THE BENEFITS OF ENEPIG WITH PURE PD FOR GOLD WIRE BONDING

Mustafa Oezkoek[1], Gustavo Ramos[1], Dieter Metzger[1], Hugh Roberts[2]
[1]Atotech Deutschland GmbH, Berlin, Germany
[2]Atotech USA Inc., Rock Hill, SC
mustafa.oezkoek@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 test results.

Key words: ENEPIG, ENEP, wire bonding, gold wire bonding, copper wire bonding

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.

COMPARISON OF 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.

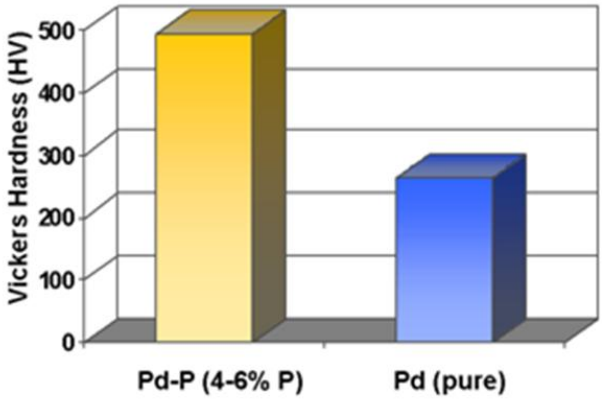


Fig. 1 Comparison of hardness of palladium-phosphorus and pure palladium autocatalytic deposits

The hardness of autocatalytically 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.

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.

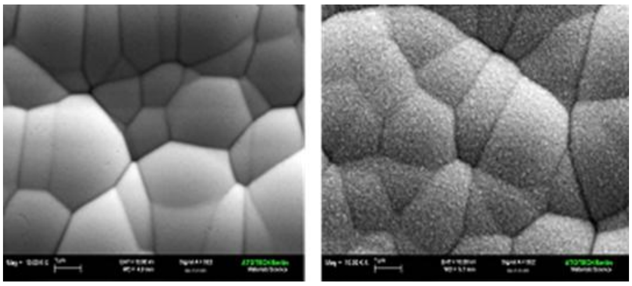


Fig. 2 (Left) PdP deposition (0.15µm) over nickel (left) and pure Pd deposition (0.15µm) over nickel (right)

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.

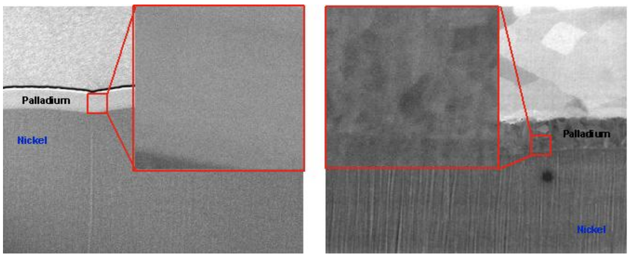


Fig. 3 PdP deposit (0.30µm) on nickel (left) and pure Pd deposit (0.15µm) on nickel (right)

TEST CONDITIONS FOR GOLD WIRE BOND INVESTIGATIONS

The test vehicle used for wire bonding investigations is shown in Figure 4. As shown, the wire bonds were placed on 125-µm bond fingers. Table 2 shows the testing and sample parameters

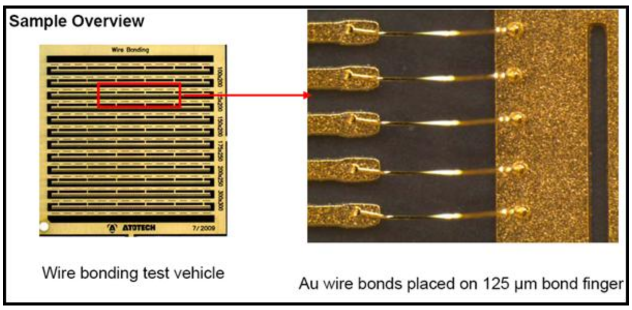


Fig. 4 Overview and detailed view of test vehicle used for wire bonding investigations

Table 2: 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 ASF II
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 5 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.

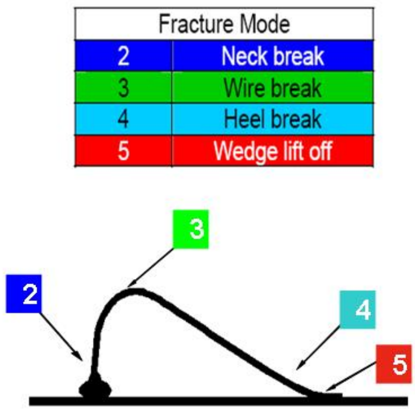
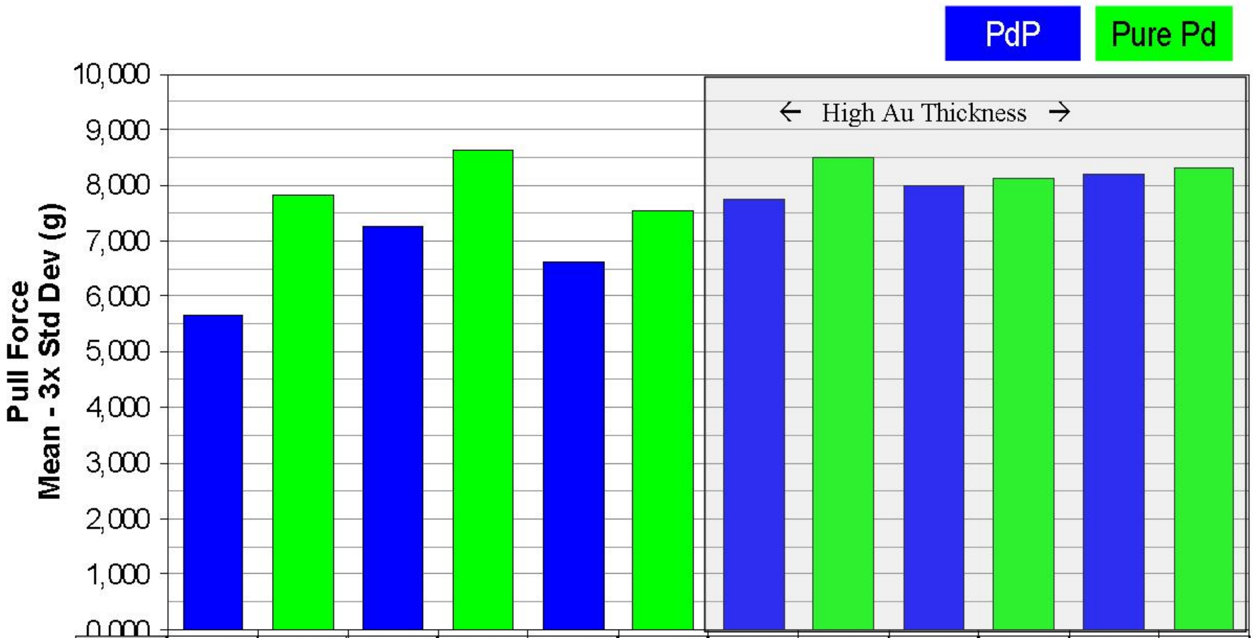


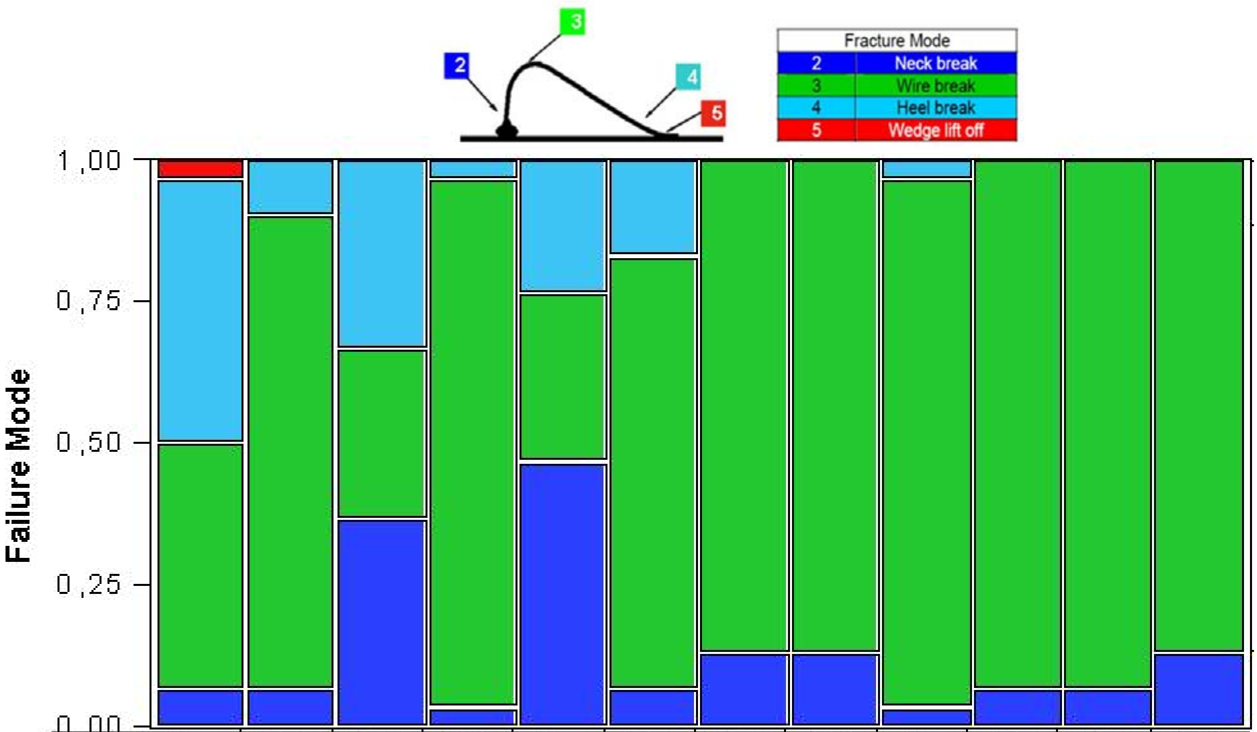
Fig. 5 Criteria to establish failure mode for wire bond pull testing

Figure 6 presents the results of wire bond pull force measurements for each test condition, while Figure 7 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.



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. 6 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. 7 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

As shown in the figures, the two electroless palladium deposits were tested with the same Ni, Pd and Au thickness conditions. The electroless nickel thickness ranged only 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 with 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 [4] [5] [6].

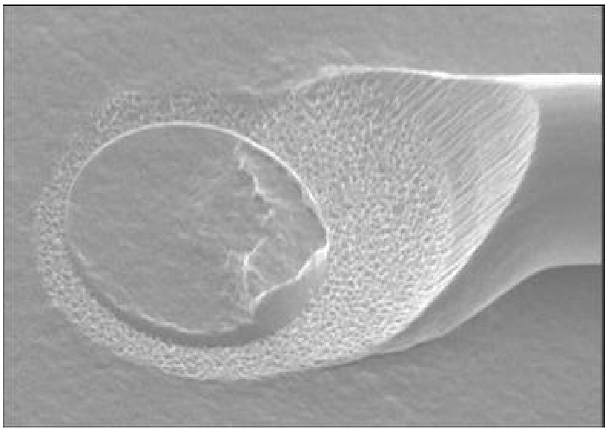


Fig. 8 Typical copper wire wedge bond

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 possible cost reduction. In addition, use of the ENEP surface finish with pure Pd enables the use copper wire bonding, representing significant savings in assembly costs, with the added cost reduction of eliminating the expense for gold depostion.

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