Jetting for semiconductor and electronic component packaging

The ability to jet liquid materials that have viscosities in excess of 20 centipoises has opened a new level of packaging miniaturization. Display components such as OLEDs, PLEDs, topside emission OLEDs, high definition LCOS and DLP chips utilize UV adhesives, liquid crystal, desiccants and conductive adhesives in high accuracy and minute quantities. Jetting underfill for semiconductor packaging provides high throughput with small keep-out areas enabling cost effective flip chip assembly in FCIP assembly. The unique ability of jetting small streams at high flow rates has enabled cell phones to pass drop tests with package on package (PoP) assembly and enabled through shield application of CSP underfill material for low cost, re-workable assembly. This paper will cover the enabling applications of jetting materials that have led to new and cost effective assembly solutions.

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Introduction

The preferred process for applying liquid materials for semiconductor packaging, electronic component packaging, display technology component assembly and printed circuit board assembly has changed to jetting and non-contact methods in the last few years (*Figure 1*).

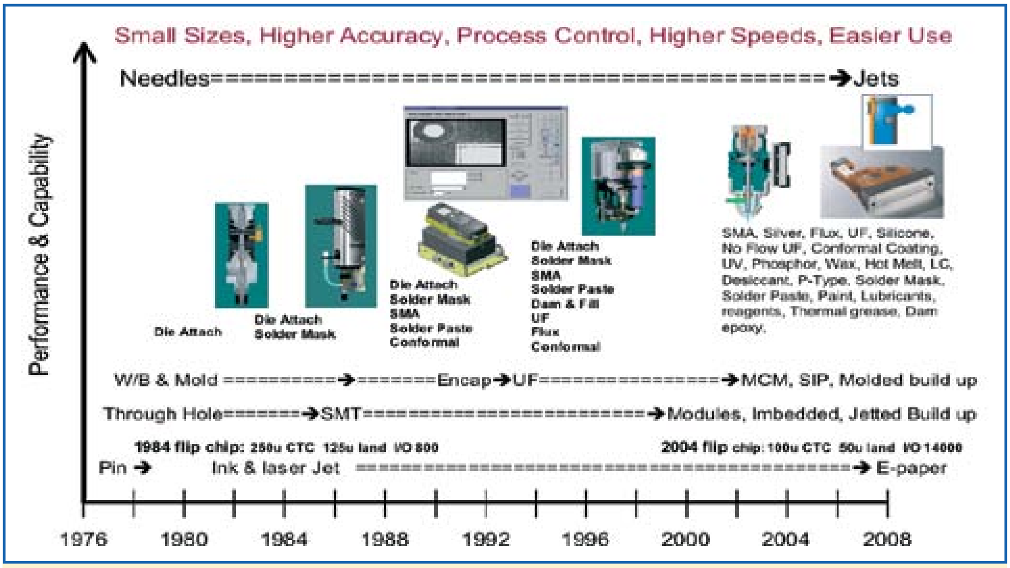

Figure 1. Jetting and other non-contact methods have grown in use in recent years.

Thermal or piezo ink jets are most commonly found in printers on your desk. However these types of jets jet materials that are less than 20 centipoises (cps). Current applications for low viscosity jets in the electronics industry are for small molecule red-green-blue OLED materials, UV inks for PCB legend printing and marking inks for bar codes and other annotations. The emerging application for 'ink jets' in electronic assembly will most likely be in printed electronics with the application of conductive and non-conductive inks, nano-particle conductive inks and semiconductor and conductive inks to make printed transistors.

Mechanical jets that utilize a ball, seat and nozzle are effective jetting materials that are greater than 20 cps and in some cases up to 100,000 cps.

Today, there are jetting machines available that in certain applications provide a more effective means for applying solder paste and flux than the traditional stencil machines. In most applications, jetting underfill adhesives, silver epoxy, UV adhesives, SMA, flux, phosphor filled silicones and liquid crystal material provides the most effective and lowest cost of ownership method for dispensing in production.

Applications in display technology

In display technology, liquid materials are applied as a means of packaging the component and as a functional part of the device. Packaging applications for OLEDs, DLPs, LCOS devices, and CMOS/CCD imaging devices involve jetting a UV sealant material. The sealant material is usually acting as a diffusion barrier or structural element. In some cases, such as DLP packaging applications, traditional applications of glob top encapsulants, metal can and window adhesives, are jetted faster and more efficiently than with needle dispensing.

The most interesting change in the industry occurs when the liquid materials provide part of the functionality of the component. There are several examples:

1. The application of liquid desiccants inside the OLED structure. The desiccant removes any unwanted oxygen and water molecules in the device.
2. The application of special UV adhesives that act as light guides in top emission OLEDs. The adhesive reduces scattering and increases light transmission.
3. The application of phosphors to cells and grooves in plasma and SED displays. The phosphor is excited by a plasma or electron beam to produce RGB light.
4. The application of phosphor filled silicone materials over the blue LEDs. The phosphor is activated by the high energy blue LED to produce a white light. Silicone is used as the media because silicone is resistant to 'yellowing,' thereby providing long light life and the correct spectral temperature.
5. The application of liquid crystal in LCOS devices. The most effective means of applying the LC is by one drop filling (ODF). Traditionally, LC was forced by vacuum to fill the space between the FPD glasses. ODF provides a 10X faster means of applying LC. After a pattern of dots is jetted, the glass panels are laminated. The LC spreads out in a similar manner as silver epoxy does in die attach processes.
6. In LCOS, OLEDs and LCD assembly, the seal adhesive carries a few % by weight of glass beads. The glass beads act as spacers to define the gap between the glass plated during the lamination process.

Applications in semiconductor packaging

In semiconductor packaging of flip chips in package (FCIP), the jet is the most effective means of applying underfill. In some cases, jetting the flux is preferred over stenciling because jetting provides a more consistent and thin film. In all cases, jetting is superior to dip fluxing flip chips because dip fluxing may cause inadequate, excessive or uneven fluxing of the bumps. Excess flux may cause voids near the bump; inadequate fluxing causes dewetting. Jetting of underfill in FCIP provides the fastest means of doing FC underfill. Since the jet is above the flip chip, fewer height senses are required, thereby increasing throughput and eliminating 'die clipping' (*Figure 2*).

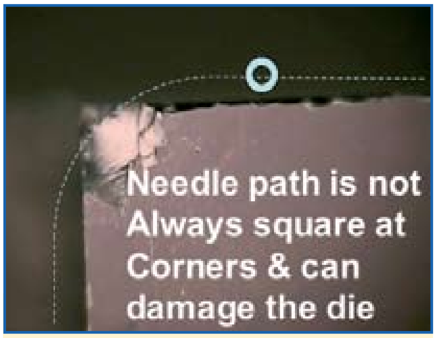

Figure 2. A die 'clipped' by a needle during dispensing.

In traditional needle dispensing, there are limitations on dispensing speed around corners because a high speed motion requires a larger radius, which may cause the needle to clip the die. Also, a bent needle can clip a die because the needle position to the servo is lost. Also, if the needle dispenser does not perform frequent height sensing, the needle can hit a die edge or substrate, thereby chipping the die and bending the needle in the process. Basically, needles cause damage and lower yields. Lower yields and slower dispensing speeds drive the COO of a needle dispenser to be 2X or 3X over a jet dispenser.

Applications in printed circuit board assembly

In printed circuit board assembly, the ranges of fluids are SMA, CSP and FC underfill, conformal coating, flux, COB die attach and glob top. Once again jet technology provides significant performance gains in throughput due to jetting while moving (Jet on Fly), eliminating bent needle issues and providing faster fluid delivery, smaller fillets and tighter keep out areas.

Small keep-out areas are a key element for tighter packaging and, consequently, smaller packages and PCBAs. In the case of flip chips and CSP packages, the closer the components can be placed near each other, near an edge of a substrate, or in proximity to other devices where contamination by underfill needs to be avoided, the more compact the end product (*Figures 3 and 4*).

A good example of a flip chip assembly is a blue tooth module used in a wireless earphone device for hands-free cell phones. In production, it is important to apply underfill quickly with the smallest stream (*Figure 5*). Also, as shown in *Figure 5*, the UF material may be jetted between the CSP packages and fill both devices at the

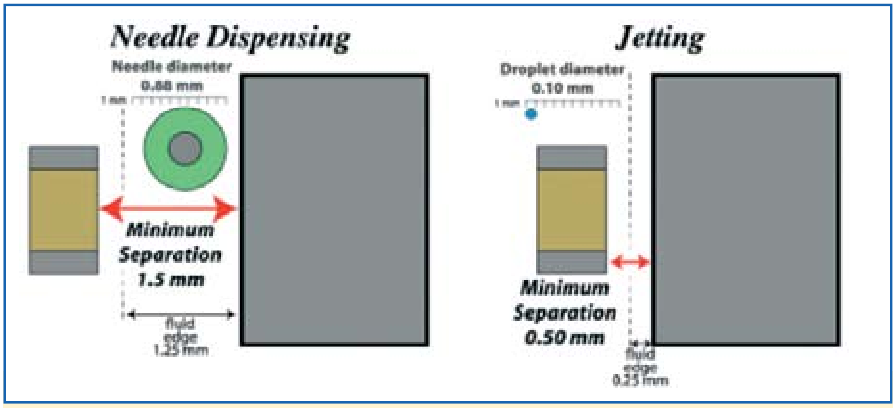

Figure 3. Needle versus jet dispensing.

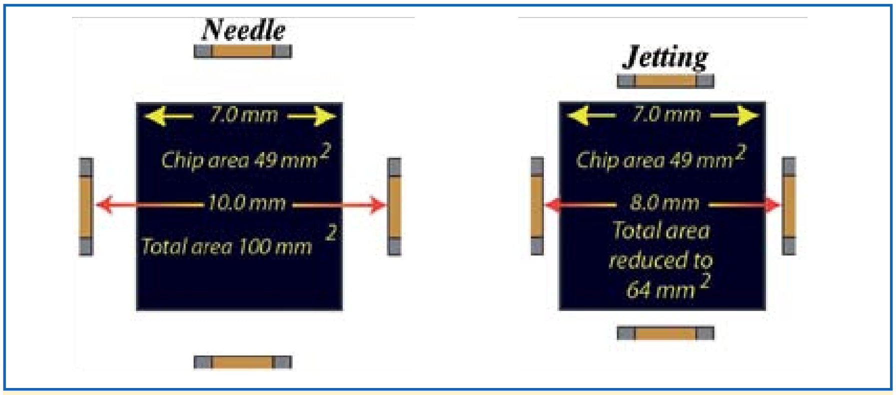

Figure 4. Jet dispensing enables tighter packaging.

same time. However, in some cases if UF is drawn away by devices that do not require underfill;- then the device that requires UF may be robbed of sufficient UF.

In cell phones and other handheld wireless-capable devices, there are increasing requirements for RF shielding and increased memory. Many times there are CSP packages and package on package (PoP) on the PCBA and under the shield. The most efficient assembly process requires that the secondary UF for the CSP and PoP components be underfilled after the shield is attached. This is accomplished by jetting material through a hole in the shield. In order to keep the shield effective, it is desirable to have as small a hole as possible. Also, since these hand held devices are typically expensive, the shield must be removable in case the assembly needs to be reworked. Jetting small streams of UF through the hole provides a fast method of underfill and the small stream size enables the smallest wet-out area. In this case the small wet-out area is required to keep UF away from the shield so the shield can be easily removed during any rework operations (*Figure 6*).

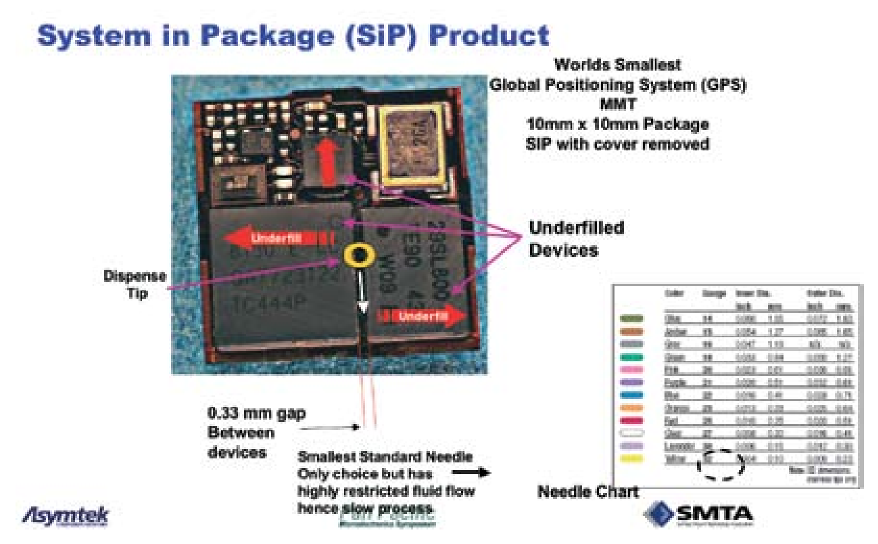

Figure 5. Underfill material may be jetted between CSP packages to fill both devices at the same time.

Experiment

An experiment was designed to determine the limitation of spacing between die.

The limitation was defined as the ability to apply underfill to only one of the die without getting material on top of the die.

Two 5 mm square glass dies were mounted next to each other at 5 different spacings in increments of 50 microns from 350μ to 150μ. (*Figures 7 and 8*) The dies were attached to an epoxy FR4 substrate with a Loctite die adhesive that was filled with 5% glass spacer beads with a diameter of 100μ. The spacers were used to establish a gap typical of a flip chip on board (FCOB) application. Then a DispenseJet 9000 was set up to jet Loctite 4530 underfill between the die. The mass jetted was 0.25 milligrams (mg) per pass.

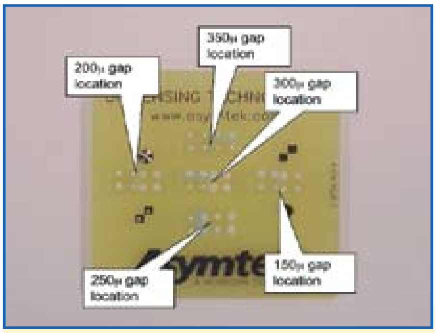

Figure 7. Pairs of glass dies were used to determine how close dies could be placed before the jet stream started to build up on top of the die.

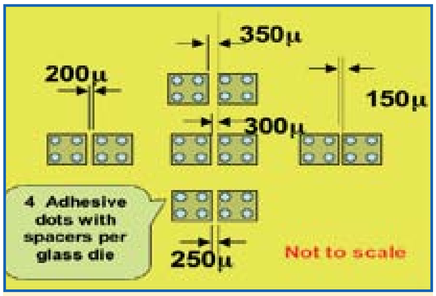

Figure 8. Glass spacer beads in the adhesive established a gap typical of a FCOB application.

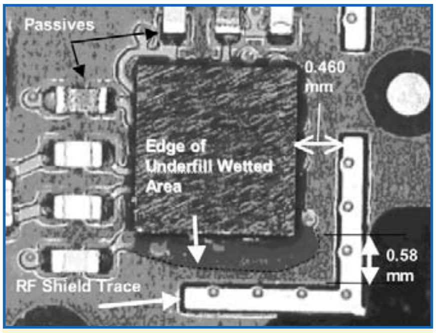

Figure 6. A small wet-out area keeps underfill away from the shield, allowing the shield to be easily removed during rework operations.

Four passes were jetted along the die edge. The dispense pattern was designed to jet as close to one die edge as possible. The experiment shows how close die could be placed before the jet stream started to underfill both die and when material would start to build up on top of the die.

The equipment and parameters of the experiment are shown in *Table 1*.

Table 1. Equipment and parameters for the experiment.

Parameter	Setting
X-1020 XYZ Dispenser	+- 50m 3 sigma
Jet	DJ-9000
Nozzle	75m
Seat	200m
Needle	2.0 mm
Fluid Pressure	0.07 MPa
Valve Pressure	0.58 MPa
Stroke Setting	15 clicks
On/Off Time	3/7 milliseconds
Line Speed	Calculated
Valve Temperature	60˚C
Part Temperature	90˚C
Jet Height	380m from die
Jet Mass Rate	0.25mg/pass
Jetting Passes	4
Underfill	Henkel/Loctite: 4530
Die Attach	Henkel: QMI 536NB-1A3

Results

Five samples of die sets were run, with the results shown in *Table 2*.

The main challenge with the application was producing consistent test cards. The process of creating test cards introduced variation in die to substrate gap, placement accuracy and cleanliness of substrate. These variations are factors known to affect the quality of underfill and cause some inconsistent results during this test. Five samples of each of the gaps were tested to arrive at the results summarized in *Table 2*. A higher confidence level

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Table 2. Results on five sample sets of die

GAP	# of Bridged Die gap	# of Both Die UF	# of One Die UF	UF on Top Side of Die	COMMENTS
150µ	5	2	0	5	Material did not wet to the substrate; collected between & on top of die.
200µ	3	2	1	3	Similar results to 150m gap. However bridging was reduced.
250µ	0	2	3	0	Consistent test panel assemblies would produce higher success rate. Residual UF was 250m. MARGINAL
300µ	0	1	4	0	Consistent test panel assemblies would produce higher success. Residual UF was 300m or less. POSSIBLE
350µ	0	2	3	0	Consistent test panel assemblies would produce 100% success rate. Residual UF was 300m or less.

could be achieved using equipment to place the parts as it is believed that surface contamination due to the hand placing of the die (and motion associated during the placing) confounded the results, especially at the 350µm gap.

Results show an approximate limit of between 300 & 250µ gap between the die as the minimum distance required to underfill only a single die. At 150µ spacing between the die all samples showed bridging between the two die preventing complete underfill of both die. Since the epoxy clung to the die gap by capillary force, as more underfill was jetted the gap filled up and produced topside contamination on the die. *Figure* 9 shows epoxy bridged between the 150µ die to die gap. Enough epoxy must be jetted to touch the substrate and bottom side of the die to start capillary underfill. If the gap between the die is equal to the gap under the die (between die & substrate), the probability of obtaining proper underfill is greatly reduced.

In one case, the epoxy did not bridge the gap between the die but underfilled both die. This result may be acceptable in some production processes; however the objective was to underfill one die.

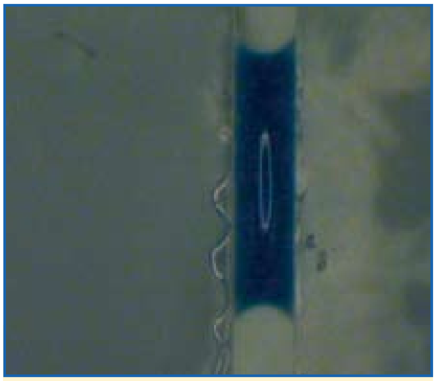

Figure 9. 150µm gap. In all cases the UF bridged the die.

Figure 11 shows the single case at 200µ gap where epoxy filled one die without underfilling the second die. In this case the residual wet-out area of the underfill is less than the gap between the die, as indicated by the red arrows. The wet-out distance of the underfill that strikes the substrate must remain less than the gap between the die to underfill one die at a time.

Figure 12 shows underfilling one die and the die adhesive used to maintain the gap between the substrate and the glass die.

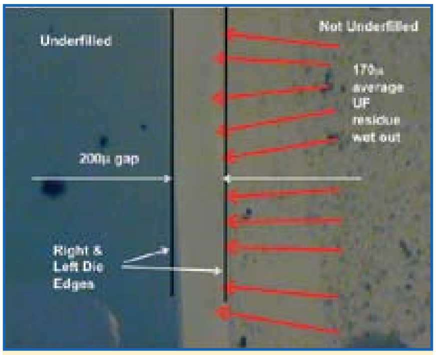

Figure 11. 200µ gap. Epoxy filled one die without underfilling the second.

Figure 12. 300µ gap. Die adhesive was used to maintain the gap between the substrate and the glass die.

Conclusions

1. A tolerance analysis shows the limitation to be greater than 150µ. The wet-out area must always be less than the minimum gap (*Figure 13*).
2. The experimental results showed that there were no cases where 150µ gap between the die provided a proper underfill. In fact an unexpected result was that the bridge stopped the underfill from touching the substrate and initiating underfill.
3. Once the gap between the die is large enough to prevent bridging, the wet out area must remain less than the gap or capillary action will be initiated under both die.
4. As the gap exceeded 250µ, the wet out area became the dominant variable in determining whether capillary action occurred under both die.
5. Provided that the surface wetting conditions of the substrate, consistent die placement, and die gap between the substrate are consistent, a 300µ gap would be the probable limit for underfilling one of the die independent of the other.
6. If it is acceptable to underfill both die, a 250µ gap would be the probable limit on die (or CSP) spacing.

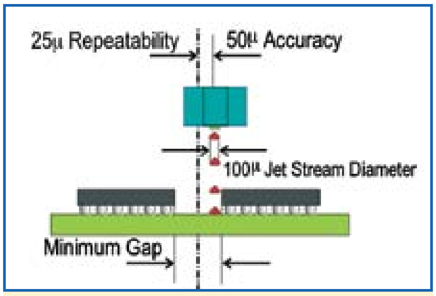

Figure 13. The wet-out area must always be less than the minimum gap.

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3. *Figures 5 and 6* courtesy of Belton.
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