Wire Bonding and Soldering on Enepig and Enep Surface Finishes with Pure Pd-Layers

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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 than 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 by using a pure palladium Layer in the ENEPIG (Electroless Nickel, Electroless Palladium, Immersion Gold) 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.

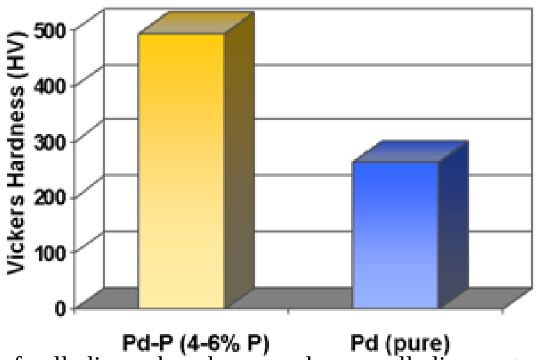


Figure 1: Comparison of hardness of palladium-phosphorus and pure palladium autocatalytic deposits.

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 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 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. 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 (4-6 w%P)	Tensile	3 800 N/mm²
Pure Pd	Tensile	2 100 N/mm²

Topography of Electroless Palladium

When comparing the surfaces of pure Pd and PdP depositions, some difference in the topography is apparent. As shown in Figures 2 and 3, 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.

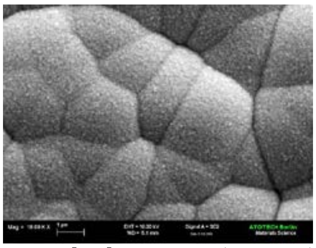


Figure 2: PdP deposition (0.15µm) over nickel, showing a relatively even and smooth surface.

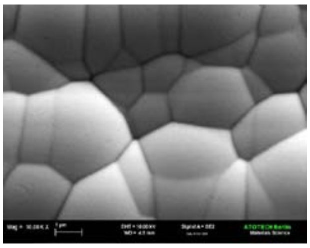


Figure 3: Pure Pd deposition (0.15µm) over nickel, showing some nano-roughness on the surface. and smooth surface.

Crystal Structure

As illustrated in Figures 4 and 5, cross sections show that the crystal structure of PdP is amorphous, whereas pure Pd is characterized by a fine crystalline structure..

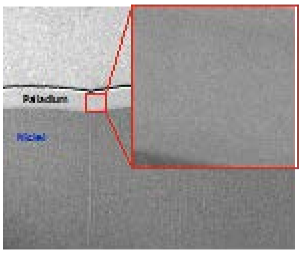


Figure 4: PdP deposition (0.30µm) shows an amorphous structure

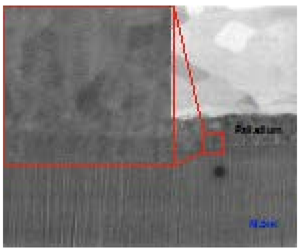


Figure 5: pure Pd deposition (0.15µm) on nickel shows a fine crystalline structure.

TEST CONDITIONS FOR GOLD WIRE BOND INVESTIGATION

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

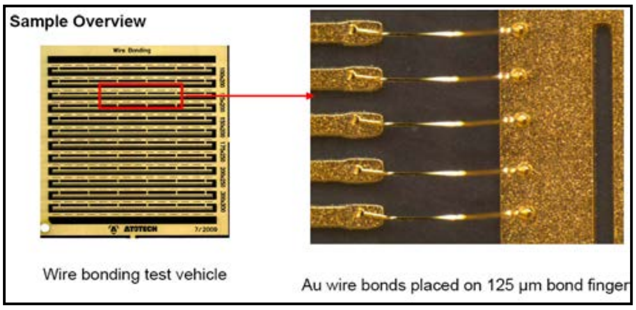


Fig. 6 Test Layout for wire bonding

Table 2: Wire bonding and sample parameters

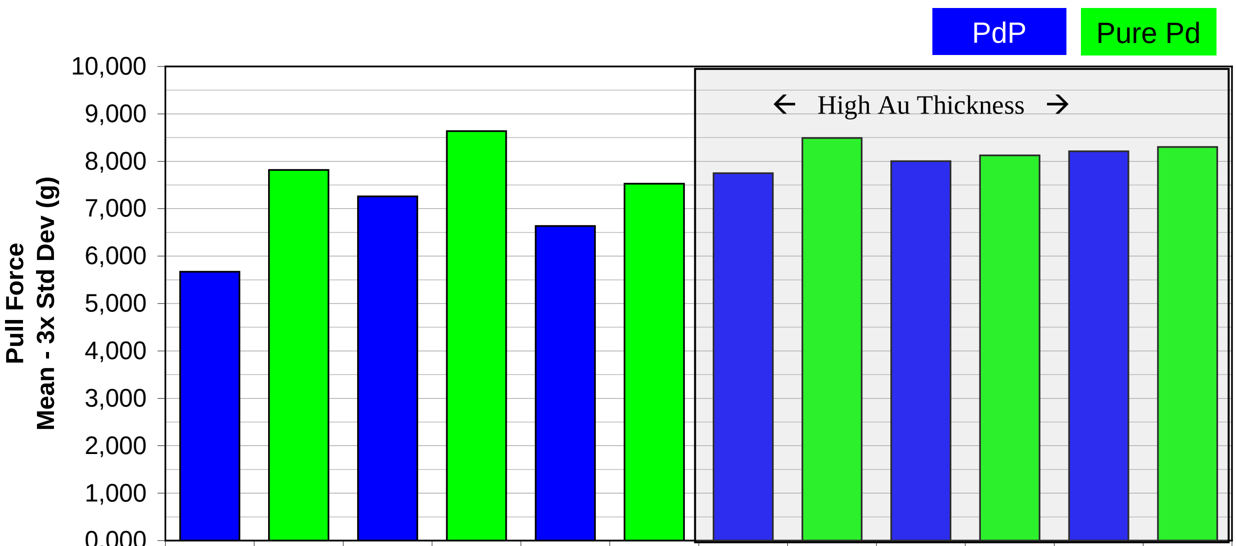
Bond Parameter	
Wedge US	0.68
Wedge Force (g)	24
Time (ms)	20
Temperature* (°C)	165

Sample Details	
Sample	WBTV
Surface Finish	Universal ASF II
Aging	4h 150°C

Equipment Details	
Bonder	Delvotek 5410
Bond capillary	41488-3823-R35
Company	Kulicke & Soffa
Au Wire	Type GMH
Ø	23 µm
Company	Tanaka

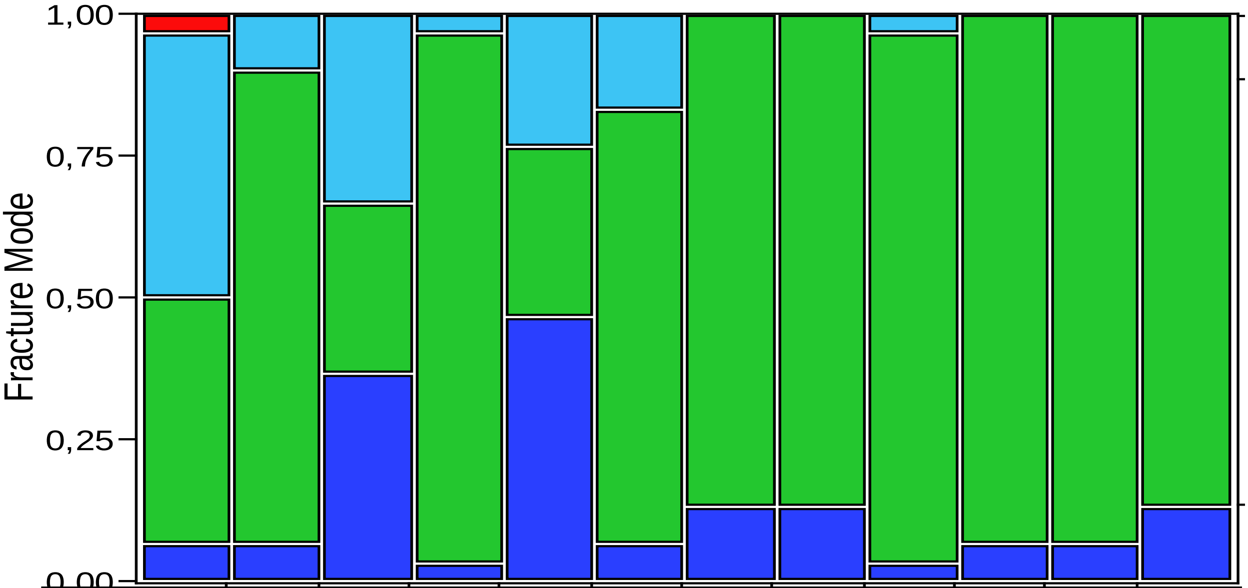
Pull Test Conditions	
Pull Tester	Dage 4000
Pull Speed (µm/s)	500

GOLD WIRE BONDING PROCESS WINDOW



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

Figure 7: 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

Figure 8 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

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 7 and 8, 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 electrolytic deposited Ni/Au (i.e. “soft” gold), the hardness does have a significant influence on gold wire bonding. Conversely, electrolytic 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 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].

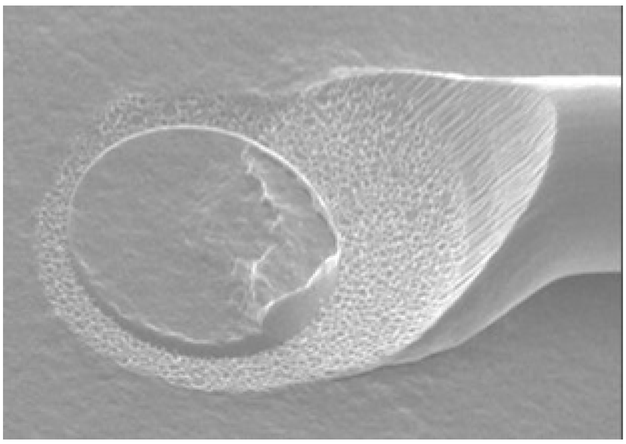


Fig. 9 Typical copper wire wedge bond

SUMMARY

These investigations show that using electroless pure Pd depositions (without co-deposited phosphorus) can enhance the performance of ENEPIG surface finish. 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. In addition the ENEP surface Finish with pure Pd is offering the associated cost reduction by avoiding the expenses for the Gold Bath and ENEP with pure Pd enables next generation interconnection techniques, namely copper wire bonding.

REFERENCES:

[1] "Electroless Nickel/Electroless Palladium/Immersion Gold Process For Multi-Purpose Assembly Technology"; Johal, K.; Roberts, H; and Lamprecht, S. Proceedings: SMTA International Conference; 2004.

[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.

[3] "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.

[4] „Nickel-Palladium Bond Pads for Copper and Gold Wire Bonding" Horst Clauberg, Asaf Hashmonai, Tom Thieme, Jamin Ling and Bob Chylak

[5] „Next Generation Nickel-Based Bond Pads Enable Copper Wire Bonding" Bob Chylak, Jamin Ling, Horst Clauberg, and Tom Thieme

[6] „Nickel-Palladium Bond Pads for Copper Wire Bonding " Horst Clauberg, Petra Backus and Bob Chylak

ATOTECH

Wire bonding and Soldering on ENEPIG and ENEP Surface Finishes with pure Pd-Layers

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TOTAL

IPC Conference USA 2012

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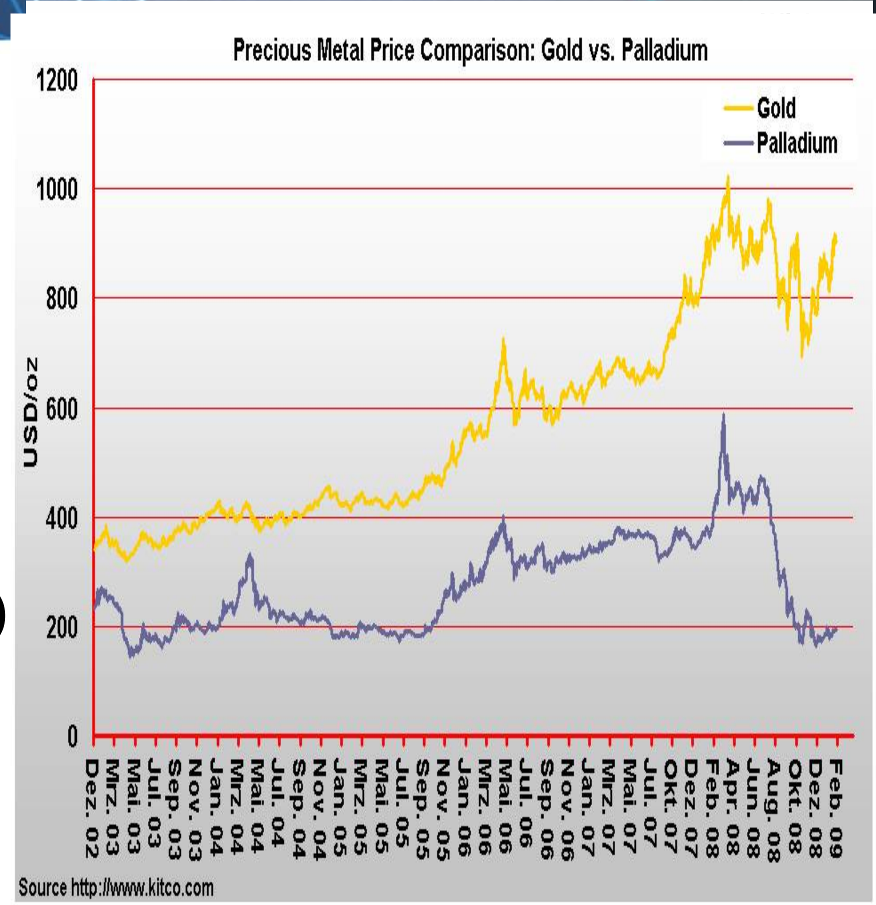
- Introduction
- Pure Pd vs. PdP – Differences in properties
- Au wire bonding performance
- Au wire bonding reliability
- Cu wire bonding data
- Summary

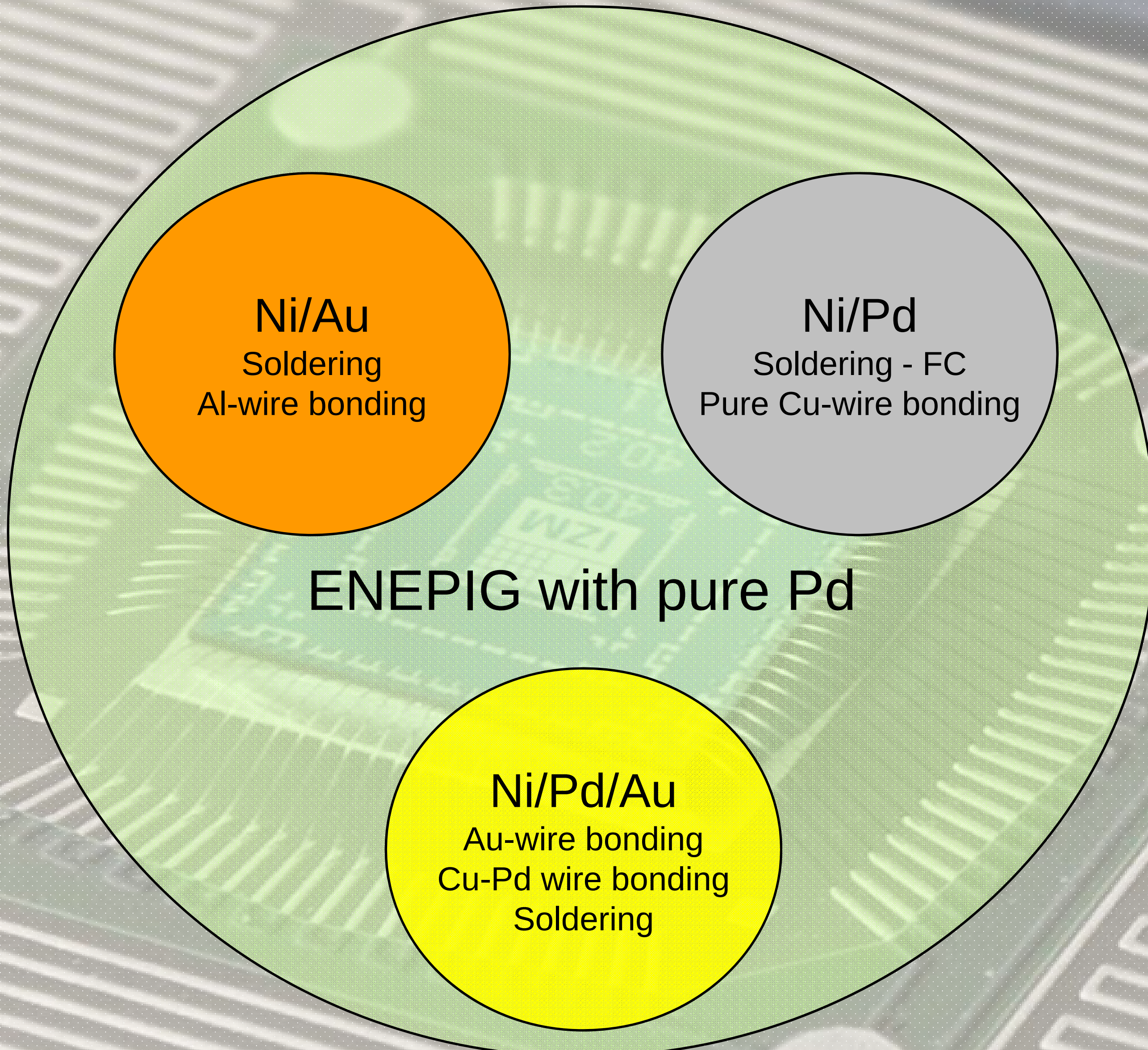
Introduction

Background: Why ENEPIG and ENEP?

- Having a diffusion barrier between copper and solder to avoid cu-consumption during soldering
- Higher mechanical strength of solder joint
- Less fractures in IMC compared to ENIG surface finish
- Gold wire bondable surface (ENEPIG)
- Cu - wire bondable surface (ENEP)
- eliminating the bussing system needed for electrolytic NiAu
- reduced precious metal cost



One Process three Surface Finishes

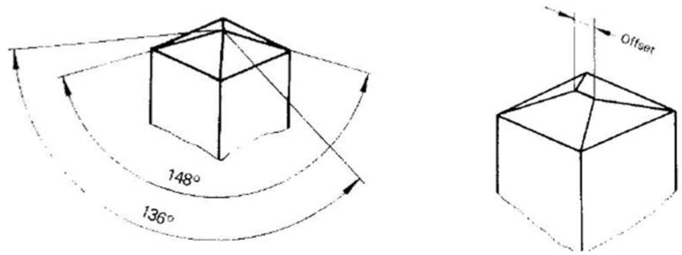


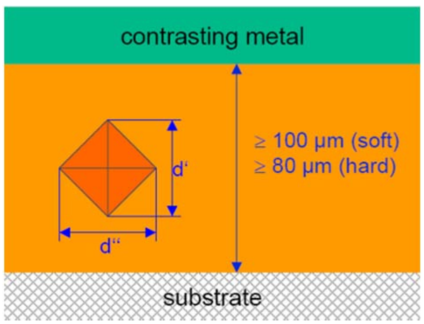
Pure Pd vs. PdP - Differences in properties

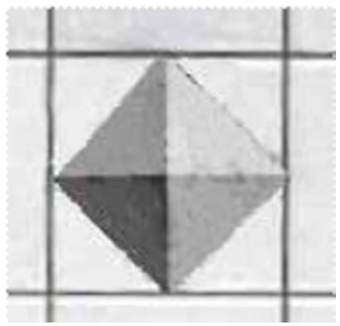
Comparison of Pure Pd and PdP Depositions

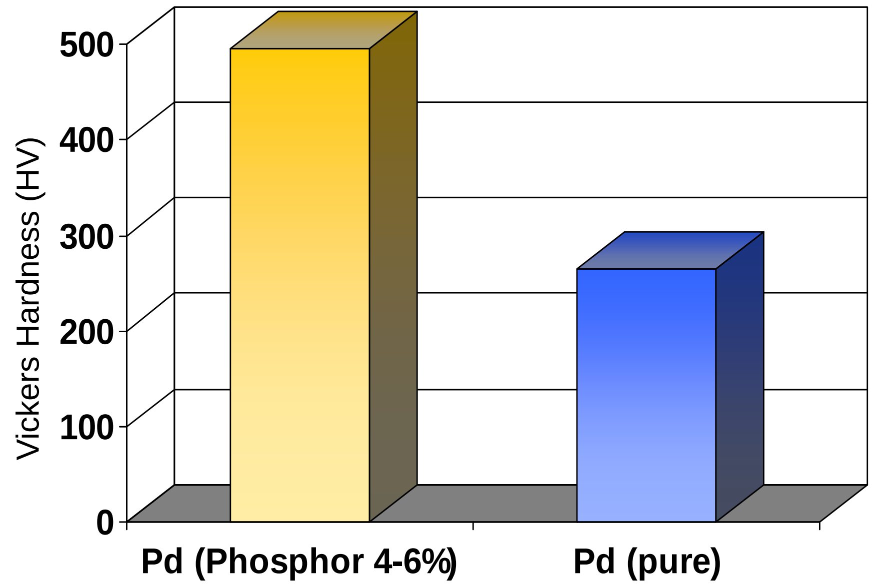
- There are 2 autocatalytic Pd bath types available on the market:
  - with co-deposition of phosphorous
  - pure Pd.
- The basic composition of bathes are different, starting from reducing agents.
- The final plated layers have also some different properties like:
  - Hardness
  - Crystal structure
  - Topography
  - Internal Stress
  - Wetting behavior → Tested by “Solder Spread”

Hardness Comparison by Micro Hardness Method (Vickers-Method according ISO 6507, ISO 4516)



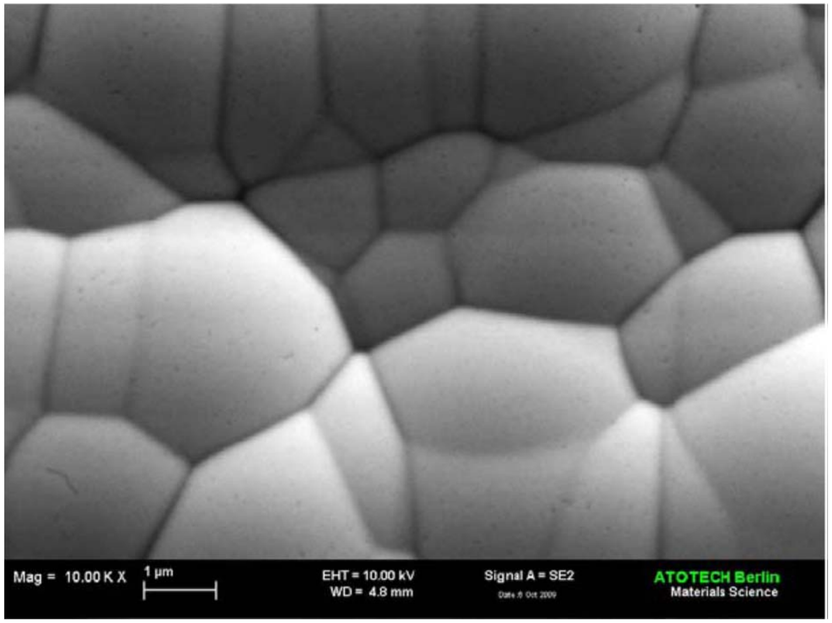






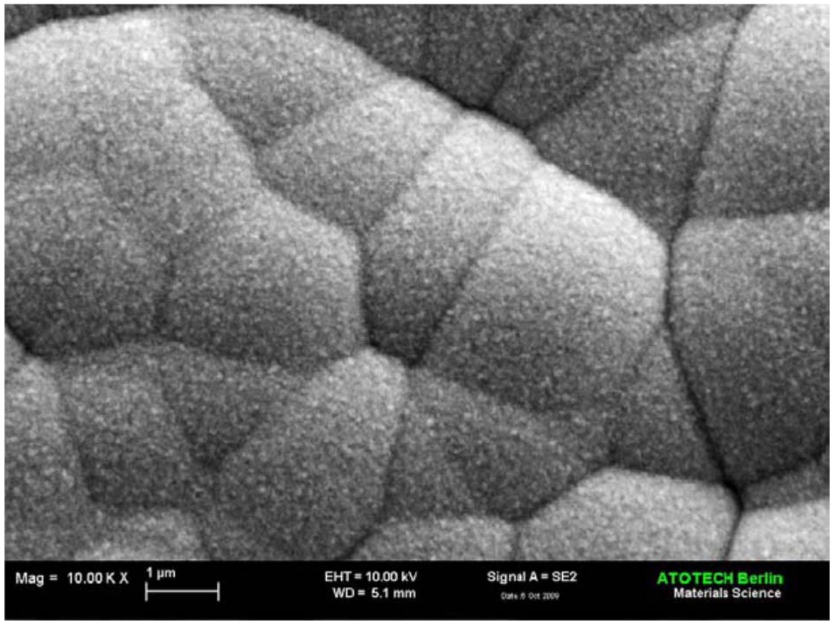
- The hardness of autocatalytically deposited pure Pd is at 250 vickers hardness.

Topography Comparison – FE-SEM



Pd-P

- 0.15µm Pd



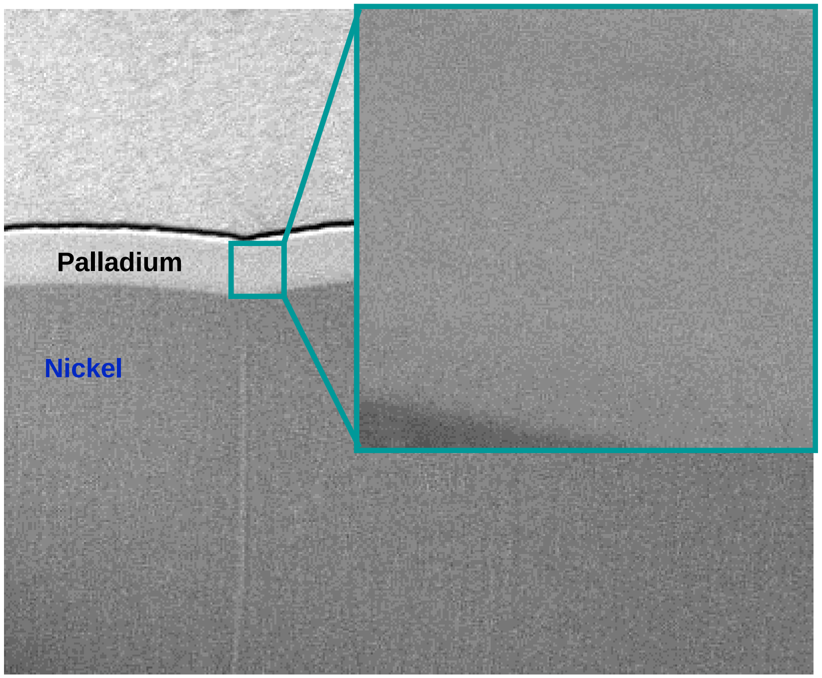
Pure Pd

- 0.15µm Pd

Pure Pd shows a nano structured surface

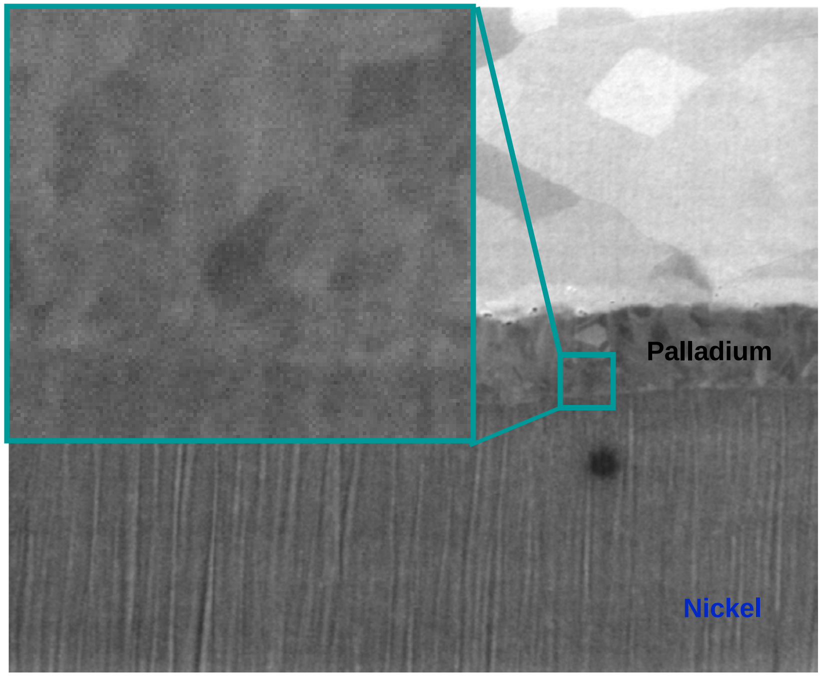
Crystal Structure – FIB

Crystal Microstructure – FIB Cuts



Pd-P

- 0.30µm Pd



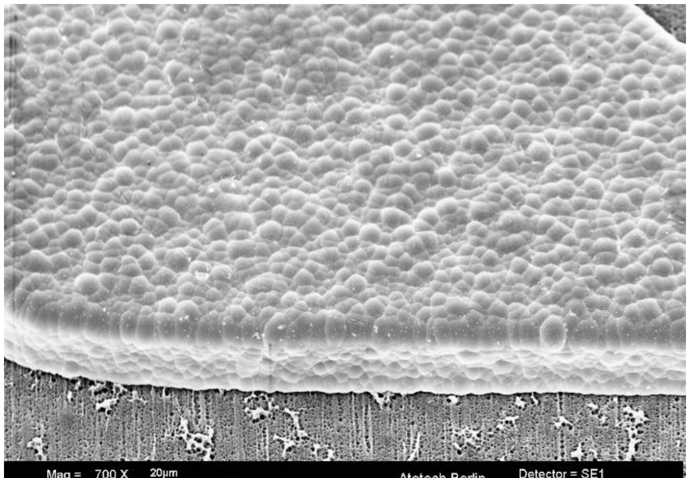
Pure Pd

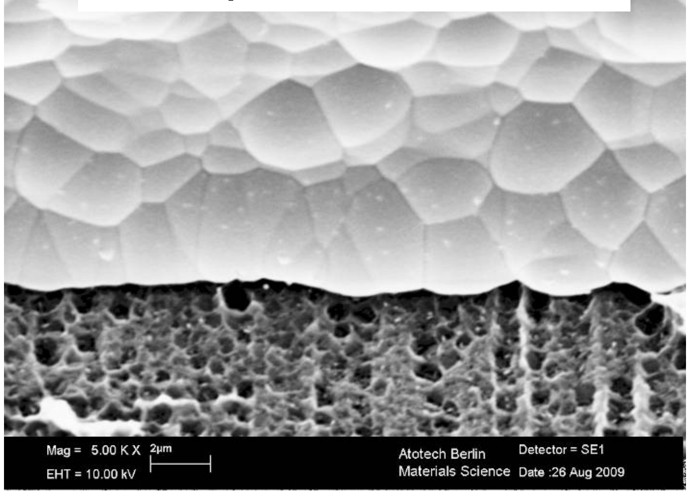
- 0.30µm Pd

No clear structure is seen for PdP - amorphous

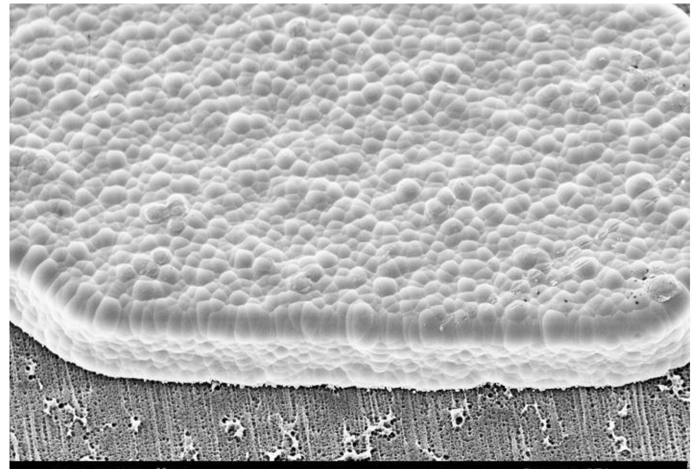
Stray Pd Plating on Substrate

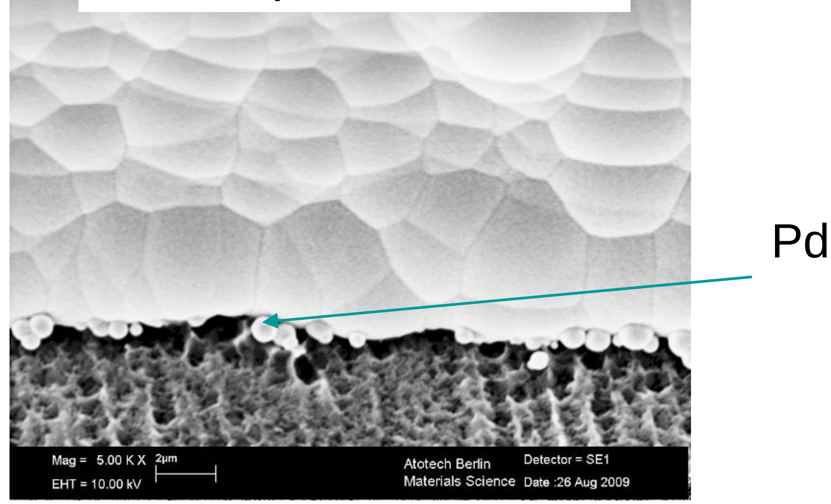
- SEM Top View





Sample 1 – Pure Pd





Sample 2 – PdP

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Internal Stress by Bent Strip (Dual Leg Method)

- **Principle: bending of a strip.**
- **Apparatus:**
  - Metal strip with two legs.
  - Alternatively lacquered on one side each, plating on the respective other sides.
- **Measurement:**
  - Plating in production tank with special cell or in laboratory test tank.
  - Reading of stress state after plating (*ex situ*).
  - Stress can be calculated quantitatively:

$$\sigma = \frac{2f \cdot C}{3 \cdot t}$$

2f distance between strip ends on scale
C calibration constant (provided by supplier)
t coating thickness

Tension   Compression

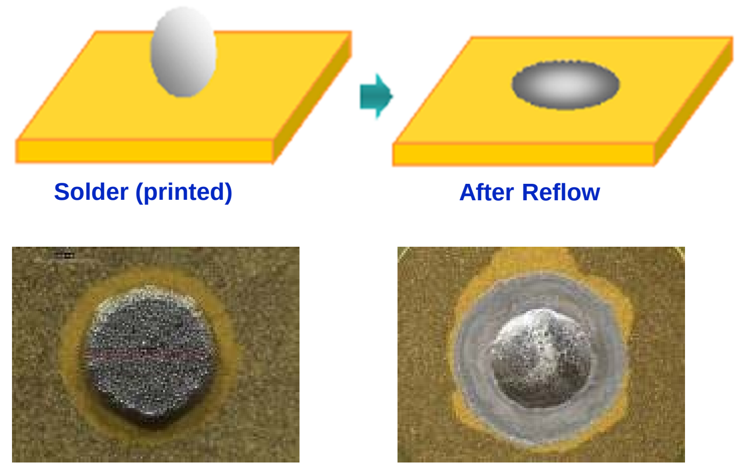
Measurement Results:

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

Internal Stress of Pure Pd is lower than Pd-P

Wetting Performance

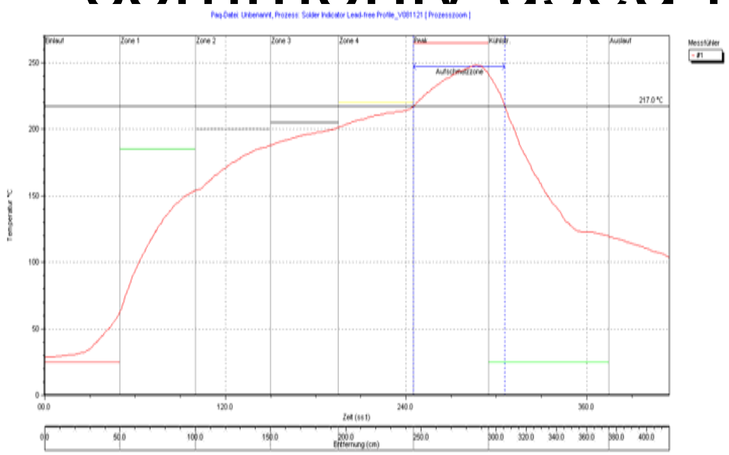
- Solder spread test was done in comparison with different final finishes also commonly used for
  - Immersion Tin



Past Type:

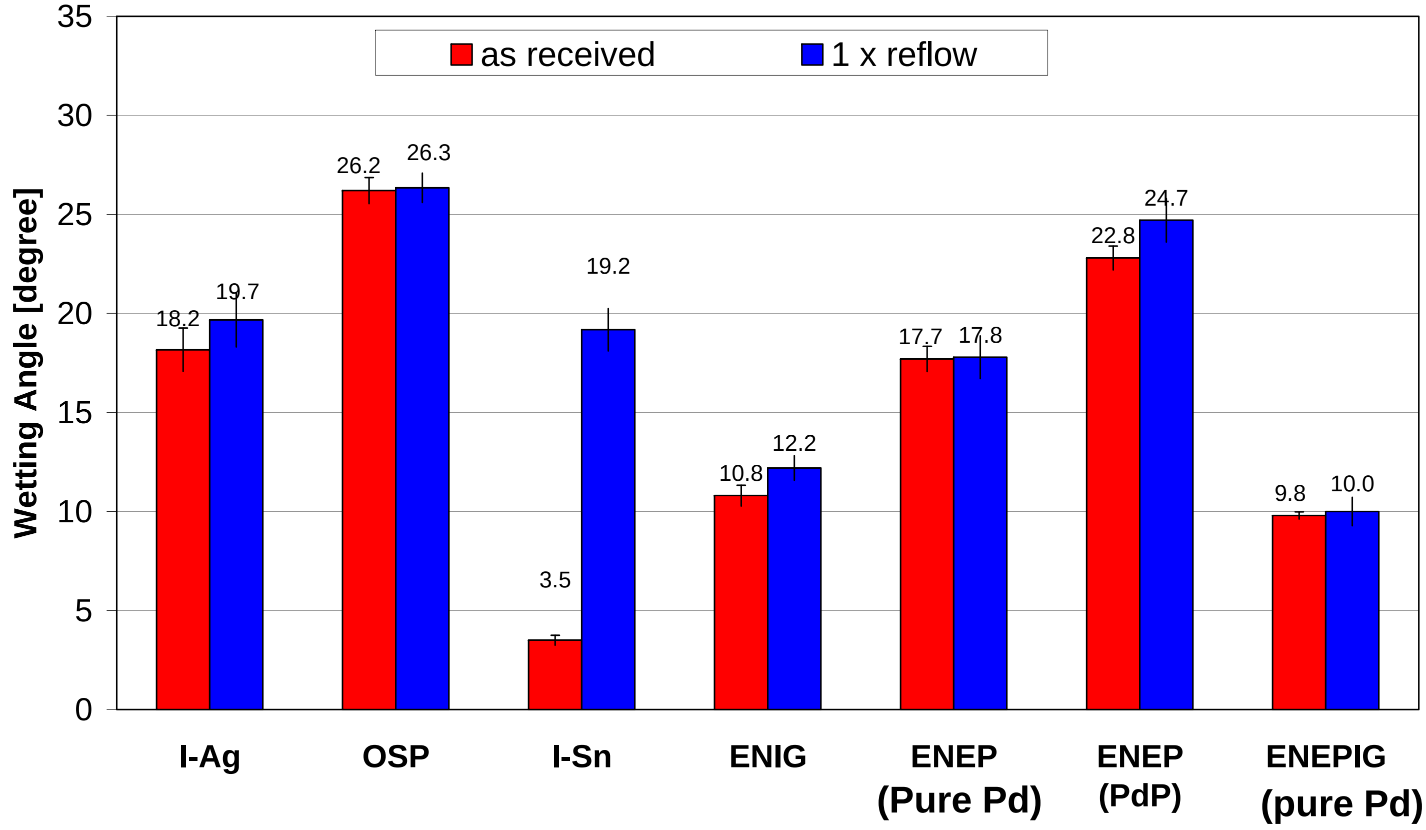
Item	M31-GRN360-KV Series
Alloy Composition	Sn 95.75: Ag3.5:Cu 0.75
Melting temperature	217 - 219°C
Powder Size	25 – 45um
Flux Type	ROL0

Height (paste) = 150µm



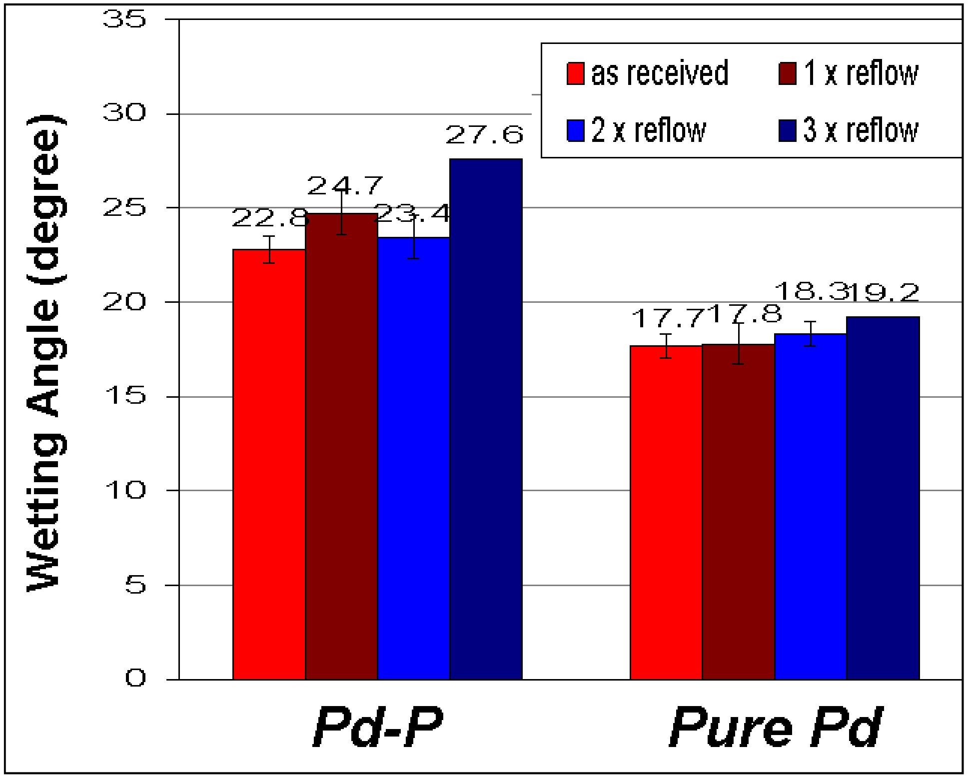
Temperature Profile	
Soak time (150-200° C)	98.5 sec.
Time above liquidus (217° C)	61 sec.
Peak temperature	248° C
Atmosphere	O_2 < 200ppm

Wetting Performance Comparison



Wetting Performance of ENEP better than OSP, I-Ag, I-Sn (after 1xreflow)

ENEP Process
Wetting Performance Comparison



ENEP **ENEP**

Wetting Performance of Pure Pd significant better than PdP type

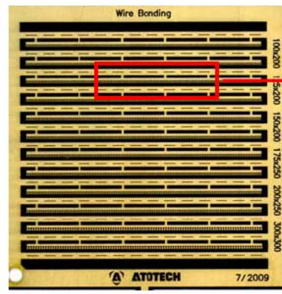
Au Wire Bonding Performance

Gold Wire Bonding
ENEPIG with pure Pd vs. ENEPIG with PdP

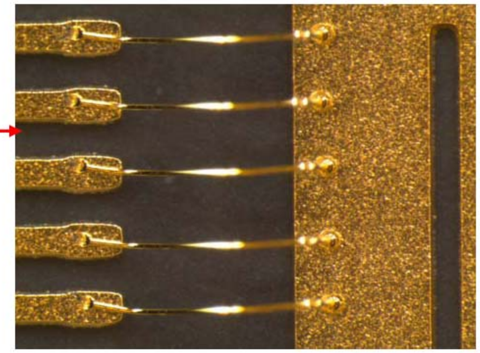
Wire Bonding Condition – Performance Tests

Equipment Details	
Bonder	Delvotek 5410
Bond capillary	41488-3823-R35
Company	Kulicke & Soffa
Au Wire	Type GMH
Ø	23 µm
Company	Tanaka
Pull Test Conditions	
Pull Tester	Dage 4000
Pull Speed (µm/s)	500

Sample Overview



Wire bonding test vehicle

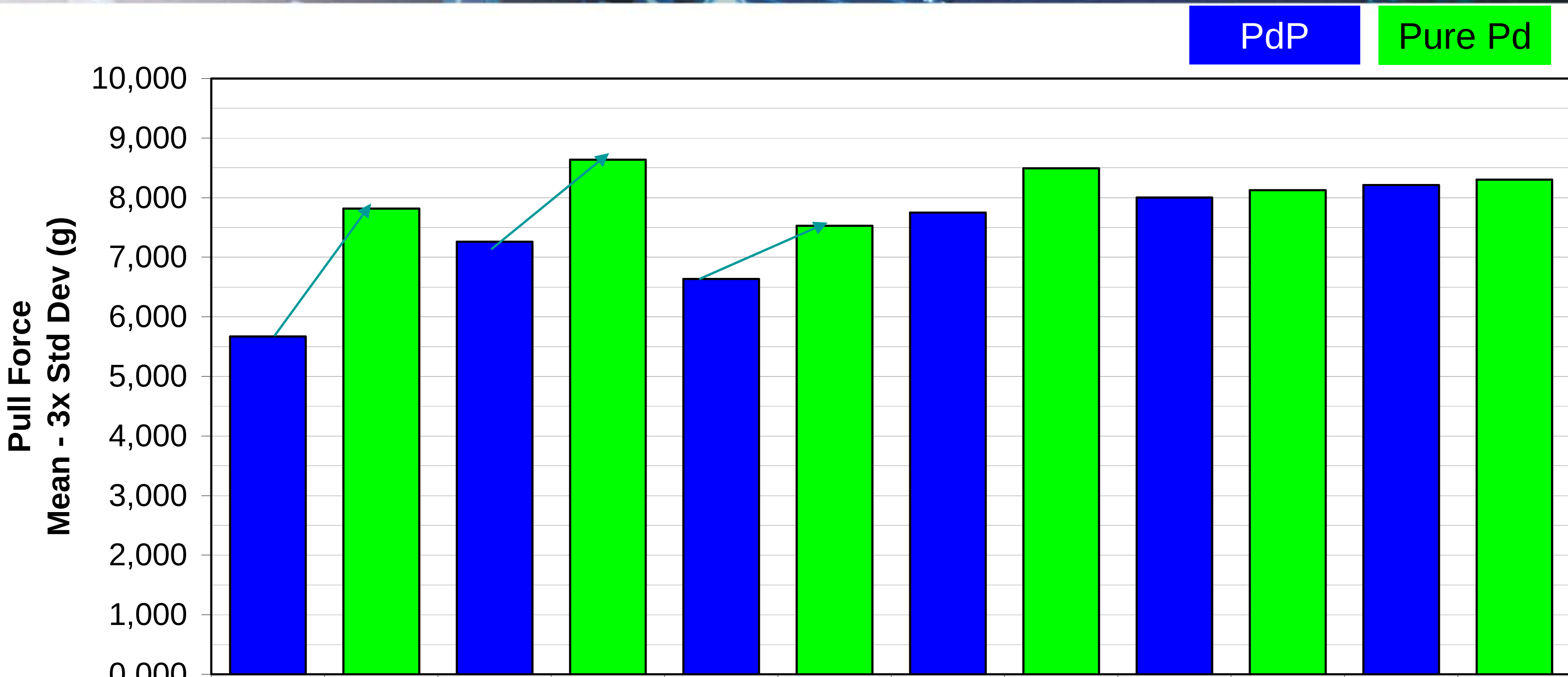


Au wire bonds placed on 125 µm bond finger

Sample Details	
Sample	WBTV
Surface Finish	Universal ASF II
Aging	4h 150°C

Bond Parameter	
Wedge US	0.68
Power (Watt)	
Wedge Force (g)	24
Time (ms)	20
Temperature* (°C)	165

Au Wire Bonding Pull Forces
ENEPIG (PdP) vs. ENEPIG (Pure Pd)

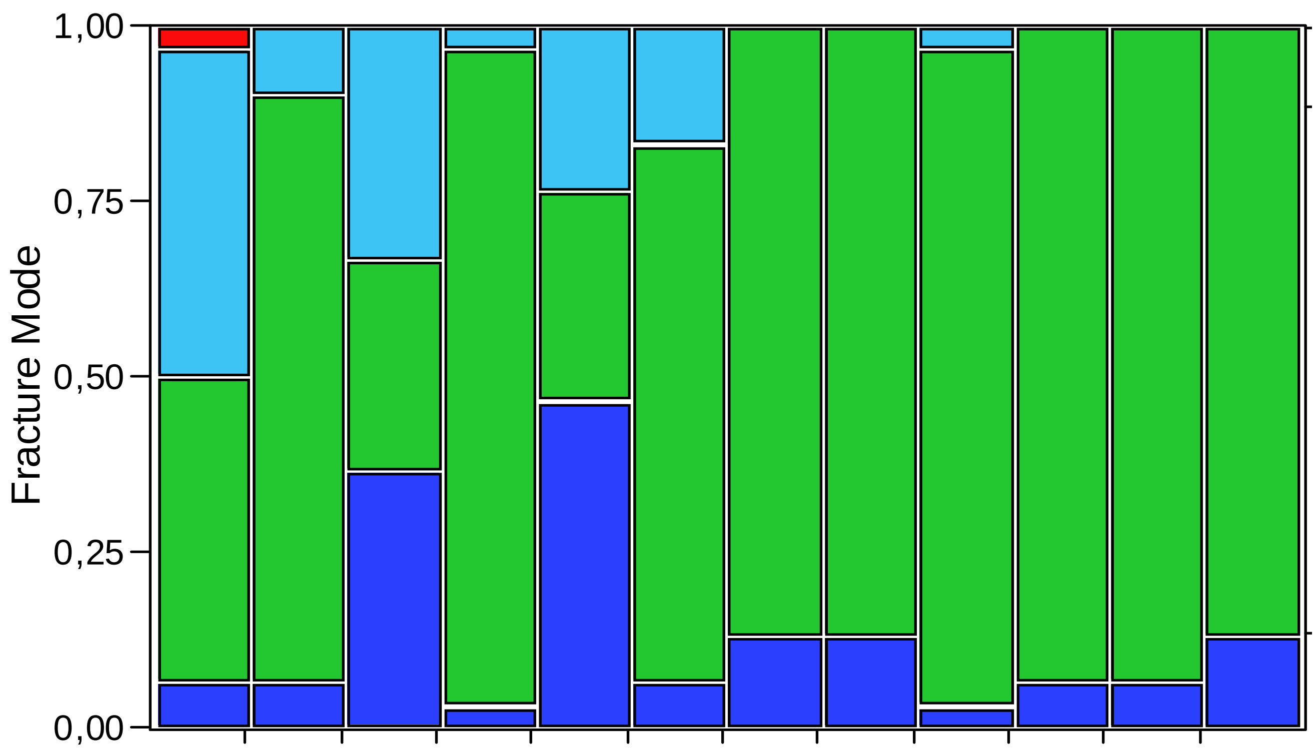


Process	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II
Pd Layer	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd	PdP	pure Pd
Nickel µm	6,0	6,0	6,0	6,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
Pd µm	0,05	0,05	0,15	0,15	0,25	0,25	0,05	0,05	0,15	0,15	0,25	0,25
Au µm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

Low Au Thickness 0.04µm | **High Au Thickness > 0.1µm**

ENEPIG (pure Pd) gets also with lower Au Thickness better wb results than ENEPIG (with PdP)

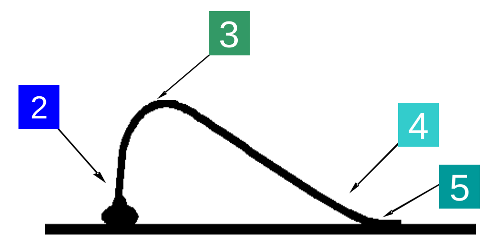
Au Wire Bonding Fracture Modes ENEPIG (PdP) vs. ENEPIG (Pure Pd)



Process	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II	ENEPIG	ASF II
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

Low Au Thickness 0.04µm | **High Au Thickness > 0.1µm**

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



Fracture modes with lower Au-Thickness better with pure Pd compared to PdP

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Au Wire Bonding – Finish comparison - Hardness

Electrolytic Ni Softgold

Electrolytic Soft Au
Au (0.3 - 0.5 µm)
Hardness < 90 HV

Electrolytic Nickel
Thickness 5-7 µm)
Hardness: 600 - 700 HV

ENEPIG with Palladium Phosphor

Semiautocatalytic Au
Au (0.1 - 0. 2 µm)
Hardness ~ 60 HV

Electroless
Palladium-Phos. (4-6wt%)
Thickness 0.15 – 0.25 µm
Hardness: 450 - 500 HV

Electroless Nickel
Thickness 5- 7 µm)
Hardness: 650 - 750HV

ENEPIG with Pure Palladium

Immersion Au
Au (0.04 - 0.06µm)
Hardness ~ 60 HV

Electroless
Pure Palladium
Thickness 0.15 – 0.25 µm
Hardness: 200- 250 HV

Electroless Nickel
Thickness 5- 7 µm)
Hardness: 650 - 750HV

Summary - Au wire Bonding

- ENEPIG with pure Pd-deposition does have a much better Au wire bonding process window because of using soft pure Pd instead of harder PdP.
- ENEPIG with pure Pd-deposition shows very good pull forces and also good fracture modes with low Au-Thickness. Better than ENEPIG with PdP.

Au Wire Bonding Reliability

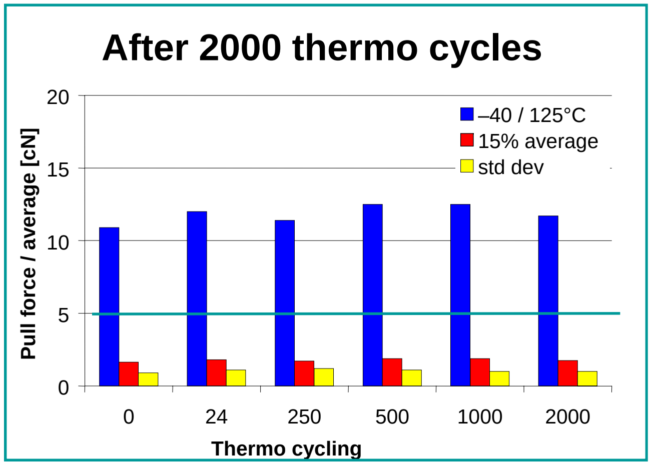
Gold wire bonding

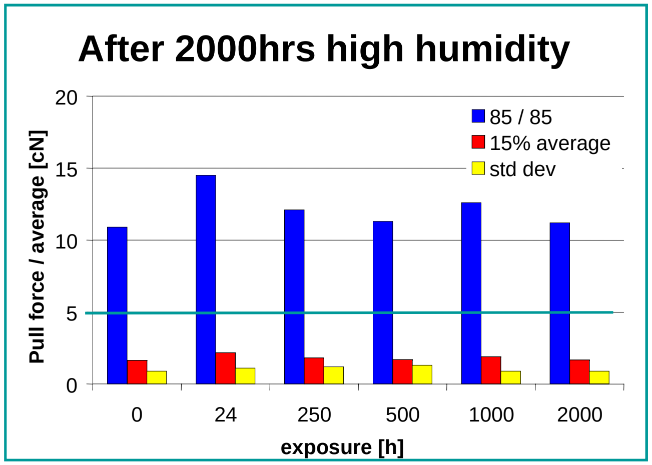
Wire Bonding Condition – Reliability Tests

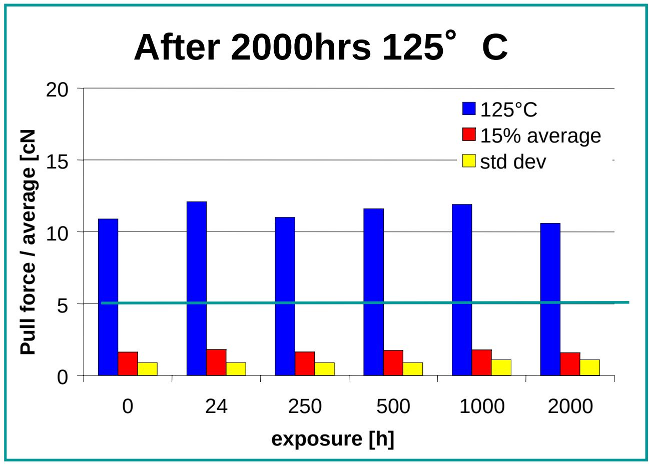
Wire Bonds:	Au-wire (30 µm) / Al-wire (32 µm)
Substrate:	FR4
Thicknesses:	Ni 6µm Pd 0.20µm Au 0.06µm
Dry heat	**0-2000h 125° C** **0-2000h 150° C**
Humidity	**0-2000h 85° C / 85r.h.**
Thermo cycling	**0-2000 cycles –40 / 125° C**

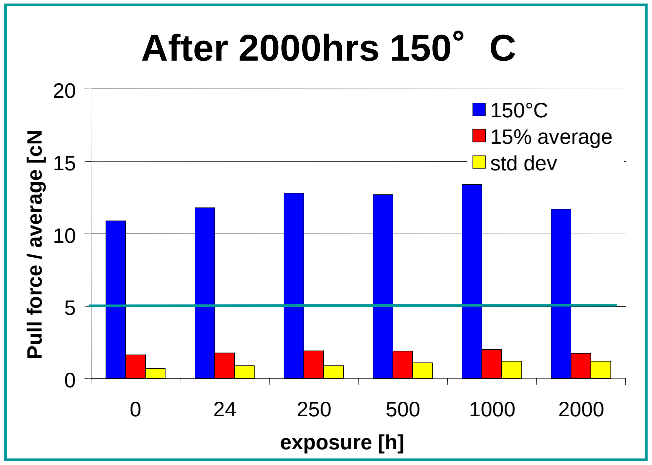
ENEPIG with pure Pd: Reliability

Institute for Semiconductor and Micro Systems Technology









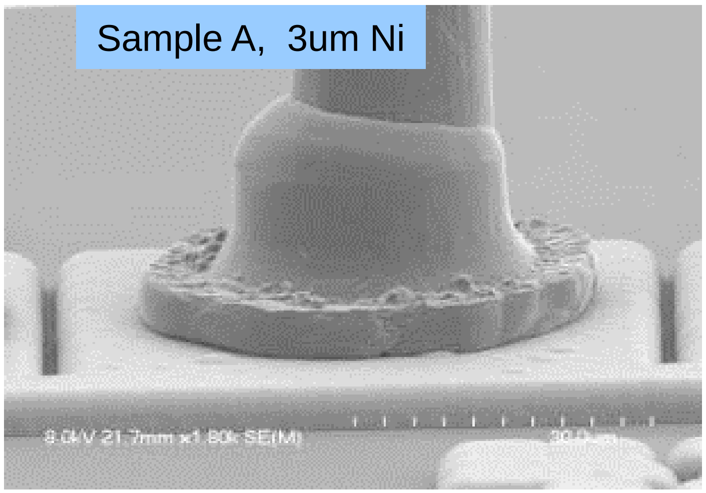
Pass : Standard deviation < 15% of average pull force

Cu wire bonding outlook
(Joint work)

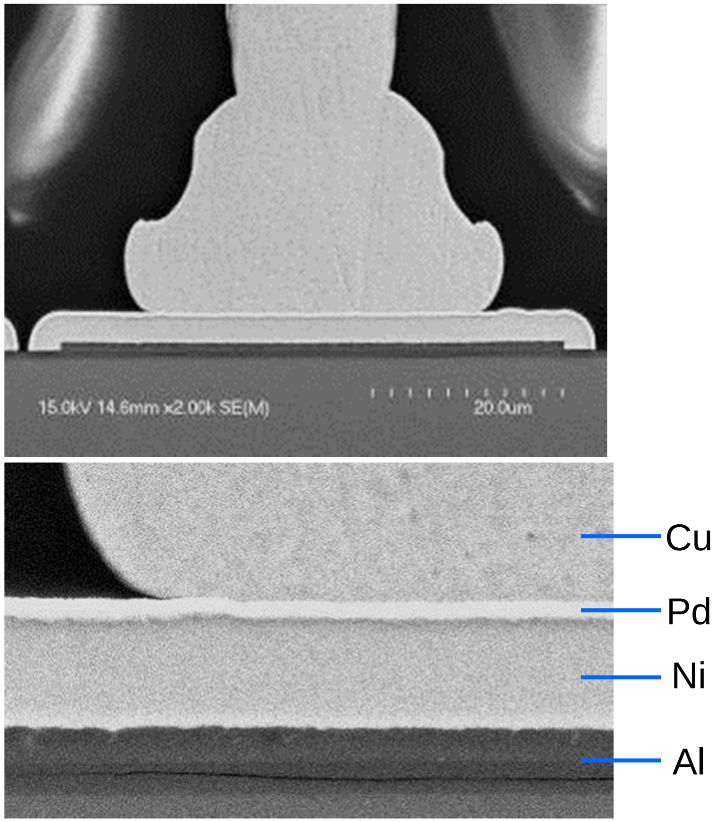
ATOTECH

Kulicke & Soffa

- On the Semiconductor Level Cu-wire



Mode)



Cross-sections of 3µm Ni, 0.3µm Pd, pad bonded with 85 mA USGC

Cu Wire Bonding – Semiconductor
3 Technical Papers Already Published

1.) „Nickel-Palladium Bond Pads for Copper and Gold Wire Bonding“
Horst Clauberg, Asaf Hashmonai, Tom Thieme, Jamin Ling and Bob Chylak

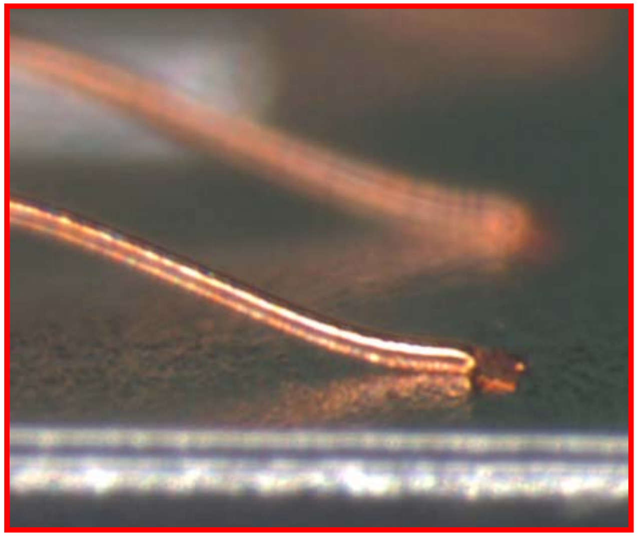
2.) „Next Generation Nickel-Based Bond Pads Enable Copper Wire Bonding“
Bob Chylak, Jamin Ling, Horst Clauberg, and Tom Thieme

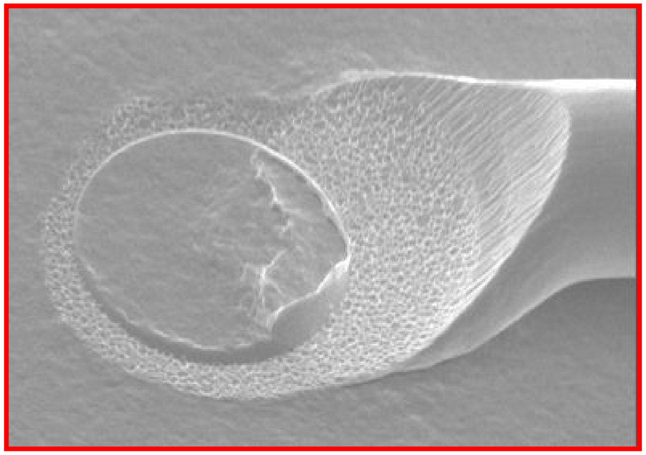
3.) „Nickel-Palladium Bond Pads for Copper Wire Bonding “
Horst Clauberg, Petra Backus and Bob Chylak

Papers are available please contact us after the presentation to get the papers.

Cu Wire Bonding Outlook

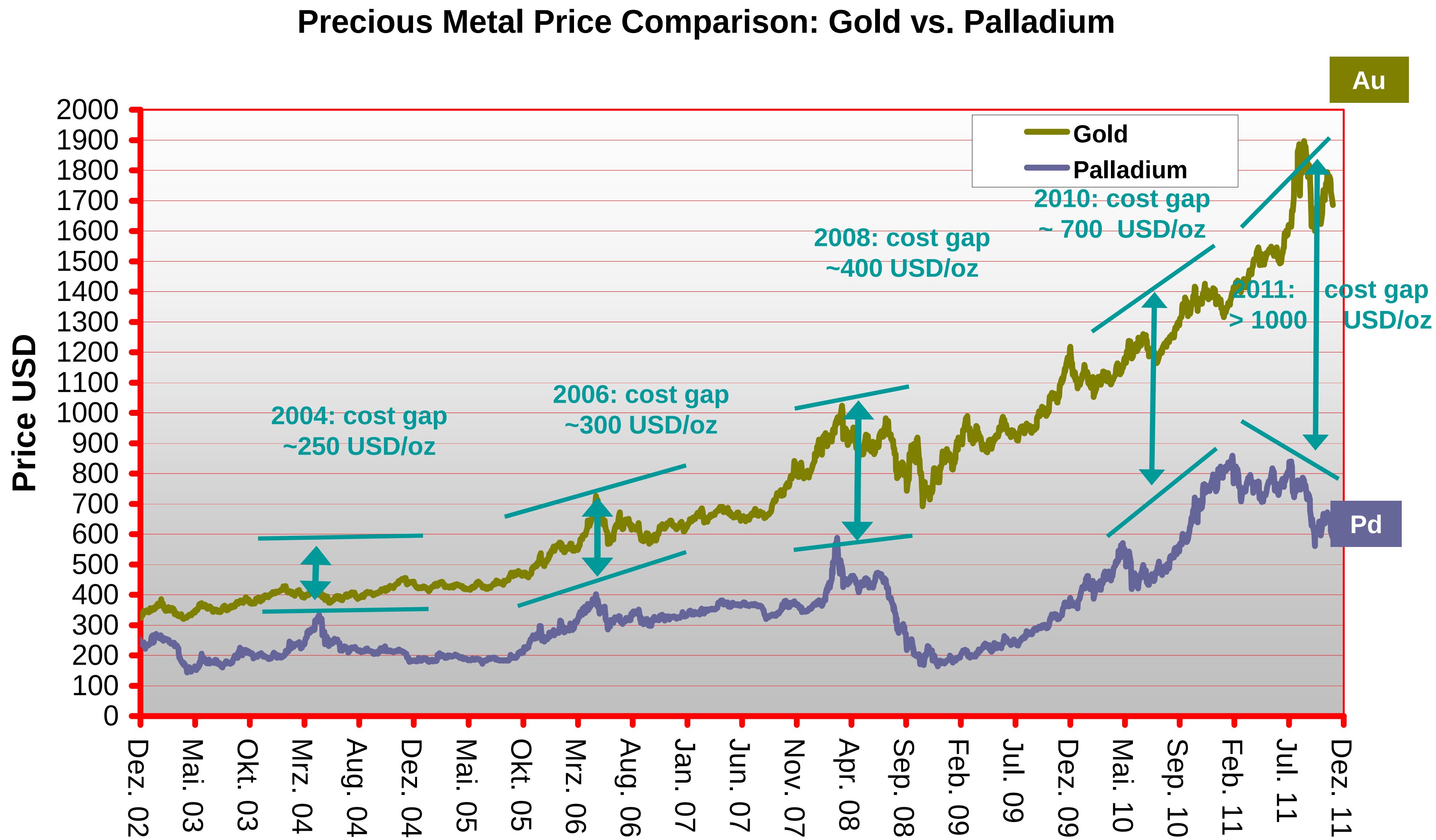
- Atotech started together with K&S also on the substrate level Cu-wire bonding in order to transfer the success of this technology from semiconductor to the substrate level.
- First Results show that ENEP with pure Pd is looking very promising for Cu-Wire Bonding
- New Developments with direct Palladium on Copper are on the way.





Summary

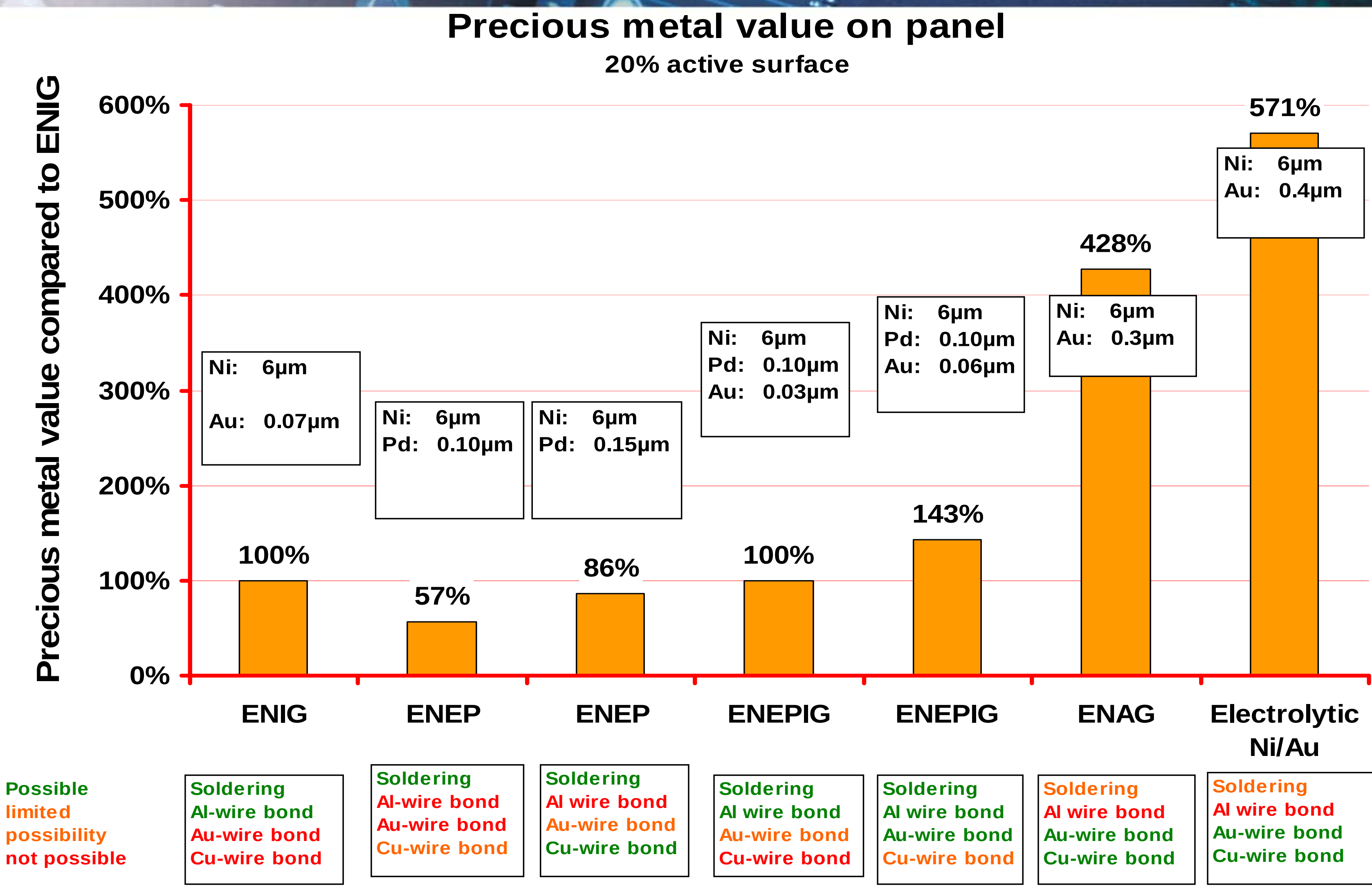
Precious metal: Palladium vs. Gold



Source http://www.kitco.com

Palladium price is much lower than gold.
→ Ni/Pd/Au with lower Au-thickness saves money !!

Precious Metal Costs



Based on precious metal prices of 20.02.2012

Summary

ENEPIG References

- **ENEPIG with Pure Pd System is qualified and used already in Aerospace, Aeronautic, Satellite and Automotive Industry.**

Summary
Differences in properties of pure Pd vs PdP

- Pure Pd is more than 50% softer compared to PdP
- Pure Pd shows significantly better wetting properties
- Pure Pd has a different Surface Structure from Top (Nano Structure)
- Pure Pd has a different crystal structure in FIB cross section
- Pure Pd
- Pure Pd shows less internal stress than PdP

Summary – Performance & Reliability of pure Pd

Gold wire bond

- ENEPIG with pure Pd does have a much better Au wire bonding process window because of using soft pure Pd instead of hard PdP.
- ENEPIG with pure Pd shows very good pull forces and also good fracture modes with low Au-Thickness. Better than ENEPIG with PdP.
- Excellent reliability after temperature aging, thermal cycling, humidity

Copper wire bonding

- ENEP with pure Pd is copper wire bondable and in production on semiconductor side.
- More DOE tests with copper wire bonding is currently done in order to transfer the success of pure Pd with Cu-wire bonding from semiconductor to the substrate side.

Simple "one line" alternative

- Compared to electroplating or electroless gold, combined with dry film masking
- ENIG, ENEPIG and ENEP in one Process

Cost Benefits

- uses much less Gold than electrolytic Gold
- Pure Pd with lower hardness offers Au wire bonding at >0.04µm instead of >0.1
- Replacement also for SIT application (OSP/ENIG)
- Using ENEP as an alternative to Gold containing surface finish

Many thanks for your attention!

Questions?