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Engineered Powders,
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TECHNIC INC

Beyond Ni/Au: Next Generation Corrosion-Resistant Finishes for Electronics Applications

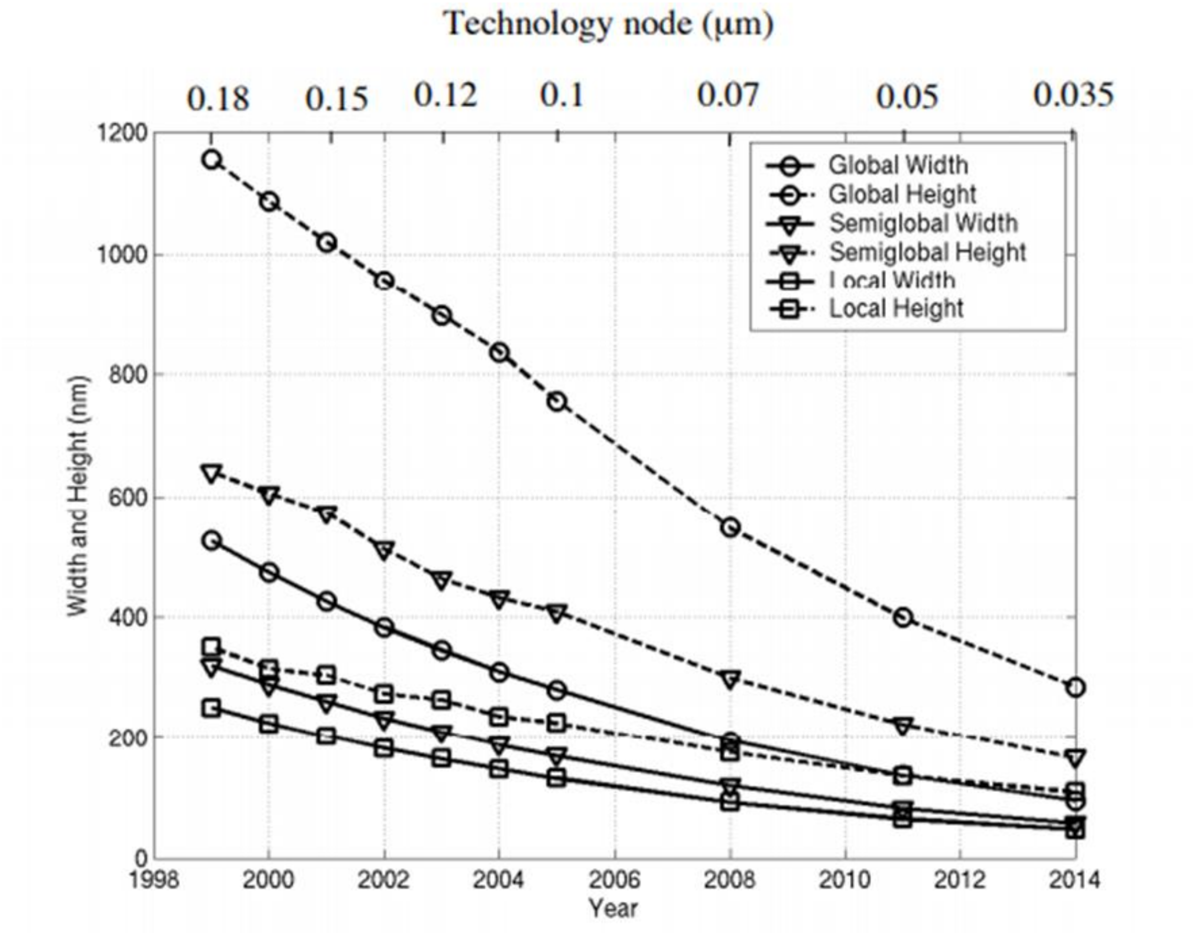
SUR/FIN 2018 – Cleveland, OH

Beyond Ni/Au:
Functions of Electronic Finishes

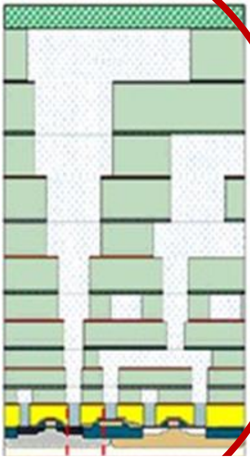
- Provide electrical conductivity
- Improve corrosion resistance
- Impart good wear resistance
- Enable attachment to other surfaces (where applicable)
  - Soldering, insertion, etc.
- Traditional electroplated Ni/Au deposits have achieved the above objectives successfully for decades
  - Ni: 1-2 µm +
  - Au: 0.1-0.75 µm (depending on application)
- ***UNTIL NOW…***

Beyond Ni/Au:
Electronic Finishes : New Requirements

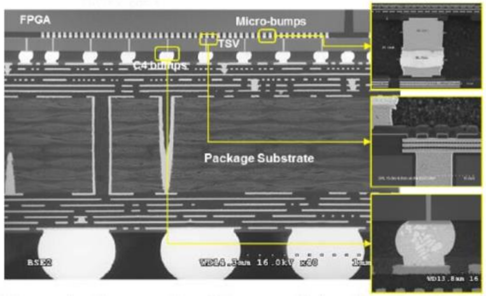
As IC semiconductor devices and PCB dimensions are scaled down, the demands on the electronic interconnects increase dramatically



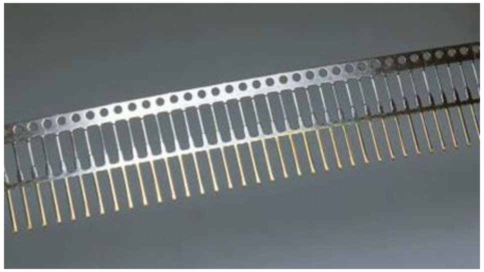
Beyond Ni/Au:
Electronic Finishes : New Requirements



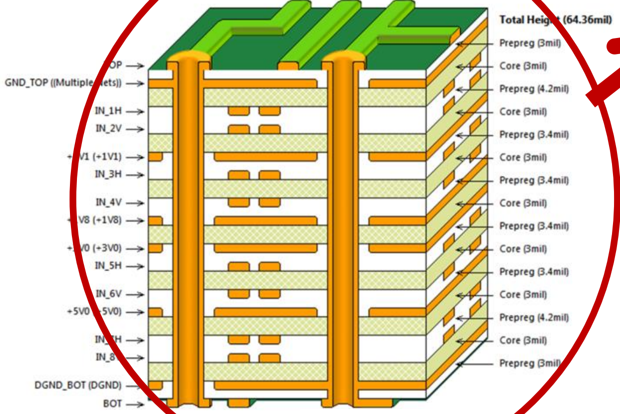
SEMICONDUCTOR



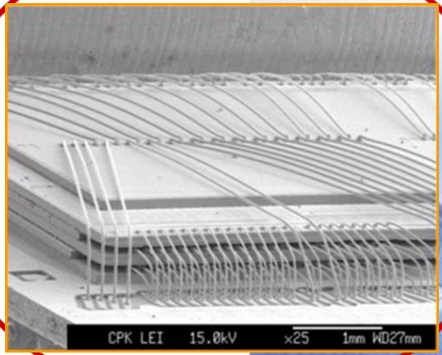
IC PACKAGING



CONNECTORS



PCB



CONFIDENTIAL

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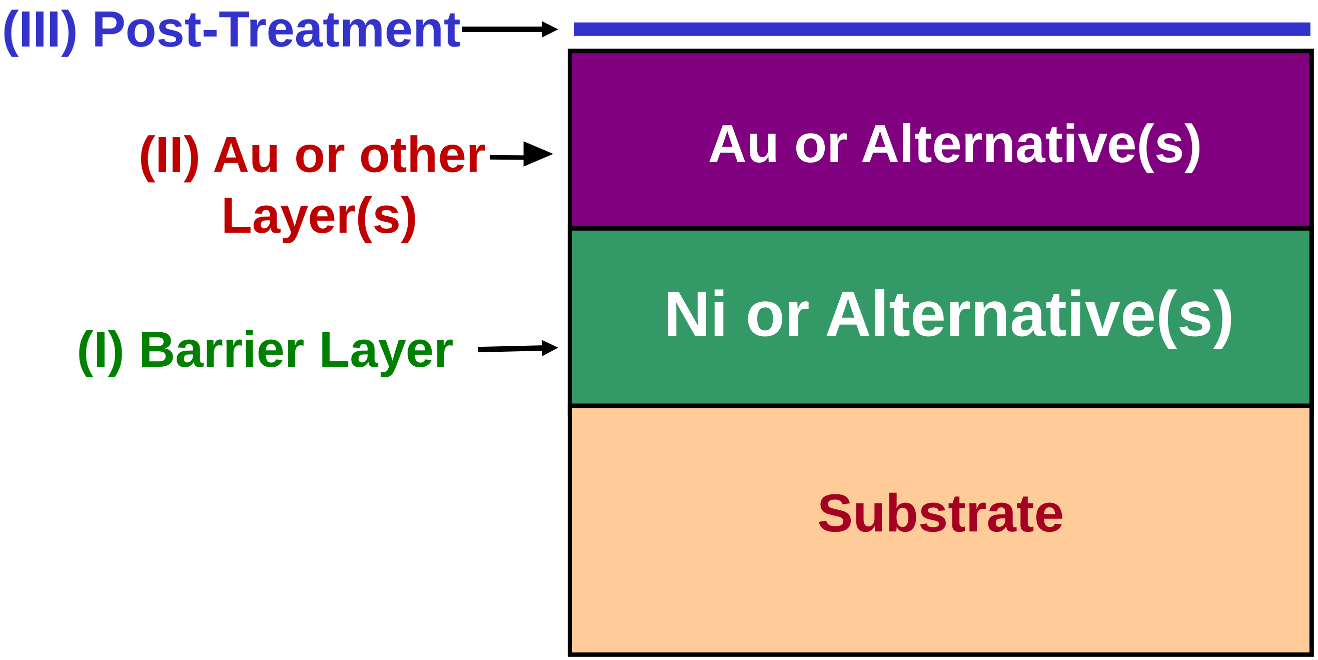
Beyond Ni/Au:
Typical Electronic Finish


(III) Post-Treatment

(II) Au or other Layer(s)

(I) Barrier Layer

Au or Alternative(s)

Ni or Alternative(s)

Substrate

Improved Barrier Layers

Nano-Crystalline Nickel

- Traditional barrier layer for electronics finishes is matte nickel sulfamate
- **Nano-crystalline Nickel** is an advanced nickel electroplating process specifically engineered to significantly improve nickel thickness distribution and corrosion-resistance from a proprietary electrolyte in high speed/reel-to-reel plating applications
- **Nano-crystalline Nickel** produces a semi-bright, low stress, ductile deposit

Nano-Crystalline Nickel vs. Ni sulfamate

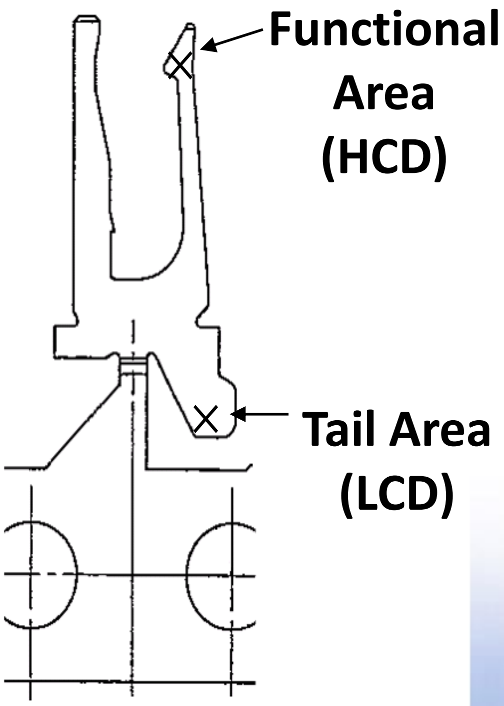
Deposit Characteristics

	Nano-crystalline Ni	**Ni Sulfamate Matte**
Appearance	**Semibright**	**Matte**
Stress	**~2500 psi (17.2 MPA)**	**~5500 psi (37.0 MPA)**
Hardness	**~450 knoop**	**~250 knoop**
Structure	Nano-crystalline	Micro-crystalline
Solution Conductivity	155.6 mS/cm	68.0 mS/cm

Nano-crystalline Ni vs. Ni Sulfamate

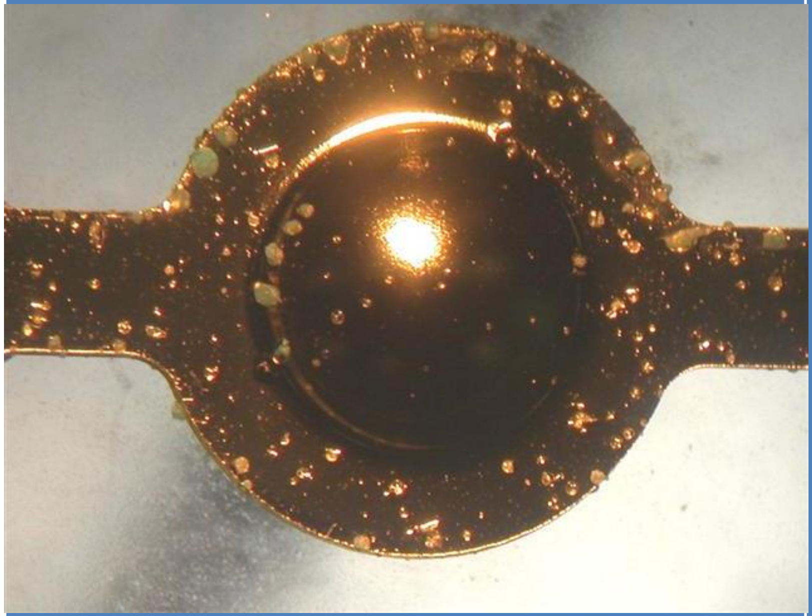
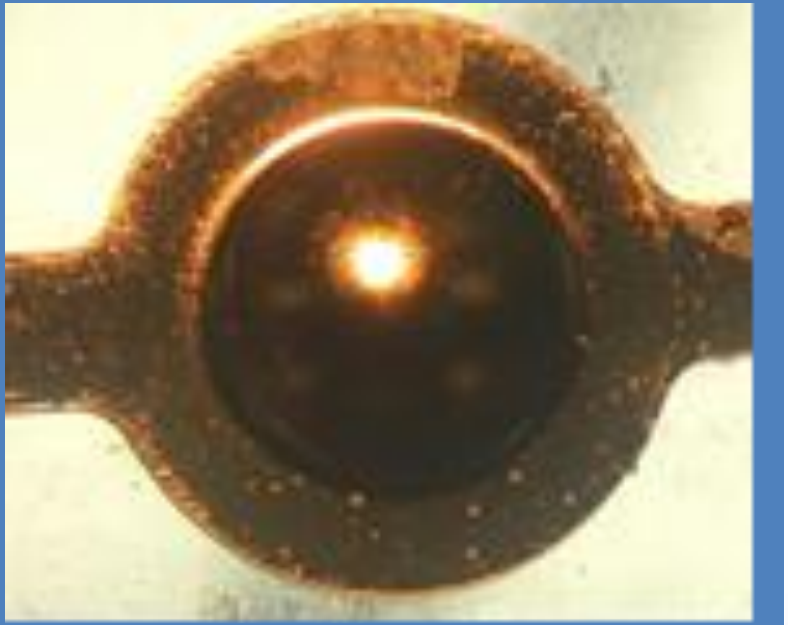
Thickness Distribution Comparison

Bath	HCD (u“)	LCD (u“)	HCD:LCD Ratio
Ni S.	41	14	2.9
GE Ni	**43**	**22**	**2.0**
Ni S.	84	32	2.6
GE Ni	**86**	**49**	**1.8**
Ni S.	123	47	2.6
GE Ni	**121**	**72**	**1.7**



The thickness distribution of the Low Current Density (LCD) area is significantly improved (30 to 40%) by Nano-Ni process.

Nano-Crystalline Nickel vs. Ni sulfamate Corrosion Comparison

	
Ni sulfamate – 120µin Au - 30µin	Nano-Ni - 100µin Au - 30µin

After 2 hour nitric acid vapor (NAV) exposure

Cobalt-Tungsten (CoW)
A Nickel-Free Barrier Layer

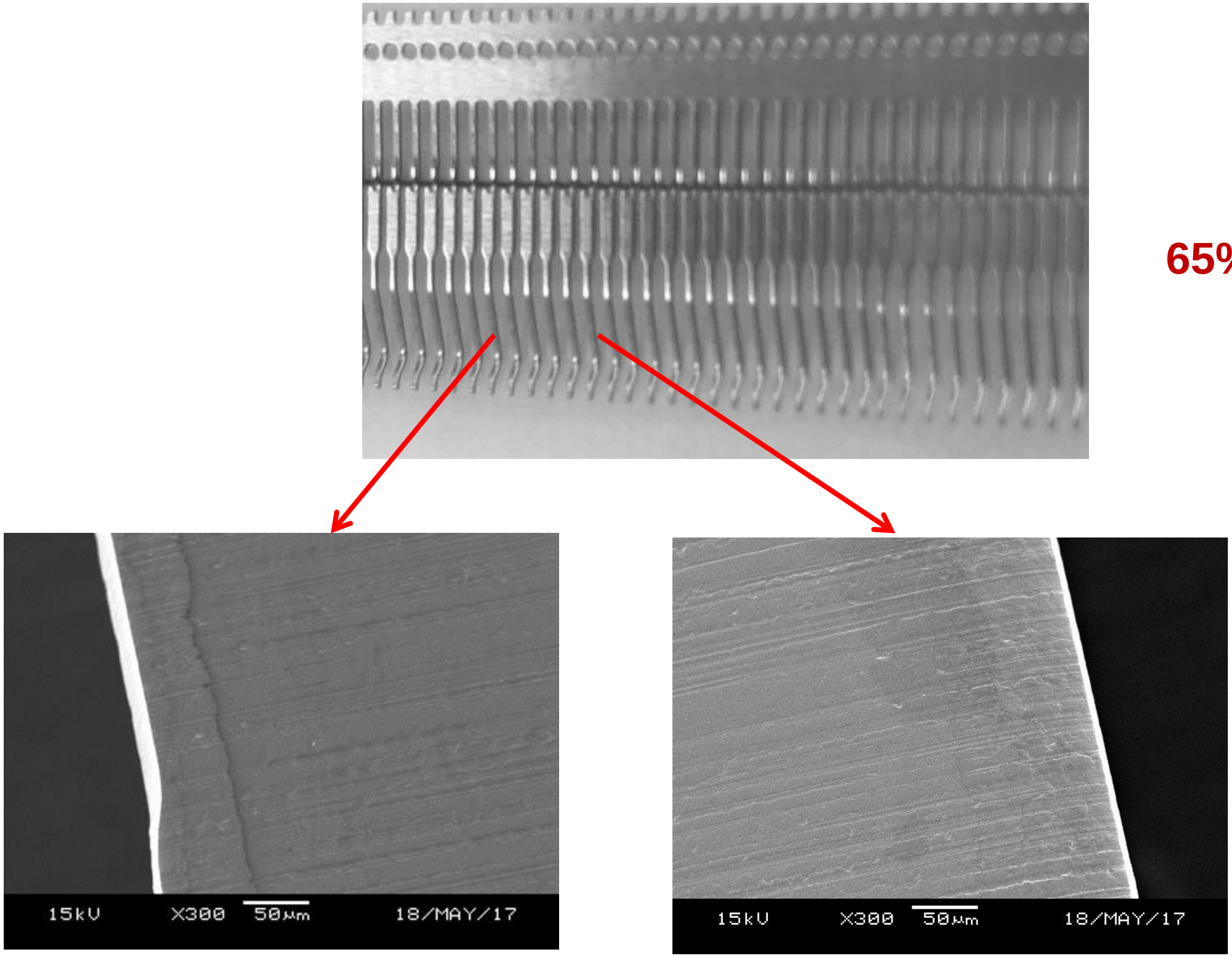
- For certain applications, elimination of nickel entirely from the plated layer system is desirable (e.g., Ni dermatitis)

- **Cobalt-Tungsten alloy (CoW) barrier layer** electroplating technology has been developed for these applications

CoW Properties

- Alloy composition: 65/35 ± 5% Co/W.
- Hardness: 600-700 HV
- Deposit structure: Nano-crystalline
- Wide operating window.
- Drop-in replacement for nickel or nickel-tungsten plating solutions in existing lines.
- Nickel-free deposit with no nickel dermatitis issues - suitable for consumer applications
- Low deposit stress
- Excellent corrosion-resistance

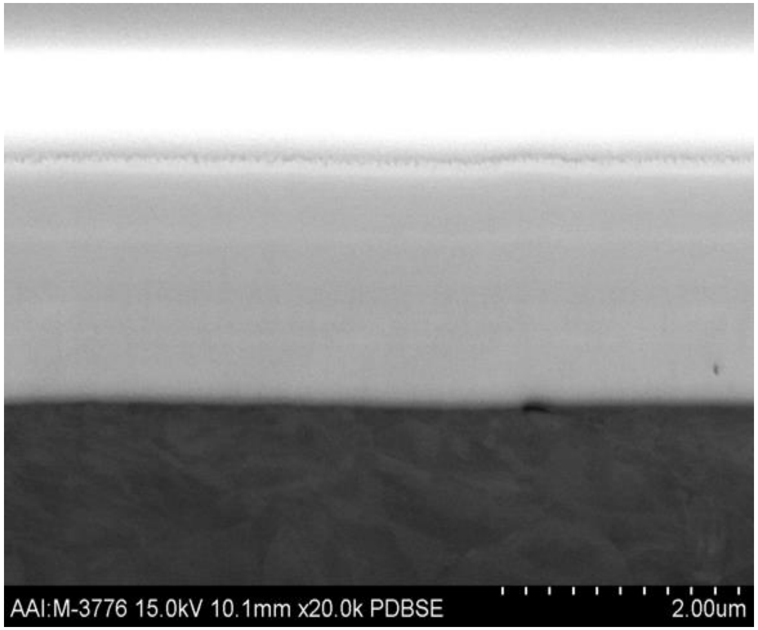
Cobalt-Tungsten Alloy
Deposit Appearance



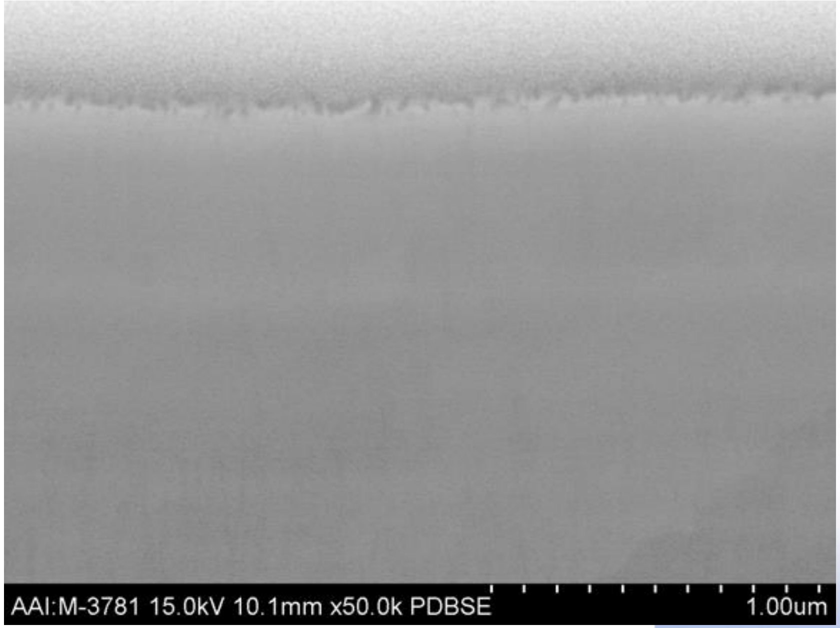
15 ASD
65% Co-35% W

Cobalt-Tungsten Alloy
FIB / SEM Cross-section data

20,000X

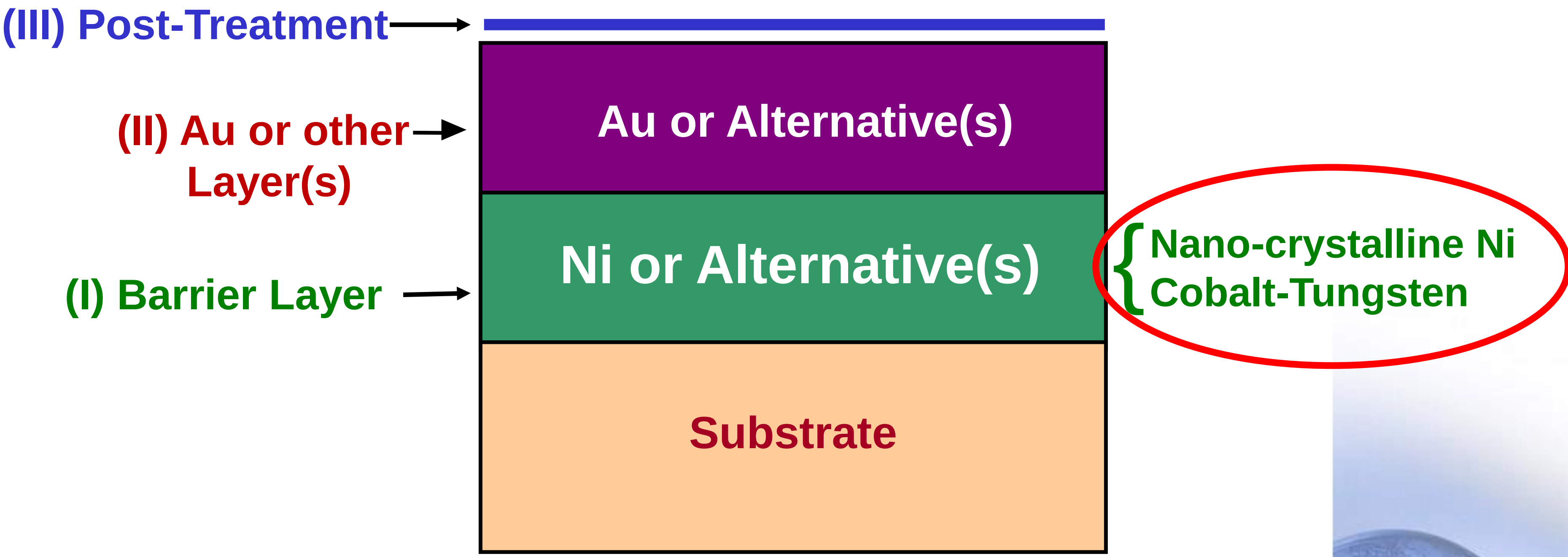


50,000X



CoW has nano-crystalline structure

Beyond Ni/Au:
Typical Electronic Finish



(III) Post-Treatment

(II) Au or other Layer(s)

(I) Barrier Layer

Au or Alternative(s)

Ni or Alternative(s)

Substrate

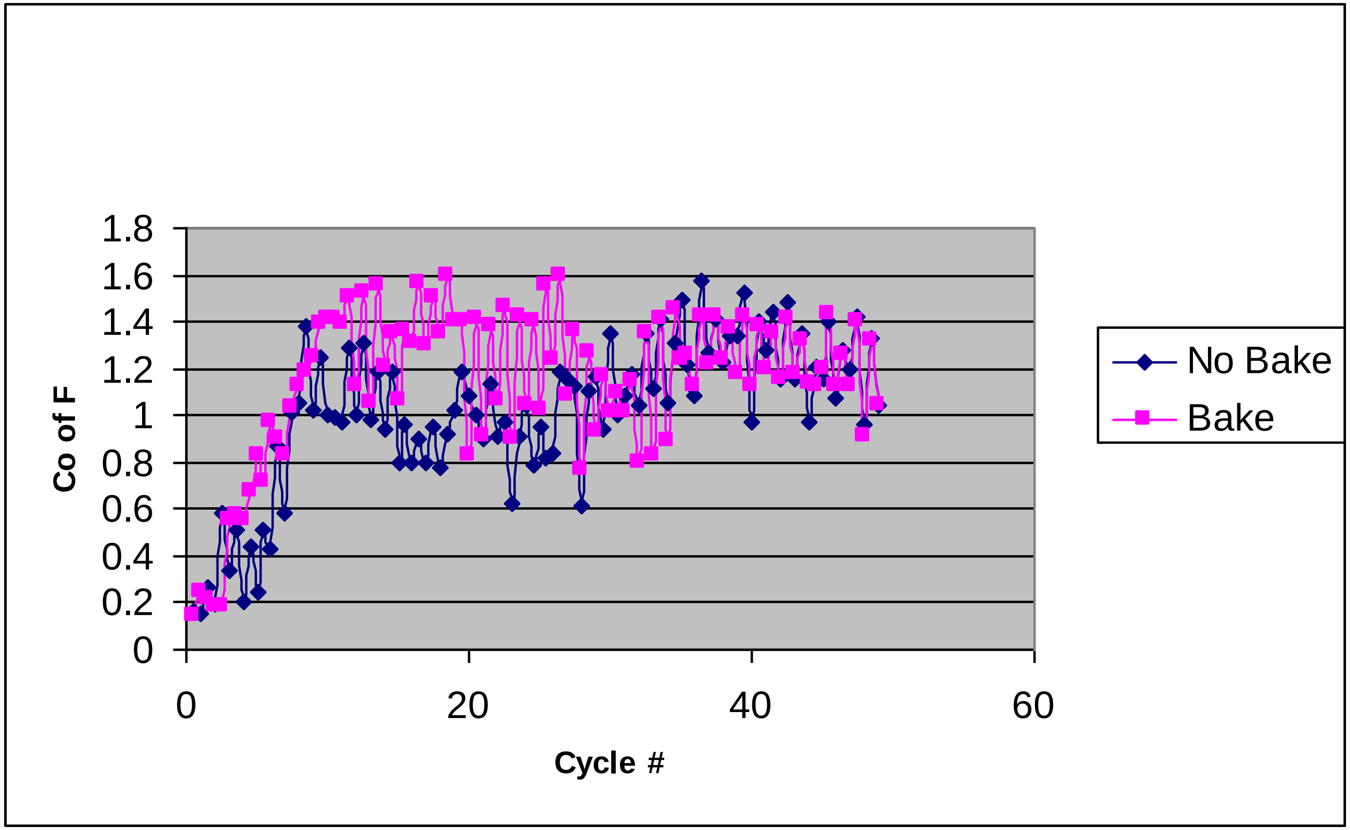
Nano-crystalline Ni
Cobalt-Tungsten

Alternatives to Gold / Post-Treatment Processes

Silver on Connectors-Introduction

- Until today, 2 technical issues have limited silver's implementation in non-automotive applications
  - Wear resistance esp. after multiple insertion cycles
  - Corrosion resistance – overcoming the silver tarnish issue
    - Automotive use of silver is currently restricted to sealed applications with minimal insertions
- Solution: Wear-resistant /corrosion-resistant silver plating process

Conventional Silver Wear Resistance Results



CoF of conventional silver is high ~1.2 before & after bake

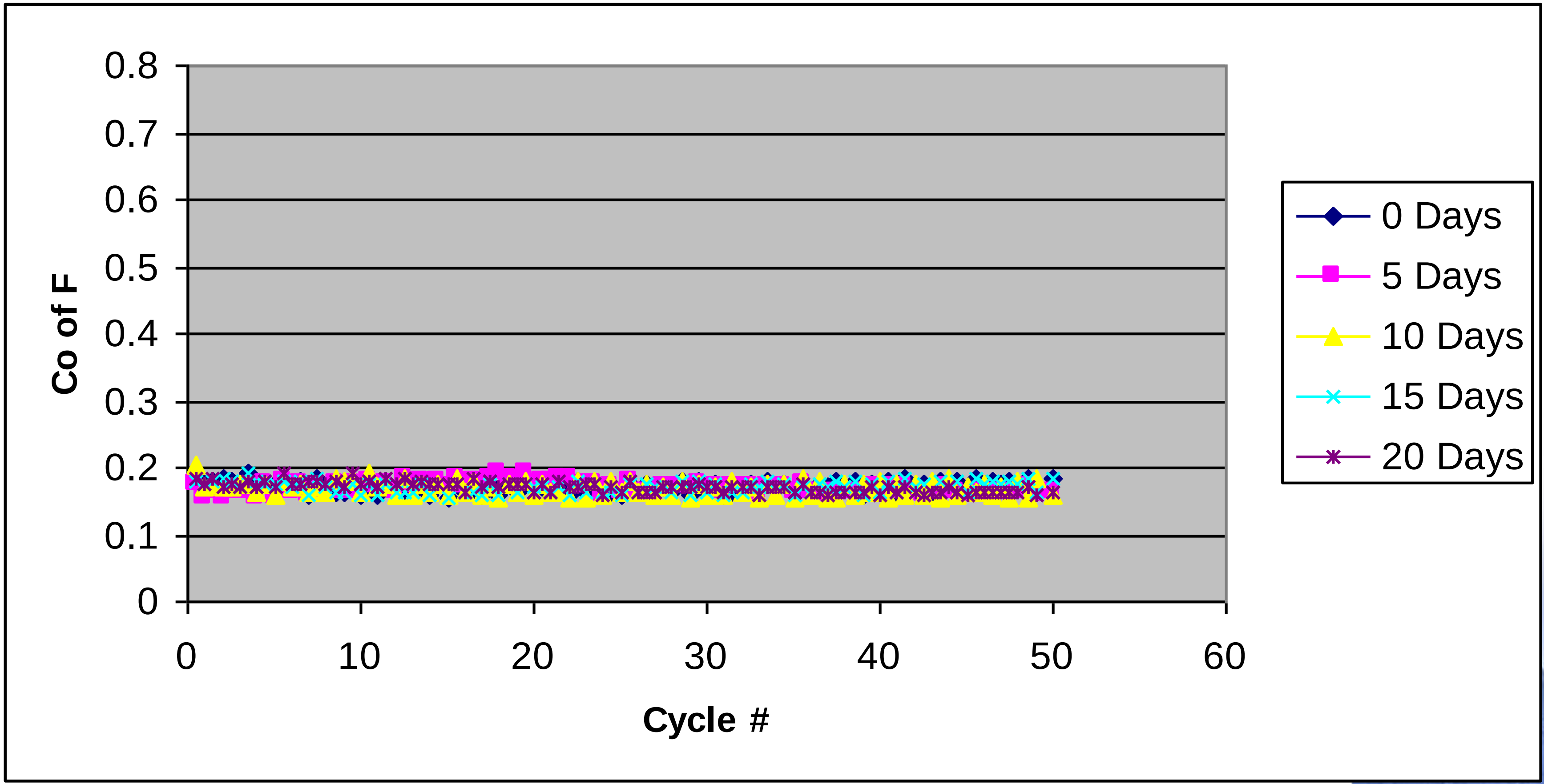
Silver Alloy Plating

- Silver alloy plating from a two-part system consisting of a silver alloy electroplated deposit and a unique post-treatment process chemistry.
- This combination provides excellent deposit conductivity combined with superior corrosion properties and significantly improved wear resistance compared to conventional silver.

Silver Alloy Plating Summary

- Deposit Hardness √
  - 175 Knoop as-plated; 145 Knoop after bake
- Contact Resistance √
  - Low and stable CR (~2.5m-ohm), after bake and/or after 20 days exposure to MFG
- Wear Resistance √
  - Low and stable CoF (~0.2) , after bake and/or after 20 days exposure to MFG
- Corrosion Resistance √
  - Minimal to no corrosion after 20 days exposure to MFG
- Solderability √
  - Passes J-STD-002C after 500 hrs bake

Durasil^{TM} Wear Resistance Results With bake / 0-20 days MFG Exposure



Durasil^{TM} Corrosion Resistance Results
0-20 days MFG Exposure

Above: no bake
Below: with bake

Conclusion: Minimal to no corrosion observed after 20 days MFG exposure

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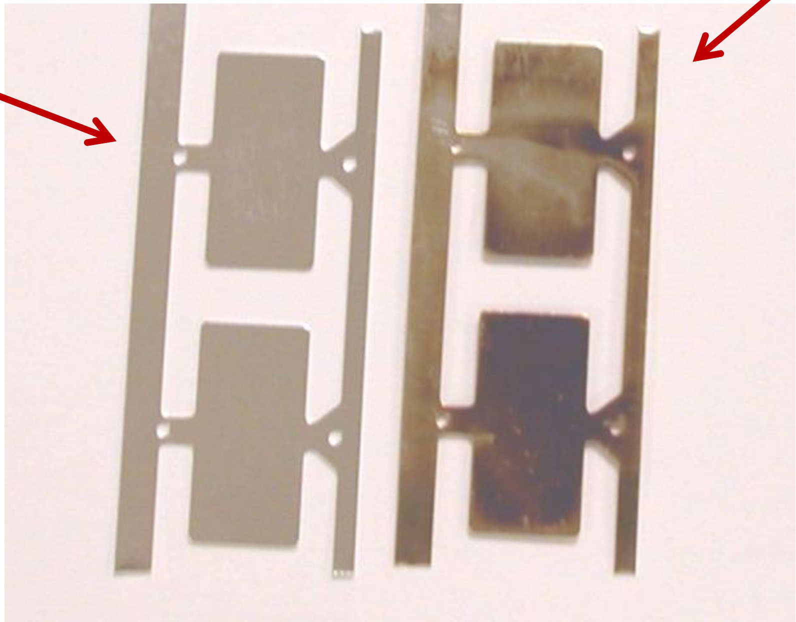
Inorganic Nano-Coating on Silver

Sulfur Corrosion Testing

5% K2S Solution
Parts fully immersed for 5 minutes

With nano-coating

No Treatment



Goldeneye

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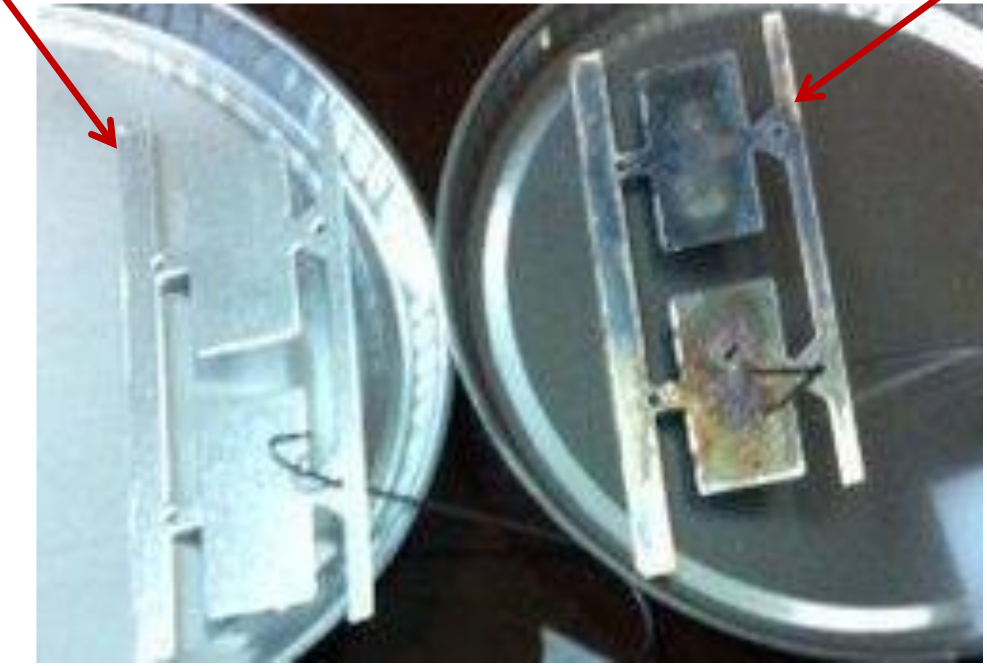
Inorganic Nano-Coating on Silver

Sulfur Corrosion Testing

Mixed Flowing Gas Exposure
per EIA-364-65B, Class IIa
5 days exposure

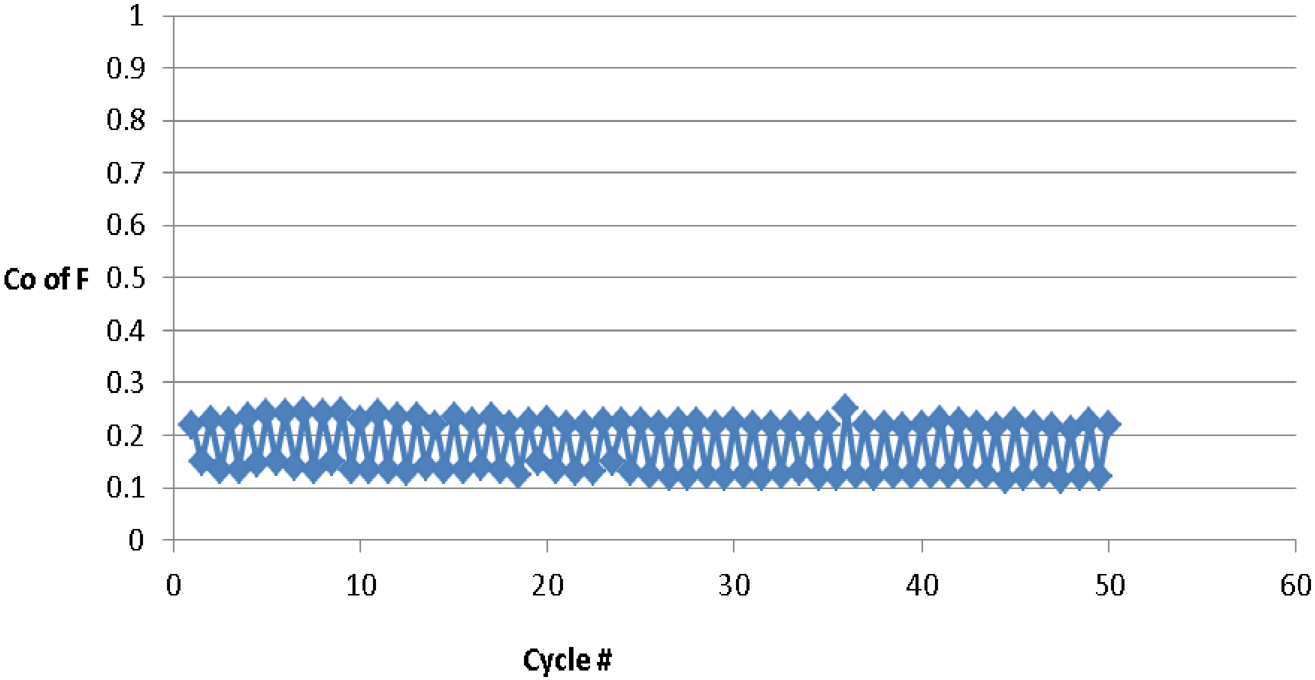


With nano-coating

No Post-Treatment

Nano-coating + lube

Wear Resistance Results

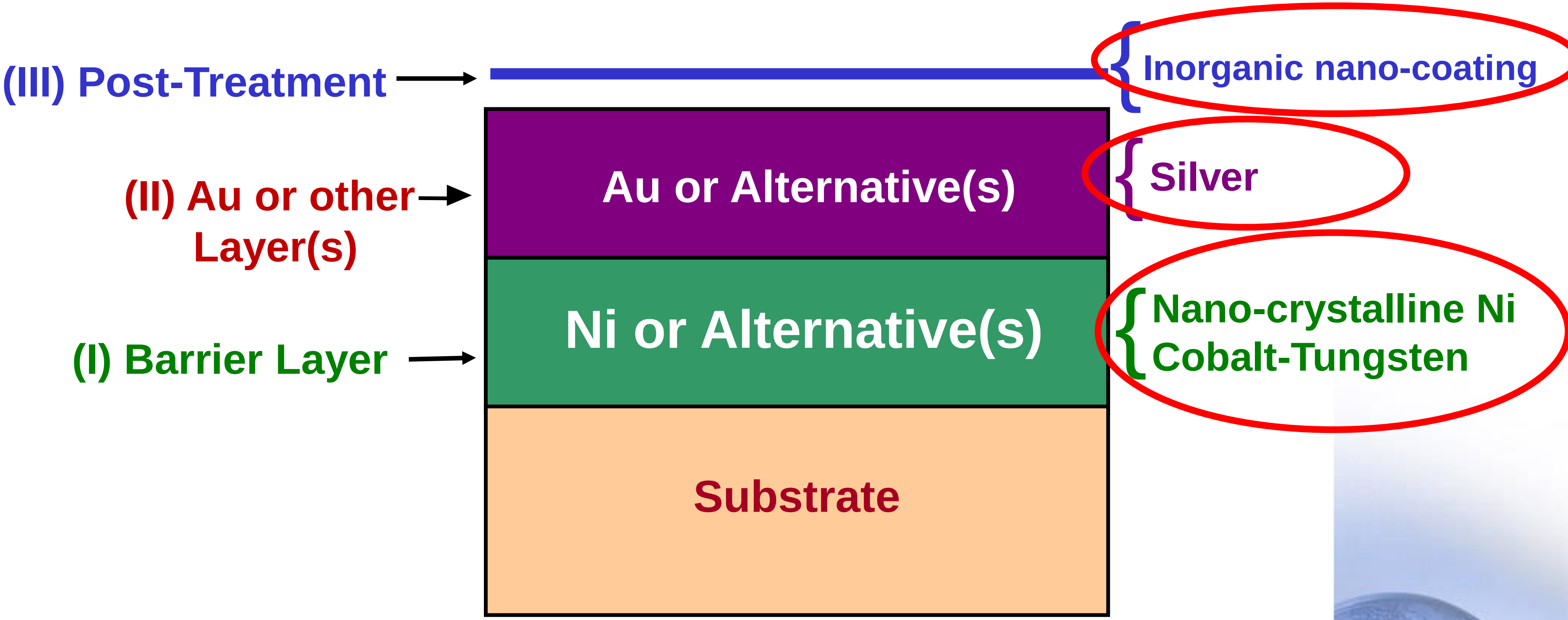


Excellent WR results equivalent to hard gold

Silver on Connectors Summary

- Several options exist :
  - Silver alloy plating + post-treatment
  - Silver plating with nano-coating for corrosion protection only
  - Silver plating with 2-step post-treatment process sequence consisting of nano-coating + Post-Dip (lube), improvements in both silver protection AND wear resistance can be achieved
- These combinations provide similar technical performance comparable to hard gold in connector and related applications

Beyond Ni/Au:
Typical Electronic Finish



(III) Post-Treatment

(II) Au or other Layer(s)

(I) Barrier Layer

Au or Alternative(s)

Ni or Alternative(s)

Substrate

Inorganic nano-coating

Silver

Nano-crystalline Ni
Cobalt-Tungsten

Emerging Applications Requiring Completely New Electronic Finishes:

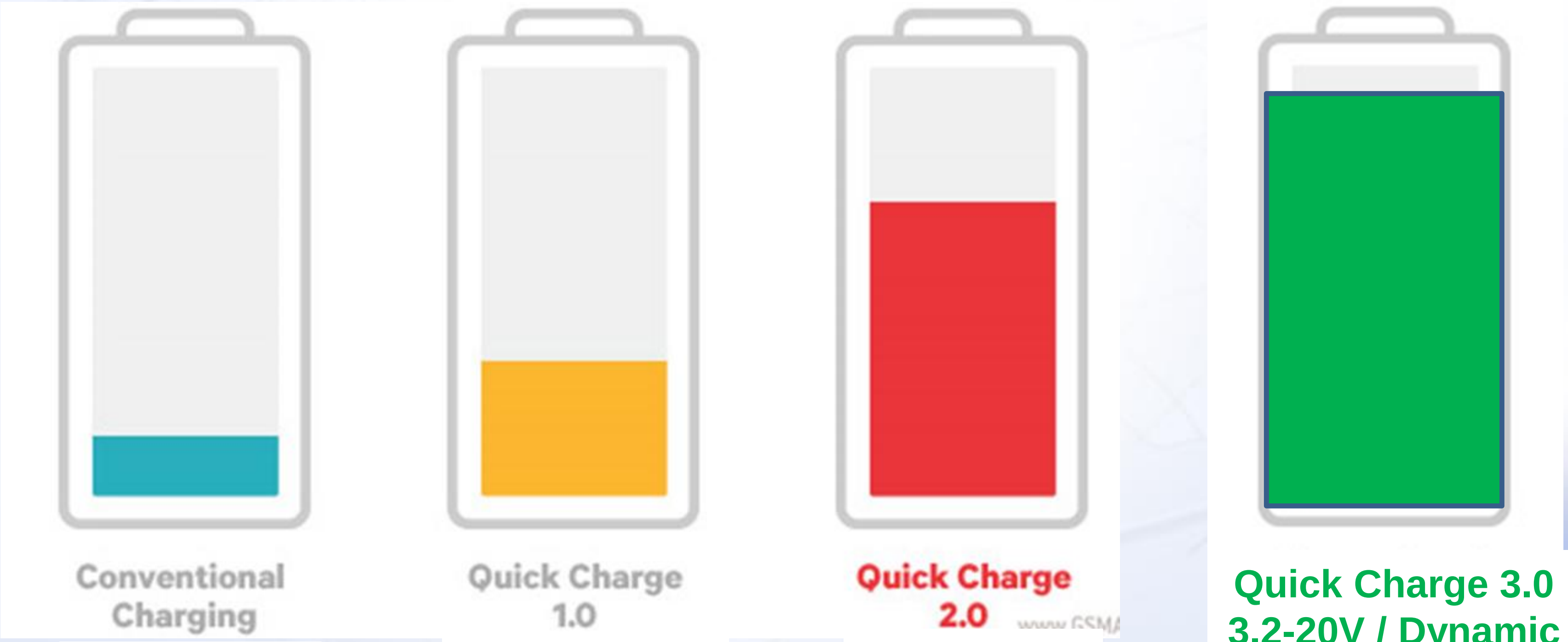
- Electrolytic Sweat Resistant (ESR) Connector Finishes
- Press-Fit Connector Pins
- High Frequency Applications (5G)

Mobile Phone Connector Plating Technology Shift

- Two recent changes in cell phone technology are having a major impact on the plated finishes used for mobile phone connectors:
  I. **Replacement of traditional headphone jack with a single connector that performs both the electrical charging function and the headphone connection**

Mobile Phone Connector Plating Technology Shift

II. Implementation of ‘quick-charge’ connector technology



5V / 1 Amp

5V / 2 Amps

9V / 1.7 Amps
18W max.

Quick Charge 3.0
3.2-20V / Dynamic
18 W max.

Increasing volts/amps through connector

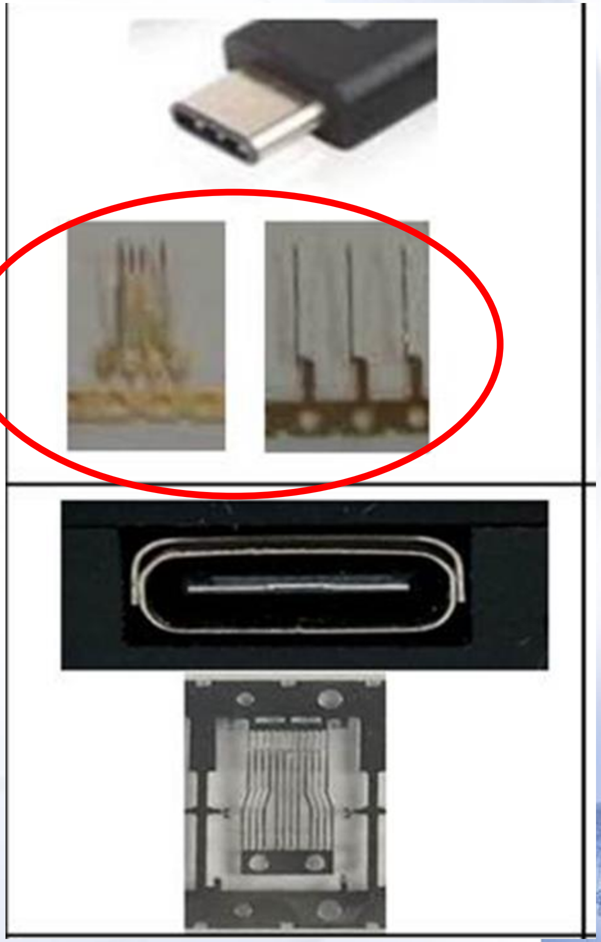
How does this affect Mobile Phone Connector Plating Technology?

I. Consumers exercising while using head phones &/or charging their cell phones (i.e., handling the connector) results in human sweat being present on the plated connector in the presence of electrical current

Sweat + Electrolysis = CORROSION

II. This electrolytic sweat-induced corrosion issue is made more severe when combined with the higher charging current/volts of quick charge technology

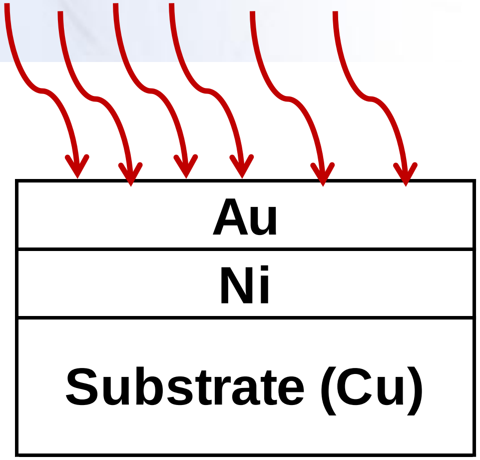
USB-C Connector Pins



Mechanism of Corrosion Using Various Test Methods

NAV Test

Nitric Acid Fumes



Au

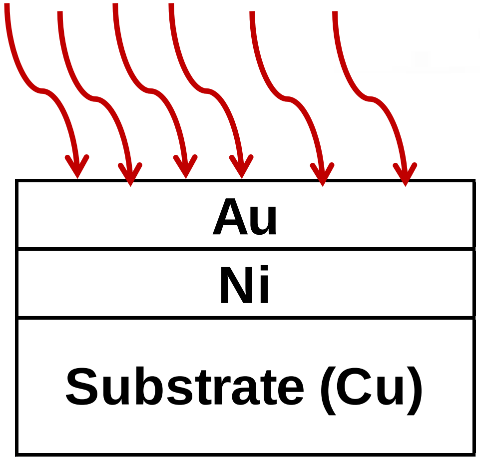
Ni

Substrate (Cu)

Mechanism = Corrosion occurs from outside to inside

NSS Test

NaCl Mist



Au

Ni

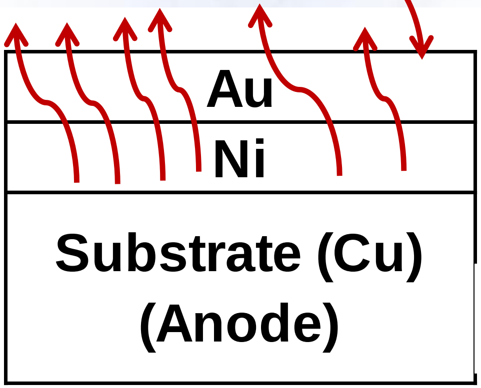
Substrate (Cu)

Mechanism = Corrosion occurs from outside to inside

Electrolytic Sweat Test

Cathode (-)Charge Applied

NaCl solution



Au

Ni

Substrate (Cu)
(Anode)

Current Flow

(+) Charge Applied

Mechanism = Corrosion occurs from INSIDE to OUTSIDE

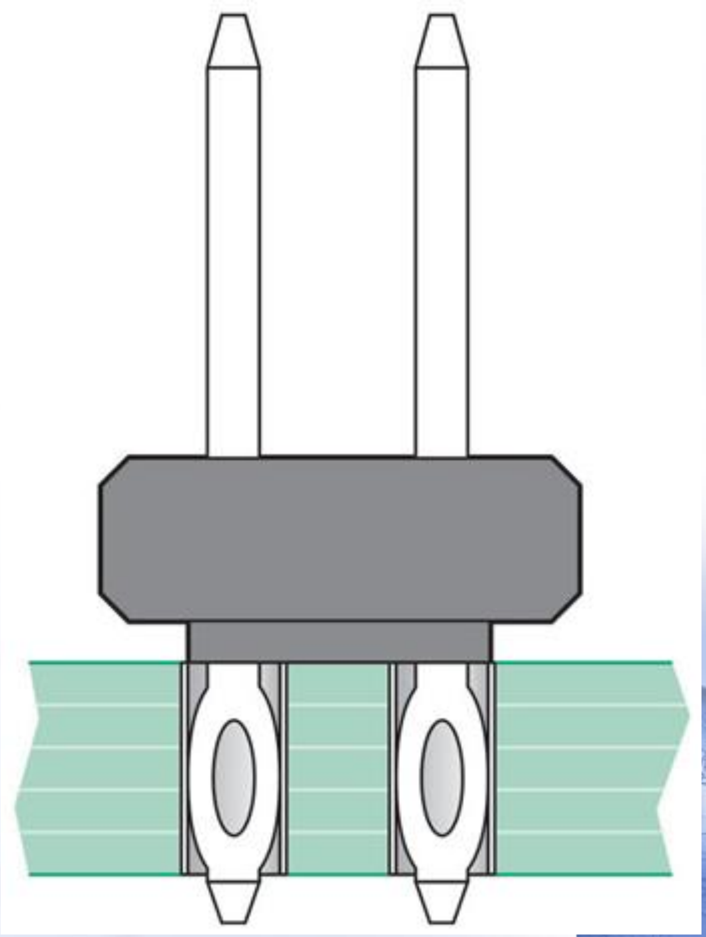
Requirements for Passing ESR Testing

- Base material preparation is critical
- Extremely corrosion-resistant barrier layer(s) is (are) required
  - Ni cannot be used for high-end applications
- Top layer must be a <u>Rh-containing deposit</u> (resistant to electrolytic sweat solution)
  - No gold (gold is easily attacked/corroded during ESR testing)
- Optimal layer system to be selected depends on trade-off of performance vs. cost

ESR Performance vs. Cost Summary

Classification	ESR Performance	Cost
Low-End	3-4 minutes	1.5 X
Mid-End	4-20 minutes	2.4 - 7X
High End	20-40 minutes	7 - 10 X
Utra High End	40-70 minutes	10 - 12X

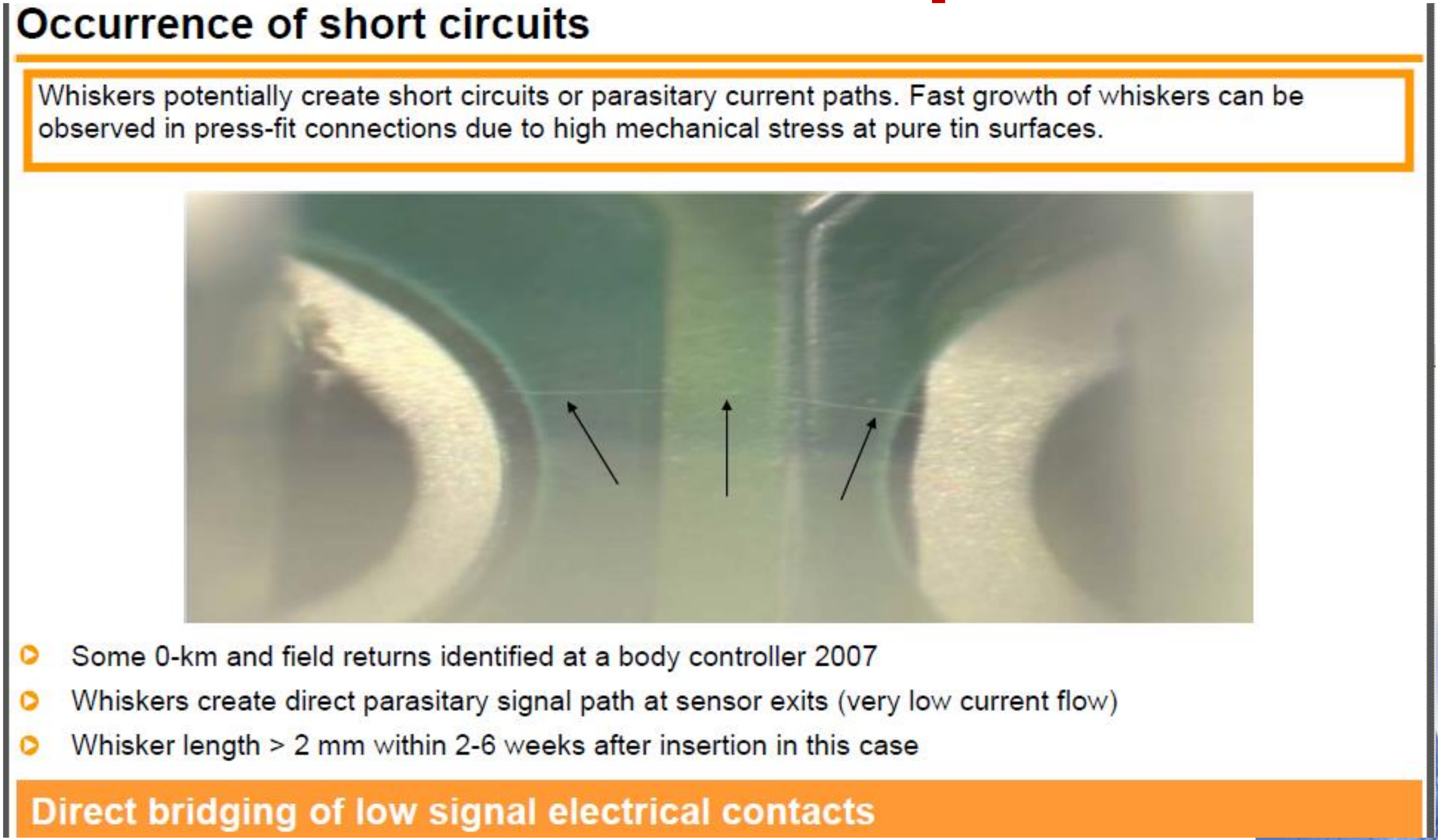
New Plating Technology for Connector Press-Fit Pin Applications



Connector Press-Fit Pin Plating Technology - Introduction

- Matte tin has resulted in extremely long whiskers under certain press-fit conditions
- Connector companies and/or end users have been experimenting with various non-tin solutions for years
- Recently two alternative finishes have emerged as potential solutions for press-fit pin whiskers formed under compression

Matte Tin – Whiskers formed under compression



Occurrence of short circuits

Whiskers potentially create short circuits or parasitary current paths. Fast growth of whiskers can be observed in press-fit connections due to high mechanical stress at pure tin surfaces.

- Some 0-km and field returns identified at a body controller 2007
- Whiskers create direct parasitary signal path at sensor exits (very low current flow)
- Whisker length > 2 mm within 2-6 weeks after insertion in this case

Direct bridging of low signal electrical contacts

Source : “Whiskers and Alternative Surface Finishes at Press-in Technology”
Dr. Hans-Peter Tranitz, Continental AG

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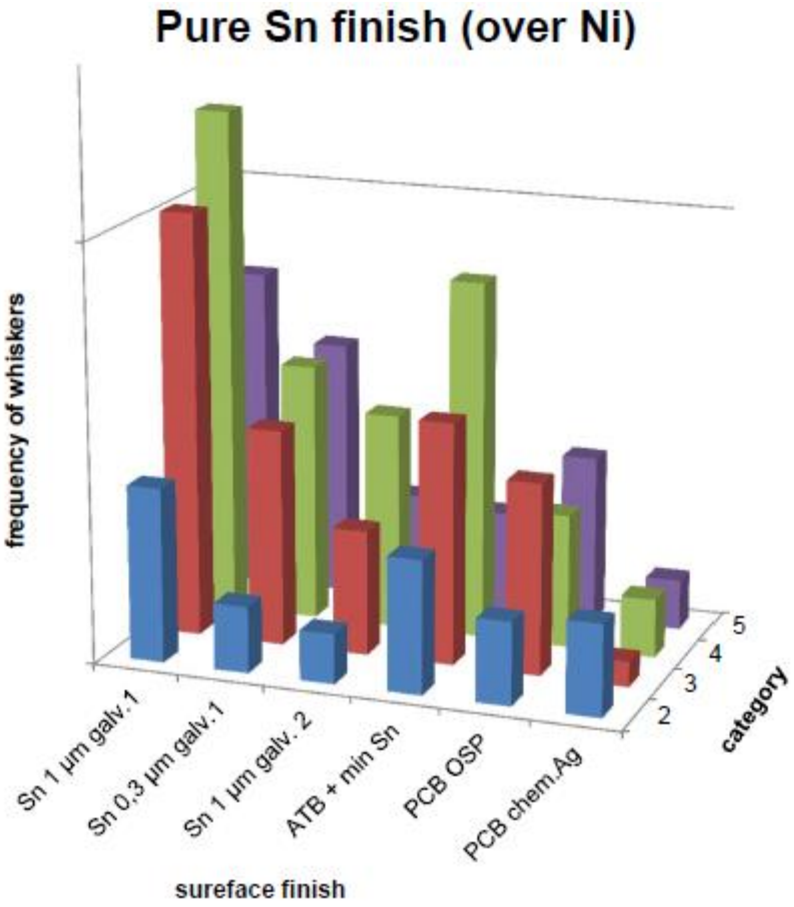
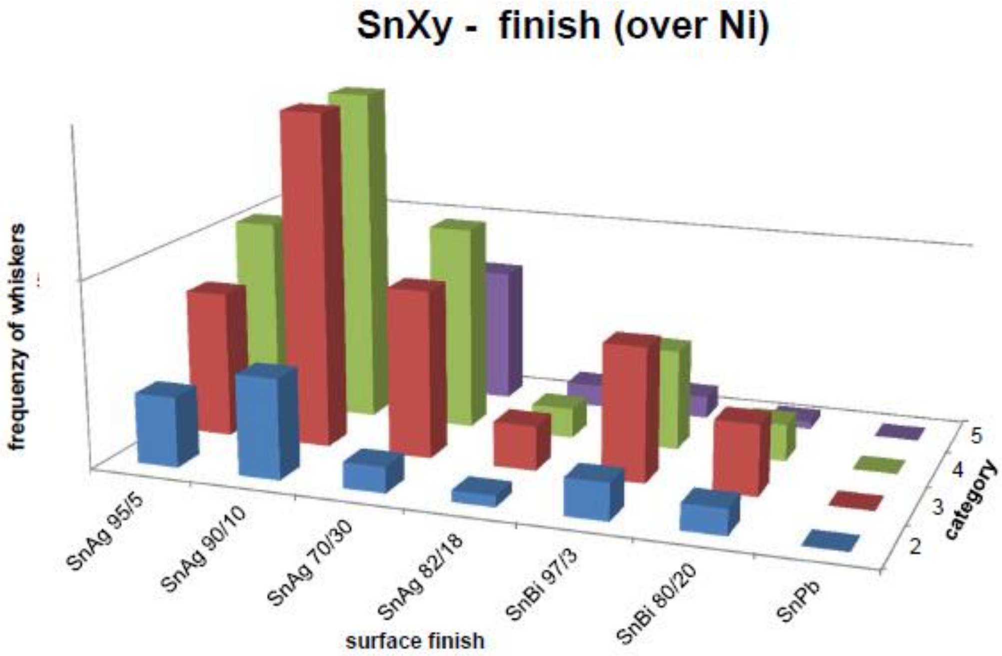
Tin Whisker Growth Comparison



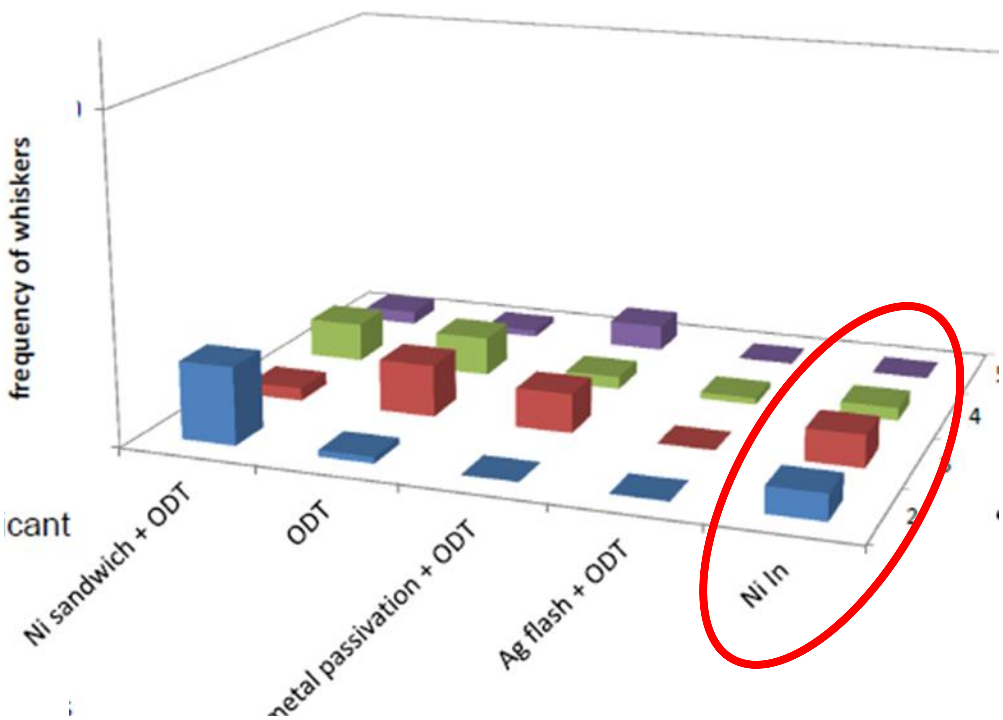
Pure Sn finish (over Ni)



SnXy - finish (over Ni)

Source : "Whiskers and Alternative Surface Finishes at Press-in Technology"
Dr. Hans-Peter Tranitz, Continental AG

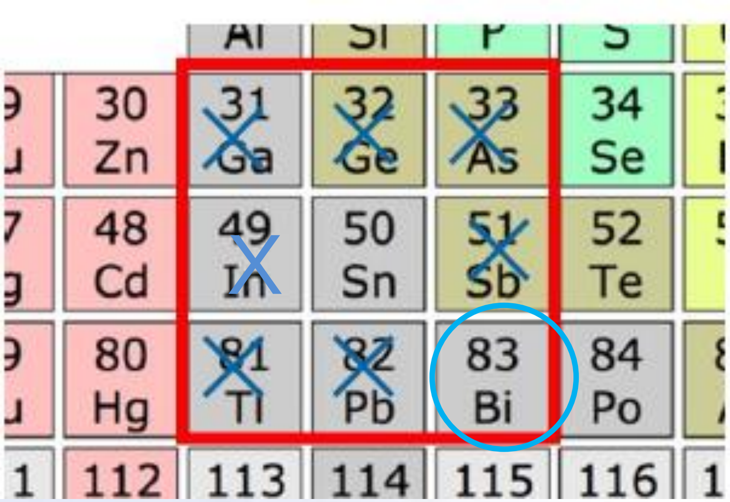
Tin Whisker Growth Comparison


Sn - free

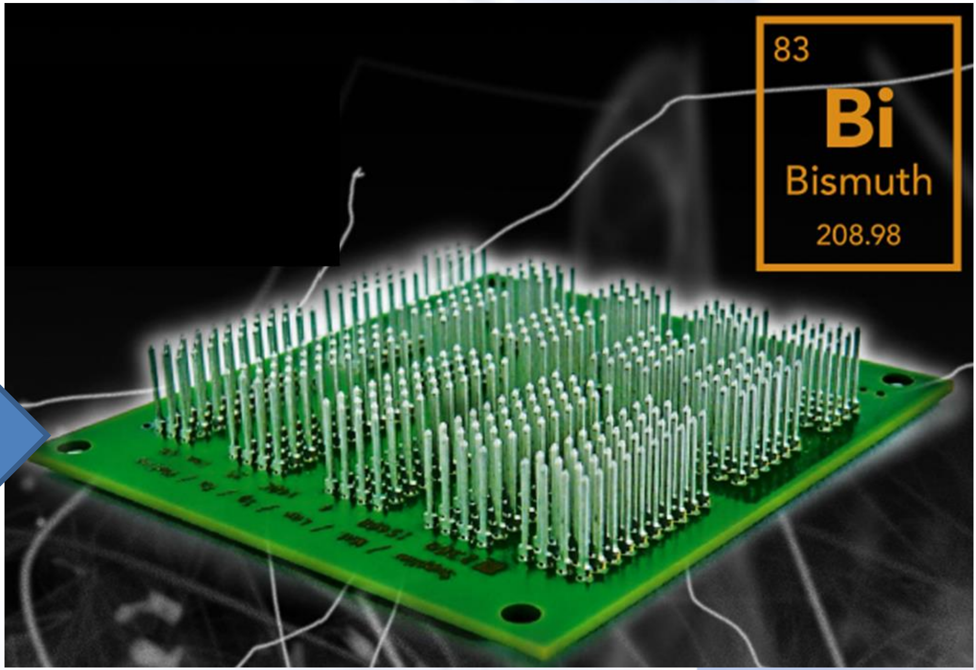
<u>Indium</u> is now a qualified/specified finish for some press-fit applications

Source : "Whiskers and Alternative Surface Finishes at Press-in Technology"
Dr. Hans-Peter Tranitz, Continental AG

Press-Fit Pins
Alternatives to Indium



Al	Si	P	S
30 Zn	~~31 Ga~~	~~32 Ge~~	~~33 As~~	34 Se
48 Cd	~~49 In~~	50 Sn	~~51 Sb~~	52 Te
80 Hg	~~81 Tl~~	~~82 Pb~~	83 Bi	84 Po
112	113	114	115	116



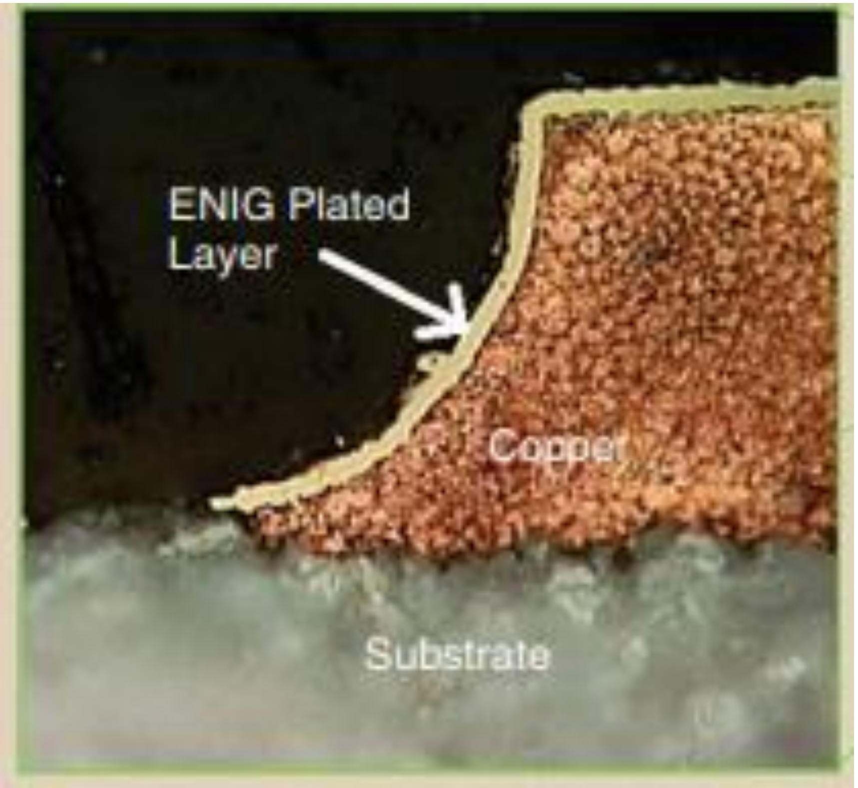
Bismuth is also being considered as an option for certain press-fit applications

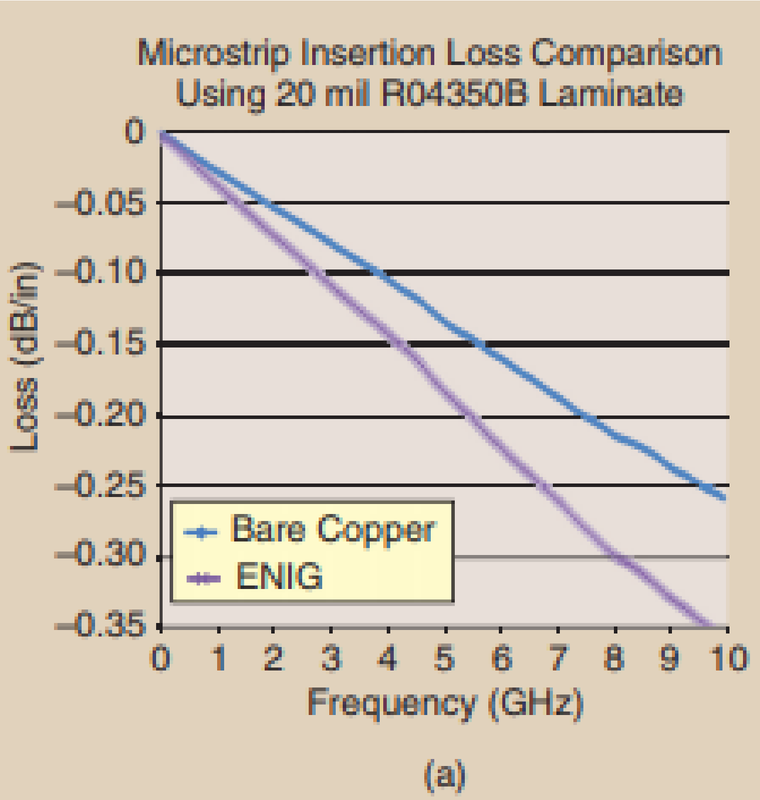
Source : "Litesurf –Tin-Free Electroplating for Press-Fit Technology," Frank Schabert
TE Connectivity, Webinar presented March 2018

High Frequency Applications (5G)

Beyond Ni/Au:
High Frequency Applications

Signal Loss vs. PCB Final Finish





<u>Nickel</u> deposit is the source of signal loss in high frequency applications

Source: "Ambiguous Influences Affecting Insertion Loss of Microwave Printed Circuit Boards"
John Conrood, IEEE Microwave Magazine, Issue 1527-3342/12

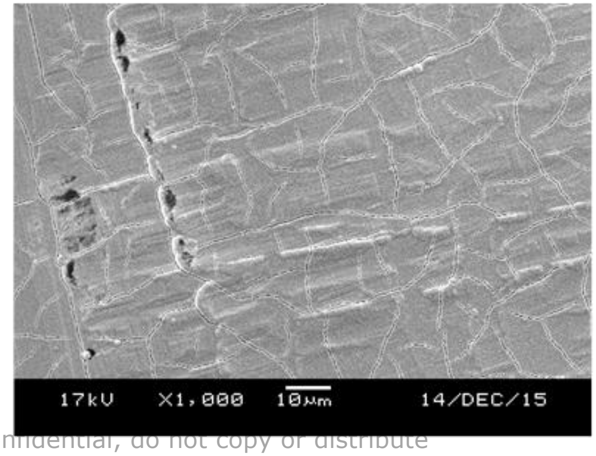
Connector Finishes for High Frequency Applications (5G)

- Ni-free barrier layer is required
- Good conductivity and corrosion resistance for final finish
- Palladium (Pd) is a suitable deposit that can function as both a barrier layer and a final finish
  - Barrier layer effectiveness requires relatively high thickness (>0.75-1.0 µm)
  - HOWEVER electroplated Palladium is notorious for micro-cracking at high thickness
- Solution : micro-crack free Palladium

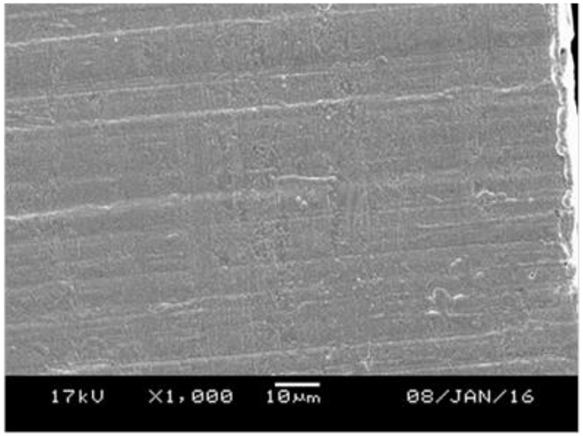
Low Stress/High Ductility Palladium

- Low stress deposits
  - No spontaneous microcracking up to 4 µm Pd thickness
  - No bending cracks (up to 2µm)
- Neutral pH / no ammonia smell
- Wide current density range
- Stable electrolyte
  - >5 MTO bath life, with periodic c-treatment

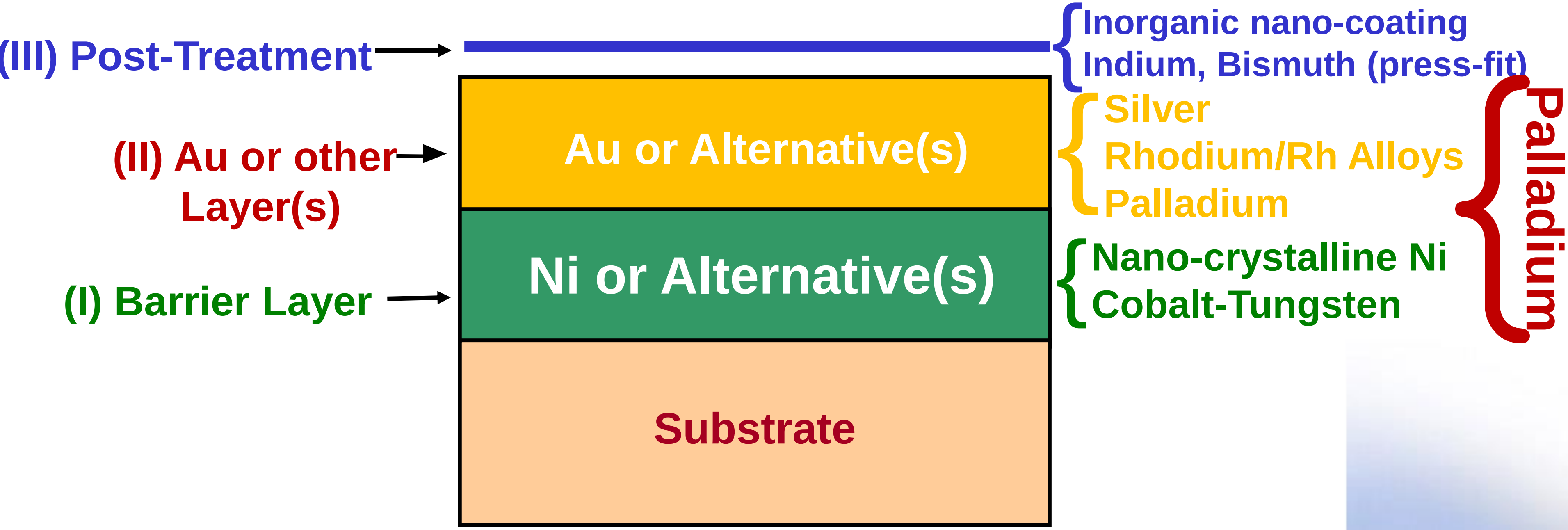
Conventional Pd-Cracked



High Ductility Pd- No cracks



Beyond Ni/Au: Summary



(III) Post-Treatment

(II) Au or other Layer(s)

(I) Barrier Layer

Au or Alternative(s)

Ni or Alternative(s)

Substrate

Inorganic nano-coating
Indium, Bismuth (press-fit)

Silver
Rhodium/Rh Alloys
Palladium

Nano-crystalline Ni
Cobalt-Tungsten

Palladium

Beyond Ni/Au: Conclusions

- Rapid changes are occurring in an industry where conventional Ni/Au has been used for 4 decades
- Alternative finishes are being considered and/or implemented, including exotic materials never before considered feasible in a connector application
- We expect additional changes will occur as connector finish technology needs to keep up with the demands of the other interconnects and/or use environments

Thank you!