

Benefits of Pure Palladium for ENEP and ENEPIG Surface Finishes

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Introduction

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 than conventional electroless nickel / immersion gold (ENIG) the ENEPIG finish offers the potential for higher reliability, better performance and reduced cost.[1,2] Similar advantages appear to be achievable through the use of the electroless nickel / electroless palladium process (ENEP).

ENEPIG

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.

ENEP

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

Comparison of Properties of Pure Palladium vs. Palladium-Phosphorus (PdP) Deposits

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 for the assembly steps of soldering and wire bonding.

Hardness

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 autocatalytically deposited pure Pd is 250 HV, whereas the hardness of Pd-P (with 4-6% phosphorus

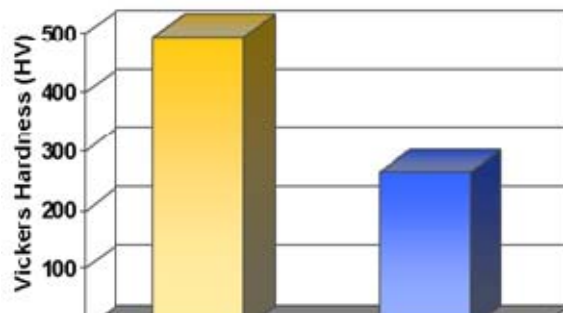


Fig. 1 Comparison of hardness of palladium-phosphorus and pure palladium autocatalytic deposits.

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.

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. 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.

Pd Type	Stress Type	Value
Pd-P	Tensile	3.800 N/mm ²
Pure Pd	Tensile	2.100 N/mm ²

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

Solder Spread Results of PdP vs. Pure Pd

Investigations were performed to evaluate the solder wetting characteristics of the two ENEP finishes. The solder spread test results indicate differences between the solder wetting of pure Pd and PdP surfaces. In this test, lower wetting angles are indicative of better solder wetting. As shown in Figures 2 and 3, improved solder wetting is achieved on pure Pd, resulting in lower wetting angles in comparison to PdP surfaces.

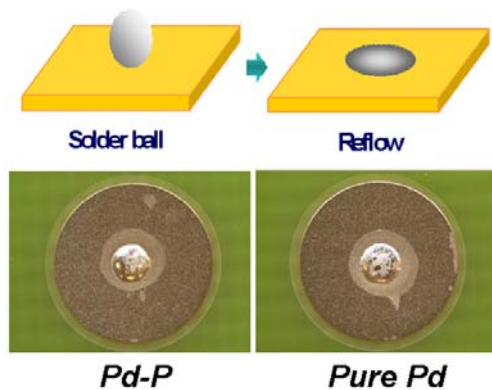


Fig. 2 Comparison of solder spread test results for PdP (left) and pure Pd (right) after one solder reflow

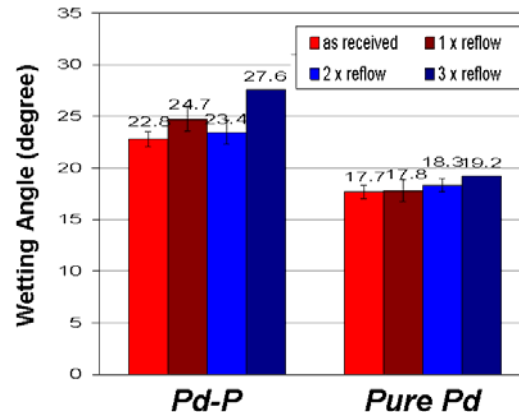


Fig. 3 Comparison of wetting angle test results for PdP (left) and pure Pd (right) for various aging conditions

Topography

When comparing the surfaces of pure Pd and PdP depositions, some difference in the topography is apparent. As shown in Figures 4 and 5, 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.

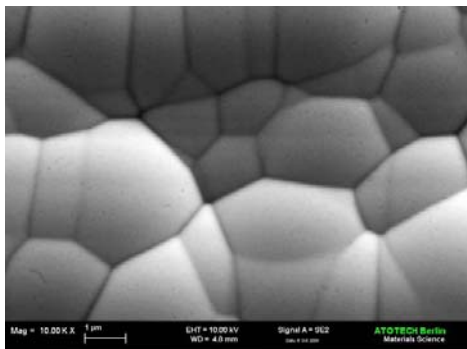


Fig. 4 PdP deposition (0.15µm) over nickel, showing a relatively even and smooth surface.

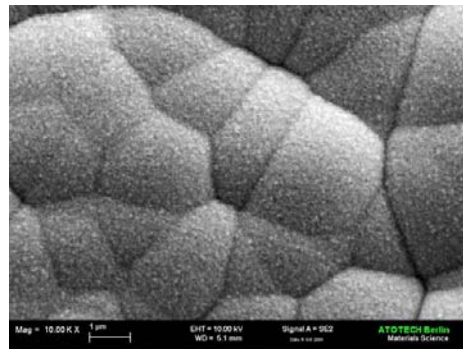


Fig. 5 Pure Pd deposition (0.15µm) over nickel, showing some nano-roughness on the surface.

As illustrated in Figures 6 and 7, cross sections show that the crystal structure of PdP is amorphous, whereas pure Pd is characterized by a fine crystalline structure.

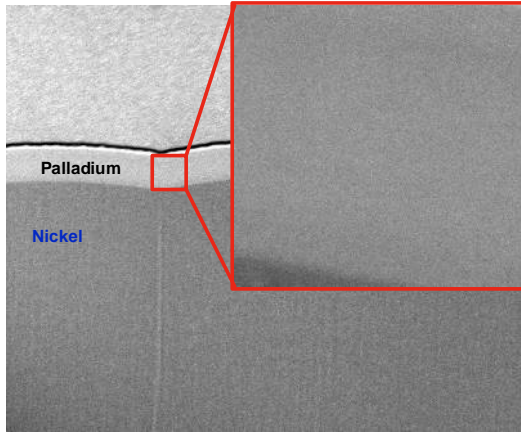


Fig. 6 PdP deposition (0.30 μm) shows an amorphous structure

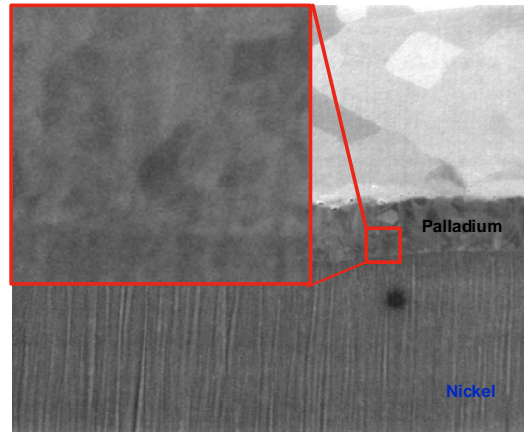


Fig. 7 pure Pd deposition (0.15 μm) on nickel shows a fine crystalline structure.

Test Conditions for Gold Wire Bond Investigation

The following wire bond test conditions were used for the further wire bond investigations:

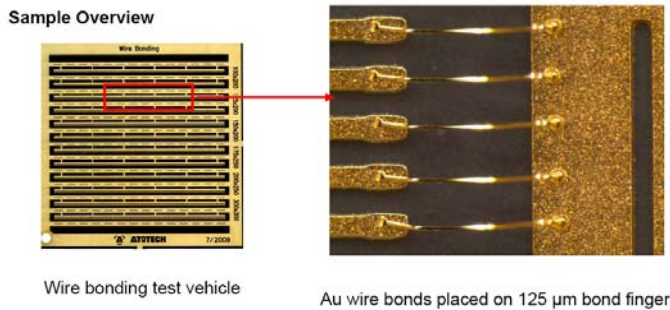


Fig. 8 Test Layout for wire bonding

Equipment Details	
Bonder	Delvotek 5410
Bond capillary	41488-3823-R35
Company	Kulicke & Soffa
Au Wire	Type GMH
\varnothing	23 μm
Company	Tanaka
Pull Test Conditions	
Pull Tester	Dage 4000
Pull Speed ($\mu\text{m/s}$)	500

Bond Parameter	
Wedge US	0.68
Wedge Force (g)	24
Time (ms)	20
Temperature* ($^{\circ}\text{C}$)	165

Sample Details	
Sample	WBTV
Surface Finish	Universal ASF II
Aging	4h 150 $^{\circ}\text{C}$

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. As shown in Figures 9 and 10, almost no difference exists between the two finishes in terms of either wire pull force or failure mode for samples with a thicker gold deposit (0.15 μm). However, in the case of 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 with a wider operating window for gold wire bonding, but more importantly, it can operate with lower gold thickness and still achieve similar results.

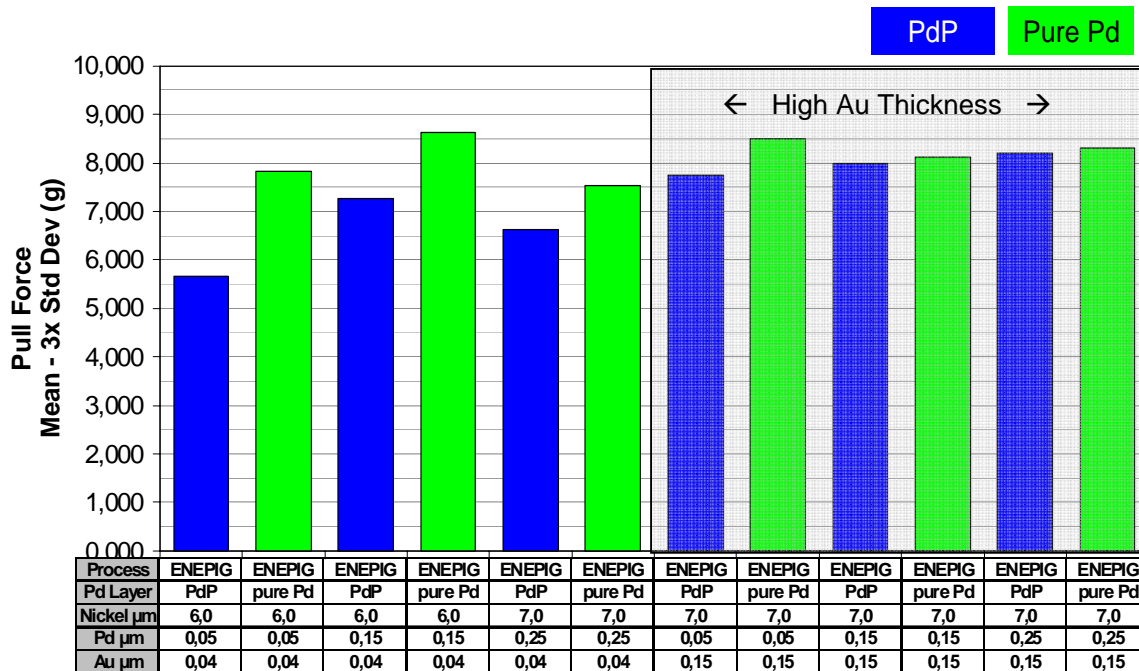


Fig. 9 Comparison of gold wire bond pull test results for ENEPIG (with PdP) vs. ENEPIG (with pure Pd) with varying thickness of Ni, Pd and Au

Fracture Mode		
2	Neck break	best mode
3	Wire break	best mode
4	Heel break	acceptable
5	Wedge lift off	FAIL

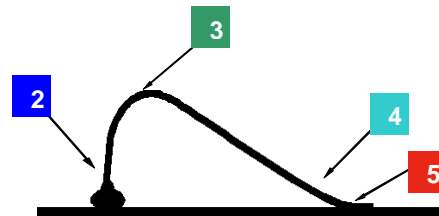


Fig. 10 Legend of Failure modes after gold wire bond pull test (for next slide Figure 11)

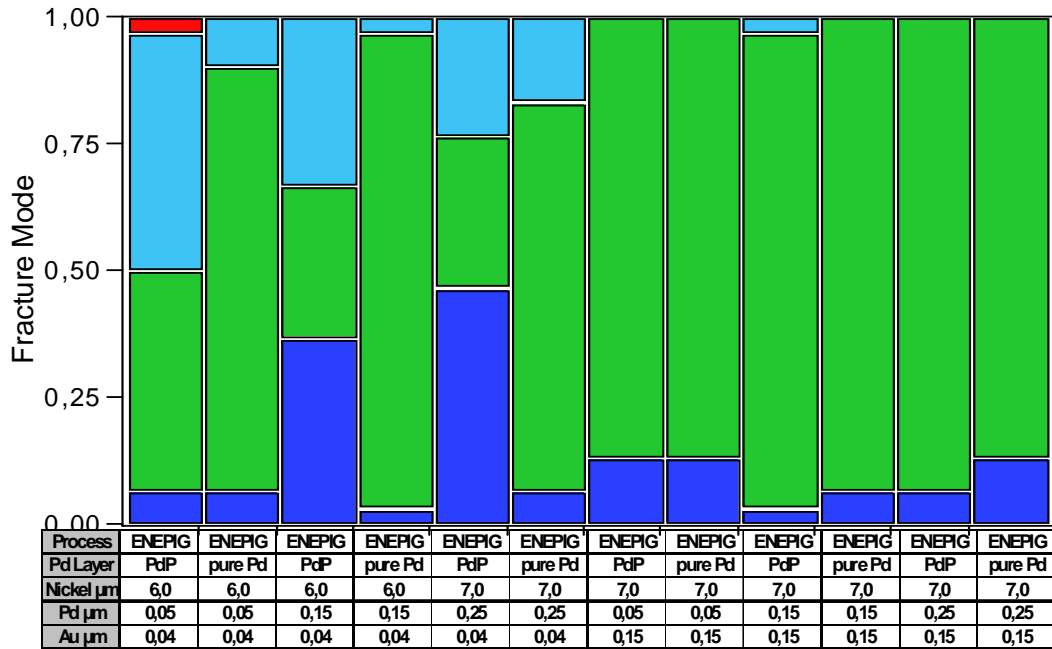


Fig. 11 Comparison of gold wire bond failure mode results for ENEPIG (with PdP) vs. ENEPIG (with pure Pd) with varying thickness of Ni, Pd and Au

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 is possible for IC substrate and PWB applications when performed on ENEP surface finishes having a pure Pd layer. For semiconductor applications, copper wire bonding on pure Pd ENEP is already established [4] [5] [6].

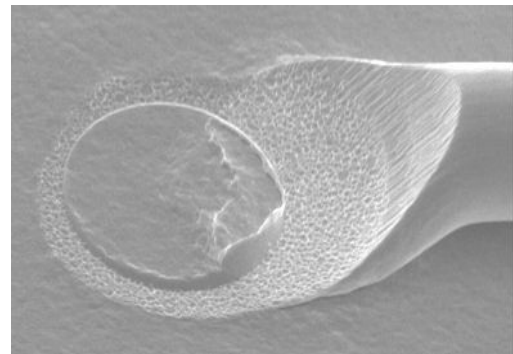


Fig. 12 Typical copper wire wedge bond

Summary

These investigations show that using electroless pure Pd depositions (without co-deposited phosphorus) can enhance the performance of ENEPIG and ENEP surface finishes. In the case of ENEPIG, the use of pure Pd widens the process window for gold wire bonding and, as demonstrated, allows a reduction in the gold thickness, thus enabling an increase in yield on the assembly side as well as a possible cost reduction. With respect to the ENEP surface finish, the elimination of the immersion gold process step clearly results in a simplified process as compared to ENEPIG. In addition to offering the associated cost reduction, the ENEP surface finish enables next generation interconnection techniques, namely copper wire bonding.

The presentation at the ESTC International Conference will provide further details, discussion and interpretation of these test results.

References:

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- [2] "Effect of Process Variations on Solder Joint Reliability for Nickel-based Surface Finishes"; Roberts, Hugh; Lamprecht, Sven; Ramos, Gustavo; Sebald, Christian. Proceedings: SMTA Pan Pacific Microelectronics Symposium; 2008.
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- [4] „Nickel-Palladium Bond Pads for Copper and Gold Wire Bonding“
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