Z-POXY AS SOLDER REPLACEMENT FOR SURFACE MOUNTING APPLICATIONS

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ABSTRACT

A novel approach for solder replacement has been introduced for surface mounting of components onto circuit boards. The material, Z-poxy, is anisotropical and conducts in Z-axis only. This novel, patent pending, technology can be used with current infrastructure used with solder cream in SMT. This novel adhesive provides the same electrical contact resistance as that of soldering. Accelerated temperatures, humidity, and voltage biased testing demonstrated that the material is intrinsically suitable for use of over 40 years life under normal commercial environment. The methodology for maximum productivity without change of infrastructure are also discussed.

Key Words: Solder Replacement, Z-poxy, Anisotropic, Conductive, Surface-mounting.

Introduction

Soldering has been one of the most reliable methods for providing low cost electrical interconnections. The reliability and manufacturability of soldering have been called into question only in recent years (1,2,3). There are two basic concerns with using soldering in the more advanced electronic devices: bridging and fatigue.

Bridging becomes a prominent problem for surface mounting circuit boards when component lead spacing is finer than 25 mils for reflow soldering. Yield and manufacturability become a big concern in the case of TAB spacing of less than 3 mils.

Fatigue problems in solder joints have always been in existence. They are more prominent for the surface mounting of circuit boards because of the limited area reserved for the extended length of leads in enhancing compliance.

Z-poxy was invented as a direct replacement for soldering in surface mounting components onto circuit boards, while enhancing the reliability and manufacturability. Data of reliability and manufacturability will be discussed.

Z-poxy electrical interconnections vs. soldering

Soldering is an intermetallic joint which is generally quite conductive, with resistances measured in terms of milli-ohms depending on the area of joint. This intermetallic joint, while conductive, is substantially lower in conductivity than the solder or the joint substrate themselves because of the scattering mechanism involved in electron movement through such a joint area.

It is generally believed that conductive contact joints, such as silver conductive epoxies, or in this case anisotropically conductive Z-poxy, will have substantially higher contact resistances. Comparative measurements, however, indicate that they are rather similar in terms of the magnitude of joint resistance. For a contact area of 40 mils square, the resistance generally measured less than 5 milli-ohms (4,5).

Figure # 1 is a chart comparing various

interconnection methods and their relative joint resistances. Z-poxy has tested in the range of soldering under similar conditions.

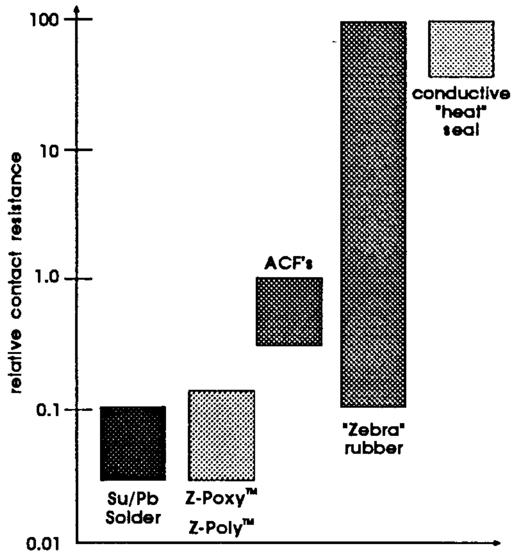


Figure 1: Z-poxy/Z-poly showed almost identical contact resistance as that of soldering. ACF's are anisotropic conductive film adhesives of Sumitomo and Hitachi. "Heat-Seal" is made by Nippon Graphite and "Zebra" is the trademark of Tecknit Corporation.

Z-poxy speed of curing vs. soldering

In order for Z-poxy and Z-poly to be competitive, they have been engineered to cure or reflow with similar speed in comparison to the solder reflow process. Both Z-poxy and Z-poly can be stencilled in much the same way as traditional solder pastes. They can also be dried or B-staged at 60-80°C for a period of several minutes depending on the thickness after the components are placed.

Z-poly can be reflowed, forming a solid bond, in a matter of milli-seconds if proper heat is transferred to the adhesive.

In the case of Z-poxy, it can be cured in less than 5 seconds at 175-200°C. This speed of curing is comparable to that of hot-bar reflow soldering processes. Without any significant changes in processing time in the normal SMT operation, it may be best that a site-specific-fixture be adopted. The details of this type of manufacturing will be elaborated below. Figure #2 is a plot of the bond strength as a function of time for various temperatures.

It is imperative that curing be activated, and the basic bonding process be performed, at temperatures higher than the maximum usage temperature. For example, if the device is to be operative at 150°C, it will be important that the bonding be performed at 175°C or above so that the joint is continuously under compressive stress. It is not as significant as the absolute value of the Z-axis compression stress as long as they are not under tension stress. This is somewhat in contrast to the X-Y shear stress which one would like to be as low as possible for a more reliable joint.

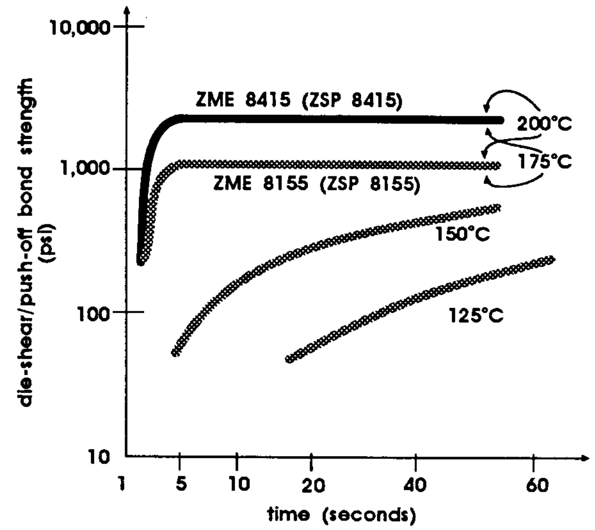


Figure 2: Z-Poxy can be cured rapidly at 175-200°C, which is similar to the time frame of soldering.

The determination of adequate cure in this short period of time is somewhat arbitrary. We have adopted a minimum of 900 psi lap-shear strength to ensure that the material will conform to the minimum standard for military applications. In a more pragmatic sense, one does not need to achieve such high bond-strengths during the heat-curing process. As long as some minimum bond-strength such as 100 psi is achieved, the heating cycle which activated the curing agent in the Z-poxy will continue the curing process at room temperature. We have test results which show that in such a system of Z-poxy chemistry, once the curing is activated, room temperature curing will achieve more than 1000 psi bond-strength over 3 days period.

Electrical migration and long term electrical reliability

One of the long-term reliability concerns for Z-axis and other conductive adhesives is the electrical insulation properties along the X-Y plane, where surface and bulk insulation is important.

Table I

PWB ELECTROMIGRATION TEST

(per Bellcore requirements with 12.5 mil line/spacing)

Product	96 Hours	500 Hours*	Copper Corrosion
ZME 8415	$7x10^9\Omega$	$3x10^{10}\Omega$	Pass
ZME 8155	$1x10^9\Omega$	$5x10^9\Omega$	Pass

*Projected life of forty years under normal conditions.

In the case of fine-pitch interconnection, the X-Y spacing can be as close as 1-2 mils. In these cases, the surface insulation will not be distinguishable from the bulk insulation properties. None of the phenomenological insulation properties will determine the usefulness of such interconnection mechanisms. The long-term reliability, based on the Bellcore specification, has been tested and the materials have proved to be reliable for more than 40 years under normal usage conditions. Figure #3 is a table of the X-Y insulation resistances for a 12.5 mil line and spacing "Daisy-chain" configuration on a standard FR-4 board with typical copper traces. Z-poxy was coated across the traces and a voltage of 10 volts was applied under the conditions of 85°C and 95% relative humidity.

Accelerated humidity bias testing will show decreasing X-Y insulation if the Z-poxy causes corrosion or electromigration. In this testing condition, the X-Y insulation resistance actually increases rather than decreases. The phenomenon is akin to that observed for a good conformal coating used for the X-Y insulation protection on copper traces. The increase in resistance is a reflection of the ionic sweeping process during testing at high temperatures and electric field conditions. The metallic Z-axis powders did not degrade the performance of the insulation properties. In this particular case, Z-poxy showed better performance than soldering without conformal coating.

Besides the 12.5 mil spacing, we have performed testing to 3 mils spacing, and more recently down to 1 mils spacing for ultra-fine pitch applications.

Fatigue and long term mechanical reliability

Another important reliability issue is the performance of contact resistance and X-Y isolation under thermal cycling conditions. In this particular testing or operational environment, excessive X-Y shear stresses will induce changes in electrical contact because of stress-induced micro-cracking and delamination in the adhesive joint. While this may not affect the X-Y insulation resistance, it will adversely affect the bond integrity and increase Z-axis contact resistance.

We have demonstrated the fact that silver epoxy contact resistance is stable in the "stress-free" adhesives pioneered by AIT (6,7,8,9,10).

Conventional silver epoxies showed much higher changes in electrical contact resistance.

We have tested Z-poxy under similar thermal cycling conditions and found similar results, with no change in electrical contact after 100 cycles of -55°C to 150°C. While there is no comparative data from competitive products, we have plotted the stress-induced changes in electrical resistance for adhesives with different rigidity, and thus different shear stresses, in Figure# 3.

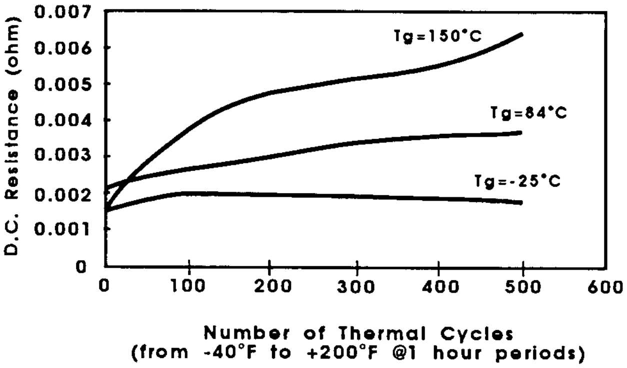


Figure 3: Change contact resistance of conductive epoxy joints upon thermal cycling. Lower Tg, more compliant bond, provides more constant contact resistance.

Contact and intermetallic joints reliability

There is one fundamental physical difference between Z-poxy/Z-poly joints and solder joints. Solder joints are intermetallic in nature and therefore the contact joint is the same in terms of resistance to oxidation as that of the bulk properties. This resistance is normally high.

Z-poxy and Z-poly are similar to all organic based adhesives, such as silver epoxies, in that they provide contact joints rather than intermetallic (13). The fact that all epoxies and polymers are not hermetic and are permeable to oxygen means that they are more susceptible to oxidation, and thus potential change in contact resistance, under normal heat aging.

In order to alleviate this, AIT has taken the proper steps in terms of using oxidation resistant gold-based Z-axis conductive powders in the material (14,15,16,17,18). However, it is also important that the contact surfaces of the joint be resistant to oxidation. While copper traces have been used for all of the reliability testing, one can predict that the following table of preferences will be applicable for the reason stated above.

Reworkability

This is one of the most important characteristics of a solder joint and is known to everyone involved in electronic manufacturing. Most of the epoxy adhesives that were introduced into the electronics industry all bear the same characteristics of high bond strength which has become "trademark" for epoxy adhesives. However, this characteristic which is considered a desirable characteristic also makes them very difficult to rework in the case of electronic applications.

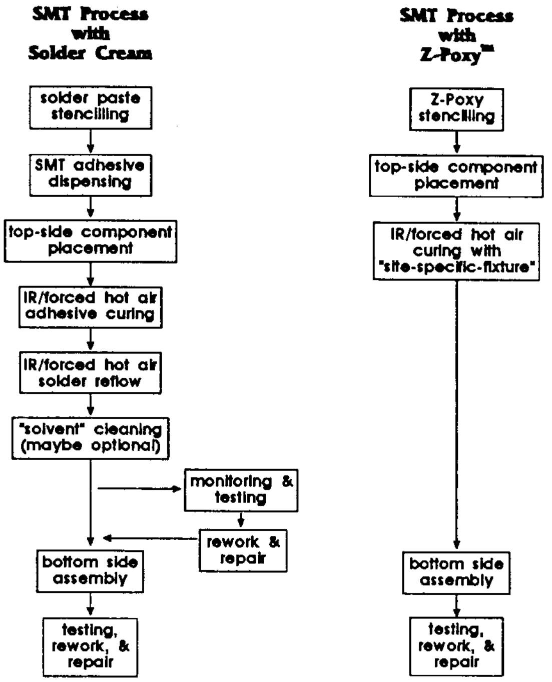
The bond strength, or the reworkability, is directly related but not proportion to the rigidity or modulus of the adhesive. The *"stress-free"* adhesives that were pioneered by AIT reduce the modulus as much as three orders, so that the adhesives can be creased without failure. In fact, they behave more like a plastic-rubber but maintain epoxy versatility and ease of application. Being rubber-like, they will maintain reasonable bond strength of 200-400 psi from 80-150°C. At this bond strength they can be reworked by "torque" and by "prying" at the edge. Directly pulling or straight shearing is not recommenced because of the 300 psi nominal bond strength will easily require more than 300 pounds if the bonding area is in the range of one square inch. The important point in reworking is to create a "stress-concentration" area so that the application of force of a few pounds can be translated to more than 500 psi locally while the bonding material is being torn away during reworking. The residues can be soaked and wiped off with a suitable non-toxic chemical agent or by mechanical scrubbing.

Basic manufacturing flow charts

In terms of the manufacturing process differences between soldering and using Z-poxy, there are substantial cost savings in using the simpler Z-poxy process. Figure #4 is a schematic representation of the SMT solder reflow process and the Z-poxy bonding process.

There is no major infrastructural changes required in implementing Z-poxy and Z-poly in solder replacement. There is the additional step of B-staging, which is analogous to the solder-paste drying process in traditional surface mount operation. The temperature for this process is much lower, in the range of 60-80°C for a period of 30 minutes.

Figure 4: Comparative process of SMT with solder cream and Z-Poxy.



There is one key step in two-sided circuit board manufacturing that will no longer be necessary when solder is replaced with Z-poxy. Z-poxy, being a thermosetting material, will not reflow when flipped over for the second side circuit board processing. Thus the traditional screening-dispensing of epoxy adhesive for stacking purposes is on longer required. Thus, along with the logistics of better material control, two additional processes are eliminated.

There is also a tremendous time and monetary saving in the elimination of cleaning processes that are commonly required for higher performance PWBs and finer pitch circuits.

Manufacturing infrastructures

The basic infrastructure for Z-poxy and Z-poly surface mounting, with respect to process and equipment, are the same. The same pick-and-place equipment, reflow soldering, and inspection processes stay the same.

There is an equipment and infrastructural simplification in the fact that dispensing and usage of traditional epoxy adhesive for passive components on two sided boards are eliminated.

There is one addition to the infrastructure in the use of Z-poxy: a site-specific-fixture for supplying the components with some nominal force so that the component leads will be in close contact with the circuit traces on the boards.

Figure #5 is a schematic representation of the fixture. A toggle-based bed and nail structure, similar to that used in the testing of circuit board traces, is used. The structure is much simpler in construction in the sense that the basic structure can be universal; toggle pins will be inserted in the required spaces only.

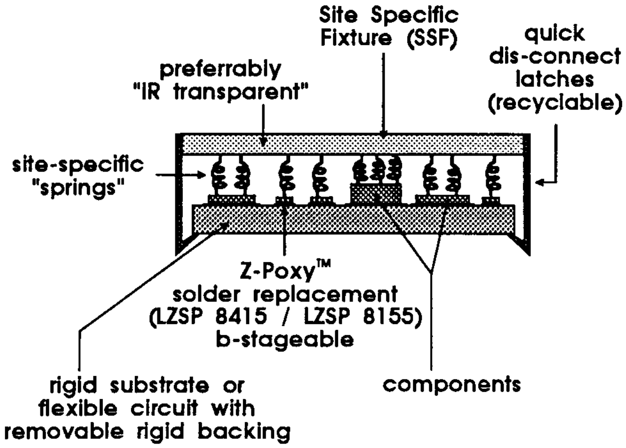


Figure 5: A schematic representation of "site-specific-fixture" using contact points with "toggle pin" similar to but much less then "bed-and-nail" fixture for testing PWB electrical circuitry.

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