# ENEP – A Cost-Effective Alternative for High Reliability Soldering Applications

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## Introduction

Electroless nickel/immersion gold (ENIG) has been recognized within the electronics packaging industry as a reliable surface finish for soldering applications. Unlike surface finishes, such as OSP, immersion silver or immersion tin, which produce a Cu-Sn intermetallic upon soldering, the nickel layer of ENIG acts as a barrier to minimize copper dissolution during the soldering application. This function is especially important for assemblies that require multiple solder reflow steps. However, if not properly controlled, excessive corrosion of the nickel by the immersion gold step can also cause the well documented "black pad" effect, often resulting in solder joint reliability issues, including brittle fracture.

As an alternative to ENIG, an electroless pure palladium layer over the electroless nickel (ENEP) provides a solderable surface without the noted risk of damage to the underling nickel layer [1]. By eliminating the corrosive attack of the gold bath, the final layer stack would be suitable for high reliability soldering involving both IC substrate and PWB applications. In addition, because of the current high price of gold, replacing it with a pure palladium deposit can offer measureable cost savings for the ENEP process in comparison to ENIG [2].

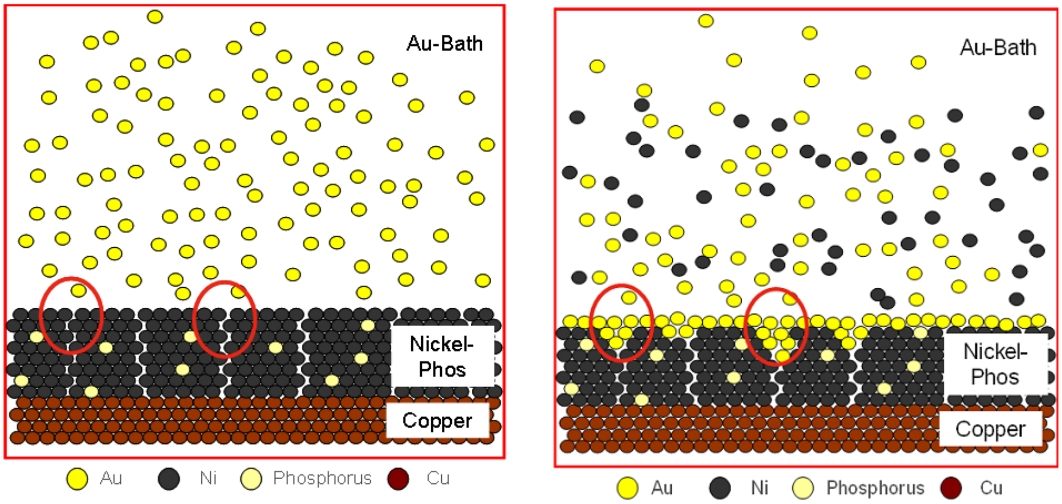
The paper summarizes an in-depth study of the effect on solder joint reliability caused by replacing the immersion gold by an electroless pure palladium layer. The study includes evaluations for both Pb-free (Sn-3.0Ag-0.5Cu) and eutectic SnPb (63Sn-37Pb) soldering applications. Results of investigations include: (1) cold ball pull testing to evaluate solder joint integrity, (2) SEM examinations of the underlying nickel surface, (3) IMC examinations to quantify nickel thickness degradation after multiple solder reflow cycles and (4) surface wetting through solder spread examinations. The paper discusses the relatively simple surface finish that, if proven effective in large-scale fabrication, may offer measureable performance and cost benefits in comparison to the more traditional ENIG finish.

## Reaction Comparison of ENIG and ENEP

To understand the difference between ENIG and ENEP surface finishes requires a comparison of the two different types of reaction: (1) the immersion deposition of gold on nickel and (2) the autocatalytic deposition of palladium on nickel. As shown in Figure 1, the deposition of immersion gold on electroless nickel is an exchange reaction, whereby nickel is exchanged by gold. The grain boundaries of the nickel are more easily accessed by the reaction. As a result, so-called "gold spikes" can occur in the nickel layer. These spikes in the nickel are characteristic of ENIG finishes and are quite normal. However, in very extreme cases if the immersion gold reaction is out of control, abnormally strong attack of the nickel can occur, which might later cause reliability issues.

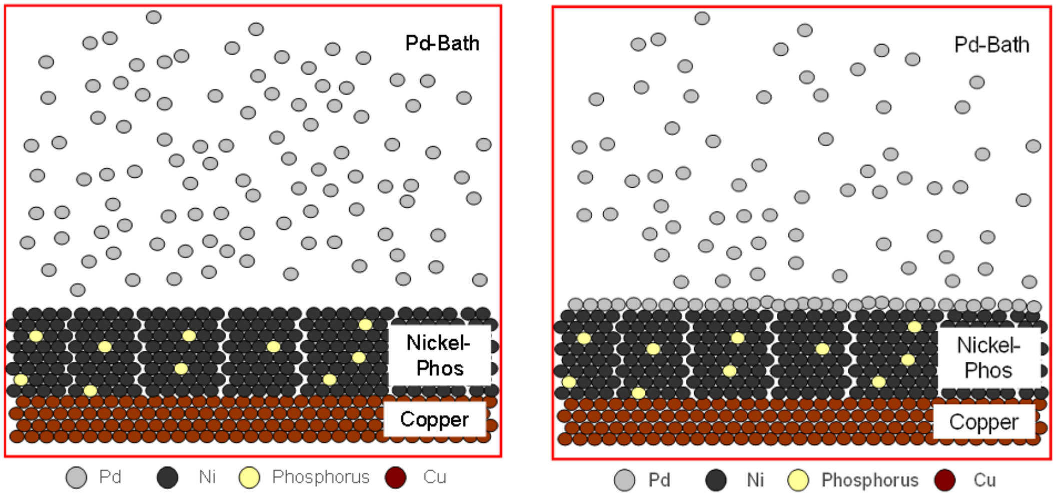
By comparison, as shown in Figure 2, the deposition of electroless palladium on electroless nickel is not an exchange reaction (i.e. nickel is not replaced during the reaction). The palladium is deposited autocatalytically on the nickel without disrupting the nickel layer. This ensures a uniform and continuous deposition of palladium without the characteristic "spikes" in the nickel.

Figure 3 presents an SEM cross-sectional comparison of the ENIG and ENEP finishes, clearly showing the presence of the gold spikes with the ENIG surface finish and the lack thereof in the case of the ENEP finish.



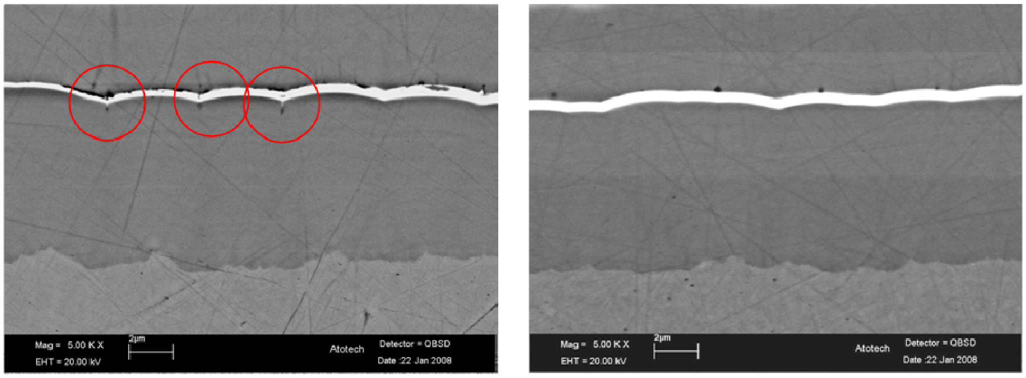
*Before deposition of immersion Gold* *After deposition of immersion Gold*

**Fig. 1** Illustration of the reaction of immersion gold on electroless nickel (ENIG)



*Before deposition of electroless Palladium* *After deposition of electroless Palladium*

**Fig. 2** Illustration of the reaction of electroless palladium on electroless nickel (ENEP)



*ENIG (Electroless Ni - Immersion Au)* *ENEP (Electroless Ni - Electroless Pd)*

**Fig. 3** Comparison of cross-section SEM photographs for ENIG and ENEP deposits. Note presence of gold spikes into the nickel layer on the ENIG finish.

## A Comparison of Pd-Phosphorus and Pure Pd

There are different types of electroless palladium processes available in the market. Palladium-phosphorus (Pd-P) alloys as well as pure palladium can be deposited with electroless (autocatalytic) reactions. The deposition reaction might be similar but the physical properties of the palladium deposits are quite different. One difference is the hardness of Pd-P and pure Pd layers. Increasing the phosphorus content in the layer also increases the hardness of the palladium deposits as shown in Figure 4.

The hardness of autocatalytically deposited pure Pd is similar to that of the pure Pd mentioned in the literature [3], whereas the hardness of Pd-P (with 4-6% Phosphorus content) is approximately twice as hard as pure Pd. The lower hardness of pure Pd is regarded as one explanation for the better wire bonding performance of ENEPIG (with pure Pd) compared to ENEPIG (with Pd-P).

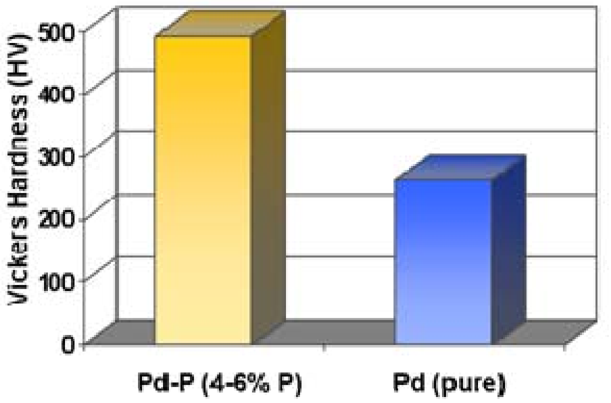


**Fig. 4** Comparison of hardness of palladium-phosphorus and pure palladium deposits

## Solder Spread Results of Pd-P 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 Pd-P surfaces. The solder wetting on pure Pd results in better wetting angles than on Pd-P surfaces. In this test, lower wetting angles are indicative of better solder wetting.

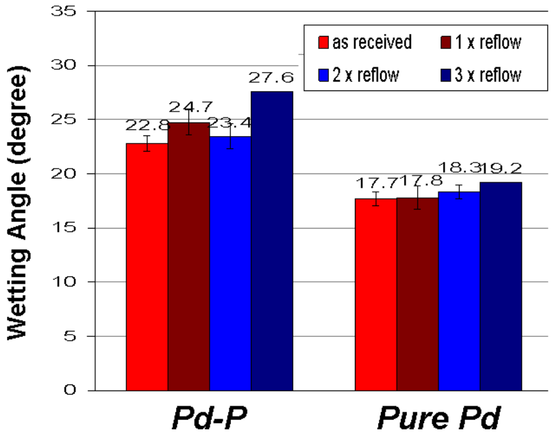


**Fig. 5** Comparison of wetting angle test results for Pd-P (left) and pure Pd (right) for various aging conditions

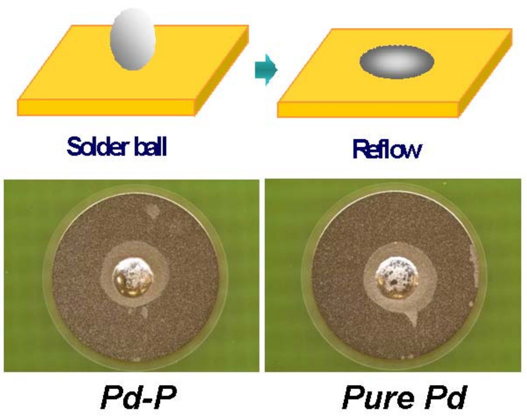
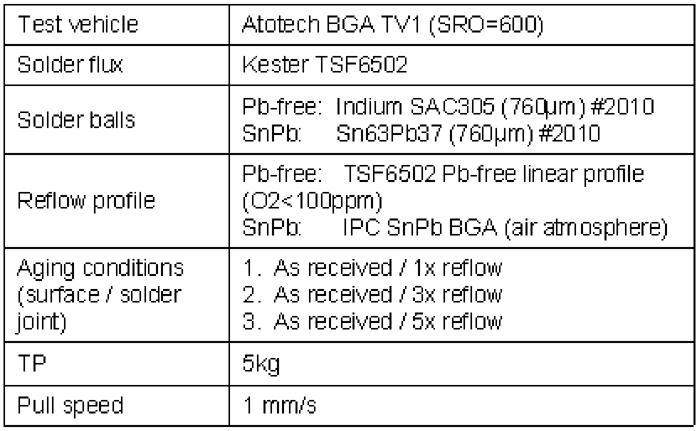


**Fig. 6** Comparison of solder spread test results for Pd-P (left) and pure Pd (right) after one solder reflow

## Solder Joint Integrity of ENEP (with Pure Pd)

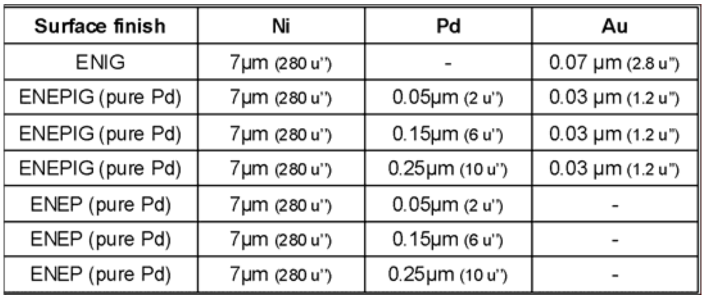
Although the RoHS requirements for Pb-free electronics are now established, there are major industry segments still using eutectic solder. As such, the solder joint integrity of ENEP was tested in this evaluation with both eutectic and Pb-free (SAC 305) solder. The solder joint integrity was tested with a Dage Series 4000 Bond Tester by the cold ball pull test. 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 1 shows a summary of test parameters and Table 2 presents a description of the various surface finishes examined.

**Table 1 -** Test Parameters and Conditions



| | |
|---|---|
| Test vehicle | Atotech BGA TV1 (SRO=600) |
| Solder flux | Kester TSF6502 |
| Solder balls | Pb-free: Indium SAC305 (760µm) #2010<br>SnPb: Sn63Pb37 (760µm) #2010 |
| Reflow profile | Pb-free: TSF6502 Pb-free linear profile (O2<100ppm)<br>SnPb: IPC SnPb BGA (air atmosphere) |
| Aging conditions (surface / solder joint) | 1. As received / 1x reflow<br>2. As received / 3x reflow<br>3. As received / 5x reflow |
| TP | 5kg |
| Pull speed | 1 mm/s |

**Table 2 –** Test Surface Finishes



| Surface finish | Ni | Pd | Au |
|---|---|---|---|
| ENIG | 7µm (280 u") | - | 0.07 µm (2.8 u") |
| ENEPIG (pure Pd) | 7µm (280 u") | 0.05µm (2 u") | 0.03 µm (1.2 u") |
| ENEPIG (pure Pd) | 7µm (280 u") | 0.15µm (6 u") | 0.03 µm (1.2 u") |
| ENEPIG (pure Pd) | 7µm (280 u") | 0.25µm (10 u") | 0.03 µm (1.2 u") |
| ENEP (pure Pd) | 7µm (280 u") | 0.05µm (2 u") | - |
| ENEP (pure Pd) | 7µm (280 u") | 0.15µm (6 u") | - |
| ENEP (pure Pd) | 7µm (280 u") | 0.25µm (10 u") | - |

## Cold Ball Pull Test Results with Eutectic Solder (SnPb)

Figure 7 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. 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 [4]. 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 8. 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.

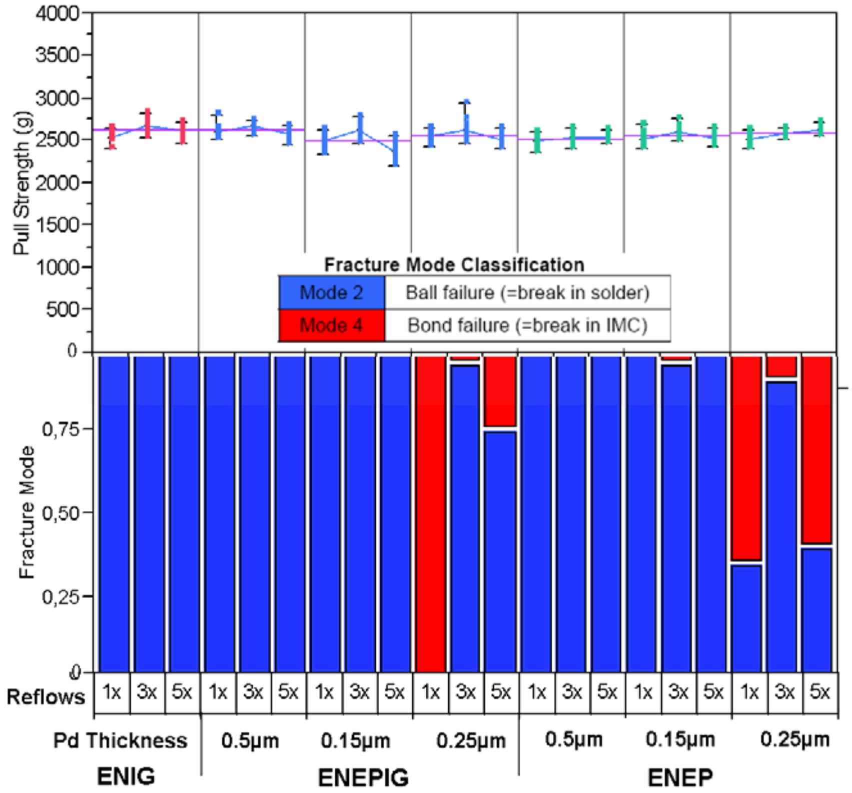


**Fig. 7** Comparison of cold ball pull results for eutectic SnPb solder with tested surface finishes following one, three and five reflow cycles

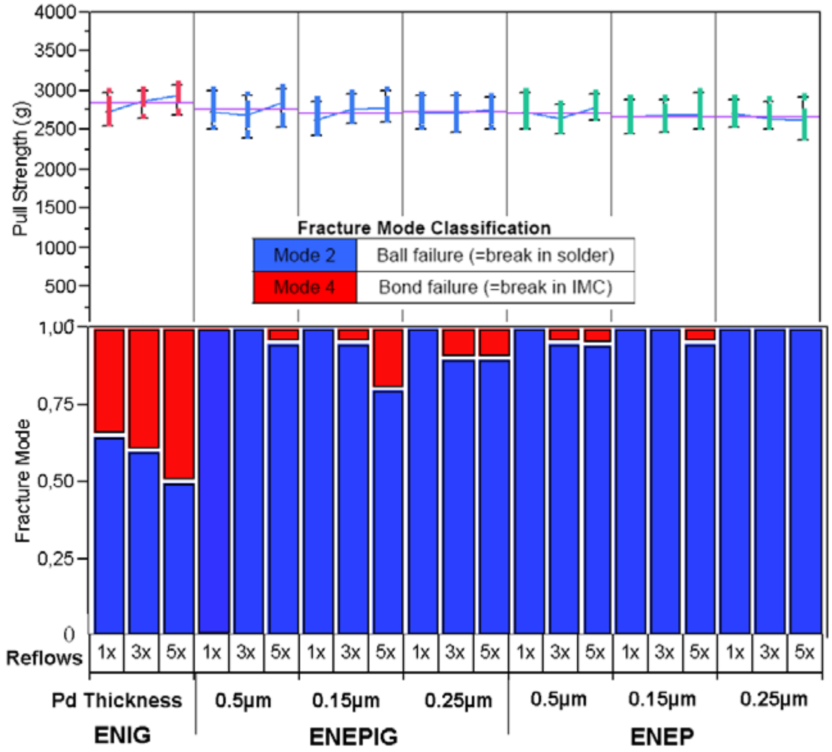


**Fig. 8** Comparison of cold ball pull results for Pb-free solder (SAC 305) with tested surface finishes following one, three and five reflow cycles

## Conclusions:

Like previous efforts, this examination has proven the electroless nickel/electroless palladium (ENEP) process to be a very reliable surface finish and has shown its benefits in terms of solder joint integrity. In those cases where assembly does not require wire bonding technologies, ENEP can be directly substituted for ENIG with the potential for added benefits in terms of solder joint reliability. In addition, from the cost standpoint, ENEP is a gold-free alternative, thus providing a cost saving opportunity compared to ENIG. For applications requiring gold wire bonding, the ENEPIG surface finish offers even more dramatic cost benefits in comparison to the traditional electrolytic nickel/gold process [6].

The use of ENEP finishes for both Pb-free and eutectic SnPb soldering applications is possible by using a pure, autocatalytically deposited pure palladium layer instead of a palladium phosphorus layer (Pd-P). ENEP with phosphorus-containing palladium has been shown to produce a finish of both lower wettability and reduced solder joint reliability. An installed ENEPIG process with pure palladium offers three surface finish possibilities, ENIG, ENEPIG and ENEP, all in one process.

The presentation at the 6th IMAPS International Conference and Exhibition on Device Packaging will provide further details, discussion and interpretation of these test results.

## References:

[1] “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.
[2] “Alternative Nickel-based Surface Finishes for IC Substrate Applications in a Pb-free Environment”; Roberts, Hugh; Lamprecht, Sven; Sebald, Christian. Proceedings: IMAPS International Conference and Exhibition on Device Packaging 2008.
[3] http://www.khulsey.com/jewelry/metal_jewelry_palladium.html
[4] “Electroless Nickel/Electroless Palladium/Immersion Gold Process For Multi-Purpose Assembly Technology”; Johal, K.; Roberts, H; and Lamprecht, S. Proceedings: SMTA International Conference; 2004.
[5] http://www.uyemura.com/solder_joint_reliability.htm
[6] “Analysis of BGA Solder Joint Reliability for Selected Solder Alloy and Surface Finish Configurations”; Roberts, H., et al; Proceedings: IMAPS International Conference and Exhibition on Device Packaging 2009.