A Novel Electroless Nickel Immersion Gold (ENIG) Surface Finish for Better Reliability of Electronic Assemblies

Kunal Shah, PhD
LiloTree
Redmond, WA

Abstract

Conventional Electroless Nickel/Immersion Gold (ENIG) currently available in the market is prone to black-pad defects (hyper-corrosion related failures) associated with de-wetting of solder. ENIG also suffers from brittle solder joint failures. Due to these reasons, there are field failures and reliability concerns of electronic assemblies - component disconnection which lead to overall malfunction of electronic assemblies. Moreover, most ENIG manufacturers/suppliers provide cyanide-based gold chemistry which has health and ecological hazards. The novel ENIG eliminates black pad- corrosion related issues, achieves robust solder joints and provides improved quality and reliability of electronic assembly. Also, it uses cyanide-free chemistry for the immersion gold process making it eco-friendly. This allows manufacturers to consume eco-friendly product while avoiding major field failures and resulting consequences.

The root cause of black-pad defects has been identified as hyper corrosion activity at the gold and nickel-phosphorous interface which involves nickel depletion and an enrichment of phosphorous in localized areas. An interfacial engineering approach had been used to successfully eliminate black pad by achieving marked improvement in corrosion resistance. Corrosion tests have been conducted using the potentiodynamic polarization method and tafel plots were generated between novel ENIG and conventional ENIG. The results show 10x improvement in corrosion resistance. This has also led to improved intermetallics at the solder joint leading to robust solder joints and elimination of brittle failures. Ball Shear and Ball Pull Tests (Industry Standard based testing: JEDEC Standard: (JESD22-B115 & JESD22-B117) were conducted on novel ENIG based solder joints and conventional ENIG based solder joints. No solder joints (intermetallics) failures were found with the novel ENIG compared to 80% of failures found at the solder joints with conventional ENIG. Also, the force to induce failure increased by more than about 48% with the novel ENIG compared to conventional ENIG. A novel ENIG is eco-friendly and cost-effective with high corrosion resistance and robust solder joints for better reliability of electronic assemblies.

Introduction

Electroless Nickel Immersion Gold (ENIG) is widely used throughout the electronic industry as a solderable surface finish. With continued circuit feature miniaturization, along with the need for maintaining signal attenuation, copper dissolution into solder joints is a critical issue. Barriers which prevent dissolution of copper into solder joints is very crucial. The principal benefit of ENIG is the role of its nickel layer, which acts as a barrier layer to the dissolution of the underlying copper into solder joints. The ENIG process includes an application of an electroless nickel-phosphorous layer followed by an immersion gold layer. The immersion gold process provides a protective barrier to passivation of the nickel surface. During subsequent reflow soldering processes, gold layer is dissolved into molten solder and the intermetallic forms the bond between Ni-P atoms & tin atoms of the solder [1].

Currently available ENIG is prone to black-pad defects, a failure associated with a poorly formed joint at the solder/nickel-phosphorous interface, which lead to solder de-wetting and failures. Root causes of black-pad defects are identified as hyper corrosion activity of the immersion gold process on the nickel surface. Galvanic hyper-corrosion occurs between gold and nickel atoms resulting in nickel atom depletion and enrichment of phosphorous atoms in the localized area [2,3]. In the case of hyper corrosion, due to depletion of nickel atoms in the localized area, the intermetallic is not allowed to form and wetting of the surface (solder) does not occur. This leads to de-wetting, a solid-to-liquid bond failure, of the solder and interfacial fracture [2].

Moreover, the solder joints involving ENIG lead to brittle failures. Even without the hyper-corrosion between gold and nickel atoms, just the displacement of nickel atoms situated at the top layer(s) leads to enrichment of phosphorous atoms in localized regions. This phosphorous rich intermetallic (larger Ni_3P & Ni_3SnP phases) layer is responsible for brittle failures at the solder joints [1].

The immersion gold processis a galvanic displacement in which gold atoms replace nickel atoms. This process is self-limiting in which once the surface is completely covered by gold atoms the displacement reaction stops. In the case of the Ni(P) layer of electroless nickel plating there are boundaries and crevices on the surface (as seen in the images below). If the boundary or crevice is deep, the supply of gold atoms is slowed down which creates a lack of concentration of gold atoms in crevices compared to the plating bath during the immersion gold process. Hence, the galvanic cell, 2 different metals connected by a salt bridge, is set up between crevice and surface, leading to hyper active corrosion reaction (black-pad defect) at the crevice[3]. Also, sometimes crevices can be so deep that it can penetrate through the thickness of the electroless nickel coating. This results in coating porosity which degrades solderability and can allow copper migration (Figure 1).

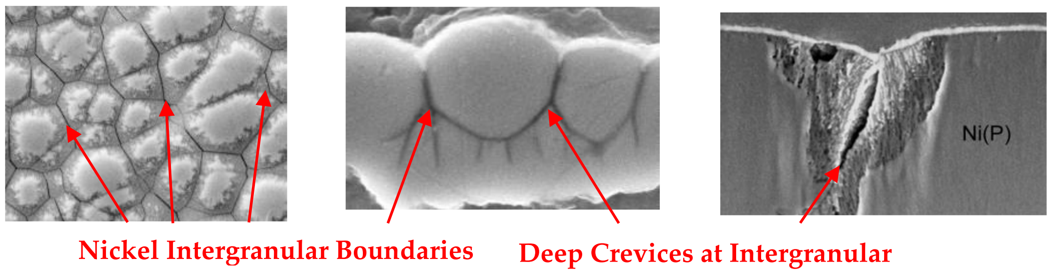


Figure 1: SEM micrograph showing corrosion assisted black pad (surface cracking)

It is essential to design a chemistry and process to curb the hyper-corrosion reaction at the Ni-P surface for a robust ENIG surface finish. Also, solder joints comprised of intermetallic compounds of nickel-tin can be regarded as prone to brittle solder joint failures depending on ENIG chemistry [1]. The newly developed Novel ENIG includes barrier layer at Ni-P and gold interface that results in very high corrosion resistance (elimination of black-pad defects) and robust solder joints which show the desired ductile behavior and are not prone to brittle failures**.** An interfacial nano-engineering approach (inclusion of barrier layer) had been used to successfully eliminate black pads and achieve robust solder joints. The novel immersion gold chemistry is also cyanide-free (eco-friendly) unlike most ENIG finishes currently available in the market.

Analysis of nano-engineered sample (Novel ENIG) compared with conventional ENIG sample

SEM Imaging

The microstructure of Ni-P surface and nano-engineered Ni-P surfaces were evaluated by Scanning Electron Microscopy (SEM). The goal of the analysis was to evaluate the smoothening of the microstructure after nano-engineering the Ni-P surface and assessing each surface treatment. SEM imaging was conducted on the Ni-P plated sample and nano-engineered Ni-P sample (Novel ENIG). The SEM images (Figure 2) show Ni-P surface and nano-engineered Ni-P surface (Novel ENIG). As seen in the SEM images the bare Ni-P surface shows multiple pits and black regions which are very non-uniform. However, the nano-engineered (inclusion of barrier layer) Ni-P surface (Novel ENIG) looks very smooth and uniform without showing any black regions or pitting.

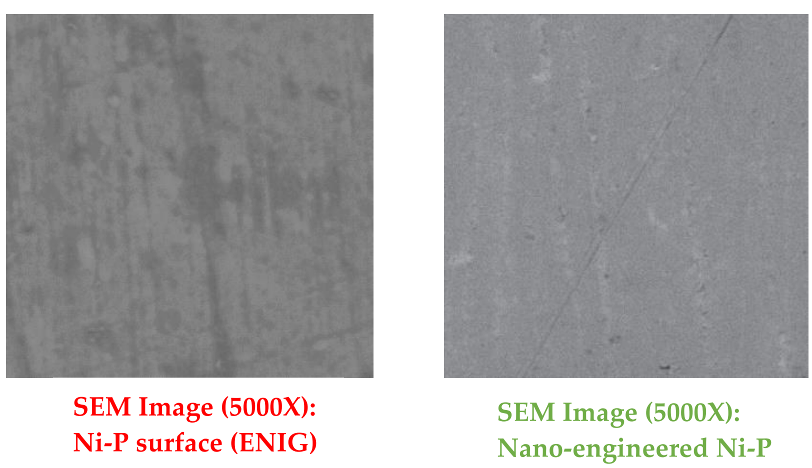


Figure 2: SEM imaging of Ni-P surface (ENIG and Novel ENIG)

Profilometer analysis
Surface roughness measurement was conducted to measure and evaluate surface evenness (unevenness) using the profilometer. Profilometer analysis provided a quantitative measure of surface roughness (Ra and RMS) and helped evaluate presence of deep crevices and intergranular boundaries. Both nano-engineered Ni-P surface (Novel ENIG) and bare Ni-P surface (conventional ENIG) were evaluated using the profilometer.

Observations
Profilometer analysis of conventional (ENIG) sample (bare): Electroless Ni-P layer on Cu surface - Surface roughness of conventional Ni-P sample (Figure 3) was Ra of 1000 Å and RMS of 1244.794.

Profilometer analysis of nano-engineered Ni-P sample (Novel ENIG): Inclusion of nano-engineering on electroless Ni-P layer of Cu surface led to the surface roughness of the nano-engineered sample (Figure 4) of Ra of 480 Å and RMS of 541.

As deduced from this analysis, the nano-engineered sample surface shows much smoother topography compared to the conventional sample (much lower surface roughness Ra and RMS for nano-engineered sample compared to conventional sample). Analysis of the conventional sample also shows the presence of intergranular deep crevices. This analysis suggests that nano-engineering (inclusion of barrier layer) on Ni-P layer helps smoothen the topography and shield deep crevices from potential attack of gold during the immersion gold process – a primary root cause of black-pad defects.

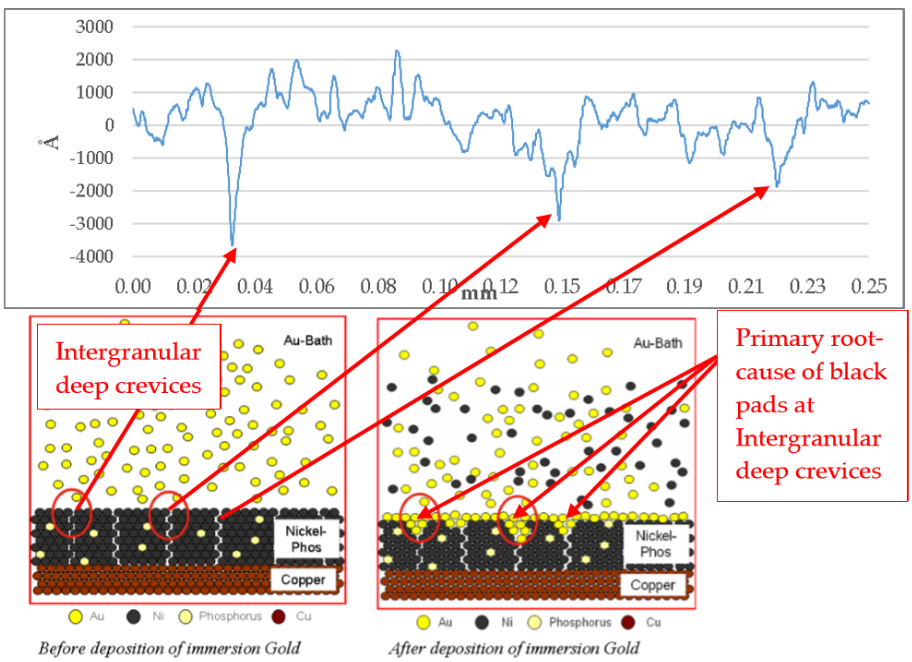


Figure 3: Profilometer analysis of conventional Ni-P surface (ENIG) and illustration of immersion gold reaction on electroless Ni-P layer [4]

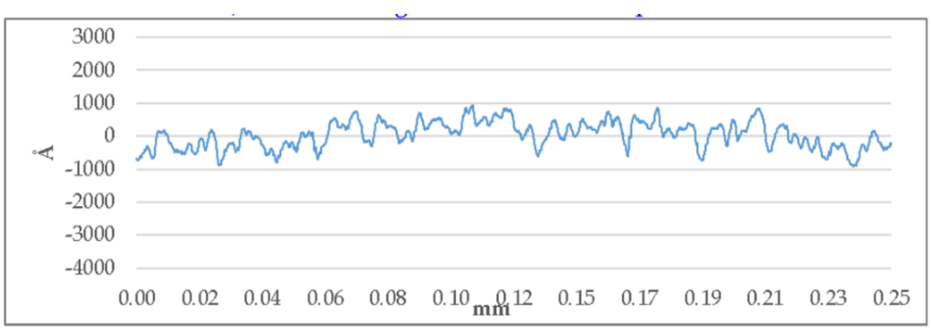


Figure 4: Profilometer analysis of nano-engineered Ni-P surface (Novel ENIG)

Electrochemical corrosion tests:

A potentiodynamic polarization technique using electrochemical set-up was used to measure corrosion resistance quantitatively for the Ni-P surface. Electrochemical polarization testing was performed by recording anodic and cathodic potentiodynamic polarization curves. Investigations such as passivation tendencies of nano-engineering on Ni-P was assessed and their effectiveness compared to untreated conventional Ni-P sample. These measurements were used to determine corrosion characteristics of the nano-engineered (novel ENIG) and untreated Ni-P samples in aqueous environments such as E_{corr} and i_{corr} (corrosion potential and corrosion current). These characteristics were compared between nano-engineered (novel ENIG) samples and the untreated sample (conventional ENIG) and evaluated based on the corrosion inhibition efficiency.

Corrosion parameters of nano-engineered (novel ENIG) and untreated Ni-P samples were evaluated using the potentiodynamic polarization test in 7% NaCl solution. The test was conducted by sweeping the potential from -400 to +200 mV versus open circuit potential at a scan rate of about 1 mV/sec using the potentiostat. The reference electrode employed was Ag/AgCl electrode. Tafel plots (Figure 5) were obtained and E_{corr} & i_{corr} were deduced. The adjacent Table 1 lists the E_{corr} & i_{corr} values for treated and untreated samples.

Observations

E_{corr} for the treated sample shifts about 45 mV towards the positive direction compared to the as deposited Ni-P (untreated) sample. The i_{corr} of the treated Ni-P sample dropped by 8-10x which suggests that the nano-engineering (inclusion of barrier layer) dramatically lowered the corrosion current (i_{corr}) and improved the corrosion resistance. This data can be correlated with the improved black-pad resistance of the treated sample since the black-pad mechanism is hyper-active galvanic corrosion of Ni (Ni-P) by gold (immersion gold process).

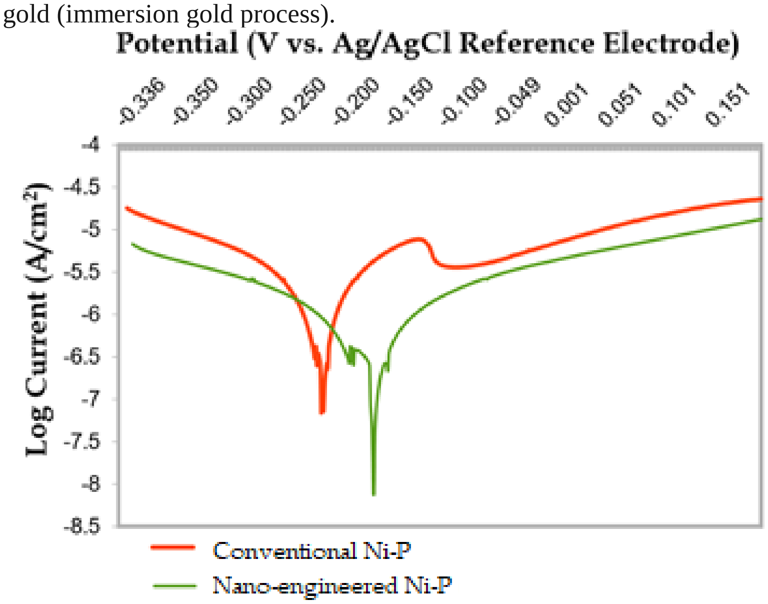


Figure 5:Tafel Plots of conventional Ni-P (ENIG) and nano-engineered Ni-P (novel ENIG) surfaces (Ag/AgCl reference electrode; sweeping potential from -400 to +200 mV versus open circuit potential at a scan rate of about 1 mV/sec)

Table 1: Ecorr & icorr values of conventional Ni-P (ENIG) and nano-engineered Ni-P (novel ENIG)

Sample Description	i_{corr} (A/cm^2)	E_{corr} (mV)
Ni-P (Untreated- Conventional ENIG)	**2.138×10^{-6}**	-207
Nano-engineered Ni-P (Novel ENIG)	**2.75×10^{-7}**	-162

Based on the SEM-EDX and surface roughness (profilometer) analysis, the nano-engineered (novel ENIG) sample looks more smooth and uniform than the conventional Ni-P surface. The potentiodynamic polarization (electrochemical set-up) test concluded that the i_{corr} decreased by 10 times.

This suggests the resistance to black-pad related failures have increased by about 10 folds. These analyses suggest that nano-engineered (novel ENIG) Ni-P surface has high corrosion resistance and will remove black-pad related failures in electronic assemblies.

Analysis of the gold surface to compare conventional ENIG and nano-engineered ENIG (Novel ENIG)

SEM Imaging of gold surface:
The microstructure of the gold surface deposited on the nano-engineered (novel ENIG) Ni-P layer was evaluated by SEM. The goal of the analysis is to evaluate the smooth and complete deposition of gold atoms on nano-engineered (novel ENIG) Ni-P layer. SEM imaging was conducted on both the gold deposited Ni-P plated sample and gold deposited nano-engineered (novel ENIG) Ni-P sample.

Below are the SEM images(Figure 6) of gold on bare Ni-P surface and gold on the nano-engineered Ni-P surface (Novel ENIG). As seen in the images below, gold deposition on bare Ni-P surface is non-uniform at the black regions. However, the gold deposited nano-engineered (inclusion of barrier layer) Ni-P surface looks very smooth and uniform (complete coverage of gold deposition on Ni-P surface) without showing any black regions.

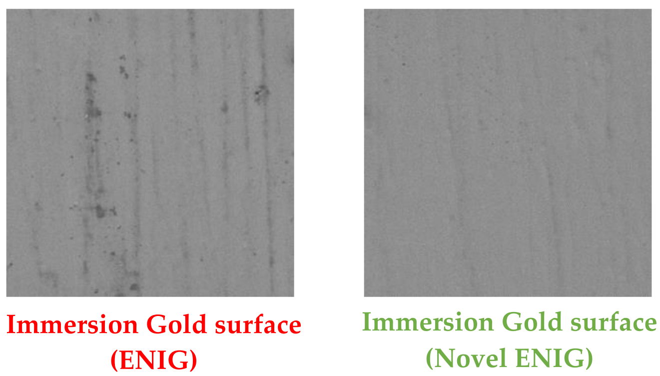


Figure 6:SEM Images (5000x) of gold surface of conventional ENIG and nano-engineered ENIG (Novel ENIG)

Solder Joint Evaluation:
Solder joint formation of the ENIG surface finish happens when the gold layer dissolves into the solder and intermetallic compounds are formed between nickel (nano-engineered (novel ENIG) Ni-P layer) and tin (solder). However, solder joints comprised of intermetallic compounds of tin-nickel-phosphorous can be prone to brittle solder joint failures due to poor ENIG chemistry.

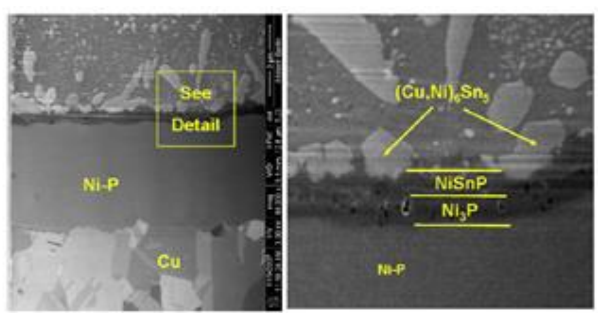


Figure 7:SEM cross-section image at 10,000x (left) of ENIG surface finish after solder ball attach and (right) detailed intermetallic formation[1]

It is essential to evaluate intermetallics in the case of the nano-engineered Ni-P layer (Novel ENIG) and reliability of solder joints to ensure the desired ductile solder joints. The solder ball composition used for this analysis was Sn96.5Ag3.0Cu0.5(SAC 305) and the ball diameter was 0.6 mm.

The solder balls were assembled on the novel ENIG/conventional ENIG plated copper pads of dummy PCBs using water soluble flux and were then subjected to reflow in an IR reflow oven (peak temperature 245°C). Samples were subjected to thermal processes, including multiple reflows (up to 6 reflow cycles).

Cross-section and SEM-EDX analysis

Solder joint formation with the novel ENIG samples was done by cross-sectioning to evaluate intermetallic compound microstructures using SEM-EDX along with conventional ENIG (gold on bare Ni-P) samples. A detailed microstructure evaluation was performed to confirm the interfacial reaction between the solder and the nano-engineered (novel ENIG) Ni-P layer analyzing for formation of different intermetallic compound phases and nickel thickness degradation after multiple reflow cycles.

As seen from the SEM images below (Figure 8), the Ni3P and NiSnP layers are much more distinct and compacting a sample containing the barrier layer (Novel ENIG) due to presence of the barrier layer preventing Ni atom diffusion. However, in the case of conventional ENIG, both Ni3P and NiSnP layers are scattered/diffused and of higher thickness (seen in the Figure2; image on the left). These thicker layers (Ni3P and NiSnP) can have Kirkendall voids and when the stress is applied, it gets concentrated at the weakest link. The voids coalesce and the crack forms/propagates leading to brittle solder joints failures. [1]

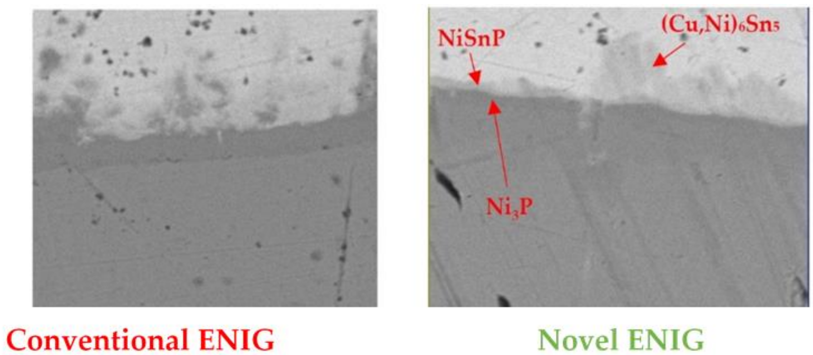


Figure 8: SEM Images (5000x) of cross-section solder joints for conventional ENIG and novel ENIG

Mechanical tests of solder joints

Ball shear test and cold-ball pull tests were conducted to assess the solder joint reliability using the nano-engineered (novel ENIG) and conventional ENIG surface finish with SAC305 solder after multiple reflow cycles (6 reflow cycles). A failure mode evaluation was conducted to understand where the failures occur during these mechanical tests.

Ball Shear Test

Ball shear testing was performed as per JESD22-B117 by a third-party accredited testing laboratory using a ball shear testing speed of 0.5 mm/sec. The solder ball used in the test samples analyzed was lead-free solder (SAC305).

Observations

The force required to induce the ball failure was 1400 grams (avg.) for the novel ENIG compared to 944 grams (avg.) for the conventional ENIG. About 48% more force was required to generate the ball failure (shear) with the novel ENIG compared to the conventional ENIG. 80% of the failures happened at the intermetallics for the conventional ENIG compared to no failures (0%) at the intermetallics for the Novel ENIG as shown in the table below (Table 2). No brittle solder joint failures were associated with the Novel ENIG finish.

Table 2: Failure locations during ball shear testing for conventional ENIG and novel ENIG surface finishes

Surface Finish	Failure Location		
	At Intermetallics (Solder Joints)	Within Solder	At Cu pad within PCB
Conventional ENIG	**80%**		20%
Novel ENIG		**20%**	**80%**

Ball Pull Test:
Ball pull testing was performed as per JESD22-B115 by a third-party accredited testing lab using a ball pull testing speed of 10 mm/sec. The solder ball used in the samples analyzed was lead-free solder (SAC305).

Observations

The force required to create the ball failure was 2717 grams (avg.) for the novel ENIG compared to 1698 grams (avg.) for the conventional ENIG finish. About 60% more force is required to generate the ball failure (pull) with Novel ENIG compared to the conventional ENIG. 80% of the failures happened at the intermetallics for the conventional ENIG compared to no failures (0%) at the intermetallics for the novel ENIG as shown in the table below (Table 3). No brittle solder joint failures were associated with the novel ENIG finish.

Table 3: Failure locations during ball pull testing for conventional ENIG and novel ENIG surface finishes

Surface Finish	Failure Location		
	At Intermetallics (Solder Joints)	Within Solder	At Cu pad within PCB
Conventional ENIG	**80%**	20%	
Novel ENIG			**100%**

Conclusions
Solder joints have been evaluated using the cross-section/SEM analysis method in which the structure of physical intermetallics have been evaluated. Nano-engineered (inclusion of barrier layer) Ni-P led to compact and distinct layers Ni3P-NiSnP phases which lead to robust solder joints. However, conventional ENIG had diffused intermetallics and thick layers of those phases.

Mechanical tests were conducted in terms of solder ball shear test and ball pull test. About 48% more force was required to generate the ball failure (shear) with the novel ENIG compared to the conventional ENIG. Eighty percent of the failures happened at the intermetallics for the conventional ENIG compared to no failures at the intermetallics for the novel ENIG finish. About 60% more force was required to generate the ball failure (pull) with the novel ENIG compared to the conventional ENIG. 80% of the failures happened at the intermetallics for the conventional ENIG compared to no failures (0%) at the intermetallics for the novel ENIG finish. Both physical evaluation of intermetallic using cross-section/SEM and mechanical tests (solder ball shear test and ball pull test) showed robust solder joints by compact-distinct intermetallic and improved mechanical performance (higher force to failure)-failure location (away from intermetallic).

Corrosion tests conducted in the form of the potentiodynamic polarization test (electrochemical set-up) suggested that the corrosion current icorr decreased by 10 times. This correlates with the resistance to black-pad related failures having increased by about 10-fold. These analyses show the nano-engineered (novel ENIG) Ni-P surface has high black-pad related failure resistance in electronic assemblies.

Elimination of black-pads related failures and ensuring robust solder joints with the novel ENIG can help to lead to improved reliability of electronic assemblies for various industry sectors. The novel ENIG involves inclusion of a barrier layer (nano-engineering) at the Ni-P and immersion gold interface which leads to smoothening of the Ni-P interface, passivation of the surface which increases corrosion resistance (helping to remove the black pad issue). Also, barrier layer helps attain robust solder joints by minimizing the intermetallic thickness and preventing Ni atom diffusion. These benefits will help manufacturers to avoid major failures and the resulting consequences.

References:

[1] Effect of Process Variations on Solder Joint Reliability for Nickel-based Surface Finishes, H. Roberts, et. al., SMTA China East- NEPCON Shanghai Conference Proceedings, April 2008.

[2] A Root Cause Failure Mechanism for Solder Joint Integrity of Electroless Nickel/Immersion Gold Surface Finishes, N. Biunno, et.al., SMTA Surface Finishes Forum Conference Proceedings, May 2000.

[3] The Root Cause of Black Pad Failure of Solder Joints with Failure of Solder Joints with Electroless Ni/Immersion Gold Plating, K. Zeng, et. al., pg. 75-79, JOM, June 2006.

[4] ENEP (Electroless Nickel Electroless Palladium) – A Cost-Effective Alternative for High Reliability Soldering Applications, Gustavo Ramos, et. al., iMAPS, Additional Conferences (Device Packaging, HiTEC, HiTEN, & CICMT) Volume 2010, pp. 002190-002224, January 2010.(https://doi.org/10.4071/2010DPC-tha22)

A Novel Electroless Nickel Immersion Gold (ENIG) Surface Finish for Better Reliability of Electronic Assemblies

Kunal Shah PhD.
LiloTree

Why Better Reliability in Electronics?

- Risk Mitigation
  - *Field failures cost money and harm one's reputation. So do non-routine quality events such as major observations, recalls, warning letters, consent decrees, warranties, and lawsuits*
- Yield Improvement
  - *Higher yield results in cost effectiveness & increased revenue*
- Better Quality
  - *Safer, stronger, durable, and brand value*

Conventional ENIG & ENEPIG

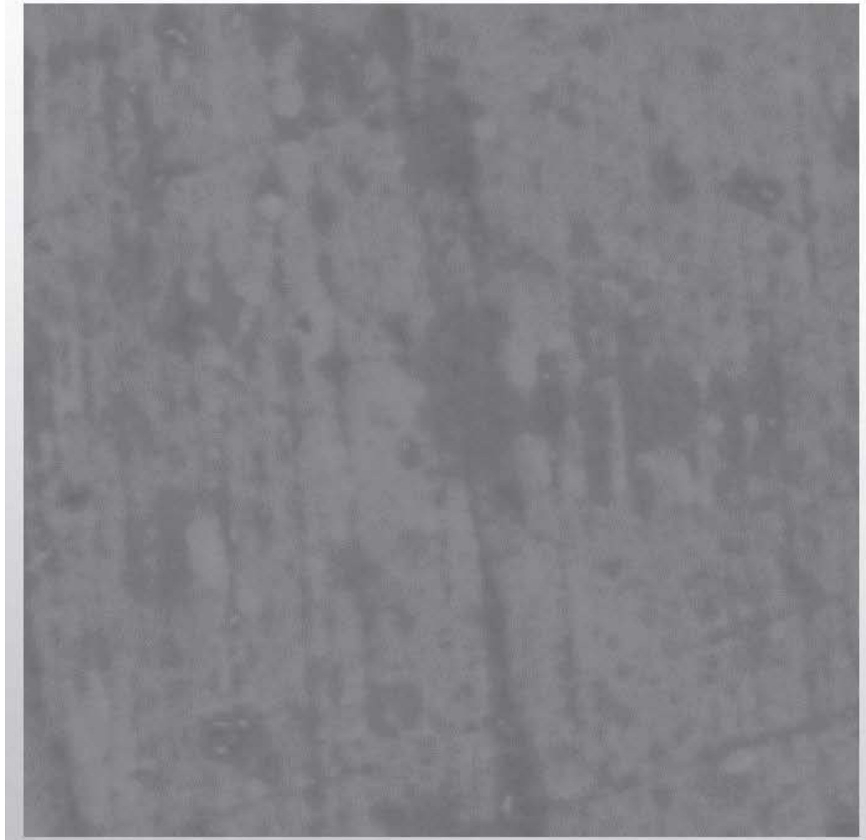
- Conventional ENIG suffers from reliability issues
  - *Black pad defects - electrical continuity failures and low quality performance, non-wetting to solder, component fall-offs, etc.*
  - *Brittle failures at solder joints*
- ENEPIG resolves the black pad defects but is expensive
  - *2-5X more expensive than conventional ENIG*
  - *Lead based solder + ENEPIG can exhibit brittle solder joint failures*
  - *Thicker Palladium (Pd) layer can also exhibit brittle solder joint failures*

Novel ENIG: Nano-engineering

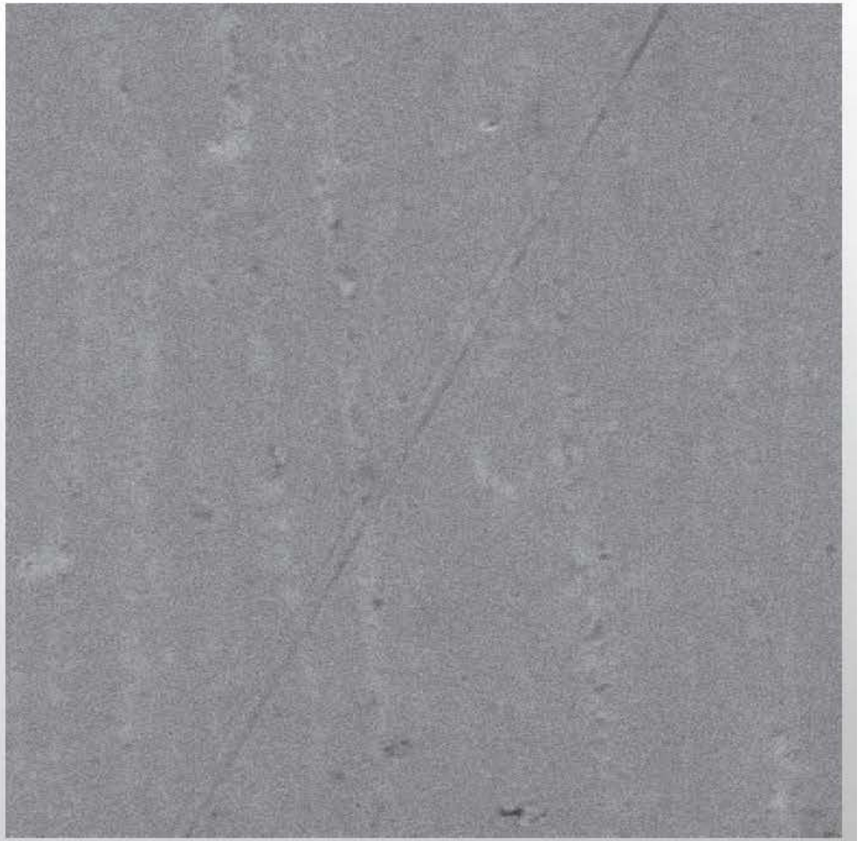
- Immersion Gold process of conventional ENIG involves displacement of Ni by Au atoms through galvanic corrosion process
  - ✘ *Uncontrolled Ni displacement by Au leads to black pad*
  - ✘ *Ni displacement by Au leads to localized P-rich area – contributing towards brittle solder joints*
- Novel ENIG includes barrier layer at the Electroless Nickel-Phosphorous & Immersion Gold interface using interfacial nano-engineering
  - ✓ *No black pad*
  - ✓ *No brittle solder joint failures- robust solder joints*

SEM Imaging of Ni-P, ENIG vs. Novel ENIG

SEM Image (5000x): Ni-P Surface (ENIG)



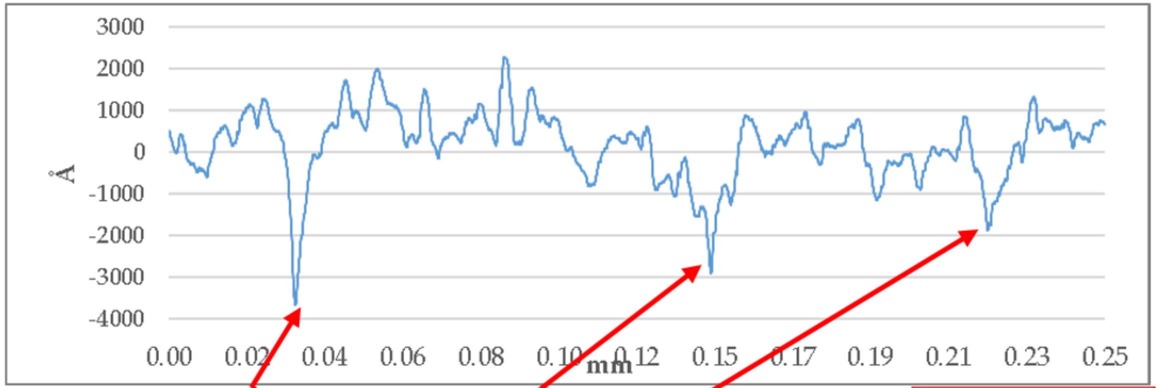
SEM Image (5000x): Ni-P Surface (Novel ENIG)



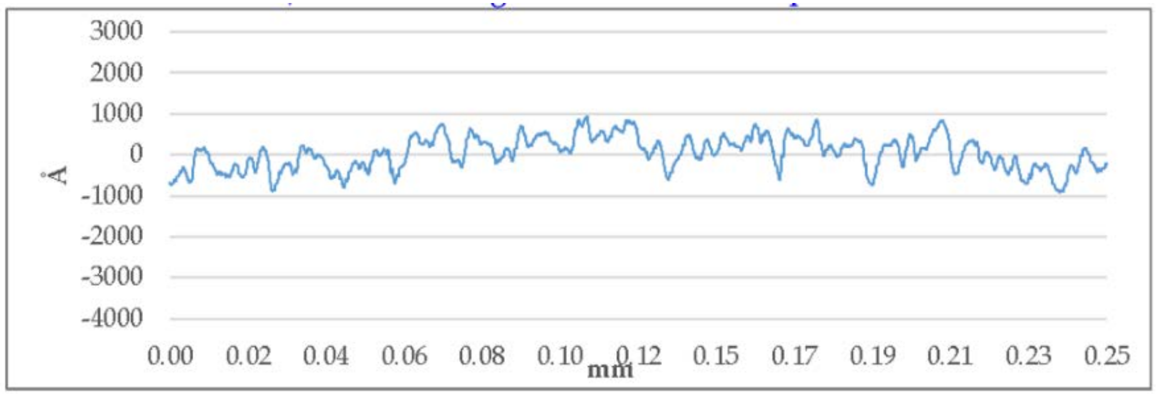
Rough & pitted Ni-P surface for ENIG vs. smooth Ni-P surface for Novel ENIG

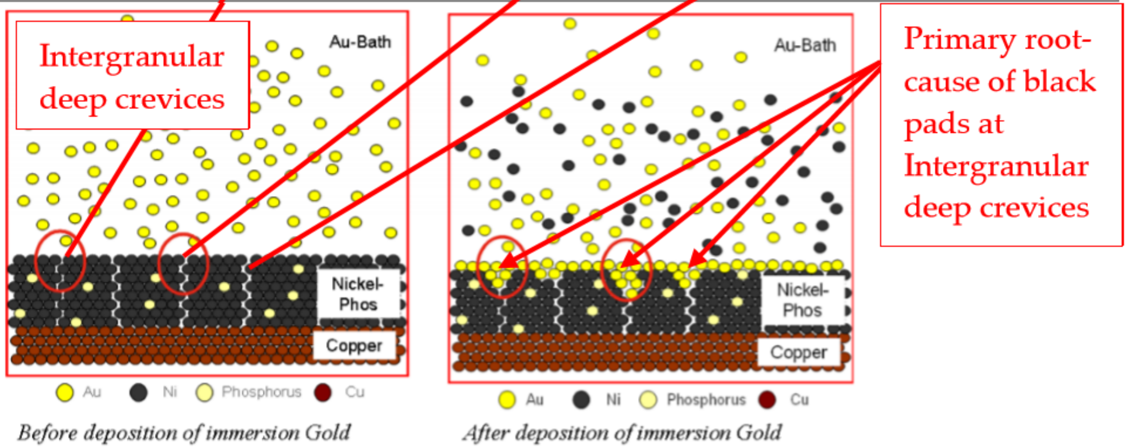
Surface Roughness Analysis of Ni-P. (ENIG vs. Novel ENIG)

Profilometer Analysis: Ni-P (ENIG) Surface
Roughness: Ra = 1000 Å & RMS = 1244.8 Å



Profilometer Analysis: Ni-P (Novel ENIG) surface
Roughness: Ra = 480 Å & RMS = 541 Å

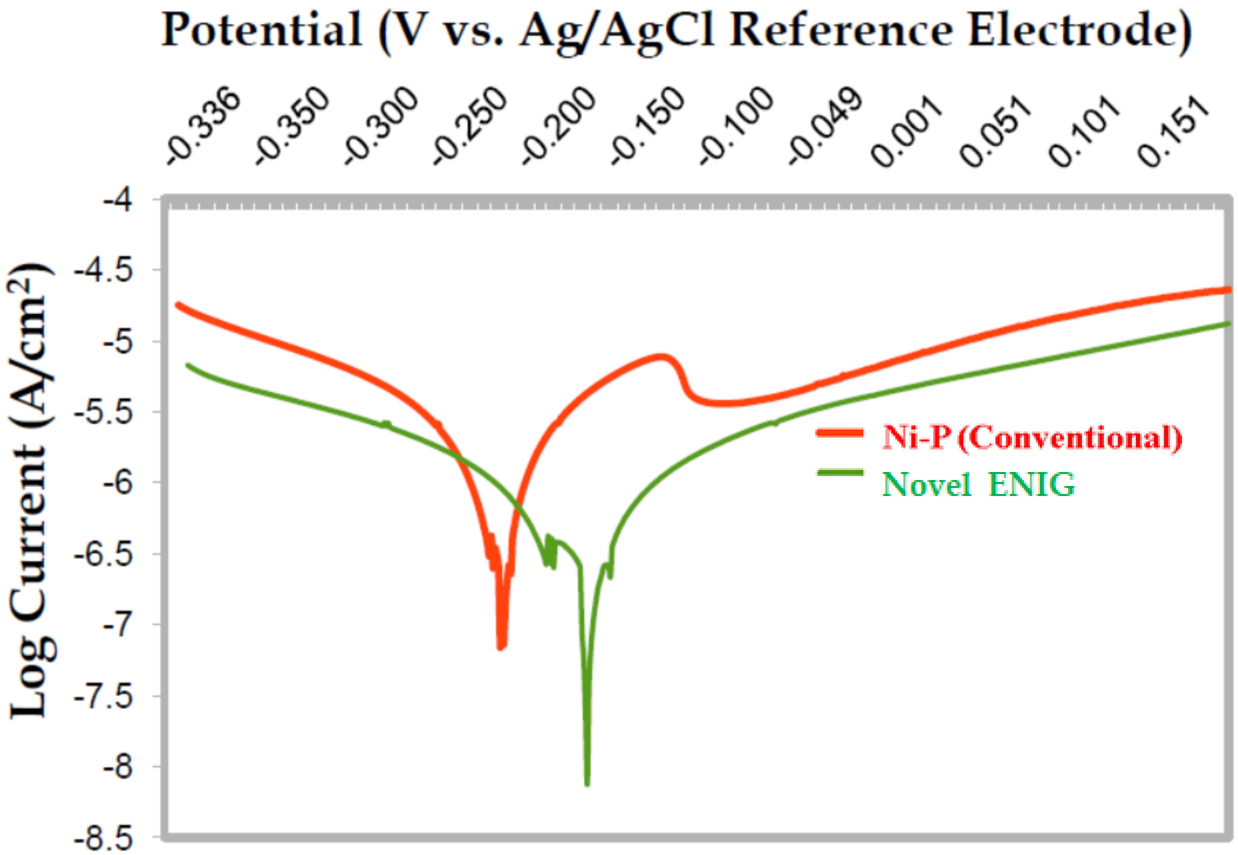




Interfacial nano-engineering at Ni-P surface smoothens and shield the intergranular deep crevices; black pads are eliminated for Novel ENIG

Novel ENIG: Improved Black Pad Resistance

Tafel Plots of Conventional Electroless Ni & Novel ENIG



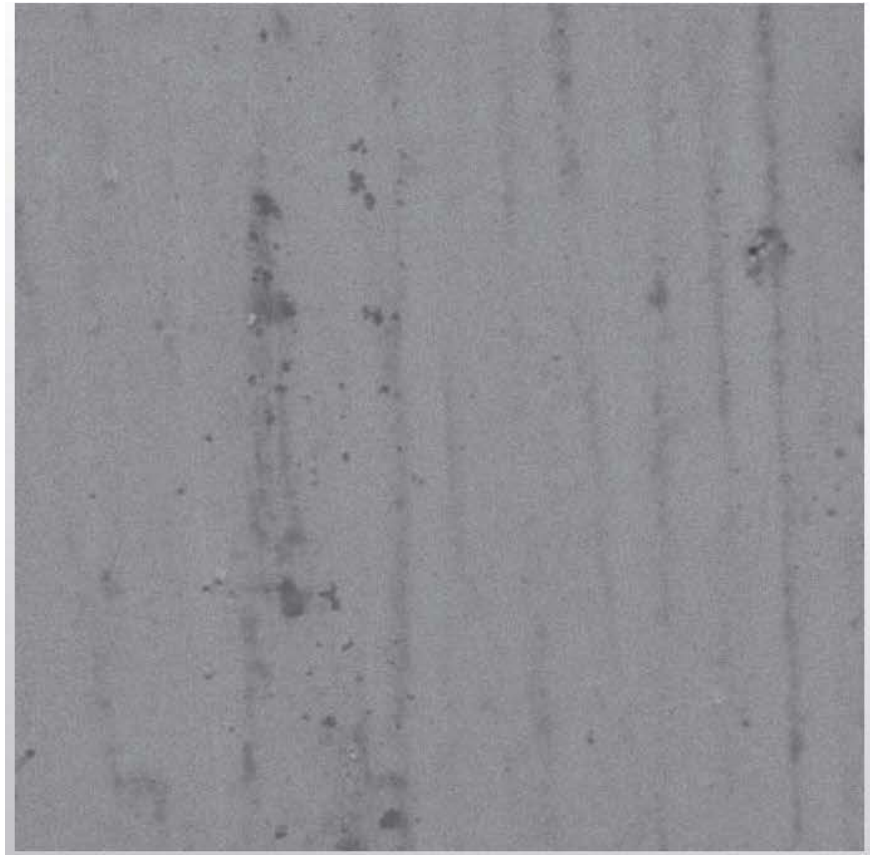
Corrosion current density of Electroless Ni layer of Novel ENIG is ~10X lower than conventional Electroless Ni layer (ENIG)

Improved black pads resistance (by ~10X) since black pad mechanism is galvanic corrosion of Ni by Au of Immersion Gold process

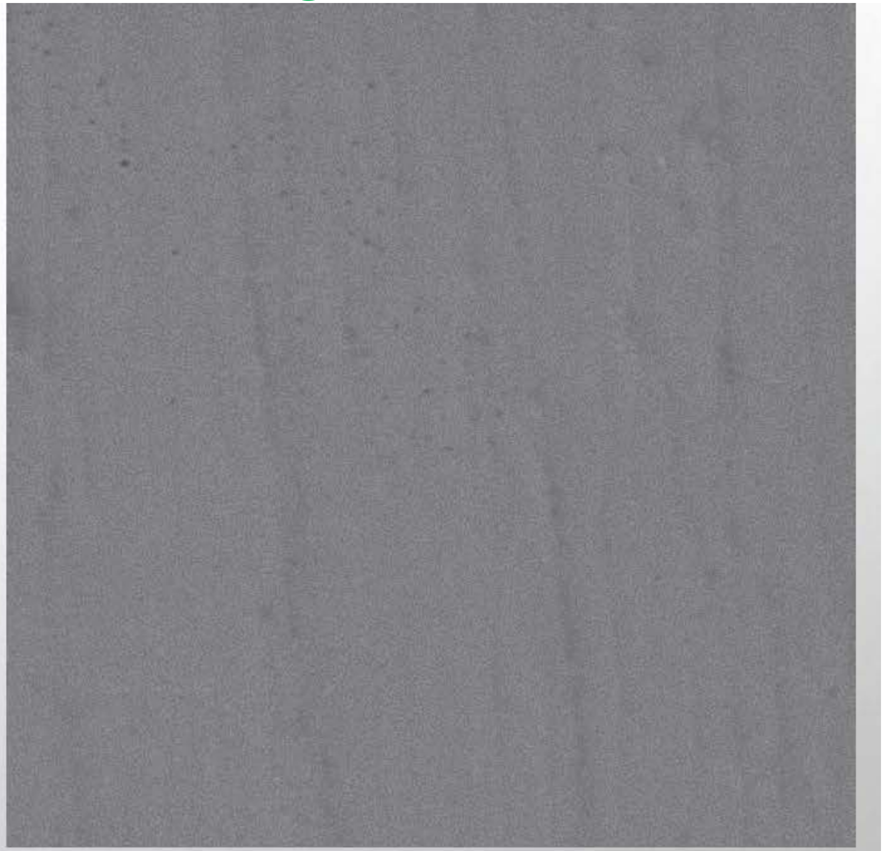
Sample Description	i_{corr} (A/cm^2)
Ni-P (Conventional)	2.138×10^{-6}
Novel ENIG	2.75×10^{-7}

SEM Imaging of Au, ENIG vs. Novel ENIG

SEM Image (5000x): ENIG



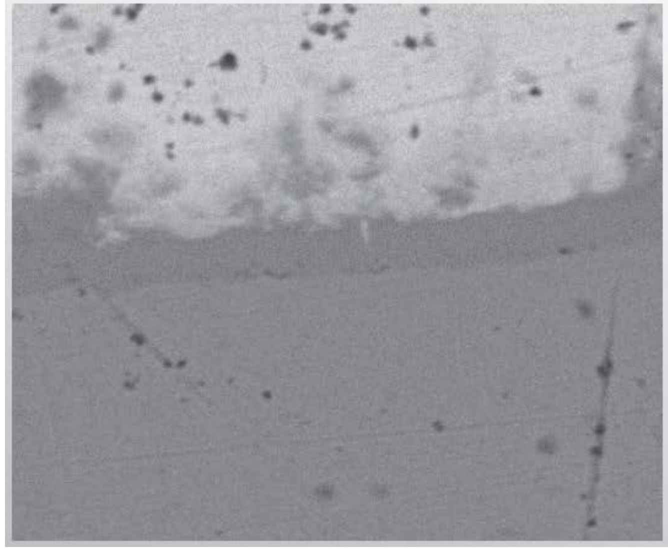
SEM Image (5000x): Novel ENIG



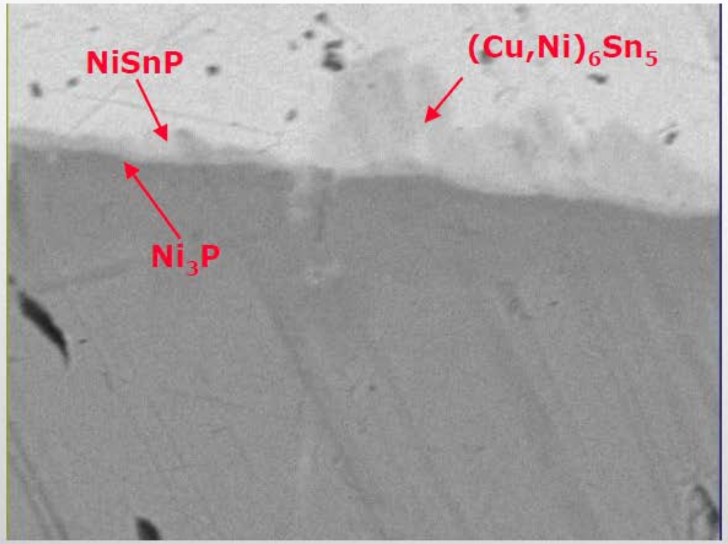
Rougher surface & blackened areas for ENIG vs. smooth surface & no black areas for Novel ENIG

Novel ENIG: Robust Solder Joints

Cross-sectioned Solder Joints to Evaluate Intermetallics:



SEM Image (5000x): ENIG

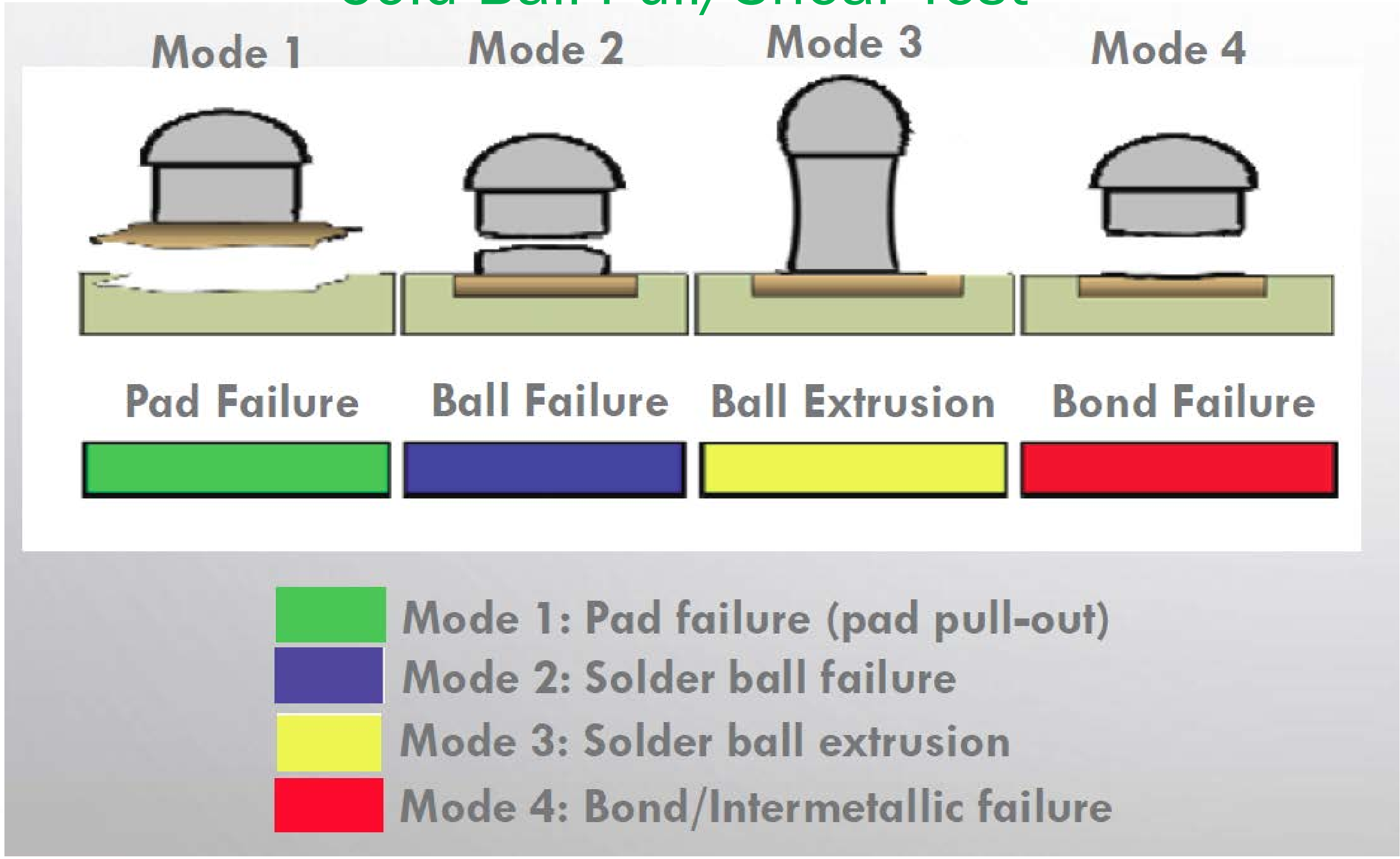


SEM Image (5000x): Novel ENIG

- Conventional ENIG exhibits
  - ✘ *Ni3P & NiSnP layers are scattered/diffused and have higher thickness*
  - ✘ *These layers have Kirkendall voids making solder joints brittle in nature*
- Novel ENIG:
  - ✓ *Ni3P & NiSnP layers are much more distinct and compact*
  - ✓ ***Robust solder joints***

Robust Solder Joint Testing

Cold Ball Pull/Shear Test



Ball Shear Test: ENIG vs. Novel ENIG

- Ball Pull testing was performed according to JESD22-B117 by accredited testing lab
  - *Ball Pull testing speed = 0.5 mm/sec*
- Solder used in the samples analyzed is lead-free solder (SAC305)

Surface Finish	Failure Location		
	At Intermetallics (Solder Joints)- Mode 4	Within Solder- Mode 2	At Cu pad within PCB- Mode 1
Conventional ENIG	80%		20%
Novel ENIG		20%	80%

- Force required to create ball failure: **1400 grams** (avg.) for Novel ENIG vs. **944 grams** (avg.) for ENIG

Ball Pull Test: ENIG vs. Novel ENIG

- Ball Pull testing was performed according to JESD22-B115 by accredited testing lab
  - *Ball Pull testing speed = 10 mm/sec*
- Solder used in the samples analyzed is lead-free solder (SAC305)

Surface Finish	Failure Location		
	At Intermetallics (Solder Joints)- Mode 4	Within Solder- Mode 2	At Cu pad within PCB- Mode 1
Conventional ENIG	80%	20%	
Novel ENIG			100%

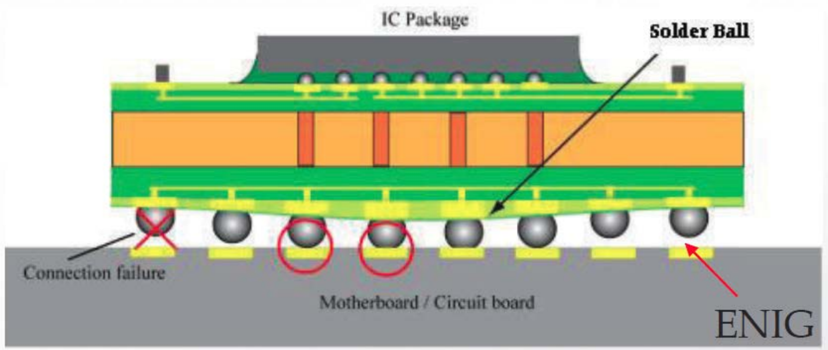
- Force required to create ball failure: **2717 grams** (avg.) for Novel ENIG vs. **1698 grams** (avg.) for ENIG

Novel ENIG: Nano-Engineering

Nano-engineering (inclusion of barrier layer) has helped improve the reliability of electronic assemblies

- ✓ *Corrosion resistant with 10X improvement in black pad resistance*
- ✓ *No brittle failures at solder joints (including Lead-free)*

Key Takeaways



- Connection (Solder Joints) between PCB & surface mount components are prone to a high number of failures
  - *Especially with lead-free solder and ENIG surface finish*

- Innovative technologies are essential to improve intermetallics (solder joints) for better reliability of electronic assemblies

Thank you!

Questions?