Immersion Silver as Universal Surface Finish for COB Technology

J. Goehre, M. Schneider-Ramelow, K.-F. Becker, M. Hutter
Fraunhofer IZM, Berlin, Germany
Volmerstr. 9a, 12489 Berlin, Germany
phone +49-30-6392-8187, fax +49-30-6392-8162, jens-martin.goehre@izm.fraunhofer.de

Abstract

Immersion Ag is currently being discussed as an innovative alternative to Ni/Au and Ni/Pd/Au metallization for PCBs in COB technology. Its advantages over conventional metallizations include its non-toxicity, due to the absence of Ni, and significantly lower costs, as Au and Pd are not required. Immersion Ag is also easily processed in die attach or SMD processes using adhesives or solder and is compatible with wire bonding. The first generations of immersion Ag in the 1990s were handicapped by a lack of storage capability. The Ag quickly reacted with oxygen and sulfur in the surrounding atmosphere and, after only a few hours of storage, high quality wire bonding was no longer viable. The current generation of immersion Ag was primarily developed to ensure long-term processability for solder technology. However, its suitability for wire bonding and other COB processes, such as glob topping, after periods of storage in non-inert atmospheres had not yet been verified.

This paper addresses this issue, presenting the results of wire bonding tests in initial state and after periods of storage in inert and non-inert atmosphere, as well as after die attach processes using adhesives and solder. In addition, the suitability of immersion Ag for die attach with adhesives and solder, as well as processability for glob-top encapsulation, was investigated. Finally, the results from reliability tests on open and encapsulated samples are presented. The results show that wire bonding on immersion Ag yields bonds of high initial quality and superior reliability even after storage in non-inert atmosphere for several months prior to wire bonding. The same was true of samples that had been exposed to soldering or gluing processes. In addition, immersion Ag performed exceptionally well in other COB processes, confirming its suitability as a universal surface finish for COB technology.

Key Words: immersion Ag, wire bonding, COB, PCB, metallization, universal finish

1 Introduction

As is well-known, rapid on-going development in the semiconductor industry and the resulting new device and microsystem technology product generations place very high demands on the miniaturization, reliability and manufacturing costs of electronic components and systems. It is a trend that continues to accelerate. Users of such technology strive to introduce products with ever-higher packaging densities and thus extended functionality onto the market. Currently, the main strategy to achieving this is to increasingly forego packaging each individual chip, instead using the chip-on-board technology to mount several bare dies together on a suitable circuit board and only then packaging them. In this technology, the chip's interconnects must be attached to the carrier's circuit traces in a way that ensures mechanical stability and electrical conduction. The combination of materials used must also ensure reliability for the respective modes of operation. The preferred processes here are flip chip technology and wire bonding. The highest packaging densities are achieved using flip chip technique, however the process involves complicated additional processing steps.

In chip-on-board technology by means of wire bonding, the Cu circuit traces of the PCBs are metallized with either a Ni/Flash-Au metallization for ultrasonic bonding with Al(Si1) wire or a Ni/"thick"-Au metallization for thermosonic bonding with Au wire. Ni/Pd/Au is also known as a suitable metallization for both wire bonding processes, however, its use is limited due to its high production and material costs, as well as very complex processing.

No single metallization is in wide use that is universally suitable for all COB technology requirements, including reliable and cost-effective thermosonic bonding, SMD soldering with lead-free solder (obligatory since 2006), adhesive and soldered chip bonding, as well as flip-chip technology and encapsulation. Immersion silver, however, may be such a layer.

2 Ag Metallization in Microelectronics Packaging

Thermosonic (TS) bonds with Au wire are widely employed on leadframes (material: CuFe3) with relatively thick (up to 5 µm) galvanic silver-plating, which are used in particular for components subject to high temperatures. As is widely known, such bonds can be realized at high processing yield and can be expected to be extremely reliable due the excellent miscibility of Au and Ag [1]. Superficially, it would seem that TS bonding on immersion Ag in COB technology would be unproblematic because of the metallurgic similarity of the circuit board's Cu traces to the leadframe material. However, a number of significant differences exist that would likely decisively affect processing parameters and bond reliability.

A galvanic metallization has a fundamentally different morphology to that of one created without electricity due to the difference between the deposition mechanisms. This significantly alters the mechanical properties (hardness, elastic modulus, etc.) largely responsible for a metallization's bondability.

Typical plating thicknesses in galvanic processes are several micrometers; electroless platings are at least 10 times smaller (several 100 nanometers). This changes the mass ratios of the bond materials and the hardness affecting the bond considerably.

Immersion-Ag finishes also have an organic inhibitor that changes the surface properties on atom level and could thus affect bondability. Furthermore, the long-term effect (shelf-life) of the inhibitor and the surface on bondability is unknown.

The problems arising from these differences and their consequences have not yet been resolved and have clearly led to ambiguity among experts regarding the use of immersion Ag in COB technology. For example, assessments of immersion-Ag's bondability on Cu in circuit-board technology vary greatly, from "Fine silver: excellent", to "Hard silver: poor" [2], "Use of chem. silver for soldering (bonding)" [3], and to „Au wire bonding on chem. Ag – no" in [4]. The goal of this work was to resolve these uncertainties.

3 Research Program

To evaluate immersion Ag's suitability as a universal PCB finish for COB technology, the question of bondability in initial state and after storage under different conditions had to be determined. Ideally, surfaces are always stored in an inert atmosphere. Where this is not possible or simply too expensive the samples are stored in air. In both cases the samples must be bondable within a parameter range of acceptable size. Another question was whether or not the surfaces can be bonded with high quality after exposure to typical processing steps. In COB technology these might include soldering and gluing of chips and passive components. The viable of immersion Ag during encapsulation after wire bonding also had to be proven. Finally, the products had to be tested for reliability under realistic stresses.

This resulted in the following research program:

- Investigation of the wire bondability in initial state
- Investigation of the wire bondability after different storage conditions and processing steps
- Assessment of gluing quality
- Assessment of glob top encapsulation quality
- Investigation of the reliability of open and encapsulated samples

The PCB layout was specifically designed for the tasks of the research project. All PCBs used were manufactured by one of the project partners to preclude any subsequent differences in the bonding results being due to differences in the substrate manufacturing.

After the optimization of the roughness, evenness, trace width and height by the PCB manufacturers, the samples were sent to the 4 different surface finishers for finish metallization processing.

The plating thickness was measured by both the individual surface manufacturers and IZM using RFA and FIB. The thickness of manufacturer 1 was approximately 400 nm while manufacturers 2-4 delivered plating thicknesses of approximately 200 nm.

4 Pulltests and Quality Criteria

A typical pulltest determines the achieved pull force and the breaking code (pull code). Depending on where the ball/wedge bond breaks different pull codes can be identified:

- Pull lift-off at 1st Bond: The ball is removed without leaving significant wire material on the bond pad.
- Neck break: The wire breaks in the heat affected zone (HAZ) directly above the ball.
- Wire break: The wire breaks somewhere along the loop.
- Heel break: The wire breaks in the transition region between the wedge and the undeformed wire.
- Pull lift-off at 2nd Bond: The wedge lifts off without leaving significant wire material on the substrate.

The critical values of the DVS-Guidelines 2811 for pull force, standard deviation and pull code distribution were used for the assessment of the achieved bonding quality.

Bonds of sufficient quality thereby had the following characteristics:

- Average pull force > 5.25 cN (50% of the wire's initial breaking load)
- Standard deviation < 15% of average value
- Pull force of single wires > 4 cN
- Proportion of bond or pull lift-off 0%

The criteria of the DVS-Guidelines 2811 apply to loop geometries with an angle of 30° at both sides in the moment of breaking. In all other cases a geometry dependent correction factor for the measured pull forces must be calculated and included in the assessment. The results presented here are based on loops with a 30° angle in the moment of breaking so that the correction factor was 1.

5 Bondability in Initial State

Wire bonding was performed on a fully automatic ball/wedge bonder with 120 kHz transducer frequency (K&S Maxum Ultra). Bonding temperature was set to 125°C. The used wire was Heraeus HA10 with a diameter of 25 µm, a breaking load of 10.5 cN and an elongation of 4.4%.

A typical approach to assessing a surface's bondability is systematic bonding trials with different bonding parameter settings. The goal is the identifying a bonding parameter window, in which bonding results in bonds of sufficient quality. Many different parameters influence the bonding quality, with the key variables being ultrasonic (US)-power and bonding force. The latter two were included in the parameter optimization process. Other important parameters such as bonding time, bonding temperature, US frequency were held constant at typical values.

With every setting of the investigated bonding parameters at least 30 loops were bonded and then destructively tested by pull testing.

In the first phase of the parameter optimization the US-power was systematically varied while the bonding force was held constant. In the second phase the bonding force was systematically varied using the optimized value for the US power of phase 1. Table 1 summarizes the results (the US-power at the used wire bonder is expressed in terms of current flowing through the generator, hence the unit mA).

The surfaces of manufacturers 1, 3 and 4 showed wide bonding parameter windows with bonds of high quality. The predominant breaking code during the pulltest was neck break, which is typical of high-bondability surfaces. The average pull forces of 8-9 cN were much higher than the required minimum value of 5.25 cN. Standard deviation was less than 8.5% of the average value.

Table 1: Results of the bonding parameter optimization in initial state

	US-Power Optimization				Bonding Force Optimization			
Manufacturer	Bonding Force [cN]	Allowable Range [mA]	Pull Force [cN]	Primary Pull Result	US-Power [mA]	Allowable Range [mA]	Pull Force [cN]	Primary Pull Result
1	60	140-200	8,7-9,0	Neck	150	30-60	8,6-8,9	Neck
2	50	150-170	5,9-6,7	Heel	150	50	6,7	Heel
3	50	140-200	8,8-9,0	Neck	150	30-70	8,8-9,0	Neck
4	40	140-200	7,4-8,4	Heel	150	30-70	8,1-8,8	H/N

The samples of manufacturer 2 showed poor bondability. Pull testing always resulted in a break in the heel. The resulting pull forces of up to 6.7 cN were significantly lower than with the other manufacturers but still above the minimum value. Standard deviation of up to 14.5% of average value was very high. The allowable bonding parameter window was very small. The samples of the other manufacturers showed good bondability in a wide parameter range.

To verify the acquired results, repeating wire bonding with the same bonding parameters is necessary. For this reason a number of samples of each manufacturer were bonded with optimized bonding parameters on different positions on the substrate and then pull tested for quality.

The pulltests on samples of manufacturers 1, 3 and 4 led to consistent results (upper 3 lines in Figure 1). These surfaces were well suited to further investigations.

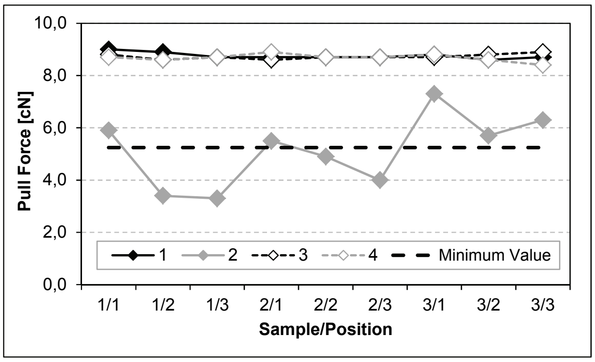

Figure 1: Repeated bonding on different samples and different positions on the substrate, n > 30

The bonding tests on samples of manufacturer 2 yielded erratic results (lower line in Figure 1). Often the average pull force fell below the required minimum value (dashed line in Figure 1) and individual pull force values were <4 cN. In addition, pull lift-offs were frequently observed. Therefore, the surfaces of manufacturer 2 were determined to be not suitable for further investigations and were thus not considered any further.

6 Bondability after Storage

Samples of manufacturers 1, 3 and 4 were stored in air and in a nitrogen chamber, and bondability was subsequently tested (samples of manufacturer 2 were not tested because bonds of sufficient quality could not be achieved in the initial state). The results of the pulltests are shown in Figure 2.

Pull forces did not change significantly with increasing storage time in nitrogen (solid lines in Figure 2). Consistent values and breaking codes were recorded over the entire time span investigated.

After approximately 1 month of storage in air, a decrease in pull force was detectable (dotted lines in Figure 2), but bonds of sufficient quality were still possible after 2 months. Although the ratio of heel breaks increased significantly, the average pull forces remained above the minimum value of 5.25 cN. Bonding testable loops only became impossible after a storage time of 4 months (manufacturer 1) and 3 months (manufacturers 3 and 4). Storage conditions seem to play an important role for the bondability of the Ag surfaces. The surfaces were still suited to quality bonding subsequent to storage in inert gas (e.g. nitrogen) even after 4 months of storage. A decrease in bondability was detectable after only one month subsequent to storage in air, which consists in part of reactive compounds such as oxygen and perhaps sulfur. After 3-4 months the samples of all manufacturers were no longer bondable. Earlier, unpublished investigations concluded that the Ag metallized circuit boards were not bondable after only one day in air. This illustrates the progress achieved in the development of immersion Ag as finish metallization for printed circuit boards.

7 Bondability after Gluing and Soldering

Samples of manufacturer 1, 3 and 4 were exposed to typical die attach and SMD processes:

- Curing of adhesive for 20 min at 120°C
- Lead-free reflow under nitrogen (peak 254°C)
- Lead-free reflow in air (peak 254°C)

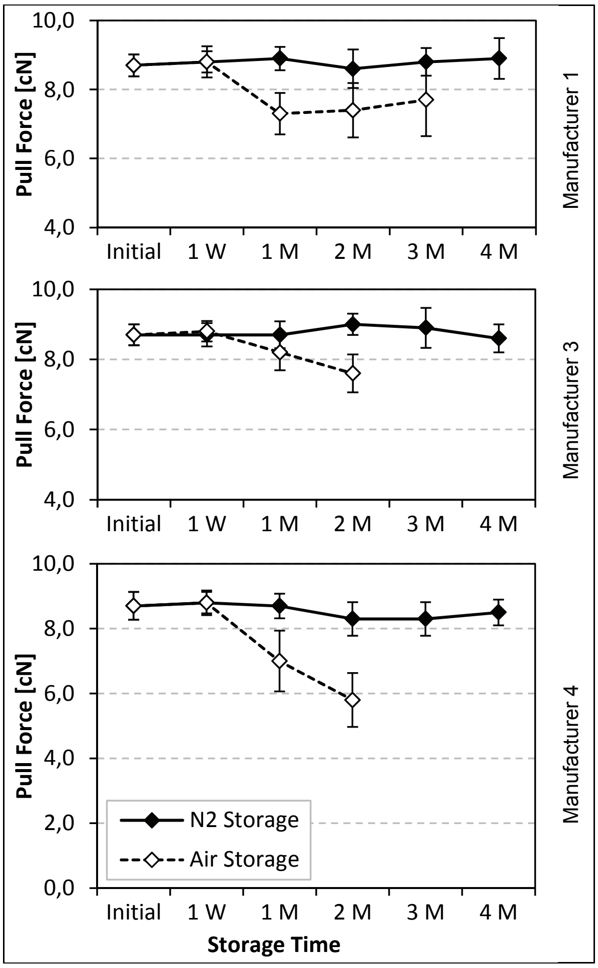

Figure 2: Pull forces after storage prior to wire bonding, n > 30

Wire bondability was then tested by systematic variation of bonding parameters (US-power) and successive pull testing on at least 30 loops. Assessment of the influence of the pretreatment on the quality of the wire bonding process was then possible by comparing the allowable bonding parameter windows in initial state and after exposure to the different processes (more details can be found in [5]).

All investigated surfaces yielded quality bonds after exposure to a typical adhesive curing process. The samples of manufacturer 1 did not show any changes from the initial state. The samples of manufacturer 3 showed a small increase in the ratio of heel breaks, which indicates a slight impairment of bondability. In contrast, the samples of manufacturer 4 showed a rise in the ratio of neck breaks above the ball, which indicates a slight improvement of bondability. In summary, the effect on the bondability of immersion Ag surfaces after temperature treatment comparable to an adhesive curing step is inconclusive. A major impairment of bondability was not detected in any case, which leads to the conclusion that the surfaces are highly suitable for COB applications with glued chips and/or SMD components [5].

After reflow in nitrogen the samples of all manufacturers were well bondable. The differences of bondability in initial state and after the reflow process were minor [5].

A significant difference in bondability was detected after reflow in air. Samples of manufacturer 1 and 3 showed smaller allowable bonding parameter windows and an increased number of heel breaks. The samples of manufacturer 4 were not bondable anymore after the reflow step. Numerous lift-offs already occurred during the bonding process. The pulltest on the remaining wires revealed very low pull forces [5].

8 Gluing Process

Samples of each manufacturer were investigated with 2 different adhesives (H20E and H70E). In each case 16 chips were die-bonded and then destructively tested by a shear test according to the MIL-883 standard (Figure 3). A glued interface is of sufficient quality if the chip size-dependent minimum shear force (in this case 144 N, dashed line in Figure 3) is achieved.

All samples fulfilled the requirements of the MIL-883 standard. The measured shear forces far exceeded the minimum values. The adhesion was so high that in some cases the shear forces were beyond the measurable range. In these cases the machine limit of 1014 N was used for the calculation of average force and standard deviation.

The samples of manufacturer 2 showed the highest shear forces for both adhesives. Adhesion between the glue's molecules and the surface is high when polar groups (e.g. oxides) can be found on the surface. In most cases these polar groups are obstructive to the wire bonding process. Presumably, this is the reason why the samples of manufacturer 2 showed such poor wire bondability in initial state (see section 5).

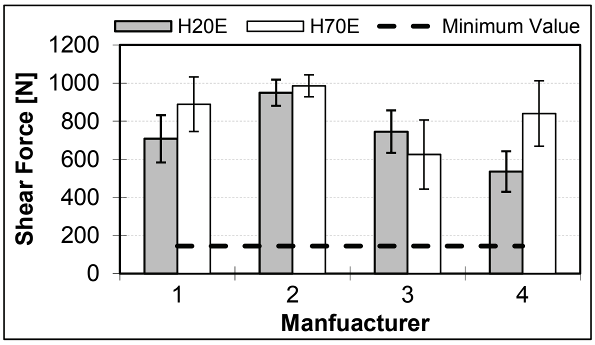

Figure 3: Die shear forces

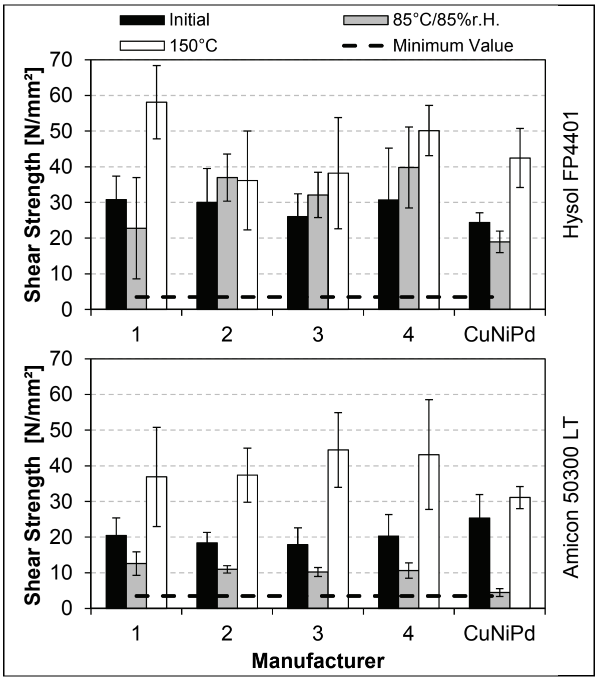

Figure 4: Glob Top shear forces

9 Glob Top Encapsulation

For the encapsulation investigations, 2 different glob top materials were selected (Henkel Hysol FP 4401 and Emerson&Cuming Amicon 50300LT). Both materials are highly filled glob top materials of medium viscosity that were dispensed without an additional dam material.

A die shear test on the basis of MIL-883 standard method 2019.5 was used to measure the adhesion strength of the glob top material on the immersion Ag surfaces. Chip size was 2x2 mm². The minimum shear stress was 3.5 N/mm². The shear strength was determined in initial state, after storage at 150°C for 1000h and after storage at 85°C/85° r.H. for all Ag surfaces and a Ni/Pd surface for comparison. In each case 6 chips were shear tested. The results are summarized in Figure 4.

For FP 4401 shear forces on all surfaces in initial state were >25 N/mm². The requirements of the MIL-883 standard of at least 3.5 N/mm² were clearly exceeded. The shear result was typically a break in the interface glob top/Ag metallization or a break in the chip. After the temperature treatment shear strengths were even higher, possibly as a result of additional curing. Humidity storage did not have a strong effect on the shear strength.

The samples with Amicon 50300LT reached shear forces of up to 20 N/mm² in initial state, which is lower than the shear forces of FP 4401 but sufficient to fulfill the MIL-883 standard requirements. A typical shear result was a break in the interface glob top/immersion Ag or a break in the chip. After storage in 85°C/85% r.H. a significant number of breaks in the interface glob top/chip combined with lower shear forces was determined. This indicates that the humidity weakened the interface of the glob top material to the chip. After temperature storage shear forces were significantly higher. This is an indication of post curing. The curing time value of this manufacturer's data sheet should be increased for optimized adhesion.

The requirements of the MIL-883 standard were fulfilled under all conditions. Both materials are well-suited to COB encapsulation processes in terms of adhesion strength to the immersion Ag surface.

10 Reliability

Samples of manufacturers 1, 3 and 4 were used for the reliability investigations. Manufacturer 2 was not considered because of the poor bondability in initial state.

IZM test chips with AlSi1Cu0.5 metallization were die-bonded and then wire bonded. In a next step, half of the samples were encapsulated.

The reliability tests included:

- Storage at 150°C
- Storage at 85°C/85% r.H.
- Temperature cycling -55/+125°C (encapsulated samples only)

Even encapsulated samples could be checked for broken wires using the IZM test chips in combination with the special layout of the PCBs by means of daisy-chain measurements. Bond lift-offs and heel breaks can be detected this way.

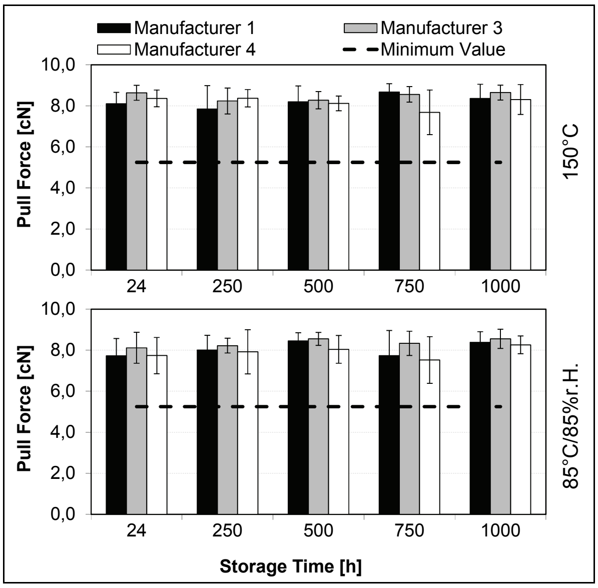

Figure 5: Results of reliability investigations on unencapsulated samples, n > 60

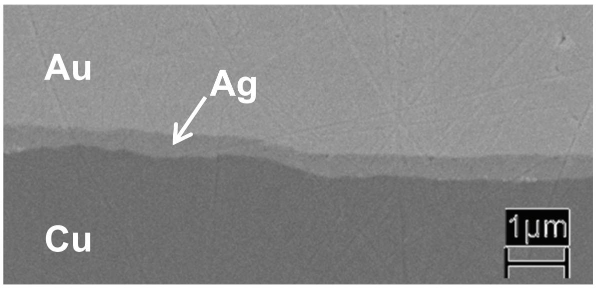

Figure 6: Bond interface after storage at 150°C for 1000h (Manufacturer 1)

Reliability of unencapsulated samples

Unencapsulated samples consisted of 3 chips. The wire bonding parameters for the chip were optimized. The parameters for the substrate were adopted from the investigations of the PCBs in initial state. Samples were removed from the storage chambers after 24, 250, 500, 750 and 1000 hours. At least 20 wires of each chip were destructively tested by pull testing, and thus for every manufacturer and every storage interval at least 60 wires were included in the test. The results are depicted in Figure 5.

No significant decline of the measured pull forces was detected for any manufacturer after storage at 150°C or after storage at 85°C/85% r.H. for up to 1000h. Average pull forces were well above the required minimum value in initial state. No individual values were below 4 cN. Neck breaks above the ball predominated for all manufacturers.

Despite the fact that bond degradation was not measurable the surface of the Ag metallization of all manufacturers showed strong discolorations especially after storage at 150°C. This brownish covering was clearly visible in SEM images [5].

The analysis of cross sections of the initial and the final states showed intact bond interfaces. No sign of degradation could be found (Figure 6).

Intermetallic phase growth or Kirkendall voids were not observed, which was expected due to the complete miscibility of Au and Ag in solid and liquid state.

Furthermore, the Ag and Au did not merge, which was also expected due to the low homologous annealing temperature. The thickness of the Ag films remained the same prior to and after temperature treatment.

Reliability of encapsulated samples

The Ag metallization of manufacturer 3 was selected for the reliability investigations on encapsulated samples. 6 IZM test chips were placed on each board, which were then wire bonded with optimized bonding parameters and then encapsulated using both glob top materials.

In regular intervals during the reliability tests daisy-chain measurements were carried out on multiple samples to detect possible lift-offs or heel breaks by an increase in total resistance. A significant rise in resistance could not be detected even after 1000h at 150°C or 85°C/85% r.H. or 1000 temperature cycles -55/+125°C [5]. This demonstrates that lift-offs or heel breaks did not occur.

11 Summary

This article examined the suitability of Ag surface finish for COB technology, using finishes from 4 different manufacturers.

First, bondability was determined in the initial state. The samples of manufacturers 1, 3 and 4 all yielded bonds of sufficient quality in a broad parameter range. The circuit boards of manufacturer 2 had a very small processing window and varied greatly from substrate to substrate. For this reason, they were not included in the subsequent wire bonding analysis.

The tests after storage in nitrogen showed excellent bondability in a wide bond parameter range, even after 4 months storage. Samples stored in air were able to be processed at sufficient quality within 2 months.

Pretreatment by temperature that corresponded to adhesive bond curing (20 min, 120°C) did not significantly affect bondability. Reflow processing using a standard lead-free profile (peak: 254°C) in nitrogen also showed only minimal changes in bondability. Reflow in air led to slight degradation of the bonding results for the samples of manufacturers 1 and 3, and to non-bondability for the samples of manufacturer 4.

The encapsulation experiments proved that both materials could be. No difference was observed between the surface finishers.

The subsequent reliability tests on encapsulated and unencapsulated assemblies showed that 150°C temperature storage and temperature humidity (85°C/85% r.H.) for up to 1000 h did not lead to failure or degradation of the joints in either variation, although particularly for the temperature storage of unencapsulated assemblies a clear change in Ag surfaces and the circuit board material was observed. Furthermore, the encapsulated samples were subjected to temperature cycles of -55/+125°C; no failures occurred, even after 1000 cycles.

The experiments prove that immersion Ag on Cu circuit boards has the following characteristics:

- Good bondability with Au wire in the initial state (for 3 of the 4 surface finishers)
- Good bondability after storage in nitrogen
- Good bondability after storage in air for a maximum of 2 months, but no bondability after 4 months storage in air
- Good bondability after gluing and soldering in nitrogen
- Limited bondability after soldering in air
- Processability of sufficient quality for die attaching by means of gluing and soldering
- Processability of sufficient quality with the use of conventional encapsulation materials
- Excellent reliability for unencapsulated and encapsulated components

These characteristics show that immersion Ag is a finish superbly suited to processing in COB technology and has long-term reliability, as long as the general requirements for wire-bondable circuit-board surfaces, such as trace evenness, minimal roughness and a good ratio of trace height to width, are ensured.

12 References

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