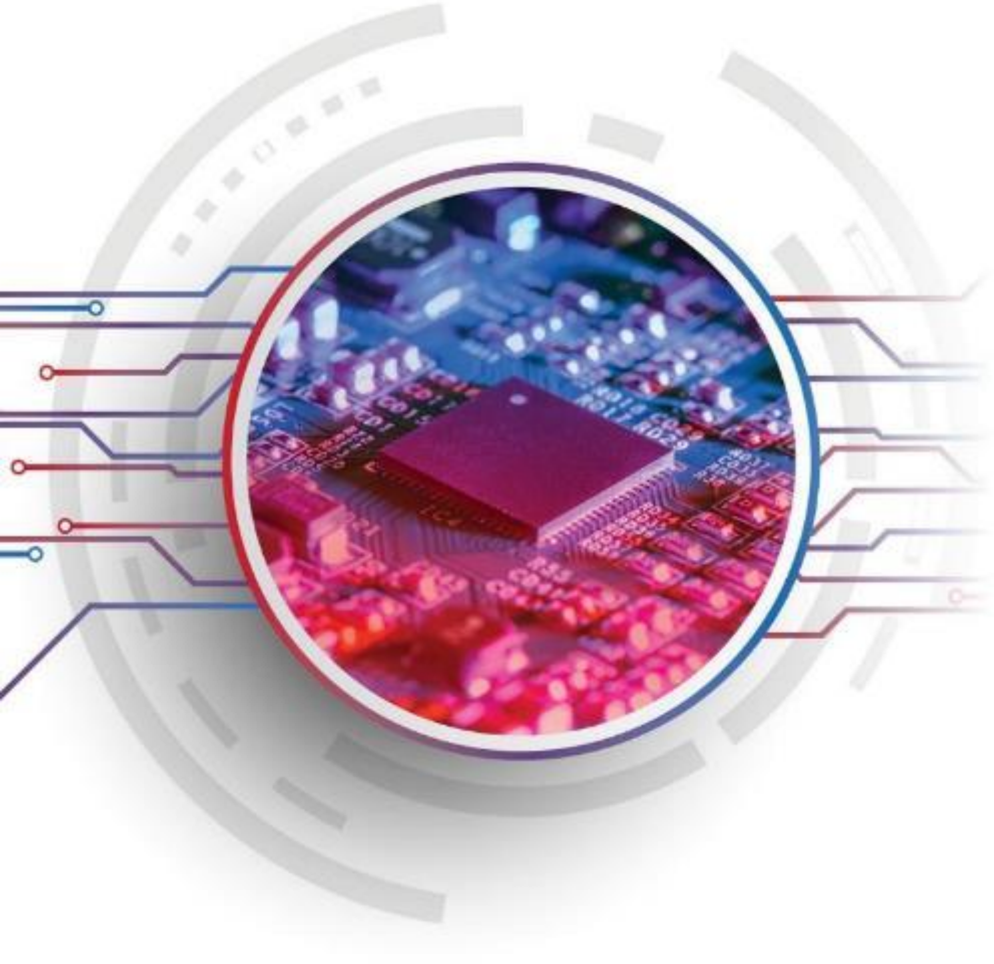


PCB/Substrate Finishing Overview

July 21/22, 2021

John Swanson, Director of Final Finishes

Watch the recorded webinar:

- **https://youtu.be/S0Ejj5wIttE**

  OR

- **http://thor.inemi.org/webdownload/2021/BdAssy-Tech_Topics/Surface_Finishes.mp4**

PCB Surface Finish Overview

MacDermid Enthone

	OSP	Imm Silver	Imm Tin	ENIG	ENEPIG
Planarity	Yes	Yes	Yes	Yes	Yes
Solderjoint	Cu-Sn	Cu-Sn	Cu-Sn	Ni-Sn	Ni-Sn
Relative Cost	$	$$	$$	$$$	$$$
Shelf Life	12 months*	12 months	6 months	24 months	24 months
Reflows	3**	6	2	6	6
Contact	Difficult	E-Test, ICT, Keypad	E-Test	E-Test, ICT, Keypad	E-Test, ICT, Keypad
Press Fit	Good	Good	Good	Good	Good
Au Wirebond	No	Limited	No	No	Yes
Al Wirebond	No	Yes	No	Yes	Yes

Surface Finish deployment ranked by surface area

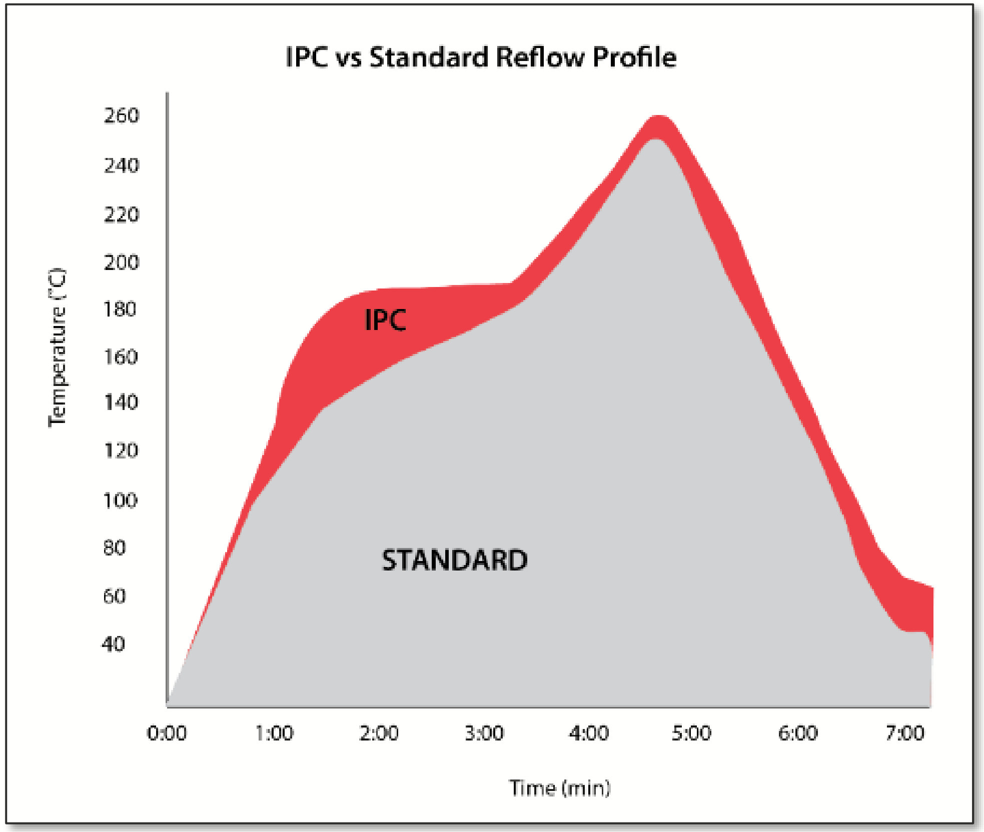
OSP	greatest
Imm Tin	
ENIG	
Silver	
ENEPIG	least

* Consult process vendor for specifics

** dependent on specifics of assembly temperature, time, etc.

Assembly/reflow considerations

- Complete PCB / device assembly commonly involves multiple exposures to significant heat cycles
- Assembly conditions (time, temperature, environment) will vary by application.
- Surface finishes vary in their performance and “resilience” to these conditions
- Subsequent longer term “performance” may be a consideration
- Tradeoffs of “fit versus cost” are considered



Characteristics for Consideration

MacDermid Enthone

	OSP (Organic Solderability Preservative)	Immersion Silver	Immersion Tin	ENIG (Electroless Nickel Immersion Gold)	ENEPIG (Electroless Nickel Electroless Palladium Immersion Gold)
	copper	copper	copper	copper	copper
Coating thickness	~ 0.3 micron	~ 0.25 micron	~ 1.0 micron	0.04 – 0.10 micron Au 3-6 micron Ni*	0.03 – 0.07 micron Au 0.05 – 0.3 micron Pd 3-6 micron Ni*
Process note	organic molecule (azole) bond with copper	immersion plating	immersion plating	electroless + immersion plating	electroless + immersion plating
Coating change with heat + time	general organic degradation	minimal oxidation	thin tin oxide + tin/copper alloy growth	minimal oxidation	minimal oxidation
Soldering mechanism	organic breakdown in flux and dissolution in solder	rapid silver dissolution in solder	rapid tin dissolution in solder	rapid gold dissolution in solder, partial nickel….	rapid gold and palladium dissolution, partial nickel….
Solder joint	Tin/Copper	Tin/Copper	Tin/Copper	Tin/Nickel	Tin/Nickel

* Thin nickel, ≤ 0.5 micron, in some specialty applications

Organic Solderability Preservative (OSP)

MacDermid Enthone

Overview:

- Lowest cost surface finish in wide use
- Most used surface finish when considering PCB surface area
- Organic coating, various varieties of benzimidazole, formed on clean copper substrate. Specific organic coating varies by chemistry vendor
- Limitations linked to poor electrical contact functionality
- Inhibits oxidation and degradation of underlying copper, but incremental decline in performance with each exposure to assembly cycle

	OSP
Planarity	Yes
Solderjoint	Cu-Sn
Relative Cost	$
Shelf Life	12 months*
Reflows	3**
Contact	Difficult
Press Fit	Good
Au Wirebond	No
Al Wirebond	No

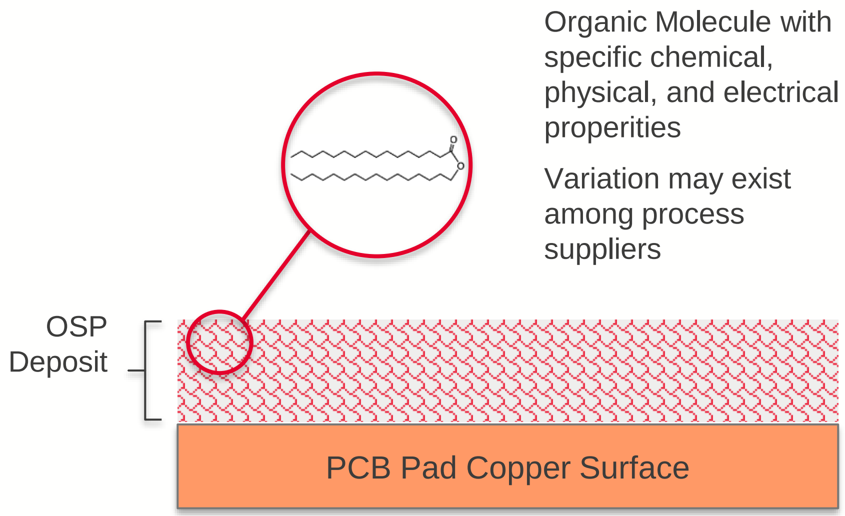
* Consult process vendor for specifics

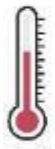
** dependent on specifics of assembly cycle

Engineering of OSP

MacDermid Enthone

OSP Coating





Hot assembly conditions cause degradation of basic organic molecule, thin coating.

Consideration regarding coating and process:

- Ease of use, stability of OSP processing chemistry
- Thickness capability
- Permeability to air
- Heat stability of coating
- Compatibility with flux/paste

OSP Process Overview

MacDermid Enthone

Process Sequence **Total Cycle Time ~ 15 minutes**

cleaner → rinse → microetch → rinse → precoat → rinse → OSP Coating → rinse → Dry

Standard Pretreatment Objectives

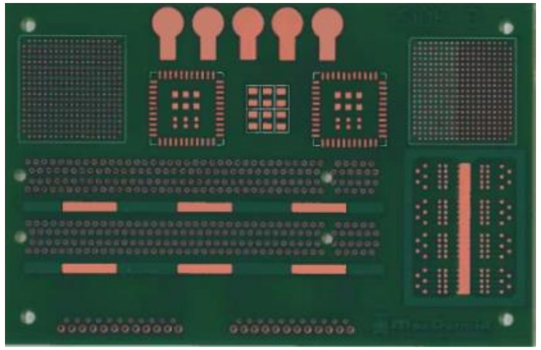
- The cleaner removes fingerprints and other contaminants.
- Cleaners may be acidic or alkaline. Alkaline cleaners are required to remove soldermask residues.
- The microetch will provide a micro-roughened surface, that is relatively oxide free.

Precoat

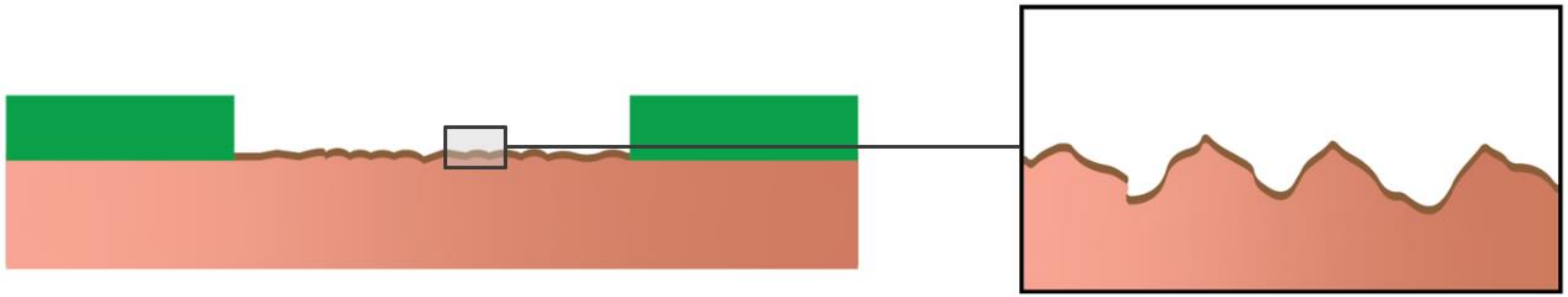
- The Precoat deposits a thin, organic film, which is covalently bonded to the copper surface.
- This organic film increases the useful life of the OSP bath and allows an easy method to adjust the OSP film thickness.

OSP Coating and Dry

- The OSP bath builds the coating thickness to the desired level.
- An immersion time of 1 minute will produce a coating thickness of 0.35 um.
- Acidity, temperature and Azole concentration are key process drivers.
- The panels must be completely dry before stacking

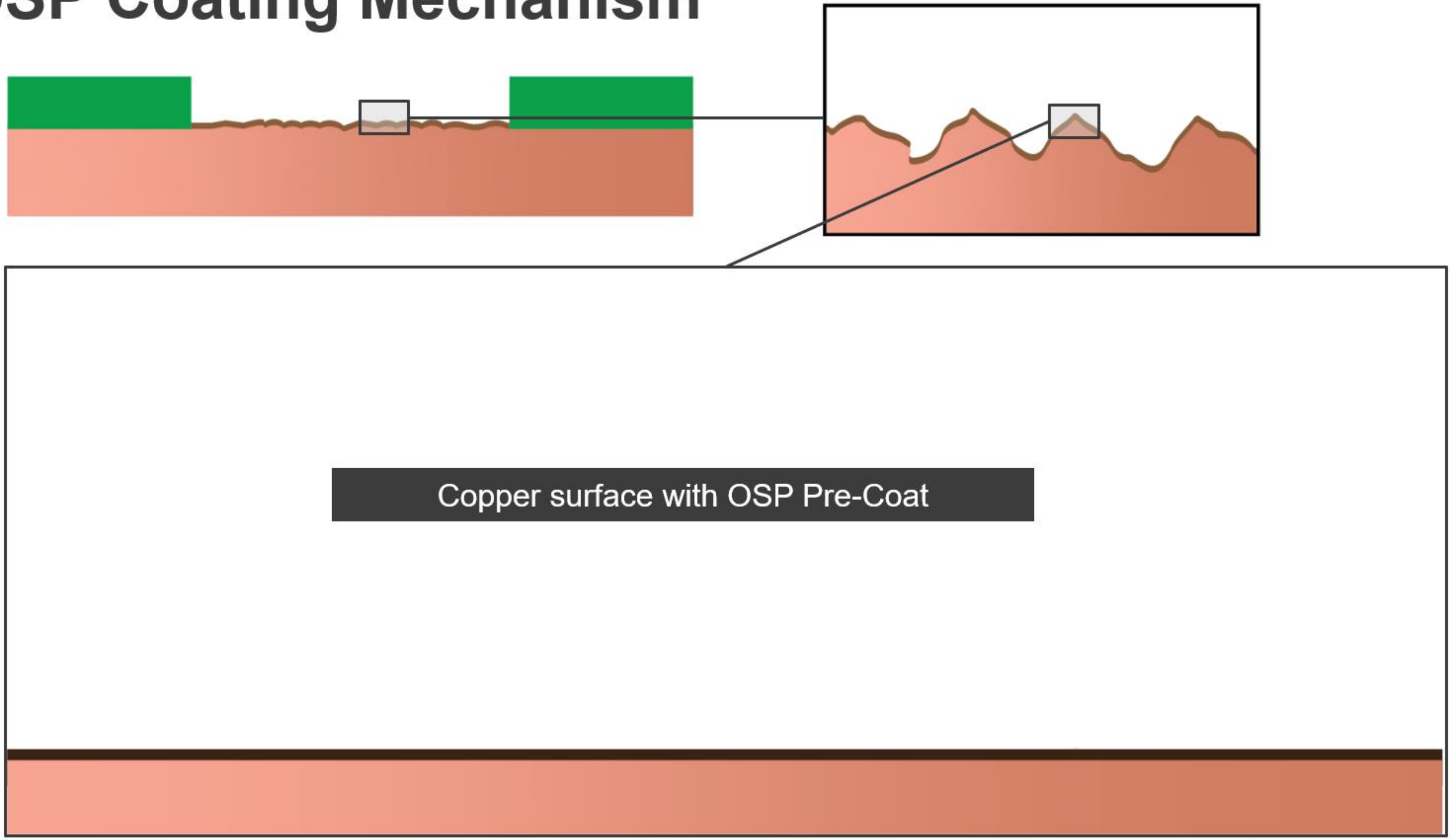


OSP Coating Mechanism

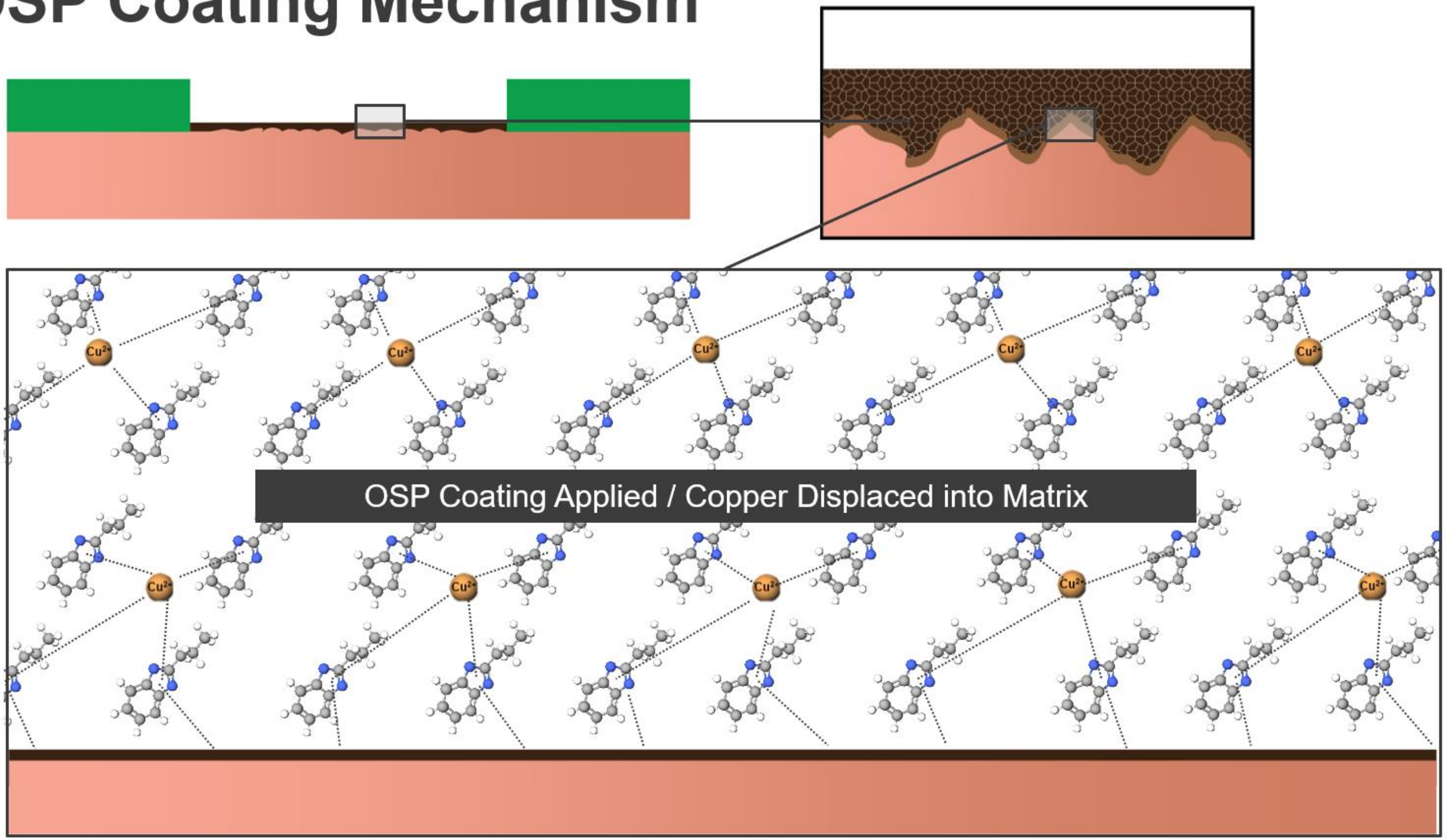


The PCB is passed through a cleaner, microetch, and the OSP pre-coat step to create a surface that allows for the OSP buildup and adhesion.

OSP Coating Mechanism

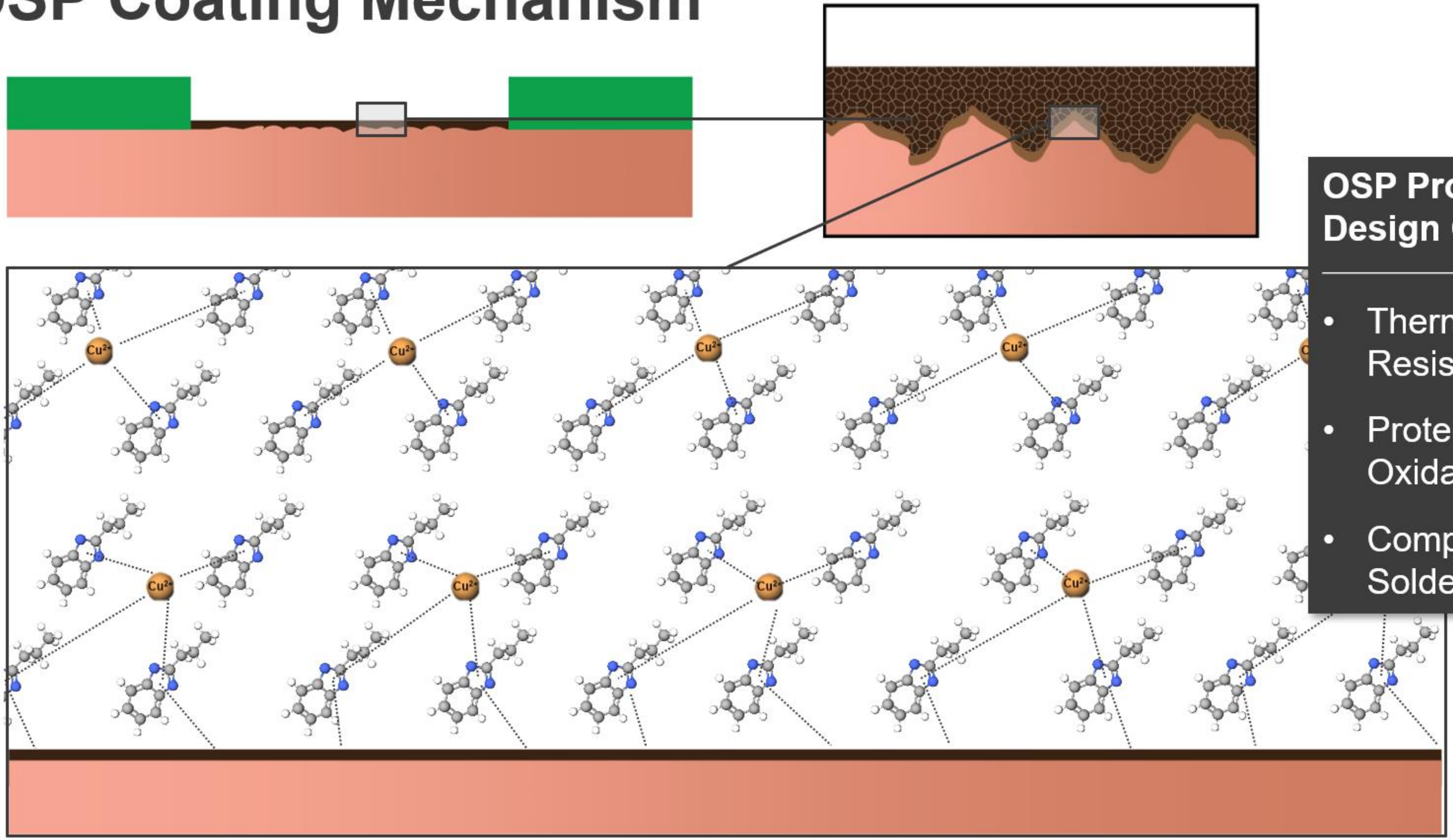


OSP Coating Mechanism



OSP Coating Mechanism

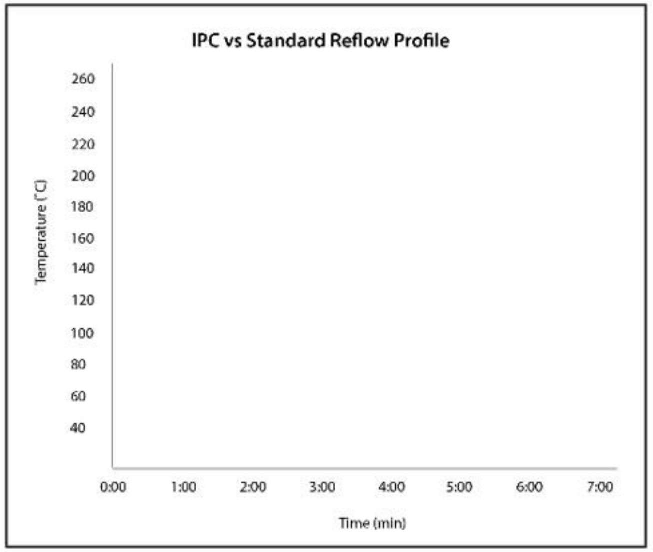
id Enthone



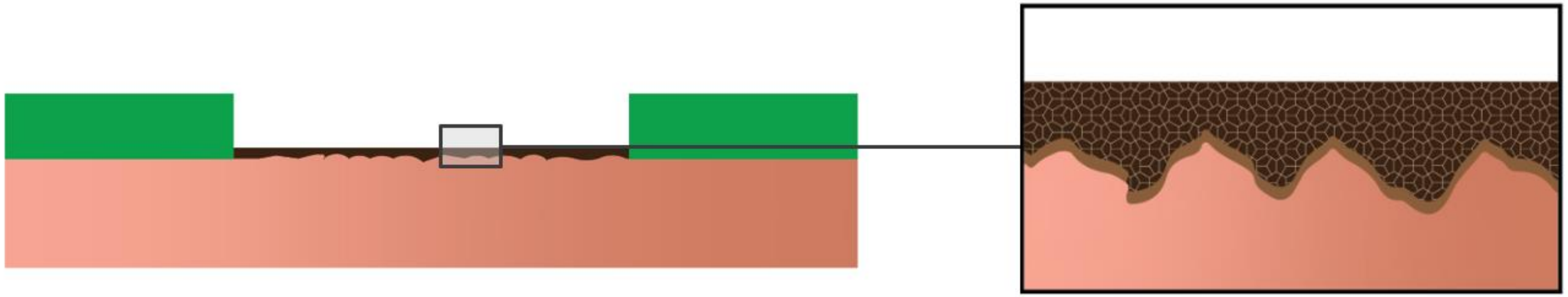
OSP Process Design Goals

- Thermally Resistant Coating
- Protects from Oxidation
- Compatibility with Solder flux/paste

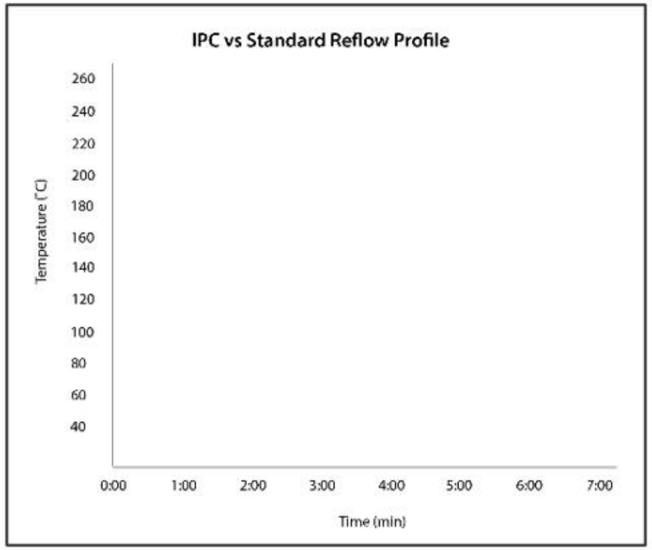
Paste Reflow Mechanism



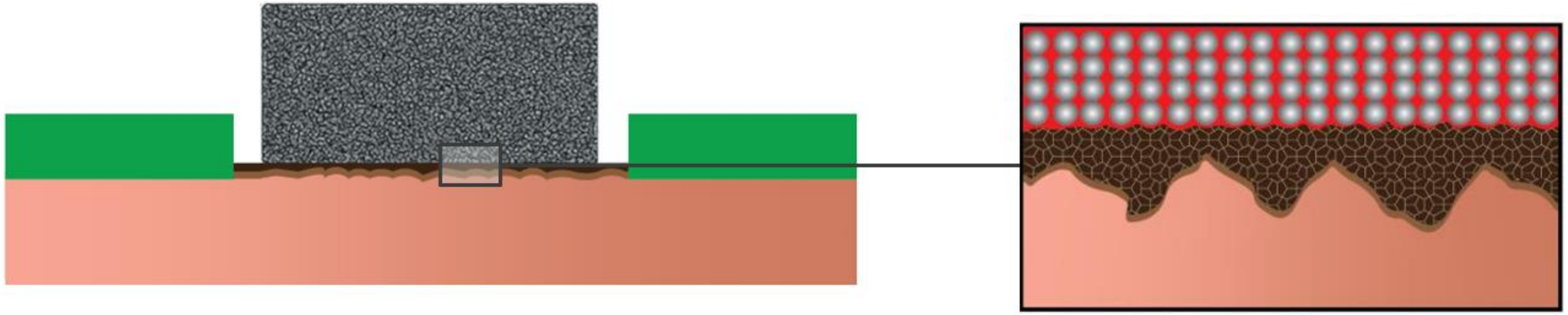
The OSP coating is applied and the PCB is now ready to have the solder paste screen printed.



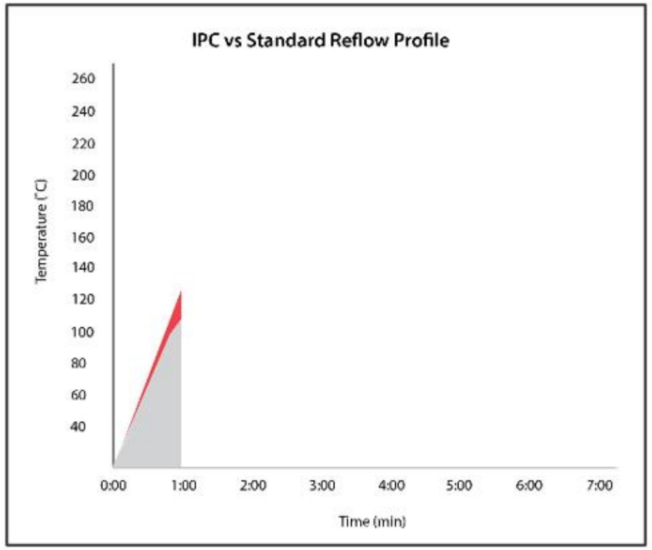
Paste Reflow Mechanism



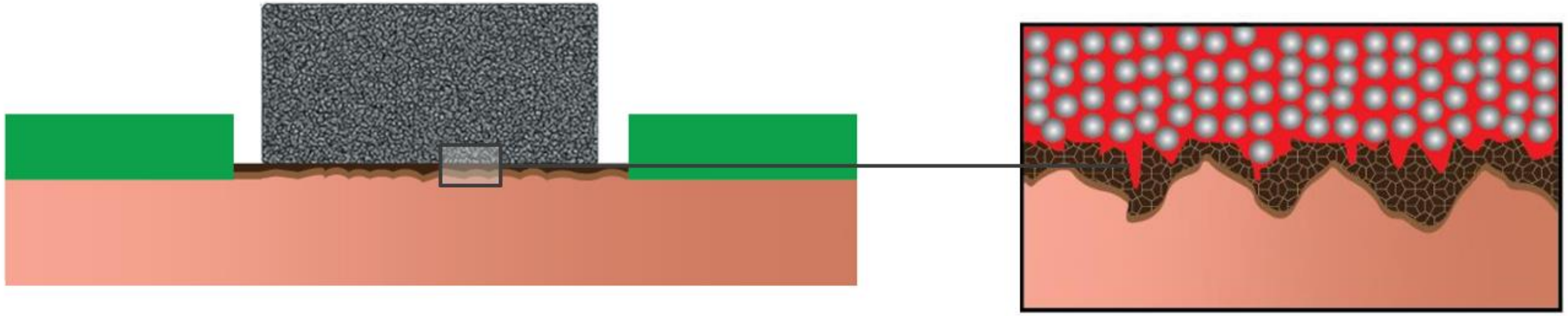
Solder paste is screened onto the pad, sitting atop the OSP. The PCB is ready for reflow.



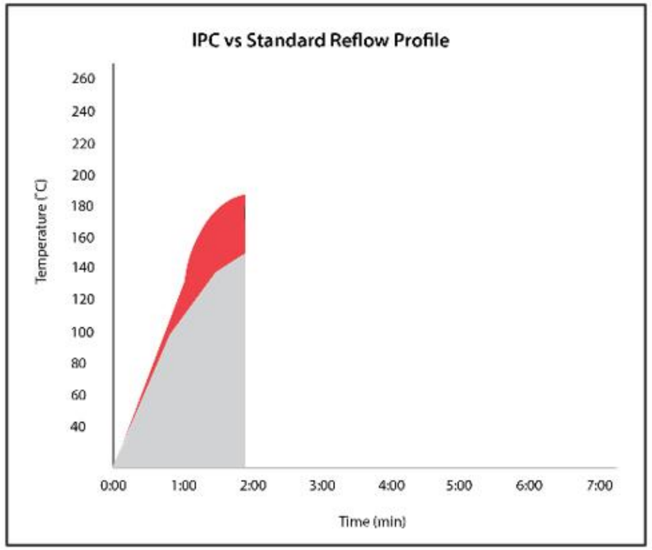
Paste Reflow Mechanism



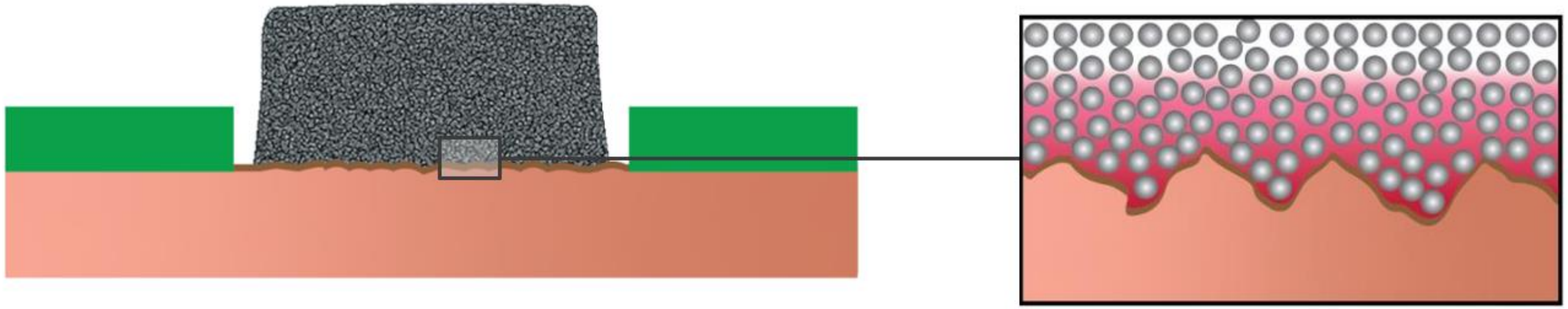
Heat activates the flux within the paste and it flows downward, mixing into and dissolving / displacing the OSP coating



Paste Reflow Mechanism

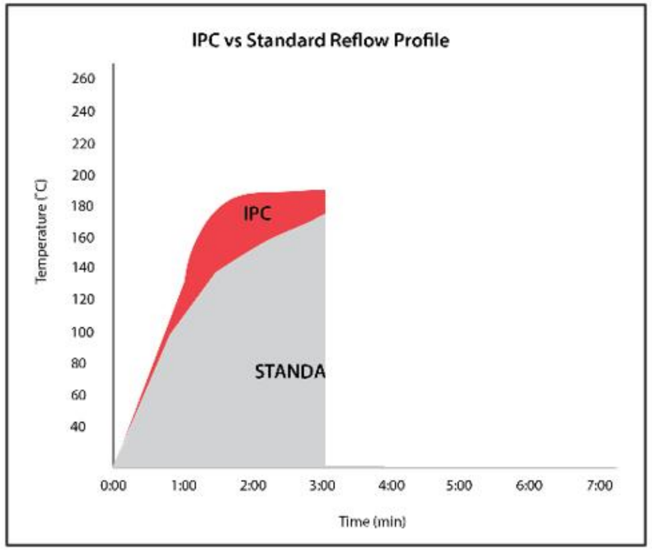


With the OSP coating removed, the solder and flux can now begin to contact the copper surface.

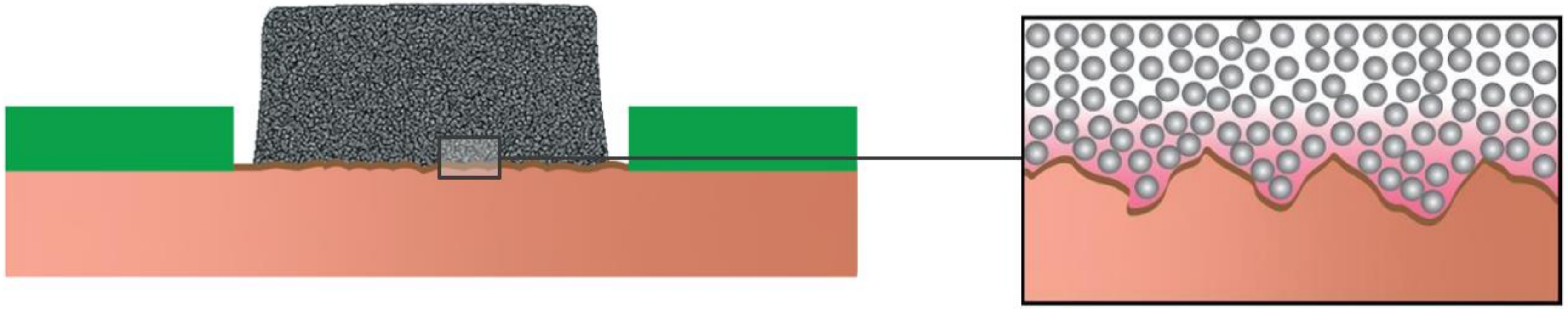


Paste Reflow Mechanism

MacDermid Enthone

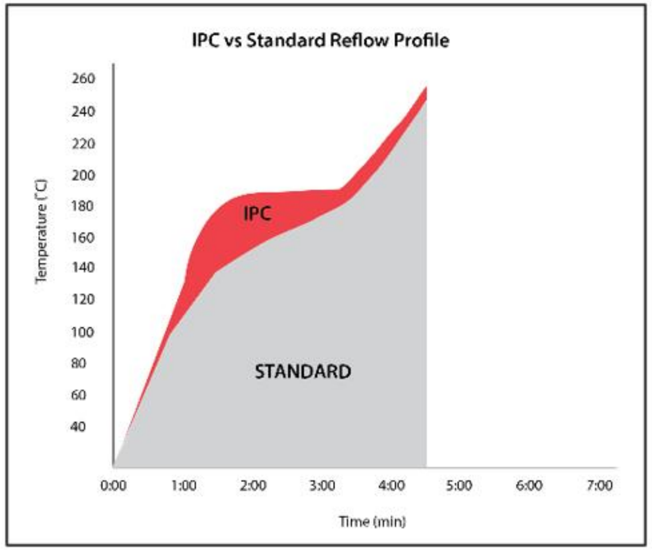


The high temperature soak of the reflow profile now drives the flux to clean any oxidation on the surface and prepare for solder

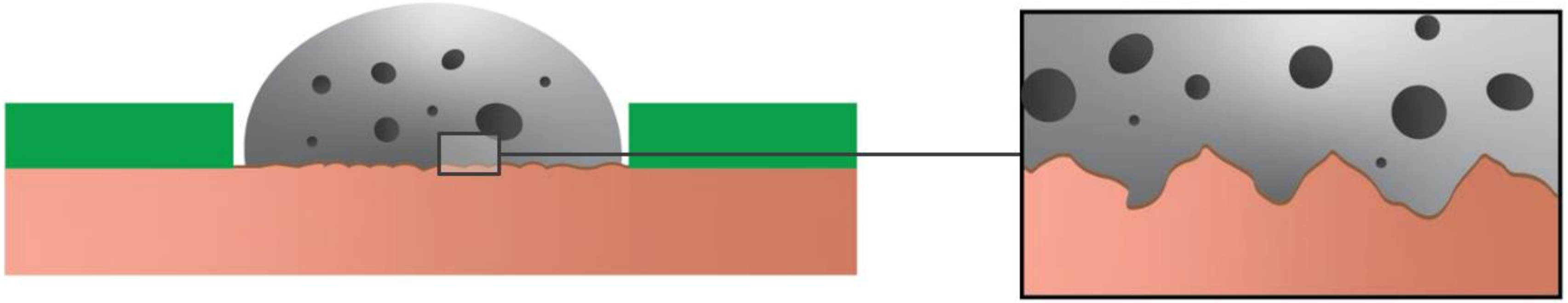


Paste Reflow Mechanism

MacDermid Enthone

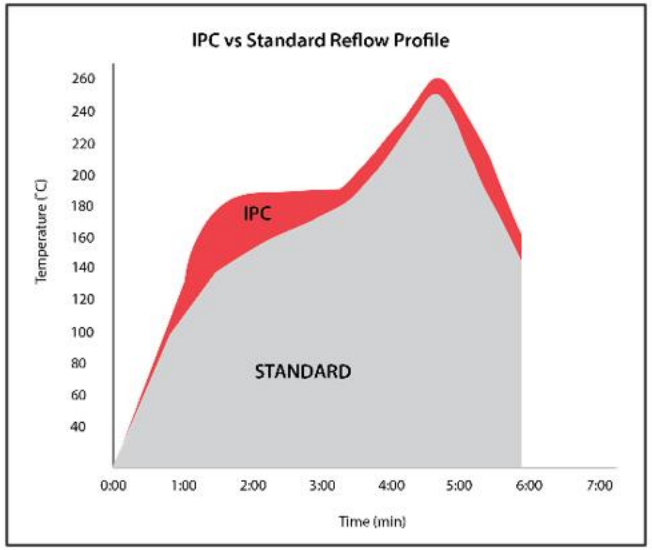


The solder balls melt at the peak reflow temperature, and the remaining flux / organics are driven off

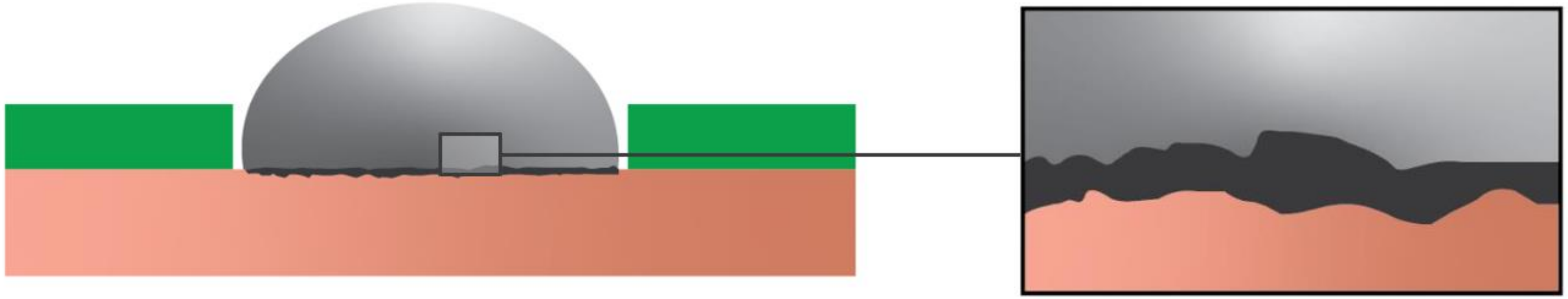


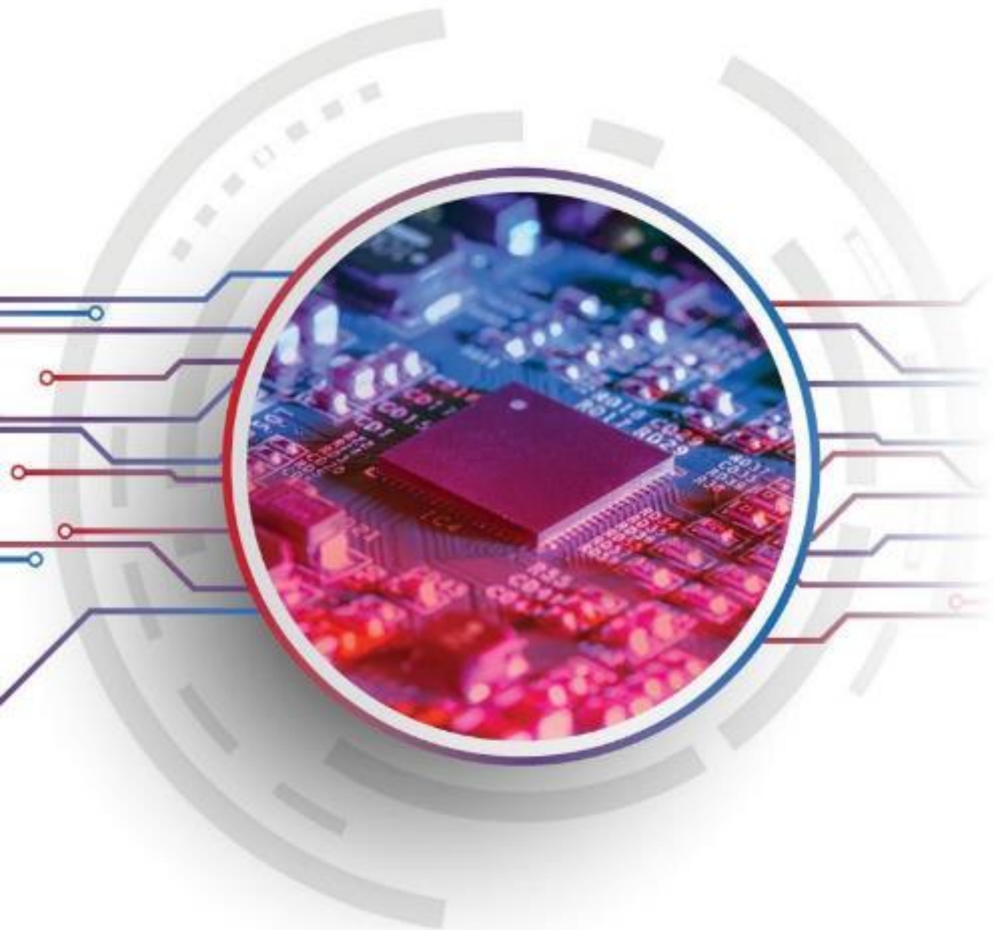
Paste Reflow Mechanism

MacDermid Enthone



Due to precise pairing of flux, solder, and OSP chemical properties, a strong copper-tin solder joint is formed.





Immersion Silver Overview

Immersion Silver

MacDermid Enthone

Overview:

- Lower cost than ENIG, ENEPIG, and Immersion tin
- Noteworthy in its Simplicity and Productivity
  - Simple immersion coating reaction
  - Time to deposit coating: ≈ 1 minute
- Best durability to multiple reflows
  - No intermetallic formed with copper and silver
  - Minimal surface oxidation
  - No thermal breakdown of silver
- Electrical contact performance
- Excellent high frequency performance

	Imm Silver
Planarity	Yes
Solderjoint	Cu-Sn
Relative Cost	$$
Shelf Life	12 months
Reflows	6
Contact	E-Test, ICT, Keypad
Press Fit	Good
Au Wirebond	Limited
Al Wirebond	Yes

Immersion Silver Process Overview

MacDermid Enthone

Process Sequence — **Total Cycle Time ~ 12 minutes**

cleaner → rinse → microetch → rinse → predip → rinse → Silver Plating → rinse → Dry

Standard Pretreatment Objectives

- The cleaner removes fingerprints and other contaminants.
- Cleaners may be acidic or alkaline. Alkaline cleaners are required to remove soldermask residues.
- The microetch will provide a micro-roughened surface, that is relatively oxide free.

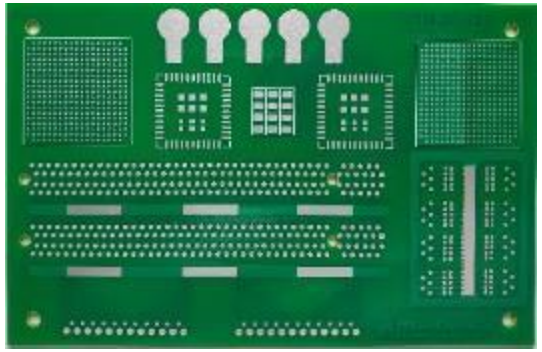
Predip

- The chemical formulation is similar to the silver bath, without silver metal.
- The Predip conditions and wets the copper surface and assures compatible plating drag-in.

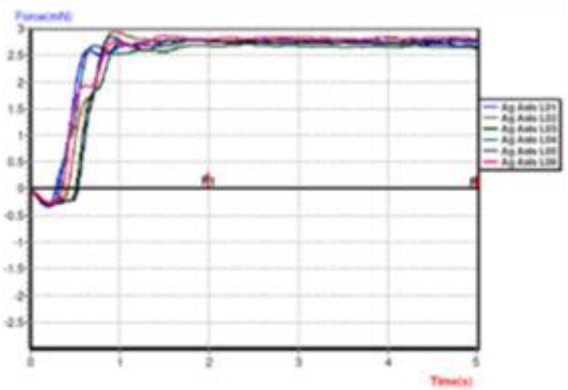
Immersion Silver Plating & Dry

$$2Ag^+ + Cu^0 \longrightarrow 2Ag^0 + Cu^{2+}$$

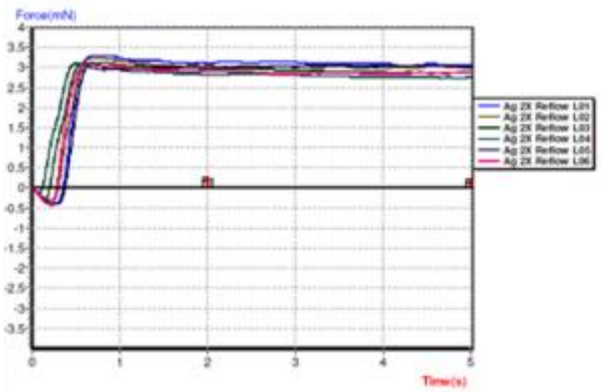
- Approximately 10 u” (0.25um) is deposited in 70 – 90 sec.
- The Ag plated panels must be rinsed sufficiently to achieve required ionic contamination specification.
- The panels must be completely dry before stacking or packaging.



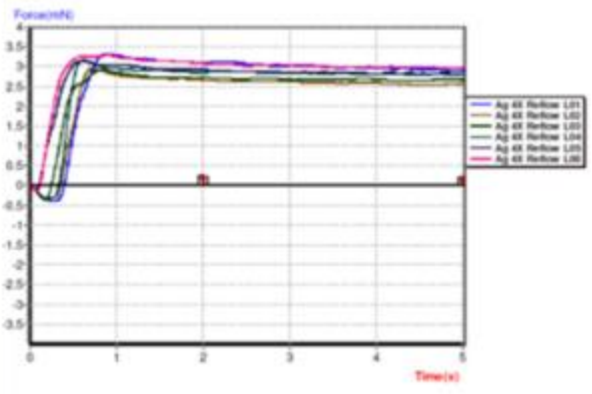
- Unlike most PCB surface finishes, silver is unaffected by multiple heat exposures
  - Minimal surface oxidation
  - No intermetallic formation with copper substrate



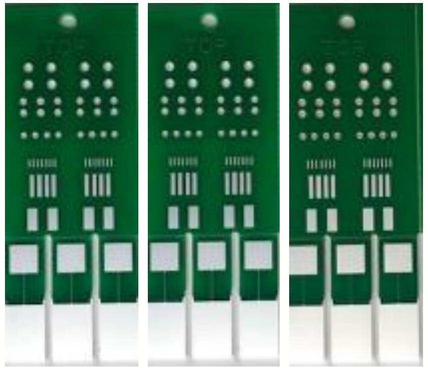
As Coated



2x lead free reflows



4 x lead free reflows

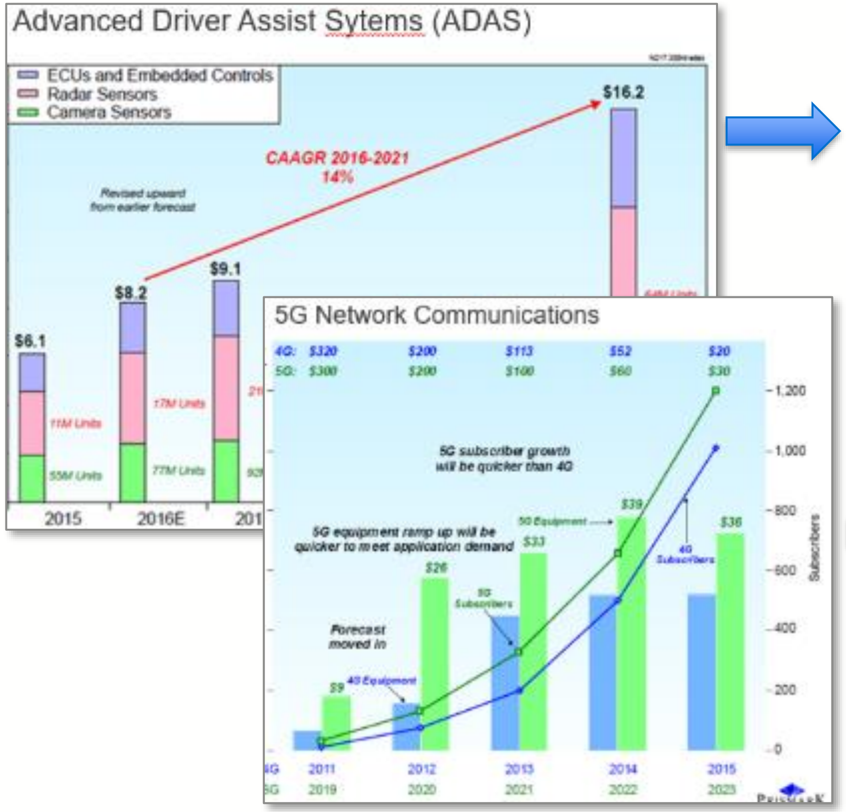


as coated 2x 4x

Minimal change in silver finish appearance after assembly exposures

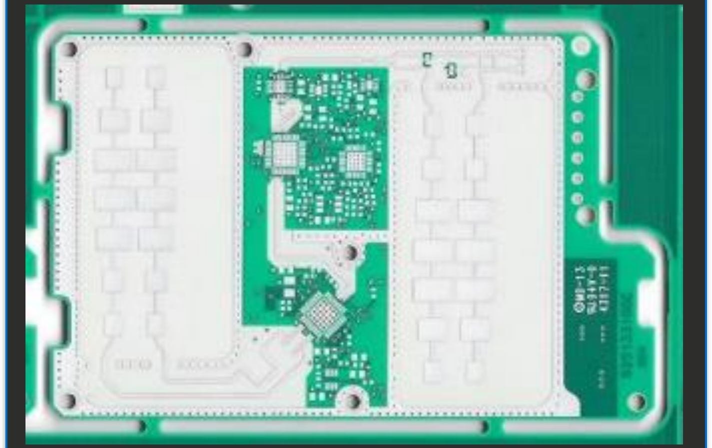
Immersion Silver in High Frequency Applications

MacDermid Enthone



24 GHz Auto Safety System

- “mid frequency”
- Larger antenna features
- Lower packaging density



77 GHz Auto Safety System

- “high frequency”
- Smaller antenna features
- Increased packaging density

Signal Loss Versus Surface Finish

MacDermid Enthone

Bulk Conductivities

Copper	5.817 x 10^7 S/m
Silver	6.301 x 10^7 S/m
Gold	4.52 x 10^7 S/m
Nickel	1.5 x 10^7 S/m
Aluminum	3.5 x 10^7 S/m
Brass	2.56 x 10^7 S/m
Solder	0.70 x 10^7 S/m
Tin	0.87 x 10^7 S/m

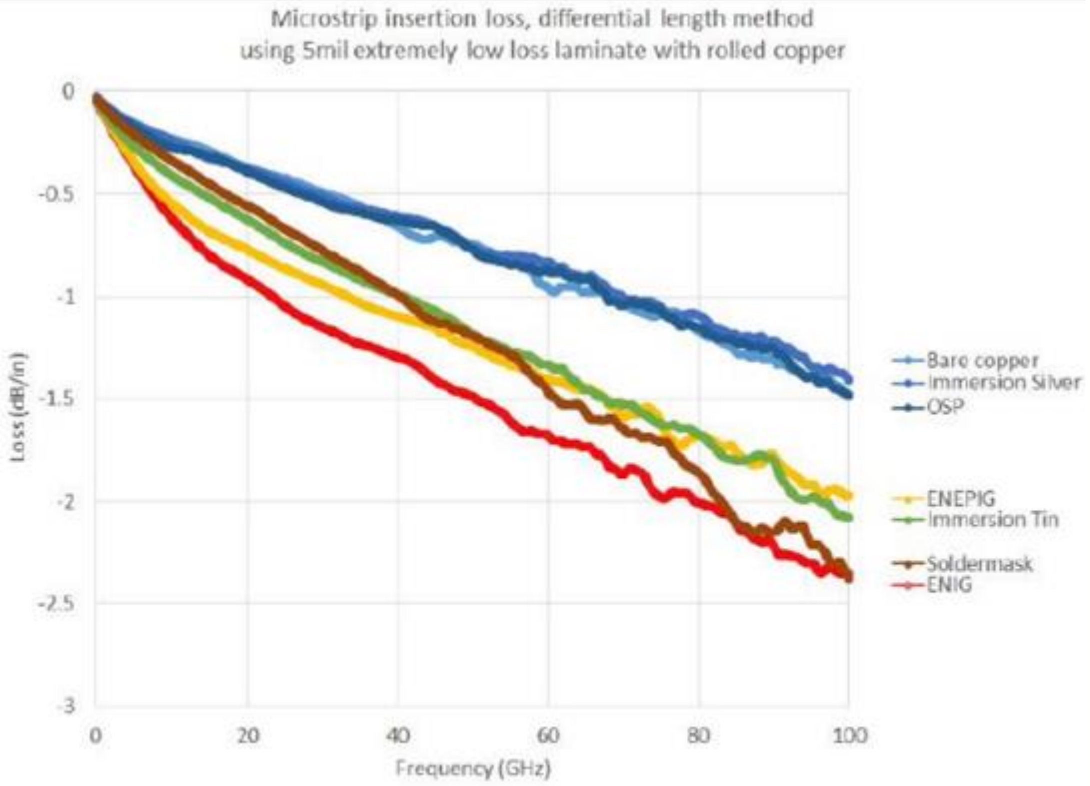
$$\delta = \sqrt{\frac{1}{\pi f_{freq} \mu\sigma}}$$

δ skin depth
µ permeability
σ conductivity

Frequency ↑ Skin depth ↓
Conductivity ↓ Skin depth ↑

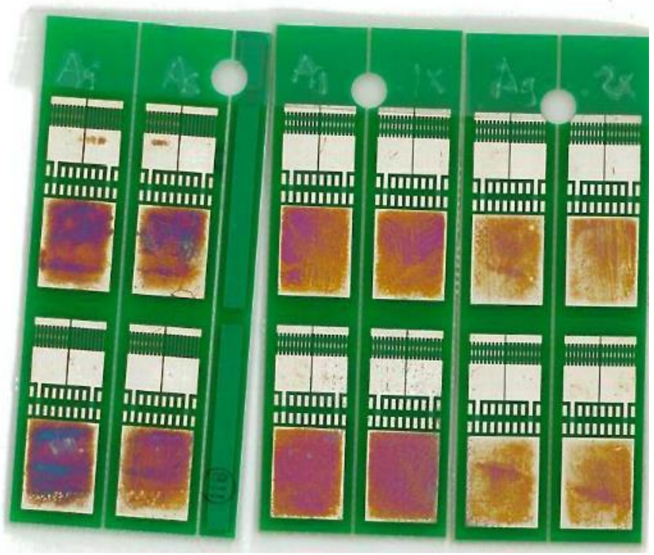
THE IMPACT OF FINAL PLATED FINISHES ON INSERTION LOSS FOR HIGH FREQUENCY PCBS

John Coonrod
Rogers Corporation
Chandler, AZ, U.S.A.
john.coonrod@rogerscorp.com



Immersion Silver – Tarnish Mitigation

Immersion silver without tarnish inhibitor



no reflow preconditioning | after 1 assembly exposure | after 2 assembly exposures

Immersion silver with tarnish inhibitor

no reflow preconditioning | after 1 assembly exposure | after 2 assembly exposures

MacDermid Alpha
ELECTRONICS SOLUTIONS

Immersion Tin

Overview:

- Moderate costs versus other finish alternatives
- Popular in automobile applications. Auto compromises 60%+ of tin final finish applications
- Widely recognized as best performance in “press fit” connector applications
- Immersion plating reaction “assisted” by complexing agent
- Excellent initial solderability with obvious compatibility with tin-based solders, but decline and sensitivity linked to tin/copper alloy formation

	Imm Tin
Planarity	Yes
Solderjoint	Cu-Sn
Relative Cost	$$
Shelf Life	6 months
Reflows	2
Contact	E-Test
Press Fit	Good
Au Wirebond	No
Al Wirebond	No

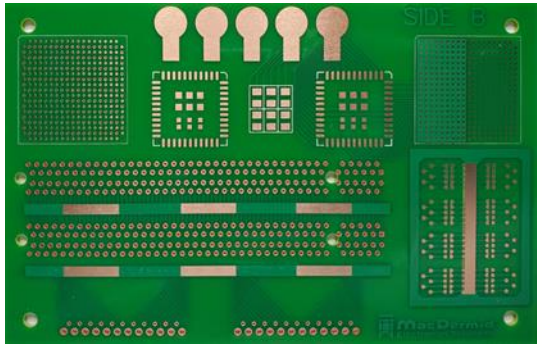
Immersion Tin Process Overview

MacDermid Enthone

Process Sequence

Total Cycle Time ~ 20 minutes

cleaner	rinse	m-etch	rinse	precoat	rinse	tin plating	rinse	anti-tarn*	rinse	rinse aid*	rinse	Dry



Standard Pretreatment Objectives

- Sometimes preceded by or including a “UV Bump” step, with objective of preventing soldermask attack in hot immersion tin process step
- Additional traditional objectives of cleaning and microetch process steps

Precoat

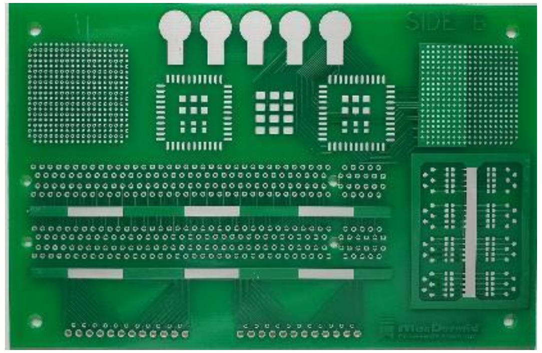
- thin tin and/or whisker prevention
- Some variation depending on chemical supplier

Immersion Tin Process Overview

MacDermid Enthone

Process Sequence **Total Cycle Time ~ 20 minutes**

cleaner → rinse → m-etch → rinse → precoat → rinse → **tin plating** → rinse → **anti-tarn*** → rinse → **rinse aid*** → rinse → **Dry**



Standard Pretreatment Objectives

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- Additional traditional objectives of cleaning and microetch process steps

Precoat

- thin tin and/or whisker prevention
- Some variation depending on chemical supplier

Tin Plating, Optional Post-treatments, and Dry

$2Cu + Sn^{2+} \longrightarrow Sn + 2Cu^{+}$

- Plating aided by complexing agent
- * Optional anti-tarn inhibits subsequent coating oxidation
- * Optional rinse aid lowers “ionic contamination” of board surface

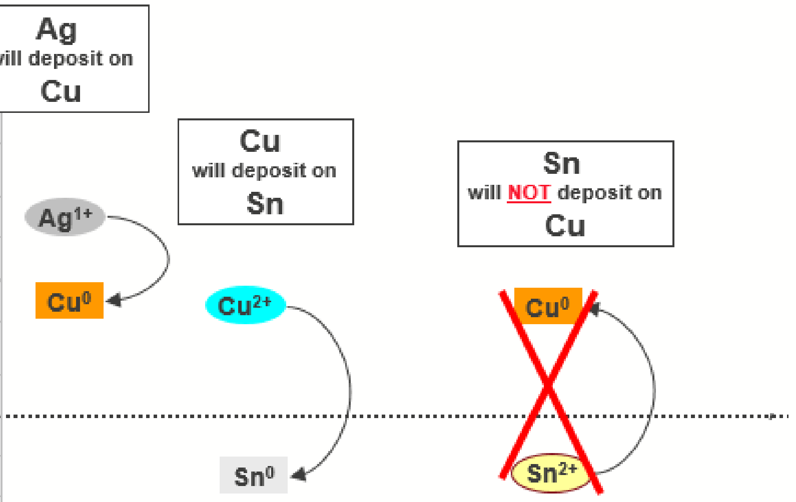
Immersion tin plating aided by complexing agent

MacDermid Enthone

General deposition rule:

The <u>more noble</u> metal will deposit on the <u>less noble</u> metal.

Au	1.50
Pt	1.20
Hg	0.85
Ag	0.80
I	0.54
Cu	0.34
Sb	0.10
H	0.00
Pb	-0.13
Sn	-0.14
Ni	-0.25
Fe	-0.40
Al	-1.66



**A deposition of Sn on Cu, is only possible with a complexing agent (e.g. thiourea)
The complexing agent will decrease the potential of Cu to a value less than the potential of Sn.**

$$2Cu + Sn^{2+} \text{ ------> } Sn + 2Cu^{+}$$

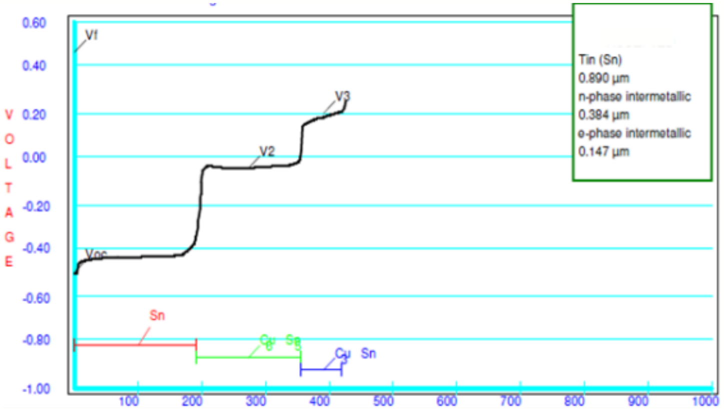
Thickness Analysis, 1.0 and 1.5 micron – Intermetallic Included

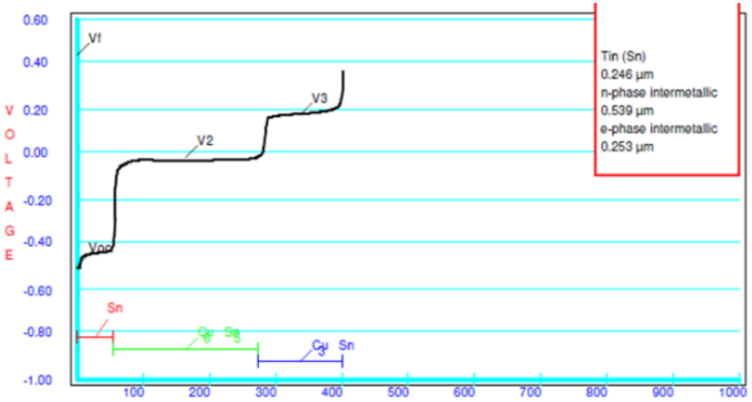
MacDermid Enthone

As Plated, No Reflow Exposure

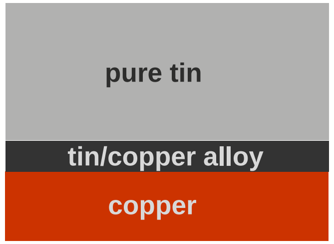
After 1 Reflow Exposure

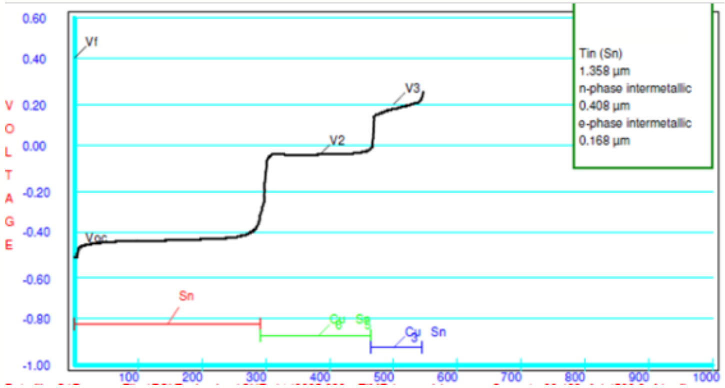
1.0 Micron

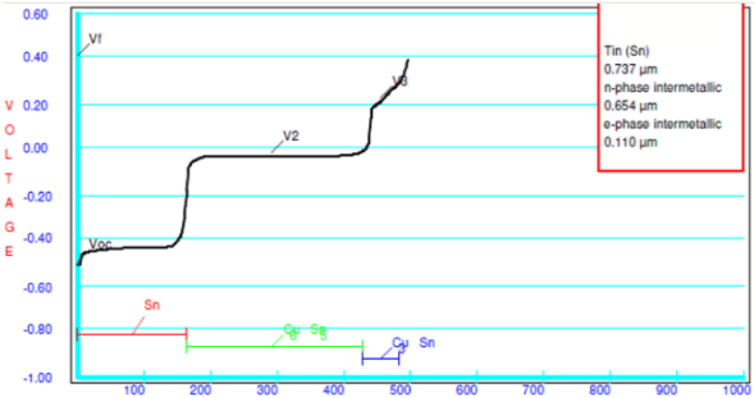




1.5 Micron





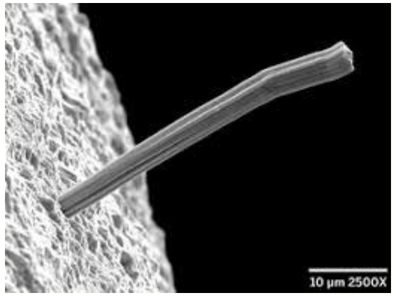


Tin Whiskers and Whisker Prevention

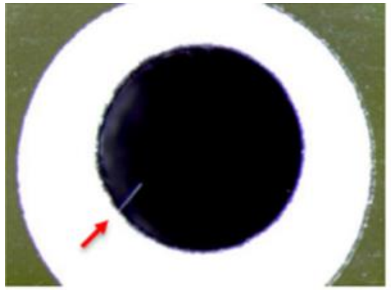
MacDermid Enthone

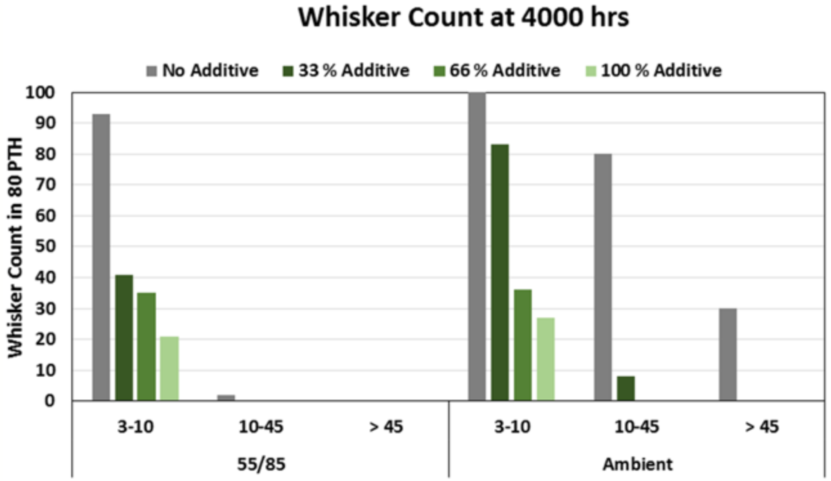
- Whisker growth, microns to millimeters in length, can occur from tin and some other metals
- Whisker formation is linked to stress relaxation in the metal / substrate system.
- Presents reliability risk

- Stress build-up and whisker growth can be prevented. Most commonly, very small amounts of a secondary metal in the coating will eliminate whisker growth
- Commercial tin processes utilize whisker prevention additives



high magnification microscope Image of tin whisker


tin whisker inside PCB thru-hole



Horizontal axis categorizes whisker lengths

ENIG and ENEPIG

MacDermid Enthone

Overview:

- High cost finishes -precious metal surfaces assure long shelf life and substrate protection.
- Generally deployed to high value, high reliability applications: smartphone, medical, mil/aero, etc.
- Electroless chemistries utilizing reducing agents and stabilizers generally mean higher process complexity.
- Nickel / Tin solder intermetallic differentiated from other finishes, debatable practical impact.
- ENEPIG primarily used in wirebond applications.
- <u>Renewed industry attention to "EN Corrosion"</u>

	ENIG	ENEPIG
Planarity	Yes	Yes
Solderjoint	Ni-Sn	Ni-Sn
Relative Cost	$$$	$$$
Shelf Life	24 months	24 months
Reflows	6	6
Contact	E-Test, ICT, Keypad	E-Test, ICT, Keypad
Press Fit	Good	Good
Au Wirebond	No	Yes
Al Wirebond	Yes	Yes

ENIG Process Overview

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Process Sequence — **Total Cycle Time ~ 90 minutes**

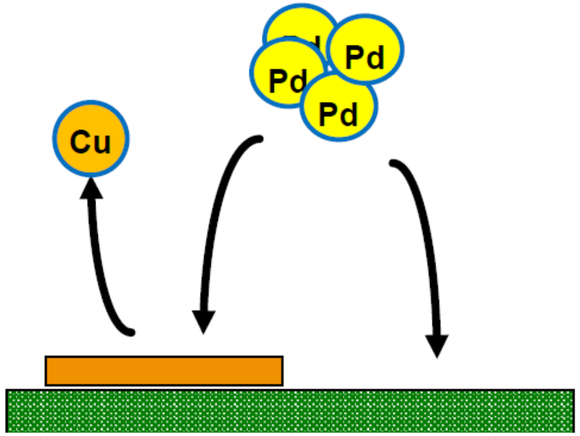
Clean → R → Etch → R → Activate Predip → R → Pd Activate → R → Post Dip → R → EN Plating → R → ImmAu Plating → R → Dry

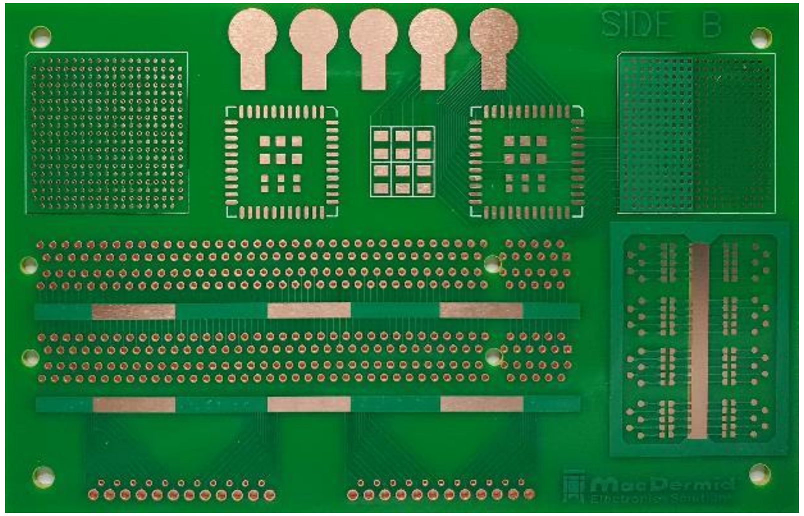
Palladium Activate Objectives:

- Electroless nickel will not plate directly onto copper without catalysis.
- Galvanic displacement reaction to form a very thin layer of palladium on copper circuitry.

Palladium Post Dip Objectives:

- Assist removal of palladium chemistry from areas of the panel (laminate and Soldermask) where EN plating is not desired preventing extraneous deposition and shorts.





ENIG Process Overview

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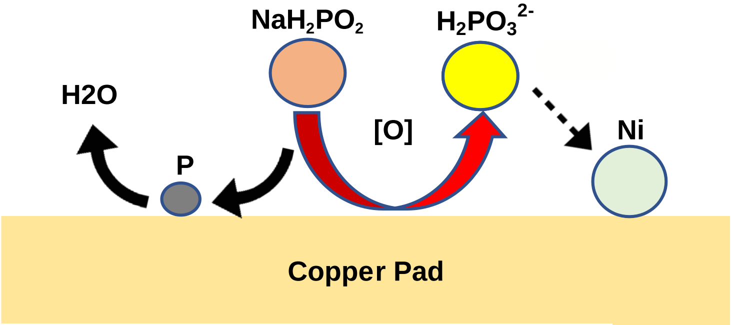
Process Sequence

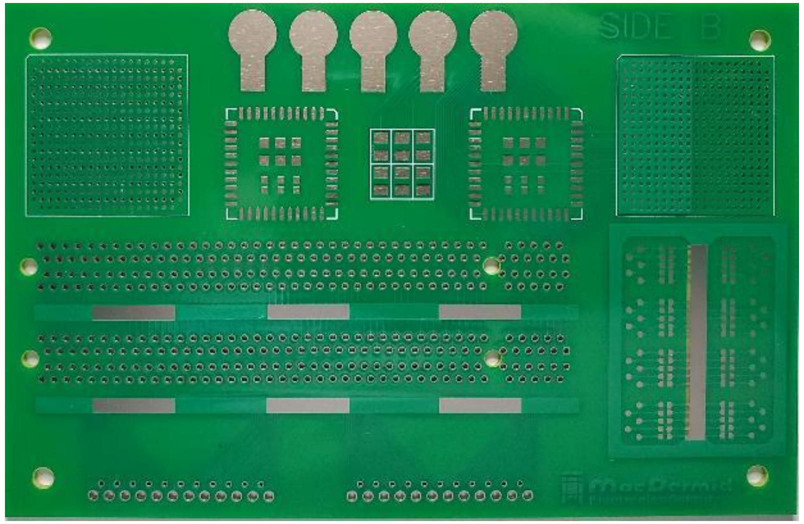
Total Cycle Time ~ 90 minutes

Clean → R → Etch → R → Activate Predip → R → Pd Activate → R → Post Dip → R → EN Plating → R → ImmAu Plating → R → Dry

Electroless Nickel Objectives:

- Deposition of a nickel – phosphorous alloy.
- Providing a barrier layer to copper migration through to solderable surface.
- Provide a surface suitable for immersion gold deposition that will allow soldering.





ENIG Process Overview

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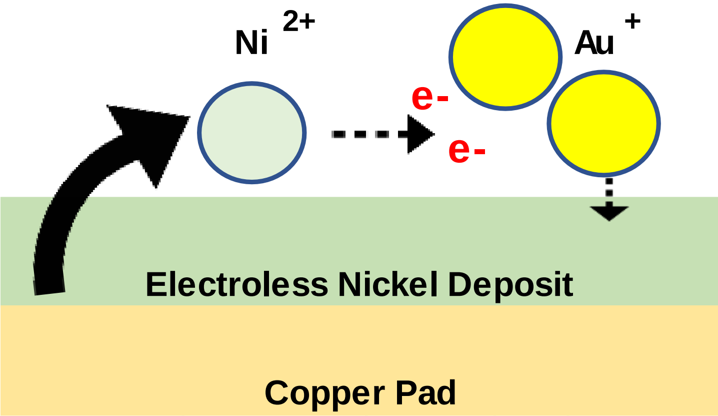
Process Sequence

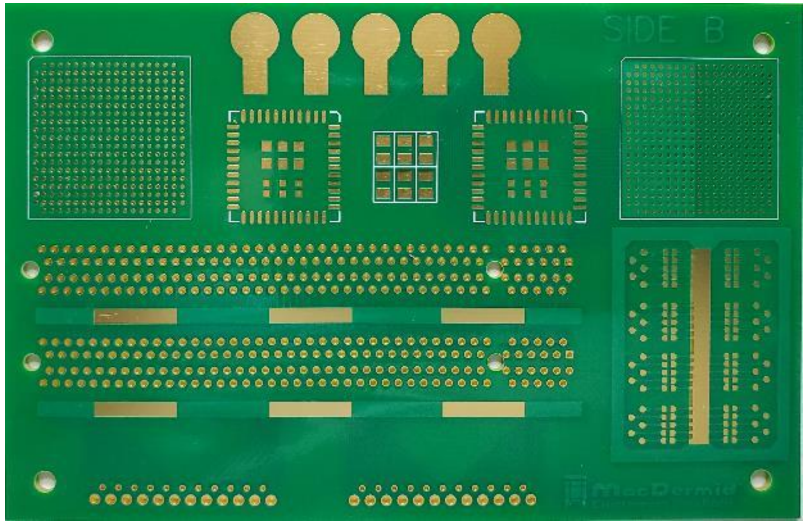
Total Cycle Time ~ 90 minutes

Clean	R	Etch	R	Activate Predip	R	Pd Activate	R	Post Dip	R	EN Plating	R	ImmAu Plating	R	Dry

Immersion Gold Objectives:

- Deposition of a thin layer of pure gold
- Prevents oxidation of the electroless nickel surface and preserves solderability.
- Gold is a noble metal and unreactive with the environment thus providing long shelf life and consistent soldering performance with increasing assembly operations.





Current Industry ENIG Spec - IPC4552 Revision A

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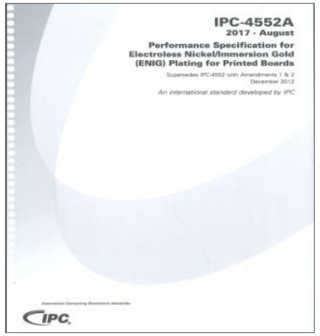
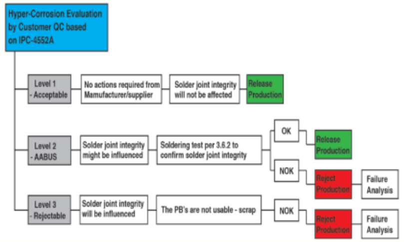

IPC-4552A
2017 - August
Performance Specification for Electroless Nickel/Immersion Gold (ENIG) Plating for Printed Boards
Supersedes IPC-4552 with Amendments 1 & 2 December 2012
An international standard developed by IPC

Table 3-1 Requirements of Electroless Nickel Immersion Gold Plating

Tests	Test Method	Requirement Paragraph	Class 1	Class 2	Class 3
General					
Measurement Capability	XRF		Gage capability $C_g \geq 1.33$[1]		
XRF Thickness Sample Size	XRF	3.5.3.2	C=0 with n (minimum) = $[2 / Cg]^2$ as necessary		
Visual	Visual	3.3	Uniform plating and complete coverage of surfaces to be plated		
Electroless Nickel Thickness Rigid Printed Board	Appendix 3	0.1	3 to 6 µm [118.1 to 236.2 µin]		
Electroless Nickel Thickness Flex Printed Board[2]	Appendix 3	3.5.1.4	1.27 to 6 µm [50.0 to 236.2 µin]		
Immersion Gold Thickness **(Exception required on Procurement documentation)**	Appendix 3	3.5.2.1	The minimum immersion gold deposit thickness **shall** be $\bar{X} - 3s \geq 0.04$ µm [≥1.58 µin] The maximum immersion gold deposit thickness **shall** be $\bar{X} + 3s \leq 0.1$ µm [≤ 3.94 µin] as measured on a pad size of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area, ± 10%. Where: $\bar{X}$= the mean gold thickness s = the standard deviation of a sample		



- **IPC4552 A (August 2017) increases the quality bar for conforming ENIG deposits.**
- **All updates designed to minimize, control and evaluate ENIG corrosion.**
  - **Changes to Gold Deposit Thickness Control and Measurement.**
    - Tighter gold thickness specification - lower minimum and introduction of new maximum gold thickness.
    - Introduces XRF capability requirement and penalties for non-conforming instruments.
  - **New Requirement to Validate Electroless Nickel Phosphorous Content Control.**
    - EN %P dictates corrosion resistance and is not traditionally controlled by SPC.
    - Adoption of new analytical techniques for compliance.
  - **New Requirement to Introduce Electroless Nickel Corrosion Analysis.**
    - X-Section evaluation for EN corrosion required as part of SPC.
    - ENIG product is now rejectable if corrosion specification is not met.

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4552B will include……

(1) Revised corrosion level grading – Level 0, improved description, scale and visual aids.
(2) X-Section locations for evaluation and a data collection plan.
(3) How to assess a "product rating" based on data collected.

	Level 0	Level 1	Level 3	Level 2
Observation	Defect free ENIG deposit.	Number of Spike-Type Defects observed < 10 and All corrosion spike depths are ≤ 20% of the nickel deposit thickness	- Number of Spike-Type and/or Spreader-Type Defects observed ≥ 10 and > 5 of the observed defects have a depth > 40% of the nickel deposit thickness or - Black Band-Type defect(s) present that extend to ≥ 30% of the field of view	All other observations

Meeting ENIG IPC4552A Corrosion

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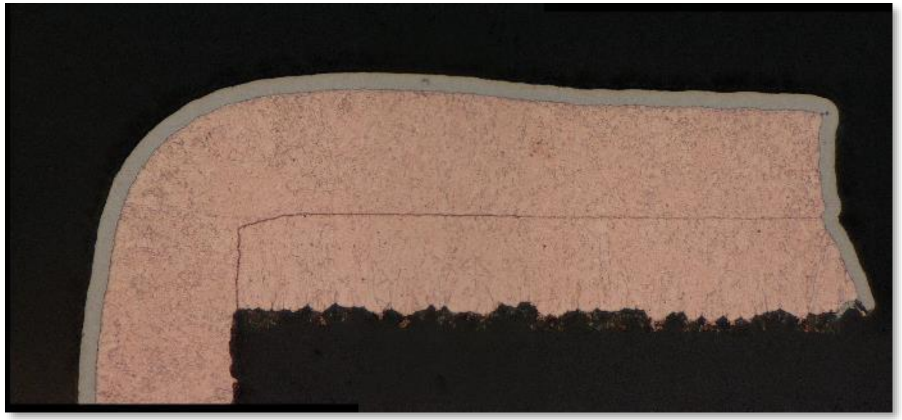
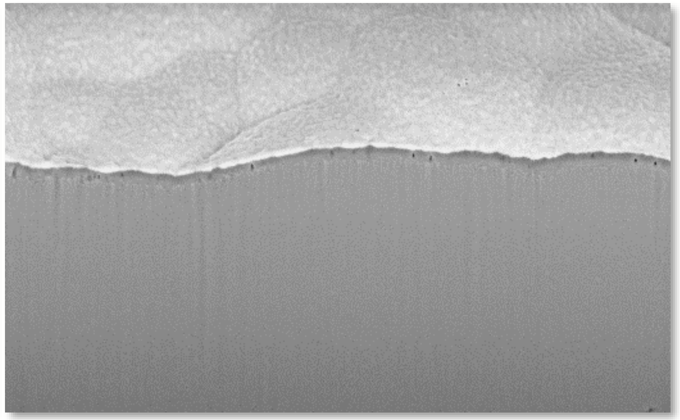
optimized ENIG control and chemistry selection





Anodic Reaction

$Ni \rightarrow Ni^{2+} + 2e^-$

Cathodic Reaction

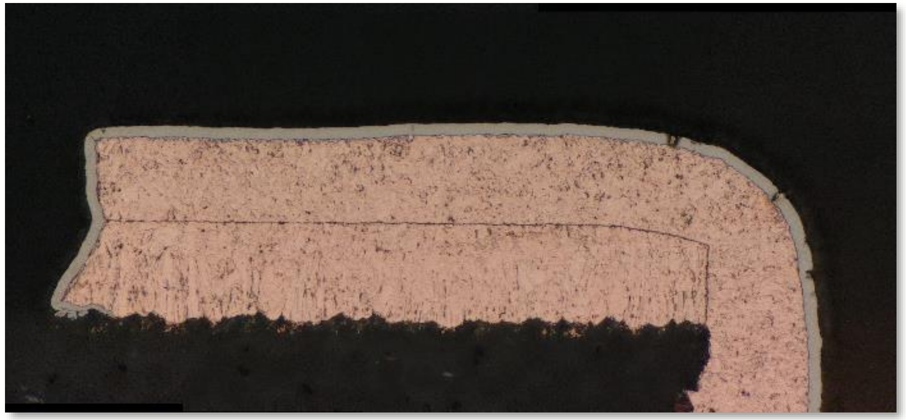
$2[Au(CN)_2]^- \rightarrow 2Au^+ + 4CN^-$

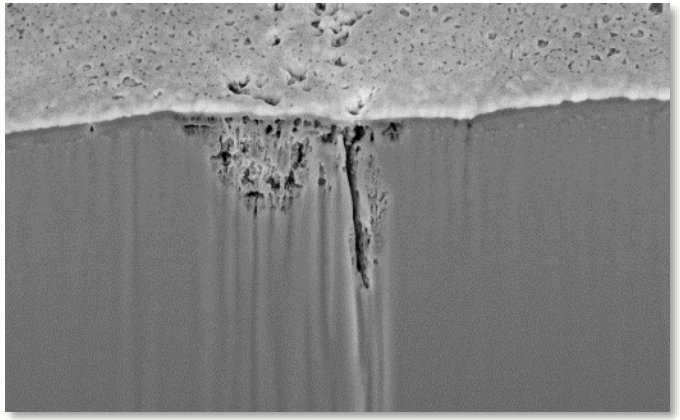
$2Au^+ + 2e^- \rightarrow 2Au$

Overall Reaction

$\mathbf{Ni + 2[Au(CN)_2]^- \rightarrow 2Au + [Ni(CN)_4]^{2-}}$

poor ENIG process control

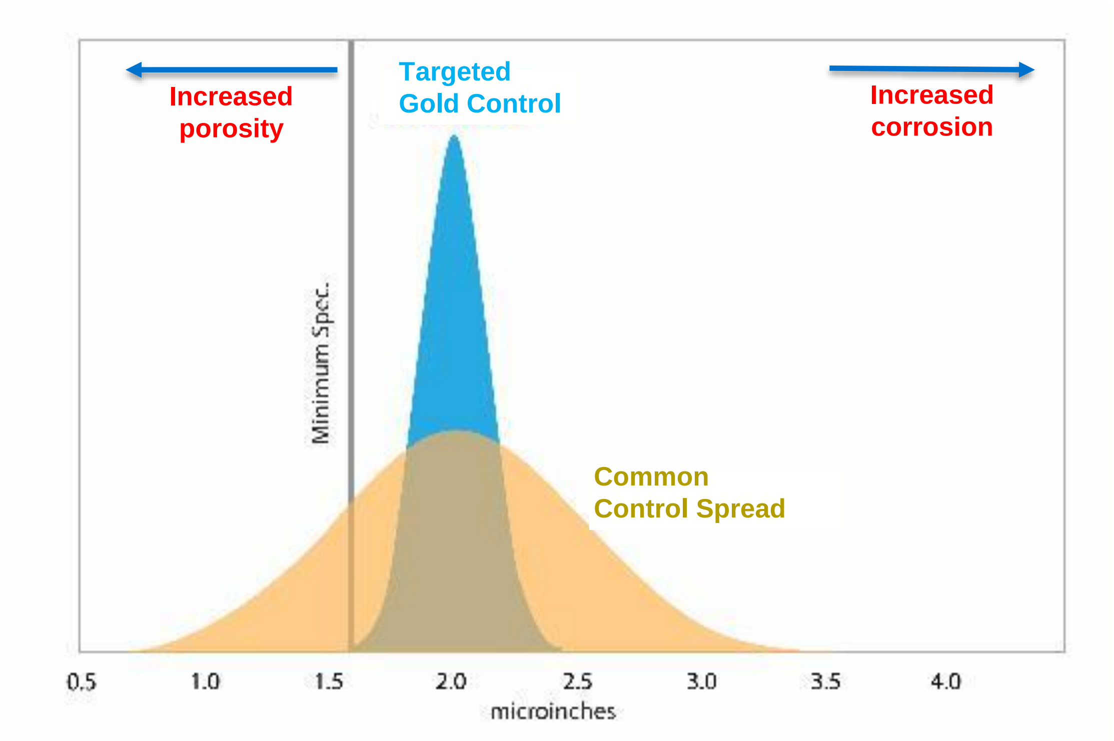




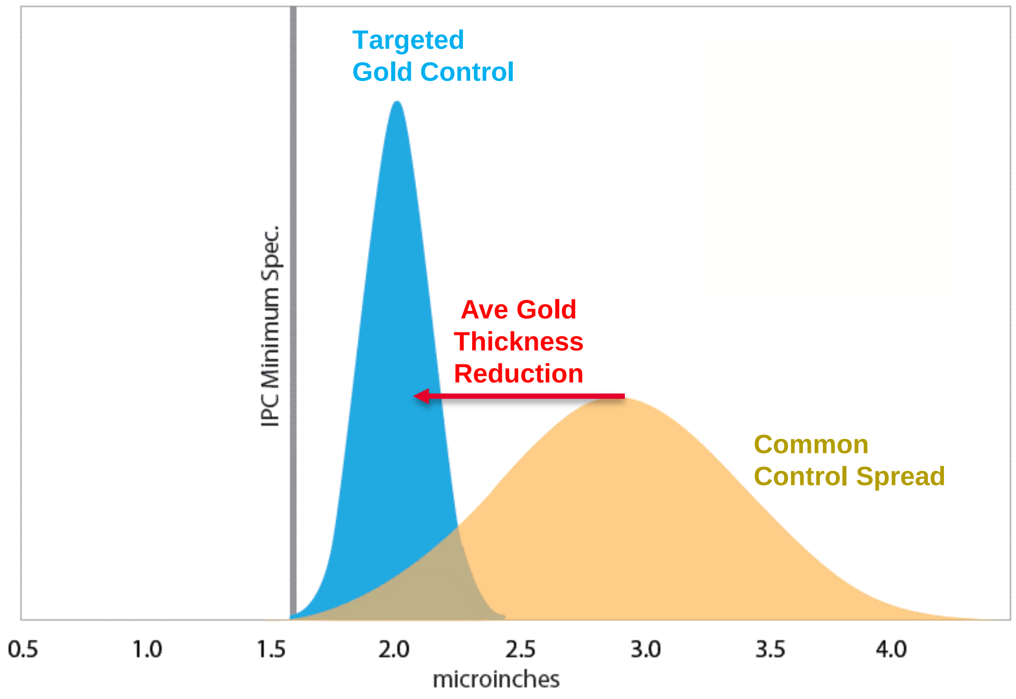
- All Immersion Gold deposition proceeds via same chemical reaction.
- Good process control + good choice of Nickel and Gold plating chemistry can minimize corrosion

Gold Thickness Control - Highlights

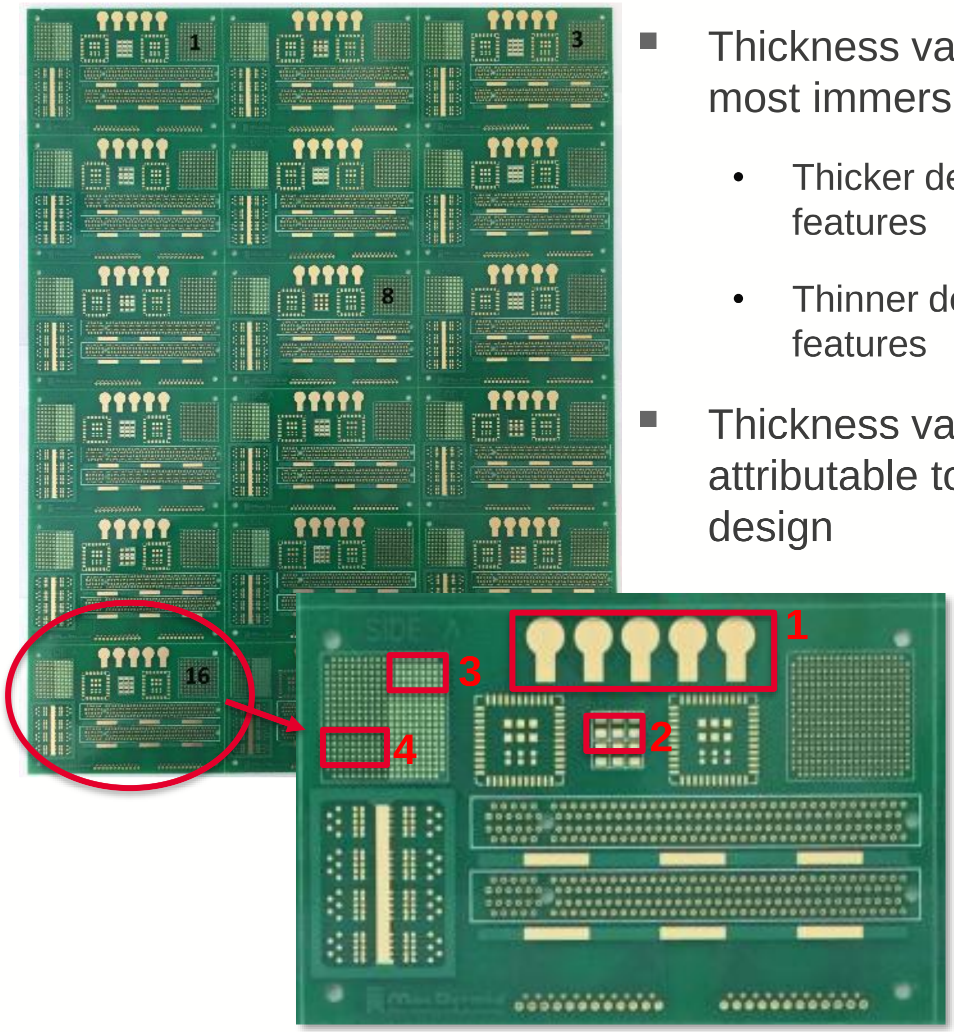
Performance/Specification Concern



Cost Concern

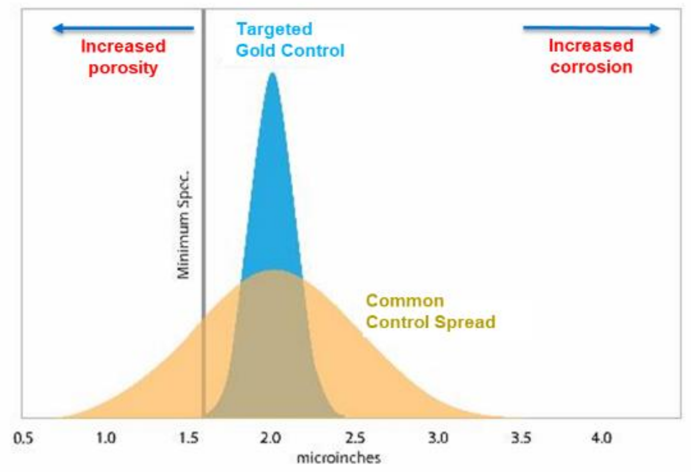


Gold Thickness: Control Considerations

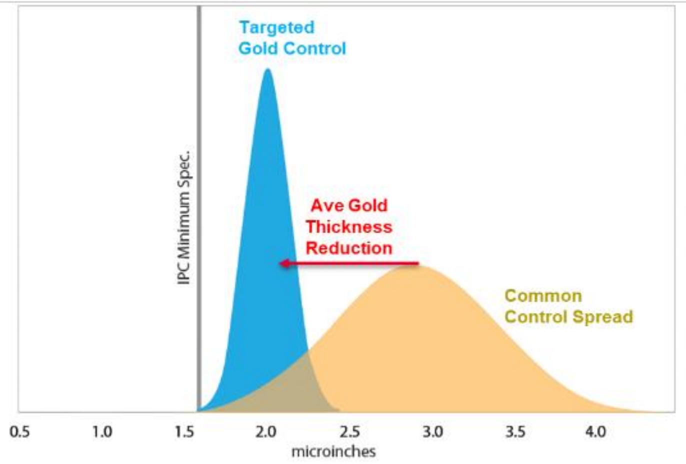


- Thickness variation trends for most immersion plated metals
  - Thicker deposit to small features
  - Thinner deposit to large features
- Thickness variation attributable to equipment design

Performance/Specification Concern



Cost Concern



ENIG in Production – Case Study

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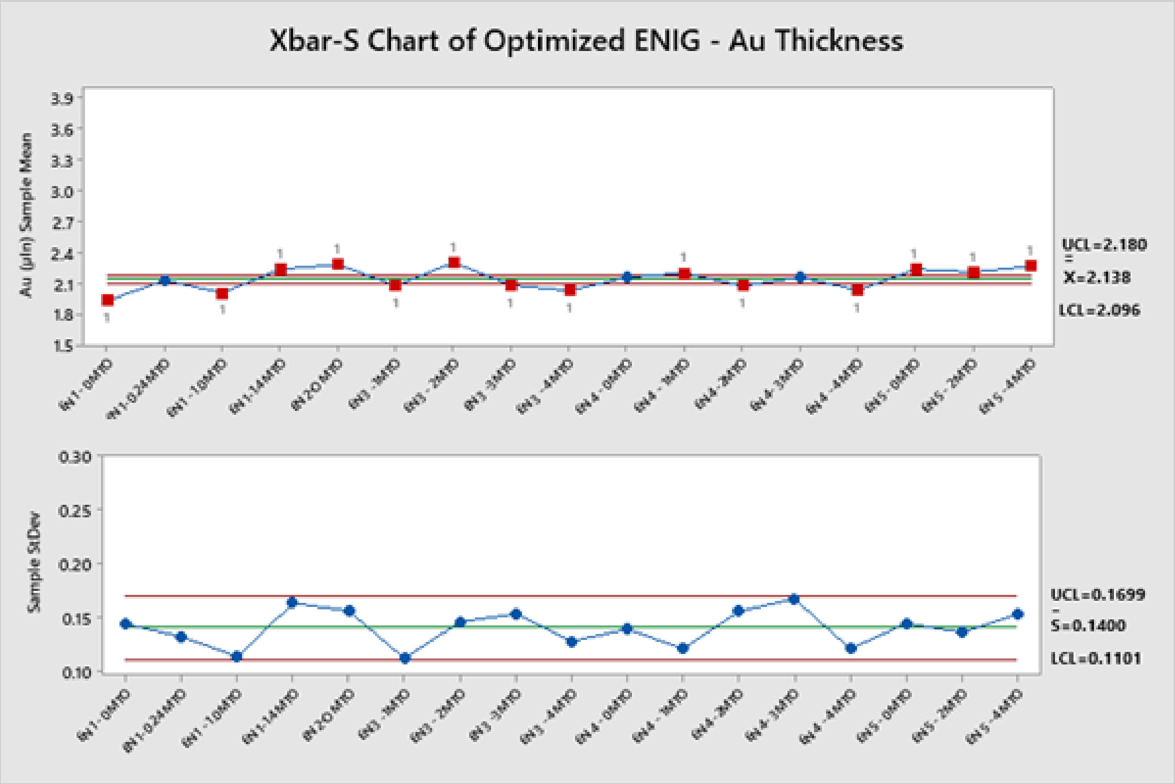

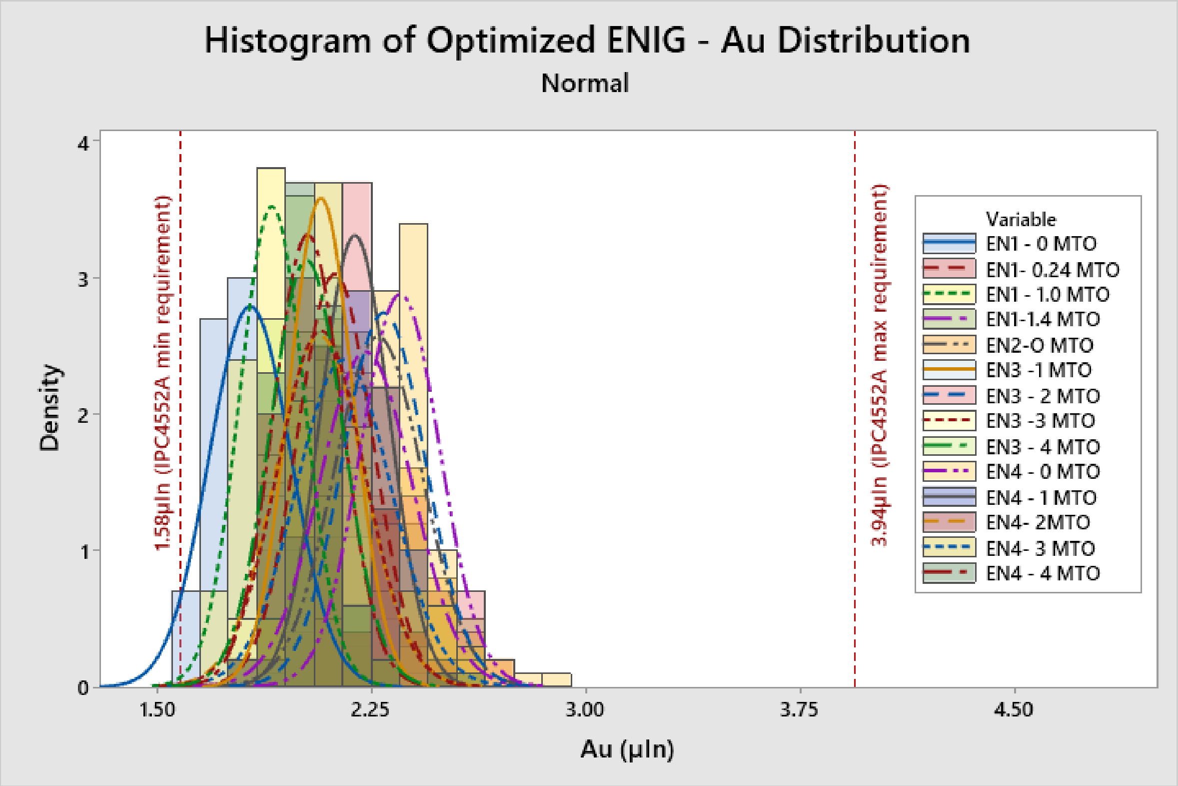

Key Characteristics:

- Consistent Au thickness over multiple Electroless Nickel lives and Immersion Gold life.
- Tight overlapping Au distributions for each sub set analyzed.
- Distribution analysis is based on 4 pad sizes / IPC requires consistent pad size measurement to minimize variation.

ENEPIG Process Overview

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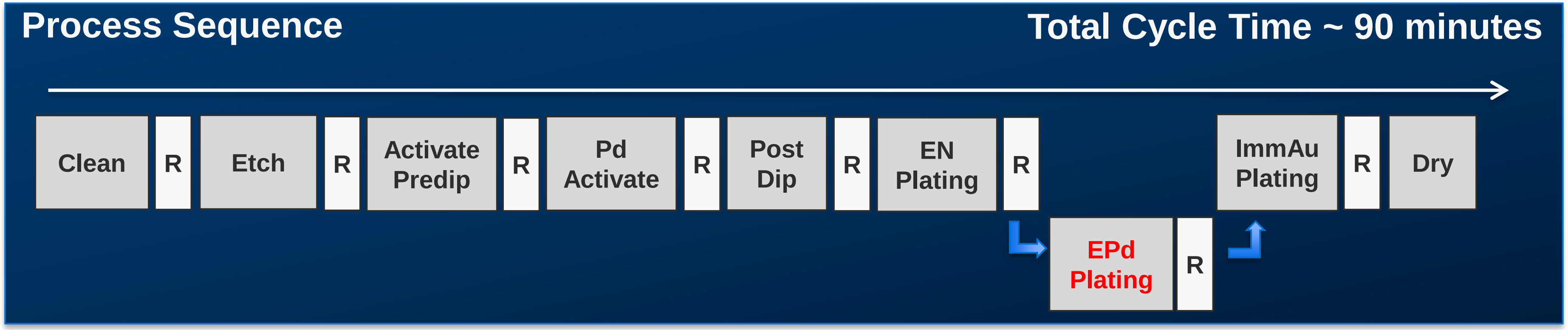
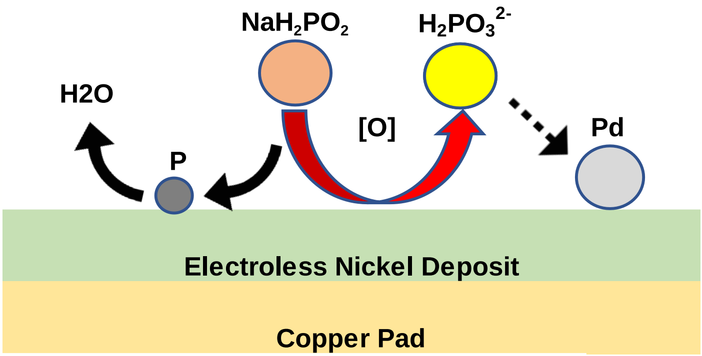
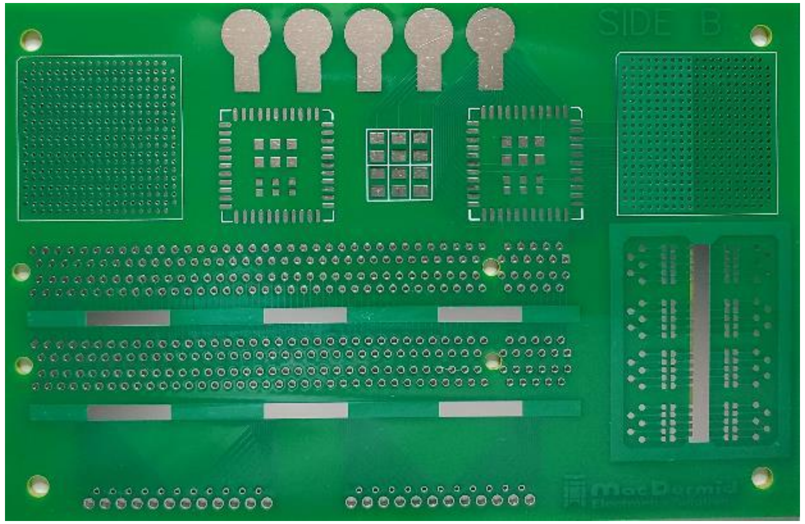


Electroless Palladium Objectives:

- Deposition of a palladium – phosphorous alloy onto EN surface.
- Provide a surface suitable for gold deposition that will allow gold wirebonding.





ENEPIG – Gold Deposition Mechanism

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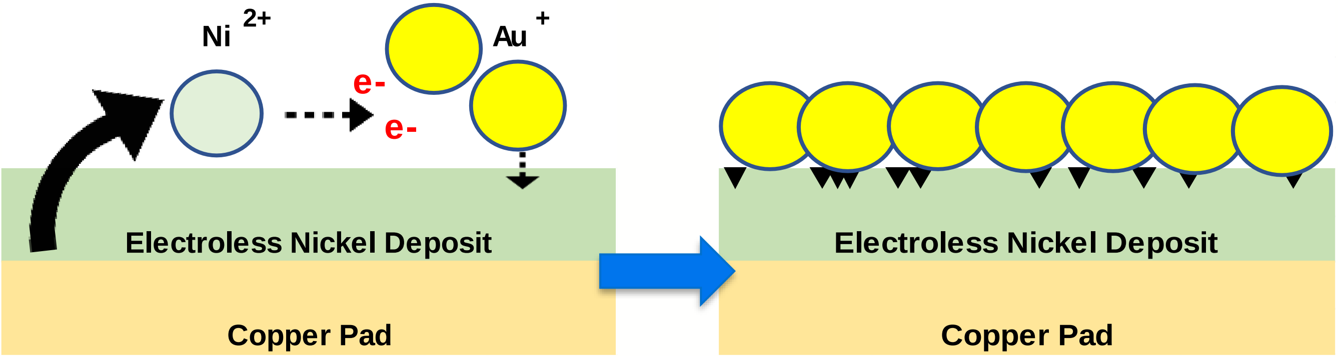
ENIG



Anodic Reaction

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Cathodic Reaction

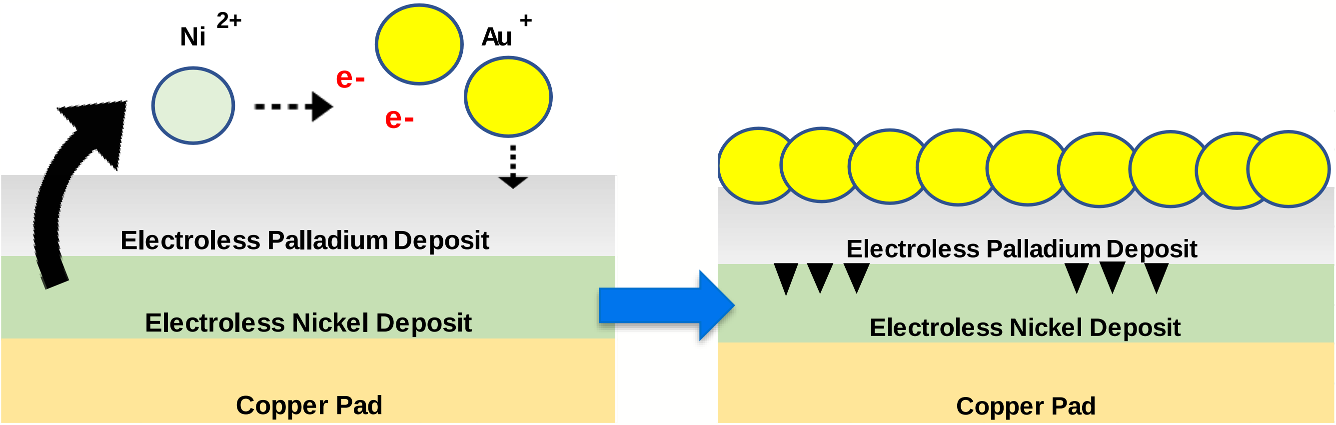
$2[Au(CN)_2]^{-} \rightarrow 2Au^{+} + 4CN^{-}$

$2Au^{+} + 2e^{-} \rightarrow 2Au$

Overall Reaction

$Ni + 2[Au(CN)_2]^{-} \rightarrow 2Au + [Ni(CN)_4]^{2-}$

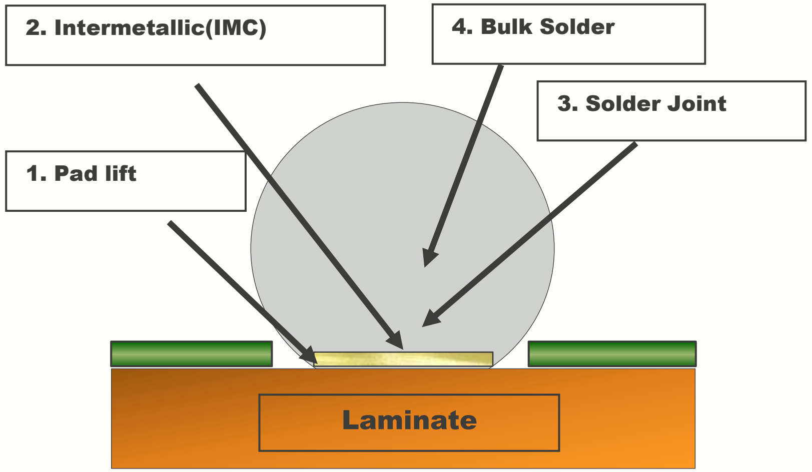
ENEPIG



- ENIG and ENEPIG rely on the same galvanic displacement of nickel to fund gold deposition.
- Excessive removal of nickel results in corrosion underneath the solderable surface.

Why Control ENIG Corrosion ?

- Too much and uncontrolled EN corrosion effects the normal IMC formation and can result in weak solderjoints !



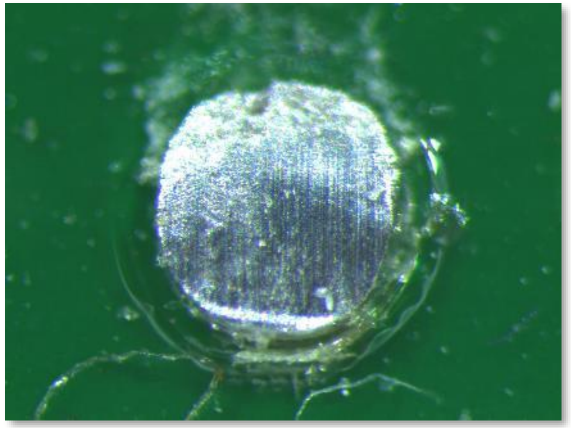


Figure A: Expected Ball-Shear Result

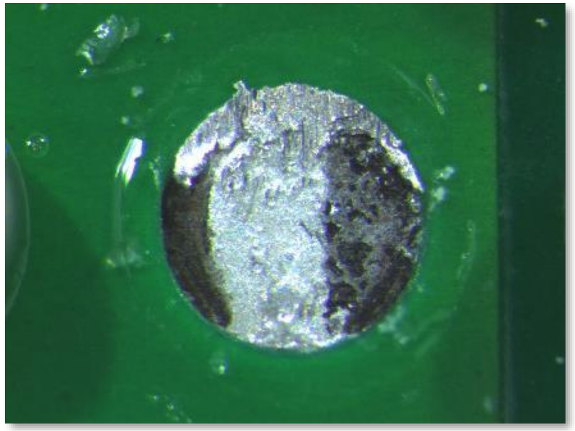


Figure B: High Corrosion Ball-Shear Result

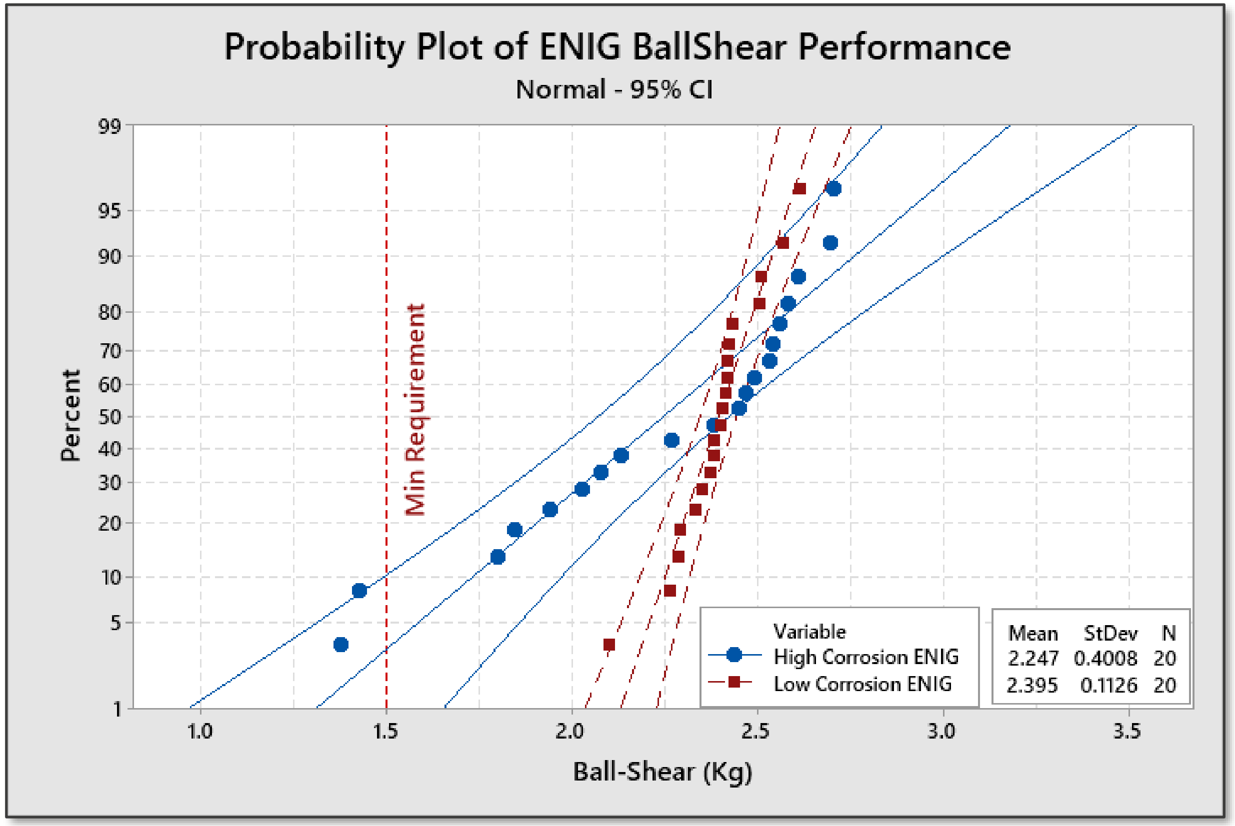
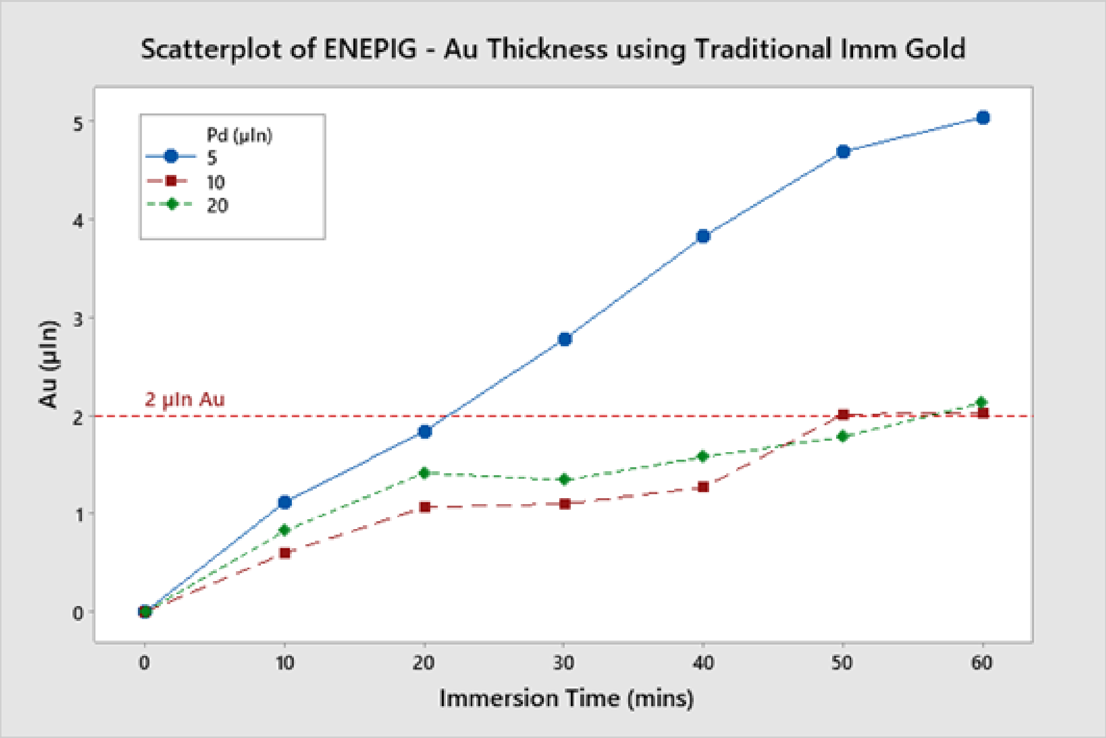
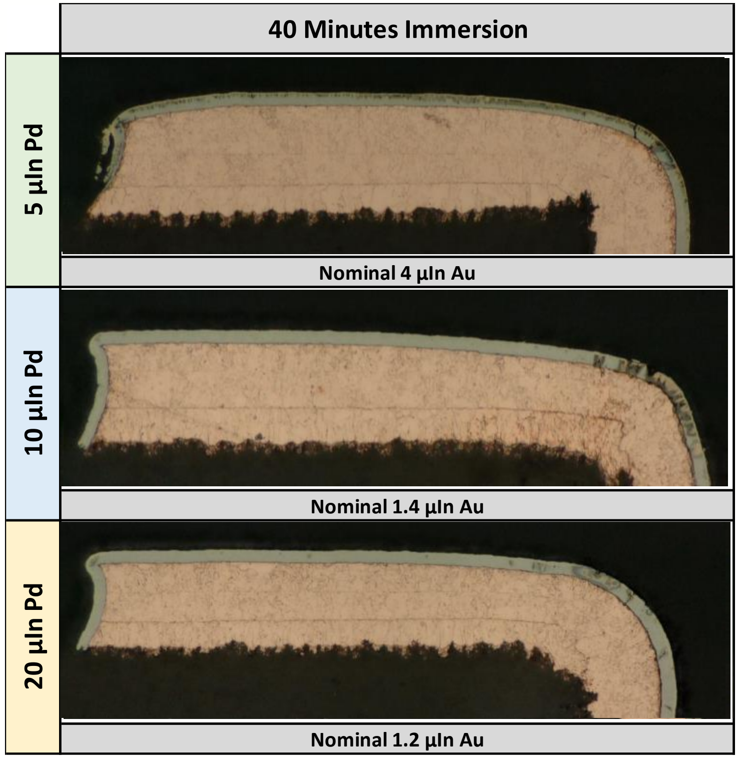


Figure C: Ball-Shear Comparison of High Corrosion vs Low Corrosion ENIG

ENEPIG – Limitations of Immersion Gold Technology

Immersion Gold – Galvanic Displacement





- Galvanic Displacement alone limit's ability to build Au thickness especially as palladium deposit thickness increases.
- Galvanic Displacement increases corrosion layer underneath the EPd layer as gold time is extended in effort to build thickness.

What is a Hybrid Gold System?

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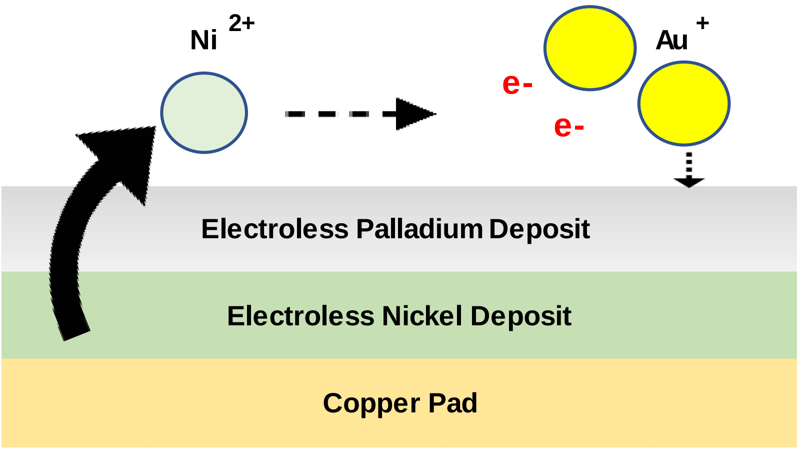
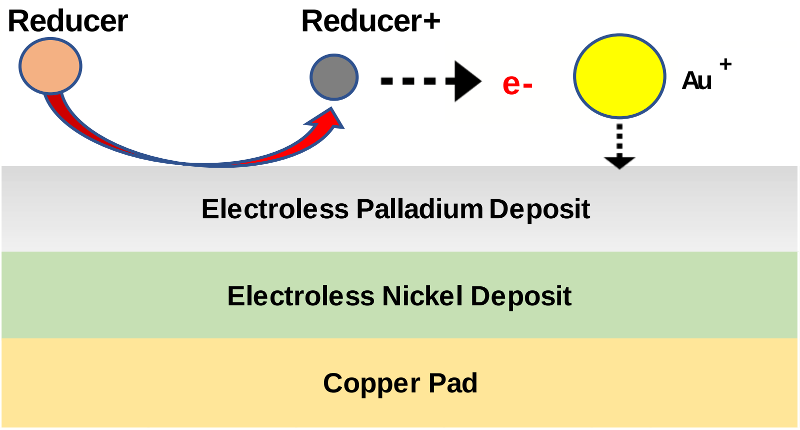
Galvanic Displacement

- Simple and stable chemistry.
- Electrons for gold deposition supplied by nickel dissolution.
- Nickel dissolution shows as corrosion.
- Thickness capability limited as gold thickness increases.



Chemical Reduction

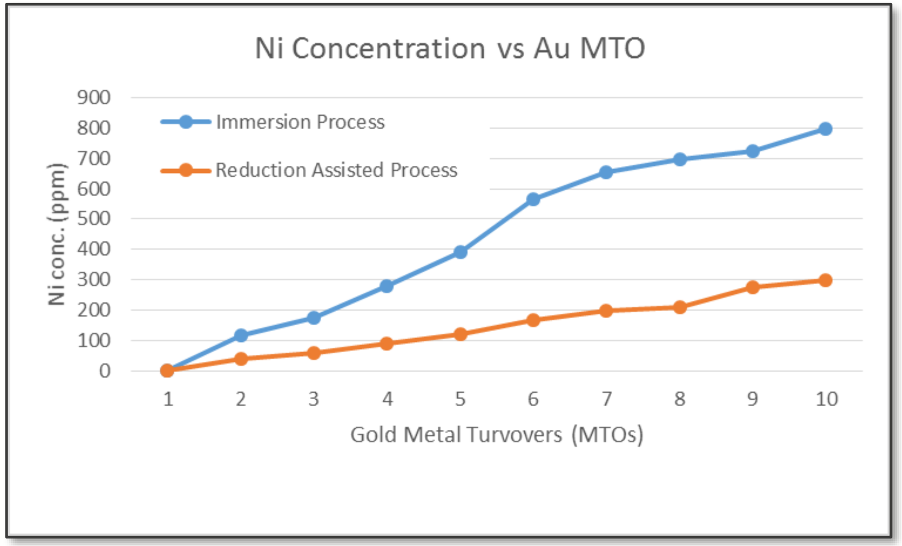
- More complicated, “meta-stable” chemistry.
- Electrons for gold deposition supplied by reducing agent.
- No nickel removal therefore no corrosion.
- No gold thickness limitation.

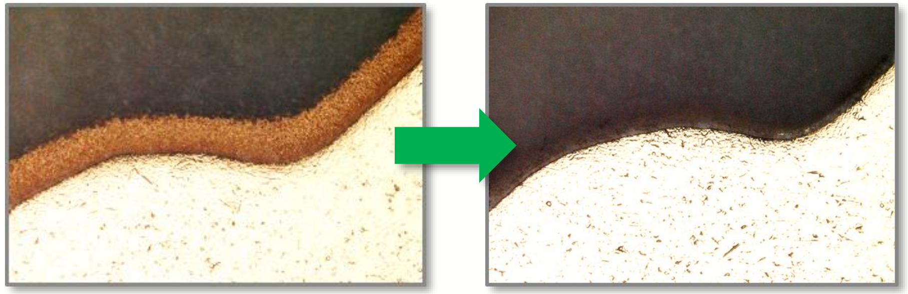


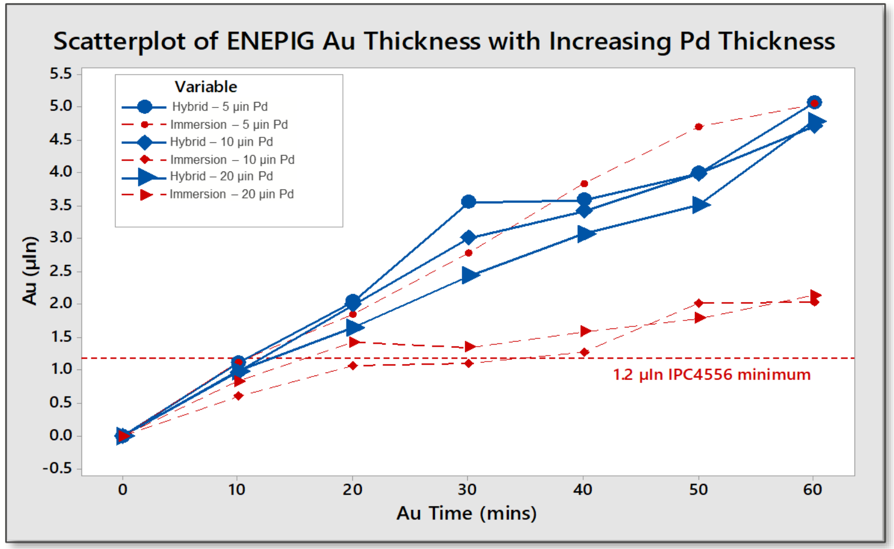
Reduction Assisted Gold balances both deposition mechanisms to provide beneficial characteristics of each process in a single gold solution.

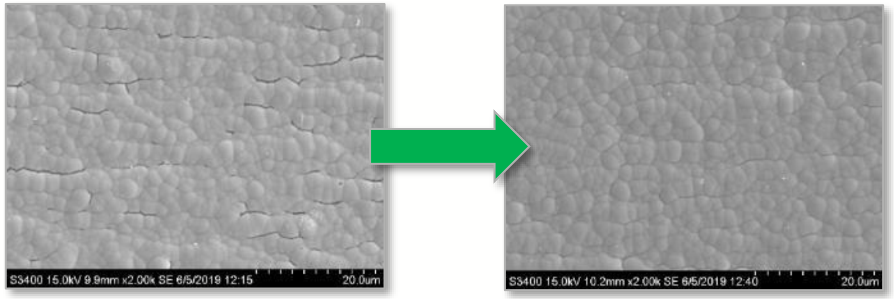
Hybrid (Reduction Assisted) gold overview

Hybrid process, dominated by electroless deposition mechanism.









Limited electroless properties reduce risk of plating in non-targeted areas

Limited immersion properties reduce corrosion of substrate and allow increased thickness capabilities.

ENEPIG – Immersion Gold System Corrosion Statistics

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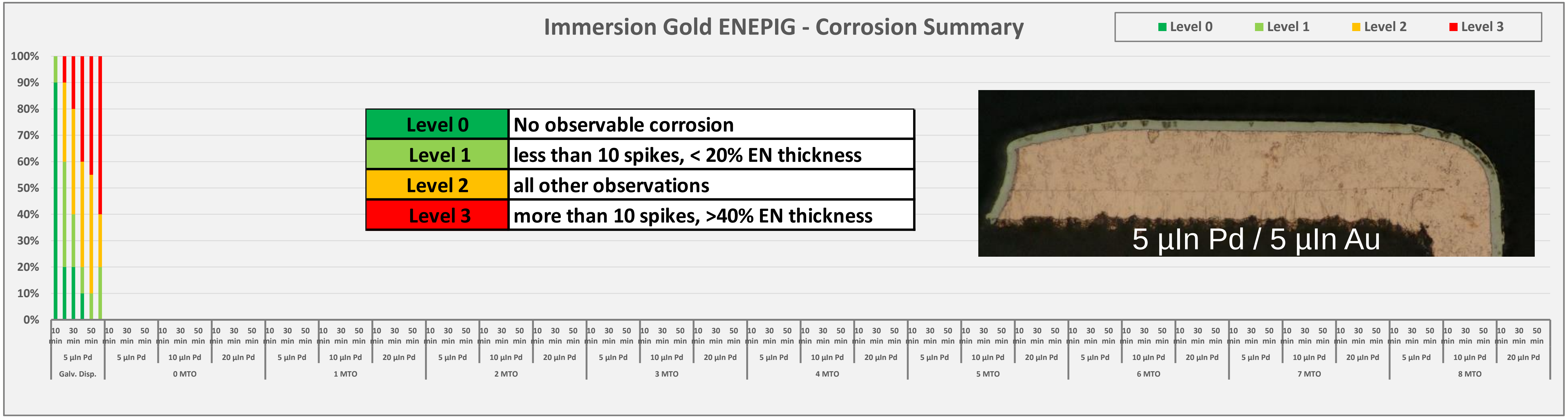
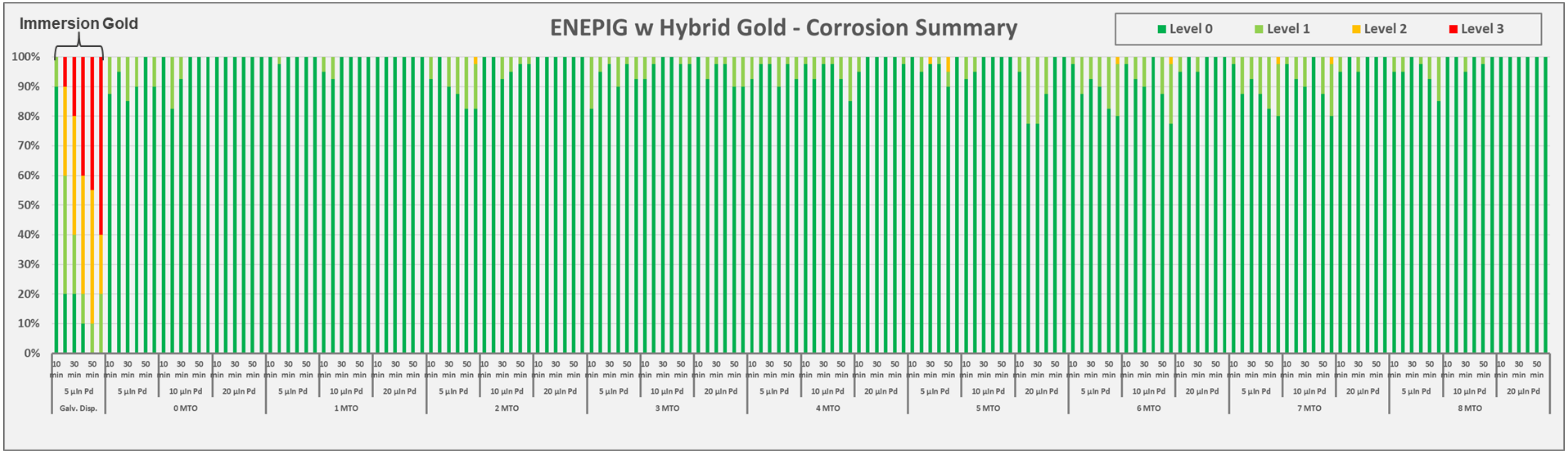
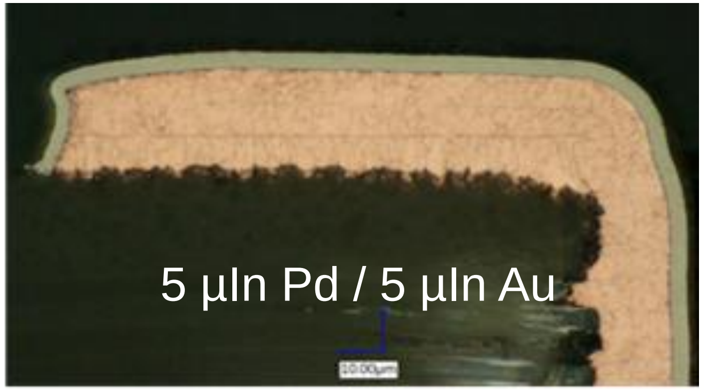


ENEPIG Corrosion Summary:

- Galvanic displacement reaction requires more nickel dissolution to deposit more gold.
- Controlling nickel dissolution uniformity becomes more difficult with extended immersion gold time and thickness.
- ENEPIG corrosion increases significantly with extended immersion gold time and thickness.

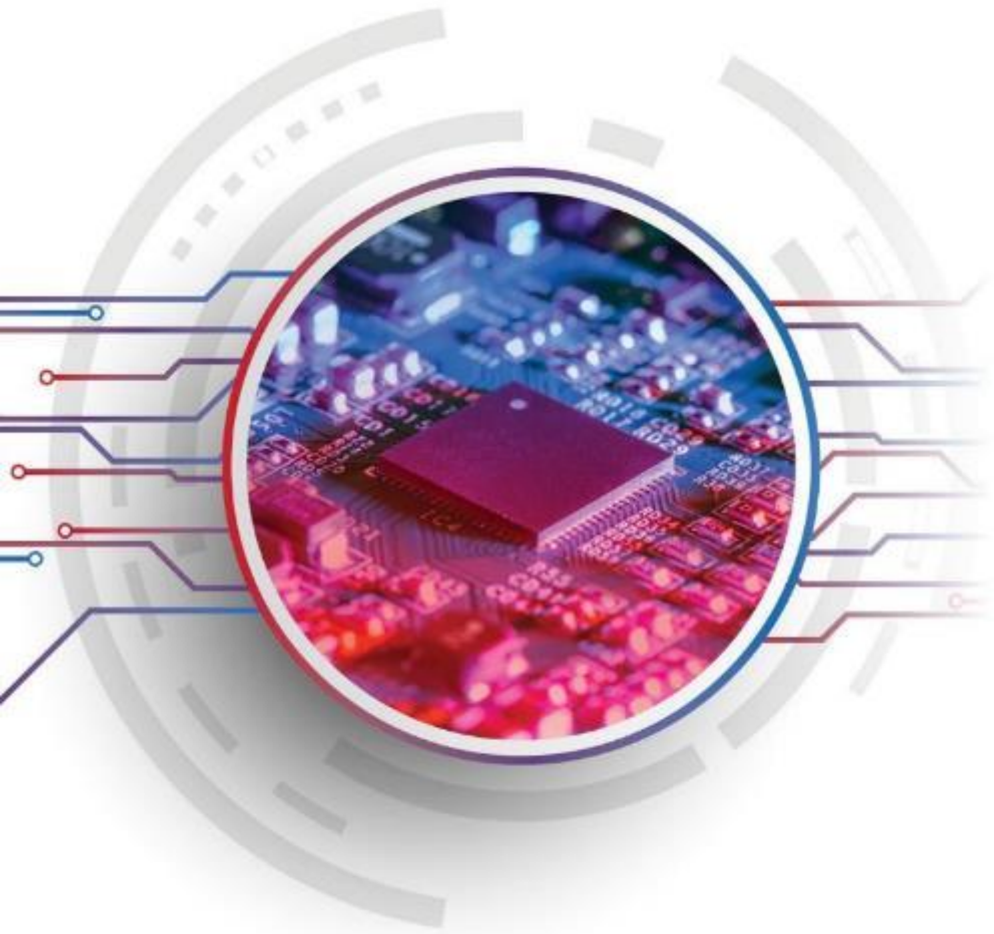
ENEPIG – Hybrid Gold Corrosion Statistics





ENEPIG Corrosion Summary:

- Near zero corrosion performance observed over 0 – 8 MTO.
- No increase in corrosion could be correlated to increasing gold thickness.



Thank you for your attention….

John Swanson, Director of Final Finishes