Reliability Tests of Aluminium Wedge Wire Bonding on Auto-catalytic Silver Immersion Gold (ASIG) PCB Metallization

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The Auto-catalytic Silver Immersion Gold (ASIG) PCB metallization is a new process that has clear advantages for PCB assembly especially with regard to lead-free soldering. As it may become a popular process in the future for electronics used in physics experiments, the quality of this metallization for aluminium wire bonding has been studied. Aluminium wedge wire bonding continues to be the interconnection method of choice for many physics detector sensors, for high density signal routing and for unpackaged die. Although advertised as having good quality for aluminium wire bonding, this study was performed to verify this claim as well as to test the longer term reliability of the wire bonds taking into consideration the environmental conditions and life-expectancy of devices, in particular for high energy physics detector applications. The tests were performed on PCBs made with the ASIG and ENIG (Electro-less Nickel Immersion Gold) processes at the same time in order to make a comparison with the current industry standard ENIG metallization process used for aluminium wire bonding on PCBs.

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1. Introduction

In this study we compare the aluminium wire bonding quality on two PCB metallizations, the Auto-catalytic Silver Immersion Gold (ASIG) [1] process and the Electro-less Nickel Immersion Gold (ENIG) [2] process. The ASIG process is a relatively new process which has the advantage of allowing for a lower soldering temperature when using lead-free solders. The ENIG process is the industry standard metallization used when aluminium wedge wire bonding to the PCB is required. The ENIG process is also compatible with both gold ball wire bonding although this technique is much less used owing to difficulties coming from the heating (typically 150°C) of the substrate required for good quality gold ball bonding. The ASIG process is claimed to also be compatible with both types of wire bonding. Because this ASIG process is new and has no long-term history in use, the quality of newly fabricated PCBs as well as the longer-term reliability should be assessed. In this study we address the quality and reliability of the ASIG metallization for aluminium wedge wire bonding because this is the interconnect technique used most widely for high energy physics experiment applications. However, the results should apply to other applications using aluminium wedge wire bonding to ASIG PCB metallization.

2. ASIG and ENIG PCB metallization

2.1 A short description of the ASIG PCB metallization used in this study

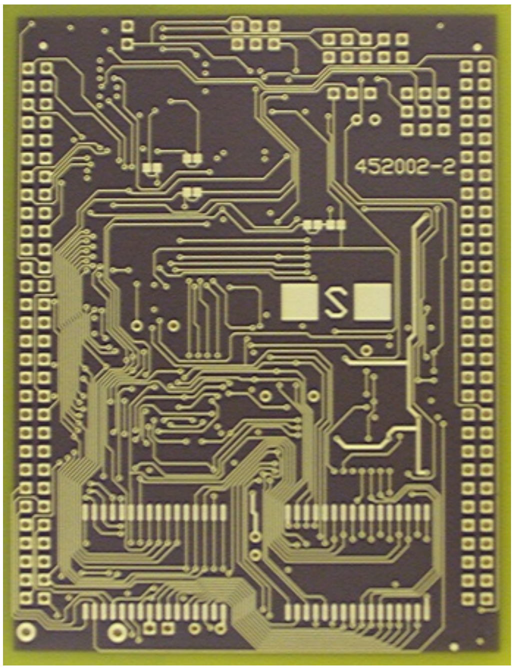

Figure 1: ASIG PCB used in tests

The ASIG PCBs used for this study were manufactured by GS Swiss PCB AG of Switzerland. The process first became commercially available in 2010. These were measured by the manufacturer to have metal thicknesses of: Cu 35-40 μm, Ag 0.17 μm and Au 0.026 μm. The thickness of the gold and silver recommended by the founders of the ASIG process is not well defined. What can be found in the documentation and presentations on the subject are <0.03 μm for gold and anywhere from 0.1 to 1.0 μm for silver. It appears that the thicknesses are to be adapted by the PCB manufacturer as they see fit. The PCB cicuit had metal layers on both sides of a FR4 substrate with through plated holes and through vias but no intermediate metal layers and no soldermask layers. The FR4 thickness was 1.5 mm and the PCB size was 70 mm x 90 mm. A photo of this PCB is shown in figure 1. The metallization pattern was that of a commercial product which had sufficient numbers of large pad areas that allowed for the roughly 200 wire bonds needed for this study. The PCBs were shipped to CERN immediately after fabrication.

2.2 A short description of the ENIG PCB metallization used in this study

The ENIG PCBs used for this study were manufactured by ELTOS of Italy. These were measured by the manufacturer to have metal thicknesses which are fairly standard for this process: Cu 35-40 μm, Ni 3.9 μm and Au 0.08 μm. The PCB circuit was similar but not identical to that of the ASIG PCB, the main difference being that the FR4 thickness was 1.0mm with a size of 70 mm x 85 mm. In addition, there was a soldermask layer on both sides of the PCBs, and the metallization pattern was different. However, there was ample metal pad areas for the wire bonds. A photo of an ENIG PCB is shown in figure 2. The PCBs were shipped to CERN immediately after fabrication.

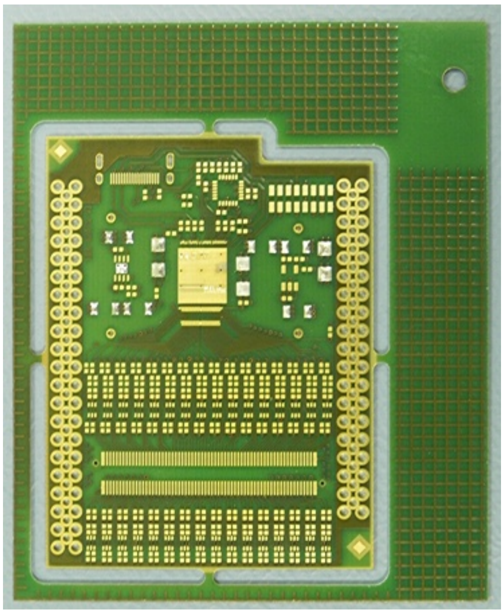

Figure 2: ENIG PCB used in tests.

3.The testing procedure

The following two types of reliability tests were performed: accelerated aging, corrosion via humidity plus thermal cycling. Two identical circuits made on the same plate were used for each of the ASIG and ENIG PCBs. One circuit was used for the accelerated aging and the other served for the corrosion via humidity plus thermal cycling test. In order to best simulate the typical processing of a PCB used in a physics experiment front-end electronics application requiring wire bonding, all circuits had the following preparatory steps:

1) Visual inspection and documentation of visual aspect as well as other non-standard features.
2) Wire bond parameter optimization (if needed). These parameters are thereafter used for all wire bonding. Wire bonding done with the same Delvotec 6400 machine using 25μm Al wire with 1% Si.
3) Wire bond pull testing.
4) Drying in oven for 12 hours at 125°C
5) Application of solder paste (leaded) in a few places to simulate component loading.
6) First solder cycle in CERN vapour phase oven (leaded cycle: 230°C maximum).
7) Application of solder paste on reverse side to simulate component loading.
8) Second solder cycle (same cycle as in step 6).

9) PCB cleaning cycle in machine using Zestron cleaning product (1hr @ 105°C dry cycle).
10) Visual inspection.
11) Wire bond application (about 100 wires) followed by pull testing of one group of 10 wires.

A very basic check of the solderability of the ASIG and ENIG circuits were performed by observing after the soldering cycles the correctness of solder appearance and coverage of the areas that had solder paste applied. The result showed correct solder appearance and adherence for both types of metallization and thus it was felt that these samples could be considered to have normal solderability.

3.1 Accelerated aging test procedure

All aging tests will be referred to an ambient temperature of 20°C. The first bonding test was performed immediately after receiving the PCBs from the manufacturers and will be considered to be the reference starting time of t=0. The soldering cycles of the ASIG PCBs occurred after nearly 8 months of storage at T=20°C and therefore this amount of additional aging should be taken into account. The soldering cycles of the ENIG PCBs occurred within about 1 month and therefore had about 7 months less aging.

The soldering cycles and cleaning cycle expose the PCBs to high temperatures for a relatively short time (minutes at 150°C-230°C for the soldering and an hour at 105°C for the cleaning) but nevertheless the effective aging at T_0=20°C=293°K should be considered. For this and all subsequent accelerated aging tests, we use the standard acceleration factor (AF) for chemical processes derived from the Arrhenius model:

$$AF = \exp (E_a \text{ x } B \text{ x } (1/T_0 - 1/T_{hi}))$$

which assumes an activation energy (E_a) of 0.6 eV based on the assumption of an electromigration failure mechanism. B is the inverse of the Boltzmann constant and has a value of about 11604 in units of °K/eV. The two soldering cycles correspond to roughly 20 days of aging at ambient temperature and the drying cycle of the cleaning machine adds another 9 days so the total aging time of the soldering plus cleaning steps is about 29 days. Therefore the effective aging time between the initial bond pull tests of the newly received PCBs and the post-solder and cleaning cycle pull tests was about 9 months for the ASIG and 2 months for the ENIG.

After the soldering and cleaning cycle, a large number of wire bonds were placed in order to measure the degradation of the connections with aging. We call these wires the connection aging test wires. In addition, each time an aging cycle was performed, a small number of wires were added in order to assess the change in quality of the surface for new bonds (surface aging test wires) as a function of aging.

The accelerated aging test procedure went as follows:

1) PCBs placed in climatic chamber at T=140°C for a specified duration
2) PCBs removed and visually inspected

3) Pull test performed on connection aging test wires
4) New wires added (if possible) and pull tested.

Four cycles of aging were performed corresponding to 100 days, 2 years, 3 years and 4 years of ambient temperature aging. Thus, at the end of these tests, the effective aging time was approximately 10 years for both ASIG and ENIG PCBs although the ASIG always had 7 months more aging than the ENIG.

3.2 Corrosion plus thermal cycling test procedures

3.2.1 Explanation for corrosion testing

Previous studies with silver as the main substrate for bonding with aluminium wire showed a frequent tendency for severe corrosion of the aluminium caused by the presence of chlorine and humidity [3]. The chemical reaction is well understood and because the chlorine acts as a catalyst and becomes available again at the end of the reaction, this corrosion can continue indefinitely as long as water is present. The reaction transforms the aluminium into aluminium hydroxide, which has a fine crystal like appearance. If the reaction is very limited, one finds traces of crystal whiskers around the wires and sometimes residue "halos" on the PCB surface near the wire bond connection. In cases where the reaction is very strong (high concentrations of chlorine for longer periods of time) the result can be a pile of crystals where the wire used to be, as shown in figure 3. The corrosion test was devised to check for this type of corrosion problem.

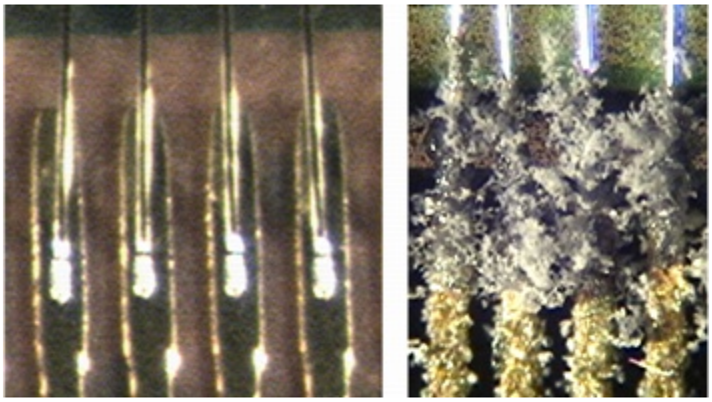

Figure 3: On the left, pristine wire bonds with feet on PCB pads. On the right, the same after chlorine corrosive attack.

3.2.2 Procedure for high temperature and high humidity accelerated corrosion

As for the accelerated aging test procedure, a large number of test wire bonds were placed in order to measure the degradation of the connections with humidity/heat/thermal cycling and to allow for detecting the presence of corrosion attack to the aluminium wires. In addition, wires were added between test cycles in order to monitor the surface degradation for new wires. The corrosion and thermal cycling test procedure went as follows:

1) PCBs placed in climatic chamber at specified temperature, relative humidity (RH) and time
2) PCBs removed and visually inspected
3) Pull test performed on connection aging test wires
4) New wires added (if possible) and pull tested.

Three cycles of temperature/humidity were performed, the first at T=55°C for 1 hour, the second at T=85°C for 20 hours and the third at T=85°C for 47 hours. All were run with an RH of 90%. Using the standard acceleration factor for corrosion as a function of humidity [4] :

$$AF = (RH_0/RH_{high})^{-2.66}$$

The combined effect of humidity and temperature is achieved by taking the product of the AF for humidity above and multiplying by the AF for temperature which is the formula given in section 3.1. Thus the three cycles correspond to 1 week, 3 years and 7 years of accelerated corrosion.

3.2.3 Procedure for thermal cycling accelerated corrosion

After the above accelerated corrosion test which produced no visible chlorine corrosion of the aluminium wires, a more aggressive set of tests were added in order to see if the presence of liquid water on the PCB surface would induce the chlorine corrosion reaction. This was added because of previous experience which showed that such reactions sometimes occurred in the presence of liquid water but which did not occur in its absence in spite of having extremely high humidities and temperatures. The method used to obtain the liquid water on the surface was to perform moderately rapid thermal cycles from -30°C to +80°C with no humidity control. In such a case, enough humidity would be present in the chamber such that during the heating part of the cycle, the PCB would remain colder than the air and more specifically below the frost or dew point such that frost or condensation would develop on the surface. This condensation would remain on the surface for the entire heating to +80°C and then the water would evaporate after a few minutes at +80°C. The thermal cycling procedure involved 1 cycle followed by visual inspection, then an additional 10 cycles followed by visual inspection and bond tests of new wires, then finally another 10 cycles followed by visual inspection and bond tests of new wires.

3.3 Wire bonding and pull test procedure

A standardized procedure was followed for the wire bonding and pull testing. In all cases the wire bonding was performed with the same Delvotec 6400 automatic bonding machine, the same wire and using the same machine parameters. This includes using a fixed wire length of 1.5 mm and a wire loop that would allow for a 30 degree angle of the wire to the PCB surface during the pull test. In all wire bond pull tests a minimum of 10 wires were pulled. A DAGE 4000 pull tester was used with the same test parameters for all testing. The mean and RMS of the sample of wires in each test was recorded as well as the statistics of the wire break failure mode. Note that the bonding machine was checked for correct and consistent bonding by making and testing bonds made on a known good substrate. Figure 4 shows typical bond wires as viewed through the pull tester microscope.

In general, an acceptable quality in a standard bond pull test for a high reliability physics experiment application would be:

1) no failure to make bonds during the bonding of the test wires (or less than 1% if 100 or more wires are made)
2) mean pull strength of >8g and and RMS of <1g
3) at least 75% heel breaks or mid-span breaks

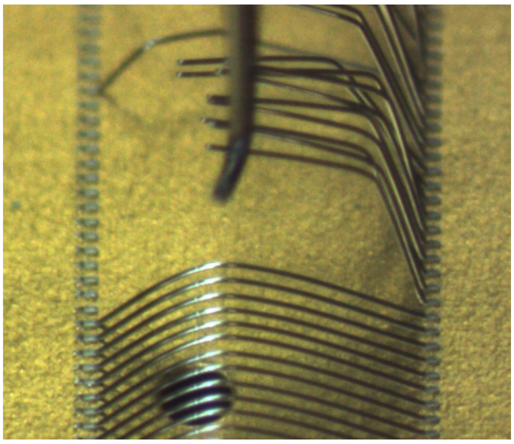
Figure 4: Example of bond wires made for pull testing on one the PCB samples. The pull tester hook as well as tested (broken) wires can be seen in the upper part of the photo.

Note that a "typical" good quality bonding surface would result in no failures in bonding (<<1%), a mean pull strength of 10-12g, an RMS of <0.5g, and >95% heel or mid-span breaks. The last criteria refers to the way in which the bonded wire breaks or yields from the substrate during the pull test. The possibilities are a heel break (the wire breaks leaving the "foot", i.e. flattened welded portion behind), a bond lift (the wire, including the foot is pulled off of the substrate), and a pad lift (the wire, foot, and a layer of the substrate metal is pulled off the substrate). The 2nd and 3rd cases are often combined into a single category know as "lifts". These categories can apply to either the first bond or the second bond made for each wire. There is one final category known as the mid-span break where the wire breaks somewhere in the middle of the loop, usually directly over the hook since that is a point of high stress on the wire during the pull test. A mid-span break is very unusual and occurs either because of a defect or damage to the wire itself (in which case the pull strength is low) or because the two bond welds at each end of the wire are extremely strong such that they exceed the tensile strength of the wire itself (in which case the pull strength is very high). The tensile strength of a 25um aluminium wire is typically 14-16g whereas a very good pull strength of a bond weld is 12g. The most likely outcome of a good pull test is a 10-12g first bond heel break. The reason that the first bond is often slightly weaker than the second bond is because during the making of the second bond, the wire is moved around such that the heel of the first bond is flexed which can create some stress weakening.

4. Results of Accelerated Aging Tests

The accelerated aging tests were primary to measure the rate of metal migration in the PCB bondpads such that the surface layer became significantly degraded. The usual mechanism for this degradation is the diffusional migration of the base layer of copper through the layers above until the copper reaches the surface and oxides. The copper oxide is not easily removed during the wire bonding process and thus would inhibit bondability. Note that in the case of the ASIG and ENIG metallizations, the intermediately metal layer, namely silver and nickel respectively, can also migrate upward and oxidize or otherwise react with the other metals to form alloys that can degrade bondability. The above mechanisms that reduce bondability would therefore be detected either during the bonding of new wires after each aging cycle or in the bond pull tests of those wires. The other goal of the accelerated aging test was to measure the degradation in the quality of wires put in place before the start of the aging cycles. This test would signal the formation of intermetallics or corrosion either in the wire itself, in the weld, or in the metal layers underneath the weld. The most likely problem would be intermetallic effects such as Kirkendall voiding where the weld would be replaced by voids owing to migration of metal atoms from the weld. An example of a corrosion type effect would be the well known "black pad" which is an oxidation of the nickel layer in the ENIG metallization. Either of these effects would lead to reduction in pull test strength but in particular, one would expect a significant increase in pull test failures of the "bond lift" type.

The results of the accelerated aging test is summarized in Table 1. In the leftmost column is the process step or name of the evaluation test performed. The next set of columns are the results for the ASIG PCB sample and the final set of columns are for the ENIG PCB sample. The first line called "initial tests" include the tests performed shortly after receiving the PCBs. The visual inspection results, the result of placing the wire bonds, and the pull test results of wires just placed. The section "long term test" is not applicable for the initial tests, it applies only to the post solder cycle tests. The initial tests of both PCB metallizations were positive. No problems were observed in the visual inspection, placement of bonds went normally and the pull test results were good. The ENIG had better pull test results (higher mean and smaller RMS) but the values for the ASIG were adequate and both easily met the criterion of section 3.3.

Accelerated Aging	**ASIG**								**ENIG**							
			surface test wires wire pull test			long term test wires wire pull test					surface test wires wire pull test			long term test wires wire pull test		
	bondpad visual aspect	failures during bonding	mean (g)	RMS (g)	break type	mean (g)	RMS (g)	break type	bondpad visual aspect	failures during bonding	mean (g)	RMS (g)	break type	mean (g)	RMS (g)	break type
initial tests	OK	no	10.0	0.4	pass	N/A	N/A	N/A	OK	no	11.3	0.2	pass	N/A	N/A	N/A
solder cycle: equivalent aging from various heating cycles is about 280 days																
post solder tests	OK	SOME	variable results *			variable results *			OK	no	11.1	0.5	pass	11.1	0.5	pass
1st accel life (AF) test: 2.4h @ 140C = 100 days																
post AF test	reddish	YES	N/A	N/A	N/A	variable results *			OK	no	10.8	1.0	pass	10.1	0.5	pass
2nd accel life test: 17.6h @ 140C = 2 years																
post AF test	reddish	YES	N/A	N/A	N/A	variable results *			OK	no	11.2	0.3	pass	8.1	0.5	pass
3rd accel life test: 26.4h @ 140C = 3 years																
post AF test	reddish	YES	N/A	N/A	N/A	variable results *			OK	no	10.3	0.4	pass	6.9	0.4	pass
4th accel life test: 35.2h @ 140C = 4 years (total 10y)																
post AF test	reddish	YES	N/A	N/A	N/A	variable results *			OK	no	10.7	0.3	pass	7.0	0.3	pass
5th accel life test: 120h @ 160C = 30 years (total 40y)																
post AF test									OK	no	10.6	0.5	pass	6.0	0.2	pass
	variable results * = depending on location and visual aspect of bondpad, bonding quality varied from "unable to get bonds to weld" to "weld made but low strength and mostly lifts" to similar good results as for initial tests.													loss of strength above from known effect of wire aging		

Table 1: Comparison of ASIG and ENIG bonding results as a function of accelerated aging.

The soldering cycles involved several steps which involved heating of the PCB although for short time periods. There was a 12 hour bake-out step at 125°C followed by application of the solder paste on a few pads. Then there were two passes through the vapour phase oven which involved a cycle of approximately 5 minutes at around 140°C and 1 minute at around 230°C. Finally there was a machine cleaning step which included a dry cycle of 1 hour at 105°C. The equivalent aging was estimated to be 280 days from all these heating steps. Because the soldering steps are considered a standard process procedure for PCBs that are meant to receive devices for wire bonding, the state of the PCB after these steps is considered the "starting" or "reference" point for the aging study. However, since the soldering steps themselves constitute a significant period of aging because of the various heating cycles, it is important to look at the difference in the bonding quality before and after the soldering cycles. For the ASIG PCB there was a clear degradation in the bonding quality after the soldering cycles. At a few percent level it was not possible to successfully place the bonds. The bond pull test results showed a large variation in both strength and numbers of bond lifts. Since the test bonds were placed in various locations on the PCB this indicated a large variation in bonding quality a function of position on the PCB surface.

After the first accelerated life test which involved 2.4 hours at 140°C, the metal surfaces of the PCB showed a clearly reddish appearance. This is often an indication of copper oxide on the metal surface. This hypothesis was strengthed by the fact that all bonding surfaces were now unbondable with the standard bonding parameters. For this reason there are no surface test wire bonding results from this point onward. Surprisingly the wire bonds placed just after the soldering step remained at approximately the same level of quality. The results were still very dependent on the location; one could find sets of wires that gave acceptable results and other sets that gave unacceptable results. By contrast, the ENIG PCB showed no change in appearance after the soldering cycles nor after the first accelerated life test. It also showed no change in the bonding quality as well. After three more cycles of accelerated life tests that represented another 2, 3, and 4 years of aging, the total equivalent aging was therefore a little over 10 years at ambient temperature. For both the ASIG and ENIG PCBs there were almost no further changes observed. The ASIG remained unbondable for new bonds although the bonds placed just after the soldering cycles remained of similar highly variable quality. The ENIG remained of very good bonding quality although the pull strength of the wires placed just after the soldering cycles showed a slow decrease. However, this was expected because there is a well known annealing type effect on the aluminium wire itself from the heating at 140°C. The wire loses strength and therefore the wire will break at a lower value. What is important is that there was no sign of bond lift failures after the accelerated life tests. Such a sign would indicate a degradation in the weld for the original wires or degradation in the surface quality for newly placed wires.

In order to verify the hypothesis that copper oxide was on the metal surfaces of the ASIG PCB giving the reddish appearance, a sample of this PCB was sent to the CERN surface analysis laboratory for an x-ray photo-electron spectroscopy (XPS) surface analysis. The result of this analysis is shown in figure 5. The analysis shows that the most prominent metal on the surface is copper, although it should be gold or silver. The high concentrations of lighter elements (carbon, oxygen, etc.) can be ignored because they result from organic and other contaminants left on the surface from the handling, soldering process, or cleaning.

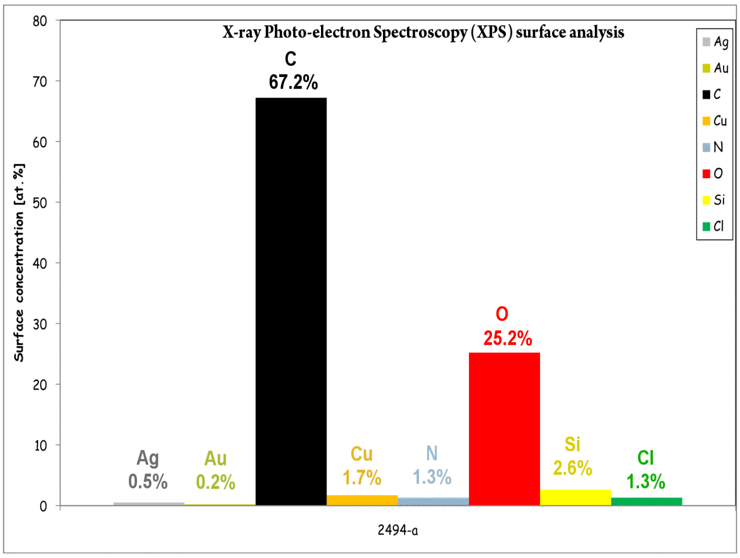

Figure 5: Surface analysis of an ASIG pad after accelerated aging.

The conclusion from the accelerated aging test was that for the ASIG PCB, there was a significant degradation in surface quality even after the soldering cycles and after the first accelerated life cycle (equivalent to 100 days) the surfaces were no longer bondable owing to presence of copper oxide on the surface. However, the bonds placed just after the soldering cycle remained of variable quality depending on the location of the wires on the PCB but no deterioration of the bond weld quality was noted as a function of aging.

5. Results of Corrosion Test

The results of the corrosion test are shown in Table 2. Both the static test using temperature and humidity as well as the thermal cycling test are included in the list of steps in this test. In the column "bondpad visual aspect" one would find the evidence of chlorine corrosion of the aluminium or evidence of corrosive attack on the pad metallization. Although some dark patches were observed on some bond pads of the ASIG test piece after the first temperature/humidity test, this did not seem to affect the bonding quality. It may have been some contamination on the surface as there was no further degradation observed in the much more severe tests that followed. The column giving the wire pull tests for "surface test wires" (wires added after each test step) is the more decisive measure of corrosion or other degradation of the substrate surface. It is only in this column for the ASIG sample does one observe a significant loss of bonding quality. This occurred after the 3rd temperature/humidity test which would represent a total of 10 years of aging. Although there was a loss of strength, more notable was the break type failure mode which showed a large fraction of bond lifts, hence the "fail" result in that test.

Corrosion Test	ASIG					ENIG				
			surface test wires					surface test wires		
	bondpad visual aspect	failure during bonding	wire pull test			bondpad visual aspect	failure during bonding	wire pull test		
			mean (g)	RMS (g)	break type			mean (g)	RMS (g)	break type
initial tests	OK	no	10.0	0.4	pass	OK	no	11.3	0.2	pass
post solder tests	OK	no	10.7	0.5	pass	OK	no	11.3	0.3	pass
1st temp/humidity (TH) aging test: 1h @ 55°C/90%RH = 7d										
post TH test	some darker	no	11.4	0.3	pass	OK	no	11.0	0.8	pass
2nd temp/humidity (TH) aging test: 20h @ 85°C/90%RH = 3y										
post TH test	no change	no	10.8	0.3	pass	OK	no	11.0	0.4	pass
3rd temp/humidity (TH) aging test: 47h @ 85°C/90%RH = 7y (total 10y)										
post TH test	no change	no	7.3	0.8	fail	OK	no	10.5	0.5	pass
1st corrosion accel therm cycle test: 1 cycle @ -30°C to +80°C										
post corrosion test	no change	no	N/A	N/A	N/A	OK	no	N/A	N/A	N/A
2nd corrosion accel therm cycle test: 10 cycles @ -30°C to +80°C										
post corrosion test	no change	no	8.9	0.5	fail	OK	no	10.9	0.4	pass
3rd corrosion accel therm cycle test: 10 cycles @ -30°C to +80°C										
post corrosion test	no change	no	10.1	0.7	fail	OK	no	10.9	0.3	pass

Table 2: Comparison of ASIG and ENIG bonding and corrosion results as a function of temperature and humidity aging followed by thermal cycle condensation formation.

The thermal cycles, which were primarily intended to produce liquid water on the metal surfaces in order to drive the chlorine-based corrosion, had no effect for either the ASIG or ENIG samples even after a total of 21 cycles (several days of testing). No signs of corrosive damage were observed on any sample. Note that although the pull test strength results were reasonably good, the break type failures on the ASIG samples remained, indicating a permanent degradation in the adhesion of the bond foot to the substrate.

The conclusion of the corrosion test was that the previous worries of chlorine traces left on the metal surfaces for the silver metallization (ASIG) were not observed. It appears that either the process has been changed at the producer such that chlorine is no longer left on the surface or the cleaning process used after the soldering step is effective in removing chlorine traces. The slight degradation in bonding quality observed for the ASIG sample is consistent with the metal migration expected from the heating cycles performed on the samples (soldering, drying, and high temperatures during the humidity test and thermal cycles).

6. Conclusion

The aluminium wedge wire bonding quality and reliability on the new ASIG PCB metallization has been studied in order to assess its potential for usage in high energy physics oriented front-end electronics applications. The bondability of the ASIG surface was compared to that of the ENIG surface which is the current standard PCB bondpad metallization. It was found that after the ASIG PCBs had some shelf life aging the surface had acceptably good bondability although slightly inferior in strength to the ENIG surface. However, immediately after typical soldering and cleaning cycles, the ASIG surface showed a high variability in bonding quality. In the worst case there were failures to weld during bonding and in the best case, no change compared to the original tests. The ENIG surface showed no changes, i.e. very good bonding results. After the first accelerated aging cycle corresponding to about 100 days at 20°C, the ASIG surface had changed appearance to a reddish color and was no longer bondable. A surface analysis showed clearly that copper had reached the surface, presumably from migration through the silver and gold layers. The ENIG surface had no change. Further aging cycles were performed in order to see if the wire bonds placed on the ASIG sample just after the soldering and cleaning steps would degrade in quality. The further aging was also of interest to see at what point the ENIG surface would show degradation. Note that at this point no bonds could be made to the ASIG surface, only pull tests on the bonds made after the soldering/cleaning steps could be performed. After accelerated aging equivalent to 10 years at 20°C, no degradation was observed for the original ASIG and ENIG bonds although the results for the ASIG tests remained variable (some areas OK, some areas failed the test). As both the old and new bonds on the ENIG surface remained good, a further aging test was applied to the ENIG sample only. After an equivalent of 40 years at 20°C in total, the old bonds showed a decreased strength that was expected since aluminium becomes more brittle with time at high temperatures. However, the new bonds showed no decrease in quality, indicating an impressive resistance to metal migration.

Unfortunately, the ASIG samples tested showed variable quality even before accelerated aging. This variability may be owing to small variations in the thickness of either the silver or gold. These results may indicate that a thicker silver and/or gold layer is needed for improving bondability. However, the very fast degradation of the surface with time showed that if one wanted to bond to this surface after an extended period of time (around one year), there would be significant degradation. It is not clear that even with a much thicker silver layer to impede the migration of the copper that this would resolve the issue, given the speed of degradation. This hypothesis would have to be tested. However, the ASIG metallization used in this study cannot be considered of sufficiently high quality and reliability to be recommended for most high energy physics applications that require aluminium wire bonding. It could be used if the bonding is done immediately after the soldering/cleaning step. However, it would rapidly become unbondable except if kept at low temperatures.

Finally, the previous worries about chlorine residues on the PCB that could lead to corrosive damage or destruction of the aluminium wire were not observed on these samples. It is not felt that this is a significant reason to avoid the ASIG process. However, it is felt that as for any PCB, a thorough cleaning should be undertaken after the soldering cycles in order to ensure that no corrosive residues remain.

7. Acknowledgements

The authors would like to thank the two companies (GS Swiss PCB AG and ELTOS) that furnished the PCB samples and the CERN TE-VSC-SCC (Surface Analysis) laboratory for their XPS analyses of those samples.

8. References

[1] See for example: http://www.rohmhaas.com/electronicmaterials/interconnect_technical_site/attachments/091009_DowEM_new_ASIG_ProdRelease.pdf

[2] Specifications for ENIG process are given in IPC-4552. Some information can be found at http://en.wikipedia.org/wiki/Electroless_nickel_immersion_gold

[3] Harman, George, *Wire Bonding in Microelectronics Materials, Processes, Reliability and Yield*, *2nd Edition, McGraw-Hill, 1997, p.142-144.*

[4] Hallberg, O. and Peck, D.S., *Recent Humidity Accelerations, A Base for Testing Standards*, Qual. and Reliability Eng. Int'l, Vol. 7, 1991, p.169-180.