Alternate Metal Finishes for Wire Bond and Soldering Applications

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Abstract

With the continual miniaturization of interconnections on printed circuit boards, the use of micro-attachment is becoming more and more popular. The use of semiconductors and multichip modules are now quite commonplace and as a result the practice of wire bonding is now being employed on many assemblies. Historically the accepted pad finish used for successful wire bonding has been either electroplated gold over nickel or electroless nickel followed by immersion gold. With the industry trend to use more of this technology, both circuit board assemblers and board fabricators have been searching for lower cost alternatives. Along with the gaining popularity of direct chip attachment, the utilization of ultra fine pitch devices has pressed the limits of Hot Air Solder Leveling to provide flat, planar surfaces for consistent component placement and reliable assembly.

This paper discusses the feasibility of using an immersion organo-metallic silver coating as an alternative to nickel/gold for wire bonding applications as well as providing an excellent finish for surface mounting and typical through hole assembly. The test results for solderability and demonstrated wire bond performance are discussed for the circuit board assembler. The process chemistry and the process advantages are also detailed for the board fabricator. These include increased yields, reduced costs and the elimination of solder mask incompatibility issues that are associated with nickel/gold processes.

Introduction

Wire bonding offers a fast, reliable means of providing interconnections to a printed circuit board. With the pitch of electronic components becoming finer and denser it is only logical that this method of attachment will become very popular. Bonding to gold has long been deemed the only acceptable substrate for providing reliable bonds as it is not susceptible to interface corrosion or intermetallic formation. However, it is strongly affected by contamination and plating impurities as well as porosity that can impede bondability. For the PC Board fabricator there have been concerns of the long process sequence as well as the cost effectiveness of providing a consistent nickel/gold surface. For the assembler there is also some debate of the effect of gold on overall solderjoint reliability. Also of some concern using selective electroless nickel/immersion gold processes is the random breakdown of alkaline developable photoimageable soldermask. Recently considerable work has been done investigating the use of electroless nickel/palladium and immersion palladium over copper for wire bonding and soldering applications. This technology seems slow to be accepted as the process sequence is as lengthy as electroless nickel/immersion gold and there appears to be little cost savings. There is also little history of the metallurgy of wire bond formation, solder joint reliability and any of the failure mechanisms using palladium in these applications.

The use of silver in microelectronics is well documented as silver has been used as the base substrate for bonding to semiconductor leadframes and thick film hybrids for many years. Silver has also been used as a substitute for gold wire for ball bonding integrated circuits. It has shown to be effective providing strong sound bonds with both gold and aluminum. The concern of silver wire bonding has been oxide/sulfide formation during storage prior to wire bonding and ensuring adequate cleaning. Silver is also used in a variety of other electronic applications from soldering alloys, contacts and widely researched for use in lead free alloys.

A new silver based coating has been developed that provides flat planar pads for surface mounting and has shown evidence that it provides excellent wire bondability for direct attachment. It is coupled with a very thin (10 Angstroms) organic inhibitor that provides excellent thermal stability and eliminates any oxide formation during storage.
For the assembler this dispels any concern for silver migration. For wire bonding this ensures a sulfide free surface that is readily bondable and possibly may eliminate or significantly reduce the plasma cleaning operation.

Process Information

The silver plated coating is applied selectively onto exposed copper circuitry by a simple three step process. In the first step, boards are chemically polished to produce a bright, shiny copper surface. This is critical to provide the necessary topography and aesthetic appearance to the silver deposit as well as the proper surface to initiate successful wire bonds. After a water rinse, boards are treated in a pre-conditioning bath which removes oxide from the copper, and leaves the surface in the optimum state for plating. From the conditioning bath, boards are transferred directly into the plating bath. A dwell time of 1-3 minutes in the plating bath, which operates at 35-50°C and neutral pH, is then required to produce the required thickness of silver deposit. The resultant deposit is extremely hard, grain refined and robust despite the thin overall coating thickness.

Coating proceeds by a simple displacement plating reaction, with copper displacing silver ions from solution:

$$Ag^{+}_{(aq)} + 1/2\, Cu_{(s)} \rightarrow Ag_{(s)} + 1/2\, Cu^{2+}_{(aq)}$$

The coating thickness has been measured as a function of time by Auger depth profiling (figure 1.) For optimum coating performance, the silver thickness should be about 0.08 to 0.16 µm. At a thickness below 0.04µm, the shelf life of the coating will be decreased. The use of a coating thickness higher than 0.16µm has no beneficial effect for soldering applications, and increases both the running costs and coating time of the process.

Additional thickness may be required for some direct attachment applications and a thorough process study will dictate the optimal thickness. The process is designed to be utilized in horizontal conveyorized wet processing equipment to provide high throughput and will increase productivity when compared to nickel/gold processes.

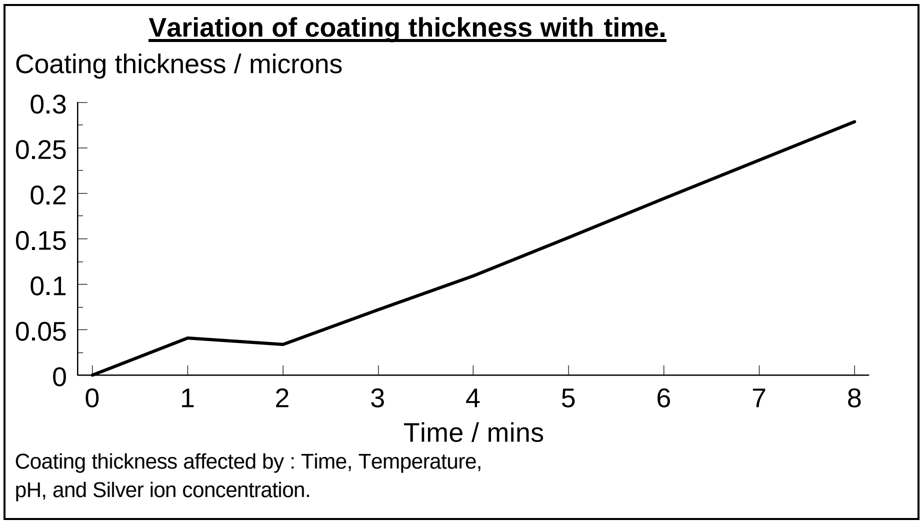

Figure 1

Silver surfaces are readily tarnished, which in preliminary work was found to affect solderability. To overcome this, an organic inhibitor system is included in the plating bath to protect the silver surface. The inhibitor co-deposits with silver to produce a hydrophobic layer on top of the silver. This layer increases the tarnish resistance of the coating during storage and assembly, and helps preserve the coating's solderability. This coating will be an essential element to ensure consistent wire bonds.

SIR & Electromigration Testing

Silver migration under the influence of an applied potential is well documented [1,2]. Migration occurs readily under conditions of high temperature and humidity due to the relatively high solubility of silver oxide in water. The presence of a hydrophobic inhibitor layer on the silver plated surface inhibits both silver oxide formation and its dissolution in water, effectively preventing the occurrence of silver migration.

SIR and electromigration tests have been carried out on silver plated boards. SIR testing was carried out using the method of IPC-SF-818. Boards were subjected to an 85°C/85%RH environment with an applied potential of 50 V for 7 days. The resistance values for both bare copper control and coated boards are shown in figure 2. No significant drop in resistance for either the silver coated boards or the control panels was observed over the duration of the test. After removal from the cabinet, all boards were tarnished, but there was no evidence of any dendrite formation when examined under a microscope at x10 or x40 magnification.

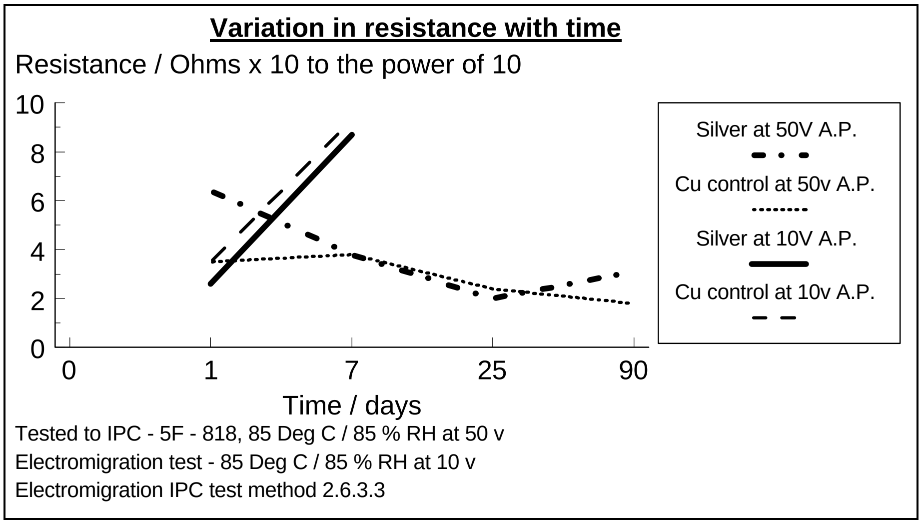

Figure 2.

Similarly, electromigration testing was carried out using an applied potential of 10 V in an atmosphere of 85°C/85% R.H. for 7 days. No significant drop in resistance was recorded (figure 2), and no evidence of silver migration was observed when the boards were examined under a microscope.

Utrasonic Wire Bonding

Ultrasonic wire bondability of silver plated boards has been assessed using AlSi1% 25µm wire. This work was conducted by a leading European telecommunications company. Boards were bonded after subjecting them to the following pre-treatments:

1. No pre-treatment.
2. 150°C, 1 hour.
3. 150°C, 1 hour + 275°C , 9 min.

Shear tests were then carried out to determine the bond quality. Values for the shear tests are presented in figure 7 & table 6. To fulfill the requirement of a good bondable surface, the minimum acceptable value for the shear force is 20 cN, with a standard deviation of less than 3 cN. As can be seen from the figure, the shear forces were significantly higher than the required minimum value after each of the pretreatments, indicating that the surface is acceptable for wire bonding. While this work provided data that shows evidence that this coating will bond with aluminum wire, another course of study has been engaged to evaluate gold wire bond effectiveness. As of this paper's publication, no data is available to report and will be published in a later paper.

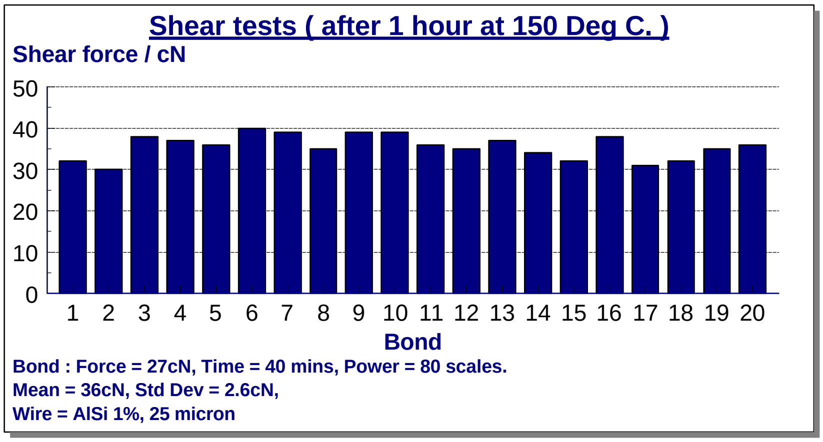

Figure 7

Wire Bonding Data

Pretreatment	**Mean Force (cN)**	**Std. Deviation**
None	32.0	1.9
150 ºC, 1 hr	36.0	2.6
150 ºC , 1 hr + 275 ºC,9min	39.1	3.2

Table 6.

Soldermask Compatibility

Alkaline developed photoimageable soldermasks have proven to be somewhat troublesome in withstanding the rigors of processing through electroless nickel and immersion gold. This has been attributed to the electroless nickel process which operates at extremely high pH and operating temperature and the relatively soft pencil hardness of these masks. The electroless nickel plating bath softens the mask at the laminate interface causing lifting or erosion of the mask. The silver process by virtue of its operation at nearly neutral pH and low operating process temperature eliminates any opportunity for attack. The process has been tested with all popular alkaline developable materials and has not shown any evidence of attack or degradation through the process.

Meniscograph Studies

Preliminary solderability investigations were carried out using an Alpha GEC meniscograph to compare solder wetting characteristics of copper coupons coated with silver, bismuth, nickel-gold and two of the third generation organic coatings based on substituted benzimidazoles (organic A and organic B). Two fluxes, Alpha Quantum (no-clean type) and a standard RMA flux (IEC Standard. 68-2-20), were employed to investigate coating properties after aging under a variety of conditions. Standard 63:37 alloy solder was used. Results presented are of the solder wetting force recorded two seconds after immersion of the sample into the solder pot. This was chosen to give a value representative of the solder wetting force which should be experienced on a board during contact with a solder wave.

Samples were tested as prepared, and after passage through three solder paste reflow profiles. The two organic coatings and silver initially show comparable solder wetting forces, which are considerably higher than nickel-gold. After passage through 3 reflow passes, the wetting force for silver shows little change. Cycled using the same conditions, both organic coatings show a considerable decrease in wetting force, indicating that degradation of the organic layer occurs during passage through reflow.

Further samples were aged at 40°C/95%RH for 96 hours prior to testing as above. Artificial aging has little effect on samples soldered without further heat treatment. However, after subsequent passage through three solder paste reflow profiles silver shows a slight drop in wetting force from 0.266 to 0.253 mN/mm, but both organics show a significantly larger degradation in wetting ability. A similar pattern of results are seen with the RMA flux. Silver shows a consistent high level of solderability, which is not affected either by passage through reflow, or by accelerated aging at 40°C/95% R.H. The solderability of nickel-gold is significantly lower under all of the test conditions, with organic B falling mid-way between the two. Results for all of these samples are presented in figures 3 & 4.

These meniscograph measurements show that the Silver plated finish retains a high level of solderability after passage through multiple solder paste reflow profiles, and also after accelerated ageing under conditions of elevated temperature and humidity. Under the same conditions, the leading organic coatings, and Ni/Au show a drop in solder wetting force, which if experienced in production could cause a reduction in assembly yields. Surprisingly, results were similar using both no-clean and RMA fluxes.

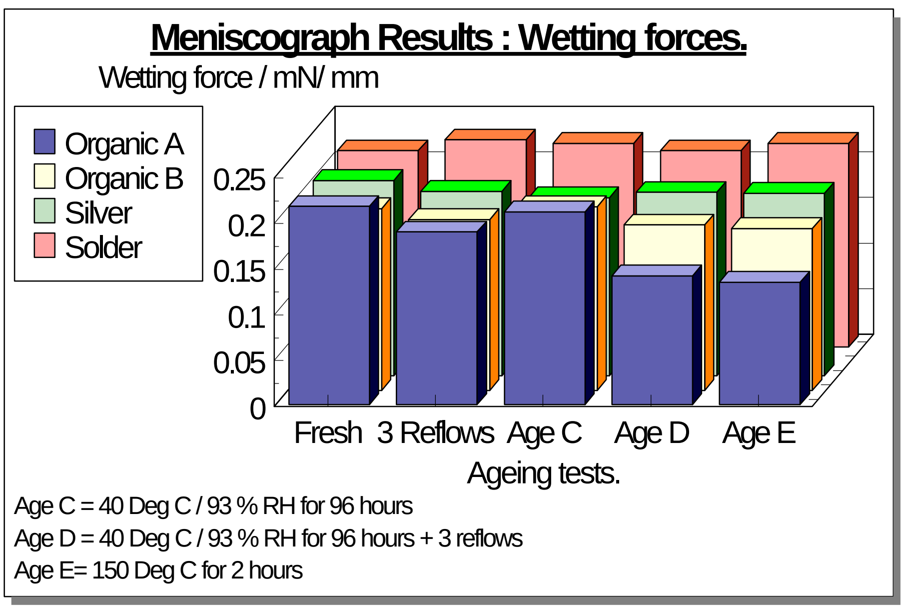

Figure 3.

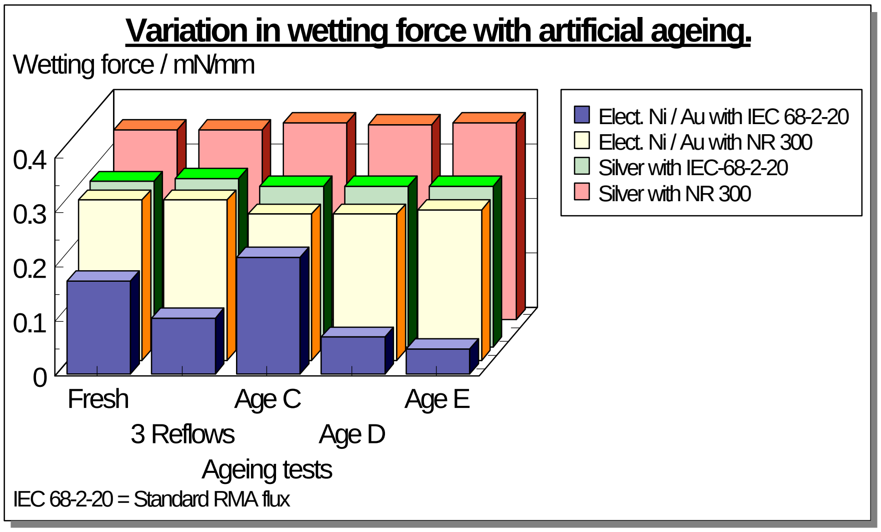

Figure 4.

Wavesolder- Assembly Testing

Meniscograph measurements provide an indication of the level of solderability of a surface. However, there is some debate as to how well these results translate into wavesoldering and reflow solderability. Wavesoldering and paste reflow trials have also been carried out by a number of independent sources, to give a more reliable indication of coating performance.

Wavesoldering trials were carried out by a major computer manufacturer to determine the hole filling ability of silver coated boards. The following test method was employed.

1. Steam age half the test boards for one hour.
2. Pre-condition boards: 2 I.R. reflow passes in air.
3. Apply Alpha NR325F flux.
4. Wavesolder in air.
5. Inspect for hole fill.

Table 2 compares the percentage of holes filled on boards coated with silver, Organic A and HASL. Holes were considered to have filled if the solder wicked up at least as far as the rim on the top side of the board. Eight boards of each type were prepared, of which half were steam aged. Each of the boards was populated with 762 plated through holes.

COATING	PERCENTAGE HOLE FILL	
	No Aging	**Steam Aged**
Silver plated	99.97	99.90
HASL	100.00	99.97
Organic A	93.57	92.62

Table 2

Results show the silver to give excellent hole filling, which is comparable with HASL, even after steam aging. The hole filling results for silver and HASL were considerably higher than for the organic.

Solder Joint Reliability

In order to verify the above, a joint reliability study was initiated and boards were assembled utilizing the silver coating . A mechanical deflection stress test was used [4]. Six cards were used for each coating, each containing 8 CBGA modules. Solder paste volume for the modules was 4600 to 5000 cubic mils. The mean lives to 50% joint failures are shown in table 5.

There is no significant difference in the performance of any of the samples in the matrix.

Coating	Mean Life (N50, # Cycles)
HASL	1194
Organic A	1095
Silver	950

Table 5.

Lead-Free Alloys Compatibility

There are three binary low temperature alloys which have been studied intensively- Sn:3.5Ag, 42Sn:58Bi and 52In:48Sn , and several others which may be of future interest including Sn:0.7Cu [3] .

Preliminary investigations have been carried out to determine the compatibility of silver with Sn:3.5Ag and Sn:0.7Cu. Meniscograph solderability measurements have been carried out with Sn:3.5Ag using Alpha NR300F and a standard RMA flux. The solder bath temperature used was 271°C. Boards were pre-conditioned using the same thermal and accelerated aging conditions as for the work with standard solder discussed earlier in this paper.

It was found that silver solders well with both flux types, the wetting forces in all cases with Sn/Ag being substantially higher than those recorded with Sn/Pb at 250°C in the earlier work. This indicates that silver is an ideal solderable finish to use with Sn:3.5Ag solder.

Preliminary wavesoldering trials have been carried out using Sn:0.7Cu under an atmosphere of nitrogen. In these trials good solderability was achieved using Alpha 351F no-clean flux.

Conclusion

Immersion silver appears to be an excellent, low-cost alternative to nickel/gold and offers excellent potential for reducing process time for increased productivity and ultimately lower costs. In addition, it provides the capability for wire bonding for use with high density assemblies. It also provides pads that are planar, conductive (not insulative) surfaces that meet the rigid requirements for fine pitch assembly. Further advantages are consistent pin testability & visual inspection capability. The silver finish is not water or solvent-soluble and therefore does not lose solderability during aqueous cleaning or re-work of solder paste misprints, a common problem with organic based coatings. It is highly-compatible with alternative lead-free solder alloys. This new technology bridges the gap between organic imidazole based coatings and HASL and provides the functionality of nickel/gold without the extended process requirements or cost.

References

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