Sustainability is a Key Parameter for Material and Chemistry Choices for Next Generation Electronic Assemblies

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ABSTRACT

OEMs have started adopting sustainable materials and chemistry technologies for their electronics as a part of better ESG score rankings. Sustainability is becoming a key parameter for material and chemistry choices for the next generation electronics. The use of non-toxic options are being evaluated and preferred.

Several published data suggests the Potassium gold cyanide which is the primary gold salt in the standard immersion gold bath is well known to be a highly toxic substance and it may be fatal if swallowed, contacted or inhaled. It is highly toxic to the environment, especially to aquatic life. Every city/county across the world has allowable cyanide levels (ppm/ppb) in the wastewater regulations; there is a cost associated to bring the gold bath waste to wastewater regulation compliance. Also, mishandling of the gold salt or gold bath may lead to human health and/or environmental issues.

Moreover, recycling and reclaiming the existing precious metals present in the electronic waste is critical instead of resorting to mining these precious metals. The paper will talk about non-toxic (cyanide-free) immersion gold (reduction assisted) option which performs superior to legacy cyanide-based options in terms of stability of the solution and cost-effectiveness. Moreover, recycling and reclaiming of the precious metals/gold from the electronic waste will be discussed.

Key words: Sustainability, Reliability, Printed Circuit Boards (PCBs), Advanced Materials, Electronic Assemblies, UHDI PCBs

BACKGROUND

OEMs have started adopting sustainable materials and chemistry technologies for their electronics as a part of better ESG (Environmental, Social & Governance) score rankings. Sustainability is becoming a key parameter for material and chemistry choices for the next generation electronics. The use of non-toxic options are being evaluated and preferred.

Several published data suggests the Potassium gold cyanide (PGC) which is the primary gold salt in the standard immersion gold bath is well known to be a highly toxic substance and it may be fatal if swallowed, contacted or inhaled. The standard immersion gold bath is one of the key solutions as a part of Electroless Nickel Immersion Gold (ENIG), Ni-free gold based finishes, etc. among the most sought after final finishing for high reliability next generation PCBs/ICs. The PGC based solution is highly toxic to the environment, especially to aquatic life due to the presence of cyanide. Every city/county across the world has allowable cyanide levels (ppm/ppb) in the wastewater regulations; there is a cost associated to bring the gold bath waste to wastewater regulation compliance. Also, mishandling of the gold salt or gold bath may lead to human health and/or environmental issues [1].

Moreover, Nickel is used prevalently as a final finish as a part of ENIG. Nickel toxicity can occur through inhalation, ingestion, dermal absorption, etc. Nickel can cause a range of health issues; in severe cases, large amounts of Nickel ingestion can cause death.

Sustainable final finishing options including cyanide-free gold solution and Ni-free final finishing is evaluated here.

Moreover, recycling and reclaiming the existing precious metals present in the electronic waste is critical instead of resorting to mining these precious metals. The paper will talk about non-toxic (cyanide-free) immersion gold (reduction assisted) option which performs superior to legacy cyanide-based options in terms of stability of the solution and cost-effectiveness. Moreover, recycling and reclaiming of the precious metals/gold from the electronic waste will be discussed.

Wettability Tests for cyanide-free gold plates surface according to MIL-STD-883, method 2003

The wettability/solderability test was conducted according to MIL-STD-883, method 2003. The total of five devices/samples were plated with Ni-free and cyanide-free gold surface finish (Nano-engineered Barrier + immersion gold plating on copper surface). The devices/samples were subjected to 8 hours of steam conditioning @ T=93°C. The devices were dried by baking at 100°C for 1 hour in a dry nitrogen atmosphere. After drying, the device's leads were subjected to solderability testing according to IPC J-STD-002.

Solderability/Wettability Test

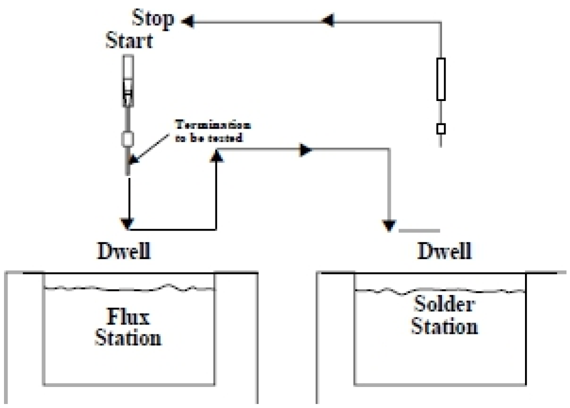


Figure 1. Schematic of solderability/wettability testing procedure

The testing parameters of solderability/wettability test are listed in Table 1.

Table 1. Solderability/Wettability Testing Parameters

Testing Parameters	
Solder Type	SAC 305 (Pb-free)
Flux Type	Standard activated rosin flux, type ROL0, conforming to IPC-ANSI-J-STD-004.
Flux Immersion Time	7 seconds
Flux Immersion Angle	90 degrees
Solder temperature	245°C ±1°C
Solder Immersion Time	5 seconds
Solder Immersion/Emersion rate	25 mm/second

Wettability Evaluation

As mentioned above, the solderability/wettability tests were conducted in accordance with MIL-STD-883, method 2003. After steam conditioning and drying as described above, the devices/sample leads (Ni-free, cyanide-free gold surface finish plated leads) were subjected to solderability testing according to IPC J-STD-002.

After dipping, the solder terminals were inspected by using a microscope at 10X minimum magnification. The surface of the device's solder terminals was covered by a relatively uniform, smooth, and unbroken film of solder that exhibits adherence on the soldered surface. The dipped portion of the terminations was at least 95% covered by a continuous new solder coating. Pinholes, nonwetting, or dewetting did not exceed 5% of the total area. All the devices/samples tested were accepted and none were rejected.

Table 2. Solderability/Wettability Testing Results

Number of samples tested	Number of samples accepted	Number of samples rejected
5	5	0

Figure 2 shows the solder terminal fully covered with the solder.

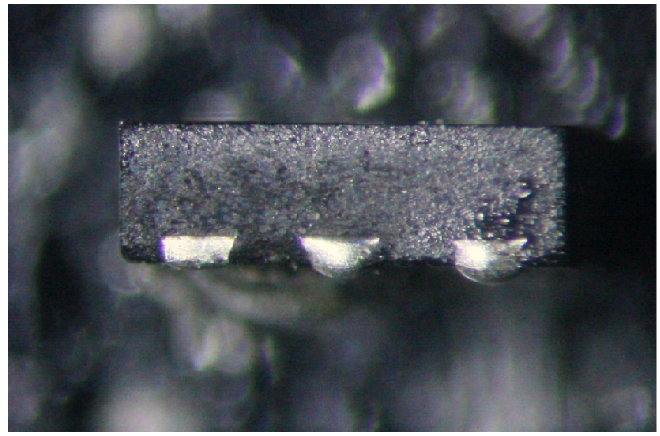


Figure 2. Magnification: 103X; External Side View Showing Solder Terminal Covered with Solder

Appearance

The cyanide-free gold appearance is rose-gold instead of yellow gold appearance through cyanide-based gold plating. As seen in Figure 3 below, the cyanide-free gold is plated on electrodeposited Cu, rolled annealed Cu & electroplated Cu. As can be seen, the shine and matte appearance of the final gold finish is due to the type of Cu underneath. The electrodeposited Cu offers matte appearance of the gold finish while, rolled annealed and electroplated Cu offers shiny appearance.

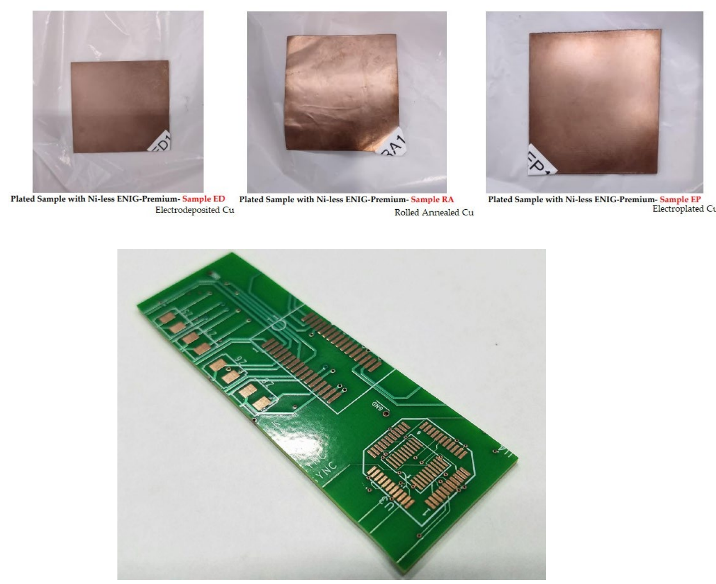


Figure 3. Appearance of cyanide-free gold on Electrodeposited Cu, Rolled Annealed, Cu, Electroplated Cu & PCB

Solder Joint Strength Tests

The solder joint strength tests were intended to greatly stress and age the solder joints in order to mimic the worst possible scenario, under which the assembly with these joints was used extensively and in unusually poor conditions. The PCBs had solder balls applied and then were put through 1, 3, and 6 lead-free reflow cycles at 260°C. Then the samples were aged in heat storage at 150°C for either 500 or 1000 hours to mimic use over the lifetime of an assembly including these solder joints [10]. After the reflow cycles and aging, the PCBs were subjected to shear test.

The solder ball shear test samples were tested under JEDEC B117 standards.. In this standard, there are 4 failure modes: mode 1, ductile solder failure, where the tin solder ball stretches and breaks away from the intermetallics (failure of solder ball); mode 2, pad lift or cratering, where the copper pad is removed from the laminate (failure of laminate); mode 3, non-wetting, where the solder ball lifts entirely off of the surface plating due to not being properly soldered in the first place (failure of soldering and/or surface finish cleanliness); and mode 4, brittle intermetallics failure, which is the most important type of failure originating in the choice of surface finish (failure of intermetallics). Failure modes were examined for brittle failure modes. Brittle failure modes (mode 4) are common in solder balls on ENIG surface finish due to the weakness of the phosphorus-rich nickel intermetallics [11], but if the Ni-free, cyanide-free gold surface finish tested in this paper is to be a viable replacement, then the samples need to have an equal or lesser percentage of brittle failures compared to ENIG.

Solder Joint Strength: Solder Ball Shear Test

Figure 14 shows the different types of failure modes during shear tests on solder balls of the Ni-free cyanide-free gold surface finish. The only types of failure modes seen are mode 1, ductile solder ball failure, and mode 2, pad lifting, which are again issues with the solder and laminate, respectively. In this testing type, there are also no failures surrounding the surface finish (solder joints) in these samples [2,3].

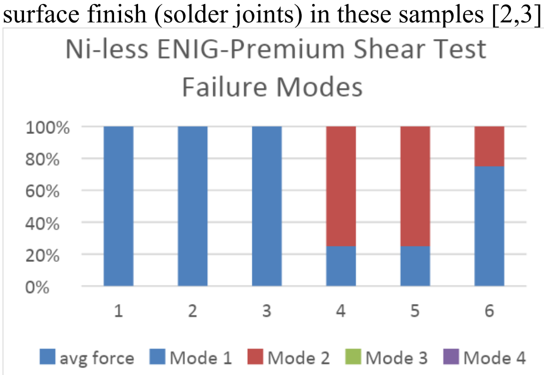


Figure 4. Failure modes during shear tests on solder balls on the Ni-less surface finish for 1, 3, and 6 reflow cycles and 500 and 1000 hours of aging.

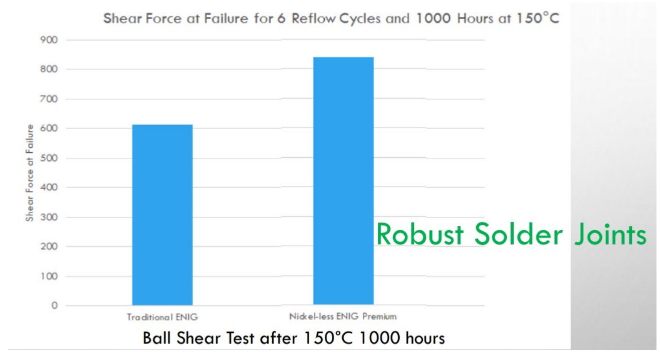


Figure 5. Comparison of shear force to failure between ENIG and Ni-free Cyanide-free gold surface finish.

In conclusion, solder shear tests showed no failures related to the surface finish, so the strong intermetallics involving Ni-free, cyanide-free gold surface finish. Since there are no brittle solder joints (intermetallics) failures, the Ni-free, cyanide-free gold surface finish creates a stronger solder joint than ENIG. Moreover, the shear force to failure involving sustainable surface finish is higher than traditional ENIG surface finish.

Sustainable final finish for UHDI PCB/PCBAs

Demanding ever-increasing performance & miniaturization have led to tremendous need for Ultra High Density Interconnect (UHDI) PCBs. High reliability and manufacturability with optimum performance are critical aspects of UHDI PCBs. The legacy surface finishing option involves Electroless Nickel (Nickel-Phosphorous) layer. Nickel metal is inherently ferromagnetic in nature and shows magnetic interference for the signals. Also, the electrical conductivity of Nickel is very low compared to Copper and Gold. Hence, the signal integrity performance involving ENIG is less optimal especially for UHDI and high frequency PCBs. Moreover, there are concerns of overplating of Nickel leading to potential bridging issues between conductive lines of the circuit.

Alternative solutions involving Ni-free solutions are explored. The proposed Ni-free, cyanide-free gold surface finish is a viable solution for UHDI PCBs. Figure below shows the cross-section of the surface finish on the Copper pad which involves, barrier layer treatment on Copper followed by cyanide-free Gold layer of 50 nanometer (2 microinches).

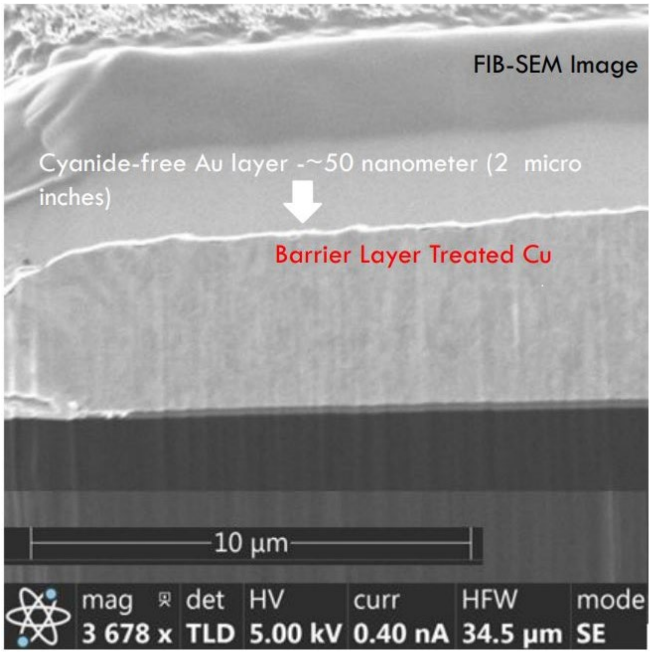


Figure 6. Cross section of Ni-free, cyanide-free gold surface finish using Focussed Ion Beam (FIB)- Scanning Electron Microscope (SEM)

The Ni-free, cyanide-free gold final finish was used in the UHDI circuit with Line/Spacing (L/S) dimensions of 10 micrometers. As seen in the Figure 7, the Gold presence in the space area between two conductive lines was negligible showing the sustainable final finishing is an appropriate solution for UHDI PCBs with no overplating issues. Also, since it is Ni-free, it performs optimally in terms of signal integrity [2,3].

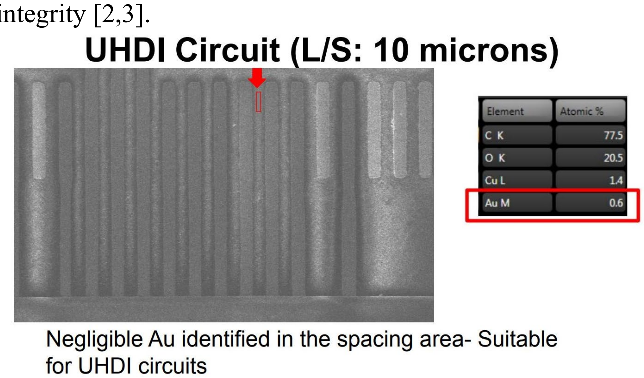
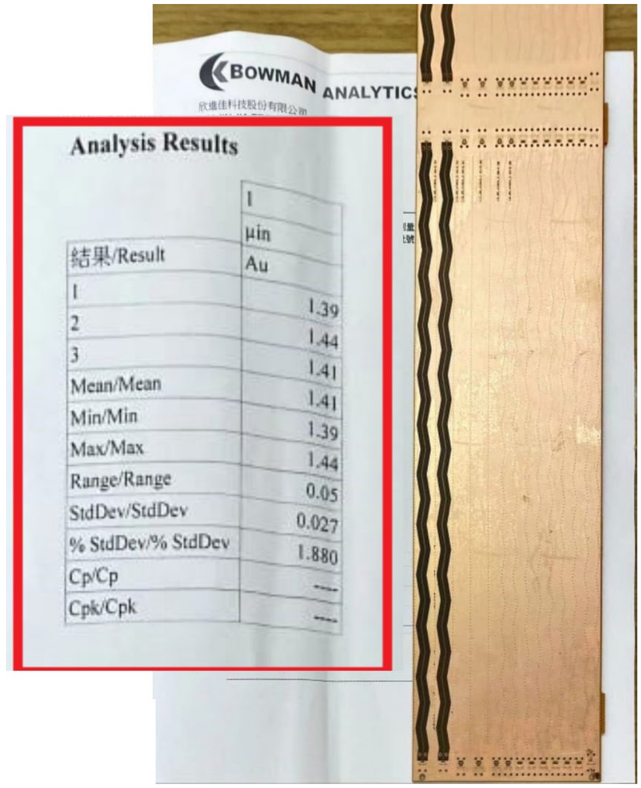


Figure 7. Ni-free Cyanide-free gold surface finish on UHDI circuits with L/S: 10 microns

Gold Layer Thickness

The cyanide-free Gold process is a reduction assisted immersion gold solution with 10+ Metal Turn Over (MTO) stability. This offers a very uniform thickness distribution. As seen in Figure 8, the lowest Gold thickness achieved is 1.39 microinches and average Gold thickness is 1.41 microinches. Typical cyanide-based Gold thickness is 2.5-5 microinches.



结果/Result	1 µin Au
1	1.39
2	1.44
3	1.41
Mean/Mean	1.41
Min/Min	1.39
Max/Max	1.44
Range/Range	0.05
StdDev/StdDev	0.027
% StdDev/% StdDev	1.880
Cp/Cp	----
Cpk/Cpk	----

Figure 8. Cyanide-free Gold layer thickness measurement of the plated panel

Recycling Precious Metals

The recycling and reclaiming the existing precious metals (i.e. Gold) present in the electronic waste is critical instead of resorting to mining these precious metals. This will lead to control of the prices of precious metals in terms of supply and demand of precious metals. Moreover, it is a more sustainable practice to reclaim precious metals from electronic waste instead of mining; this promotes ESG practices for OEMs. We plan to report the efficiency of the recycling process of Gold from electronic waste and make the recycling process more economically viable. The Figure 9 shows the recycling process that reclaims Gold from the electronic waste into 100% Gold bars that get converted into cyanide-free Gold salt which is the raw materials for subsequent plating on to PCBs and ICs.

Figure 9. Recycling of precious metals from the electronics waste and circularity of the precious metals

CONCLUSIONS

The novel Ni-free, cyanide-free surface finish offers a sustainable option for next generation electronic assemblies. The solderability results are successful after exhaustive conditions according to MIL-STD-883, method 2003. Also, the sustainable surface finish offers robust solder joints with better reliability compared to ENIG. It has a rose gold appearance and offers cost-savings by tight Gold thickness distribution and lower thickness. Moreover, the recycling and reclaiming the precious metals (i.e. Gold) will help source gold instead of traditional mining. This will promote sustainability and support ESG for OEMs.

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