Development of High-Density Interconnection Techniques for Contactless Smart Cards

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Abstract

This paper deals with techniques that are used for fabricating high density and very thin assemblies with emphasis on materials, implementation and reliability. Moreover, a new potential interconnection and packaging technique being particularly suitable for contacting ultra-thin chips is also introduced.

In the production tests electroless fine-pitch Ni/Au bumped chips were bonded with solder paste but the results were unsatisfactory. Commercial isotropically or anisotropically conductive adhesives allowing denser interconnections than conventional soldering gave markedly better results and are now in volume production. A new type of ACA containing fusible filler particles was employed for bonding flip chip bumps on the substrate with metallurgically compatible contact pads proved very promising.

A solderless interconnection technique, which is especially suitable for producing very fine pitch interconnections, was used successfully to fabricate contactless smart cards. In this technique the substrate conductors are directly deposited on shallow bumps of the embedded chips that increase the reliability of the interconnections.

1. INTRODUCTION

Soldering is widely used and reliable technique for interconnecting electronic components on printed wiring boards, but at very high interconnection densities soldering will meet increasing difficulties [1]. Further requirements follow from the need to implement Pb-free solder pastes and halogen free boards which present contradictory actions. Decreasing solder volumes increase oxide area of solder balls per unit solder volume that calls for higher flux activity. Likewise, narrow gaps between connections increase the risk of short circuits due to the bridging, and the relative amount of brittle intermetallic compounds and impurities is increasing leading to decreased reliability of the joints. Another disadvantage of the solder joining is the flux residue that may lower the adhesion of the underfill considerably.

Some of the Flip Chip solder bonding problems can be avoided with the land grid array (LGA) technique where the typical dense peripheral interconnection pads of dice are redistributed to a wider pitch bump array. Excessive amount of solder paste is stencil printed on the corresponding pads, "lands", on the substrate. In the reflow oven the solder paste forms ball shaped joints lifting the die at the same time higher above from the substrate leaving a gap that can be underfilled afterwards if necessary.

Other approaches in solving potential soldering problems associated with very high density interconnections are the use of the following solderless bonding techniques either based on conductive adhesives or on chemically depositing the substrates' wiring directly to the bonding pads/bumps on the dice. The last mentioned additive "built-up" method, the Integrated Module Board (IMB) technique, does not need any bonding process. Both of these solderless interconnection techniques allow the use of very fine pitch at higher reliability than is possible to achieve with the soldering.

Despite the advantages of the conductive adhesive bonding it cannot be used in all of the applications. In the ultra-high density substrates in the near future the bonding pad sizes will be less than 50 µm [2], so the probability of getting the conductive particles between the bonding pad and the bump is low. Also the soldering using very small solder volumes makes the fabrication of uniform reliable joints difficult. Thereby depositing the solder alloy components by electroplating or electroless plating on the bonding surfaces and then using the transfusion soldering may give reliable and very fine pitch interconnections at high productivity and reasonable cost.

By depositing the substrate's conductors directly to the contact bump of the chip is technically very tempting alternative to achieve reliable solderless joints. In this IMB technique the active components are embedded inside a substrate by using the Chip-in-Board (CIB) technique. After that the wiring on the substrate and the bonds of the chips are manufactured in the same processes. The passive components could be integrated inside the substrate concurrently, which decreases the conductor lengths. Therefore, an additional soldering process will not be needed anymore which improves considerably the reliability and the electrical properties of the high-density packaging [2].

In this paper the development of the high-density interconnection techniques for contactless smart cards are described and discussed. Also, the interconnection techniques

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are compared to each other considering the implementation, the materials and the reliability.

2. HIGH DENSITY INTERCONNECTION TECHNIQUES

2.1. Isotropically Conductive Adhesive (ICA)

In this reel-to-reel technique the substrates are in the polyimide tape carrier and the processes can be executed sequentially without any delays. The volume of the process is 1,000,000 modules per month for contactless Radio Frequency IDentification (RFID) tags. The assembly yield has been well over 99%.

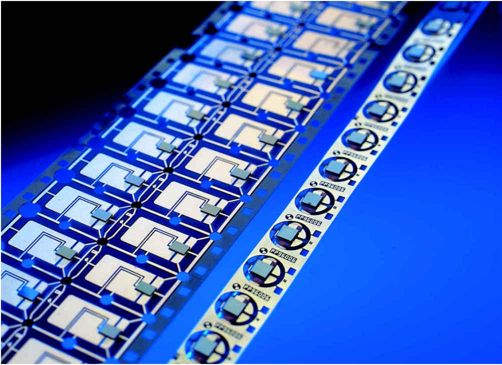

Fig. 1. ICA bonding of Flip Chips on polyimide substrate tape

The modules can be fabricated in two different ways. In the first process a tool with an array of sharp needles is dipped into the adhesive and then stamping small isotropically conductive adhesive dots on the substrate's bonding pads. A rather uniform material transfer can be achieved with this way but the method is practical only for the chips with limited number of bumps. Another technique that suits better to the chips with higher number of bumps is the conventional stencil printing. After printing the adhesive the chip is flipped, aligned and mounted on the adhesive dots.

The adhesive is precured at a set temperature of 150 °C for 1 minute. The precuring time is long enough to make sure that the chip can stand firmly in place during the whole process. In the next process step the tape is moved to the hot plate where the underfill is injected. The hot plate's working temperature is 90 °C and it will make the underfill flow properly under the dice due to capillary force. Therefore, the injection needle could be at the same position during the injection. After few seconds the underfill is spread out properly and the tape is taken to the heat conductive track where the temperature is 150 °C. After 80 minutes the adhesive and the underfill are properly cured and the bonding process is completed. The production rate is about 450 units per hour.

In the other process the first steps are the same as described above, but two chips are attached simultaneously and after underfilling only 20 min precuring at 150 °C is done. The length of the production line is shorter because the final cure is done in the box oven at 160 °C for 120 minutes. This increases the production speed up to 900 units per hour.

In some applications gold has been used as a plating material of the pads resulting a poor adhesion with epoxy-based adhesives. When tin plating is used instead, the adhesion has been twice as much as it was with gold. One of the several adhesives used is Epoxy Technology's silver epoxy H20E-PFC with the transferred/stenciled dot diameter of 80 µm. The dispensed underfill material is Epoxy Technology's OE-100. All production machines are tailor made for this application.

The bumped chips were bonded to polyimide tape substrates with the isotropically conductive adhesive (fig. 1). These active modules were laminated into contactless IC-Cards. The cards were tested according to the test standard ISO/IEC 10536-1:1992. The test results exceeded the standard's requirements by an order of magnitude indicating that isotropically conductive adhesives offer viable alternatives to the soldering of flip chips. More results are presented in reference [3].

2.2. Anisotropically Conductive Paste/Film (ACP/ACF)

Several years ago a number of anisotropically conductive pastes and films were evaluated based on the works of L. Ljungkrona et al. [4]. The anisotropically conductive adhesives were in the forms of thermosetting paste and film. The pastes' conductive filler material were 2-3 µm Ag particles (Hysol TS-9000R and TG-9000R) and films had Au-Ni plated plastic spheres with sizes of 5 and 7-10 µm (Hitachi Anisolm AC-7073 and C48d(3) respectively) [4].

For the adhesive pastes force of 50-60 cN/bump was enough to establish electrical contact. For the adhesive film C48d(3) 100-200 cN/bump was used. The bonding temperature for all adhesives was 180°C and times 20 to 60 s. [4]. Due to the long curing time these processes and materials were abandoned as non-productive for the suggested contactless RFID tags.

Only recently the availability of new materials with high curing temperatures and short curing times has made anisotropically conductive adhesives attractive in high volume, low cost applications. Evaluation tests were made in the Laboratory of Electronics Production Technology (EPT) with Fineplacer manual bonding equipment. Picopak Oy is using a modified Farco F-120 inner-lead bonding machine that repeated the most promising ACP/ACF bonding tests. The materials used in these tests are listed in table 1.

Table 1. New thermosetting epoxy based anisotropic adhesives.

Product	Manufacturer	Form	Filler material
LID3497	Loctite	Paste	Au coated polymer, 5µm
CP7730M	Sony	Film	Ni particles
Anisolm AC-2052	Hitachi	Film	Ni particles, 2µm
FC-262B	Hitachi	Film	Ni particles, 3µm

The tests indicated the best process consistency with film materials (ACF). Fastest reliable bonds were made with FC-262B. The following process description was specified for the own construction of automatic bonding equipment:

First the protective coating of the ACF tape is peeled off and the adhesive layer is cut to the proper length. Adhesive tape is then pressed against the substrate and prebonded at 90°C for 5s. The carrier tape is pulled off and the substrate is moved to a heated bonding stage and kept at 90°C. A vacuum tool picks up the corner prealigned die and places it on the still tacky adhesive layer. The vacuum tool is removed and a thermode that is heated up to 220 °C bonds the die in 5 s using up to 150 MPa pressure per the total bump area.

The automatic bonding equipment will be transferred to production in June 2000. The expected production rate of stamp-size contactless RFID tags as shown in figure 2 will be 600 units per hour.

Fig. 2 Contactless RFID tag with ACF bonded Flip Chip

The RFID tag using ACF bonding has gone through the thermal shock test for 1000 cycles (-40°C – 125 °C) and after that the environmental test for 1000 hours (85°C / 85%RH) as a reference to another tag construction using the IMB technique with following results: None of the tested RFID tags did damage during the thermal shock test and during the environmental test until 350 hours. Right after the test 40 % were unfunctional but after 48 hours drying time all the tags were functional. The environmental tests were done for another test series of RFID tags. 20 % of these did not pass the data read test immediately but again after 48 h drying time all the tags were functional. For both of the tests this was obviously due to moisture that was absorbed into the adhesive. The adhesive was swelled and the mechanical contact was broken. After drying the adhesive shrunk and the joints became functional again.

Since that we have increased bonding temperature in the pilot production to 230°C. Tentatively results are much better and we have all reasons to believe that this process in volume production will give at least as good results as the ICA process.

2.3. Bismuth Filled Anisotropically Conductive Adhesive

With the conventional ACAs the interconnections between the chip bumps and the contact pads are based on mechanical contact. This decreases the joint's reliability during the operational lifetime. To increase the joint's mechanical properties the joint must be based on metallurgical bond as is the case with soldering. We combined the easiness of adhesive joining and the reliability of soldering with solder particle filled ACA.

In this method called also transfusion bonding pure Bi-particles are used to bond the Sn (or Sn-Pb) plated contact pads. The joint's interface starts to melt at about 139 °C, which is the eutectic temperature of the tin-bismuth system. Small amount of bismuth is quickly diffused into the bigger volume of tin thus forming a bismuth-lean tin alloy with a remelting temperature approaching the melting temperature of pure tin, about 232 °C (fig. 3).

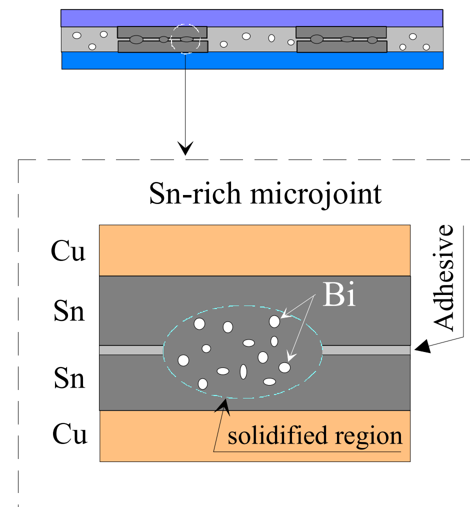

Figure 3. Schematic presentation of transfusion bonding.

2.4. Integrated Module Board

This method uses a solderless fully additive production technique where the substrate manufacturing and interconnections of the active components are made in the same process. The active chip is embedded inside the substrate. Rest of the substrate can be used for embedded passive components. The interconnections between the chip bumps and the wiring are made concurrently with the PWB manufacturing without additional soldering. The benefits of this method are low process temperatures, good accuracy and the electrical and the mechanical strength of the joint [5].

This process starts with the embedding of the active components, fig. 4.a.

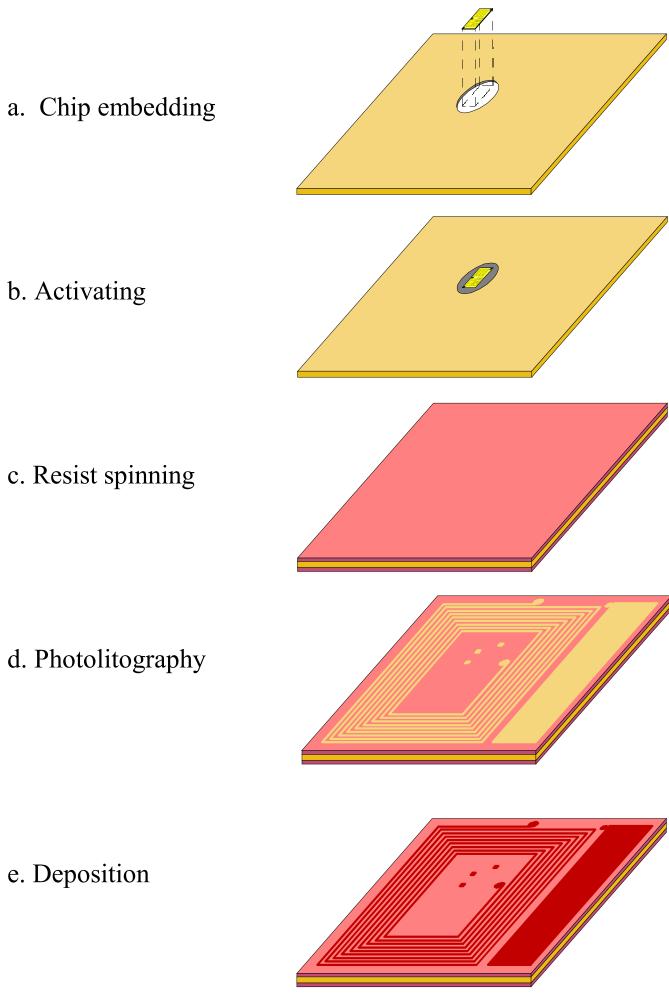

Figure 4. The CIB based IMB technique [5]

After embedding the chips inside the substrate the chips' interconnections and the wiring of the PWB are fabricated with the fully additive multilayer PWB process. This process starts with activating the substrate's surface (fig. 4b). The activating enables the deposition of conductive material. In the next process step the resist is spin coated and exposed (fig 4c-d). The unexposed patterns are dissolved and the activated surface is emerged. The exposed resist is then hardened and copper can be deposited on the activated surface (fig. 4e). Before fabricating the second layer the resist is roughened to increase copper's adhesion to the resist [5].

The passive components could be integrated concurrently with this process (fig. 5). Therefore, functional applications could be fabricated in the same process. As one practical example a "smart card" chip SLE44R35 was embedded inside the substrate with Nagase-Ciba's molding epoxy R-1004. The substrate's surface was activated with a colloidal PdSn solution. The photodefinable polymer Probelec® XB 7081 (negative resist) was used in the photolitography process. In order to enhance the adhesion of the copper, Probelec®'s surface was roughened with three step epoxy desmear process.

Alfachimici's resin sweller Cuprolite PHP 92 was used to swell the surface of Probelec® to assure uniform surface micro-roughness for adequate adhesion. The epoxy resin etcher Epoxymod MLX 60 was used to form adequate surface roughness. A sulfuric acid based Finisher PHP was used to reduce permanganate from the polymer to avoid manganese dioxide (MnO_2) precipitation. Alfachimici's high build electroless copper bath Cupro-T-Eco was used in the copper deposition process.

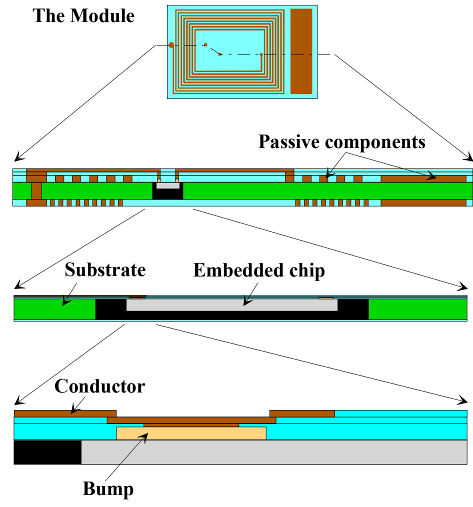

Fig. 5. Cross section of contactless RFID tag manufactured by the IMB technique [5]

A test series of 25 contactless RFID tags were fabricated by using the IMB-technique to demonstrate the technique's manufacturability and the reliability. The tags contained an embedded "smart card" chip SLE44R35 and three integrated passive components in four resist layers. The fabrication of the passive components and the chip's bonding to the PWB's wiring were made only in two copper deposition steps. This procedure made the structures more reliable due to decreased amount of interfaces between the components and the PWB's wiring.

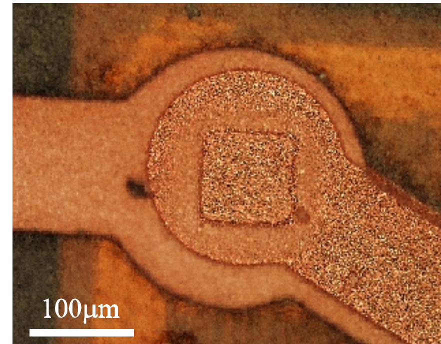

Fig. 6. Top view of the interconnection between the bump and the wiring. The structure of three resist layers can be seen easily. The bump is in the middle of the picture and the chip is visible through the resist layers [5].

The functionality of the RFID tags were tested and compared with ACF bonded tags. The minimum reading distance for the fully functional ACF bonded tag is 45 mm. 16 tags of the test series were fully functional and six tags' reading distances were between 12 and 36 mm and only 12 % were damaged (fig. 7) [5].

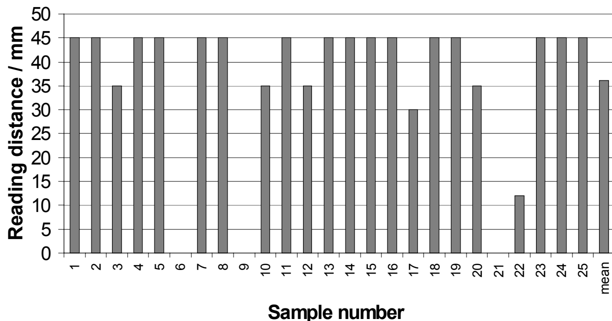

Figure 7. Reading distances of test series

These tags were tested with similar tests as the ACF bonded tags. None of the tested contactless IC-Cards did damage during the environmental and thermal shock tests but the decrease of the reading distance was recognized for some of them. The reading distances for the environmental tested tags were monitored and measured accurately three times (fig. 8). The last measurement was done after 72 hours drying time. The mean reading distance was 5-10 mm lower in the middle of the test than after the test. This is possibly due to moisture absorbed into the substrate. The high relative permeability constant (~80) of water increases the capacitance of the integrated capacitor and lowers the resonant frequency resulting as decreased reading distance. The reliability tests show that the IMB-technique may be a new potential way of fabricating electrically and mechanically reliable joints [5].

This method may be the ultimate target in the quest for ultra-high density Multi Chip Module (MCM) manufacturing alternatives. Undoubtedly a dedicated high volume processing

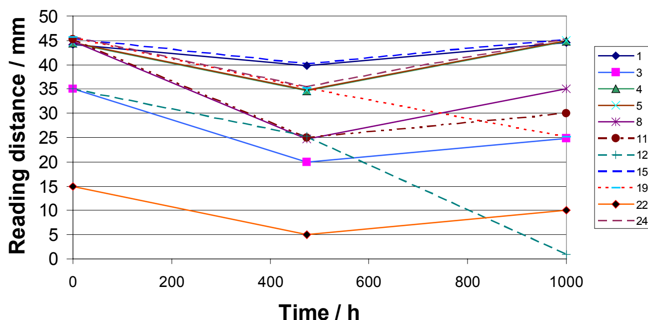

Figure 8. The reading distances during the environmental test

line will be needed for economic production. The substrates may be best handled in tape form for reel-to-reel process or as substrate sheets like semiconductor wafers.

3. CONCLUSIONS

In this paper different high-density interconnection Flip Chip techniques for contactless IC-Cards were presented and discussed. These bonding techniques were described considering the implementation, the materials and the reliability. The processes were described generally with some information of materials and process steps.

The Radio Frequency Identification (RFID) tags fabricated by the Isotropically Conductive Adhesive (ICA) have been found reliable and they have very good productivity. Also the later test series of the RFID tags manufactured by Anisotropically Conductive Paste/Film (ACP/ACF) indicate good reliability and productivity. The Integrated Module Board (IMB) technique shows good reliability potential especially for "paper-thin" contactless IC-Cards but may require heavy investment for the production line.

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