Navigating the PCB Surface Finish Maze

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Field Applications Engineer

Navigating the Surface Finish Maze...

Electroless Nickel / Electroless Gold (ENEG)
Direct Immersion Gold (DIG)

What is a Surface Finish?
A plating or coating applied to the exposed copper features of a Printed Wiring Board (PWB).

- Plating (metallic)
- Coating (metallic or organic)

Note: Base Metal Plating is typically copper (in most cases).
But for some Nickel or Nickel-Phosphorous serve as the solderable surface.

How is the Surface Finish Applied?

- Coating
  - OSP, HASL, Carbon etc.

- Plating (metallic)
  - Electrolytic
  - Electroless
  - Immersion

- Equipment
  - Horizontal or Vertical equipment
  - Automated or Manual

We are the only PCB Shop that has Global Footprint in 4 continents

Over 13,000 people world wide, ~ 12,000 in China
Why is a Surface Finish Required?

The Surface Finish prepares and protects the conductors of a PWB for assembly, installation, and use.

- Coplanar (flat)
- Solderability (wetability)
- In Circuit Test
- Lead-Free (RoHS and WE EE compatible and compliant)
- Contact Resistance
- Grounding Rails
- Tarnish Resistance
- Wear Resistance
- Hardness
- Chemical Resistance
- Hard Gold
- Soft Gold
- Flash Gold (thin, solderable – may be hard or soft)

Surface Finish Requirements

- Wire Bonding
- Gold
- Aluminum
- Compatibility with other Surface Finishes
- Multiple Solder Cycles
- Cost
- Reliability
- Shock
- Vibration
- Thermal Cycling

Surface Finish Types

Most Common:
- OSP (Organic Solderability Preservative)
- ENIG (Electroless Nickel/Immersion Gold)
- Imm Ag (Immersion Silver)
- Imm Sn (Immersion Tin)
- Sn-Pb HASL (Hot Air Solder Level)
- Electrolytic Ni/Au (Electrolytic Nickel/Gold)
- Hard Gold
- Soft Gold
- Flash Gold (thin, solderable – may be hard or soft)
- ENEG (Electroless Nickel/Electroless Gold)

Under Investigation:
- ENEPIG (Electroless Nickel/Electroless Palladium/Immersion Gold)
- ENIPG (Electroless Nickel/Electroless Palladium/Immersion Gold)
- Lead Free HASL
- HP ENIG (High Phosphorous Electroless Nickel/Immersion Gold)
- Direct Gold on Copper (Direct Immersion Gold, etc.)
- Lead Free ENIG
- Ag/Lu (Immersion Silver/Immersion Gold)
- Nanofinish

Less Common:
- Carbon Ink (Screened on)
- Electroless Nickel – Immersion Palladium
- Selective Solder Strip (SSS)
- Sn Ni (Tin-Nickel)
- Unfused Tin-Lead
- Reflow Tin-Lead

Multiple Surface Finishes:
- Hard Gold + Immersion Silver
- Hard Gold + ENIG
- Hard Gold + HASL
- ENIG + OSP
- ???

Electrolytic Plating

Electrolytic plating is achieved by passing an electric current through a solution (electrolyte) containing dissolved metal ions allowing the metal to deposit on the conductive surface of the PWB.

Electrolytic Plating requires:
- Anode
- Cathode
- Electrolyte
- Rectifier

The PWB serves as the cathode and is connected to negative polarity of the rectifier
- The metal ions in the plating bath are reduced at the conductive surface of the PWB building the metal thickness.
- The Voltage, Amperage, Temperature, Time, and Purify of the solutions determine the properties and amount of the deposit.
**Electrolytic Plating**

**Electrolytic Nickel-Gold (Depicted Below)**

**Electrolytic Plating**
- Process is Non-electrolytic and Non-galvanic
- No external electrons are needed (ie: no rectifier)
- Electroless deposition uses chemical reducing agents to supply the electrons needed for metal deposition.
- Hydrogen is released by the reducing agent, oxidized, creating a negative charge at the surface.
- A catalyst is normally deposited on the copper surface to facilitate further deposition.
- Process is Autocatalytic
  - Deposit continues once the plating starts.
- Examples: electroless nickel, electroless palladium, electroless gold, etc.
- Uniform plating
  - Not prone to differences in circuit density
- Generally harder and more brittle deposit than electroplated

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**Immersion Plating**
- Process is Non-electrolytic
- No external electrons are needed (ie: no rectifier)
- Galvanic displacement reaction causes exchange of metal atoms on the surface with those in the solution.
- Nickel is dissolved and Gold replaces the nickel during ENIG process.
- Examples: immersion palladium, immersion gold, etc.
- For ENIG, the phosphorous co-deposited with the nickel is the reducing agent that allows for the immersion gold plating.
- Uniform plating
  - Not prone to differences in circuit density
- More prone to localized galvanic etching of sacrificial metal

**Surface Finish**

- **Silver (Depicted Below)**
  - Galvanic Displacement: Simply an Exchange of Copper and Silver Atoms
- **Tin**

**Base Foil + Plated Copper**
OSP (Organic Solderability Preservative)

Typical Equipment used for the Coating of OSP

- Conveyored Horizontal OSP and Pre-Flux Line

Advantages
- Flat, coplanar pads
- Re-workable by PCB supplier
- Cheap & simple process
- Short and easy to control process
- High reliability for SAC based solder joints
- High temperature OSP’s are available
- No additional investment over today

Disadvantages
- Limited heat cycle capability
- Not as wear resistant as other coating processes
- Having exposed Cu after PCBA in Circuit Test (ICT) is a concern
- In Circuit Test pins cut through organics leaving residues on test probes

ENIG (Electroless and Immersion Plating)

Typical Equipment used for the Plating of ENIG

Advantages
- Flatter, coplanar pads
- Withstands multiple heat cycles
- Long shelf life
- Good solderability
- No exposed copper
- High barrel reliability
- Easy to use for ICT
- Not handling sensitive

Disadvantages
- Expensive (gold)
- Process is difficult to control
- Black pad potential
- Brittle fracture for BGA type packages (under mechanical load)
- May not be suited for high speed signals (skin effect)
- Adjustments necessary for Press Fit technology
- Great concerns with reliability on SAC solders (mechanical load)
**Immersion Silver Plating**

Typical Equipment used for Horizontal Immersion Silver Plating

Conveyorized Horizontal Immersion Silver Plating Line

Smaller Proto Shops may use a Vertical Batch Process

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**Immersion Silver or Immersion Tin**

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**Immersion Silver**

**Advantages**
- Flat, coplanar pads
- Consistent coating thickness
- Withstands multiple heat cycles
- Good shelf life
- Best wet ability of all alternatives
- Easy to repair (PCBA)
- High solder joint reliability with Cu Sn inter-metallic
- Easy to probe at ICT
- Relatively simple process at PCB manufacturing
- Can be reworked

**Disadvantages**
- Adjustments necessary for press fit technology (high friction coefficient)
- Anti-tarnishing is critical to control
- Likes to build oxides
- Potential issues with voids (champagne voids)
- Very handling sensitive
- Not recommended for wear surfaces
- Creep corrosion in high sulfur environments
- Diffuses into the copper

**Immersion Tin**

**Advantages**
- Flat, coplanar pads
- Very easy solderable
- High reliability with Cu Sn IMC
- Works well at ICT
- Same metal as CuSnAg alloy (does not change alloy ratio much)
- Well suited and proven for press fit technology
- Relatively inexpensive

**Disadvantages**
- Fewer heat cycles possible than IAg due to IM growth
- Grows inter-metallic (0.1µm/2 months) at RT and with every heat cycle
- Anti-tarnishing is critical to control
- Rinsing is highly critical
- Likes to build oxides
- Diffuses into the copper
- Expensiv Cu
- Fear of Sn Whiskers

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**HASL (Hot Air Solder Level)**

Typical Equipment used for the Coating of HASL

Vertical and Horizontal HASL Equipment

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**Tin – Lead HASL**
### Tin – Lead HASL

**Advantages**
- "Nothing Solders Like Solder"
- Easily Applied
- Lengthy Industry Experience
- Easily Reworked
- Multiple Thermal Excursions
- Good Bond Strength
- Good solder joint reliability
- Long Shelf Life
- Easy Visual Inspection
- Cu/Sn Intermetallic (solder joint)

**Disadvantages**
- Co-Planarity Difference
- Potential Off-Contact Paste Printing
- Inconsistent Coating Thickness (on Varying Pad Size)
- Contains Lead
- Not Suited for High Aspect Ratios
- Not Suited for fine-pitch SMT and Grid Array Packages
- PWB Dimensional Stability Issues
- Bridging Problems on Fine Pitch
- Subjects the PCB to High Temp

### Electrolytic Plating of Nickel and Gold

**Typical Equipment used for the Electrolytic Plating of Nickel and Gold**

**Electroplated Nickel / Gold**

**Advantages**
- Flat, coplanar pads
- Very easy solderable
- Works well at ICT
- Very high barrel reliability (PCB)
- Very easy to rework (PCBA)
- Very long shelf life
- Long and proven track record for high end products
- Hard gold provides good wear surface

**Disadvantages**
- Limitation is aspect ratio 10:1 max
- Limitation in fine spacing at about 4-5 mil (100-125 µm)
- Gold is expensive
- Recent great concerns with reliability
- Lower joint strength using SAC alloys
- Inter-metallic phase fractures
- Sporadic in nature
- Problem is not yet well understood
- Not so widely available in the industry

### Surface Finishes - 2012

- **ENEPIG**
- **ENPIG**
- **HiPhos ENIG**
- **DIG**
- **Immersion Silver / Immersion Gold**
- **Lead-Free HASL**
- **LF ENIG**

### Lead – Free HASL

**Equipment being used for the Coating of Lead-Free HAL**

Same as for Leaded Versions but with a few Modifications

- Higher Temp Steel Solder Pots and Stronger - Higher Temp Pumps
- Effective heat transfer by improved alloy circulation
- Pre-heat panel (pre-dip)
- Longer contact time with PCB
- High temperature resistant chemistries (oils and fluxes)
- Copper control (Drossing – Dilution and Skimming)

*Source: CEMCO/ FSL*
Lead - Free HASL

Advantages
- Easily Applied and Reworked
- Familiar HAL Dynamics
- Good Bond Strength
- Long Shelf Life
- Easy Visual Inspection
  - Wetability
  - Cu/Sn Solderjoint

Disadvantages
- Subjects the PCB to VERY High Temperature
- Copper Feature Dissolution
- Co-Planarity Difference
  - Potential ON Contact Paste Printing
  - Inconsistent Coating Thicknesses (on Varying Pad Sizes)
- Not Suited for High Aspect Ratios
- May not be suited for fine-pitch SMT and Grid Array Packages
- PWB Dimensional Stability Issues
- Bridging Problems on Fine Pitch
  - “Dull” and “Grainy” Appearance
  - More Process Controls Req'd

The main considerations in changing a HAL process from 63/37 Sn/Pb to SN100C (Ni-stabilized Sn-0.7Cu) is:

- **The higher melting point**

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*Source: Nihon Superior Co., LTD*

Lead - Free HASL

 Lead-Free Solder

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Corrosion of Copper Pad

After 6 Passes over Wave Soldering Machine
105°C Preheat, 256°C Solder Temperature, 4 seconds contact time

Copper Dissolution Rate

- Boards were waved and reworked with 2 different alloys. Simulated mini-pot rework (no component removal) was performed from 0 – 120 second exposure.

**ENEPIG**
Electroless Nickel / Electroless Palladium / Immersion Gold
**ENEPIG**

- Electroless Nickel / Electroless Palladium / Immersion Gold
- Sometimes called the Universal Finish
- Ni is 3-8 um thick (120 – 315 microinches)
- Pd is 0.1 – 0.3 um thick (4 – 12 microinches)
- Au is 0.02 – 0.05 um thick (0.8 – 2.0 microinches)

**Advantages:**
- Gold and Aluminum Wirebonding
- Good solderability
- No bussing bars needed to plate (not electrolytic)
- No concern with “Black Pad” because the Phosphorous is plated on the Electroless Nickel by chemical reduction, not galvanic like in ENIG, so there is no attack of the Electroless Nickel layer during ENEPIG.
- No excessive corrosion of the EP layer by the IG due to low phosphorus content of the EP layer and low thickness of the gold.
- Good surface wear resistance

**Disadvantages:**
- Less common in the industry
- Doesn’t have the track record of the other finishes. So don’t know if there are no issues, or no issues...yet.

**Further Investigation:**
- Thin IMC layer – good or bad?
- High volume processing window – large or narrow?
- Surface finish cost?
- Palladium bath is still galvanic with Electroless Phosphorous, are there any hidden issues with galvanic corrosion of the EP layer?

**ENIPG**

- Electroless Nickel / Immersion Palladium / Immersion Gold

**Advantages:**
- Gold and Aluminum Wirebondable
- Good solderability (also in lead-free assembly)
- Palladium bath is less sensitive to impurities than with ENEPIG
- Faster processing time than ENEPIG
- Wider process window than ENEPIG
- Thinner Palladium deposit 0.3-0.5 um (1-2 microinches)
- Lower cost than ENEPIG

**Disadvantages:**
- Replacement of galvanic deposition of Palladium on the Electroless Nickel.
- Unknown issues with black pad type phenomenon
  - However, there is a very thin deposit of the palladium, so the corrosion attack should be minimized

**Direct Gold on Copper**
Direct Gold on Copper

- Gold is plated directly on the copper without a nickel barrier layer.
- Direct Immersion Gold
  - Immersion Gold and Electroless Gold type deposition is used (not intuitive from DIG acronym)
  - A mixed autocatalytic reaction and displacement reaction
  - Uyemura study (>80% autocatalytic) – www.uyemura.com/library-3.htm

Advantages
- Good for mixed surface finish PWB
- Multiple solder exposure during assembly
- Compatible with press fit connectors
- Good for flexible circuits
- Eliminate lossy nickel in high speed / RF applications
- Better coverage than standard immersion gold

Disadvantages
- Shelf Life – gold / copper migration concerns
- Tight gold deposit is supposed to produce a non-porous deposit that resists copper migration into the gold.
- Slow deposition time
- High process bath temperature

High Phosphorous ENIG

- Phosphorous >10% codeposited with the Electroless Nickel

Advantages
- Corrosion resistance
- Supposed to eliminate Black Pad risk
- Solderability and Reliability as good as Medium Phosphorous ENIG
- Drop-in to existing ENIG plating lines
- Lower internal stress in the Nickel deposit (better for flexible circuits)

Disadvantages
- Not well known.
- Needs more testing
- Slower deposit rate than standard ENIG
- Nickel bath sometimes reacts with Sulfur content in some soldermasks

Lead – Free ENIG

- No lead as a stabilizer in the Electroless Nickel bath

The main reactions in the Electroless Nickel bath are
- the deposit of Nickel and Phosphor
- buildup of orthophosphite and other byproducts
- Orthophosphite causes higher stress in nickel deposit which increases the risk of nickel corrosion
- Other byproducts lead to breakdown of the soldermask which leads to sulphur buildup which increases the risk of nickel corrosion.
- Heavy metals (Lead) and organic stabilizers are used to limit these buildups and corner attack.
- Removal of Lead reduces corner attack, therefore a reduction in the amount of sulphur accelerator needed. This leads to an increase in corrosion resistance and a reduction in the associated risk of black pad.
ENAG
Electroless Nickel / Immersion Gold / Electroless Gold

• ENIG with additional Electroless Gold plated on top.
• Used for thicker gold deposit

Advantages
• Excellent for gold wirebonding (packaging, camera modules, etc.)
• Reason for the thicker gold

Disadvantages
• Not recommended for soldering – solder joint embrittlement risk due to amount of gold.

Immersion Silver / Immersion Gold

• Immersion Silver deposit followed by Immersion Gold deposit
• Currently under investigation

Final Finish Market Survey

Source: Prismark Partners

2011 Surface Finish – select factories

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## Surface Finish Comparison

<table>
<thead>
<tr>
<th></th>
<th>HASL (Sn-Pb)</th>
<th>ENIG</th>
<th>Sn-Pb</th>
<th>OSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatness</td>
<td>poor</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Solderability</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>fair</td>
</tr>
<tr>
<td>Reliability (sheen)</td>
<td>good</td>
<td>fair</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Reliability (2 mil obs)</td>
<td>n/a</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Contact Resistance (Wear)</td>
<td>acceptable in some applications</td>
<td>good - button, poor - wiping</td>
<td>good - ICT, poor - wear</td>
<td>poor</td>
</tr>
<tr>
<td>Snad (conventional)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Snad (Resin)</td>
<td>oxidizes</td>
<td>yes</td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td>Solder Joint Reliability (thermal cycle)</td>
<td>good</td>
<td>fair</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Solder Joint Reliability (circuit)</td>
<td>good</td>
<td>poor</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Cost</td>
<td>low</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

## Conclusion Finish I

There is no SINGLE perfect finish that "fits all"

- Finishes should be selected based on specific product application (OEM-EMS key)
- US market tends to favor Sn-Pb (larger and thicker boards)
- EU tends to favor Sn (smaller and thinner boards)
- Handhelds prefer OSP/ENIG
- OSP is used in all product application areas
- All other finishes will be niche (currently)

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**Thank You**