IMPLEMENTING SMT WITH CONDUCTIVE ADHESIVES

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INTRODUCTION

The major division in electronic hardware is components and interconnects. Since the invention of the integrated circuit (IC) decades ago, the electronic component field has experienced unprecedented growth. Remarkable developments in high performance logic devices can be expected into the foreseeable future. Design rules for semiconductor architecture will continue to shrink as computer chips surpass the 10 million transistors mark. The size limits of today's IC transistors and memory cells have not even been reached as new even smaller quantum effect structures begin to move out of the lab. New packages and design concepts are being introduced at an unprecedented rate as *densification demands* outpace traditional methods. Area array concepts are bringing new solutions and also challenges.

But what is happening in joining technology? The wiring layers and the powerful ICs remain inoperable and completely useless until they are properly mated together. The most important joining process in use today is still soldering. Though soldering has been successfully used for perhaps 5,000 years, the materials and processes are beset by problems that are exacerbated by downsizing and environmental regulations. The rather crude approach of heating metal to a molten state, wetting the adherands and freezing the metal to produce a connection, is certainly useful but plagued with inherent disadvantages. Thermal stress during assembly, challenges of finer pitch, the need to reduce metal oxides with chemicals, and need for nitrogen gas, conspire against solders. Fine pitch pastes that can be cleaned without CFCs have been introduced as the answer to the myriad of problems, but deficiencies and stringent process control requirements plague the assembler. High process temperatures of soldering have produced new defects in new packages such as the infamous “popcorning” effect. The need to eliminate the use of lead in solders will eventually confront electronics industry.

TRADITIONAL METAL SOLDERS

Assembly of electronic and electrical systems has been dominated by the use of Sn/Pb solder; primarily Sn63, Sn60 and Sn62. The comfort level in using these solders has been established with design, manufacturing and quality engineers as the industry progressed from hand soldering to wave soldering and surface mounting of components. Because of changes in requirements, for example, a solder used for a clinched lead to make an electrical connection to a surface mounted joint of a surface mounted 0.4 mm PLCC where both mechanical and electrical integrity are required, has resulted in continuing upgrade in available data and investigation of solder alloy properties. For Sn/Pb alloys, the property criteria listed in Table 1 below:

TABLE 1

SOLDER PROPERTY CRITERIA	
Melting Point	Copper Dissolution Rate
Ultimate Tensile Strength	Intermetallic Growth Rate
Lap Shear @ 20° and 60°C	Effects of Solder Solidification Rate
Elongation	Surface Tension and Fluidity
Modules of Elasticity	Corrosion Rate
Electrical Resistivity	Joint Conductivity
Stress Rupture @ 20 and 60°C	Thermal Fatigue (Operating Temperature)
Slow Cycle Fatigue -10°C to 85°C	Lead Pull (Shear)

Intense activity within our industry, universities and federal labs is now directed at the investigation of lead-free solders. Much of the "new" information, however, is a resurrection of old data for long-existing solders. Tin/bismuth (Sn42/Bi58) data, for example, was published more than a decade ago and the alloy has been in use for low temperature wave solder assembly of PCBs for over 20 years. The tin/silver alloys have also been investigated in depth since they have been used over the years for assembly of electric components, medical/dental fillings (lead free) and structural joining of equipment used in food preparation.

The purpose of the soldering process is to form an intermetallic bond between two metals by melting the solder alloy in contact with chemically clean metal surfaces. The type of bond which occurs is dependent on a number of factors including the solubility of the solder in the basis metal, the time/temperature cycle during the soldering process and the surface condition of the materials to be joined. Since Sn/Pb solders and copper conductors are the most widely used, the two intermetallic compounds Cu_6Sn_5 and Cu_3Sn represent the bonding connection which has been established as maintaining satisfactory electrical conductivity for extended periods.

Unfortunately, the total soldering process, regardless of solder alloy, is very complex since many different metals and processing techniques are used to manufacture printed wiring boards, flexible circuits and a wide range of components. Copper pads and copper plated through-holes are the primary surfaces exposed to surface oxidation and are protected from the environment with organic coatings, Sn/Pb, Sn. Ni and Au finishes which result in differences in bonding from surfaces which melt during the soldering process (Sn/Pb) to Au which rapidly dissolves in Sn, to Ni which has a very low solubility in the soldering alloy. In examining the surface finish on components, the possible range used may be significantly greater and includes organic-coated copper, Sn/Pb, Sn, Au, Ni, Ag and Pa. Methods have been developed for plating of both PCBs and components with 42Sn/58Bi to eliminate lead from the process.

Component manufacturers provide products which are capable of withstanding the thermal process used for PCB assembly. During wave soldering, this temperature can be as high as 260°C when Sn63 is used in the wave. During surface mount assembly, the component internal temperature does not normally exceed 220°C and Sn/Ag and Sn/Pb type solders have been successfully used. Unfortunately, very little consideration has been given to replacing the high lead content solders used component assembly.

The metallurgical joining process has been involved in a series of *environmental adjustments* associated primarily with fluxes used to pre-clean the bonding surfaces prior to wetting with solder and the subsequent removal or non-removal of residue fluxes. A few years ago, the choice was to clean with solvent (CFCs, 1.1.1 trichloroethane, etc.) or water. The choice today is normally between clean (water, saponification, semi-aqueous) or no clean, with a further selection based on use of VOC free flux system. These changes in type of flux used has increased pressure on solderability requirements for both PCB surfaces and component terminations and makes possible changes in selection of new soldering alloys even more difficult. Many require the additional expense of inert atmospheres.

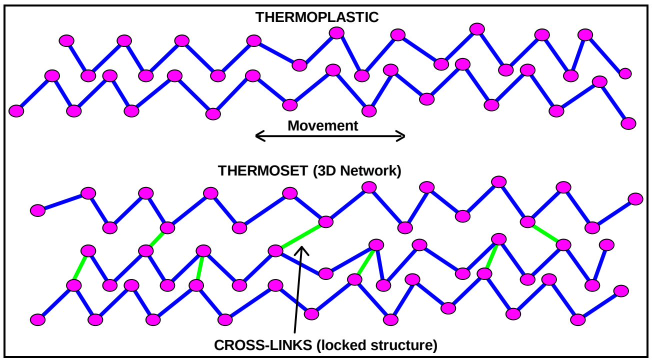
As solder and the solder process is forced to make small and eventually large *course corrections*, it prudent to investigate other methods of creating electrical interconnections. The leading alternative to soldering is conductive adhesives since they offer environmental, processing and product advantages. Polymer-based conductive adhesives, although closer to being a *drop-in replacement* for tin/lead solder than many of the lead-free alloys, are different in many ways. We will now move onto polymer-based joining technology and contrast solder vs. polymer differences while also noting similarities in the technologies.

POLYMER BASICS

Polymers are the most important class of high performance adhesives. They are long-chain molecules, such as epoxies, that are widely used to produce structural products, specialty coatings, sealants and adhesives. Although polymers occur naturally, most commercial ones are now synthesized. Their properties can be tailored to meet thousands of different applications. Polymer-based adhesives are used in every major industry because of this capability to customize and engineer performance. Polymers are among the best dielectric materials and, for this reason, are used extensively as electrical insulators. This means that every conductive adhesive is made by adding conductive fillers to non-conductive polymer binders. However, recent progress with Intrinsically Conductive Polymers (ICP) suggests that these emerging materials will be the joining products of the future.

Thermosetting polymers are the most important class of electronic polymers. True to their name, heat "sets" them and permanently changes the properties. Most thermosetting systems, especially the pastes used for isotropically conductive adhesives, are polymer precursors - ingredients that will polymerize on demand. Epoxy adhesives typically consist of low molecular weight liquids with reactive epoxy groups and a co-reacting hardener. The addition of heat causes the two ingredients to chemically react forming very high weight, cross-linked polymers. Cross-links, or chemical bonds between adjacent chains, produce the thermoset characteristic of shape retention even at high temperatures. The 3-dimensional network of cross-links in the thermoset polymer restricts chain movement. Thermoplastics, on the other hand, are made up of polymer chains that are independent - not linked. Heating allows the individual chains to move past one another and to be reshaped. The re-application of heat again softens the thermoplastic making them somewhat analogous to solders. Figure 1 compares thermosets to thermoplastics.

FIGURE 1
THERMOSET VS. THERMOPLASTIC POLYMERS



The most common conductive adhesives are silver-filled thermosetting epoxies that are typically provided as thixotropic pastes. They can be used to electrically interconnect and mechanically bond components to circuits. Heat is most often used to activate a catalyst or co-reactant hardener that converts the paste to a strong, electrically conductive solid. The materials which conduct equally in all directions are referred to as isotropic conductive adhesives and are the main contender for use as a solder alternative. These metal-filled thermosetting conductive adhesives have been successfully used as die attach materials for many decades and are still the most popular products for bonding ICs to lead frames. More recently, metal-filled thermosets have been formulated as component assembly materials. New polymer-based products are now being used to replace metallurgical solders in some both SMD and flip chip assembly.

Silver remains the most popular conductive filler, although gold, nickel, copper and carbon are also used. Silver is unique among all of the cost-effective metals by nature of its conductive oxide. Oxides of most common metals are good electrical insulators and copper powder, for example, becomes a poor conductor after aging. Nickel and copper-based adhesives do not have good stability. Even with anti-oxidants, copper-based materials will show an increase in volume resistivity on aging, especially under high humidity conditions. However, inks made of copper and solder in a polymer binder are now being used for circuit conductors and may evolve into joining materials.

Silver-plated copper has also found commercial application in conductive inks and this type of filler can work in adhesives as well. While composites made with pure silver particles often show improved conductivity when heat aged, exposed to heat and humidity or thermal cycled, this is not always necessarily the case with silver-plated metals, such as copper flake. Presumably, the application of heat and mechanical energy allows the particles to make more intimate contact when pure silver is used, but the silver-plated copper may have coating discontinuities that allow oxidation of the copper and thus reduce electrical paths. Improvements can be expected.

SOLDER VS. CONDUCTIVE ADHESIVES

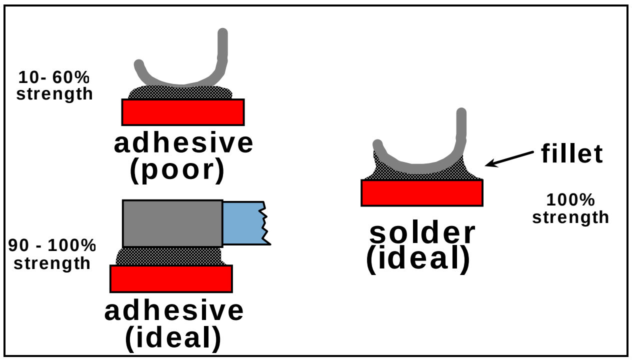
The processing of conductive adhesives and solder pastes are intentionally similar so that existing assembly equipment can be used. Like most solder pastes, isotropic adhesives can be dispensed from a syringe, screen printed or stenciled onto the substrate. The components are then mounted with a standard pick-and-place machine and sent for heat exposure. Conductive adhesive curing conditions provide a key advantage. Many adhesives can be processed as low as 130ºC. Most boards assembled with solder usually have to be subjected to temperature excursions exceeding 200ºC as was pointed out in the solder section. Lower temperature processing is one of the most important advantages of adhesives over solder since it allows lower cost substrates to be used and damage to components is essentially eliminated. "Pop corning", the explosive and destructive release of moisture from the package, does not occur over the typical heat ranges used for adhesive assembly.

Another extremely important difference for adhesives, and one that is gaining significance, is the total absence of flux or cleaning requirements. This is a strong advantage for difficult to clean components like flip chips. Cleaning under Ball Grid Arrays (BGA), micro-BGAs and flip chips can be quite difficult and the total absence of a cleaning requirement offers a significant benefit for adhesives as will be seen later.

Exceptional compatibility is one more feature that has driven the transition to adhesives in certain applications. Adhesives not only bond to virtually all metals, they bond strongly to tarnished and oxidized surfaces. However, only adhesives with built-in reducing agents and/or penetrating particles are compatible with substantial oxide thickness. No fluxes are needed to remove or reduce oxides. The result is that no flux removal is required and cleaning requirements are eliminated, not just reduced. Adhesives are therefore, intrinsically clean. In tandem with the absence of lead or other significant hazards, adhesives are the most environmentally acceptable joining material available today.

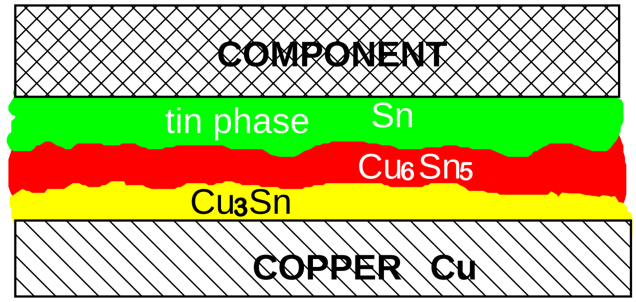
Unfortunately, there is a notable processing disadvantage for adhesives that should be pointed out, however. Molten solder has a very high surface tension which accounts for its wicking and filleting on bare metal surfaces. Solder will flow into plated through-holes in circuit boards and form good junctions with feed-through components. High surface tension is a requisite for wave soldering. Adhesives have a very low surface tension which means that there is no polymer equivalent for wave soldering. Although feed-through devices are being assembled with adhesives, material must be deposited at each junction. The low surface tension also means that adhesives are not self-aligning and will not orient components. Components must therefore be placed more accurately than for solder. This also means that components that are designed for solder wicking, especially the "J" lead, are poorer choices for adhesives as shown in Figure 2. While "J" lead components can be bonded successfully with adhesives, mechanical strength is always lower than for solder.

FIGURE 2
COMPONENT GEOMETRY EFFECTS



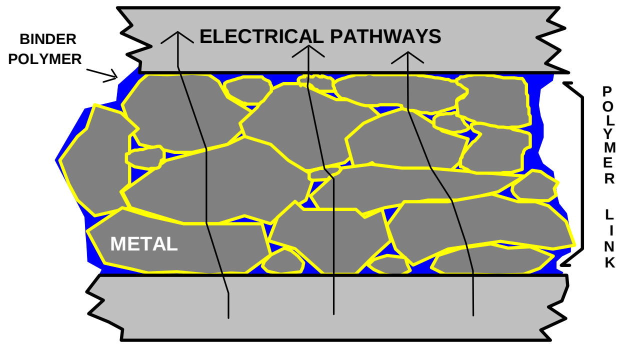
The metallurgical joint, typified by tin/lead solder, is the de facto standard for electronic component assembly today. The solder junction is made up of a continuum of metal phases and intermetallic compounds. All of the several phases formed in the classical solder joint, shown in Figure 3, are electrically conductive. Solder forms bonds directly to the metal surfaces of the component and the circuit board. Thin finishes on the circuit and component, especially gold plating, dissolve into solder and become part of the junction alloy. Figures 3 and 4 illustrate the junction differences. Solder joining processes requires that any oxides on the adherend surfaces are removed prior to, or during soldering. Soldering of oxidized surfaces therefore requires an oxide-removing agent known as flux. Any residual active flux should later be removed. Although aqueous, semi-aqueous cleanable and transitory fluxes have been introduced, many problems remain with these systems. Furthermore, the *water clean* and *no clean* solder pastes are much less tolerant than the earlier solders and the process window is narrower.

FIGURE 3
METALLURGICAL SOLDER



Conductive adhesives are composites of discrete conductive particles in a matrix of dielectric polymer adhesive. The filler provides conductivity, both electrical and thermal, while the polymer produces the mechanical performance characteristics. Electrical conductivity requires that the metal filler particles be in close contact to form "chains" of metal particles. The ideal arrangement is pure silver or silver-plated base metal flake that overlaps other flake particles. Small powder spheres fill in the gaps. The polymer binder contacts the particles without forming insulative barriers between them. Although the ideal composite structure might seem difficult to obtain, it is achieved by the use of filler surface treatments and various additives to the polymer. Conductivity enhances, for example, adjust the wetting of the metal particles by the polymer to allow intimate metal-metal contact without interfering with metal-polymer bond strength. Figure 4 depicts the composite construction of a metal-filled conductive adhesive.

FIGURE 4
CONDUCTIVE STRUCTURE



Although the adhesive should be viewed as an integrated system, this separation of mechanical and electrical properties provides advantages over solder, but also a few disadvantages. Since the electrical and mechanical performance can be independently modified, much more tailoring is possible than with solders. However, this independence also means that good mechanical performance is no assurance of electrical integrity. Understanding the independence of mechanical and electrical properties of adhesives is the key to their successful use. The problem of junction instability is shown in Figures 5A & B. Oxygen from surrounding air can permeate the adhesive bonder and allow the bond surfaces to oxidize. The oxide then acts as an electrical insulator between the base metal of the circuit or component and the conductive particles in the adhesive. The common accelerated aging criteria is 85%RH/85ºC for up to 1000 hours.

FIGURE 5A
ELECTRICAL MODEL

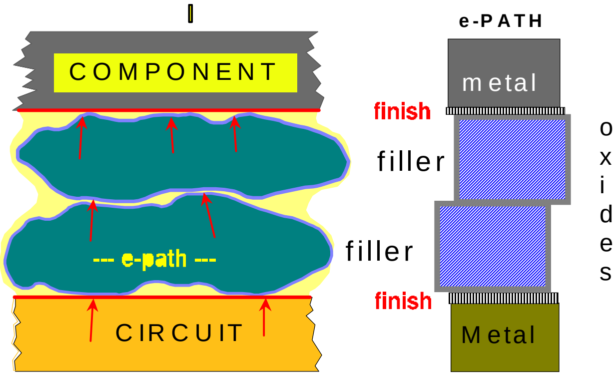
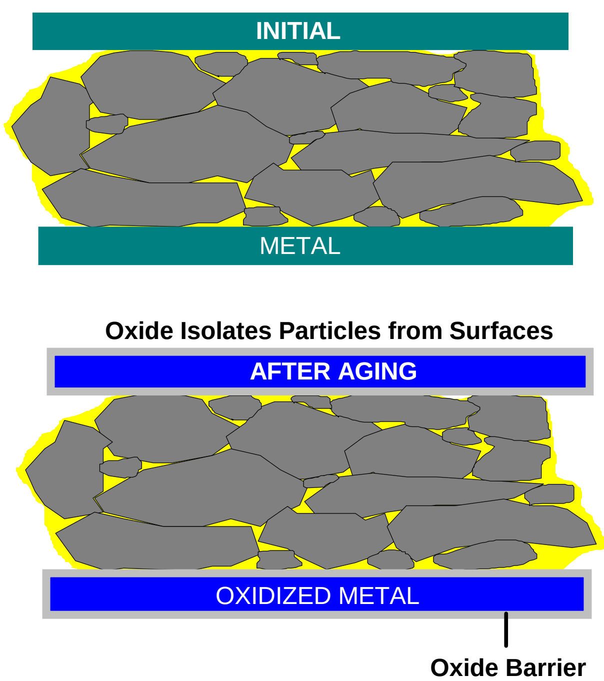


FIGURE 5B
JUNCTION INSTABILITY



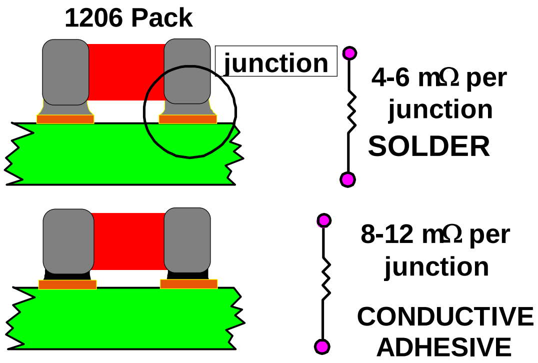
Although reinforced polymers are stronger than solder, highly loaded isotropic conductive adhesives usually have less cohesive strength. Typical bond strengths range from about 2200 - 3400 PSI. The adhesive junction is also smaller than the solder joint because wicking and filleting does not occur. This phenomenon amplifies the difference between adhesives and solder on certain types of component packages, especially those with "J" leads as mentioned earlier. Solder may be more than twice as strong on a J-lead package compared to adhesives. Lap and butt joints, produced with chip components, gull-wings and flat packs are strong and show a much smaller difference. Mechanical shock resistance is definitely poorer for adhesives at this time in their development.

One of the major limitations of tin/lead solder is metal fatigue under thermal cycling of assemblies that have a thermal mismatch; a different Coefficient of Thermal Expansion (CTE) between components and the circuit board. Temperature excursions may differential expansion which stresses the solder joint unless the circuit is very thin and compliant (flexible circuit). The solder becomes work hardened and the grain structure becomes coarse. Eventually the joint breaks. An almost endless number of work-around approaches are used to accommodate this major deficiency in solder.

Polymers do not *work harden* during temperature cycling although high modulus materials can fracture under high stress. The high metal loading also makes isotropic conductive adhesives behave as if they are much stiffer than the polymer's modulus would indicate. Fortunately, polymers can be modified to provide the right elasticity to prevent fracturing. However, if the polymer binder is too soft, temperature cycling may cause an increase in electrical resistance as resin creeps between conductive particles during each expansion-contraction cycle. Based on our latest results, the correct modulus can allow conductive adhesives to pass nearly one thousand temperature cycles even when tested for automotive, under-the-hood performance. Thermocycle tests must therefore include electrical as well as mechanical testing. Once again, good mechanical performance is not assurance of good electrical performance.

Isotropic conductive adhesives can have up to an order of magnitude more volume resistivity than solder although a few materials do have about the same electrical conductivity. The electrical pathway through discrete conductive particles in close contact accounts for the higher resistivity. This was shown in the diagrams in earlier sections. Volume resistivity is the common measurement criterion for intrinsic electrical conductivity of isotropic materials; however, this measurement should be independent of junction resistance which must be measured using the finishes that will be encountered in the actual assembly. Volume resistivity is also measured after heat aging, humidity and thermal cycling. In most cases, the value will improve, presumably because the conductive particles move into more intimate contact.

FIGURE 6 - JUNCTION RESISTANCE



Characteristic	Sn/Pb SOLDER	POLYMER SOLDER
Volume Resistivity	.000015 ohm-cm	.00035 ohm-cm
Typical Junction R	10 - 15 mW	<25 mW
Thermal Conductivity	30 W/m-deg.K	3.5 W/m-deg.K
Shear Strength (1206)	>2200 PSI	2000 PSI
T & H (85%/85C)	0	<20%; Ωmay drop
Finest Pitch	12 mil?	6 - 8 mil
Min. Proc. Temp.	215^{o}C	150^{o}-170^{o}C
Environmental Impact	possibly negative	very minor
Thermal Fatigue	yes	minimal

Table 2 summarizes solder/polymer differences.

TABLE 2 - Metallurgical vs. Polymer Solder

APPLICATIONS

Given the information about the two joining technologies, solder and polymer adhesives, one can now ask the question, "Which material should one choose for surface mount?" Should a company stay with a material that has literally stood the test of extreme time or should the it venture into less known regions and embrace the newer technologies. The answer, in a political spirit is an unequivocal, "it depends." For ordinary PC board surface mount applications, e. g. mounting chip resistors, capacitors, PLCC's, etc. on FR4, solder is probably the right choice at this moment in time. These applications have been well geared for solder. All of the components and the circuit board materials have been manufactured to withstand the high excursion temperatures required for solder processing even though this has added cost. All major assembly houses have manufacturing lines which already use solder pastes in production for years. Assuming procedures are correctly followed, the final product will have bonded components with strong mechanical bonds with good electrical properties. Solder has the distinct advantage of having use even before biblical times. Solder is a tried and true technology, the properties and potential uses have been documented for ages. There are few processing surprises left as long as no regulatory surprises occur. In essence, most engineers treat Pb/Sn alloys like a comfortable old pair of jeans. That comfort concept is dominant in many industries including surface mount assembly and many other areas of electronics.

The environmental movement, "Green Manufacturing", continues to be a source of concern for many in the industry. The Montreal Protocol will require full compliance at the end of this year, 1995, with its profound affect on CFCs. Experts in the field continue to predict a lead tax or a "take-back" program for the future although the timetable is unclear. The taxing and then banning of lead solder cannot be ignored although the presence of business-friendly Republicans into Congress is giving some a false sense of regulatory security. Whether anti-lead action has been postponed, only time will tell, but reasons for switching to conductive adhesives still exist beyond environmental ones.

Research departments of many top companies in an effort to follow the successful strategy of smaller, faster and cost-effective, are developing many products which simply cannot be assembled successfully with traditional solder alloys and techniques. Some companies are leaving solder behind as some ancient relic from the past to investigating and implement conductive adhesives in their products. Assembly with conductive adhesives is now providing the significant benefits albeit in niche applications. Reasons for the change include:

- Compatibility with a range of surfaces; includes non-solderable substrates.
- Low temperature processing; low thermal stress during processing.
- Low thermal mechanical fatigue; excellent temperature cycle performance.
- Low or no significant VOC's.
- No residuals; high SIR.
- No pre-clean or post-clean requirements; no CFC's or washing equipment.
- No lead or other toxic metals.
- Fine pitch capability.
- Wide processing latitude; easy process control.
- Solder mask not required.

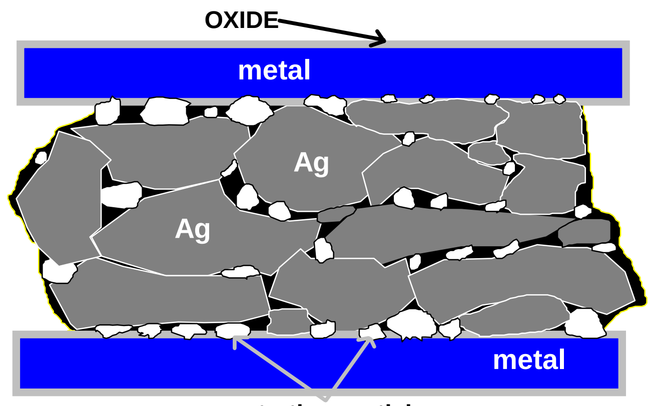
CASE HISTORIES

One company to successfully bring conductive adhesives into full production is Poly-Flex Circuits, Inc. When solder failed to fulfill their attachment needs, Poly-Flex set out to solve their problem with bonding alternatives. The search for a conductive adhesive that would work with ordinary SMDs, those coated with solder, failed. No adhesive available in the late 1989's would pass environmental aging. The problem was traced to oxide formation on the component surface which interfered with the particle connection provided by adhesives. Solder, of course, forms a continuous metallurgical joint and so this "oxide barrier" problem was new. Research led to a solution, however, and production began with a new adhesive in 1989.

Their solution to oxidation, and there may be other viable approaches, was to use the mechanical forces produced during curing to force conductive particles against and through the oxide barrier. Whether this is exactly what happens, has been difficult to prove, but the extreme junction stability of joints made with solder-coated SMDs has been unequivocally demonstrated.

Adhesive junction stability is derived from using purposeful polymer shrinkage during curing to force irregular particles through interface oxides. Small, agglomerated conductive particles are blended in with silver flake in a polymer adhesive system that first forms initial bonds, and then shrinks to push the agglomerate particles against the surfaces. The result is good junction stability on solder-coated and even bare copper surfaces. Figure 7 displays the concept of particle penetration. Perhaps the constant force of small, irregular particles against the surfaces even allows some metal diffusion. Tests at IVF and Chalmers University, both in Gothenburg, Sweden, have been inconclusive. Regardless of the precise mechanism, the performance of conductive adhesives as a solder alternative has been confirmed in several laboratories and in production on both flexible and rigid circuit boards. Electronic polymer bonded assemblies are now in the field built with standard active and passive SMDs. This novel isotropic conductive adhesive, the first of the *polymer solders*, now has been used to produce hundreds of millions of stable junctions. Tables 3 and 4 show the data that an independent laboratory acquired during their evaluation of the conductive adhesive. Recently, the material was optimized for rigid boards and is in production on both ceramic and rigid substrate using non-noble surfaces.

FIGURE 7 - PENETRATING PARTICLES



Flexible Circuitry Products

Presently, Poly-Flex is building several in high volume with conductive adhesive on polyester Polymer Thick Film circuitry. The presentation will cover the newest subassemblies, including several telephone products made for AT&T. All examples will represent reel products that are in production using SMT assembly.

TABLE 3

Polymer Solders on Common PCB Finishes and Sn/Pb Finished SMDs - 85%RH/85^{o}C

(Note drop in resistance for gold and solder plate)

FINISH--->	Bare Copper	PTF Silver	Electroless Gold	Solder Plate	Solder Joints
85%RH/85C	Change in 1000 hrs.	Change in 1000 hrs.	Change in 1000 hrs.	Change in >500 hrs.	Change in 1000 hrs.
PLCCs	18%	-8% (drop)	-22% (drop)	-22%(drop)	0%
1206 res.	15%	-3% (drop)	-10% (drop)	0%	0%

TABLE 4

***Polymer Solder* on Polymer Thick Film (PTF) Flex Circuits with Sn/Pb Finished SMDs**

TEST	CONDITIONS	CHANGE in Junction Resistance
Thermal Cycle	-55C to 85^{o}C, 30 min. dwell, 5 min. trans., 25 cycles	-3.8% (drop)
Constant Humidity	60^{o}C, 90% RH, 1000 hrs.	-3.9% (drop)
Humidity Cycle	6^{o}C, 60^{o}C, 90%RH, 3 cycles/day, 10 days	-6.0% (drop)
Thermal Age	85^{o}C, 500 hrs.	-7.8% (drop)

J-lead PLCC-68, PLCC-44, 1206 chip resistors

Facile and Frugal Flip Chip

Perhaps the most significant implementation success with conductive adhesives involves flip chip assembly. While a somewhat complex process involving stenciling of adhesive onto to create “polymer bumps” has been described, a new, elegantly simple process has recently gone into production. The process starts with simple non-noble metal bumps using one of the new electroless bumping processes. Adhesive is next applied to the bumps without stenciling or printing. The “wet pumped” flip chip is then placed on the circuit and the adhesive is cured. This new break-through process involves no tooling and only one adhesive application step. This means that isotropic conductive adhesive can be used as simply as anisotropic materials, but with superior performance and lower cost. The new flip chip adhesive process should to gain wide acceptance when available, but for now, the information is proprietary.

While the presently commercialized “wet bump” flip chip assembly process uses thermoset conductive adhesive, work is also underway on thermoplastic conductive adhesives in a program between Alpha Metals and The University of Berlin. The goal is to define an isotropic conductive adhesive and process that offers reworkability. While thermoplastic conductive pastes tend to be more difficult to stencil than thermosets, this issue is eliminated in the “no print” process. We hope to be able to report results and the process in 1996.

Polymers - a Place in the Sun

A very novel approach for polymer solders was developed by two US universities, the U of Michigan and George Washington University. Both groups have entered Sun Race '95 - a solar car race sponsored by The DoE. Both were seeking a better method to form electrical connections between their silicon solar cells and the power bus. Conductive adhesives offered the advantages of being, lighter, compatible with the “non-solderable” surface and the ability handle the thermal stresses caused by the sun's rays. Patterns of adhesive are stenciled onto bus bars and small solar cells are placed like SMDs. Thousands of solar cells were mounted in this fashion for the GWU racer alone. They have reported that the contact resistance for the conductive adhesive was excellent and stable. How will the polymer cars fare in the race? At the time of this writing, the race is about to begin, so we’ll report the results at SMI. We sure hope the students and engineers who *got the lead out* - win!

Hybrids Made Easier

The hybrid industry has used conductive adhesives for many years because of problems caused by solder, such as metal leaching. Components can be metallized thin, non-solderable finishes when conductive adhesives are to be used. Recently, a military hybrid manufacturer discovered the “oxide barrier” problem the hard way. Tin/lead finished components were assembled with a good, but conventional conductive adhesive. Although good initial conductivity was achieved, the junctions began to show a severe increase in electrical resistance during 85%RH/85^{o}C exposure.
Recently, this large, well-known hybrid manufacturer switch to a polymer solder that used particle penetration to overcome the oxide barrier on components. That company is now in full production with ordinary SMDs using conductive adhesive. Once again, although a scientific proof of particle penetration has not yet been demonstrated, the excellent success with oxidizable surfaces does add credibility to the hypothesis. As is often the case, *technology leads science*.

CONCLUSIONS

The exact characteristics of Sn/Pb solder are unlikely to be duplicated by another material or technology. Solder forms an extremely stable electrical junction composed only of metal atoms. But solder is deficient in other areas, especially substrate compatibility and thermomechanical performance. But perhaps the greatest weakness of solder is its unfriendly processing conditions that most have just accepted because there was no other choice. Today, there is a choice for many applications.

Conductive adhesives offer an exciting alternative to solders for electronic assembly. These materials are intrinsically clean and are considered the most environmentally acceptable joining materials available today. Polymer solders can also provide process and performance advantages over solders that can be critical to some applications. Very low temperature processing, very fine pitch capability, compatibility with almost any surface and wide processing latitude are key attributes.

Although conductive adhesives are still in their embryonic stage, they are starting to make inroads for some applications where solder no longer performs. High technological applications such as surface mount on flex circuits, flip chip and solar cell attachment are in production today. The high tailorability of polymers can be expected to make polymer-based electronic adhesives the right choice for the future. After 5,000 years of dominance, solder is making way for modern polymers.

ACKNOWLEDGMENTS

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