Jet Dispensing Underfills for Stacked Die Applications

Steven J. Adamson
Semiconductor Packaging and Assembly Product Manager
Asymtek
Sadamson@asymtek.com

Abstract

It is not uncommon to see three to five layers of silicon in stacked die packages. By going vertical, designers get greater utilization of the board space and can implement mixed silicon technologies, such as memory and microprocessor technology. Stacked packages often use combinations of flip chip and wire bonded die. When a flip chip is used as one of the layers of the stack, dispensing space is often tight, with limitations on the area where underfill fluids can be dispensed. Any time a needle has to be positioned accurately in a restricted space between a die and wire bonds, the process can run slow. Jet dispensing of underfill overcomes this limitation by shooting dots from a safe height above the flip chip and wire bonds. The lower tolerance positioning requirements for jet dispensing leads to higher throughputs.

This paper will review the state of dispensing for stacked die applications and contrast jetting technology with needle dispensing. It will also offer guidelines for layout rules for Printed Circuit Boards / packages designed to utilize the benefits of jetting technology.

Introduction

For the last twenty years, dispensing has evolved from pushing fluid through a needle using air pressure, to a highly automated production process with linear positive dispensing pumps and now: jetting. Controlling fluid deposition,
needle position and dispensed volume accuracy has dramatically improved in recent years.

Additionally, speed has increased while software has simplified operational control. Jetting underfills and encapsulants is now practical, and it is having a large impact on the electronics assembly.

Higher Packaging Density – 3D Stacked Packages

To improve the packaging density of electronic devices, particularly in such devices as cell phones where board space is limited, device manufacturers have turned to 3D packaging. In figure 1 (ref1) families of devices are shown for mixed Radio Frequency (RF) and memory devices. The upper group of devices, surrounded by the dotted line, is produced using a combination of wire bond and flip chip devices. The construction of these stacked package devices is silicon mounted on another silicon device. This should not be a problem with

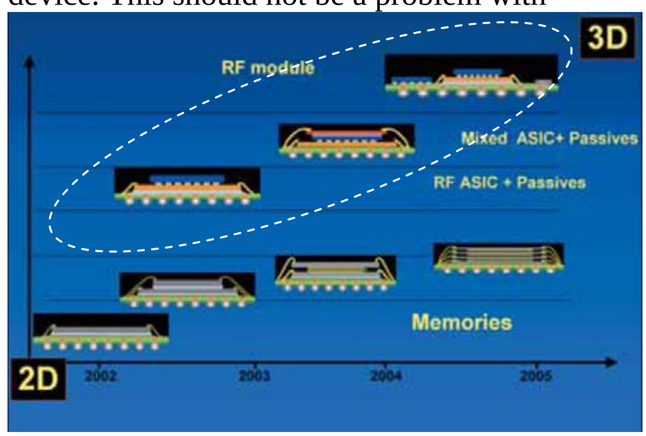

Figure 1: Ball Grid Array (BGA), from the "single chip" version to multiple stacks and Modules (REF 1)

differential thermal expansion; however underfill is still required for the flip chip to survive sudden impact shocks.

Package manufactures do not like to see underfill fluids on the wire bonds or on top of the flip chips. Therefore due to the space restrictions small needle diameters are required and the dispensing system must move slowly to have greater positional accuracy.

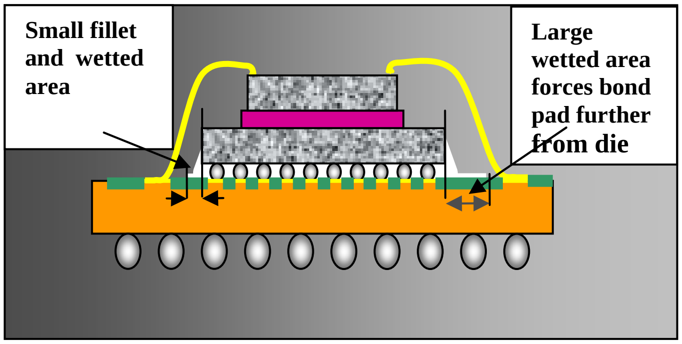

Figure 2: Flip chip on bottom of stack

With a simple two stack design the flip chip can either be the top or bottom die. In figure 2 where the flip chip is on the bottom of the stack, the distance from the edge of the flip chip die to a wire bond pad cannot be less than the wetted area used for dispensing, the underfill. Therefore a designer has to allow 1 to 1.5mm distance between the flip chip and bond pads, when using needle dispensing in manufacturing.

In figure 3 the flip chip is on the top of the stack and the distance from the edge of the flip chip to the wire bond can present a challenge if the designer does not want to see underfill on the bond wires or the die.

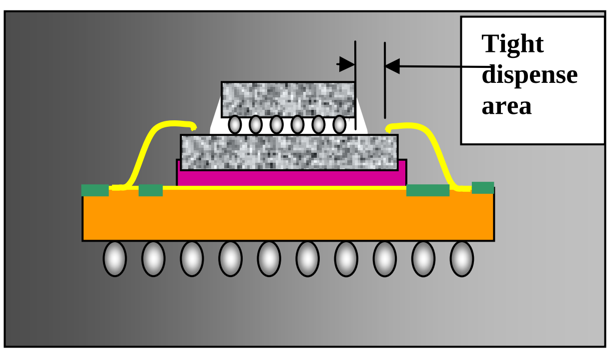

Figure 3: Flip chip on top of stack

Underfill Process

Conventional underfill dispensing uses an auger or linear positive displacement pump with a needle to apply underfills around a flip chip. The needle tip has to be positioned alongside the die, a 125-micron gap is left between the flip chip and the side of the needle to avoid contact between the die and needle. The needle is also positioned in Z to be at a mid-point between the substrate and the top of the flip chip. The goal is to dispense enough material in the wetted area next to the component, to completely underfill the die and form a fillet around the edges. To minimize wetted area next to the die the underfill can be put down in multiple shots. The fillet should be about 50 to 80% up the side of the flip chip edge. Fluid on top of the flip chip or the needle clipping the die corner or wire bonds cannot be tolerated. In stacked module packages it is also not desirable to coat adjacent components such as chip resistors with underfill, as they cannot be reworked.

When using needle to dispense underfill with a glass test die as in Figure 4, it can be seen that the wetted area where the needle deposited

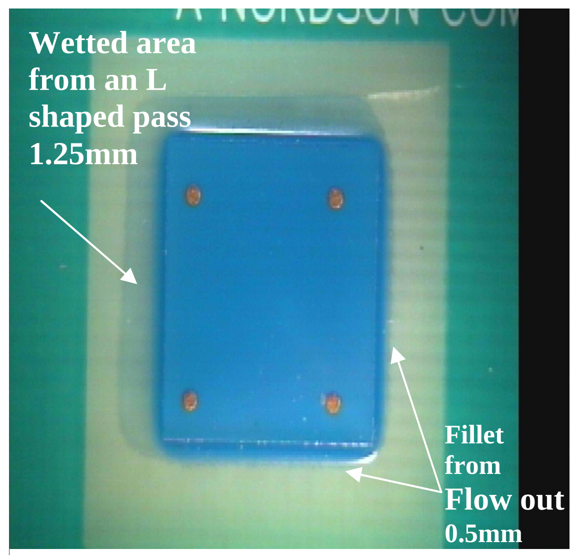

Figure 4

underfill material tends out from the die 1.25mm. If the underfill fluid is allowed to self-fillet and a seal pass is not employed, the finished fillet size for all sides of the die is approximately 0.5mm wide. If the flip chip had components or wire bond pads placed within the wetted zone, they would be coated with the underfill material, which would cause a problem for making good wire bond welds.

Why Dispense Jets

Ink jets used in commercial printing applications are highly flexible and can print complex patterns, but they cannot dispense fluids with viscosities higher than 20 cps. Underfill fluids have viscosities ranging from 5k to 20k centipoise. Due to the higher viscosities of underfill materials the jet developed for this work uses a mechanical action to shoot approximately 0.02mg shots of underfill.

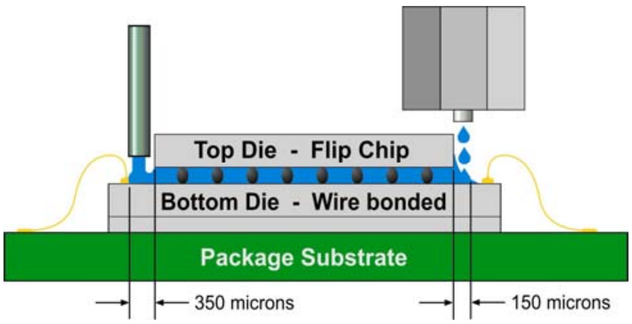

Figure 5

Because the Dispense Jet can shoot drops of underfill at a rate of 200 times per second, lines of underfill can be formed along side a die edge. The rapid rate of jet dispensing dots results in a similar fluid flow rate from the jet tip as a needle, but it can be positioned faster, because it is above the flip chip and the bond wires as in figure 5. The jet shoots drops of fluid from 0.5 to 3mm above the substrate, unlike needles that must have a precise distance set between the end to the needle tip and the substrate to get consistent breakoff, of the fluid from the needle tip. This ability to move into position and shoot from above the flip chip or wire bonds has had a dramatic impact on throughput.

Figure 6 demonstrates the advantages of being able to reduce the distance from the flip chip die to wire bond pads or adjacent components. In

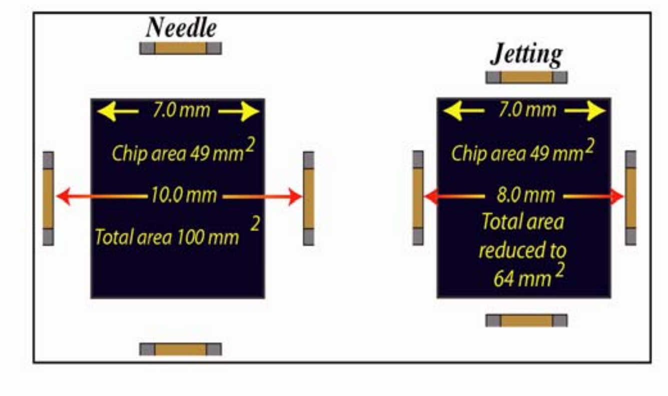

Figure 6

both examples the die size is the same but the distance from the edge of the die to the pads in the needle diagram is 1.5mm on each side and 0.5mm in the jetting case. By minimizing these distances it can be seen that jetting can reduce the substrate area required by almost 40%

Dispense Jet Theory of Operation

The mechanical jet, uses a piston with a ball tip, to push fluid through a narrow orifice at the jet nozzle, see figure 7. Air pressure raises the piston, and that allows fluid to flow around the pistons ball end and into the nozzle. Spring pressure returns the piston to the nozzle seat when the air is removed. As the ball on the end of the piston engages in a nozzle seat, the fluid is energized to shoot a droplet from the end of the jet. The nozzle orifice and several other factors control the size of the droplet. The typical diameter of the fluid stream is approximately 100 microns.

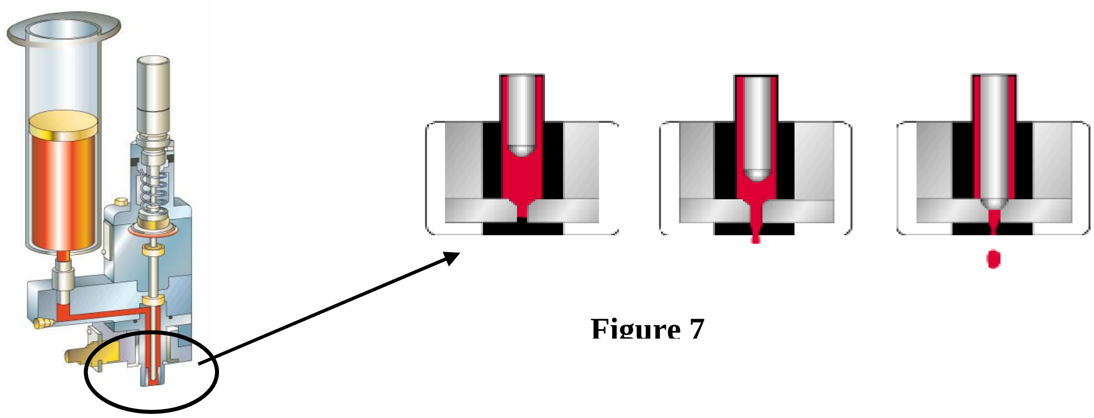

Figure 7

The dispense rate is two hundred drops per second. This stream of underfill can be positioned very close to the edge of a die, and in some cases can be directed at an angle to shoot at the die board interface. By moving and dispensing simultaneously, lines are formed, and no artifacts of the dispense method can be discerned between needle and jet dispensing.

Jetting Modes

The jet is moved as dots of adhesive are fired from the jet to form a line of fluid; this is called as jetting on the fly. It requires the system software to be able to make predetermined, precise moves, timed to firing the jet, to place a line of underfill in a defined position. Figure 8 shows four

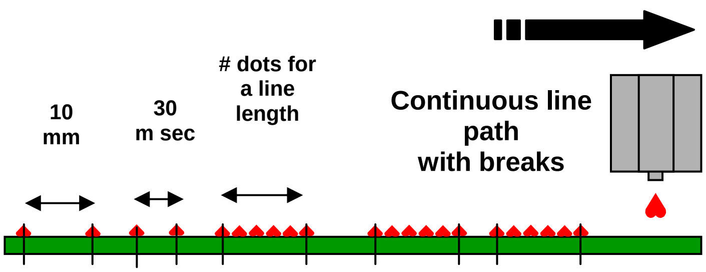

Figure 8

different modes of jet dispensing "on the fly." The four modes are distance based, time based, fixed number of dots in a line and the fastest mode, continuous line with breaks. In this mode, the head does not stop moving between the ends of the first line to the start of the second line.

TEST RESULTS

Dispensing Speed / Throughput

With needle dispensing it is necessary to ensure a consistent gap between the needle and the dispensing surface, to eliminate strings and blobs to ensure consistent quality. Needle dispensing requires numerous height senses at each chip site

on board. Height sense measurements take approximately one second which may not seem like a long time, but these can add up to a significant portion of the overall dispensing time. Jets shoot from 0.5 to 3mm above the board. A single height sense measurement is taken on a board and no further height senses are required.

A series of tests were conducted to compare needle and jet dispensing throughputs. The volume of fluid was calculated for several die sizes and a dispense pattern developed for each die size. A comparison test was run between a positive displacement pump with a needle and a jet on the same platform. As can be seen in Figure 9, the jet throughput was consistently higher throughout the range of the test.

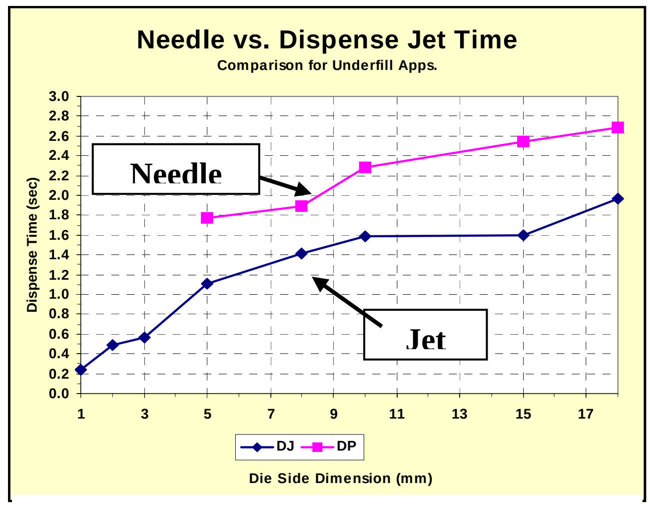

Figure 9

Limited Space Dispensing

In figure 10, two 5mm square glass die have been placed with a 1 mm separation between them. The white underfill material was dispensed in two passes for each die, in an L shaped pattern that runs along the right side of the die, and the front edge of the die. As can be seen, the underfill fluid did not bridge between the two die during

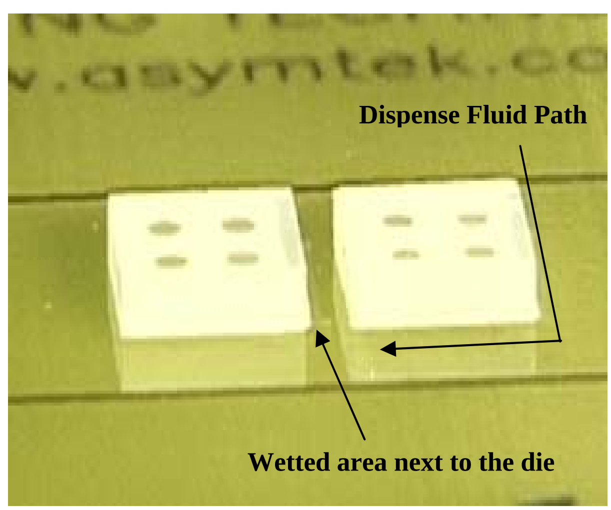

Figure 10

dispensing and the wetted area is approximately only one quarter of the gap between the die (0.25mm). Fillets / wetted area have been dispensed as small as 125 microns wide.

Figure 11 show one quarter of stacked assembly. The distance from the flip chip to the wire bond pads on the package substrate is 0.7mm. In this case the wetted area and fillet at the die edge take up less than half the available space. It was possible to dispense this unit using a 30 gauge needle. But the positioning requirement and the accuracy required limited throughput to 600 units per hour. Using a jet the throughput was increased to over 2000 units per hour.

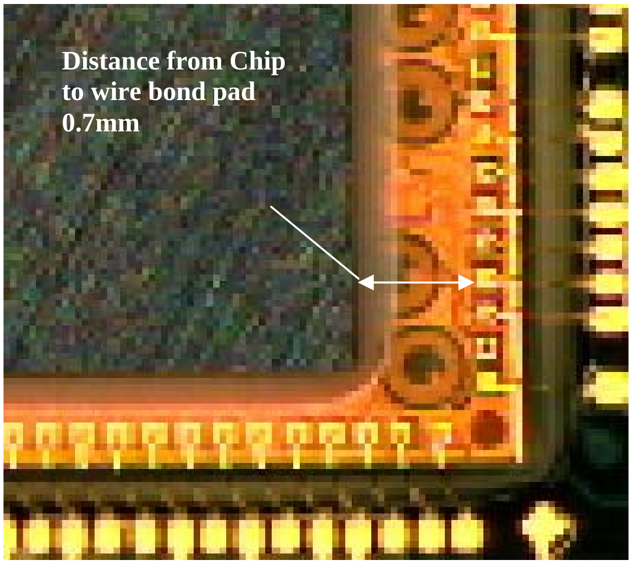

Figure 11

Summary

In this paper it has been shown how underfill materials flow on a substrate, bond pads and passive components. If bond pads are positioned in an area where underfill can flow onto them, this will cause manufacturing problems. Jet dispensing of underfills in stacked die applications can help reduce the foot print of the package, by reducing the amount of space that has to be left open between a flip chip and adjacent wire bond pads. This technique of can also be applied in module design where passive components surround a flip chip. It has also been shown that not only space can be saved but production throughputs can be increased by moving from needle dispensing to jet dispensing of underfill materials.

References:

1) From Single Chip Packaging to System In A Package, Carlo Cognetti, STMicroelectronics, OnBoard Technology September 2003 - page 49