FAST UNDERFILL PROCESSES FOR LARGE TO SMALL FLIP CHIPS

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ABSTRACT

The biggest conceptual impediment to capillary underfill is the perception that the process is a major bottleneck in the production line. However, in the last few years, great strides have been made in equipment, materials and dispensing processes that have removed underfill as a bottleneck. A combination of substrate temperature, material, equipment and dispense process can show complete flow out under a 25mm square die with 60μm gap in under 35 seconds. The optimization of throughput in a production line is achieved by matching the dispense time to the flow out time of the capillary underfill. This paper covers the combinations and configurations of dispensing processes & equipment and the flow out theory to achieve maximum throughput. Capillary flow models used for today's geometries are shown to be valid and accurate for significant different form factor products of the future, large die with small gap (LDSG). Flow out time data for LDSG densely populated arrays with several thousand interconnections is presented. Process variables and material parameters that influence capillary fluid flow are examined.

INTRODUCTION

Virtually all-high performance microprocessors produced in volume today use flip chips (FC). The package designs vary by manufacturer, but the majority of designs utilize up to five different dispensing processes. Flux is applied to the bump pads by jetting, solder paste is needle dispensed for the bypass circuit SMDs, expensive thermal grease for the heat spreader is accurately dispensed by linear pumps and lid sealant is needle dispensed with high flow auger pumps. Currently, the standard of the industry is to underfill the flip chips by capillary flow, using linear pumps to dispense the adhesive in "L" or "I" patterns with multiple passes, concluding with a "seal" pass.

In the past the capillary underfill process was considered a bottleneck. Today, the dispensing techniques, materials, and equipment are at a performance level that meets the throughput requirements of the production line. In the near future we will see large die (25mm) with high I/O (8K to 20+K) with smaller pitch and bumps (35u). The shrinking bump size leaves an increasingly smaller gap between the substrate and the FC. The smaller gaps and bumps imply more reliability issues because there is more strain on the bumps during thermal cycling. Capillary underfill has advanced to keep up with the challenge and there is new research on forced underfill that shows promise of very fast flow out.

UNDERFILL REVIEW

The three key reasons to underfill are to increase the thermal fatigue life of the solder bump interconnect, environmentally protect the interconnect and provide greater mechanical shock and robustness to the package. The thermal fatigue life of FC solder bumps has been analyzed in the literature many times. The different expansion rates of package components result in relative displacements that induced shear and axial strains in the interconnection The axial component is greatly diminished by the presence of the underfill. During power cycling the axial strain may be the largest component of the total strain for flip chip without underfill. Simple mechanical geometric analysis on the system shows that the bump strain is directly proportional to the differential thermal strain times the distance from the neutral point and inversely proportional to the bump height. By the modified Coffin-Manson equation, the fatigue life is inversely proportional the square of the strain. See Figure 1.

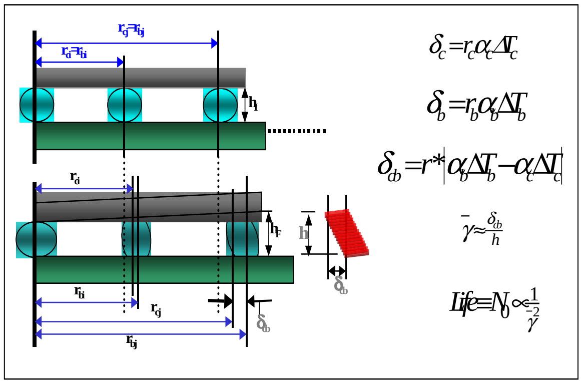


Figure 1.

This model does not entirely explain the increase in life of the bump after underfill. The bump life is also increased by the fact that the cured adhesive, which completely encapsulates the bump, shrinks thereby putting the bump in hydrostatic compression. Metal in compression shows an increase in fatigue life and the complete encapsulation of the bump prevents the bump from moving: there is no open space. The completely encapsulated bump represents a passivated surface and is less prone to crack initiation.

In many cases the underfilled FC fails in other ways than bump fatigue. A summary of secondary failures is as follows:

1. Loss of epoxy adhesion at substrate or die. Loss of adhesion means the bumps will see excessive strain and fail as if no underfill were present.
2. Separation of the fillers in the adhesive. The epoxy loses its material properties and fails to contain the strain.
3. Epoxy failure at the fillet. A crack in the adhesive forms and propagates to the perimeter bump. The perimeter bumps are under the highest strain and once the underfill has lost its integrity the bump will fail.
4. Voids near a bump. A void near the bump means the bump is no longer in hydrostatic compression.
5. Excessive or residual flux on the bump. Flux on the bump acts just like a void.
6. Die cracking at the edge due to dicing stress concentration.

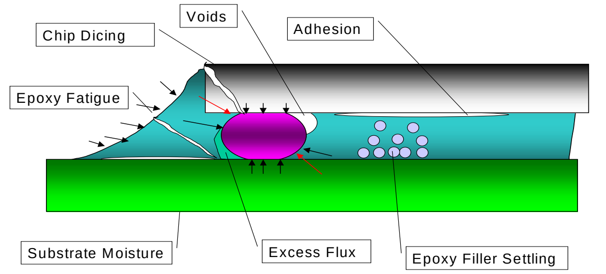


Figure 2.

The process of capillary underfill is quite simple. An epoxy with a low viscosity is deposited at the gap interface between the die and substrate. The surface tension then pulls the material into the gap. The physics of capillary flow are well known. The time to flow out is inversely proportional to the gap and cosine of the contact angle and proportional to the viscosity and the square of the die length. Typically the underfill epoxy's viscosity is reduced by applying the epoxy to a preheated (>70C) substrate.

The standard dispensing patterns are the I and L pass. The required mass of fluid to dispense can be calculated using the mass flow calculator. The mass is divided up between the number of I or L passes applied and the final seal pass. If used, the seal pass represents about 25-30% of the total mass. I pass dispensing provides the slowest flow out time and the lowest probability of trapping an air bubble. Multiple passes are used to minimize fillet residue and to maintain even fillets around the die. See Figure 4.

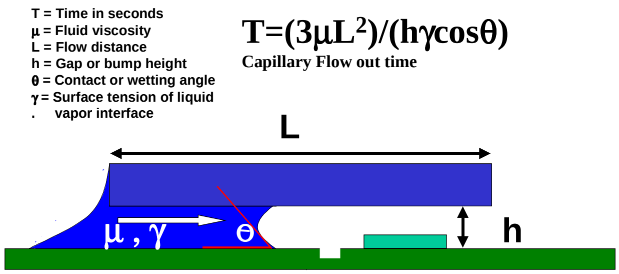


Figure 3

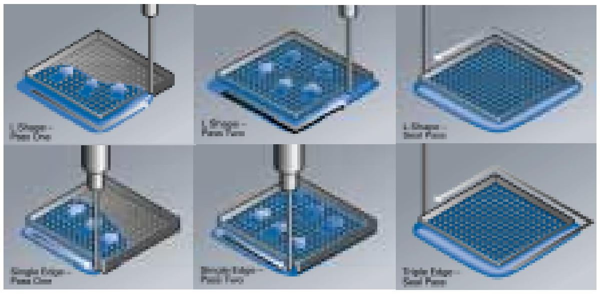


Figure 4.

ANALYTICAL AND EMPIRICAL ANALYSIS OF I AND L DISPENSING

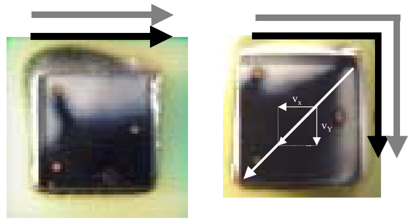
A vector analysis of the flow field for an "I" pass versus an "L" pass yields the following result.

$$t_{Line} = \sqrt{2} \cdot t_{L-shape}$$

An experiment was performed to compare the "I" and "L" dispense patterns versus flow out times. See Figure 5.

The "I" and "L" patterns were dispensed in two passes. Two different color underfill materials were used. The dark arrow represents the black material and the grey arrow represents the white material. The innermost arrow was dispensed first.

The flow results show an interesting result. The apex of the L is a stagnation zone. It also shows that stagnation zones form behind the bumps. In this case, the white material has lower viscosity and smaller particle sizes than the black. Figure 6 shows similar results when the order of materials is reversed.



Time to Underfill 100% Area =27 s

Time to Underfill 100% Area =19 s

Figure 5

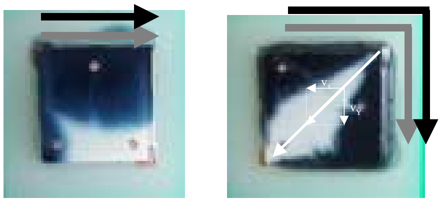


Figure 6

In both Figures 5 and 6 the gap was 300 microns with only 3 bumps. The first fluid dispensed typically stays in the front flow front, since this is the driving force of the capillary flow. The leading fluid pulls the new fluid. When a large die with 35-micron gap and 20K bumps is used, (See Figure 6) some secondary flow results due to the different particle size and viscosity. The lower viscosity material appears to be drawn around the first material dispensed.

Figure 6

LARGE DIE CAPILLARY UNDERFILLING

The trend in the microprocessor industry to move to higher I/O, smaller gaps and larger die all point to the flow out weakness of capillary underfill. The results of the above experiments provide some guidance on enhancing flow out for large die. Certainly, the first pass should be an L pass. From the flow out experiments we can see that the apex of the L pass becomes a flow stagnation point. By adding more fluid to the sides and moving the dispensing along the remaining two edges, the flow out time can be further enhanced over a 2 L pass version. An experiment on a 25mm die, where underfill material was continuously applied along the edges of the die and expanded over the L pattern, produced complete underfill in 24 seconds. The comparable double L pass experiment produced complete flow out in 42 seconds.

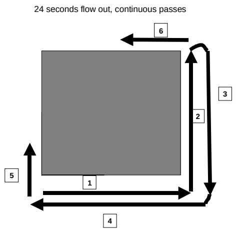


Figure 7 (24 secs)

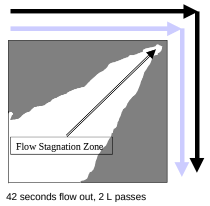


Figure 8 (42 secs)

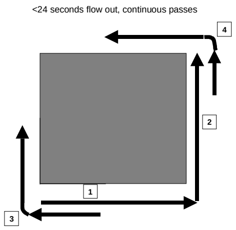


Figure 9 (proposed)

CONFIGURATIONS FOR HIGH THROUGHPUT

The negative focus on capillary underfill is due to the low throughput perceptions. Currently, underfill can be dispensed at speeds of >50 mm per second at flow rates of >50 mg per second. Using the flip chip calculator, a 25mm square die with 1.2mm fillets and 40micron gap would require about 78mg of material. Using these numbers, dispensing can be accomplished in 2 seconds per part. With additional overhead of finding fiducials and height sensing of about 1.5 seconds per part, the total processing time is about 3.5 seconds per part. This works out to about 1000 units per hour. The number of parts per pallet can be calculated by dividing the flow out time by the total processing time per part. In this case, to completely mask out the flow out time, the pallet should be designed to hold at least 12 parts. If 12 parts cannot fit in the standard boat, then a dual lane machine can be utilized to hold two 6 part pallets. In any case, the object is to keep the dispensing machine always moving, and not waiting for flow out to occur.

NON CAPILLARY UNDERFILL TECHNIQUES

There have been several US patents issued on alternate methods of underfilling FC. Reducing flow out time has driven the purpose of finding alternate methods of

Patent 6000924

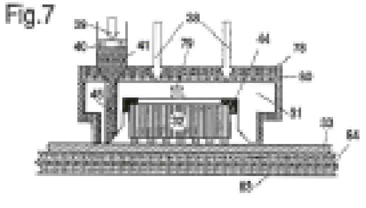
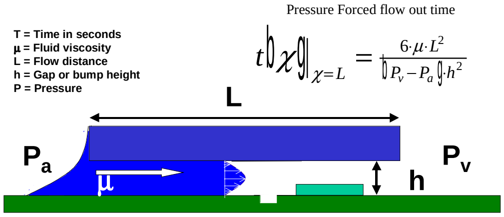


Figure 10

underfilling. One patent (US 6000924) issued to Wang et al, of Cornel Research Foundation, Inc on December 14, 1998 explains an injection molding method. Closing off along the top of the die and the substrate creates a mold. A molding compound can then be injection molded into the device. The fillets are created and contoured by the mold. This design provides complete underfilling in less than a second or two. Other injection molding techniques allow fluid to be injected from the sides or below.

The injection molding and pressurized injection techniques are fast but the effects of high-pressure differentials on the FC and substrate may adversely effect the bump reliability. The flow out equation for forced underfill is shown in figure 11.


Pressure Forced flow out time

T = Time in seconds
μ = Fluid viscosity
L = Flow distance
h = Gap or bump height
P = Pressure

$$t(\chi)\Big|_{\chi=L} = \frac{6\cdot\mu\cdot L^2}{(P_v - P_a)\cdot h^2}$$

Figure 11

Another method of hastening flow out is to assist the underfill flow out. In this case the fluid may be injected on one end of the die and sucked through the underfill process on the other side of the die. There are several US patents on assisted underfill. One patent shows a process that can be accomplished in a lab. First, dams are dispensed along 2 or more sides of the die. Then, upon opposing sides of the remaining open surfaces, and apparatus may be applied to inject fluid and suck out air on the opposite side. (See figure 13).

From Patent 6048656

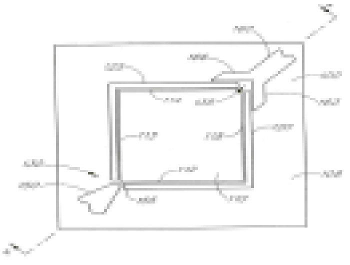


Figure 12

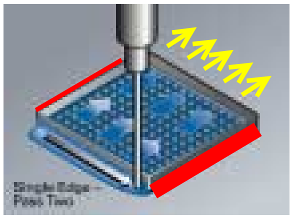


Figure 13

The assisted methods of flow out are slower than pressurized molding techniques but are a lot faster than capillary flow. The process requires a cumbersome apparatus and a two step manufacturing process. The dispensed dams are effective in not initiating capillary flow and act as a flow barrier. However, they must be dispensed and cured prior to dispensing the underfill material. Also, the dispensed dam material may not meet the mechanical requirements for the fillet.

CONCLUSIONS

Large die, small gap, capillary flow materials can successfully underfill high I/O flip chips. The capillary flow dispense patterns can have a significant effect on the flow out times, and for large die the I pattern may be obsolete. The new materials with small particle size and good flow characteristics allow the continued use of capillary flow. The capillary flow process in well known and production safe.

Once the flow out time is in the 40-second range, machine and dispense capability allow the flow out time to be masked over with concurrent dispensing processes. Also, the use of a dual conveyer allows more parts to be placed in the dispense window of the machine, thereby maximizing machine efficiency.

Forced underfill will remove all bottlenecks due to flow out time. However, the effects of the added stress due to injection molding are not known and the process is unproven in production. More research is required to make this process available.

Assisted underfill is also 10 times faster than capillary flow out. However, the processing equipment may make this process unattractive.

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