Pure Palladium and Palladium Phosphorus Depositions Used in ENEPIG and ENEP Surface Finishes – Comparison of Physical Properties and Their Influence on Soldering and Au Wire Bonding

Mustafa Oezkoek
Atotech Deutschland GmbH
Erassmusstrasse 20, 10553 Berlin/Germany
Phone: +49 (0) 30 - 349 85 845   E-mail: mustafa.oezkoek@atotech.com

Hugh Roberts
Atotech USA Inc., Rock Hill, SC
1750 Overview Drive Rock Hill, SC 29730 USA
Phone: +1 803 817 3500   E-mail: hugh.roberts@atotech.com

Joe McGurran
Atotech USA Inc., Rock Hill, SC
1750 Overview Drive Rock Hill, SC 29730 USA
Phone: +1 803 817 3500   E-mail: joe.mcgurran@atotech.com

ABSTRACT

As a surface finish, electroless nickel / electroless palladium / immersion gold (ENEPIG) has received increased attention for both packaging/IC-substrate and PWB applications. With a lower gold thickness compared to conventional electroless nickel / immersion gold (ENIG) the ENEPIG finish offers the potential for higher reliability, better performance and reduced cost.[1,2]

This paper shows the benefits of using a pure palladium layer in ENEPIG and ENEP (Electroless Nickel / Electroless Palladium) surface finishes in terms of physical properties and in terms of gold wire bonding and solder joint integrity.

Key words: ENEPIG, ENEP, wire bonding, gold wire bonding, copper wire bonding, solder joint integrity

INTRODUCTION

The ENEPIG surface finish originated in the mid-1990s as a modification of the conventional ENIG finish. During development of ENEPIG, it was recognized that the addition of a palladium (Pd) layer between the nickel and gold enabled both gold and aluminum wire bonding operations, in addition to the normal soldering application. In addition, the Pd layer was found to limit the corrosion of the nickel by an overly aggressive immersion gold process. An electrolytic nickel/gold finish was typically the process of record (POR) for such wire bonding needs.

Investigations into the ENEP process, which is essentially the ENEPIG process without the immersion gold step, actually followed the introduction of ENEPIG to the market. In comparison to ENEPIG, the ENEP process appears to offer a surface finish with benefits like stronger solder joint reliability under Pb-free condition, lower cost (by elimination of gold) and, as recently investigated, Cu wire bonding capability.

Also, in the case of ENEP the pure Pd deposition allows the use of palladium surfaces for soldering and Cu wire bonding, without having the disadvantages of phosphorus on the finish or in the deposited Pd layer.

COMPARISON OF PALLADIUM DEPOSIT PROPERTIES

One subtle difference in the ENEPIG processes available in the market pertains to the deposition of electroless palladium. The electroless palladium layer in ENEPIG can be deposited either as a palladium-phosphorous alloy (PdP) or as “pure” palladium. The deposition mechanism may be similar, because both can be deposited in an autocatalytic (electroless) manner. However, the physical properties of the two deposits are quite unique, resulting in differences regarding assembly steps for soldering and wire bonding.

Hardness of Electroless Deposited Palladium

One key difference between the two types of palladium layers relates to the hardness of PdP and pure Pd deposits. Increasing the phosphorus content also increases the hardness of the palladium deposits, as shown in Figure 1. The hardness of autocatalytic deposited pure Pd is 250 HV, whereas the hardness of Pd-P (with 4-6% phosphorus content) is approximately twice that value. The lower hardness of pure Pd is regarded as one explanation for the better wire bonding performance of ENEPIG with pure Pd in comparison to ENEPIG with Pd-P

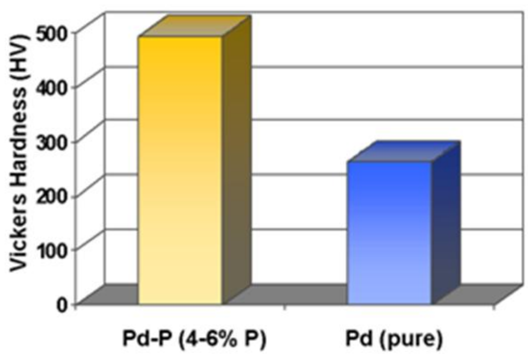


Fig. 1: Comparison of hardness of palladium-phosphorus and pure palladium autocatalytic deposits

Internal Stress in Deposited Pd Layer

The value of internal stress is an indicator of the amount of mechanical energy captured within the layer after the electroless deposition. Table 1 shows a comparison of the internal stress for PdP and pure Pd deposits. The Pd crystal structure and the type of electroless deposition influence this value. Lower internal stress is clearly shown for pure Pd. The reason for this difference is presumed to be the different crystal structures of pure Pd and PdP.

Table 1: Comparison of internal stress of PdP and Pure Pd deposits

Pd Type	Stress Type	Value
Pd-P*	Tensile	3 800 N/mm²
Pure Pd	Tensile	2 100 N/mm²
* P content = (4-6 wt %)		

Topography of Electroless Palladium

When comparing the surfaces of pure Pd and PdP depositions, some difference in the topography is apparent. As shown in Figure 2, the PdP surface shows an even and smooth topography within the individual grains, whereas pure Pd exhibits a form of nano-roughness. The larger grains reflect the known structure of the underlying nickel layer.

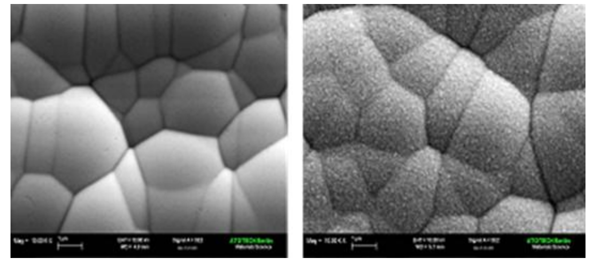


Fig. 2: PdP deposition (0.15µm) over nickel (left) and pure Pd deposition (0.15µm) over nickel (right)

Crystal Structure

As illustrated in Figure 3, cross sections show that the crystal structure of PdP deposited on nickel is amorphous. In contrast, the pure Pd deposited on nickel is characterized by a fine crystalline structure.

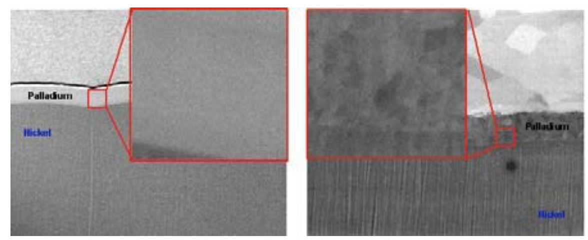


Fig. 3: PdP deposit (0.30µm) on nickel (left) and pure Pd deposit (0.15µm) on nickel (right)

Solder Spread Results of Pd-P vs. Pure Pd

Investigations were performed to evaluate the solder wetting characteristics of the two ENEP finishes (i.e. directly on the Palladium, without gold). The solder spread test results indicate differences between the solder wetting of pure Pd and Pd-P surfaces. In this test, lower wetting angles are indicative of better solder wetting. As shown in Figure 4, the solder wetting on pure Pd resulted in better wetting angles in comparison to the Pd-P surfaces.

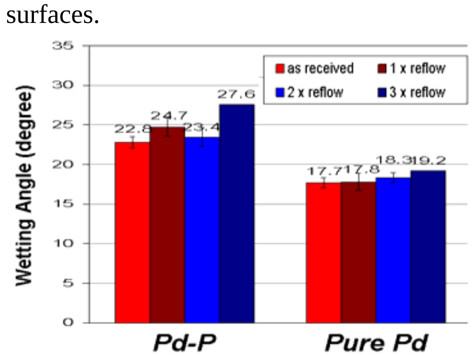


Fig. 4: Comparison of wetting angle test results for Pd-P (left) and pure Pd (right) for various aging conditions

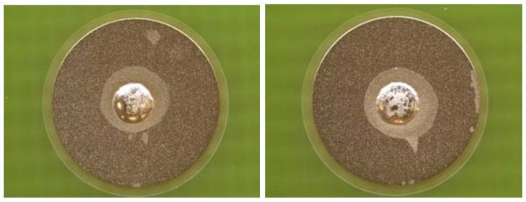


Fig. 5: Comparison of solder spread test results for Pd-P (left) and pure Pd (right) after one solder reflow

SOLDER JOINT INTEGRITY OF ENEPIG AND ENEP WITH PURE PD

Although the RoHS requirements for Pb-free electronics are now established, there are major industry segments still using eutectic solder. As such, the solder joint integrity of ENEP with pure Palladium was tested in this evaluation with both eutectic and Pb-free (SAC 305) solder. The solder joint integrity was tested by the cold ball pull test with a Dage Series 4000 Bond Tester. As a reference, the ENIG surface finish was tested in comparison to both ENEP and ENEPIG finishes with various thicknesses of the pure palladium. Table 2 shows a summary of test parameters and Table 3 presents a description of the various surface finishes examined.

Table 2: Test Parameters and Conditions of the Cold Ball Pull Test

Test vehicle	Atotech BGA TV1 (SRO=600µm)
Solder Flux	Kester TSF 6502
Solder Balls	Pb-free: Indium SAC 305 Eutectic: Sn63Pb37
Ball Size	760µm
Reflow Profile	Pb-free: TSF 6502 Pb-free linear profile (O2<100ppm) SnPb: IPC SnPb BGA (air atmosphere)
Aging Conditions	1. As received / 1xreflow 2. As received / 3xreflow 3. As received / 5xreflow
TP	5 kg
Pull speed	1mm/s

Table 3: Test Parameters and Conditions of the Cold Ball Pull Test

Surface Finish	Ni	Pd	Au
ENIG	7µm	-	0.07µm
ENEPIG	7µm	0.05µm	0.03µm
ENEPIG	7µm	0.15µm	0.03µm
ENEPIG	7µm	0.25µm	0.03µm
ENEP	7µm	0.05µm	-
ENEP	7µm	0.15µm	-
ENEP	7µm	0.25µm	-

COLD BALL PULL TEST RESULTS WITH EUTECTIC SOLDER (SnPb)

Figure 6 shows the results of the cold ball pull testing performed with eutectic SnPb solder. The results show that with pure Pd thicknesses of 0.15µm or less both ENEPIG and ENEP finishes performed similar to ENIG. However, in those cases where the Pd layer thickness was in the range of 0.25µm, the percentage of fractures occurring in the IMC increased, indicating the solder joint was more brittle.

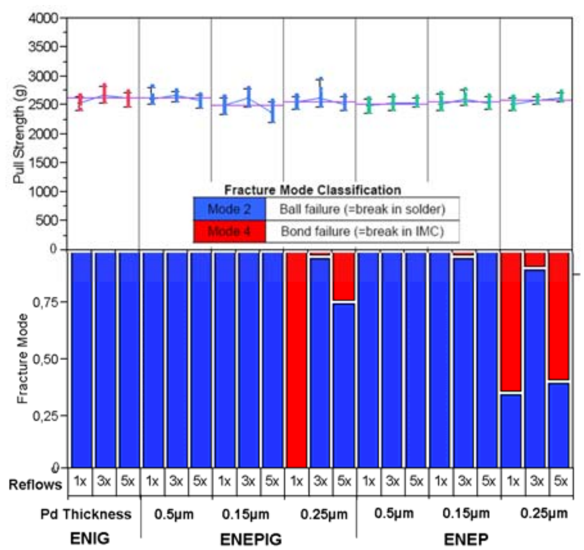


Fig. 6: Comparison of cold ball pull results for eutectic SnPb solder with tested surface finishes following one, three and five reflow cycles

In previous investigations of ENEPIG (with pure Pd) using ball shear testing as the measure of solder joint reliability, it was determined that satisfactory results were achieved only with a palladium thickness of 0.1µm to 0.2µm. Those tests, which were conducted before and after thermal cycling, showed that the optimum performance occurred with deposits having palladium layers within this thickness range. Applying a thicker deposit resulted in a significant increase in brittle fracture, as confirmed with a palladium thickness of 0.3 microns. As such, lower Pd-thickness (below 0.15µm) are recommended for use of ENEPIG or ENEP finishes with eutectic SnPb solder to achieve reliable solder joint integrity. In publications describing other ENEPIG processes on the market, in which Pd-P layers were investigated, it is noted that ENEPIG is not recommended for use in combination with eutectic solder for reasons of joint integrity [5]. In opposition to these reports, the results with pure palladium show that eutectic soldering on ENEPIG and ENEP (with a pure Pd deposit of 0.15µm or less) provides a solder joint of high reliability.

COLD BALL PULL TEST RESULTS WITH PB-FREE SOLDER (SAC 305)

Results of cold ball pull testing performed with Pb-free solder (SAC 305) are presented in Figure 7. As expected, because of the increased thermal demands of Pb-free soldering the ENIG finish shows more failures within the IMC in comparison to the ENEPIG or ENEP finishes. The best results were achieved with the ENEP finish with a pure Pd thickness of 0.25µm. Overall, the ENEP finish performed as well (or perhaps, better than) the ENEPIG finish employing similar palladium thicknesses, which is a significant finding considering it allows elimination of the costly gold deposition.

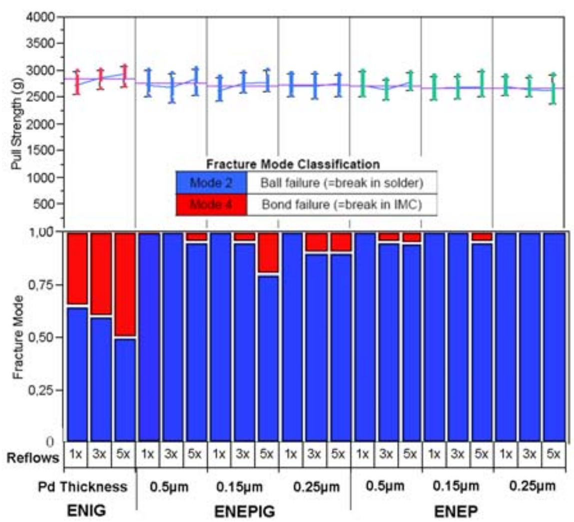


Fig. 7: Comparison of cold ball pull results for Pb-free solder (SAC 305) with tested surface finishes following one, three and five reflow cycles

TEST CONDITIONS FOR GOLD WIRE BOND INVESTIGATIONS

The test vehicle used for wire bonding investigations is shown in Figure 8. Wire bonds were placed on 125-µm bond fingers. Table 4 shows the testing and sample parameters.

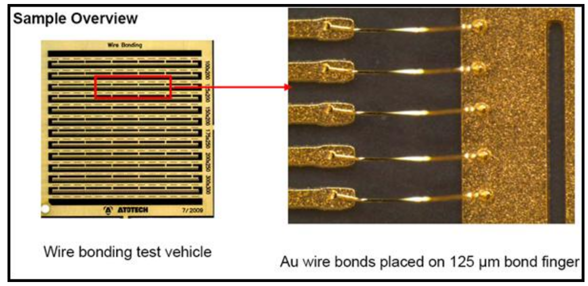


Fig. 8: Overview and detailed view of test vehicle used for wire bonding investigations

Table 4: Wire bonding and sample parameters

Bond Parameters	
Wedge (US)	0.68
Wedge Force (g)	24
Time (ms)	20
Temperature (°C)	165
Equipment Specifications	
Bonder	Delvotek 5410
Bond Capillary	41488-3823-R35
Manufacturer	Kulicke & Soffa
Gold Wire	Type GMH
Wire Diameter	23 µm
Wire Manufacturer	Tanaka
Sample Details	
Sample	WBTV
Surface Finish	Atotech Universal ASFII
Aging	4 hours / 150°C
Pull Test Conditions	
Bond Tester	Dage 4000
Pull Speed (µm/s)	500

GOLD WIRE BONDING PROCESS WINDOW

To assess the wire bond performance of ENEPIG finishes with pure Pd in comparison to PdP, investigations were conducted with varying thicknesses of gold, palladium and nickel. Bond pull strengths were measured and the mode of each bond failure was observed and recoreded. Figure 9 presents the criteria for assessing the different types of wire bond failures. The preferred types of failure are either neck breaks (Mode 2) or wire breaks (Mode 3). Heel breaks (Mode 4) are acceptale failures, however, wedge lifts (Mode 5) are not acceptable and fail the test.

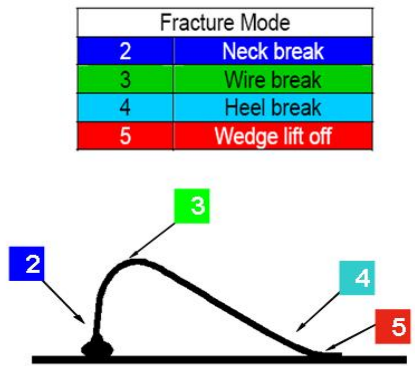


Fig. 9: Criteria to establish failure mode for wire bond pull testing

Figure 10 presents the results of wire bond pull force measurements for each test condition, while Figure 11 shows the results of the failure mode analysis. The tested thicknesses of electroless nickel, electroless palladium and immersion gold are shown within the two figures for ease of reference. As shown in the figures 10 and 11, the two electroless palladium deposits were tested with the same Ni, Pd and Au thickness conditions. The electroless nickel thickness ranged from 6.0µm to 7.0µm. However, the thickness of electroless palladium was varied from 0.05 µm to 0.25 µm for each of two different groups of gold thickness, which was deposited at thicknesses of 0.04 µm and 0.15 µm. For samples with a thicker gold deposit (0.15 µm) almost no difference exists between the two finishes in terms of either wire pull force or failure mode. However, in the case of the lower gold thickness (0.04 µm) the ENEPIG finish with pure Pd exhibits significantly greater pull strength results and a higher incidence of the preferred wire bond failure mode. It is theorized that reducing the gold thickness increases the effect of the palladium hardness on the wire bonding process. Furthermore it is assumed that a softer Pd layer is beneficial for the wire bonding process. As known from electrolytically deposited Ni/Au (i.e. "soft" gold), the hardness does have a significant influence on gold wire bonding. Conversely, electrolytically deposited hard gold is not used for wire bonding in the market. As such, ENEPIG with pure Pd can operate within a wider operating window for gold wire bonding, but more importantly, it can operate with lower gold thickness and still achieve similar results.

COPPER WIRE BONDING CAPABILITY OF ENEP SURFACE FINISH

With respect to the ENEP surface finish, the use of pure Pd does provide a further significant benefit. Recent investigations have shown that copper wire bonding to an ENEP surface finish on IC substrates or PWBs is possible, providing an ENEP surface finish having a pure Pd layer is used. For semiconductor applications, copper wire bonding to die bond pads treated with pure-Pd ENEP is already established [5] [6] [7].

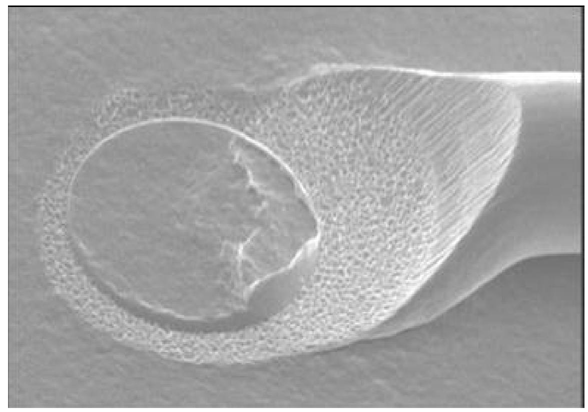
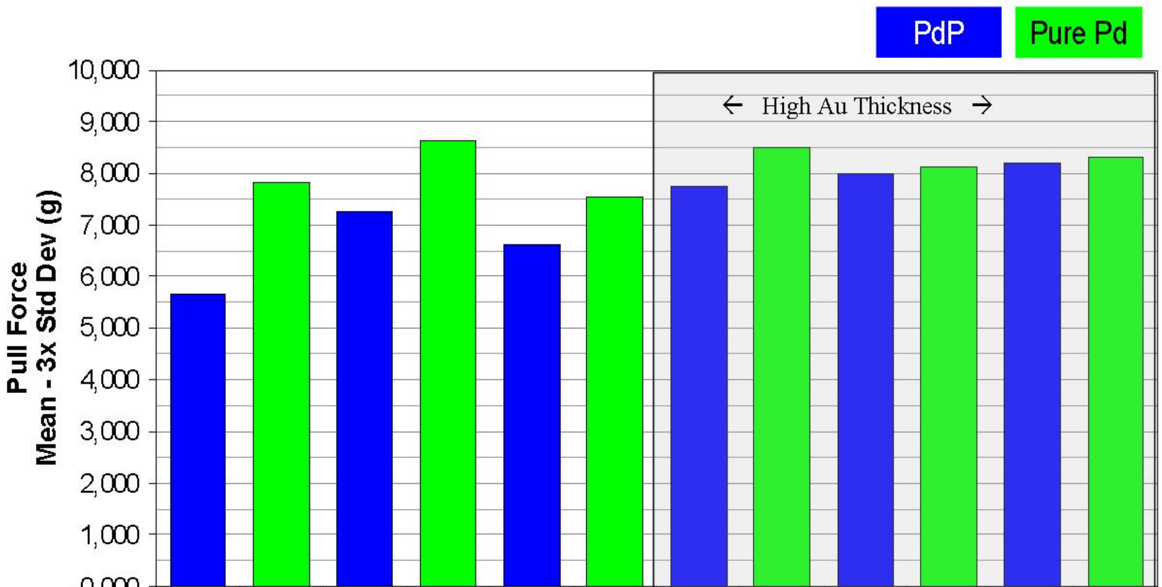


Fig. 12: Typical copper wire wedge bond

SUMMARY

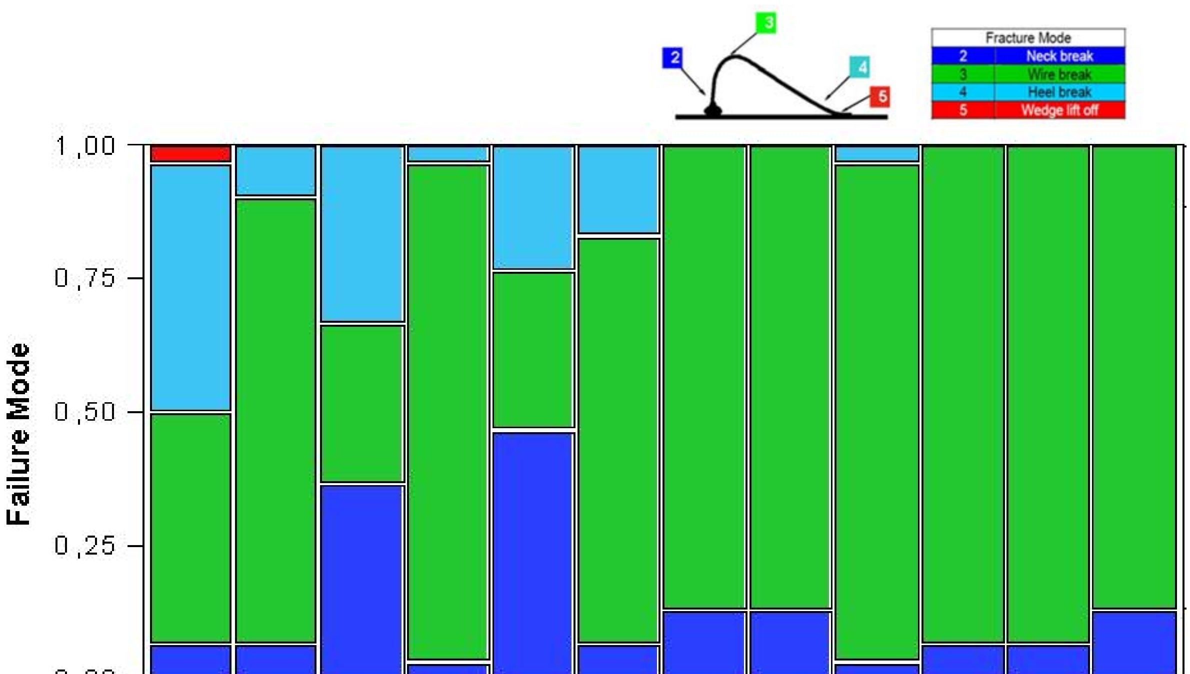
These investigations have demonstrated that using an electroless pure Pd deposit (without co-deposited phosphorus) can enhance the performance of an ENEPIG surface finish. In the case of ENEPIG, the use of pure Pd widens the process window for gold wire bonding and, as also demonstrated, allows a reduction in the gold thickness. This reduction in gold thickness offers the potential for an increase in yield on the assembly side, as well as a manufacturing cost reduction.

The solder joint integrity tests showed that ENEPIG and ENEP with pure Palladium deposits do create a reliable solder joint with both eutectic SnPb and Pb-free solder types. In addition, use of the ENEP surface finish with pure Pd enables the use of copper wire bonding, representing measureable savings in assembly costs, with the added cost reduction of eliminating the expense for gold in the finish.



Process	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG
Pd Layer	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd
Nickel µm	6,0	6,0	6,0	6,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
Pd µm	0,05	0,05	0,15	0,15	0,25	0,25	0,05	0,05	0,15	0,15	0,25	0,25
Au µm	0,04	0,04	0,04	0,04	0,04	0,04	0,15	0,15	0,15	0,15	0,15	0,15

Fig. 10: Comparison of gold wire bond pull test results for ENEPIG (with PdP) vs. ENEPIG (with pure Pd) with varying thickness of Ni, Pd and Au



Process	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG	ENEPIG
Pd Layer	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd
Nickel µm	6,0	6,0	6,0	6,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
Pd µm	0,05	0,05	0,15	0,15	0,25	0,25	0,05	0,05	0,15	0,15	0,25	0,25
Au µm	0,04	0,04	0,04	0,04	0,04	0,04	0,15	0,15	0,15	0,15	0,15	0,15

Fig. 11: Comparison of gold wire bond failure mode results for ENEPIG (with PdP) vs. ENEPIG (with pure Pd) with varying thickness of Ni, Pd and Au

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