Flip Chip Assembly with Conductive Adhesives

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Abstract

Conductive adhesives have been used for SMT assembly on organic PCBs for over a decade, but only in niche areas. Significant limitations, such as lower mechanical strength and electromigration concerns, have restricted general use. Fortunately, these problems vanish when conductive adhesives are used for Flip Chip. Underfill, whether built into the adhesive or applied separately, resolves these critical problems. Conductive adhesives not only provide reliable connections, they offer additional benefits not possible with standard solders. Adhesives are Lead-Free and process at low temperatures that enable practically any substrate to be used, even paper. Lead elimination not only appeases environmentalists, troublesome alpha-particle emission is prevented without resorting to isotopically refined metal. Emission-sensitive devices, like memory and high-density CPUs, can harvest the value of solderless assembly. What's more, FC assembly with adhesives is now an efficient, high-volume process offering low cost. This paper will discuss adhesive materials and processes for both isotropic and anisotropic with examples that include new RFID tags.

Keywords: conductive adhesives, solderless, flip chip, underfill, lead-free

Introduction

Modern conductive adhesives (CA) are composite materials consisting of solid conductive particles dispersed in a non-conductive liquid polymer matrix that can be hardened when required. CAs have advantages over solder, but significant limitations that restrict their use. CAs should not be viewed as polymer analogues to metallurgical solders since their conducting mechanism and basic characteristics are completely different. The most fundamental difference is that the mechanical and electrical properties of conductive adhesives are not directly related as they are with solder. The electromechanical properties of CAs vary with composition and manufacturing process so that good electrical values do not guarantee acceptable mechanical properties. The inverse is also true.

Generally, the most significant limitation of conductive adhesives is lower mechanical strength compared to solder, especially when compared by mechanical shock tests. This problem has been seen in larger SMDs where the adhesive bond area is small compared to component weight. However, this issue is fortunately eliminated with flip chip.

While adhesives can be more compliant and more fatigue-resistant than common solders, they still require underfill. Underfill eliminates the common problems attributed to adhesives like low mechanical strength and electromigration sometimes seen with the popular silver-filled adhesives. The CA/underfill combination also has natural synergy and high compatibility since both are polymer-based systems. For example, underfills can more easily match the higher CTE values of adhesives since less filler is needed. Underfill shrinkage during cure tends to improve adhesive conductivity by placing the joint in compression. Let's now look at the two basic classes of conductive adhesives and their conducting mechanisms as within the flip chip assembly environment.

Conductive Adhesive Categories

The two basic types of adhesives used for flip chips are isotropic conductive adhesives (ICA) and anisotropic (ACA). We suggest that ACA is a better descriptor than terms like using "film" since films can be formed in situ using liquids.

ICA

This class of conductive adhesive requires a high loading of conductive filler so that a continuous pathway for electrons is produced. Loadings range around 80% by weight when silver is used. Ideally, the filler loading would be 100% but at least 15%

polymer is needed to hold the structure together and to provide even minimum mechanical strength. High levels of polymer binder conversely yield very high mechanical strength, but electrical conductivity is lost. The adhesive formulator must therefore perform a balancing act in attempting to maximize two properties that tend toward mutual exclusivity. The problem is exacerbated since the mixing process can change a good conductive formula into one with poor electrical properties. The mixing process has to be just right since inadequate mixing reduces mechanicals and over-mixing can encapsulate and thus insulate conductors. However, the right formula and process provide excellent materials for flip chip assembly that will be covered later.

ACA

These adhesives derive their uni-directional conductivity by employing lower loadings of conductive particles so that no electron pathway is provided within the X-Y plane. In a sense, the ACA is an ICA with inadequate filler loading. However, an optimized ACA uses special micro-spherical filler in specialized polymer matrix. The preferred conductive particle should have some compliancy and resilience with a non-oxidizing metal finish such as gold. Gold-coated elastomeric micro-spheres are excellent although gold-flashed nickel-plated plastics are acceptable and more common.

Most ACAs use randomly dispersed particles and we have used the term RACA to describe them. RACAs are the easiest to make and the most common. They are being used for flip chip today. The patterned anisotropic conductive adhesives (PACA) consist of ordered arrays of conductors, such as columns of ICA type, in a dielectric film. These systems have not been really commercialized but represent a potentially viable and superior concept for FCs in the future.

Flip Chip Assembly with ICAs

There are several processes that can be used for FCs. The adhesive should be made with finer conductive particles than typically required for SMDs because of the much smaller junctions used for FCs. Silver-filled epoxy-based adhesives are the most popular for both SMT and FC. The ideal adhesives will be made with silver flake and powder that ranges from about 1 – 4μ in size. The mixture should not have any silver agglomerates' often found in ordinary adhesives, as these can cause opens for fine pitch FCs. Three-roll milling is generally used to reduce or eliminate these agglomerates. The ICA should have high resolution printing and dispensing characteristics that often result from the milling step.

Stencil printing can be used to deposit ICA onto substrate pads provided a high quality laser or electroformed stencil is used and thickness is 4-μ or less. Poor printing will result due to poor release if the stencil is too thick and the wall-to-open ratio is too high. Once a clean print has been obtained, and the thickness can be as little as 25-μ, the chip is placed into the paste. We have found that the ICA should be cured at the lowest temperature that will give full adhesive properties. If the chip and substrate are locked together at a higher cure temperature, more stress is produced during cooling that can stress and even fracture the adhesive joints. The assembly will remain fragile until underfilled. Lower modulus adhesives can greatly reduce cool-down fracturing.

Underfill

Standard capillary underfill can be used by following the usual guidelines. The particle size should be at least 1/3 the chip gap height. The CTE of the underfill should match that of the joint. Adhesives can have a CTE value of twice that of solder. However, underfill with a lower CTE will place the adhesive junction in compression that can actually improve conductivity. The underfill should not attack or soften the conductive adhesive. There should be no problem when the adhesive and the underfill are both made with epoxies, the most common choice.

Polymer Dip Chip Process

Many years ago, Motorola and Poly-Flex Circuits looked at ways to dispense ICA for FC assembly. Stencils, at that time, could not be easily made with the required resolution. Motorola had been applying both flux and solder paste to flip chips by dipping into a reservoir of material. It was found that adhesive paste worked much better than solder paste because of finer particles and higher tack. The simple rule was to maintain the adhesive reservoir at a thickness that was less than the bump height. The adhesive coated bumps could then be placed onto substrate pads. This simple process eliminated one registration step and gave good results.

The PDC process can be run with existing equipment by fitting the flip chip bonder with a fluxing drum. Suitable units are available from many of these equipment vendors, such as Siemens. The method works best with conical bumps. Electroless Ni bumps are difficult to run because of their low height. Several companies have successfully used the PDC approach with gold stud bumps and even eutectic solder bumps. The gold bumps may be ideal since the interface is non-oxidizing and the bump shape can be modified and accurately controlled. Figure 1 shows the process.

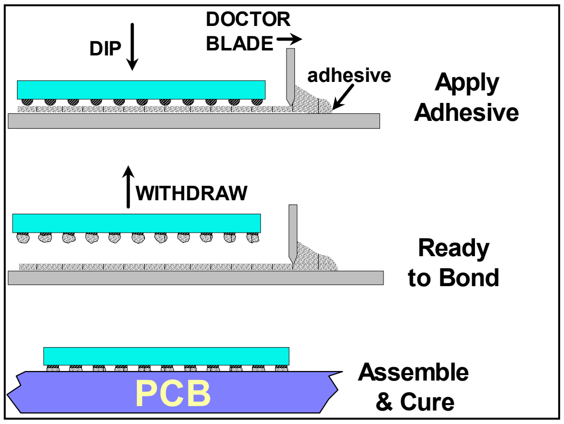

Figure 1- PDC Process

After the adhesive is cured, underfill must be added as with any ICA FC process. There are some interesting variations that have been tried and others that have only been suggested. Many ICA polymer systems allow B-staging, or the partial polymerization that permits the material to be bonded by applying sufficient heat to cause softening or melting. A B-staged system permits underfill to be pre-applied to the chip or substrate. The underfill can be a liquid or a meltable solid. For example, a liquid underfill can be dispensed onto the substrate bond site, the ICA coated chip is then pressed against the pads to displace underfill and finally heating polymerizes both the adhesive and underfill.

Underfill can also be applied to the chip, or wafer, and partially hardened by B-staging or solvent evaporation for thermoplastics. The flip chip is now a ready-to-bond package that is assembled by forcing it against the bond site while applying heat. We can look at this concept as wafer-level underfill. However, the astute reader will recognize this structure as a form of anisotropic conductive adhesives, the next topic.

ACA

Anisotropic conductive adhesives, invented in the 1970's, were viewed as the ideal material for flip chip more than a dozen years ago [1,2]. The ACAs could deal with very fine pitch and did not need selective high-precision dispensing like ICAs. Many eventually concluded that the pressure contact type of junction represented a somewhat fragile connection with a certain amount of unpredictability. Figure 2 shows the contact interface that relies on continuous tensional force. The conductive particles also pose a problem since their curvature reduces contact area that is directly related to junction resistance through Ohm's Law.

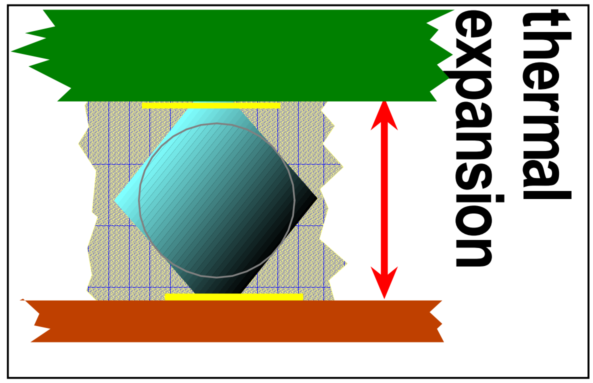

Figure 2 – ACA Contact Close-Up

Modern ACAs have improved the situation by utilizing conductive particles that will deform and partially flatten when force is applied, but maintain some elasticity. Polymer chemists have also developed polymers, such as the inter- penetrating network type, for the continuous phase with lower expansion and some degree of elasticity to help sustain long-term tension. When these products are used and the process is tightly controlled, reliable flip chip assemblies are produced. However, best results have been obtained on highly planar glass used for displays and we may expect less optimum results for other substrates.

The ideal anisotropic conductive adhesive for flip chip appears to be the patterned or PACA type. The concept is to form a pattern of conductive columns within a dielectric matrix that corresponds to the flip chip bumps. B-staged ICA adhesive could provide full contact with the bump and even adhesive bonding instead of the pressure contact of RACA. The bonding, or interposer film, could be made in several ways, but most suggest laser drilling the dielectric and filling with ICA. The conductive adhesive could be thermoplastic, elastomeric thermoset or B-staged thermoset. The dielectric could be thermoplastic film, similar to commercial die attach adhesives, solid unreacted thermoset cast from solution or B-staged thermoset. A minor amount of work was done on this concept but no products have been commercialized [3,4]. Figure 3 shows the PACA concept.

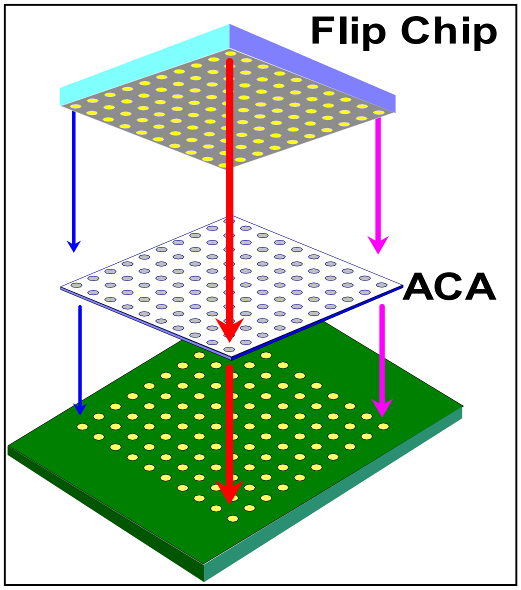

Figure 3 – PACA

CA Applications for Flip Chips

The earliest commercialized applications probably dealt with flat panel displays. Most of the Japanese display makers developed materials and processes for bonding FCs to glass circuits with some form of adhesive since reflow solder assembly was impractical. ACAs were appealing because the glass substrate met the high planarity requirement and did not degrade under the heat and force required for bonding. This application is often referred to as Chip-on-Glass or COGS.

Smart cards have been slowly moving from wire bonding to flip chip for several years. One European company made the transition several years ago using low-temperature bonding thermoplastic ACA. The thermoplastics have extremely long shelf life at room temperature and fast bond cycles since they are already polymerized. Their biggest drawback is poor high temperature performance (<110°C). The credit card application only requires passing 100°C permitting their use.

RFID tags represent a reborn idea that could be poised for high volume success. The concept is to untether the smart card and other addressable information products by moving to radio frequency, of RF. Since the card or tag identifies itself, the term radio frequency identification (RFID) has moved into the lexicon. The idea of contactless cards and tags is not new, but success requires the low cost materials and processes only just now emerging. Back in the mid-1980's, for example, Bell Labs tested contactless smart cards that used two embedded antennas. One received an electromagnetic impulse for power while the other handled two-way radio communications. Today, one antenna does both.

The RFID electronic unit is really a two-way radio with a computer. The product will do all the things that a conventional contact smart card will do, but from a distance. The need to make electrical contact with smart cards has limited the product and added unnecessary cost. The RFID attempts to add the highly desirable contactless feature while lowering cost. While this seems like a paradox, two technologies make this possible – low cost flip chips and conductive adhesives. In fact, most developers feel that RFID can only hit cost and high volume production using adhesively bonded flip chips.

The low cost target goals for RFIDs require low cost substrate like polyester film, long used to make low-cost membrane switches. The system consists of a single dipole antenna and an IC although multi-chip systems are under consideration. The antenna can be printed with PTF (Polymer Thick Film) conductive ink on high-speed automatic screen printers. Adhesively bonded flip chip is the logical package and probably the only practical answer for the connection to PTF circuitry on temperature-limited thermoplastic substrate. Companies, such as Poly-Flex, have developed the process for antenna production, but the jury is still out on the chip assembly method since there are several imperfect options.

ACA would seem to be the ideal material here since small chips are typically used and now high temperature tests are required. The problem with ACA is assembly rate. Cost targets require FC assembly of over 5,000 placements/hour with 10K preferred. This means that bonding must occur in less than 1 second, not practical with film. While it is possible to print ACAs, none have worked without hardening the adhesive while force was applied to the chip. The ideal ACA paste would allow the chip to be placed and curing to take place in an oven just like ICAs. The viable ACA for RFID will need to be processed in less than 1 second on the flip chip shooter or bonder to be viable.

All work has pointed toward the ICA assembly as the most economical since chips can be placed in about 0.5 seconds. The cure time of several minutes is not a problem since a conveyor oven can accommodate thousands of parts/hour. Stencil printers can deposit ICA at dozens or even hundreds of bonding during each print cycle. A reasonably small line with a high speed flip chip shooter can run at 5K to 8K chips per hour with ICA. The drawback compared to ACA is that underfill must still be added. However, the small, low bump count RFID chips are easily underfilled and no filleting step is used. Two dispensing heads can keep pace with the chip shooter line. Figures 4 and 5 show RFID circuits.

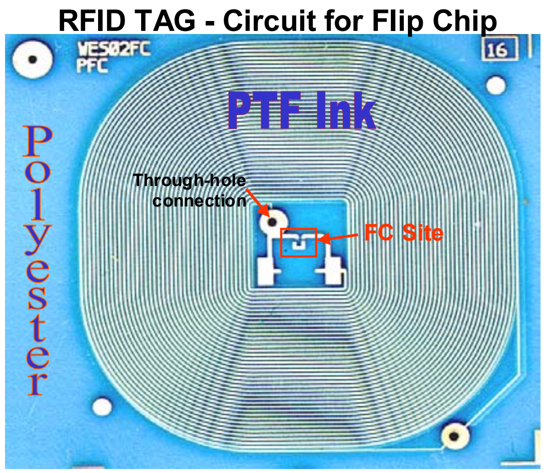

Figure 4 – RFID Antenna

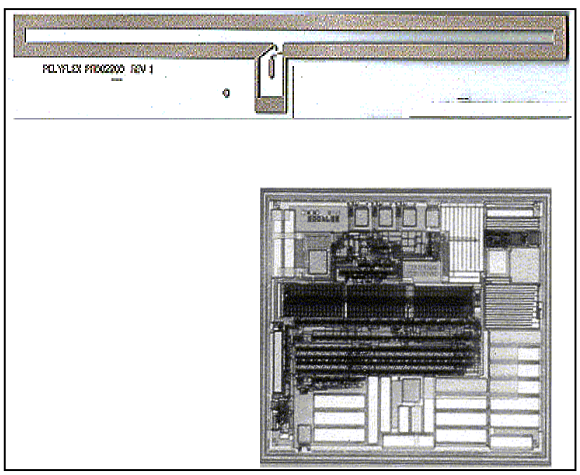

Figure 5 - RFID Flip Chip & Antenna Circuit

Conclusions

All types of conductive adhesives are well suited for flip chip assembly. ICAs produce reliable and robust structures provided that underfill is used. ICAs have a productivity advantage where very high assembly rates and minimum cost is needed. ACA materials also form reliable assemblies and have a built-in underfill. These systems form reliable connections but have a slower assembly rate. Both adhesive systems offer advantages for flip chip assembly that includes lower temperature processing, lead-free composition and absence of alpha particle emission.

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