TACK-FREE FLEXIBLE FILM ADHESIVES

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INTRODUCTION

In the past, the use of film adhesives in microelectronics has been somewhat restricted to the area of substrate applications in hybrid devices. There are some distinct advantages in using this format of adhesive as opposed to the conventional paste format.

The advantages that can be directly attributed to the use of film as opposed to paste include: precision placement and dimension of the adhesive and thus the assembly; easy placement of adhesive and thus asssembly when the part is relatively large, where a conventional paste application method requires multiple dispensing or stencilling; less mess and thus less chance of human sensitivity to epoxy resins. However, these advantages, and the fact that film adhesives are primarily used in large area substrate attach applications, make it critically important to be able to accomadate the stress created by the thermal mis-match of the substrate and carrier.

Traditionally, a film adhesive is most successful if it is used in a dielectric and insulating application. Most of the conductive film adhesives do not compare well with the conductive paste materials and thus make them unsuitable for higher frequency microwave applications. They are typically in the range of 0.005 ohm-cm, in comparision to pastes, which are normally in the range of 0.0005 or below in electrical resistivity.(Ref# 1,2)

In addition, because the drive of applications is primarily in the substrate attach area, the requirement in terms of ionic cleanliness is not high. Most of the more traditional film adhesives suffer from high ionic impurities of Na, K, Cl, etc.

Since the introduction of "rubber-like" epoxy films, the use of film adhesive has been extended to the areas of die-attach and component attach, in addition to the more conventional substrate attachments. This new technology has made possible successful assembly of devices such as silicon to copper, silicon to aluminum, alumina to aluminum, FR-4 to aluminum, polyimide to aluminum, etc., for areas as large as 8 inches by 10 inches.(Ref# 3,4)

However, the use of this technology, with the basic films being somewhat tacky, is more suitable for smaller volume applications. In response to this trend, a new series of film adhesives has been developed that are dry to the touch and thus extremely adaptable to a more automated assembly process(Ref# 5). In this paper, we will discuss some of the applications and details of this technology.

STRESS, STRESS, STRESS: THE ULTIMATE PACKAGING PROBLEM!

Stress related failures represent one of the more important concerns for the reliability of electronic devices in all levels of packaging. There are essentially two ways of accomoadating thermally induced stress on an assembled device. One is the creation of substrates and adhesives to match the thermal coefficient of expansion(TCE) of the materials involved. The other solution is the use of a compliant die-attach adhesive.

In the case of a matching approach, such as that of high power transistors, the TCE of silicon, at 3 ppm/$^{\circ}$C, is matched with Molybdenum, or other similar materials such as silicon, as substrates. However, the adhesive is still widely mis-matched. Metallic eutectics or solder usually range in the area of 15 to 25 ppm/$^{\circ}$C in TCE while conventional epoxies range in the area of 20-50 ppm/$^{\circ}$C; glass-frit based adhesives range in the area of 10-15 ppm/$^{\circ}$C. It is obvious that the adhesives are the biggest problem for thermally induced stress on a device.

While there are many detailed 3-dimensional models available to predict the stress levels of assembled devices based on some kind of stress or strain distribution assumption(Ref# 6,7,8), it is extremly illuminating to simply look at a 1-dimensional elastic model. The stress levels predicted by this type of "intuitive" 1-dimensional model actually compare well with the 3-dimensional models. However, the 3-dimensional models help to predict how the stress levels will be reduced when the adhesive thickness increases and when the area of the bonding decreases.

All of the theorectical models generally do not predict stress concentration unless a factor is assumed in the calculation. Therefore, all calculations most of the time represent the best possible mode. The actual situation is usually worse! The stress concentration can be several times or more higher than the average stress level being calculated.

The only helping factor is the 5 to 50 % stress relaxation of the materials involved in the assemblies, which is also one thing that theorectical models cannot predict easily (Ref# 9).

Figure #1 represents a simple 1-dimensional model for the stress involved in an adhesive assembly. Notice the fact that the stress on the substrate(in our model, it may represent die, component, or substrate board), and carrier(here we refer to the base of the electronic device, which can be lead-frame, header, substrate, board or heat sinking carrier, etc.) are assumed to be independent in this simple elastic model. Thus, the only factors that affect the internal stress are the difference in TCE's and the modulus of the adhesives.

FIGURE #1

The reason for internal stress is that the assembly is brought to a typically higher temperature such as 150^{o}C for curing. At this temperature, the adhesive(which can be solder) is allowed to flow and solidify to form an assembled unit. This "curing" temperature, or solidifying temperature, is actually the equilibrium temperature, in terms of stress, involved in the assembly. The device is then allowed to cool down to ambient temperature, which is usually assumed to be 25^{o}C. This represents 125^{o}C or more in temperature excursion. If temperature cyclings are involved, it may go down to -55^{o}C or -65^{o}C, which is an additional 80 to 90^{o}C temperature excursion. The strain, or elongation or contraction of the adhesive, can be calculated by assuming that it is elastic within the limit and thus it is equal to the TCE difference times that of the temperature excursion. Since the adhesive is typically contracting faster than the substrate, the compressive stress exerted onto the substrate is the same as the tensile stress on the adhesive(Newton's Law) and is equal to the strain times the modulus(rigidity) of the adhesive. Since most epoxy adhesives and high glass-transition thermoplastics are rather rigid and in the order of 1-10 million psi, the stress induced by this assembly is also rather high and typically in the order of 10-50,000 psi. Table #1 is a tabulation of stresses calculated using this simple model for various substrates and adhesives.

Table #1

It is clear from the prediction that the use of a flexible adhesive provides a stress-free bond. Temperature cyclings and shock tests demonstrate that this prediction is accurate and passes all tests when traditional adhesives will de-bond or cause the circuits to fail.

THERMOPLASTICS VERSUS THERMOSETS: ADVANTAGES AND DISADVANTAGES:

The basic difference between thermoplastics and thermosets for electronic applications is thermoplastics can melt and re-melt again and again once the glass-transition temperature or melting point of the crystallites in the thermoplastics has been reached. This is an advantage for "reworking" and a disadvantage if the device operation or manufacturing processes have to come close to that temeprature.

In order for thermoplastics to circumvent this difficulty in electronic uses, one is forced to choose those that have a high Tg. This also means that the adhesive has to be processed at above this temperature with a substantial amount of pressure. For example, a processing temperature of over 425^{o}C and pressure of over 60 psi is recommended for the first thermoplastic-based die-attach adhesive(Ref# 10). Most electronic devices cannot survive such processing conditions. Potentially, there are some compromises to this aspect of material properties which can be processed in the temperature range of 280 to 320^{o}C(Ref #5).

In addition to this difficulty, thermoplastic adhesives generally have poor solvent resistance and thus cannot be used when any further manufacturing processes involve solvent cleaning after the bonding of devices.

Thermosets, such as epoxies, generally have high a Tg, in the range of 100 to 200^{o}C(Ref#9, 11). They have high bond strength at both low and high temperatures. However, in most cases, they also exert tremendous stress on both the substrates and carriers. Lower Tg polymers, such as silicone, remain rubbery from -55 to 150^{o}C and maintain reasonable bond strength in the range of 400-800 psi. The problem with silicone-based adhesives are that they release uncured materials that possess extremely low surface energy and "swim" everywhere to cause bonding and other assembly related problems. They also possess poor chemical and solvent resistance as well.

Flexible epoxy film adhesives eliminate all of the problems related to silicone and still have a low enough Tg with high enough mechanical strength to be functional for use as an adhesive for all substrate and carrier combinations. Typical mechanical properties of thermosets and thermoplastics are shown in Figure# 2.

FIGURE #2

These kinds of properties were achieved with some molecular engineering of the epoxy structures. Even though it is flexible and low in glass transition, it still maintains high temperature stability like that of the best epoxies and silicones. This is in contrast to polyurethanes, which have similar mechanical properties but do not have the thermal stability needed to withstand the normal 125 or 150^{o}C thermal aging tests that are commonly used in electronic industries.

TACK-FREE VERSUS TACKY FILMS: APPLICATIONS EASE

The first flexible epoxy film adhesives introduced by AIT were the TACK-FILM adhesives. Tack-film is a self-supporting film adhesive, which is achieved through partial polymerization(B-staging); and is novel in the sense that no solvent is used in the manufacture of the material, which assures low outgassing, making it suitable for a wide range of applications.

The original Tack-film series of flexible epoxy film adhesives are available in both electrically conductive or insulating, thermally conductive versions. Both the conductive and dielectric versions have found wide acceptance in a variety of applicactions, including substrate attach, component attach, and in some cases, die-attachment.

In order to improve the handling characteristics and address requirements of high volume for automated assembly, a new family of tack-free film adhesives has been developed. The Tack-free series possesses most of the same characteristics of the original Tack-film except that the films are not tacky and therefore allow a wider range of handling options

This type of free-flowing film can be picked and placed with tools similar to those used to pick-up dice or components. They can also be in a reel format and cut as needed in the assembly process. The adhesive can be tacked onto the substrates at temperatures from 60-80^{o}C. It can be "reflowed" to allow the components or dice to be placed on the adhesive with a nominal pressure of 1-2 psi. The assembled devices can then be cured at higher temperatures. A direct "flow-and cure" process can also be used with a higher temperature of processing in the range of 250-350^{o}C. A simplified flow diagram for the use of these approaches is illustrated in Figure# 3.

FIGURE #3

FLEXIBLE EPOXY FILM ADHESIVES FOR LARGE AREA DIE-ATTACH APPLICATIONS:

Epoxy film adhesives have not been used in die-attach applications previously. The reason is primarily historic. Because the sizes of dice were generally small, it was easy to use paste adhesives. However, as the sizes of dice increased with higher integration, such as VLSI and ULSI devices, it became cumbersome and sometimes difficult to use paste adhesives. Paste adhesives have to be dispensed with a complex pattern to assure full coverage of the die and the bonding pad.

It is extremely easy if one can pick the adhesive and place it in the same manner one would place the die. Since the area of the die is larger, the stress level can be reduced dramatically with a flexible adhesive.

FLEXIBLE EPOXY FILM ADHESIVES FOR COMPONENT THERMAL MANAGEMENT:

In the component level of electronic packaging, thermal management is becoming as important as that in die-level because of the heat that is directly transferred from the die. Even though the heat has been spread into a larger area in the substate level, the power density can be still quite substantial and in the range of 2 to 10 watts per square centimeter.

This level of packaging thermal management is usually more applicable in military electronics. But with the advance of more powerful chips for the computer industry, thermal management is becoming critical even for the commercial market. Thermal management for this level has been traditionally achieved with flexible adhesives in a paste format.

The tacky film adhesive has been used successfully in both traditional multi-layer boards and in hybrids for thermal management. Depending on the power density of the component, film adhesives filled with diamond, aluminum nitride and alumina powders have been used in many programs. The availability of tack-free film adhesives, with similar thermal conductivity, enables this method of thermal management to be applicable even in higher volume commerical applications. Initial customer evaluation shows outstanding thermal characteristics and precision positioning of both the adhesive and components.

The successful minimizing of the temperature rise of the component and the life expectancy of the devices are often closely coupled with the fact that internal stress on the devices also increases with an increase in temperature. In some cases, the reduction of temperature rise and stress means substantial reduction of cost as well as improvement of the reliability of the devices.

FLEXIBLE EPOXY FILM ADHESIVES FOR SUBSTRATE ATTACH:

This type of application is very similar to traditional epoxy film adhesive applications. The exception is these flexible epoxy film adhesives permit bonding of any combination of substrates and carriers, even in the worst case of alumina to aluminum.

The difficulty in substrate attach is primarily created by bonding areas which are usually quite substantial, and a close matching of the TCEs of different materials must be clearly chosen so that stress is reduced to an acceptable level. In the 3-dimensional stress models, it is clear that the stress increases as the dimension of the device increases. This kind of stress evaluation often makes it close to impossible to predict whether the device packaging can survive the same type of testing and service when the areas of the packages increase substantially. Because of the inadequacy of the theorectical models, almost all of the new designs or new devices are forced to be tested for reliability again each time they are made.

It has been proven in commerical applications that the use of "stress-free" adhesives has helped in many cases. The dependence on area is not as critical as it was previously with traditional adhesives. In the component level, there has been no difficulty experienced in using this type of flexible, epoxy adhesive.

FLEXIBLE EPOXY FILM ADHESIVES FOR MICROWAVE APPLICATIONS:

The use of film adhesives for microwave filters and other device applications is mechanically equivalent to that of conventional substrate attach applications. In this area, because a lot of circuits are made out of alumina and other ceramics, matching of the substrate to carrier is crtical and typically limited to Kovar-types of controlled TCE metal alloys, which are heavy and expensive in terms of material and fabrication. These types of circuits are limited to space applications and lower cost commercial applications.

Such technical difficulties can be readily modified with the ability to use a less expensive and lighter weight aluminum carrier. Besides being easier in fabrication, it is superior in terms of thermal conductivity. The use of aluminum and silver, or gold-plated aluminum, is now possible and proven to perform in commercial scale for microwave circuts due to the use of conductive flexible epoxy film adhesives.

In some cases, "teflon" based low dielectric constant laminates are also used, which require the adpatation of a more compliant bonding material for long-term reliability. Flexible epoxy film adhesive has also proven to work very well. The tack-free version also allows for easier handling and improved manufacturability.

The use of these novel epoxy adhesives not only lowers the overall cost, but improves the reliability and design flexibility of the finished device.

CONCLUSION:

The use of epoxy film adhesives has been substantially diversified, from substrate attach to all levels of electronic packaging. This diversification has been made possible partly because of a material technology improvement and partly because of the higher degree of circuit integration and higher functionality and power density in all levels of electronic packaging.

The fact that flexible, stress-free epoxy film adhesives are available make some modern packaging schemes possible. In fact, this material technology, in some cases, has advanced state-of-the-art computer technology. It is now possible to bond dice to any substrate, such as aluminum or copper. It is also possible to mate any components to any circuit structure without fear of stress-related failures. In the case of substrate-attach, it is possible to lower the cost and weight of both the circuit and device, without the penalty of loss of reliability.

The fact that these adhesives are available in both tacky and tack-free films with minimal bonding pressure of 1-5 psi required, allow some of the more automated assembly processes to be utilized.

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