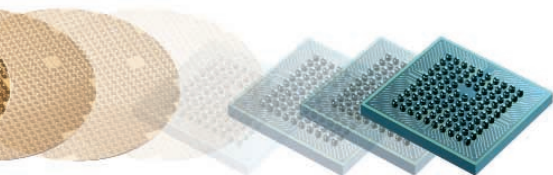


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# Wire Encapsulation

## Improves Fine-Pitch Device Yield

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**F**or years, flip-chip packaging technology has been touted as the replacement for wire bonding when this latter technology could no longer handle industry requirements for fine-pitch or high-I/O-count devices. Yet wire bonding continues to extend its capability to cost-effectively address these challenges. Today's leading-edge wire bonders are capable of 35  $\mu\text{m}$  inline pad pitch in production environments. They have been able to overcome wire count limitations by developing multi-tier staggered pad bonding over active circuitry. At the same time, state-of-the-art wire bonders offer improved overall

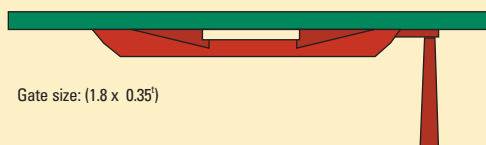
throughput, with raw wire cycle speeds of more than 16 wires per second. This capacity translates into production throughput rates of 10-13 wires per second, including process and indexing time, depending on the type of device and wire count.

In addition, wire bonders have proved to be most effective in bonding stacked die in 3-D packages. Unlike flip-chip, wire bonders have the flexibility to handle an increasing number of die per package.

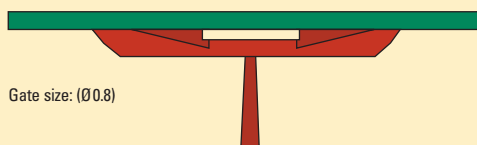
But, no matter how capable wire bonders are in handling ever-decreasing pitch, increasing wire counts and productivity improvements, the entire assembly process must be evaluated to ensure there

### SIDE GATE VS. TOP GATE CAVITIES

Side gate



Top gate



**1.** Center gate molding, which provides a radial flow pattern, puts less molding force on wires.

## At a Glance

Recent advances in polymer encapsulation technology prove effective in reducing wire sweep during bonding.

are no barriers to achieving high yields. One of these potential barriers is wire sweep.

### Wire sweep

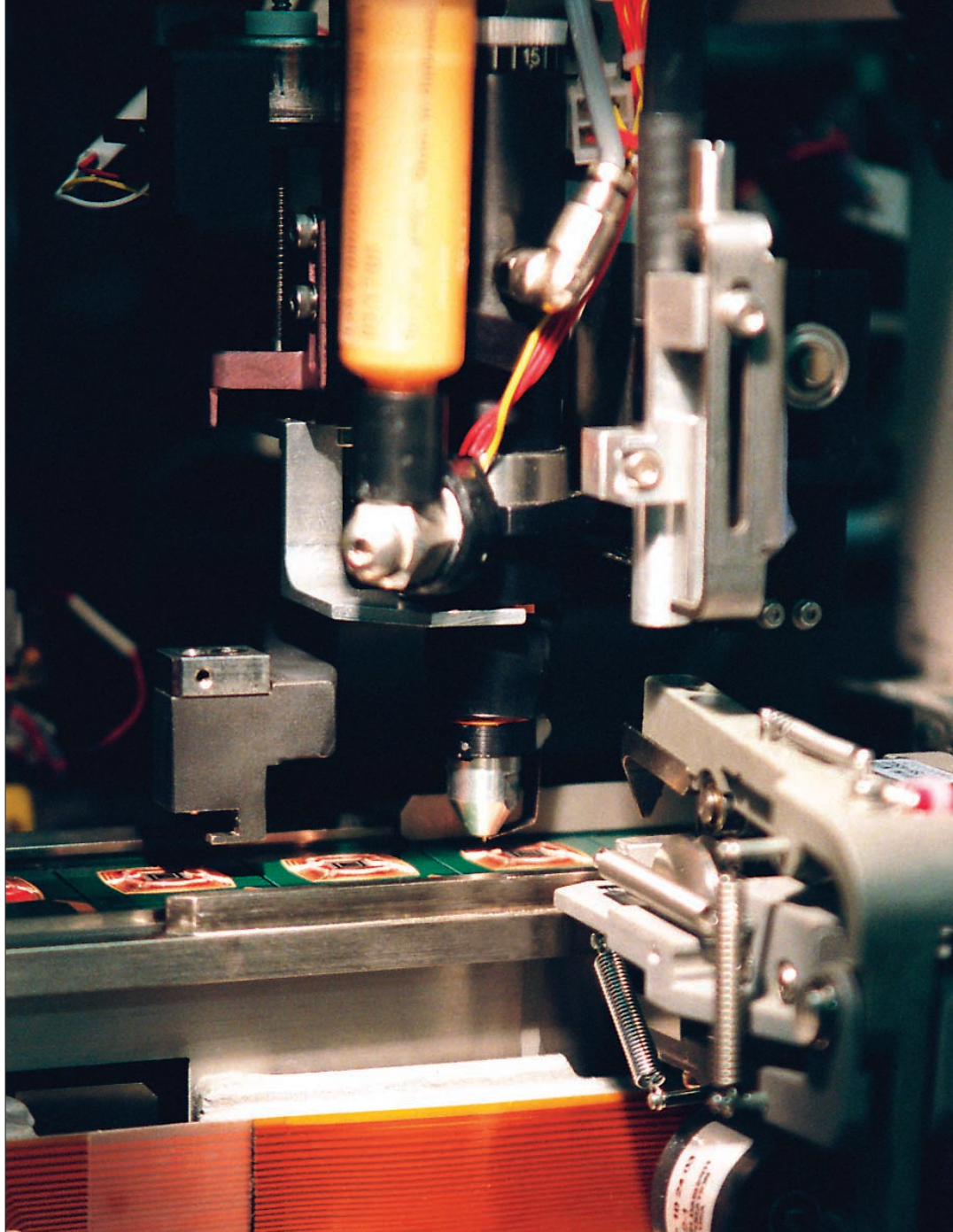
Wire sweep occurs when bonded wires are not correctly aligned in the horizontal plane (as opposed to wire sag, which is in the vertical orientation). Wire sweep can occur during the wire bonding process, handling after wire bonding, or during molding. Wire sweep is undesirable, as it can affect electrical performance by changing the mutual inductance of adjacent wires and simultaneous switching noise. If the wires actually touch, they will short.

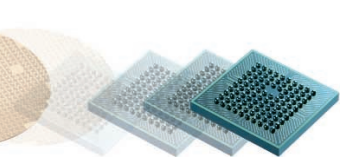
Proper process development and setup can reduce or eliminate wire sweep at bonding. Automation can reduce the risk from handling. Wire sweep during molding, however, is more difficult to eliminate, particularly with the finer pitch and more complex wiring schemes in today's advanced packages. Wire movement is most often caused when molding materials flow transversely across the bond wires during mold encapsulation. Wire sweep usually occurs near the mid-span of the wire or near the second bond.

In today's advanced packages, production wire bond pitches are 35-45  $\mu\text{m}$ , and sub-35  $\mu\text{m}$  pitch is in development. Smaller wire diameters are used to achieve these finer pitches. At the same time, wire lengths can be longer than 7 mm in stacked die and die shrink ap-

plications. These fine-pitch and/or long wire applications are extremely difficult to mold with low-cost molding materials and processes because of the increased propensity for sweep.

Conventional encapsulation materials and processes are not adequate for sub-35  $\mu\text{m}$  spaced wires. In tests conducted by Kulicke & Soffa, corner gate molding was not successful on 35  $\mu\text{m}$  pitch die with 15  $\mu\text{m}$  wire diameter and 4.7 mm long gold wires. The molding materials and parameters simply moved the wires too much because of the flow characteristics of the materials. The problem is that standard molding compounds are primarily comprised of spherical silica filler. Typically, this filler has an average diameter distribution that can be higher than the gaps between the





fine-pitch wires. Trying to inject this material through the wires causes wire movement.

### Reducing sweep: the conventional approach

Mold equipment makers and mold compound makers have been working for years to reduce sweep. Assemblers prefer a solution that utilizes their current capital assets and limits reinvestment, and any material or process solution needs to be cost-effective.

The move below 45  $\mu\text{m}$  pad pitch has generated a new set of challenges that are stretching the capabilities of conventional processes and materials. Many new mold compounds with lower viscosity and smaller filler diameter are being developed for use in conventional edge gate and new center gate molding processes, but there are significant technical chal-

lenges. The materials use smaller average particle size fillers, which increase the compound's viscosity. The increased viscosity generates more drag on the wires during injection. Therefore, the higher surface area of the smaller fillers must be offset by lower viscosity resins and slower injection speeds.

Tests with several of these new encapsulation materials at Kulicke & Soffa have demonstrated 10% reduced sweep in an edge gate molding process to 30% reduction using low-sweep mold compounds. These results were achieved using K&S AW99 wire. Approximately 5% overall sweep was achieved for corner gate molding at 35  $\mu\text{m}$  with low flow compound in a collaborative test with plastics pioneer, Sumitomo Bakelite (Tokyo). Researchers expect yield loss caused by sweep to be further reduced by lowering productivity or raising material costs. Additionally, many of these developmental compounds have not yet passed JEDEC 2A, 260°C reflow reliability testing at OEMs.

Many assemblers still feel compelled to invest in center gate molding machines to reduce sweep (Fig. 1). Center or top gate molding provides a radial flow pattern, which puts less molding force on the wires

### Wire insulation technology: a new/old idea

Sweep doesn't matter if the wires are sufficiently insulated. Insulated wires could alter the way companies approach device design and process engineering. Devices could become far more complex if wire touching were no longer a concern. This capability would be a boon to the rapidly expanding stacked-die packaging market, enabling almost unlimited design flexibility. And the focus of wire bond process engineers would shift rapidly from loop profiles to bond integrity.

There are at least two wire manufacturers offering wire with an insulated coating. This technology, used for a century in magnet wire, has been in stop-and-go development for over 20 years for wire bonding applications.

While simple in theory, the wire insulating process is technically challenging. The low-k coatings on the wire must be applied evenly without affecting the wire bonding process. Also, the wire coating cannot:

- Radically alter the looping behavior of the wire.
- Scrape off and contaminate the capillary.
- Chemically disrupt the formation of the first ball bond.
- Degrade the strength of the second bond.

The most developed technology for wedge-wedge bonding avoids ball contamination, however, wedge bonding is a slower process than ball bonding.

The system costs of using insulated wire are not yet proven. In theory, only a small amount of polymer would be required. However, since the industry has very limited experience coating 15 and 12  $\mu\text{m}$  diameter wire, the cost would be process-driven — both from the wire coating phase and the effects of the wire on wire bonding productivity.

### A less radical approach

A new patented, sweep-resistant encapsulant technology offers a unique solution to sweep. This sili-

### TWO WIRES PUSHED APART BY SILICA FILLER AND POLYMER

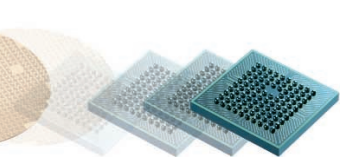


**2.** Two wires are being pushed apart by silica filler and polymer.

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ca-filled liquid polymer, developed by Polysciences Inc., easily disperses to encapsulate wires, locking them in place and prohibiting their movement during process transition and transfer molding. The material is dispensed onto the wires immediately after wire bonding, flowing easily between and around the wires without causing sweep, sag (wire in the Z direction) or voids. Quickly jelled with UV light, wires are secured in place so that the device can be handled and molded without damage. Test

would increase yield from 99.5 to 99.9% (Fig. 2).

### How it works

In simplified terms, sweep-resistant technology is designed to lock the wires in place after wire bonding. Figure 3 shows the process flow on a typical PBGA application. After wire bonding, the encapsulant is dispensed onto the wire-bonded device and solidified by UV cure. Then, just as in a normal process, the device is molded for encapsulation. The anti-sweep encapsulant is then fully cured along with the molding compound during post-mold cure (Fig. 4).

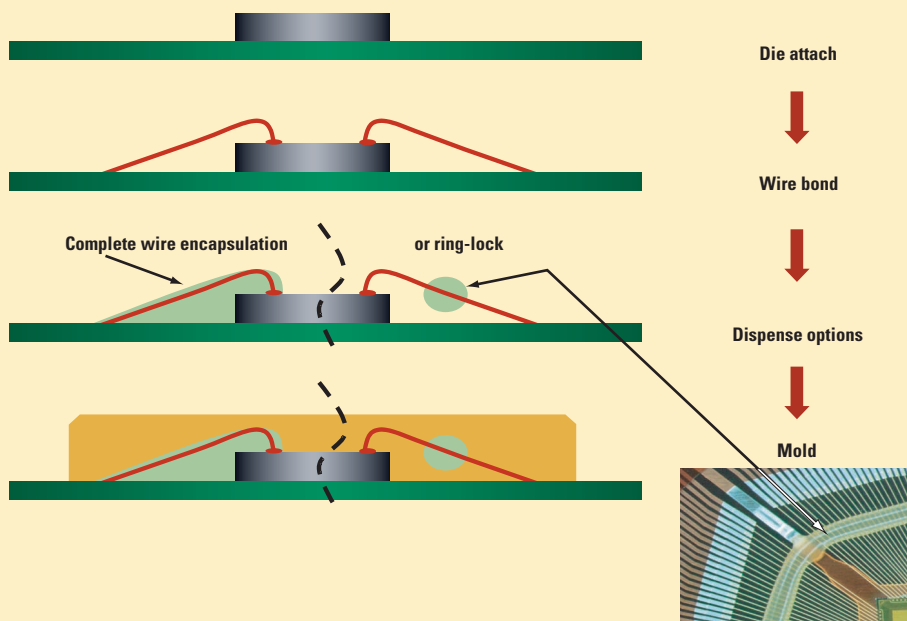
Encapsulants can be applied in one of two ways: They can be dispensed onto the device fully surrounding the wires or they can be strategically applied in a ring or line configuration. The second method — controlled dispensing — marks a major improvement, as it can significantly reduce the amount of encapsulant material used as well as the time required to dispense and cure the material. On a typical PBGA package, this “ring application” method reduces the amount of encapsulant by 80-95%, making the technology very cost-effective. Incremental cost per package can be less than one cent.

For dispense and cure, there are two options: online process and offline process. With the offline process, the sweep-resistant encapsulant is dispensed and cured with a regular “glob-top” standalone dispenser and conveyor UV equipment. Of course, it requires proper temperature, pressure and speed setting

according to the applied package and dispensing pattern. Generally, this is suitable for those processes that need wire rework or repair after wire bonding. Wires can be locked in 3-5 seconds with UV curing.

The online process is used for high-yield wire bonding applications that require optimal design flexibility and production space utilization. A dispense-and-cure kit installed on the wire bonder allows the encapsulant to be dispensed and UV-cured right on the bonder as part of the normal process. The dispense/cure time normally does not impact the wire bonder throughput, as wire bonding occurs simultaneously with downstream devices that are undergoing dispense and cure. This process is especially applicable to high-wire-count devices, since the dispense/cure cycle time is typically much shorter than the time required to bond all the wires on the device. Once through this process step, all wires are locked and fully protected from movement. The device is ready for mold — sweep free

### ENCAPSULATION PROCESS

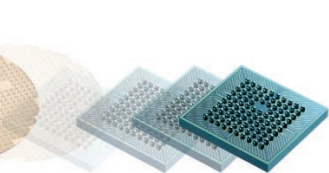


**3.** An example of a typical PBGA NoSWEEP process.

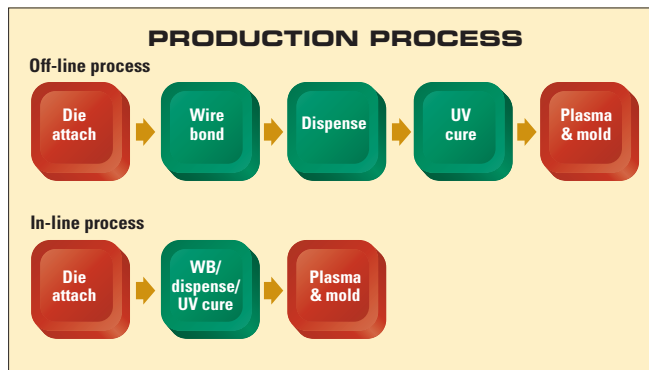
results at assembler locations show that sweep decreased from 6.5% using conventional molding process and material to only 0.12% using the sweep-resistant encapsulant technology.

Another study demonstrated that the polymer encapsulant successfully eliminated existing shorts. Results showed that the unique properties of the polymer and the small diameter filler particles actually separate shorted wires during encapsulation. During dispensing, the capillary action of the liquid encapsulant wicks polymer and filler between the wires. The wires remain separated after the compound is cured. Obviously, eliminating or reducing existing shorts can significantly decrease rework and improve overall yield.

Experiments run at Kulicke & Soffa, reported at SEMICON West 2002, demonstrated that using a wire-locking polymer eliminated 80% of existing shorts. Applied in production, this phenomenon



## Wire Encapsulation



4. The typical dispense process of anti-sweep encapsulation fully cured with a molding compound during post-mold cure.

— and can be safely handled.

Since the dispense/cure is performed on the wire bonder, additional savings can be realized from reduced floor space requirements, as both the stand-alone dispenser and UV cure oven are eliminated. Furthermore, as the dispense/cure process program is entered as part of the wire bonding process program through the same interface, assemblers reduce training and teach times.

### Performance in a 'multimedia' environment

Once the assembled device is molded, the encapsulant is in the middle of a fairly complex environment where it must interface with a variety of materials, including the molding compound, die, substrate and die attach adhesive. Developers of the sweep-resistant encapsulant technology accounted

for this when formulating the encapsulant material. To maintain reliability and function well in the process, the encapsulant was formulated with the following key performance properties: excellent adhesion, unique flow characteristics to enable both complete wire encapsulation and bead type dispense, low modulus to reduce stress from CTE mismatch, and low moisture absorption and minimized CTE for excellent reliability.

The sweep-resistant polymer and dispense system are being widely evaluated in the industry with favorable results. One major assembly OEM reported that their yield increased more than 2.5% on a stack-die application. Another major assembler, who is evaluating the material as an enabling technology, found that they could now cost-effectively produce a fine-pitch long-wire device design, which previously would have produced a yield below 90%. Variants of the sweep-resistant technology have achieved the following results on a wide array of devices and substrates: JEDEC Level 2A - 260°C reflow as well as JEDEC Level 3 at 220, 240 and 260°C reflow.

### Conclusion

Sweep-resistant encapsulant technology can be used in all wire-bonded applications. However, it is especially suitable for long-wire, fine-pitch, high-I/O-count, or complex wiring applications. Target applications are devices susceptible to wire sweep issues during the molding process, such as laminated packages like PBGA, leadframe QFP, matrix array BGA, cavity down BGA and stacked die. •

### Suggested additional readings

1. B. Chylak, S. Tang, L. Smith and F. Keller, "Overcoming the Key Barriers in 35  $\mu$ m Pitch Wire Bond Packaging: Probe, Mold, and Substrate Solutions and Trade-offs," SEMICON West 2002, IEEE.
2. H. Wang and D. DeGrappo, "NoSWEEP Technology for Wire Bonding Applications," white paper from Kulicke & Soffa Industries.
3. A. Hmiel and C. Rutiser, "Wire Bond Short Reduction by Encapsulation," SEMICON West 2003, IEMT.

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