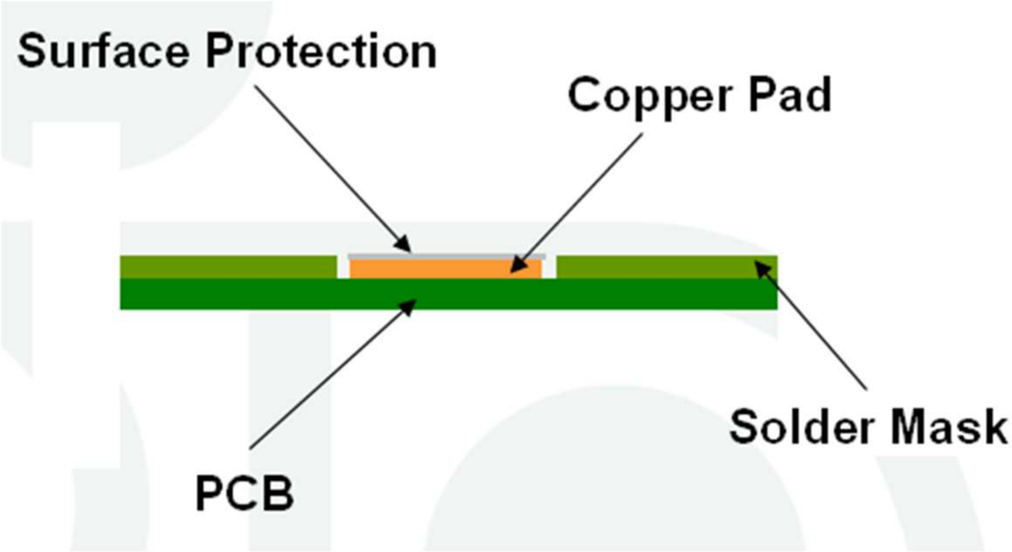
PCB Surface Finishes – Implication on the SMT Process Yield

Liyakathali.K

What is a Surface Finish?

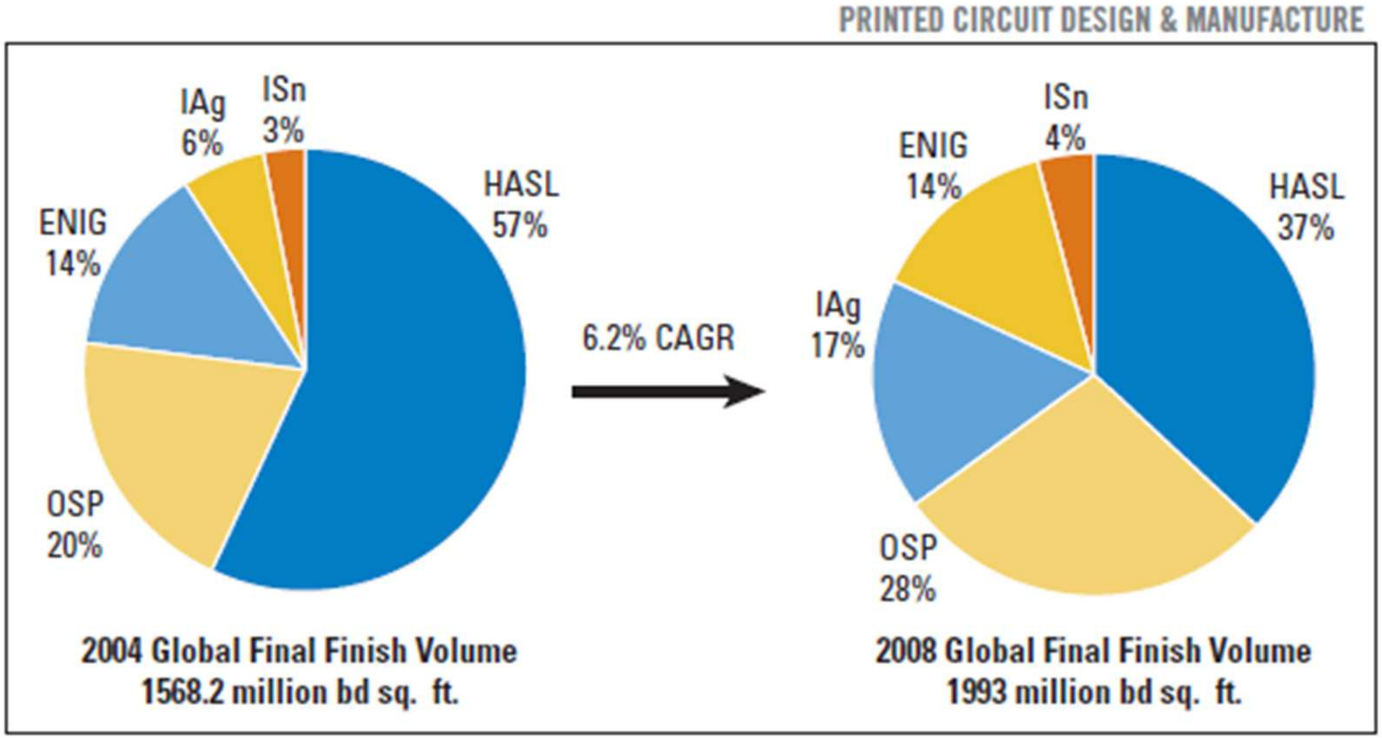
- The surface finish/coating preserves the solderable surfaces as the PCB moves from PCB manufacturing to assembly



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



Worldwide final finish market for 2004 and projection for 2008

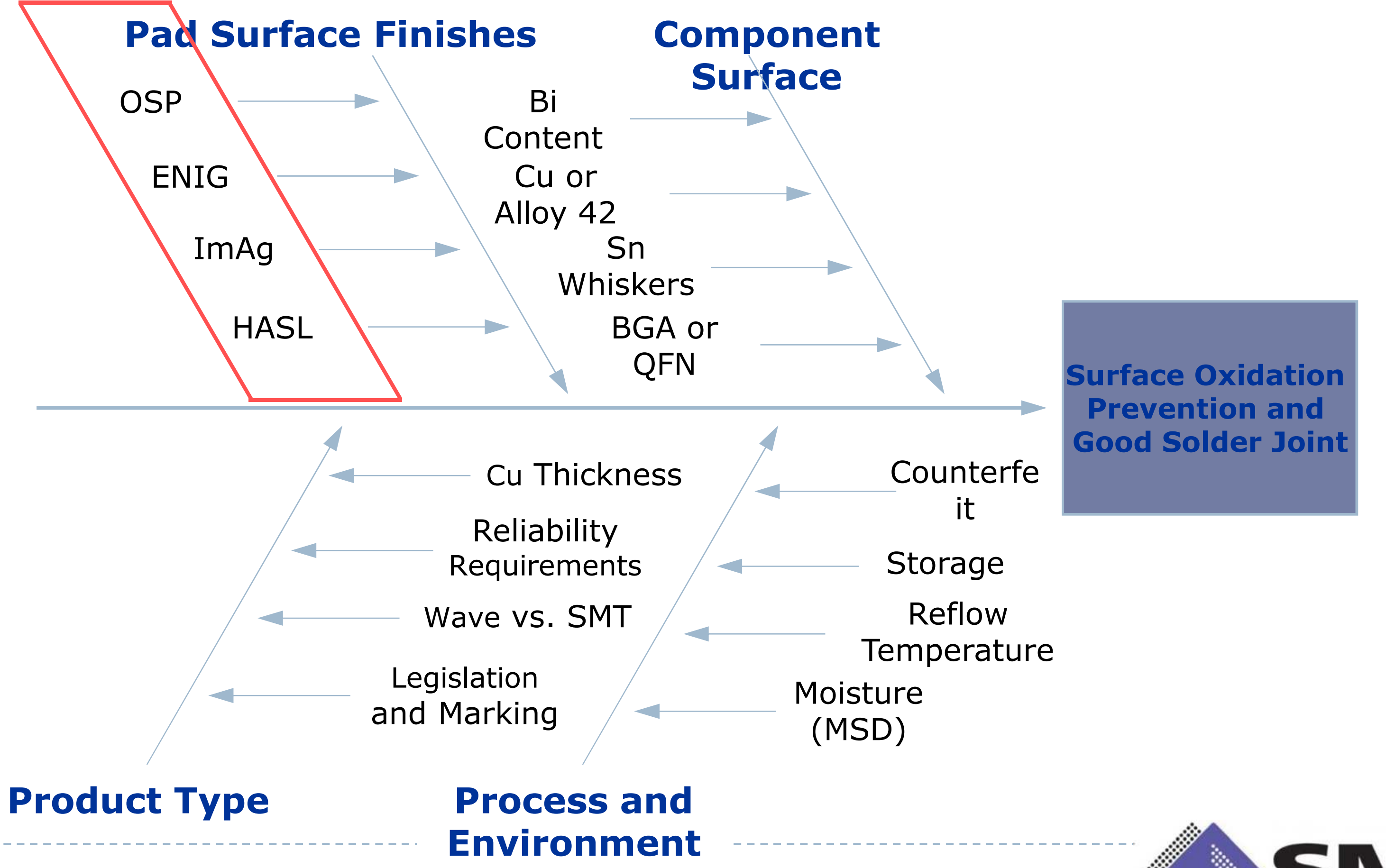
Source: Printed Circuit Design & Manufacture, March 2007

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 Whiskers

BGA or QFN

Surface Oxidation Prevention and Good Solder Joint

Cu Thickness

Reliability Requirements

Wave vs. SMT

Legislation and Marking

Product Type

Counterfe it

Storage

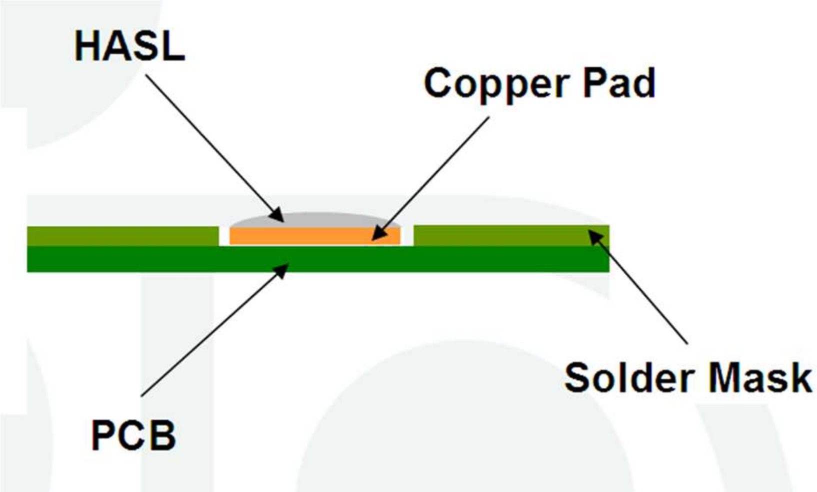
Reflow Temperature

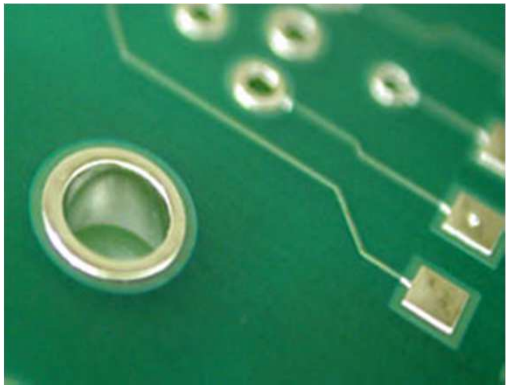
Moisture (MSD)

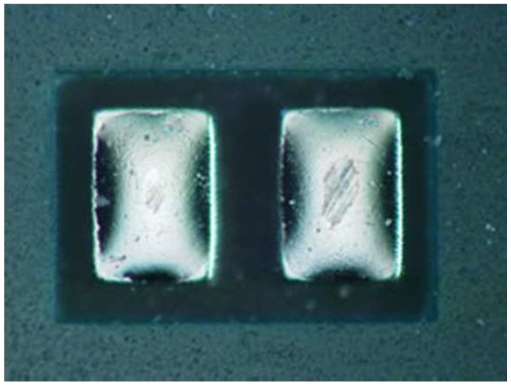
Process and Environment

HASL: Hot Air Solder Leveling

HASL



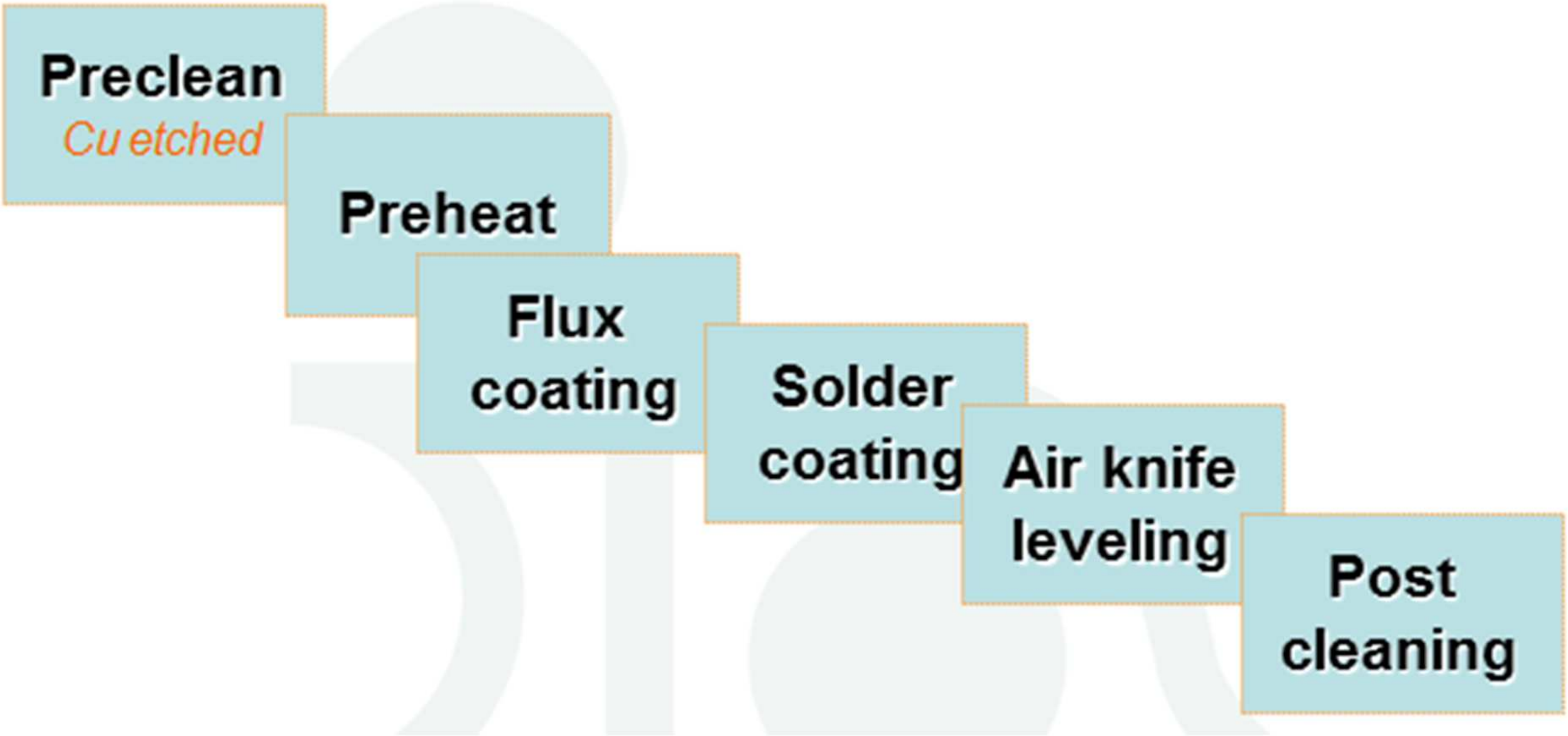

picture source: electroloy


picture source: Bob Willis

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

HASL: Process

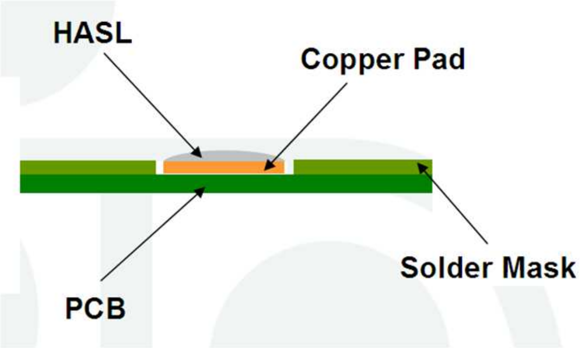
HASL

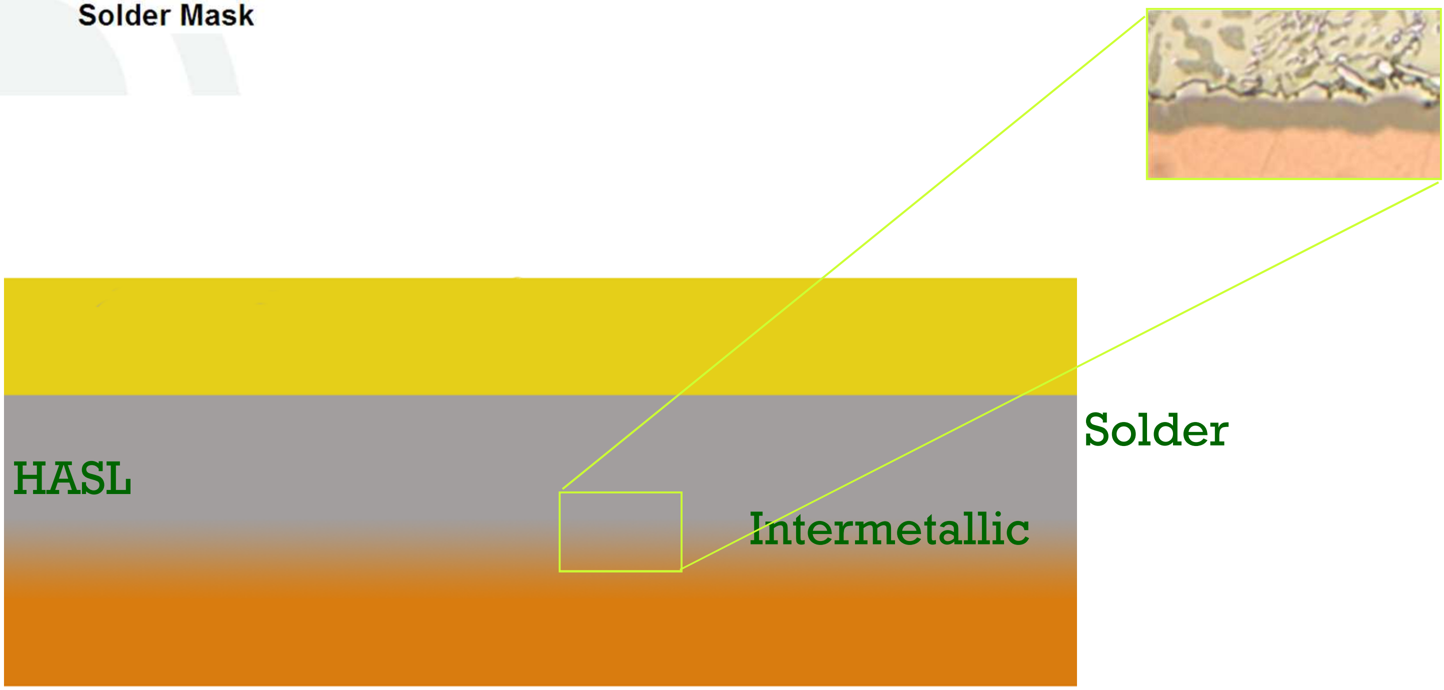

Preclean
Cu etched
Preheat
Flux coating
Solder coating
Air knife leveling
Post cleaning

Typical thickness is 100 ~ 500 micro-inches

HASL: Soldering

HASL

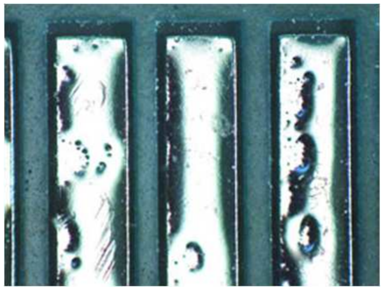




HASL: Pros & Cons

HASL

Pros	Cons
"Nothing solder like *solder*"	Planarity issue/Uneven surface
Long shelf life	Thin/thick coating (solder beads/balls)
Short wetting time/easy to wet	PTH dia issues/bridging in fine pitch
High durability/reliability	Thermal shock/warpage of PCB
Intermetallic formation prior to SMT	Impurities in the solder (solder bath)



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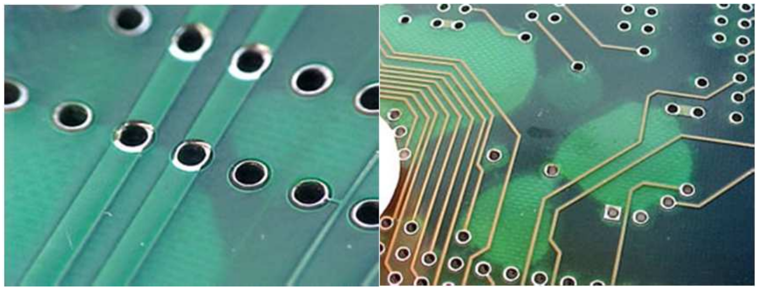
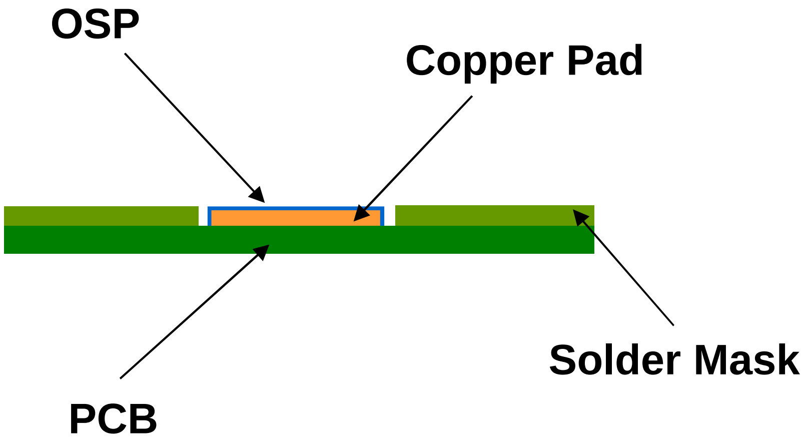


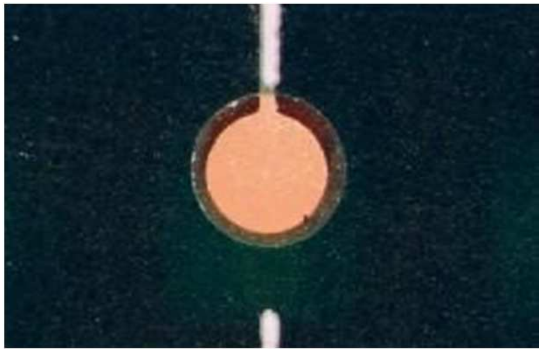
2

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





OSP is a transparent organic material coating

OSP: Process

OSP

Preclean/ Microetch

Pre-dip/ acid

Organic coating

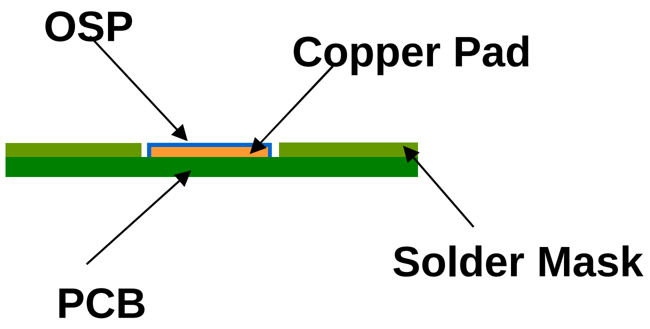
Rinse/ clean

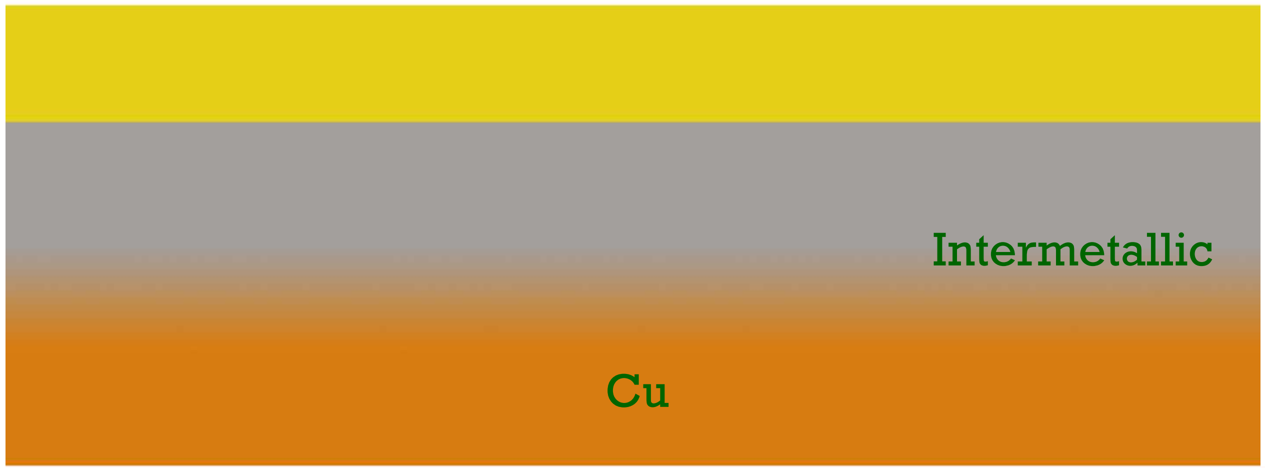
picture source: Multek

Thickness = 0.3 – 0.5 micron

OSP: Soldering

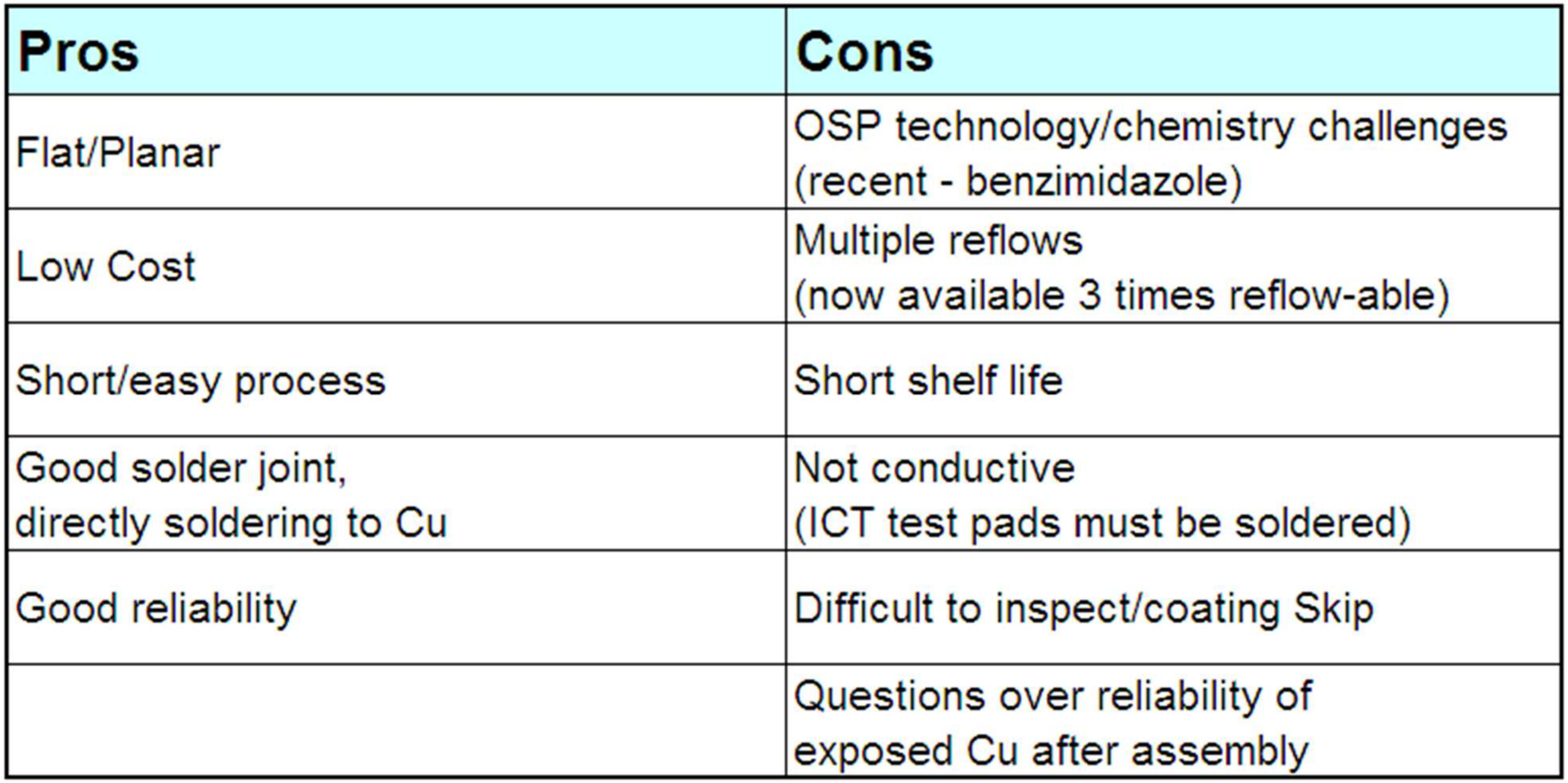
OSP





OSP: Pros & Cons

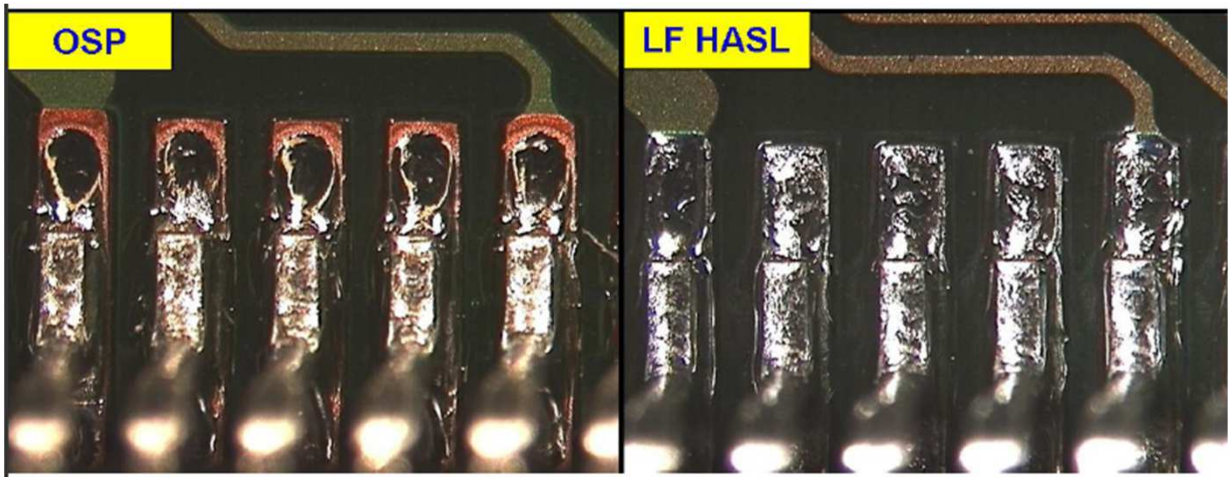
OSP



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

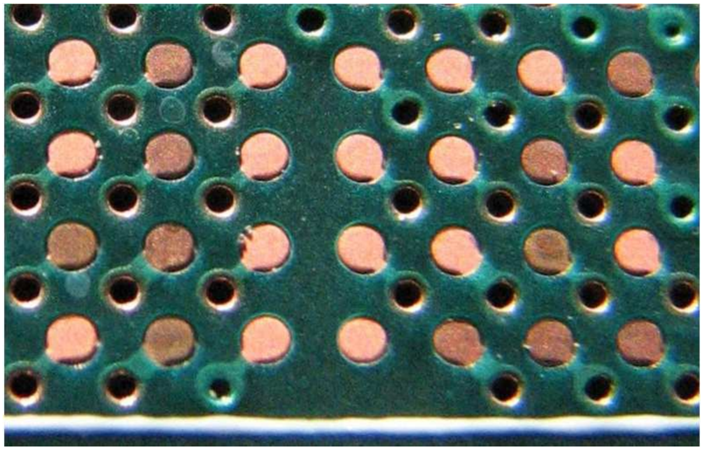
OSP: Issues

OSP



Photos courtesy of Randy Schueller, Dell, SMTAI Conference 2007

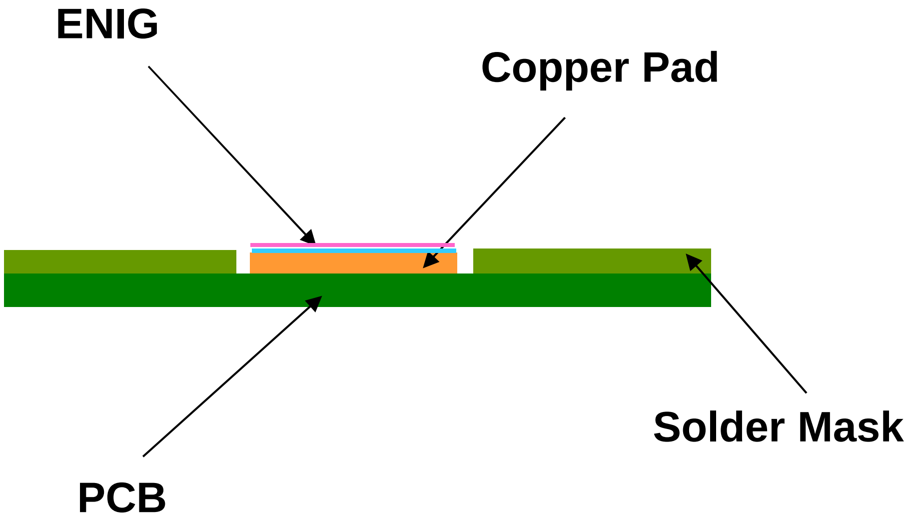
Exposed Cu



picture source: screamingcircuits

Skip/oxidized Cu

ENIG: Electroless Nickel/Immersion Gold



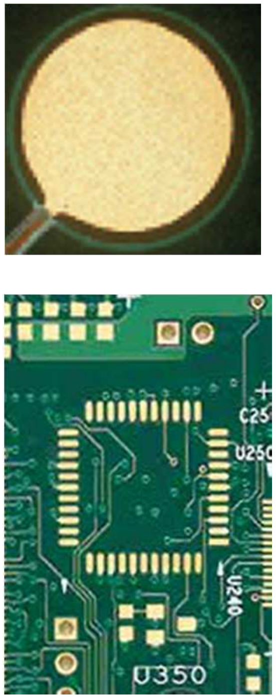
ENIG

Copper Pad

Solder Mask

PCB

ENIG



Nickel is plated over Cu then gold is plated over Nickel

ENIG: Process

Clean/ Microetch

Catalyst

Electroless Nickel

Rinse

Immersion Gold

Rinse/ Clean

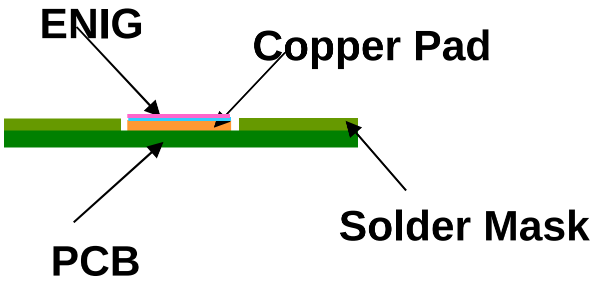
ENIG

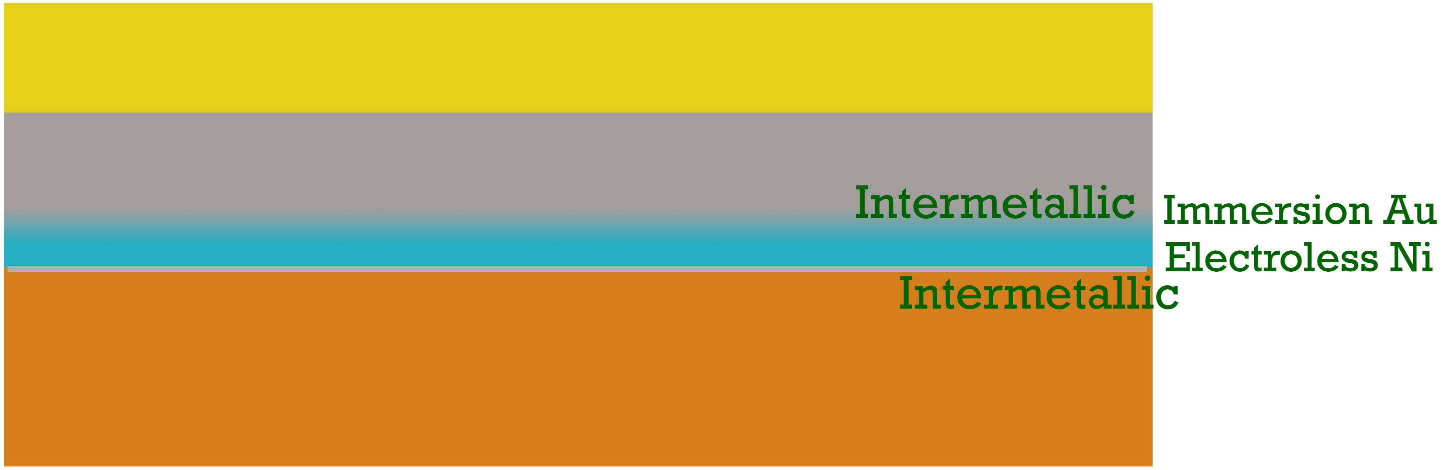
picture source: Multek

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

ENIG: Soldering
Two Intermetallics

ENIG

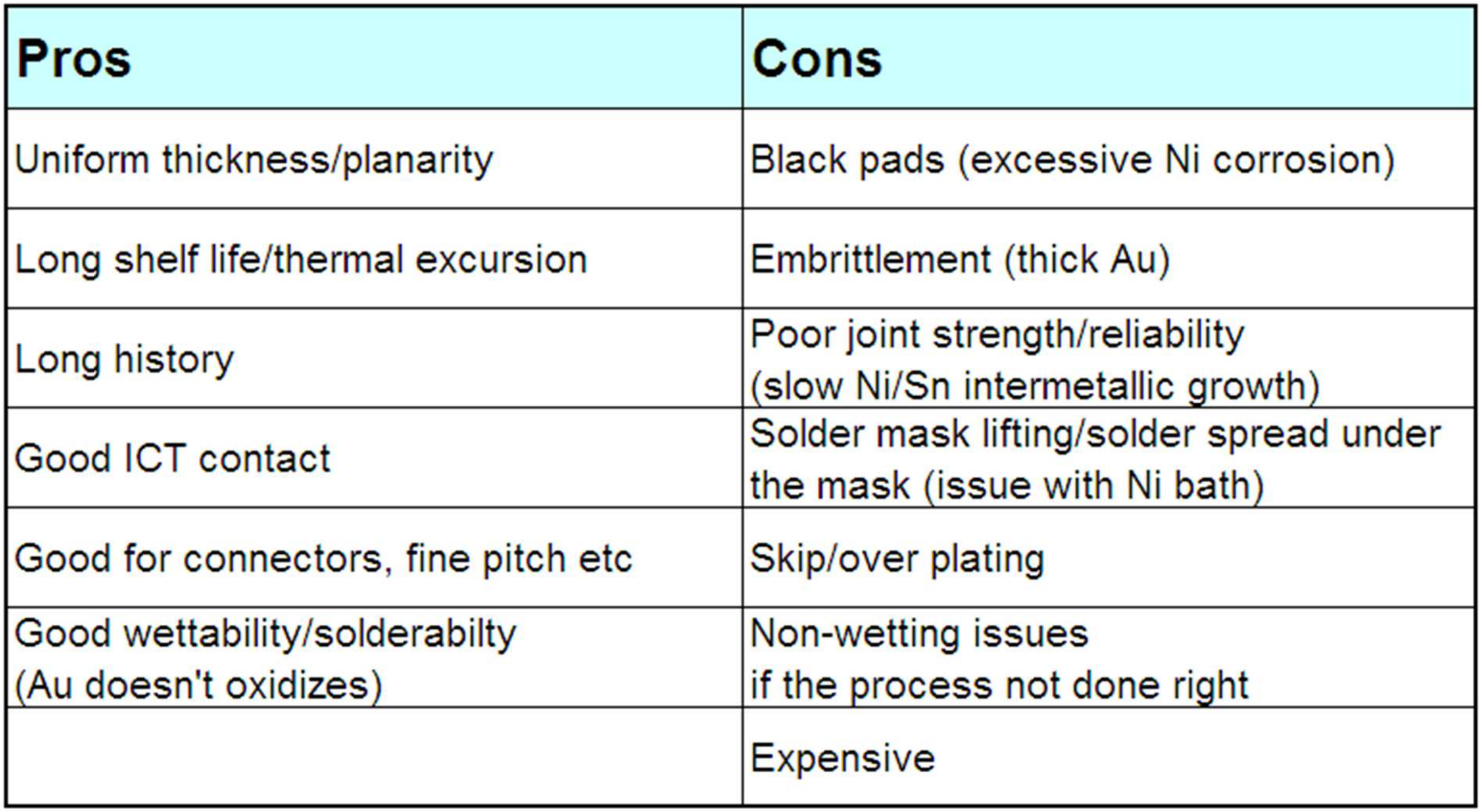




Required more TAL & peak in soldering

ENIG: Pros & Cons

ENIG



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

ENIG: Issues

ENIG

- **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

ENIG

- **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

ENIG

- **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

ENIG

- **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 approach two reduce this
    1. increase corrosion resistance of nickel by depositing phosphorus,
    2. reduce aggressiveness of Im gold
    - generally 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

ENIG

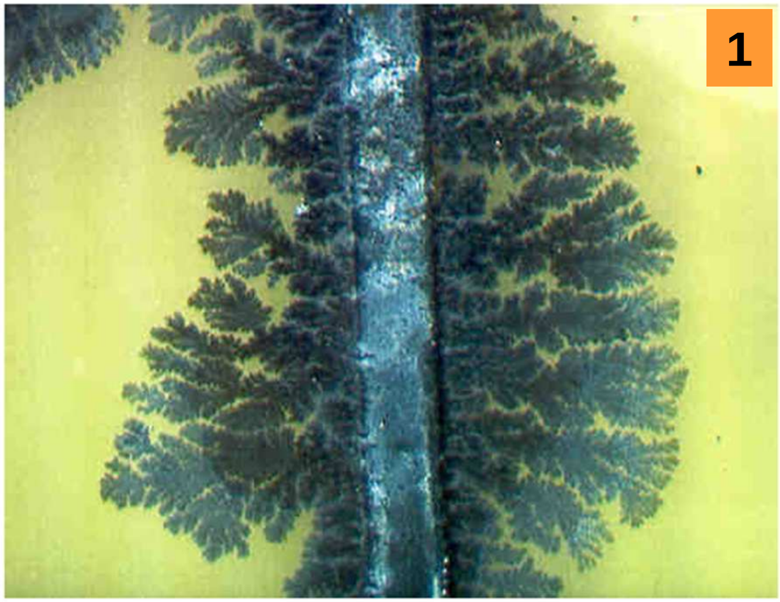
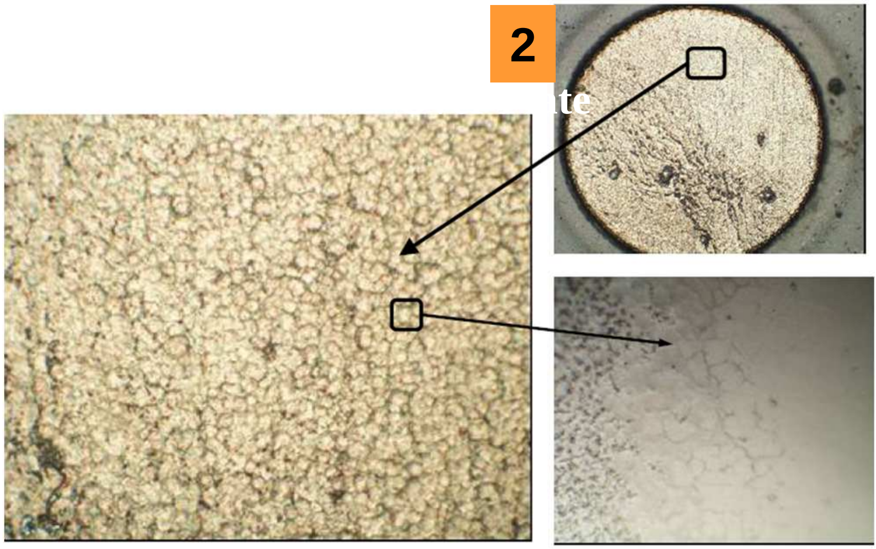
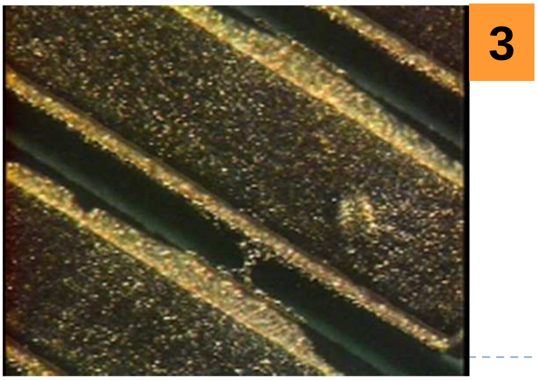
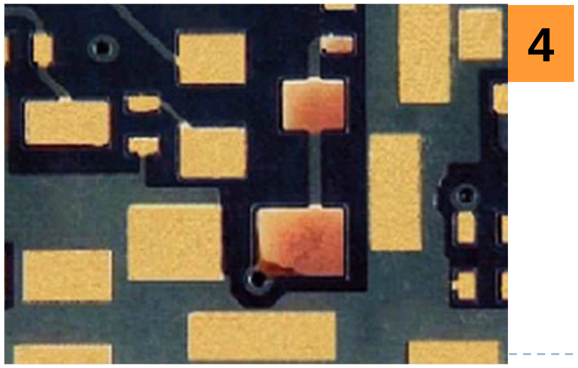


Photo courtesy of Bob Veale, Rockwell Automation



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



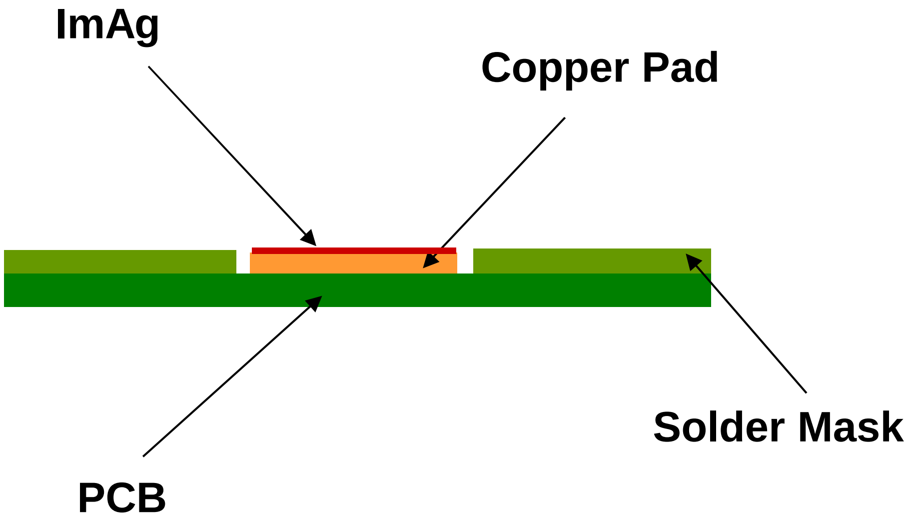


1. ENIG corrosion?
2. Black pad
3. Over plate
4. Skip

Image Courtesy: K. Johal, Atotech

ImAg: Immersion Silver

ImAg

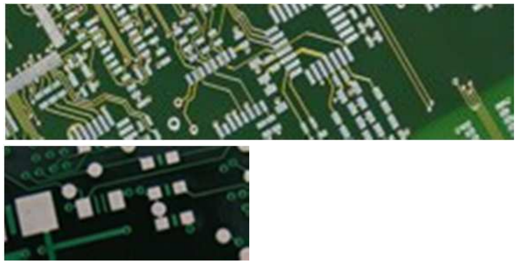


ImAg

Copper Pad

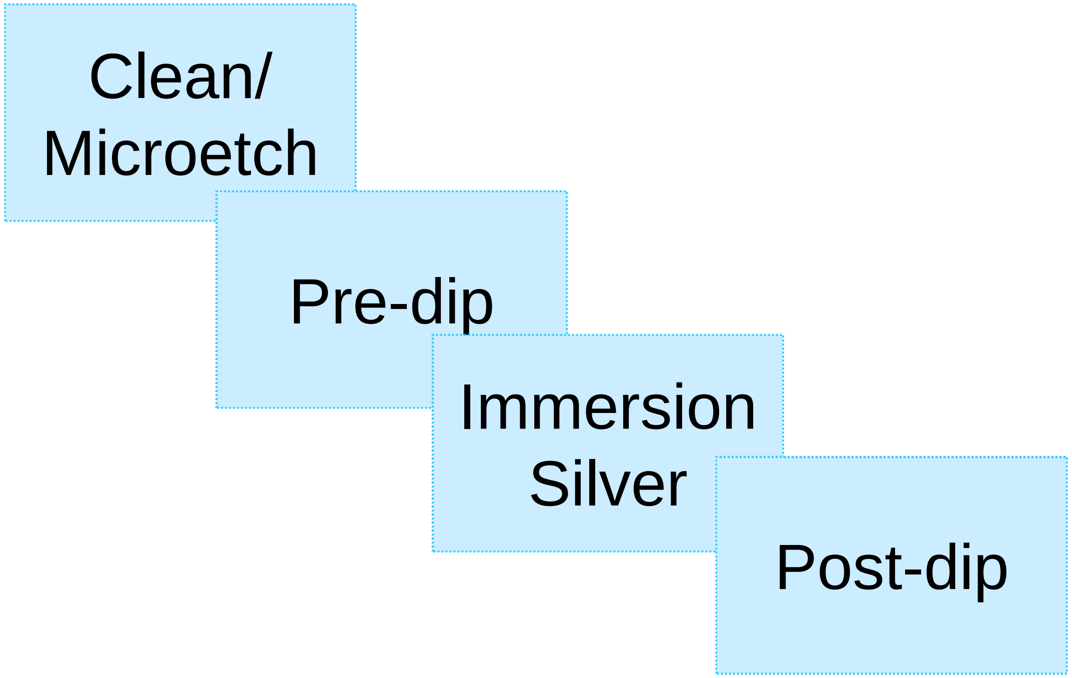
Solder Mask

PCB



ImAg: Process

ImAg



Clean/ Microetch

Pre-dip

Immersion Silver

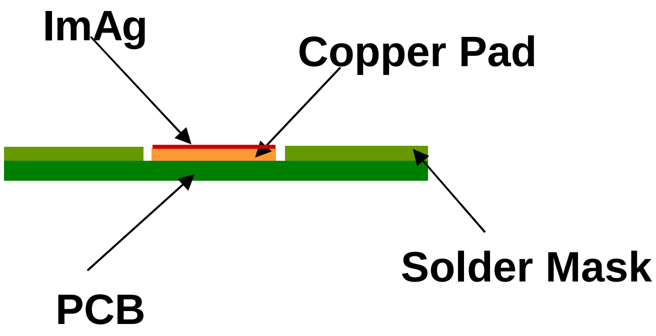
Post-dip

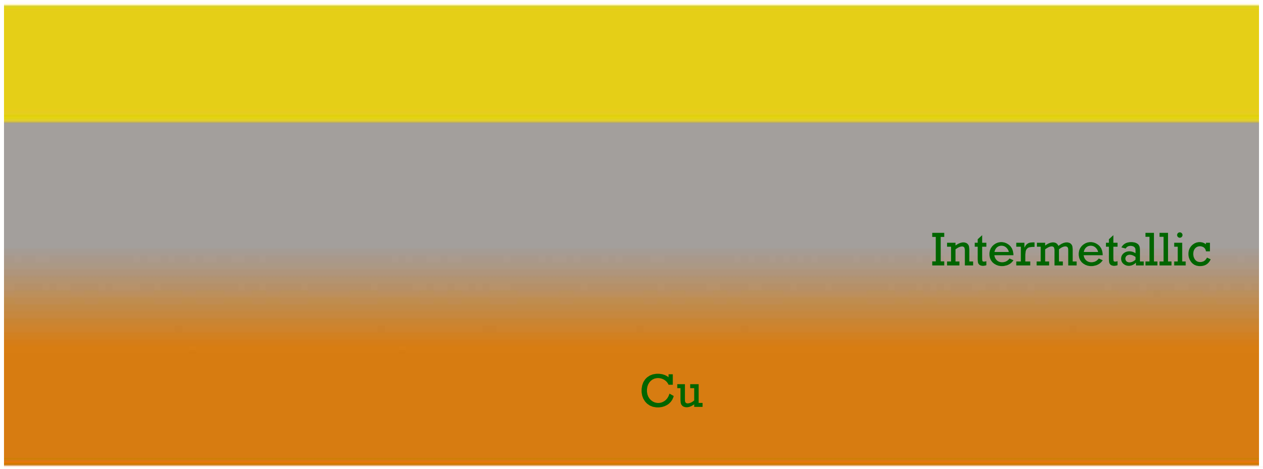
picture source: Multek

Thickness = 3 – 12 micro-inches

ImAg: Soldering

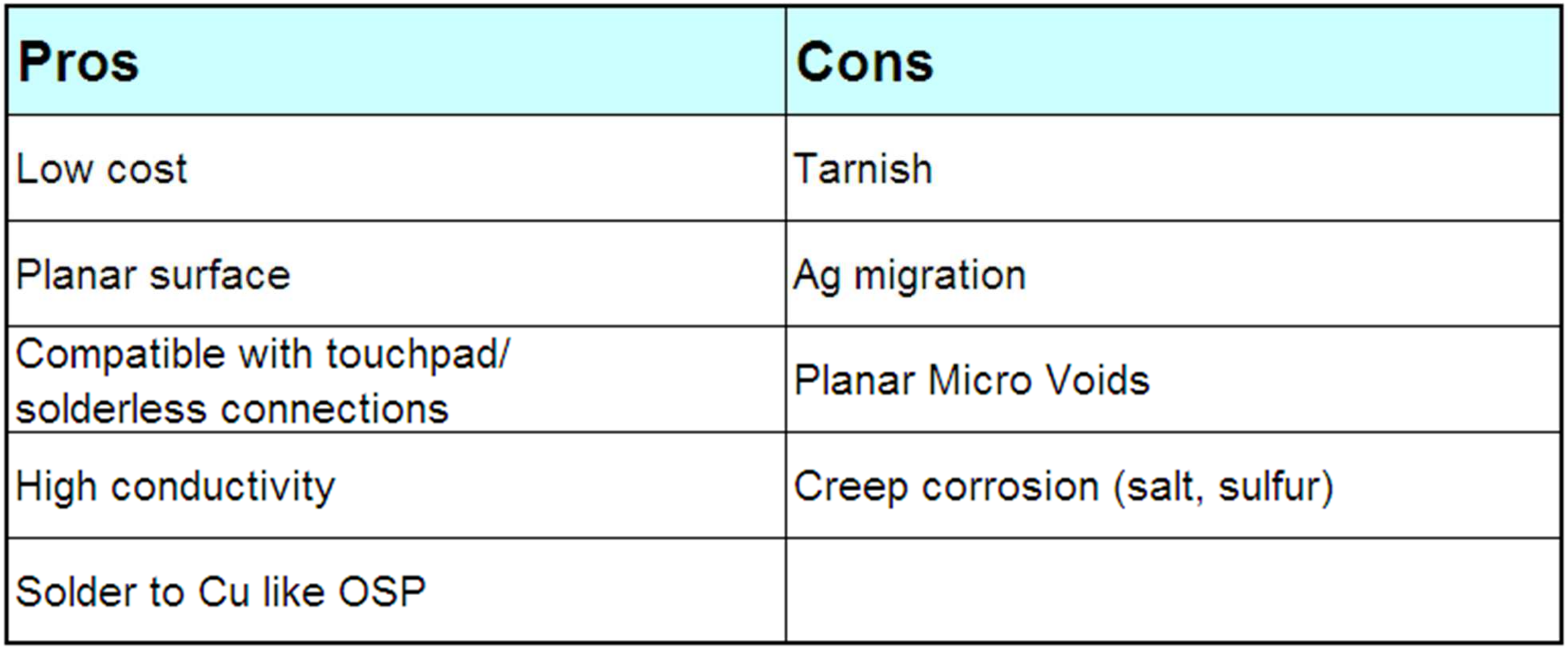
ImAg





ImAg: Pros & Cons

ImAg

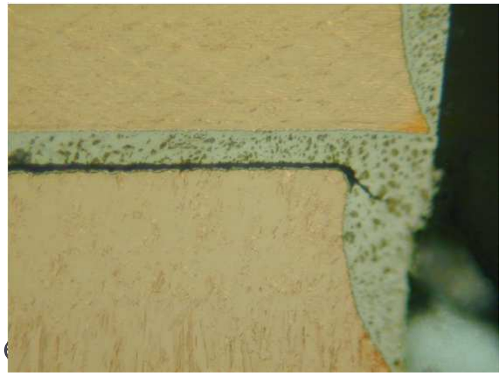


Pros	Cons
Low cost	Tarnish
Planar surface	Ag migration
Compatible with touchpad/ solderless connections	Planar Micro Voids
High conductivity	Creep corrosion (salt, sulfur)
Solder to Cu like OSP	

ImAg Issues

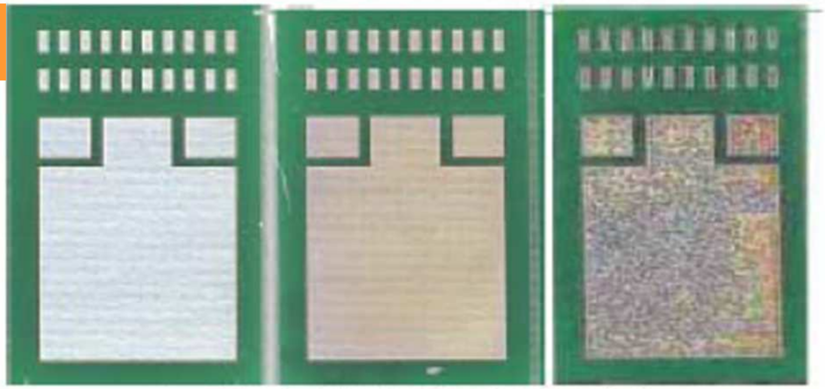
ImAg

- **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/solde



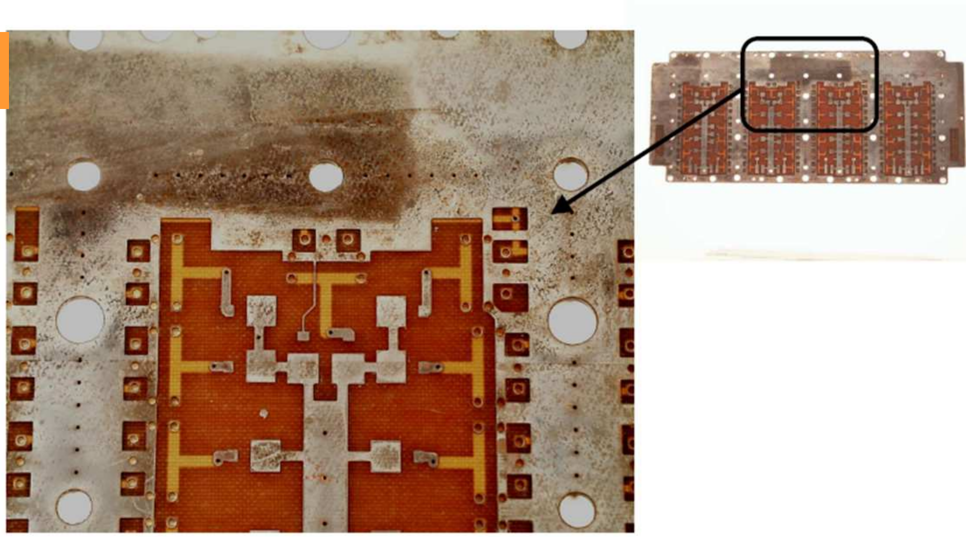
ImAg: Issues

ImAg

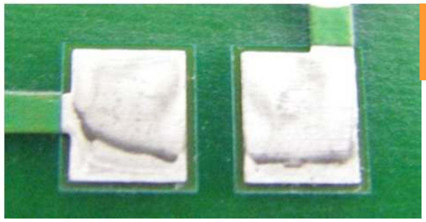


Varying Silver Tarnish Levels

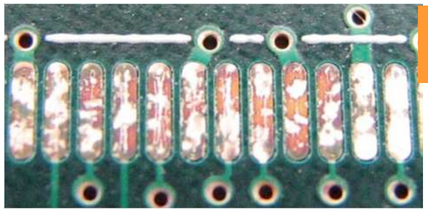
Photos courtesy of Lenora Toscano, MacDermid



Courtesy: Dave Hillman, Rockwell Collins. SMTA March 2008



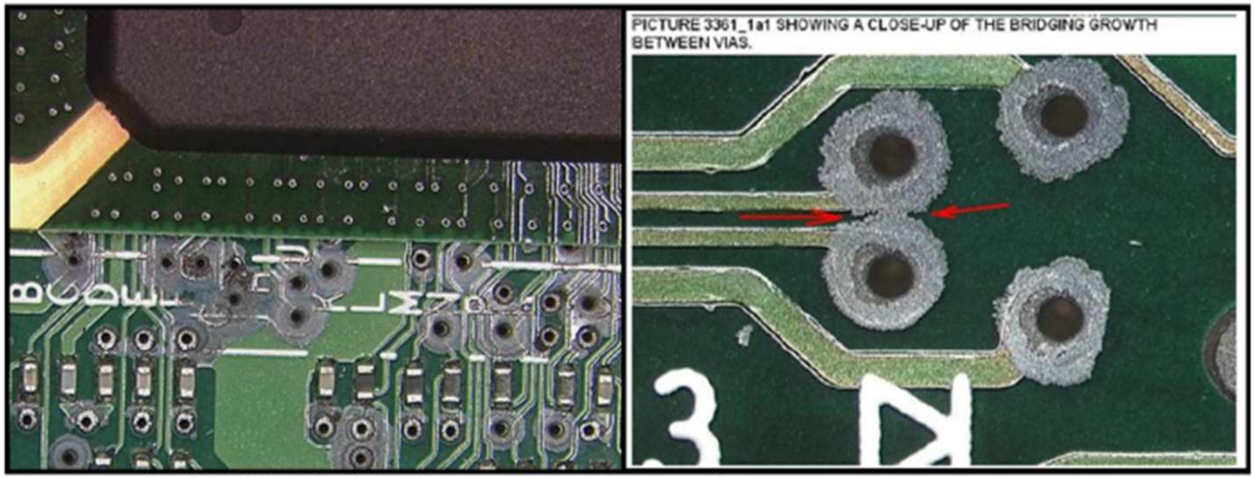
Picture source: screamingcircuits



1. **Tarnish**
2. **Migration**

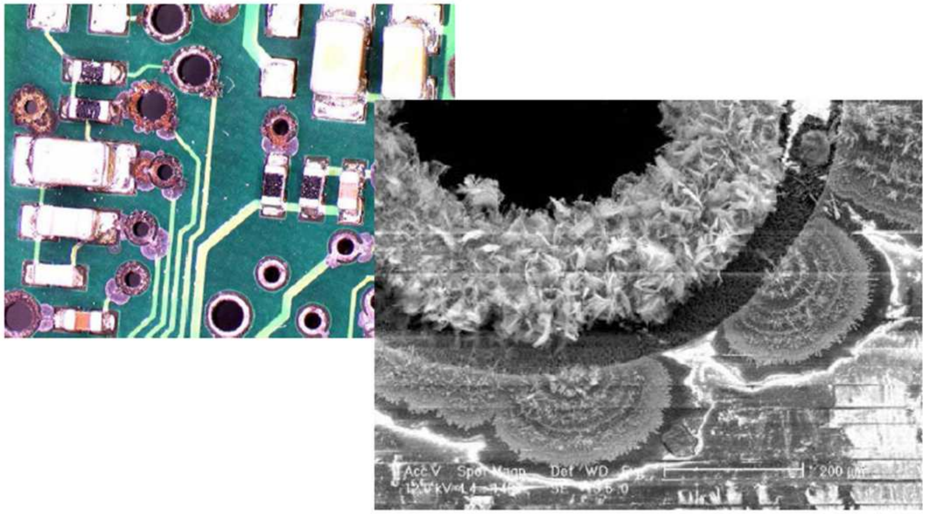
ImAg: Creep corrosion

ImAg



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

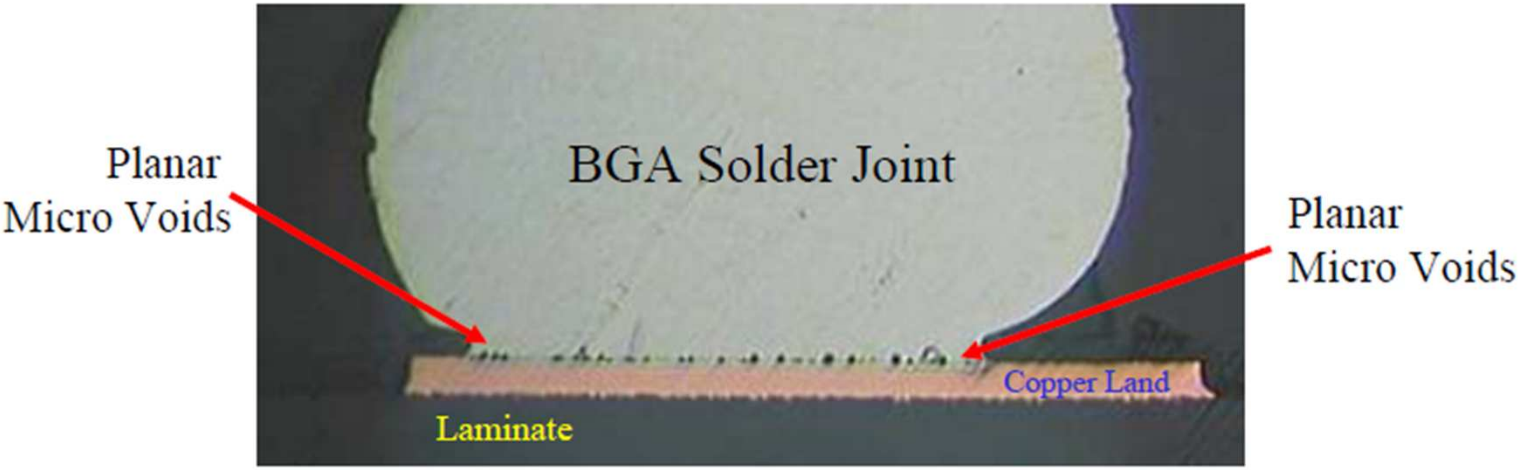
Randy Schueller (Dell), "CREEP CORROSION ON LEAD-FREE PRINTED CIRCUIT BOARDS IN HIGH SULFUR ENVIRONMENTS", SMTAI, p.643-654, Orlando, FL, Oct. 7-11, 2007



Photos courtesy of Don Cullen, MacDermid

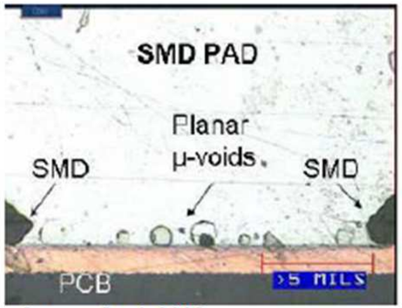
ImAg: Planar micro voids

ImAg

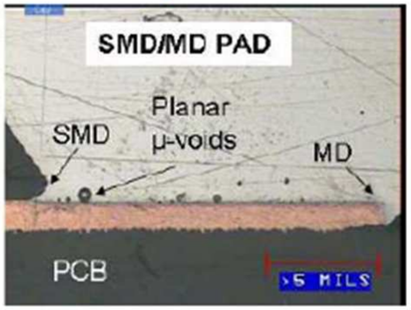


Source: Intel, 2005

Cross-sectional Analysis

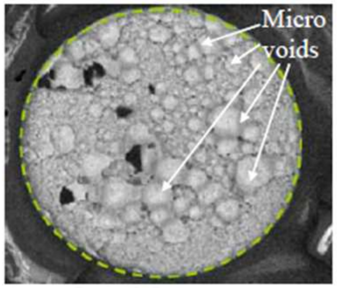


Source: Intel, 2005

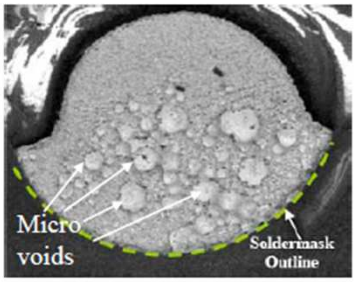


Source: Intel, 2005

Pull off solder joint from land

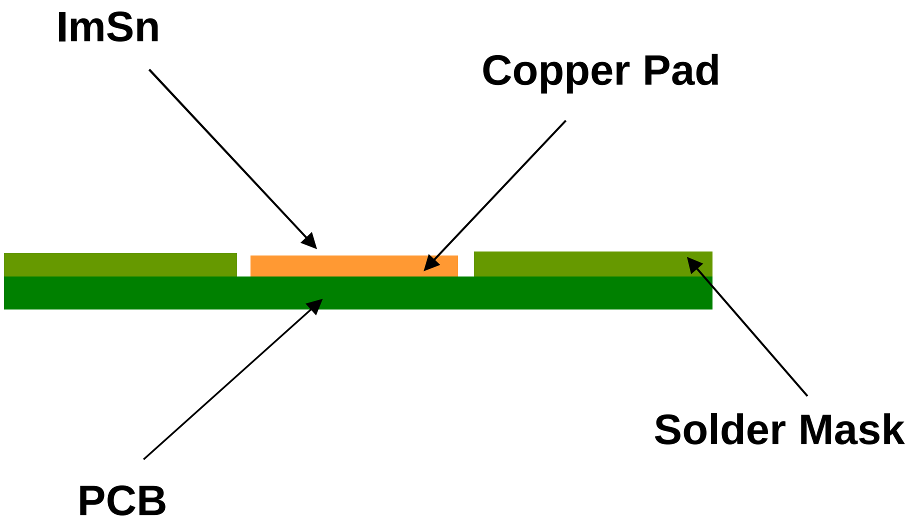


Source: Intel, 2005

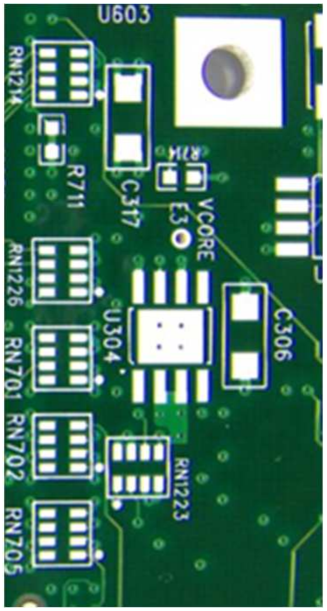


Source: Intel, 2005

ImSn: Immersion Tin

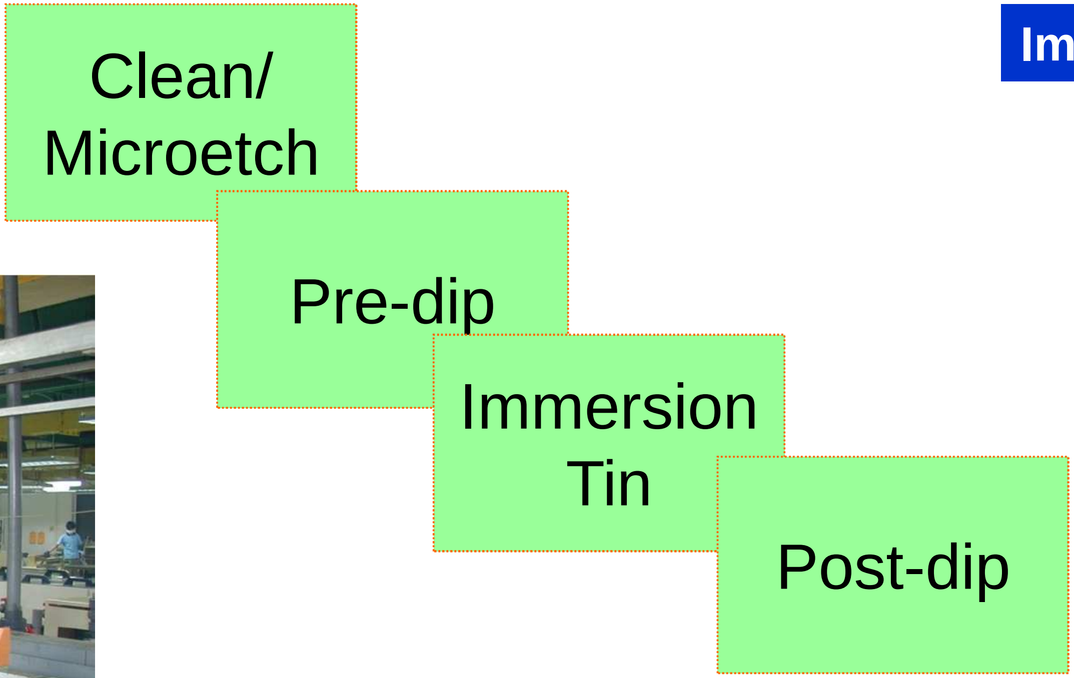


ImSn



ImSn: Process

ImSn



Clean/ Microetch

Pre-dip

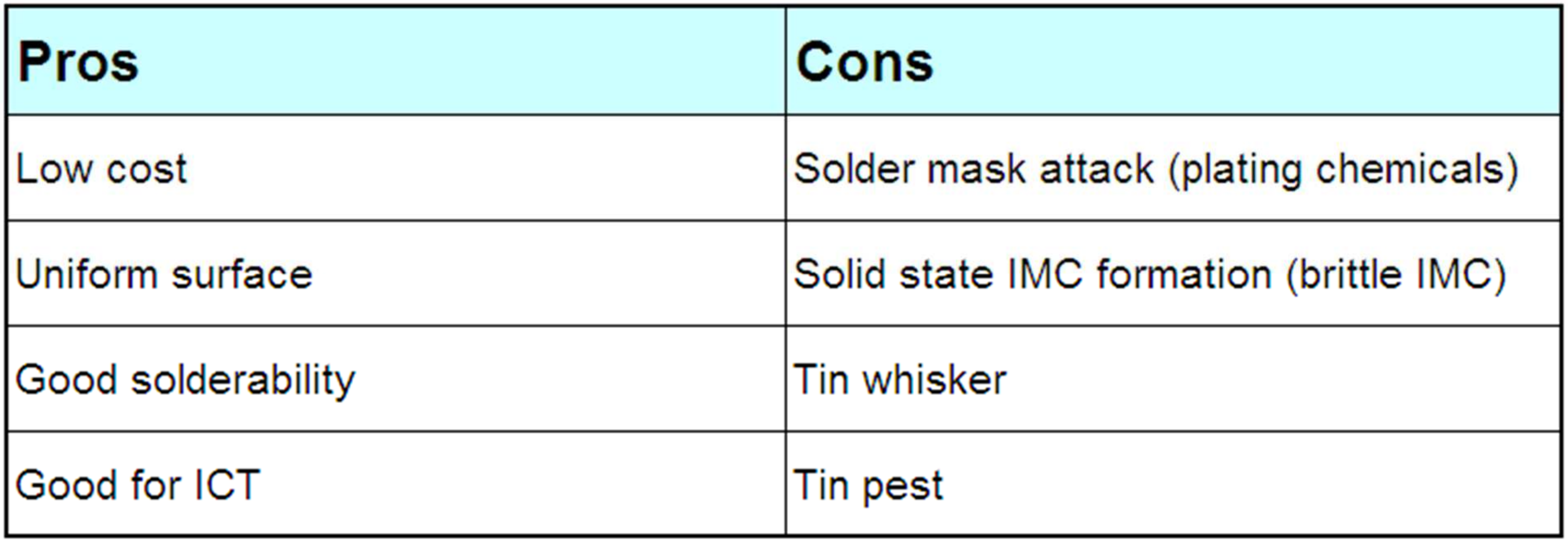
Immersion Tin

Post-dip

picture source: Multek

ImSn: Pros & Cons

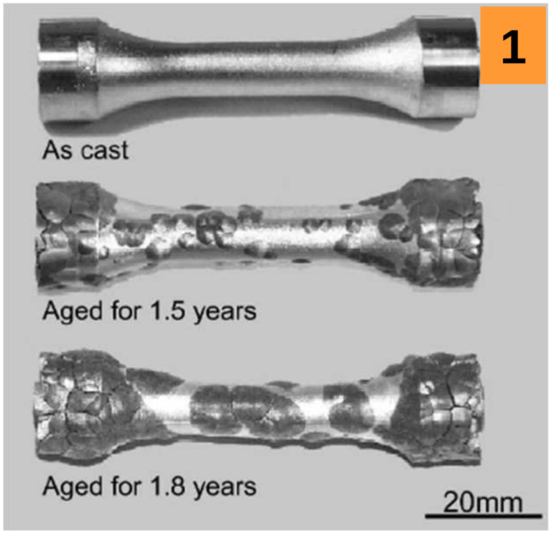
ImSn



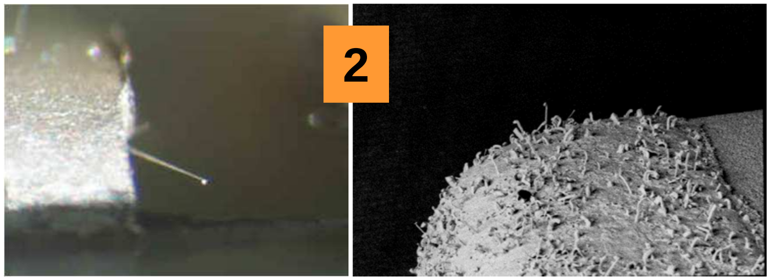
Pros	Cons
Low cost	Solder mask attack (plating chemicals)
Uniform surface	Solid state IMC formation (brittle IMC)
Good solderability	Tin whisker
Good for ICT	Tin pest

ImSn: Pros & Cons

ImSn



picture source: SMARTGroup



picture source: NASA

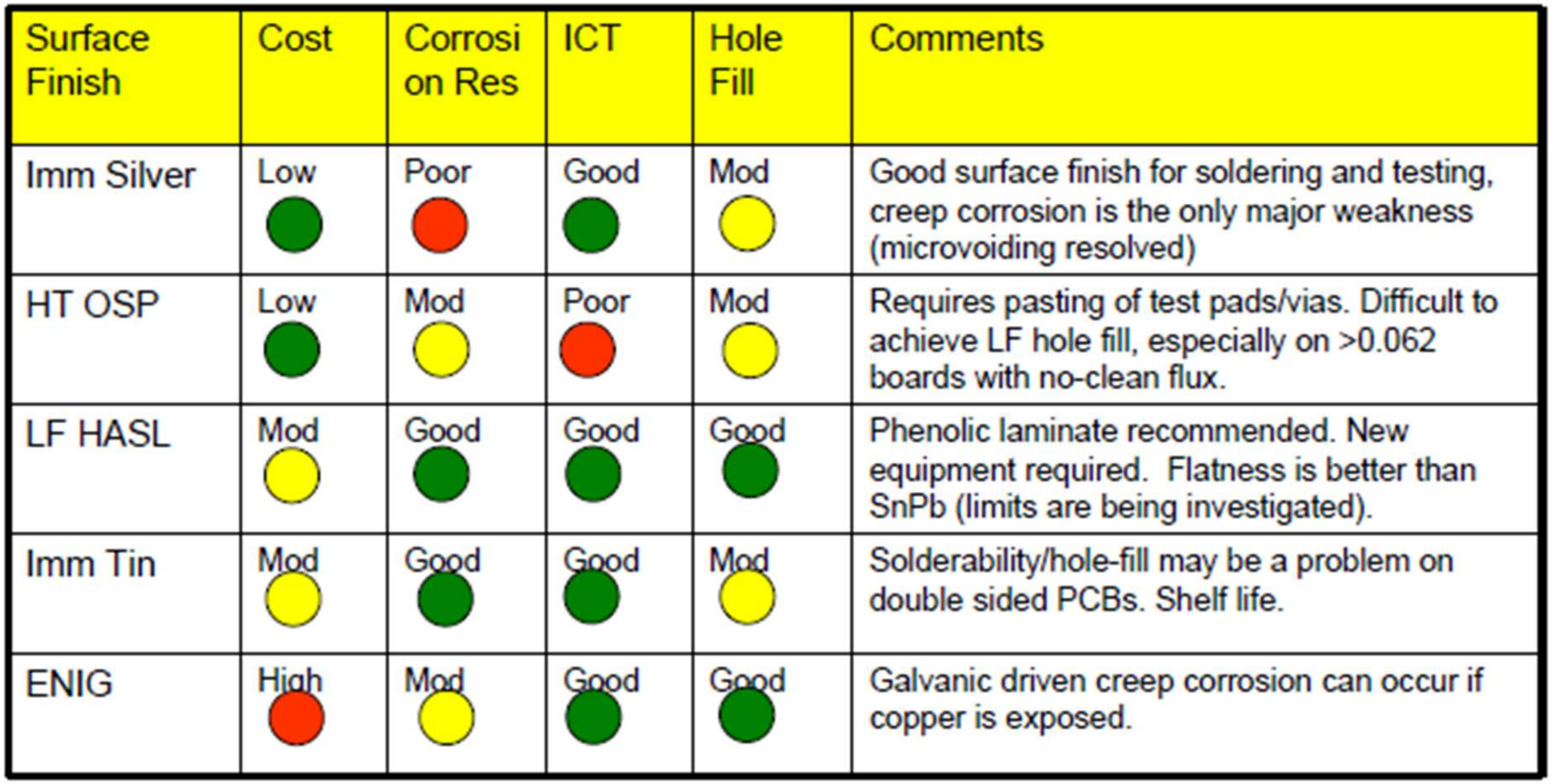
picture source: OMGroup Inc

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



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

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

Questions?

THANK YOU!

Closing Slide

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