PCB Surface Finishes – Implication on the SMT Process Yield

Liyakathali.K
What is a Surface Finish?

- The surface finish/coating preserves the solderable surfaces as the PCB moves from PCB manufacturing to assembly.
Most Common Surface Finishes

- **HASL** (hot air solder leveling)
- **OSP** (organic solderability preservatives)
- **ENIG** (electroless nickel/immersion gold)
- **ImAg** (immersion silver)
- **ImSn** (immersion tin)
Surface Finishes: Overview


Source: Printed Circuit Design & Manufacture, March 2007
Yield vs. Surface Finish

- Assembly = interconnecting/soldering
- Many known factors for poor first pass yield (FPY), but surface finishes issues are being neglected
- Surface finish quality affects FPY and final product reliability
Ishikawa

Goal: Prevent Oxidation and Promote a Good Solder Joint Formation

Pad Surface Finishes
- OSP
- ENIG
- ImAg
- HASL

Component Surface
- Bi Content
- Cu or Alloy 42
- Sn

Surface Oxidation Prevention and Good Solder Joint

Product Type
- Cu Thickness
- Reliability Requirements
- Wave vs. SMT

Process and Environment
- Counterfeit
- Storage
- Reflow Temperature
- Moisture (MSD)
- Legislation and Marking
- Counterfeit

Sn Whiskers
- BGA or QFN
HASL: Hot Air Solder Leveling

HASL is a solder coating, available in both Pb and Pb-Free.
HASL: Process

Preclean (Cu etched)

Preheat

Flux coating

Solder coating

Air knife leveling

Post cleaning

Typical thickness is 100 ~ 500 micro-inches
HASL: Soldering
# HASL: Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Nothing solder like solder&quot;</td>
<td>Planarity issue/Uneven surface</td>
</tr>
<tr>
<td>Long shelf life</td>
<td>Thin/thick coating (solder beads/balls)</td>
</tr>
<tr>
<td>Short wetting time/easy to wet</td>
<td>PTH dia issues/bridging in fine pitch</td>
</tr>
<tr>
<td>High durability/reliability</td>
<td>Thermal shock/warpage of PCB</td>
</tr>
<tr>
<td>Intermetallic formation prior to SMT</td>
<td>Impurities in the solder (solder bath)</td>
</tr>
</tbody>
</table>

1. Solder mask residue preventing HASL from flowing
2. Poor bonding, contamination on the surfaces of the copper prior to bonding or resin issues in the laminate
OSP: Organic Solderability Preservatives

OSP is a transparent organic material coating.
OSP: Process

Preclean/Microetch

Pre-dip/acid

Organic coating

Rinse/clean

Thickness = 0.3 – 0.5 micron

picture source: Multek
OSP: Soldering
## OSP: Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat/Planar</td>
<td>OSP technology/chemistry challenges (recent - benzimidazole)</td>
</tr>
<tr>
<td>Low Cost</td>
<td>Multiple reflows (now available 3 times reflow-able)</td>
</tr>
<tr>
<td>Short/easy process</td>
<td>Short shelf life</td>
</tr>
<tr>
<td>Good solder joint, directly soldering to Cu</td>
<td>Not conductive (ICT test pads must be soldered)</td>
</tr>
<tr>
<td>Good reliability</td>
<td>Difficult to inspect/coating Skip</td>
</tr>
<tr>
<td></td>
<td>Questions over reliability of exposed Cu after assembly</td>
</tr>
</tbody>
</table>
OSP: Issues

Exposed Cu

Skip/oxidized Cu

Photos courtesy of Randy Schueller, Dell, SMTAI Conference 2007

picture source: screamingcircuits
ENIG: Electroless Nickel/Immersion Gold

Nickel is plated over Cu then gold is plated over Nickel
ENIG: Process

- Complicated Chemical Process, 6 Chemical Steps; 20 chemical ingredients
- Ni Thickness = 50-150 microinches
- Au Thickness = 3-10 microinches

Clean/Microetch → Catalyst → Electroless Nickel → Rinse → Immersion Gold → Rinse/Clean

picture source: Multek
ENIG: Soldering Two Intermetallics

Required more TAL & peak in soldering
### ENIG: Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform thickness/planarity</td>
<td>Black pads (excessive Ni corrosion)</td>
</tr>
<tr>
<td>Long shelf life/thermal excursion</td>
<td>Embrittlement (thick Au)</td>
</tr>
<tr>
<td>Long history</td>
<td>Poor joint strength/reliability (slow Ni/Sn intermetallic growth)</td>
</tr>
<tr>
<td>Good ICT contact</td>
<td>Solder mask lifting/solder spread under the mask (issue with Ni bath)</td>
</tr>
<tr>
<td>Good for connectors, fine pitch etc</td>
<td>Skip/over plating</td>
</tr>
<tr>
<td>Good wettability/solderability (Au doesn't oxidizes)</td>
<td>Non-wetting issues if the process not done right</td>
</tr>
<tr>
<td></td>
<td>Expensive</td>
</tr>
</tbody>
</table>
ENIG: Issues

**Phosphorus content:**

- Phosphorus-containing reducing agents are used for the reduction of the electroless nickel during the deposition process.
- Phosphorus is thus incorporated in the nickel deposit.
- The level of these co-deposited elements should be controlled within the specified process limit.
- 8~10% is allowed... variation of phosphorus level, outside the specified process limits, may have adverse effects on the solderability of the finish.
ENIG: Issues

Nickel exposure/oxide:

- Nickel is used as diffusion barrier in ENIG plating and protects Cu dissolution into solder to ensure better reliability.
- Etching of the nickel surface immediately prior to and during the deposition of Im gold leads to interfacial tarnishing (corrosion) and bond separation.
ENIG: Issues

- **Gold embrittlement**
  - Appears at solder joint microstructure level; affects reliability
  - Gold will quickly dissolve into molten solder
  - More gold means creates a thicker AuSn intermetallic
  - A thicker intermetallic cause embrittlement
  - This threshold is ~ 3 wt% gold
  - In other words, thicker gold plating is bad for the reliability
ENIG: Issues

- **Black pad/black Ni (can be seen visually)**
  - Black pad is formed during the Im gold process as a result of hyperactive corrosion reaction of the nickel surface.
  - There are two approaches to reduce this:
    1. Increase corrosion resistance of nickel by depositing phosphorus,
    2. Reduce aggressiveness of Im gold.
    - Generally, the first approach is used in the industry.
  - So if you have less phosphorus, black pad can occur and if you have more phosphorus, it adversely affect solderability.
ENIG: Issues

1. ENIG corrosion?
2. Black pad
3. Over plate
4. Skip

Photo courtesy of Bob Veale, Rockwell Automation

Best Reference to Read: “The Root Cause of Black Pad Failure of Solder Joints with ENIG”, JOM, June 2006, authors: Zeng/Stierman/Abbot/Murtuza

Image Courtesy: K. Johal, Atotech
ImAg: Immersion Silver
ImAg: Process

- Clean/Microetch
- Pre-dip
- Immersion Silver
- Post-dip

Thickness = 3 – 12 micro-inches
ImAg: Soldering
# ImAg: Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost</td>
<td>Tarnish</td>
</tr>
<tr>
<td>Planar surface</td>
<td>Ag migration</td>
</tr>
<tr>
<td>Compatible with touchpad/solderless connections</td>
<td>Planar Micro Voids</td>
</tr>
<tr>
<td>High conductivity</td>
<td>Creep corrosion (salt, sulfur)</td>
</tr>
<tr>
<td>Solder to Cu like OSP</td>
<td></td>
</tr>
</tbody>
</table>
ImAg Issues

- **Tarnish**
  - May impact solderability
  - Solderless connections appear very tolerant of tarnish
  - Thicker Ag less prone to tarnish

- **Ag Migration**
  - In the presence of temperature and moisture, Ag will migrate from cathode to anode
  - Organic co-deposit appears to eliminate this issue

- **Premature Intermetallic Failure**
  - Thick Ag means more organic co-deposit
  - Organic co-deposit must be forced out of molten solder
  - Non-expulsion of organics can result in microvoids along board/solder
ImAg: Issues

1. Tarnish
2. Migration

Courtesy: Dave Hillman, Rockwell Collins. SMTA March 2008

Picture source: screamingcircuits
ImAg: Creep corrosion

Creep corrosion field failure in high sulfur environment (bridging vias).

Randy Schueller (Dell), "CREEP CORROSION ON LEAD-FREE PRINTED CIRCUIT BOARDS IN HIGH SULFUR ENVIRONMENTS", SMTAI, p.543-554, Orlando, FL, Oct. 7-11, 2007

Photos courtesy of Don Cullen, MacDermid
ImAg: Planar micro voids

Cross-sectional Analysis

Pull off solder joint from land
ImSn: Immersion Tin

PCB

Solder Mask

Copper Pad

ImSn

ImSn

ImSn
ImSn: Process

Clean/Microetch

Pre-dip

Immersion Tin

Post-dip

picture source: Multek
## ImSn: Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost</td>
<td>Solder mask attack (plating chemicals)</td>
</tr>
<tr>
<td>Uniform surface</td>
<td>Solid state IMC formation (brittle IMC)</td>
</tr>
<tr>
<td>Good solderability</td>
<td>Tin whisker</td>
</tr>
<tr>
<td>Good for ICT</td>
<td>Tin pest</td>
</tr>
</tbody>
</table>
ImSn: Pros & Cons

1. Tin Pest
2. Tin Whisker
3. Conventional ImSn (whisker growth)
4. ImSn with additive (no whisker growth)
Other surface finishes

- ENEPIG – Electroless Nickel/Electroless Palladium/Immersion Gold, outperforms ENIG
- OMN – Organic Metal Nano finish*; alternative to OSP
- Selective ENIG/OSP
- DIG – Direct Immersion Gold over copper
## Summary

<table>
<thead>
<tr>
<th>Surface Finish</th>
<th>Cost</th>
<th>Corrosion Res</th>
<th>ICT</th>
<th>Hole Fill</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imm Silver</td>
<td>Low</td>
<td>Poor</td>
<td>Good</td>
<td>Mod</td>
<td>Good surface finish for soldering and testing, creep corrosion is the only major weakness (microvoiding resolved)</td>
</tr>
<tr>
<td>HT OSP</td>
<td>Low</td>
<td>Mod</td>
<td>Poor</td>
<td>Mod</td>
<td>Requires pasting of test pads/vias. Difficult to achieve LF hole fill, especially on &gt;0.062 boards with no-clean flux.</td>
</tr>
<tr>
<td>LF HASL</td>
<td>Mod</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Phenolic laminate recommended. New equipment required. Flatness is better than SnPb (limits are being investigated).</td>
</tr>
<tr>
<td>Imm Tin</td>
<td>Mod</td>
<td>Good</td>
<td>Good</td>
<td>Mod</td>
<td>Solderability/hole-fill may be a problem on double sided PCBs. Shelf life.</td>
</tr>
<tr>
<td>ENIG</td>
<td>High</td>
<td>Mod</td>
<td>Good</td>
<td>Good</td>
<td>Galvanic driven creep corrosion can occur if copper is exposed.</td>
</tr>
</tbody>
</table>

Comparison Table courtesy of Randy Schueller, Dell, SMTA 2007 Conference

---

![SMTA Logo]
Questions?

THANK YOU!
Closing Slide

- Liyakathali.K
- Asst Technical Manager, Tech Support – India
- E-mail: LKoorithodi@indium.com
- Mobile: +91 99406 84038
- Indium Corporation
  Asia Pacific Operations
  Singapore