Executive Summary Report

Approved in SAP by Workflow	**CM Release**
Prepared by Ralf Bölter / Timothy MacLucas	
Engineering Susanne Kownatzki	
Quality Tobias Baisch	
Configuration Management Iris Rock	
	TESAT This document has been configured electronically and is valid without handsignature. The TESAT configuration management department certifies, that this document has been approved by the responsible people/functions in accordance with the TESAT configuration management process. Iris Rock 2024.09.12 15:11:24 +02'00'

CHANGE RECORD

Issue	Details of Change	Date
A	Initial issue	2024-09-11

INDEX

1 Introduction

1.1 Scope

This document is the Executive Summary Report (ESR) of the project NOVEL SURFACE FINISHES FOR PCBS AND ELECTRONIC ASSEMBLIES with the ESA Contract number 4000129610.

1.2 Abbreviations

Abbreviation	Description/Beschreibung
ASIG	Autocatalytic Silver Immersion Gold
CGA	Column Grid Array
BGA	Ball Grid Array
DIG	Direct Immersion Gold
EPAG	Electroless Palladium Autocatalytic Gold
FP16	Flatpack Package with 16 leads
EPIG	Electroless Palladium Immersion Gold
ENIPIG	Electroless Nickel Palladium Immersion Gold
IGEPIG	Immersion Gold Electroless Palladium Immersion Gold
ISIG	Immersion Silver Immersion Gold
VPS	Vapour Phase Soldering
HS	Hand Soldering

1.3 Documents

1.3.1 Applicable Documents

AD 1 ECSS-Q-ST-70-61

High reliability assembly for surface mount and through hole connections; Issue C

AD 2 TEC.ADSE.PL.1001127679

Evaluation plan Novel surface finishes for PCB’s and electronic assemblies

AD 3 SMT-TP-3004-09-CRS

Novel surface finishes for PCBs and electronic assemblies test procedure

AD 4 SMT-TR-3004-95-CRS

Novel Surface finished for PCB´s and electronics assemblies - Environmental Test Report

2 Technology Review

During task1 of this study, a review of the different Ni-free surface finishes was conducted, both by Airbus and Tesat. The need of Ni-free finish is pushed by the increase of signal speed.

2.1 Airbus review

The following table summarizes the Ni-free finishes available in the market.

Finish	Pros	Cons
ASIG	-Nickel free finish -Dense silver surface thanks to autocatalytic process -Typical thickness: Si: 0.7 to 1µm / Au: 0,04µm -Flatness and good wettability	-Not recommended for Al wire bonding (quick surface deterioration) -
ISIG	-Nickel free finish -Dense Si surface thanks to autocatalytic process -Typical thickness: Si: 0,1 to 0,4µm / Au: 0,04µm -Flatness and good wettability	-Copper diffusion into gold due to thin Silver layer. -
DIG	-Nickel free finish -Good for wire bonding	-Poor shelf life -Copper diffusion into gold
EPIG / EPAG	-Nickel free finish -Good for wire bonding -Palladium protection from copper diffusion -Typical thickness: Pd:0,3µm / Au: 0,01 to 0,04µm -Shelf life >12 months	-Different metal thickness regarding the applications aimed -Compromise is various application -Risk : copper diffusion
ENEPIG / ENIPIG	-Well known -Several studies on this finish	-Nickel content -
IGEPIG	-Nickel free finish -Good for wire bonding -Prevent from copper diffusion	-UYEMURA only supplier -Gold embrittlement?
Nanofinish and plasma coated	-Nanofinish developed by Ormecon, withstand 10 reflows -Plasma: very hydrophobic / good shelf life / compatible to lead free process -	-Sensitive to moisture -No applications in EU -No EU suppliers -Risky finish

Table 2-1: Comparison of different Ni-free finishes

From Tab 2-1, several different finishes were selected for a more detailed comparison.

2.2 TESAT review

2.2.1 ENIG - Electroless Nickel, Immersion Gold

ENIG is formed by the deposition of electroless nickel-phosphorous on a catalyzed copper surface, followed by a thin layer of immersion Gold. ENIG is a very versatile surface finish. It is a solderable surface, aluminum wire bondable, and an excellent electrical contacting surface. It has excellent shelf life, is easy to inspect (visual), and the thickness is easily verified by non-destructive XRF measurement. ENIG continues to gain market share.

2.2.2 Electroless Nickel, Electroless Palladium, Immersion Gold (ENEPIG)

ENEPIG is formed by the deposition of electroless Ni followed by electroless Pd with an immersion gold flash. ENEPIG is the finish with the widest latitude for a variety of applications and is sometimes referred to as the "Universal" finish. ENEPIG is suitable for soldering, gold wire bonding, aluminum wire bonding, and contact resistance. ENEPIG has again come under close scrutiny, as the industry evaluated its capabilities using lead-free assembly conditions. ENEPIG came through with flying colours as it formed one of the most robust solder joints with lead-free SAC type alloys. SEM studies and elemental analysis shows that the presence of Pd in the joint interface dramatically reduces inter-metallic (IMC) propagation, making ENEPIG the leading finish for packages that require soldering and wire bonding with lead-free SAC type alloys.

2.2.3 Electroless Nickel, Immersion Palladium, Immersion Gold (ENIPIG)

The general features of ENIPIG are similar to those of ENEPIG. An advantage of ENIPIG in comparison to ENEPIG is the stable Palladium bath even for small a throughput. ENIPIG is formed by the deposition of electroless Ni followed by immersion Pd with an immersion gold flash.

2.3 Literature Survey

A comprehensive literature review was conducted and delivered the following conclusions:

- ENEPIG provides a good alternative to PbSn fused PCB surfaces.
- The solder join reliability of ENEPIG is better than of EPIG after heat treatment. Even the wire bond reliability of ENEPIG is better than of EPIG, if the Pd and the Au layer were thin, according to the process parameters.
- The solderability of ENIG degraded massively after steam ageing due to the formation of Nickel oxides, which inhibit the solderability. The EPIG finish seems unaffected by steam ageing, due to the inert Palladium layer over copper.
- An increased Au layer thickness does increases the wire bonding reliability, but does not decrease the solder joint reliability. Compared to this, a higher Pd layer thickness does not affect the wire bond reliability, but shows signs of reducing the solder joint reliability.

Following this comparison and discussion with Hofstetter, ISIG was selected initially but some months later, Hofstetter stopped to provide this product. It was then decided to switch to EPIG (also provided by Hofstetter).

3 PCB Coupon Tests

3.1 PCB results for ISIG and ENIPIG

3.1.1 Group 1:

Cu-plating: The results show an overall consistent copper plating within each panel and within the produced batches.

ENIPIG-plating:

- Ni- thickness is consistent for both batches, top-to bottom and there is also no dependency of position on panel or pad size seen
- Pd-thickness has the biggest variation from measuring point to measuring point, from top to bottom and from panel to panel. It has to be taken into account, that the size of the pad has an influence on the thickness
- Au-thickness is in spec for every reading with an average value of ~46 nm. Values for top and bottom as well as for batch-to-batch are comparable. A slight influence of the pad size can be detected

ISIG-plating:

- For Ag- and Au-layer high layer thickness variation over the panel were detected
- For both layers, a significant amount of readings has not achieved the required minimum layer thickness of 100 nm
- A dependency of layer thickness of position on the panel for Au and pad size for Ag hardly any difference of top to bottom side for Au, but more variation for Ag

- Impedance: The highest impact on the impedance proceeds from the application of the solder mask and thus the solder mask on bare copper is an inherent factor for the impedance calculation. There are similar impedances no matter if solder mask was applied before or after final surface finish.

3.1.2 Group 2

- Peel strength: Overall, the peel strength results for the as-received and after Group 6 are acceptable.
- Tape test: None of the test coupons showed any sign of nonconformance.
- Cross-cut test: Solder mask over bare copper shows the best adhesion results, followed by solder mask over ISIG and ENIPIG.
- Solderability: The wetting of ISIG is unstable and varies strongly over a test coupon and between batches. The ENIPIG surface shows stable wetting over the test coupons and between batches. Although the wetting results of the ENIPIG surface are in the vicinity of non-conformance, the overall stability and comparability of the wetting of ENIPIG is superior.

3.1.3 Group 3

- Solder bath float: There were no deviations, regardless of surface finish or date of manufacturing.
- IST-test: All IST coupons have passed without abnormalities, regardless of the final surface finish. No abnormalities have been detected in microsections after IST-testing for ENIPIG and ISIG.
- ECM test: No electromigration on any coupon was detected.

3.2 Assembly results for ISIG and ENIPIG

- Solder ball test: The ISIG surface does not result in any improvements over ENIPIG.
- Solder shear test: Advantages of any configuration neither for ENIPIG nor for ISIG could be demonstrated, due to the strong variations of the test results.
- Adhesive bondability and reliability: Testing showed that the ISIG surface does not result in any improvements over ENIPIG.
- Wire pull test: ENIPIG and ISIG show comparable results. The results for ISIG are slightly better than those for ENIPIG.

- Ball bond shear: The solder mask application had a significant effect on the ball shear results, especially when applied prior to the final surface finish. The number of ball lifts increases, for the condition of solder mask after ENIPIG, it decreases for solder mask after ISIG.
- Ball bump shear: The solder mask application has a significant effect on the ball bump shear results. The decrease of the surface quality affects ISIG more than ENIPIG.

3.3 Conclusion

The above results are summarized in Tab. 3-1. There is no clear advantage for one surface finish, however, in total, ENIPIG showed the best results followed by samples with solder mask prior to ENIPIG.

Tests	SM + ENIPIG	ENIPIG	ENIPIG + SM	SM + ISIG	ISIG	ISIG + SM
Plating thickness / appearance	+	+	+	- (porosity, less scratches)	-- (porosity)	-- (porosity)
Final surface finish adhesion	++	++	++	- (End of pads show issue)	- (End of pads show issue	- (End of pads show issue
Peel strength[i]	na	(--)	na	na	(++)	na
Corrosion	--	-	--	+	+	+
Solder mask adhesion[1]	(++)	na	(++)	(++)	na	(++)
Solderability	+	+	+	0	0	0
PCB evaluation as-received / solder bath / Group 6	++	++	++	- (porosity / end of pads)	- (porosity / end of pads)	- (porosity / end of pads)
IST	++	++	++	++	++	++
Influence on impedance value	0 (SM has most impact)	-	0	0	+	0
ECM	++	++	++	++	++	++
Solder ball	++	++	++	- (dewetting)	- (dewetting)	- (dewetting)
Solder shear	+	+	+	+	+	+
Adhesive bondability	++	++	++	0	0	0
Wire pull	+	+	+	++	++	++
Ball shear	0	++	-	--	++	-
Ball bump shear	0	++	-	--	++	-
Performance Points	**14**	**18**	**12**	**1**	**8**	**1**

Tab. 3-1: Summary of results

4 Assembly Test

4.1 Test Vehicle

Three following packages were selected for the test vehicle definition

- BGA484 with SAC solderballs in daisy chain package
- FP16 daisy chain
- R2512

The printed circuit board was made of Megtron 7N with 12 layers, solder mask. Three boards with EPIG and three boards with ENIPIG surface. On each boards two BGAs, two FP16 and 8 R2512 have been assembled with vapour phase soldering including several times rework with solder iron and repair with solder iron or hot air gas (BGAs). Lead free soldering process with SAC305 was used.

4.2 Test flow

In total, 6 boards were submitted to standard flow: Vibration + thermal cycles with electrical monitoring. ECSS-Q-ST-70-61C conditions were applied in vibration and thermal cycles.

5 Verification Tests

5.1 Thermal cycling test

All boards were submitted to thermal cycling, between -55C to 100C, with 15 minutes dwells both in high and low temperatures, and transitions with a slope of 10 °C/min. Thermal cycling was conducted at ambient pressure as defined in AD2. A total of 1500 cycles were applied. The solder joints were permanently electrically checked by electrical monitoring. Daisy Chain packages for BGAs and Flatpacks have been used.

5.1.1 Results of Temperature Cycles

All BGAs and all Flatpacks that were not damaged due to the high displacements in the vibration tests survived electrically 1500 temperature cycles. Rework, repair and hot air had no negative impact to the results.

The large resistor R2512 started to electrically fail in the Online Monitoring already after 100 temperature cycles and most of them were failed when reaching 1500 temperature cycles. It was the expected behavior.

5.2 Microsectioning of Solder Joints

Microsections are made after vibration and 1500 temperature cycles.

5.2.1 **Flatpack16**

All solder joints of the Flatpacks have a good wetting and only sometimes beginning cracks in the heel area of the leads. In general the result is quite similar to solder joints of Flatpacks with tin lead soldering. No differences between ENIPIG and EPIG surfaces were observed. The solder joints fullfill the requirements of AD 1

5.2.2 **R2512**

As expected the resistors failed during online monitoring in the temperature cycles.

In the past TESAT has tested RM1206 resistors soldered with tin lead solder to FR4 PCBs with ENIPIG surface in an SMT verification with microsectioning after 500 temperature cycles (-55°C to 100°C). Typical cracks are located in the critical zone (between package and PCB).

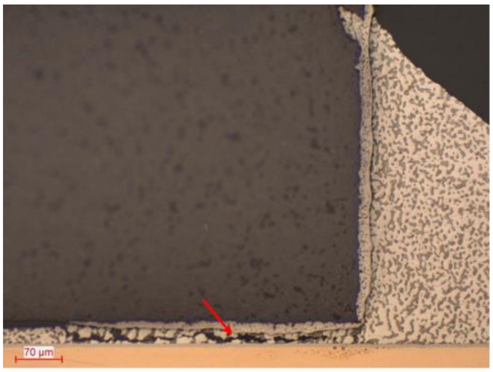

Fig. 5-1: Typical Crack in the Solder Joint of an RM1206 Resistor after temperature cycles

The microsections of the RM2512 resistors soldered with SAC305 show the following results:

Resistors soldered by vapour phase show cracks similar to the RM1206 soldered with tin lead solder. There are cracks in the critical zone as well as in the solder fillet running along the solder pad of the resistor. Due to the significant height of the RM2512 compared to the smaller RM1206 there are also cracks in the solder fillet.

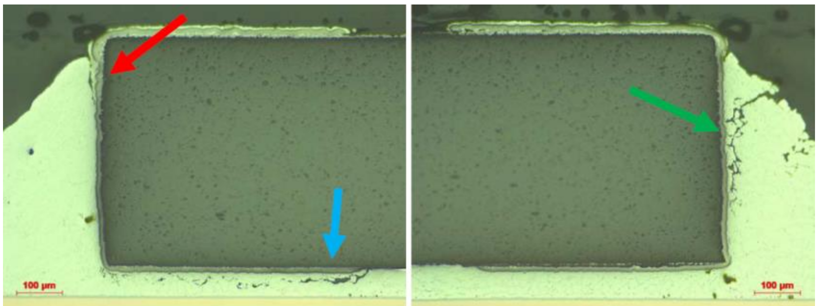

Fig. 5-2: Resistor R3 on PCB TESAT1 soldered by Vapour Phase

Delaminations of the plating of the resistor from the resistor body can sometimes be observed (see bottom termination on the right side in Fig. 5-2). The cracks are running in the solder material. Similar results were found on ENIPG (e.g. Fig. 5-2) and EPIG (e.g. Resistor R3 on Crisa2) surface.

Similar results were found for ENIPIG (e.g. **Fehler! Verweisquelle konnte nicht gefunden werden.**) and EPIG (e.g. Resistor R7 on Crisa2) surface. The same behavior was also found at Resistor R7 on

ELC1 PCB that is soldered by vapour phase. Maybe the high amount of solder at these solder joints supports this result.

No differences between ENIPIG and EPIG surfaces were observed

5.2.3 BGA484

All Balls have a very good wetting on the Pads of the PCB. Sometimes there are voids in the balls. The balls at the edges of the BGA packages have beginning cracks at the connection to the BGA packages. Fig. 5-3 shows the worst case of these cracks running nearly along the whole connection area to the BGA package. This connection worked well electrically up to 1500 temperature cycles.

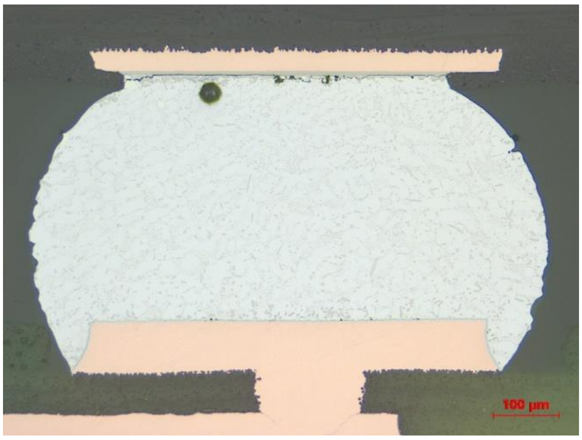

Fig. 5-3: Microsectioning of a ball at the corner of BGA484 on Crisa 2 board - worst case

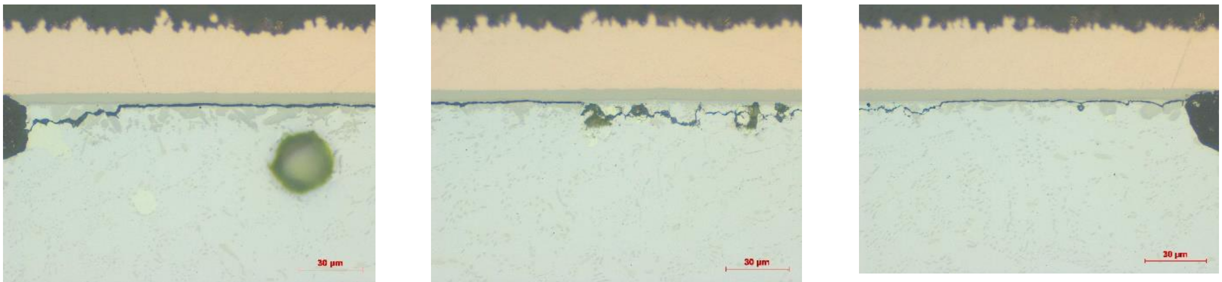

Fig. 5-4: Detailed views of Fig. 5-3

The balls from the BGA assembled in the repair process have slightly different shape.

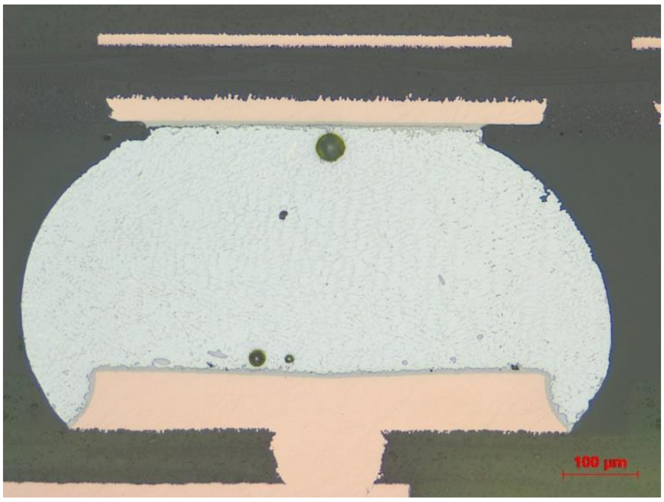

Fig. 5-5: Ball at the corner of the BGA on TESAT 2 (Repair)

The ball in Fig. 5-5 has also beginning cracks at the interface to the BGA package. No differences between ENIPIG and EPIG surfaces were observed.

5.3 Pull- and Sheartest of US Gold Wire Bonding

5.3.1 Bonding Process

200 Gold wire connections (ball-wedge; 25µm gold wire) were implemented on PCBs with ENIPIG and with EPIG surface each. The wedge was created on top of a ball (bump).

5.3.2 Pull- and Shear test Results

100 Connections were destructively pulled on each surface following MIL-STD-883-2.

	Mean (X)	Standard Deviation (S)	X-3xS
ENIPIG	10.67 cN	0.63 cN	8.78 cN
EPIG	10.75 cN	0.63 cN	8.86 cN

Table 5-1: Pullforces

According to MIL-STD-883-2 a gold wire with a diameter of 25µm shall give a minimum pull force of 3 cN begin of life. The balls and the balls of the bumps were destructively sheared from the PCB surface following MIL-STD-883E and ASTM F1269-89.

	Mean (X)	Standard Deviation (S)	X-3xS
ENIPIG	57.32 cN	2.25 cN	50.56 cN
EPIG	57.63 cN	2.44 cN	50.30 cN

Table 5-2: Shear Forces of the Balls

The internal requirement at TESAT is a minimum shear force of 36 cN.

	Mean (X)	Standard Deviation (S)	X-3xS
ENIPIG	60.58 cN	2.83 cN	52.09 cN
EPIG	63.09 cN	3.27 cN	53.27 cN

Table 5-3: Shear Forces of the Bump Balls

The diameter of the balls of the bumps is slightly higher than of the balls. Therefor the shear forces of the bumps are a little bit higher. All shear forces are well above the limits.

5.4 Microsectiong of US Gold Wire Bonding

The balls and the bumps welded to the PCB were microsectioned. All microsections showed a good welding connection to the PCB for both surfaces. ENIPIG and EPIG surfaces are suitable for gold wire bonding and the results are quite similar.

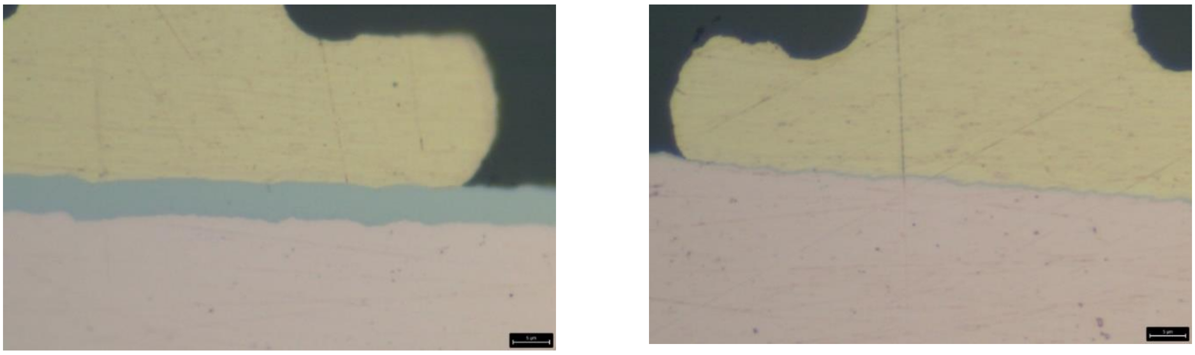

Figure 5-1: Ball on ENIPIG (left) and on EPIG (right)

A complete welding to the PCB with ENIPIG (Figure 5-1 left) over the whole length of the ball is visible. At the EPIG surface (Figure 5-1 right) the grey line between copper and gold is the thin Palladium layer. A complete welding on EPIG surface of the wire bonding is visible.

5.5 Electrical RF tests

For a comparison of the RF performance of the two PCB finishes the transmission with help of a ring resonator and the insertion with the help microstrip-to-waveguide assembly.

For the transmission measurement a ring resonator was realized in the PCB surface. For EPIG a higher transmission was measured as the Nickel in the ENIPIG surface creates higher losses. But the difference is very small (about 1dB) because both surfaces have a relative thick gold surface with low losses and only a small amount of the current runs through the Nickel of the ENIPIG surface.

The RF attenuation of PCBs with these surfaces was measured with a microstrip-to-waveguide assembly. The measurements were performed at 17 GHz to 19 GHz. No differences for the insertion loss of EPIG and ENIPIG were found.