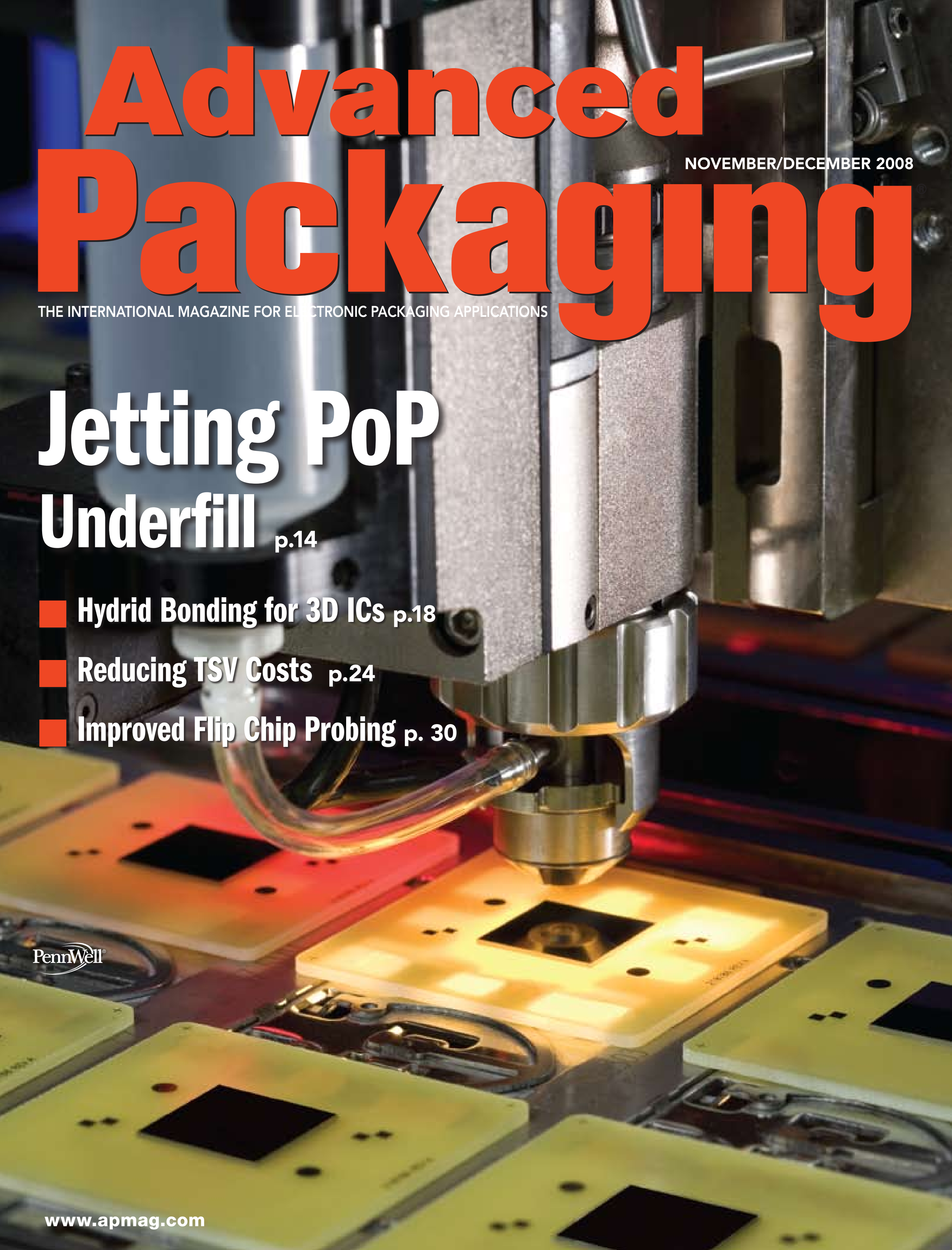

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Design Considerations for Package on Package Underfill

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Package-on-package (PoP) answers the call to save space in hand-held devices where board layout requires 3D integration. To ensure device reliability, many PoPs require underfill to compensate for how mobile electronics are bumped, dropped, and subjected to somewhat harsh environments.

In PoP, logic and memory are stacked on top of each other allowing for a reduction in the overall board size (Figure 1).

THE SHORT STORY

Package-on-package (PoP) is a recognized technology that is becoming more commonplace in mobile electronics with the increased demand for features like cameras, Bluetooth, FM radio, WLAN and mobile TVs. The demand for reliability of higher cost mobile handhelds and smaller form factors, in conjunction with the success of jet dispensing underfill are making this procedure more widespread for PoP assembly.

Similar to standard CSPs, underfill is applied, holding solder joints in hydrostatic compression and acting as a mechanical coupling between the device and the board to ensure that the components can withstand shock. Both interconnect layers of the PoP are underfilled at one time, adding additional challenges over standard CSP underfill processes.

The preferred method of applying underfill to a PoP is through jetting technology, as it allows for smaller underfill wet-out areas and greater process control. The best manufacturing processes are realized when the board designers factor this process step into their designs because it can alter the positioning of the components and the placement of the gap between the devices; however, it is possible to underfill PoPs that are on a board not designed for underfill.

Designing for Underfill

Underfill is dispensed in a weight-controlled pattern along one or two sides of a component, and then capillary action draws the underfill to the other side of the component completely encapsulating the solder joints under it. Initially, the underfill forms a fluid reservoir that is depleted once capillary forces have pulled the material to the other side of the component. The fluid reservoir requires a wet-out area. The size of the wet-out area will determine the placement of neighboring components and their proximity to the underfilled part. For manufacturing reliability and rework requirements, the underfill should only come in contact with the component being underfilled. If underfill comes in contact with other components, surface tension pulls the material to that area and can cause incomplete underfill. The underfill reservoir is greater than the fillet, which is the visible underfill around all sides of the component in a cured package. The dimensions of the fillet are determined by the underfill contact angle and the amount of material dispensed relative to the amount required for complete underfill. With PoP, both layers of the package are underfilled simultaneously, creating larger wet-out areas and fillets than seen with similar single level CSP length and width dimensions.

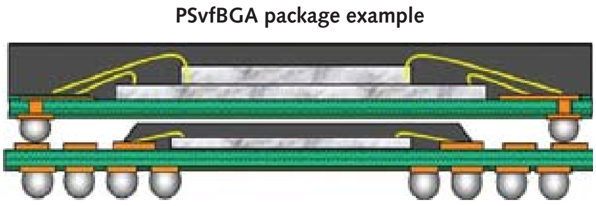

FIGURE 1. PoP Package. Illustration Courtesy of Amkor Technology.

In the underfill process, there is

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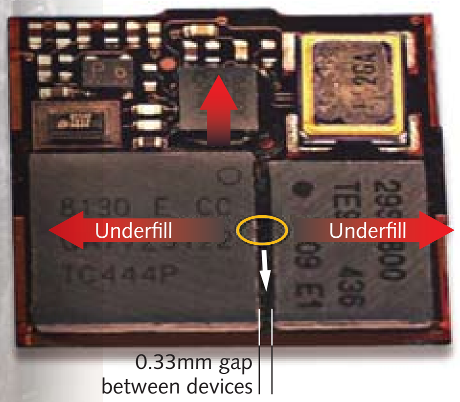

FIGURE 2. High-density component placement.

a direct correlation between the amount of material dispensed in a single pass and the size of the fluid reservoir that corresponds to the wet-out area. This becomes a factor when investigating the trade-off between throughput and the board layout, as proximity to other components determines the percentage amount of material required to be dispensed in each pass. Dispensing less fluid enables the wet-out areas to be closer to the fillet dimensions because the fluid doesn't spread as much and can flow under the component more quickly. Obviously, more passes take more time. However, time-to-flow can be somewhat masked by having one dispenser underfilling numerous components in one load cycle. Often in boards not designed for underfill, the only solution is a high number of passes, which requires more processing time. It therefore becomes advantageous to design the board for underfill, taking into account the wet-out area.

When dispensing underfill for PoP, larger fillets extending higher in the Z-direction occur because of the 2nd layer interconnect and the material contact angle. The reservoir also wets out farther than with a single-level CSP because underfilling both layers simultaneously requires twice as much material. Thus, more space along the dispense edges of a PoP is required than with a similarly dimensioned CSP with only one level to underfill.

When laying out a board with a PoP, the keep-out zone will not necessarily be symmetrical. This is because of the difference between the area required for the fluid reservoir and the area required for a complete fillet on the non-dispensed edges. Therefore, it is best to off-center the component.

Similar to the distance to passive components, any RF shielding should also be considered. While the RF shields do not have as large of an affect on drawing material away from the intended component, if contaminated with underfill, it is more challenging to rework. If there are not any rework considerations, the RF shield becomes less of a concern since it will act as a dam preventing material from flowing past the edge, which can be helpful if the PoP is laid out at the board edge. The RF shield should not be so close to the PoP that capillary forces are present between the shield and PoP, as it will draw material up the package side to the top of the component.

FIGURE 3. RF shield providing access for underfill.

The number of edges along which underfill can be dispensed makes a difference in throughput. If two sides are available for the dispensed reservoir, then the total amount of material is spread over a greater distance resulting in a smaller overall fluid reservoir. Conversely, if less than a full side is available, the process will require more dispense passes and more processing time.

In high-density applications, a PoP can be placed in relatively close proximity to other components. This is possible because one fluid reservoir could be used to underfill two components simultaneously. A successful result is more challenging with this method, as the required dispense accuracy is relative to the dimensional tolerances of two components and solder ball height variation. Placing two components so that the dispense edges are opposed has an advantage in the overall board layout as there is one less total area given to the fluid reservoir. For many years, cell phone designers have been placing parts requiring underfill next to each other so one line of fluid underfills both components.

Thermal management is another consideration for the PoP process. For optimal capillary flow, the substrates and components are typically heated to 70-90°C. In handheld devices, the substrate is usually heated from the bottom side of a double-sided board. Because the heater will blow hot air from underneath the board, it's important hat the design does not include a large heatsink on the top of the heated area, which will draw heat away from the component. Large temperature deltas around the underfill area can cause a loss in repeatability as the material flows more where there is a greater amount of heat. To achieve a substrate temperature of 70-90°C quickly, impingement heaters are typically set to 110-125°C. Board layout should take into consideration whether some components are sensitive to the higher temperatures.

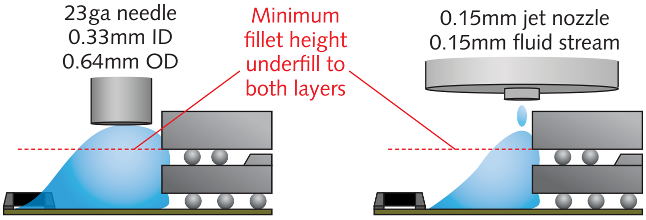

FIGURE 4. Dispensing technology affecting the degree of wet-out for a package.

How the designer positions the chip within the keep-out area will make a difference to the RF shield. If the RF shield is placed prior to the underfill process, the underfill is jet dispensed through a hole in the RF shield. There will need to be cut-outs or holes allowing access for the underfill to be jetted into the package. The access holes should be positioned such that the edge of the PoP can be seen. With jetting, the access holes can be less than 0.5mm in diameter without compromising throughput or accuracy. Placing the shield after the underfill process poses fewer challenges accessing the component edge, however, an extra reflow process is needed.

The Underfill Process

Underfill dispensing for PoP is viable with jetting technology, as it overcomes the drawbacks and impracticalities of needle dispensing. Jetting reduces the wet-out area because the proximity of the dispensed material to the component is constrained by the inner diameter of the nozzle, not the outer diameter of the needle, therefore fluid can be jetted within 100µm of the device. Additionally, the z-action is eliminated because the jetting nozzle passes above the surface. As a non-contact process, there is less contamination of surrounding components and higher yield. A patented technology, called “jetting on-the-fly”, dispenses the fluid rapidly, which increases speed and throughput. When jetting through an RF shield, holes can be smaller for jet dispensing than needle dispensing. Flow rates for a jet nozzle are higher than for a needle dispenser of the same size. This is because of the internal forces created with the valve technology and the significantly shorter flow paths for the fluid to go through.

In PoP, the top and bottom packages are usually the same size. Both levels must be underfilled for good reliability. They also must be filled simultaneously. The top layer underfills more slowly than the bottom layer because of the thermal delta between the top and bottom levels. In order to underfill both levels simultaneously, the fluid must reach the top of the second level gap. The fluid reservoir can never drop below the surface of the top die or else the underfill at that level will cease. As the underfill fluid flows under in the gaps, the fluid level drops. For this reason, it adds a level of complexity not seen with single level underfill processes. One of the big advantages of jet dispensing is that by using patented dot-on-dot technology, the dots can be quickly stacked close to the die’s edge. A higher level of underfill is achieved, which is critical to underfilling the second level. It also reduces spreading of the fluid to nearby components and reduces the amount of material required for complete underfill.

FIGURE 5. Simultaneous underfill of both PoP layers.

It is important that underfill material not be fast flowing or have too low a viscosity. To successfully underfill the 2nd layer of the PoP, material must remain in contact with the bottom side of the top package, or capillary action will no longer flow to that level. If the material is too low in viscosity there are issues created at the 2nd level because the underfill “slumps” out before the 2nd layer is underfilled. If the material flows to fast, the 1st level pulls a disproportionate amount of material from the reservoir and robs material from the 2nd level, again dropping the height of the underfill reservoir resulting in an incomplete fill of the 2nd level. This is a consideration that does not exist in single-level CSP underfill as it is relatively easy to keep fluid in contact with the bottom side of the component.

Conclusion

PoP technology allows for higher device functionality with a reduction in overall form factor. It uses existing placement and solder technology well understood within the industry; however, the use model of today’s handhelds shows a need for underfill that originally package designers were hoping to get away from. In the process of PoP underfill, not only is reliability improved, but with jet dispensing board designers are offered unique opportunities for component placement and space savings. However, it is important to take into account the actual underfill process and the wet-out areas before designing the board. **AP**

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