	0.004	0.10	0.009	0.23

Figure 15

Figure 15 is a standard needle chart for traditional needle dispensing (Ref 5). It illustrates that only a 32 gauge needle could be placed into the gap between the devices on the GPS module.

Figure 16 is a picture of a SiP module with a half millimeter gap maximum between the edge of the die and the RF shield trace on one side. The die is 1.7mm square and there is approximately 0.4 mg of underfill fluid under the die which deposited in two discreet lines along one edge. The decision to dispense along a short edge was driven by the need not to get fluid on the passives or the RF shield which are closer than 0.5 mm. By splitting the fluid volume into two discrete quantities, it gave more control to the flow out than if deposited in one large dispense volume. Clearly this level of control of volume and deposition positioning is something that could not be attempted with a needle dispenser.

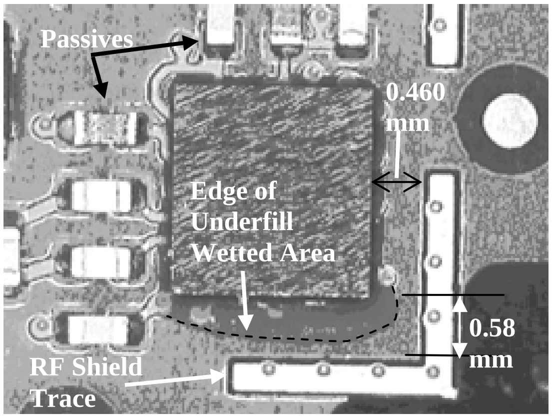


Figure 16

Summary

This project to build a GPS device based on SiP technology enables new generation of products that minimizes the use of board space. This level of miniaturization could not have been achieved in part without the use Jet dispensing technology to dispense underfills on a device with exceptionally tight keep out areas.

Approximately 200 prototypes were subsequently built at the Belton Advanced Development and Production Centre in the Bangkok, Thailand, before volume production commenced. High-yielding product output was quickly achieved by Belton as it was able to draw upon in-depth high-volume experience gained from its daily manufacturing production practices used in producing flip chip-on-flex assemblies for the HDD market. MMT publicly introduced this GPS device at the Institute of Navigation Satellite Division conference at Long Beach, California in September 2005.

Acknowledgement

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Note: DispenseJet® is a registered trademark of the Asymtek