How PCB Surface Finishes Impact Assembly Processes from an OEM Perspective

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Rockwell Collins
SMTA March 2008
What Rockwell Collins Does

Aviation Electronics and Airborne / Mobile Communications Systems for Commercial and Military Applications Worldwide

So, this is a IPC Class 3, Hillman Personal Bias Babble!
Surface Finishes

Agenda:

- PWB Surface Finishes
  - State of the Market
  - Pbfree Hot Air Solder Level (HASL)
  - Organic Solderability Preservative (OSP)
  - Immersion Tin (ImSn)
  - Immersion Silver (ImAg)
  - Immersion Gold/Electroless Nickel (ENIG)
- References and Comparison Tables
Agenda:

- “Other” Related Surface Finish Stuff
  - Pbfree Solder Alloy Impact
  - Mixed Metallurgy Issues
  - Copper Dissolution
  - Wave Soldering
  - Palladium
  - Electrolytic Silver
  - Tin Pest
  - Tin Whiskers
Surface Finishes

- PWB Surface Finishes

Projected Global Growth and Changes in the Market

- 2004 Global Finish Volume
  - HASL 57%
  - ENIG 14%
  - ImSn 3%
  - ImAg 6%
  - OSP 20%

- 2008 Global Finish Volume
  - HASL 37%
  - ImSn 14%
  - ImAg 17%
  - OSP 28%

6.2% CAGR

<table>
<thead>
<tr>
<th>Board Sqft</th>
<th>CAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>HASL</td>
<td>-4.4%</td>
</tr>
<tr>
<td>OSP</td>
<td>14.5%</td>
</tr>
<tr>
<td>ImAg</td>
<td>42%</td>
</tr>
<tr>
<td>ImSn</td>
<td>22%</td>
</tr>
<tr>
<td>ENIG</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

Source: Internal, Prismark, IPC/TMRC
Section Topics: PWB Surface Finishes

- Pbfree HASL:

**Advantages:**
- Thermal Excursion
- Robustness
- Metallurgical Compatibility
- Corrosion Resistance
- Cost
- Availability

**Disadvantages:**
- Reworkability
- Coplanarity
- Impact on Laminate and PWB Structures
- Solderability
Surface Finishes

- Section Topics: PWB Surface Finishes

  - Pbfree HASL: HASL vs. ImSn, Wave, SnCu Alloy, 14 layer PWB

![Graphs showing cumulative failure vs. cycles for HASL and ImSn finishes.](image-url)
Section Topics: PWB Surface Finishes

- Pbfree HASL: “I have been on this train before”
Section Topics: PWB Surface Finishes

OSP:

Advantages:
- Coplanarity
- Metallurgical Compatibility
- Cost
- Availability
- Reworkability

Disadvantages:
- Thermal Excursion Robustness
- Use Environment Impact
Surface Finishes

Section Topics: PWB Surface Finishes – OSP
  – Wetting Behavior

Photos courtesy of Randy Schueller, Dell, SMTAI Conference 2007
The first indication that your winter season has been extremely harsh!

aka - This is a filler slide!
Section Topics: PWB Surface Finishes

- **Immersion Tin:**

  **Advantages:**
  - Coplanarity
  - Metallurgical Compatibility
  - Cost
  - Availability

  **Disadvantages:**
  - Thermal Excursion Robustness
  - Soldermask Impact
  - Tin Whisker “Myth”
Surface Finishes

- PWB Surface Finishes
  - Immersion Tin:
# Surface Finishes

## PWB Surface Finishes

- **Immersion Silver:**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coplanarity</td>
<td>• Electrochemical Migration “Myth”</td>
</tr>
<tr>
<td>• Thermal Excursion Robustness</td>
<td>• Handling/Tarnishing</td>
</tr>
<tr>
<td>• Availability</td>
<td>• Cost</td>
</tr>
<tr>
<td>• RF Design Aspects</td>
<td>• Creep Corrosion</td>
</tr>
</tbody>
</table>
PWB Surface Finishes: Immersion Silver:

Figure 9 - Through Hole Solderability versus Total Tarnish

Figure 10 - Varying Silver Tarnish Levels

Photos courtesy of Lenora Toscano, MacDermid
Surface Finishes

- PWB Surface Finishes
  - Immersion Silver:
Surface Finishes

- **PWB Surface Finishes**
  - Immersion Silver: Creep Corrosion

Photos courtesy of Don Cullen, MacDermid
Surface Finishes

- PWB Surface Finishes - ImAg: Creep Corrosion

Photo courtesy of Randy Schueller, Dell
Surface Finishes

- PWB Surface Finishes - ImAg: Creep Corrosion

Photo courtesy of Randy Schueller, Dell
## PWB Surface Finishes

### ENIG:

**Advantages:**
- Coplanarity
- Thermal Excursion
- Robustness
- Availability
- Aluminum Wirebondability

**Disadvantages:**
- “Black Pad” Boogyman
- Sn/Ni Intermetallic System
- Cost
- RF Design “Myth”
- Soldermask Impact
PWB Surface Finishes - ENIG:

The materials “stack” at the time of printing.

Reflow: The Au layer is dissolved into the solder.

Service: The Au in the solder diffuses back to the solder/Ni interface, forming a complex IMC layer composition.

(Au, Ni, Cu)_xSn_y IMC layer

The complex IMC stoichiometry causes further embrittlement and the likelihood of premature failure, especially under mechanical loads.

Cell courtesy of Dr. Paul Vianco, Sandia National Laboratories
Surface Finishes

- PWB Surface Finishes
  - ENIG

Best Reference to Read: “The Root Cause of Black Pad Failure of Solder Joints with ENIG”, JOM, June 2006, authors: Zeng/Stierman/Abbot/Murtuza
Even ENIG can undergo corrosion under the right conditions!

Photo courtesy of Bob Veale, Rockwell Automation
Useful References:

- **Very Good Books:**


- **IPC Specifications**
  - ENIG: IPC-4552 (Published)
  - Immersion Silver: IPC-4553 (Published)
  - Immersion Tin: IPC-4554 (Published)
  - OSP: IPC-4555 (currently in draft stage)
### Surface Finishes

<table>
<thead>
<tr>
<th>Subject</th>
<th>HASL</th>
<th>OSP</th>
<th>ENIG</th>
<th>ImAg</th>
<th>ImSn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard solder joints are predictable</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>BGA solder joints are predictable</td>
<td>P</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Solderability shelf life is one year</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Soldermask compatibility</td>
<td>P</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>M</td>
</tr>
<tr>
<td>Via plugging is safe and reliable</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Improves overall via reliability</td>
<td>M</td>
<td>–N–</td>
<td>P</td>
<td>–N–</td>
<td>–N–</td>
</tr>
<tr>
<td>Flat surface benefits assembly</td>
<td>M</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Conductive contact surface</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Solderable over four heating cycles</td>
<td>P</td>
<td>P</td>
<td>M</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Thickness variation is minimal</td>
<td>M</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Coating is environment friendly</td>
<td>M</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Tin whiskers are not a problem</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>M</td>
</tr>
</tbody>
</table>

### Comparison Table

| P = plus, M = minus, N = neutral | 8 P | 8 P | 9 P | 9 P | 7 P |

Comparison Table courtesy of Dr. Dongkai Shangguan, Flextronics, SMTAI 2007 Conference Surface Finishes Panel
## Surface Finishes

<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
Surface Finishes

- Any Questions So Far?
TMS/SMTA Webinar: Progress In Lead-free Solders: Industry Issues on Lead-free Soldering

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October 2007
Solder Alloy of Choice

- Temperature, Temperature, Temperature
  - 34°C Increase Over Current Processes !!!
  - SAC Solder Alloys Vs. SnCu Modified Alloys
- Cost and Microstructural Rationale

<table>
<thead>
<tr>
<th>Solder Alloy</th>
<th>Melting Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>42Sn - 58Bi</td>
<td>138</td>
</tr>
<tr>
<td>68Sn - 32Cd</td>
<td>176</td>
</tr>
<tr>
<td>63Sn - 37Pb</td>
<td>183</td>
</tr>
<tr>
<td>77.2Sn - 2.8 Ag - 20 In</td>
<td>187</td>
</tr>
<tr>
<td>96.1Sn - 2.6Ag - 0.8Cu - 0.5Sb</td>
<td>210</td>
</tr>
<tr>
<td>Sn - 3-4Ag - 0.5-0.9Cu</td>
<td>217</td>
</tr>
<tr>
<td>95.5Sn - 3.5Ag</td>
<td>221</td>
</tr>
</tbody>
</table>
Mixed Metallurgy Solder Joints

- Pbfree BGAs: Solder Joint Uniformity
  - How does your PWB surface finish influence the solder joint?
Mixed Metallurgy Solder Joints

BGA-225 SnPb Reworked to SAC solder joint; Failed after 822 thermal cycles
(Original pwb finish was SnPb HASL!)  Data From JCAA/JGPP Consortia Reports:

http://acqp2.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html
Copper Dissolution

- Role of Plating and Solder Alloy
  - Specialized Process/Alloy for Plated Thru Holes Rework Only?

ENIG – 1.5 mil Copper – 60 Sec

ImSn – 1.5mil Copper – 60 Sec
PWB Surface Finish Contribution Concerns

- Wave Solder

Photo References:
2) “Real Life Tin-Silver-Copper Alloy Processing”, A. Rae et al, APEX Conference Proceedings, 2003
PWB Surface Finish Contribution Concerns

- **Wave Solder:** What pwb finish you subject your wave solder pot to isn’t trivial!

- Palladium Concerns – Slow Diffusion, Embrittlement, Solderability

PdSn₄ Intermetallic Phase

(Graph from W. Bader reference)
Gold Embrittlement Concern – Formation of AuSn₄ Phase

AuSn₄ Intermetallic Phase

[needle-like structures]
• Electrolytic silver plating has been shown to be very “mobile” in a number of use environments (don’t confuse electrolytic silver with immersion silver!!)

• The solderability of electrolytic silver is very poor – formation of silver sulfide from environment sulfide sources (cardboard, tape, etc)
Silver plating is suspect to sulfur attack! Don’t have a cow – you need a serious source of sulfur to create these structures!!!
**Tin Pest:**

- Test Pest Concern – Allotropic Transformation $\beta$-Tin to $\alpha$-Tin
- $\beta$-Tin (Body Center Tetragonal structure) to $\alpha$-Tin (Cubic structure)
- Volume Change $= +26\%$ Increase @ $13.2^\circ$C
- Transformation very sensitive to elemental impurities: Pb, Sb, Bi will eliminate occurrence
- Tin Pest risk thought to be low to no risk

(Photo from Kariya reference)
• Tin Pest

As cast and machined slug of high tin alloy in β form

Partially transformed to α form

Completely transformed to α form

(Cell from Sweatman reference)
• Tin Pest
  - Rockwell Collins/Iowa State University Project

• SMT Resistors
• PLCC68
• SOT
• Dpak
• SOIC16
• SMT Resistors

Results Published in September –SMTAI 2006 Conference: Study still in progress:
No Tin Pest after 36 months -40C storage
• Tin Whiskers

• Why is There a Concern?
  – Spontaneous Growth from Pure Tin Finishes
  – Can be 9.5 mm Long (0.374 inches)
  – Can Carry 25 mA Current, 1 A for a Short Duration
Tin Whiskers
Shuttle Issue – Honeywell Equipment circa 1985 Tin Whiskers in ATVC 34

Figure 1: View of tin whiskers on card guide surface of ATV Control (S/N 6036). Many of these whiskers exceed 5 mm in length.
- Tin Whiskers

- What Causes Tin Whiskers?
  - No Industry Consensus Yet!
  - Primary Factor: Plating Stress
  - Significant Copper/Tin Intermetallic Interaction

Matt Tin finish – Cu/Sn Intermetallic and Tin Whisker Interaction

(Photo courtesy of N. Vo, Motorola)
• Useful References:
  
  - **Palladium:**
    - “Dissolution of Au, Ag, Pd, Pt, Cu and Ni in a molten tin-lead solder”, W. Bader, Welding Journal 48, 1969
  
  - **Tin Pest:**
    - “Tin Pest in Lead free Solders”, Y. Kariya etal, Soldering & Surface Mount Technology, Volume 13, Number 1, 2001
  
  - **Tin Whiskers:**
    - “Annotated Tin Whisker Bibliography and Anthology” Dr. George T. Galyon, IBM; (updated November 2003, v1.2)
      http://www.nemi.org/projects/ese/tin_whisker_activities.html
QUESTIONS