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

PCB

CONNECTORS

IC PACKAGING

CONFIDENTIAL
Beyond Ni/Au: Typical Electronic Finish

(I) Barrier Layer

(II) Au or other Layer(s)

(III) Post-Treatment

Substrate

Ni or Alternative(s)

Au or Alternative(s)
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
## Deposit Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Nano-crystalline Ni</th>
<th>Ni Sulfamate Matte</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance</strong></td>
<td>Semibright</td>
<td>Matte</td>
</tr>
<tr>
<td><strong>Stress</strong></td>
<td>~2500 psi (17.2 MPA)</td>
<td>~5500 psi (37.0 MPA)</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>~450 knoop</td>
<td>~250 knoop</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>Nano-crystalline</td>
<td>Micro-crystalline</td>
</tr>
<tr>
<td><strong>Solution Conductivity</strong></td>
<td>155.6 mS/cm</td>
<td>68.0 mS/cm</td>
</tr>
</tbody>
</table>

**Nano-Crystalline Nickel vs. Ni sulfamate**

Company confidential, do not copy or distribute
Nano-crystalline Ni vs. Ni Sulfamate

Thickness Distribution Comparison

<table>
<thead>
<tr>
<th>Bath</th>
<th>HCD (μ&quot;&quot;)</th>
<th>LCD (μ&quot;&quot;)</th>
<th>HCD:LCD Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni S.</td>
<td>41</td>
<td>14</td>
<td>2.9</td>
</tr>
<tr>
<td>GE Ni</td>
<td>43</td>
<td>22</td>
<td>2.0</td>
</tr>
<tr>
<td>Ni S.</td>
<td>84</td>
<td>32</td>
<td>2.6</td>
</tr>
<tr>
<td>GE Ni</td>
<td>86</td>
<td>49</td>
<td>1.8</td>
</tr>
<tr>
<td>Ni S.</td>
<td>123</td>
<td>47</td>
<td>2.6</td>
</tr>
<tr>
<td>GE Ni</td>
<td>121</td>
<td>72</td>
<td>1.7</td>
</tr>
</tbody>
</table>

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

After 2 hour nitric acid vapor (NAV) exposure

Ni sulfamate – 120µin
Au - 30µin

Nano-Ni - 100µin
Au - 30µin
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

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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™* Wear Resistance Results
With bake / 0-20 days MFG Exposure
Durasil™ Corrosion Resistance Results
0-20 days MFG Exposure

Conclusion: Minimal to no corrosion observed after 20 days MFG exposure
Inorganic Nano-Coating on Silver Sulfur Corrosion Testing

5% K2S Solution
Parts fully immersed for 5 minutes

With nano-coating
No Treatment
Inorganic Nano-Coating on Silver Sulfur Corrosion Testing

Mixed Flowing Gas Exposure per EIA-364-65B, Class Ila
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

(I) Barrier Layer

(II) Au or other Layer(s)

(III) Post-Treatment

Substrate

Ni or Alternative(s)

Au or Alternative(s)

Inorganic nano-coating

Silver

Nano-crystalline Ni Cobalt-Tungsten

Typical Electronic Finish

{ Silver

{ Inorganic nano-coating

{ 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:
  
  1. 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

- **Conventional Charging**: 5V / 1 Amp
- **Quick Charge 1.0**: 5V / 2 Amps
- **Quick Charge 2.0**: 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 headphones &/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

\[
\text{Sweat} + \text{Electrolysis} = \text{Corrosion}
\]

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**
- **Mechanism:** Corrosion occurs from outside to inside

**NSS Test**
- **NaCl Mist**
- **Mechanism:** Corrosion occurs from outside to inside

**Electrolytic Sweat Test**
- **Cathode (-) Charge Applied**
- **NaCl solution**
- **(+ ) Charge Applied**
- **Substrate (Cu) (Anode)**
- **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 Rh-containing deposit (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

<table>
<thead>
<tr>
<th>Classification</th>
<th>ESR Performance</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-End</td>
<td>3-4 minutes</td>
<td>1.5 X</td>
</tr>
<tr>
<td>Mid-End</td>
<td>4-20 minutes</td>
<td>2.4 - 7X</td>
</tr>
<tr>
<td>High End</td>
<td>20-40 minutes</td>
<td>7 - 10 X</td>
</tr>
<tr>
<td>Ultra High End</td>
<td>40-70 minutes</td>
<td>10 - 12X</td>
</tr>
</tbody>
</table>
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
Tin Whisker Growth Comparison

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Tin Whisker Growth Comparison

**Indium** 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

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

High Frequency Applications (5G)
Beyond Ni/Au: High Frequency Applications

Signal Loss vs. PCB Final Finish

**Nickel** 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

(I) Barrier Layer

(II) Au or other Layer(s)

(III) Post-Treatment

- Ni or Alternative(s)
- Au or Alternative(s)
- Substrate

Alternative(s):
- Inorganic nano-coating
  - Indium, Bismuth (press-fit)
- Palladium
  - Silver
  - Rhodium/Rh Alloys
- Nano-crystalline Ni Cobalt-Tungsten
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!