Reworkable Packaging Materials – Die Attach & Underfills

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Abstract

Electronic Polymers are used in practically every modern electronic product today. Packaging polymers are used to attach die, enhance the performance of Flip Chips and to encapsulate components and systems. Most of the polymers in today's electronics are thermo*sets* exemplify by epoxies, the workhorse insulators of our industry. Thermosets are high temperature-stable materials that won't melt and are not considered reworkable.

Reworkability is a valuable attribute for attached die and assembled Flip Chips. Enter thermo*plastics*! The thermoplastics are the other major class of polymers. They can be softened, melted, cast, extruded, molded and readily reworked. Thermoplastic pastes and films have been used during the 1990's as versatile die attach adhesives and have established an outstanding record of reliability. These reworkable adhesives can also dramatically increase productivity by offering millisecond bonding because no curing is required. We will describe commercial materials and their assembly & rework processes.

More recently, Flip Chip technology has been reborn to become a popular micropackaging method for ultimate density and performance. This chip-size package typically requires polymeric underfill for high reliability. Unfortunately, the commercial thermoset underfills can't be reworked. They also come with the penalties of added cycle time, additional equipment, more floor space and extra COST. Enter again, thermoplastics! Newly emerging wafer-level thermoplastic underfills are being developed that are reworkable. What's more, the W-L Flux-Underfills will substantially boost productivity to reduce cost since the entire process takes place in the solder reflow oven. We will describe new developments in Wafer-Level Flip Chip (W-L FC) and tell how these breakthroughs will enable **FC = SMT**. Cost data will be included.

Introduction

There are only two ways to interconnect an integrated circuit (IC); with wires or joints. About 95% of ICs are wire bonded and TAB (Tape Automated Bonding), also called Tape Carrier Package, should be included here albeit a circuitry process produces the "wires". The jointing process is better known as Direct Chip Attach (DCA) or Flip Chip. Each of these two fundamental processes uses polymeric adhesives with very few exceptions. The wire bonding method requires that the die is secured to a carrier or lead-frame with die attach adhesive. The Flip Chip typically requires and underfill, even for ceramic substrate for maximum reliability. The underfill is really a form of die attach adhesive that mechanically couples the chip to substrate to reduce thermomechanically-induced movement that would lead to joint strain. The common die attach adhesives

and underfills are NOT reworkable. Inability to rework die cuts yield and adds cost, especially for MultiChip Packages (MCP) that are becoming more prevalent.

The modern strategy of placing often larger, more powerful die in smaller packages is a key principle for achieving more computing power and greater portability. Computer Processing Units (CPU) are become more complex and more costly. MCPs are being offered be several companies in area array format like BGA. These trends are increasing the need for reworkable die attach adhesives. The expanding popularity of plastic packages using thin organic substrates creates requirements for new die attach materials that are better able to reduce stress. Higher compliancy and elasticity help mechanically decouple die from organic substrates.

But what about reworkable underfill? Many do not consider the Flip Chip be a true package because it can't be reworked. Reworkable underfill has been sought after for most of the decade but it has been an elusive goal. Attempts to formulate reworkable capillary flow liquids have not met with much success although work continues at universities and in industrial labs. However, the very same strategies used for the successful die attach reworkable systems can be applied to underfills if we *step out of the box*. Let's first look at the basics of polymer chemistry to understand why some materials are easily reworkable while others are unyielding.

Polymer Basics

Polymers are the most interesting and versatile substances in the world of material science and in the bio world. They provide an incredibly wide range of physical and chemical properties. Then can be as simple as polyolefin, made up of just carbon and hydrogen, or as complex as DNA, the blue print of life. Engineering polymers can be viscous liquids, like silicones, or steel-like solids with high temperature performance. Although there are natural polymers, such as rubber, most of the thousands of commercial products are synthesized. Our ability to design polymers with specific properties is what makes them so useful. Polymers are now the most critical ingredients for electronic circuitry and packaging.

Polymers are macromolecules made up of long chemical chains. These chain-like structures impart the strength, elasticity and general resilience so common to many polymers. Polymers are readily classified into two major categories: thermoplastics and thermosets. Thermoplastics can be softened and melted by heated, but return to the original solid when cooled. The process is repeatable and does not normally alter the polymer properties. Heating just adds the thermal energy (molecular motion) that allows the long polymer chains to move freely past one another and take on new shapes. Cooling reduces molecular motion to a level where chains no longer move past one another. Melting and hardening is an easy-to-control mechanical cycle. We can think of thermoplastics as "organic solders".

Thermosets do not offer this reversible phase change. Thermoset polymers form links, or chemical bonds, *between adjacent chains*, during the polymerization. The result is a three-dimensional network that is much more rigid than the linear thermoplastic structure. The inter-linked chains are not free to move when heat is applied, and the

thermoset, as the name implies, is "set" into a permanent shape after polymerization. One valuable property of thermosets, however, is that they can start off as liquid pre-polymers without using solvent. The initial liquid property has made them valuable for use in capillary flow underfills that must quickly fill the narrow gap between the assembled Flip Chip and substrate.

Although thermoplastic adhesives are widely used in all industries, they have only gained wide acceptance in electronics during this decade. Advanced thermoplastics now can provide the high melting points and impressive dimensional stability that earlier polymers could not deliver. State-of-the-art thermoplastics now perform in the same temperature ranges as the thermosets. Low moisture absorption and thermal coefficients of expansion (CTE) are now possible, making thermoplastics useful for applications such as package overmolding, encapsulation and die attach. The remeltability also sets thermoplastics apart and provides special advantages. Let's first see how thermoplastics have been adapted for die attach.

THERMOPLASTICS DIE ATTACH ADHESIVES

Polymers are by far the most popular class of adhesive throughout the world. Thermoplastic adhesives are especially valuable because they can be used in a dry form. They are already fully polymerized as received. The bonding process simply involves softening or melting the polymer while in contact with the adherents and then allowing the joined construction to cool. The structure can be easily disassembled or repositioned by reheating while applying force. Thermoplastics are the most convenient, safe and reliable adhesives available to the electronics industry. Their use has been limited by the requirement of bonding while concurrently applying heat and pressure, however. Most of the bonders now in use cannot provide the heat requirement. Modification or purchase of a different type of bonder is necessary and this creates an obstacle for many.

Thermally and electrically conductive thermoplastic adhesives can be used in dry film or paste form, but with certain limits for the latter. The adhesive system can be filled with silver particles when electrical and thermal conductivity is needed. Non-electrically conductive, but thermally-transmissive fillers, like aluminum nitride (AlN) and others, are also being used. Both the film form and pastes are pre-polymerized. All of the chemistry has been completed by the manufacture unlike thermosets where the asssembler must become a chemist-of-the-moment.

Thermoplastics provide very fast processing, more accurately controlled properties and virtually unlimited shelf life without refrigeration. The paste and film forms each have their own advantages and limitations. Pastes can be printed or deposited in virtually any pattern. This reduces inventory, since "one container size fits all die" and allows efficient mass-application processes to be used. However, the additional steps of deposition and drying are required although small die can be applied to "wet" paste. The dry film form of adhesive is easy to use, but the film must be cut or punched into the desired shape by the supplier (preform) or by the user. However, the dry film process is simple, clean, easy to control and simple to automate. Let's look at the thermoplastic process options.

PROCESSING

Paste Application

Pastes are ideal for applications where many different shapes and sizes of components are bonded. However, the use of paste adhesives requires more equipment, a higher level of operator skill and more process control. Film and preform processing is quicker, has no VOC emission and is the simplest die attach method available, but heat and pressure must be simultaneously applied The final properties of both paste and film products are identical, only the processing is different.

Paste materials can be screen-printed, stenciled, spun on (wafers) and needle dispensed onto die, wafer or substrate. Stenciling, the same process used to apply other adhesive pastes is ideal since the maximum thickness control with the highest pattern precision is achieved. Screen printing and stenciling are mass application methods that allow material to be deposited at hundreds of sites in a single step. A squeegee moves across the stencil or screen, and material is selectively deposited through openings. Laser-cut and electroformed stencils provide even greater precision.

Heating next removes solvent to dry the deposited coating of paste. Conduction, convection or radiation heating can be used. A specific oven profile is required for a particular adhesive to insure adequate solvent removal as the liquid polymer-solvent system is converted to a solid polymer-only structure. Two different process options may be used in the next step. Die can be placed on the paste or the material can be dried before bonding. In the "wet bond" process, the assembly is dried with the die in place as the final step. The die must be small enough (~6-mm) so that solvent can escape from the sides. In the second process, solvent is evaporated first in the "dry bond" method followed by die bonding with heat and pressure. Pre-drying is recommended for larger die. The dry bond process for paste is identical to the one for film and preforms described under Bonding.

Wafer-Level Die Attach Adhesive

There is one more method for applying thermoplastic die attach adhesive and it involves coating the finished wafer before it is diced. The die attach paste is applied to the back of wafer by any one of several methods. Spin coating, screen printing, stenciling and spraying have all been tried and can be used. But spin coating and stenciling has worked best. The spin-coating process is commonly practiced by the semiconductor industry and is preferred by many. Adhesive solution is dispensed into the center of the wafer and spun out in the normal manner. The next step is to oven dry. The coated wafer can then be singulated by sawing. Sawing runs smoothly provided that the wafer is kept at a reasonable temperature by water-cooling. The die attach materials are relatively high melting and saw cleanly. Stenciling may also be used, followed by drying and sawing. The singulated die are now ready to bond by just applying heat and pressure.

Dry-Film Adhesive Application

Die attach adhesive is available in sheets, thin strips, rolls or in pre-cut shapes designed to fit a specific die, lid, heat sink or other component. The form factor will determine the method of handling and the equipment used. Pre-cut shapes of film are popular for die attach since automatic equipment can pick and position the small pieces of film. Pre-cuts, or preforms, can be supplied in waffle packs, in tape and reel form, on release carrier or in just about any format used in assembly. The user, who wishes to die cut, a relatively simple punch press operation, can use sheets, strips or reels of film on release liner. Laser cutting is becoming popular as equipment improves.

The Bonding Step

The process control parameters for dry film die bonding are heat, pressure and time. All three are interactive and the assembler can trade off one variable against another. For example, bond time can be reduced if the temperature or pressure is increased. Time can be minimized, down to milliseconds, if both pressure and temperature are increased. Conversely, increasing one or both of the other factors can minimize either pressure or temperature. This parameter interplay allows the assembler to optimize the process to fit a wide range of products and applications. Some level of pressure is typically used during the dry bonding process even though the value may be small. This requires die attach equipment that can apply force. Some existing die attach equipment may apply adequate die bond pressure since low force has proven adequate but a heated collect is required. High force, heated bonders are available. Figure 1 shows the bonding step.

FIGURE 1
Die Attach Film Bonding

positioner

heated collet

die

adhesive film

heater
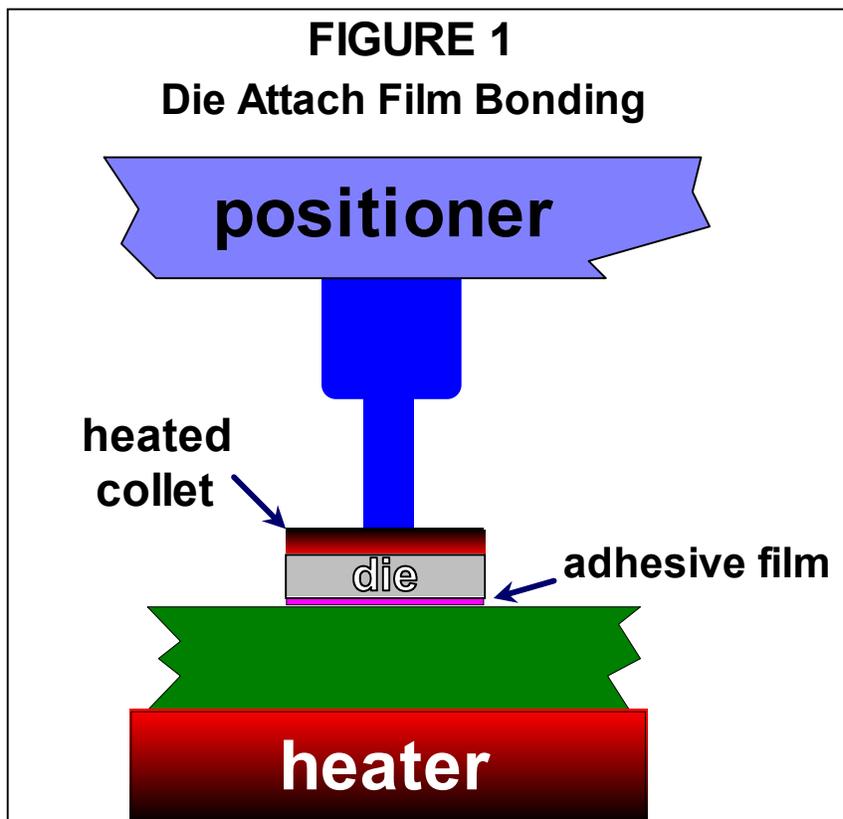
The bonding mechanism is primarily a mechanical interlocking process and is therefore more dependent on surface topography than substrate composition. The triad of bonding parameters creates a wide processing window that enables thermoplastics to fit into various assembly manufacturing systems, particularly those with processing restrictions such as temperature sensitivity and time constraints.

Thermoplastics can thus span the full range of lead-frames, chip carriers and MCPs.

Adequate bonding is achieved by bringing the thermoplastic adhesive to the right viscosity range. Figure 2 relates viscosity to temperature and shows the process bonding window. Thermoplastic adhesives can bond over a broad process window - as low as 100°C and up to over 300°C. Bonding limits fall between the glass transition temperature (Tg) of the polymer and the decomposition point. Applied pressure forces the softened or liquefied polymer into the surface microstructure of the adherends, producing a mechanical link. The time factor, or dwell, allows heat to distribute at the interface and the fluid polymer to penetrate the surface microstructures.
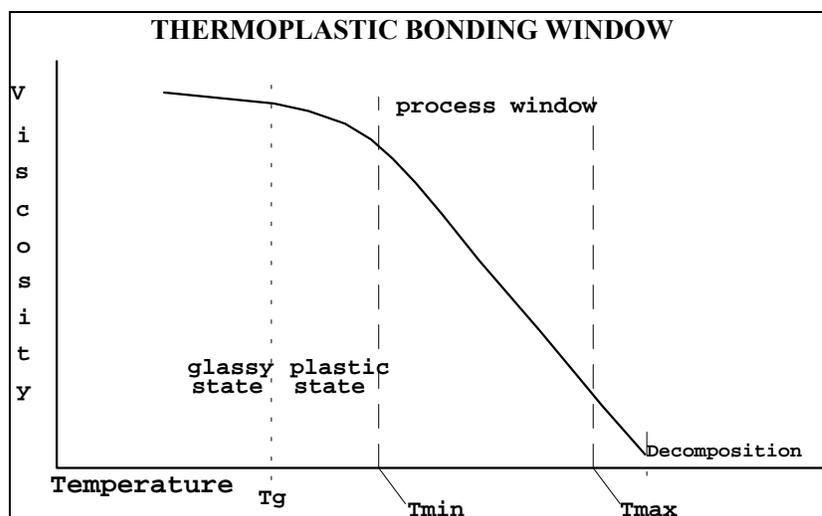

FIGURE 2

The polymer changes from a more rigid, glassy state to a rubbery form above the Tg. Raising the temperature continues to soften the plastic, which is seen as a drop in viscosity. Viscosity continues to drop as temperature is increased. Some thermoplastics will become high viscosity, deformable masses, while others will be changed to thin fluids. However, it is not necessary to reduce the polymer to a fluid for bonding. A viscosity level is reached where the plastic flows into the substrate microstructure and wets the surfaces. As the plastic cools to ambient temperature, the viscosity increases and the mechanical bond structure is locked in place. Very little squeeze out occurs under typical bonding conditions since the viscosity is still relatively high at suitable bonding temperatures. Thermoset adhesives experience a much greater drop in viscosity on heating and spreading can occur.

The triad of key bonding parameters, temperature, pressure and time are interactive as mentioned earlier, but they are also non-linear. Temperature has the most pronounced effect. The interaction between process parameters is shown in Figure 3. The minimum operating temperature must be somewhere above the glass transition temperature in a region where viscosity begins to drop off (Tmin). The upper limit (Tmax) must lie at a safe level below the polymer decomposition temperature. Pressure is determined by the minimum that will cause polymer flow, wetting and subsequent bonding. The high-pressure limit is less defined and may be limited by equipment, substrate and components. At very high pressure, squeeze-out can occur, however. Temperature and

time can be increased so that virtually no force on the die is required, but most customers apply pressure for control.
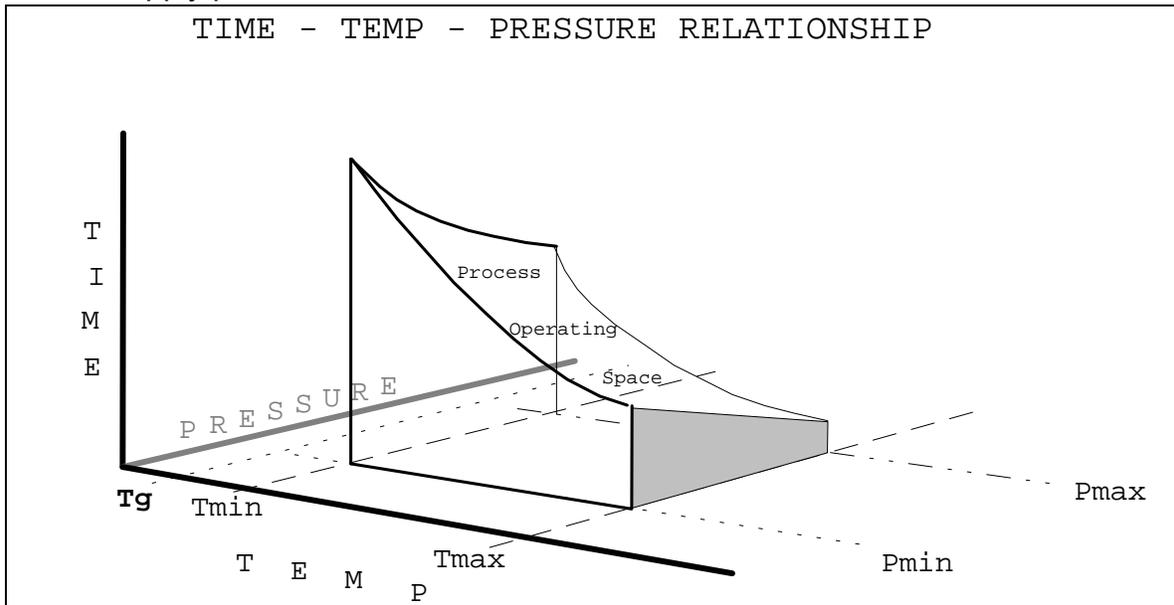
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TIME - TEMP - PRESSURE RELATIONSHIP

T
I                        Process
M
E                     Operating
                        Space
  P R E S S U R E
                                                            Pmax
  Tg  Tmin
                                                    Pmin
      T   E   M        Tmax
              P
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FIGURE 3

Applications

The most common package today is still the single chip on metal lead frame type. ICs are being bonded to organic structures with increasing frequency as new package designs evolve, however. The area array packages, typified by Plastic Ball Grid Arrays (PBGA), bond the die directly to an organic circuit substrate that is then encapsulated. Since the circuit substrate nearly always has a higher thermal coefficient of thermal expansion than the die, stress occurs. Evidence of thermomechnical stress is seen in the poorer solder joint fatigue resistance of many BGA packages. Solder balls directly under the die fail first, suggesting that the die attach adhesive is locking the die to the board and constraining its expansion. The net result is a CTE mismatch between the package and the motherboard. A low modulus thermoplastic die attach can decouple the die from substrate to reduce strain. Most BGA designs now depopulate the solder balls under the die area but this increases packaging size.

Other high density, highly stressed plastic packages, as well as MultiChip Packages, are key targets for thermoplastic electronic adhesives. These products can take advantage of the unique characteristics of thermoplastic adhesives. The most important thermoplastic features are low modulus and easy reworkability. Adhesives can be chosen for just the right elasticity. MCPs benefit doubly since dies can be removed quickly and without damage to module or die. Thermoplastics, available in a wide range of bond temperatures, provide a good solution. The die attach films can serve as mechanical decouplers permitting die to be attached to modules with a much higher coefficient of thermal expansion (CTE). The low elastic modulus and compliant character of the thermoplastic adhesive allows extremely mismatched materials to be

joined. What's more, the modulus is stable and there is no tendency to "advance", or embrittle, as can be the case with thermosetting adhesives.

Performance

The performance of thermoplastic adhesives is much more consistent and reproducible than thermosets for fundamental reasons. First, a thermoplastic has been fully polymerized by the manufacturer under highly controlled conditions. Thermoplastic adhesives can be bonded in a dry state, which significantly reduces the possibility of voids so often experienced with epoxies and polyimide thermosets. Voids and adhesive stress are the major causes of failures related to die attach. However, another increasingly important attribute of thermoplastic adhesives is their low modulus and corresponding elastic characteristics. The result is very low stress on the die. The advent of larger and larger dice makes low stress imperative, especially when dice are mounted directly to organic circuit substrates. Table 1 gives the properties of a range of thermoplastics now in commercial use.

TABLE 1

Fillers	Tg	Bond Temp	Rework	Die Shear	Thermal	Modulus
	^oC	^oC	min. ^oC	PSI @ 25^oC	Wm^oC	PSI
none	-40	100 - 150	110	1,700	0.20	60,000
Ag, AlN, none	25	150 - 200	160	2,200	0.3-3.0	60,000
Ag, AlN, none	45	160 - 220	170	2,600	0.3-3.0	500,000
Ag, AlN, none	85	160 - 250	170	3,000	0.3-3.0	400,000
none	145	200 - 230	210	3,800	0.22	150,000
Ag, Au, AlN, none	180	325 - 400	350	4,000	0.3-3.0	360,000
none	280	350 - 450	400	4,900	0.25	370,000

Typical electrical conductivity is 1×10^{-4} ohm-cm for metal-filled and 1×10^{12} for non-metal. Typical thermal conductivity is 3.0 W/m^oC for silver and 1.0 W/m^oC for AlN.

Environmental stress testing always brings out the best and the worst in materials. Temperature cycling, high temperature aging and long-term humidity conditions have been run on a standard silver-filled thermoplastic adhesive film on several substrates. Heat aging and temperature cycling improved bond strength in all cases. This effect is commonly seen with pressure-sensitive and thermoplastic adhesives. Temperature/ humidity reduced adhesion initially, but stabilization is observed over time. However, adhesion exceeds the passing limits of MIL-STD 883D, Method 2019.5. Table 2 summarizes the results.
Bonding conditions were 180^oC for 10 seconds at 135g on 80 mil x 80 mil Ni/Au plated Kovar tabs.

REWORK

Applying heat and some amount of force can debond attached die. The minimum rework temperatures are listed in Table 1. A good technique is to apply localized heat and torque off the die. A twisting motion allows removal with a minimum force. The rework temperatures in Table 1 gives the value where softening, not melting occurs, and die removal is possible. It isn't necessary, nor desirable to melt the adhesive. The adhesive film will usually remain with the substrate. This film can be removed be peeling

it off while heating. The film should come off as a single piece and no cleaning is needed to attach a new die.

TABLE 2

SUBSTRATE	CONDITIONING	**Initial** Bond Strength	**Final** Bond Strength
Ceramic	150°C, 1000 hours	2,500 PSI	4,800 PSI
Gold-Plated Ceramic	150°C, 1000 hours	3,100 PSI	4,900 PSI
Aluminum	150°C, 1000 hours	4,100 PSI	4,500 PSI
Ceramic	85%RH, 85°C, 1000 hours	2,500 PSI	1,800 PSI
Gold-Plated Ceramic	85%RH, 85°C, 1000 hours	3,100 PSI	2,600 PSI
Aluminum	85%RH, 85°C, 1000 hours	4,100 PSI	3,600 PSI
Ceramic	-65°C to +150°C, 500 cycles	2,500 PSI	4,000 PSI
Gold-Plated Ceramic	-65°C to +150°C, 500 cycles	3,100 PSI	3,700 PSI
Aluminum	-65°C to +150°C, 500 cycles	4,100 PSI	4,800 PSI

Although the old film can be reused, the best practice is to start with a fresh piece of die attach film. This can be placed on die bond site. The die is then placed on the film and bonded using heat and pressure.

A second method, popular for known good die and burn-in work, involves the use of solvent-debondable adhesive. Special die attach films are available that swell in IPA (isopropyl alcohol) and lose bond strength. These materials, while providing a strong bond, lose strength in alcohol but not in most other solvents.

FLIP CHIP AND UNDERFILL

Now let's look at the flip side of the chip called Direct Chip Attach assembly. More recently, Flip Chip has experienced a rebirth and transition when Motorola and other vertically integrated electronics giants began to move FC into the consumer product area. Manufacturers in Japan are also using FCs in consumer products including the very high volume electronic watch business, still the largest application. The numerous technical problems have been solved, but one of the solutions for making organic PCBs compatible is underfilling, an added step. However, after a few set backs, underfill materials and processes began to work reasonably well. Today, nearly every class of IC-containing product has begun to embrace FC technology except those that don't benefit from higher performance or densification. But how much of a problem is the underfill step?

Thermoset Underfills

Many foretold of the future offered by Flip Chip with its exquisite simplicity in earlier articles like "Flip or Flop?" and "Flip Chip 1,2,3" [refs.]. Most then thought that the key to dazzling success was the emerging class of *snap flow snap cure*/underfills [refs.]. Better capillary flow underfills would break the bottleneck so enthusiastically publicized by the Chip Scale Packaging (CSP) competition. The snappy underfills did help but FCs are still hindered by the underfill step. The fast flowing 5-minute cure state-of-the-art capillary flow thermoset underfills still aren't quick enough to wring out cost and aggravation for many products. What's worse, the materials have reached a

performance plateau and may be close to the ***laws-of-science*** barriers. And they aren't reworkable! Although the capillary flow products work and they're in production in many factories, but industry demands more, much more. Figure 4 shows the FC process.

Flux chip	Pick & Place	Reflow solder	Under fill	Fill et	Cure UF

Figure 4 – Flip Chip Assembly Steps

Thermoplastic Underfills

The industry's Flip Chip involvement has taken on the characteristics of a love-hate relationship. Many love the simplicity, minimum size and maximum performance of the FC that provides all that we could want in a package – well almost. There are two problems of consequence. Die shrink, the size reduction of the IC's internal and external geometries, is commonly used to increase performance and productivity (more chips per wafer) while cutting cost. The die shrink downside is that the chip gets outwardly smaller. But if the chip pad layout changes, this spells trouble for Flip Chip. While wire bonders only need re-program, FC assemblers may need a new circuit board. The CSP community also needs to re-fabricate their packages, but that's easier than modifying an entire multilayer PCB. There is really no easy solution here. Bumps can be rerouted or the initial bump pattern can be pre-shrunk so that the same layout works for the 1st and maybe the 2nd shrink. Sooner or later the FC won't fit the circuit PCB pads.

Still, there is a more critical problem – underfill processing. Cured thermoset underfill works well and adds only a miniscule amount of material cost. But the common capillary underfilling step wreaks havoc with the SMT process. Flip Chip starts off as a clean and simple SMT process with the assembly solder built right into the chip for eutectic bumped chips. The self-alignment performance of FC is extraordinary. But just when the process should be complete, another non-standard step is just starting – underfilling. The underfill process requires a dispenser and curing oven that are extra.

Underfill processing is the bottleneck that only gets worse as the solder assembly steps get faster. Underfilling adds a significant amount of cost when we rigorously analyze productivity. Even a few seconds of added cycle time will translate to a large sum of money at the end of the day - a fortune at the end of the year. The cycle time increase will typically add more cost than the savings that "no package" assembly can offset. Again, the underfill material cost is not the problem – it's insignificant. But the underfilling step can increase manufacturing time by 50%, double floor space requirements and add significant dollars in capital equipment. We have estimated that reduced productivity from underfilling will add up to 1-2 billion dollars per year. Table 3 in the cost section shows how the numbers were generated using SPACE [refs].

How can we overcome underfilling to take the next step along the road to success in making Flip Chip the ultimate package? What if we use solid, meltable thermoplastic polymers? As stated earlier, thermoplastics have been used in electronic packaging for a long time. Solid die attach films just discussed, are used to bond large and small die

for the past decade. These low stress thermoplastics have established an excellent record. Why not use similar polymers for underfill? And why not use the same type of wafer-level application method – coat-dry-dice. The resulting *ready-to-bond* chips would be easy to handled and assembled quickly using heat activation. There is no curing and no surprises - only the simple mechanics of melting, bonding and cooling a <u>pre-polymerized</u> adhesive.

Underfill is clearly an adhesive as pointed out earlier. Its primary purpose is to strongly bond the chip to substrate and mechanically couple or "lock" the structure together thus preventing strain-producing movement within the interconnect region. We should be able to coat the face of the chip with underfill adhesive in a process analogous to coating the back of the wafer with die attach material. This is more challenging than coating the back of a wafer, but certainly feasible. Flux must also be included, either as a separate component or built into the underfill.

We now report work on solid flux and underfill designed for wafer-level application to Flip Chip and other array products. Several strategies are possible for achieving the goal of FC=SMT®. Although reworkable underfills have not been successful, this is because thermosets have been used out of necessity. But shifting to solid underfill opens up the world of thermoplastics recognized for practical reworkability. Just as with die attach, thermoplastics can be repeatedly melted and hardened just like solder. Utilization of thermoplastics as the underfill layer thus bestows the elusive workability feature. Note that pre-polymerized thermoplastics have not been used for capillary flow underfill because they are made into liquids by adding solvent. Solvent evaporation within the confines of an assembled Flip Chip would produce unacceptable voids and shrinkage upon drying.

The W-L fluxed and underfilled Flip Chip becomes a true SMT package if we create the right materials. Our primary approach among a plethora of possibilities has been to keep the underfill and flux layers as separate entities although a single flux-underfill material has been made. There are two reasons for the dual-layer approach. First, it is easier to optimize the individual sets of flux and underfill properties without compromise. Secondly, the underfill, or UnderFlip layer, can contain filler since it will not interfere with soldering. The flux layer does not have nor does it need filler. Figure 5 shows the dual-layer concept but there are many possibilities including fully surrounding the bumps with flux.

Figure 5 – W-L FC

The flux design is straightforward since it can be based on the patented ChipFlux2020 epoxy system that has been in commercial use for several years and is well characterized. The main challenge is converting over to solid epoxy resins and defining the solvents. The judicious choice of solid epoxy, flux-active hardener, solvent and tackifier allows formulation of coatable flux with an engineered melting ranging from 60°C up to 160°C. The level of tackiness required to hold the chip in place can be adjusted. The solid version of ChipFlux2020 has afforded good soldering and joint formation. The flux is thermally converted to a strongly bonding inert polymer that can also serve as a primer for the thermoplastic underfill that does not need to melt during reflow. Figure 6 depicts the proposed FC=SMT® process.
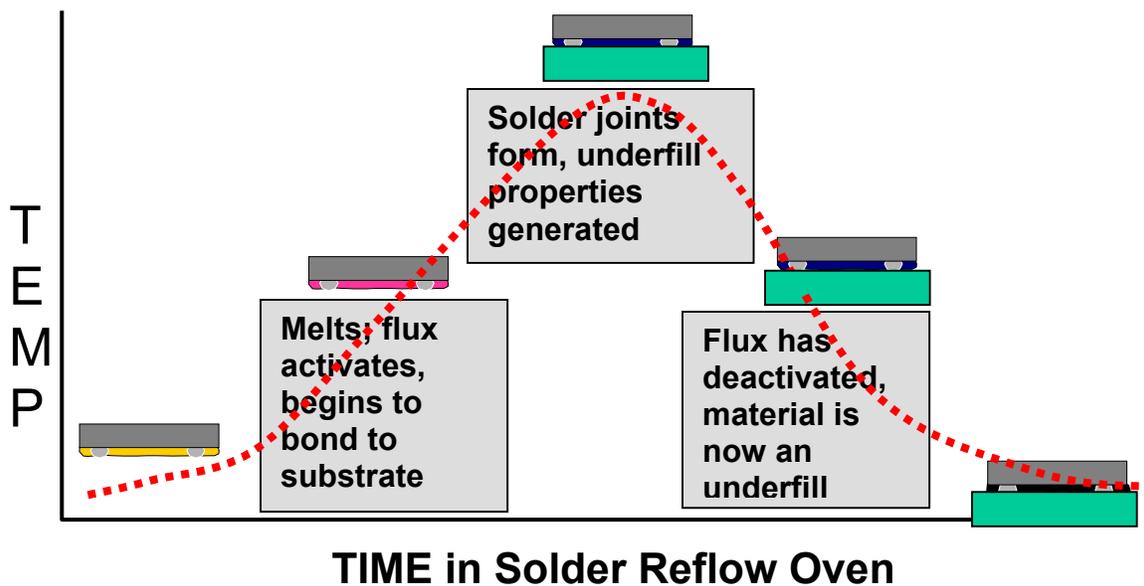

TIME in Solder Reflow Oven

Figure 6 – Reflow Profile

Application Methods

Let's next explore wafer-coating methods. Once again there are many options including traditional methods like spin coating. Stenciling, one of the successful processes used for die attach pastes, can also be used here. Work at Speedline/MPM and Georgia Tech will define the parameters. However, development continues at SCS/Alpha Metals on spin coating, a process more familiar to the semiconductor industry. Spraying and curtain coating are other possibilities.

Flux paste can be selectively applied to bumps by roller coating or wafer dipping. The wafer dipping approach is similar to the flux application process for single Flip Chips using a rotating drum. The required amount of paste is spread out on a very smooth and planar rotating disk using a precision doctor blade. The solder-bumped chip or wafer is pressed into this reservoir with bumps down and then withdrawn. Bumps become coated with a specific amount of material that is determined by doctor blade height, withdrawal rate, bump geometry and the paste rheology.

Rework

The anticipated rework process should be similar to that described for die attach adhesive since similar thermoplastics are planned for use here. The rework temperature should be above solder's melting point. While work is planned here, not has been done yet.

Future Work

During the remainder of 1999, work will continue on W-L application methods and SMT Flip Chip assembly at Cookson, Alpha Metals, SCS, Georgia Tech and Binghamton University with materials modification as required. Beta site testing is expected in 2000 and positive results will lead to product introduction in the same year.

Success with this Ready-to-Bond FC concept or any other that enables FC=SMT® will radically enhance the value of Flip Chip. Underfilling will become transparent to the assembler. There will be no extra-step penalties for assembly and the FC will be just another SMD. Triumph over today's underfill limitations will take Flip Chip to the next and final level - a true package.

The result: **FC=CSP**.

COST

Die Attach Costs
[Need to run SPACE]

Underfill Costs

Our analysis, using the cost estimating software, *SPACE*[3], has indicated that the industry may lose $1-2 billion dollars
In lost production if the FC process remains a slow secondary process. It must be understood that this analysis was "generous" in that we assumed that significant incremental improvements would occur in the underfill application and curing processes. Incremental improvements, however, will never be enough. FC must become a part of the standard SMT process. Until it does, it will never be universally embraced.

In the manufacture of expensive products, the penalty is extreme. To appreciate this penalty, the following cost analysis will be performed with SPACE. Let us assume that cellular phones are being manufactured for a period of one year. The current design calls for four 100 I/O QFPs that cost $10.00 each. These QFPs can be replaced with four FCs that cost $9.50 each. It would appear that choosing the FC would be a "no brainer." The FC process, however, increases the cycle time from 25 to 32 seconds, a relatively modest 28%. We will also assume that the phones are manufactured in a "four up" PWB (i.e. there are four phones per board). Reasonable values for other variables will be assumed consistent with the assembly cost metrics in the 1996 NEMI Roadmap. See Figure 6 shows the input using SPACE software.

Description	QFP Assembly		
Assembly Equipment(SP:$200K, PP:$800K, RO:$100K, T:$500K, BH:$100K)	$1,700,000.00		
Floor Space and Utilities (sq ft.) and Cost (per sq ft/month)	3682.5	$0.83	
Components (per unit)	$100.00		
Stencil, squeegee, lifetime (cost each, uses)	$600.00	$200.00	1000000
Solder Paste ($/g), grams	$0.1000	1	
PCB (per unit)	$5.00		
Workers (number, rate per hour)	7	$28.00	
Selling Price	$130.00		
Hours per shift, Shifts per day, Days per week	10	2	6
Cycle time (seconds)	6.25		
Downtime (%)-Setup (hours per week)-Maintenance (hours per week)	8	10	12.5
Workers Supported (number, rate per hour)	26	$42.00	
I/O	950		
Yield first pass reworkable (%)	97		
Years Equipment Depreciation	3		

Figure 6. Input for SPACE software to calculate QFP assembly cost and profit.
Cycle time is 6.25 seconds per phone because of "four up" assembly design.

Input for the FC assembly case requires 1) an increase of 7 seconds in unit cycle time (28 seconds divided by 4), 2) an increase in assembly equipment cost from $1.7 million to $2.0 million, 3) a 20% increase in floor space cost, 4) an increase of $0.50 each PWB ($0.125 per phone) in consumable materials (for the underfill and supporting materials, this increase is inputted with the solder paste), and 5) an increase of two line workers and one support worker. On the positive side, the component cost is reduced by $1.00.

	A	B	C	D	E
20	Cost		$ Per Board	%	Total $
21	Components		$ 100.00	91.938	$ 263,267,700.00
22	Labor		$ 3.05	2.807	$ 8,037,120.00
23	PCB		$ 5.00	4.597	$ 13,163,385.00
24	Consumables		$ 0.10	0.093	$ 265,373.84
25	Machine Cost		$ 0.29	0.262	$ 750,719.72
26	Rework		$ 0.32	0.290	$ 829,293.26
27	Floorspace,Utilities		$ 0.02	0.014	$ 39,842.25
28	Total		$ 108.77	100.000	$ 286,313,591.81

Figure 7. Cost output from SPACE for the QFP assembly.

The cost analysis from SPACE is in Figure 7. It is interesting to note the small relative unit cost of assembly equipment, consumables, and floorspace/utilities. A comparison of the unit cost, profit, and number of phones produced in the two processes is given in Figure 8.

Clearly, the unit cost difference is not great, but the total profit difference is stunning. The increased cycle time for FC results in significantly fewer units being produced. In a facility with eight such lines, the total profit lost in one year would be over $100 million.

Run Comparison

Descriptor	Unit Cost	Unit Profit	# Units	Total Profit
QFP Assembly	$108.77	$21.23	2,632,677	$55,894,574.85
FC Assembly	$108.99	$21.01	2,056,779	$43,210,813.26

Figure 8. A cost comparison of the QFP and FC assembly processes.

Conclusions/Summary

Thermoplastic adhesives offer advantages for die attach over other technologies for new high-density packages and MCMs. The easy reworkability is a unique and important advantage, especially for MCMs. Low elastic modulus produces low stress bonds so that thermomechanically mismatched die and substrate can be reliably mated. Very quick bond times, a wide processing window, inherently low ionics and no outgassing are other important characteristics. However, not all die bonders can be used with thermoplastic adhesives.

Reference

FC=SMT is a registered trademark of Cookson Electronics.
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