Comparisons of various surface finishes for lead free PCB'S

The White Swan
Arundel
7th November 2006

Nigel White
Atotech - Europe

Selective Finishing

Pb-free surface finishes

Forward

or

Why do we see an shift in board surface finishes

Selective Finishing

Pb-free surface finishes
Forward

WEEE **Waste Electrical and Electronic Equipment**

- reducing waste and saving on natural resources
- reuse, recycling, composting and recovery of energy from waste

RoHS **Restriction of the use of certain Hazardous Substances in electrical and electronic equipment**

- directive will restrict the use of hazardous substances **in the EU**
  (this effects world wide PCB production and assembly)

Which substances are effected ?

- Pb, Hg, Cr^{6+}, PBB (polybrominated biphenyls), PBDE (polybrominated diphenyl ethers) **0.10 wt. %**
- cadmium **0.01 wt. %**

Eliminating Pb from solder changes assembly environment

Selective Finishing

Pb-free surface finishes Forward

Timeline

- Europe — July 1st 2006 — date effective for electronics sold to house holds !

forecast

others will follow

- Japan — end of 2006
- Americas & Asia — end of 2007

no current legislated ban, but interest and sentiment in lead free

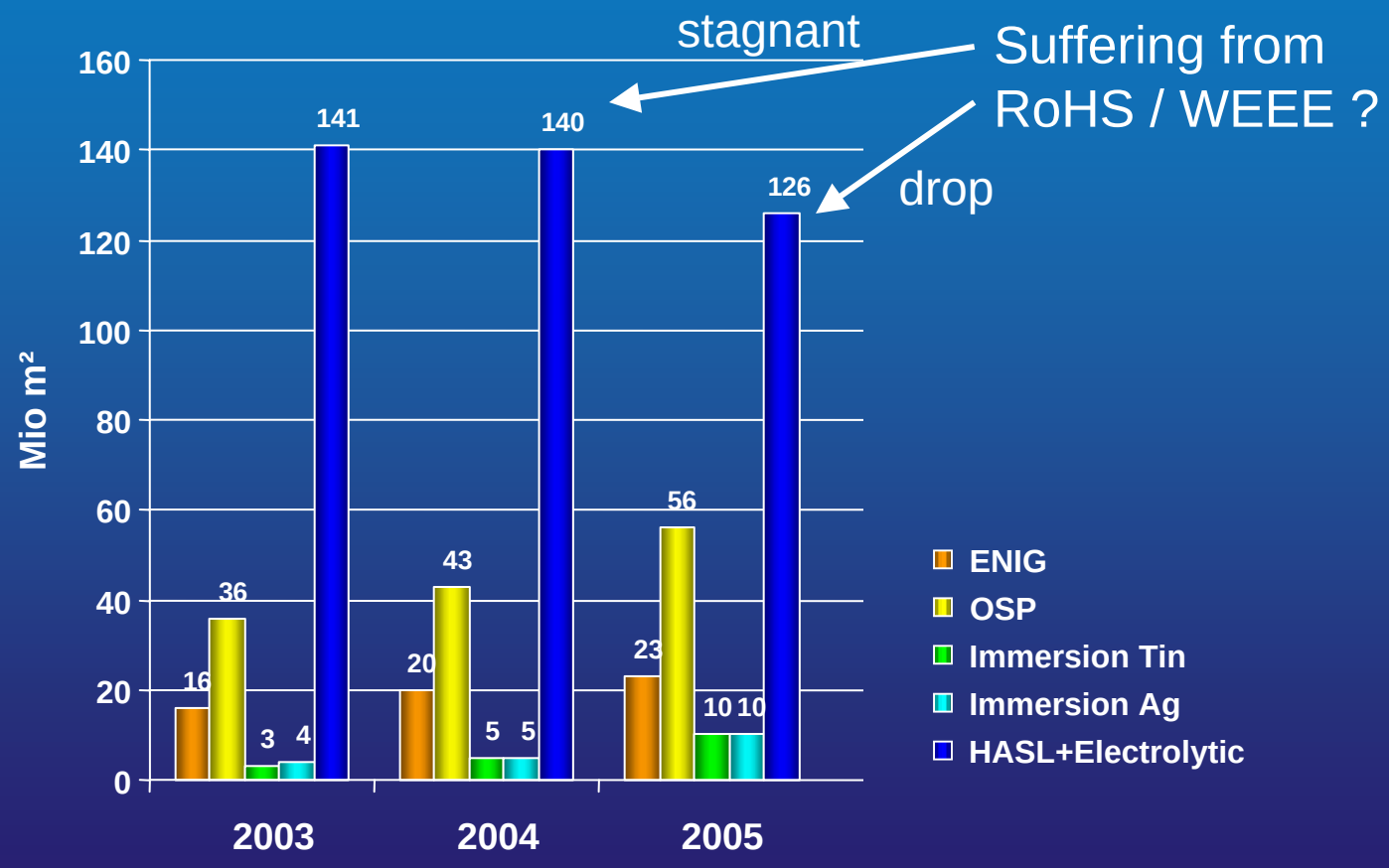
Selective Finishing

Pb-free surface finishes

Pb-ban,
effect on market shares of board surface finishes

Selective Finishing

Pb-free surface finishes
Effect on market shares of board surface finishes



*** Based on supplier data collected by Data4PCB (~70% of market) and Atotech estimation for forecast.**

Selective Finishing

Pb-free surface finishes
Content

Introduction

Selective Finishing

Pb-free surface finishes

Introduction

In the move to Pb-free electronics
surface finishes received great attention

This is as the surface finish represents the last major step
in PCB fabrication before assembly

It represents the interface between the external board circuitry
and the bonding medium (i.e. solder)

Generally, the use of Pb-free solders requires
higher assembly temperatures. This increases demands
to the surface finish if it has to survive multiple reflow cycles

Selective Finishing

Pb-free surface finishes

Surface finish functions

- **protect the underlying copper**
  (oxidation or chemical corrosion)
- **enable strong solder joints**
- **minimize copper dissolution** (barrier)
  (during assembly and operation)
- **suitable for certain bonding operations**
  (i.e. wire bonding or press fit)
- **functional interface for final product use**
  (i.e. contact switching operations)
- **…**

Selective Finishing

Pb-free surface finishes
Content

Process Overview

- Hot Air Solder Leveling (HASL)
- Organic Solderability Preservative (OSP)
- Immersion Silver (IAg)
- Immersion Tin (ISn)

- Electroless Nickel / Immersion Gold (ENIG)
- Electroless Nickel / Electroless Palladium / Immersion Gold (Ni/Pd/Au)
- Electrolytic Nickel / Electrolytic Gold (E-Au)
- Custom Finishes

Selective Finishing

Pb-free surface finishes

Hot Air Solder Leveling (HASL)

Selective Finishing

Pb-free surface finishes
Hot Air Solder Leveling

- For many years first choice for many PCB assembly applications
- Same alloy was used as for soldering of components (best match for wave soldering and solder paste reflow techniques)

However

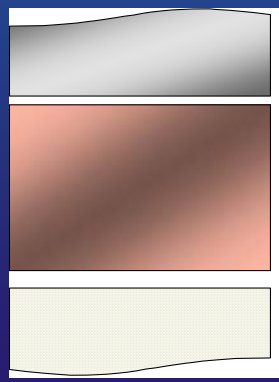
- with the move to Pb-free assembly the HASL solder alloy is now quite different
- This requires some key modifications in the process

Selective Finishing

Pb-free surface finishes
Hot Air Solder Leveling

Key modifications

- Higher process temperatures for Pb-free solder
- Longer contact time
- Improved alloy circulation for better heat transfer
- Pre-heating the panel (pre-dip)
- High temperature resistant chemistries (oils and fluxes)
- Copper control (removing copper from Pb-free solder)



HAL Solder **2 - 15 µm**

Base Copper

Dielectric

Pb-free Solder Alloy	Thickness Range (µm)
Sn-0.3%Ag-0.7%Cu	2.6 - 14.2
Sn-3%Ag-0.5%Cu	1.0 - 12.3
Sn-0.7%Cu-0.06%Ni	2.7 - 14.7

Measured on an iNEMI test panel

Selective Finishing

Pb-free surface finishes
Hot Air Solder Leveling

Benefits

+ shelf life (>12 months)
+ complete wetting of copper surface
+ suitable for Pb-free soldering
+ well known process
+ suitable for compliant pin (press-fit, up to thick 2.4mm boards)
+ relatively low-cost
+ optical inspection and ICT (In-circuit testing) possible

Selective Finishing

Pb-free surface finishes
Hot Air Solder Leveling

Concerns & limitations

- SMT applications (planarity)
- fine feature geometries
- existing HASL equipment
- additional thermal stress
- copper dissolution
- not wire-bondable
- wear resistance, contact switching
- limitations with thin or thick PCBs

Selective Finishing

Pb-free surface finishes

Organic solder preservative (OSP)

Selective Finishing

Pb-free surface finishes
Organic solder preservative

- typically derivatives of benzotriazole, imidazole or benzimidazole
- in the early 1990s a shift from HASL to OSP
  (steady growth of surface mount technology)
- bond selectively to copper
- protection against oxidation or tarnish
- needs to removed by flux to enable solder joint
- early versions were limited often to only a single reflow

Nowadays

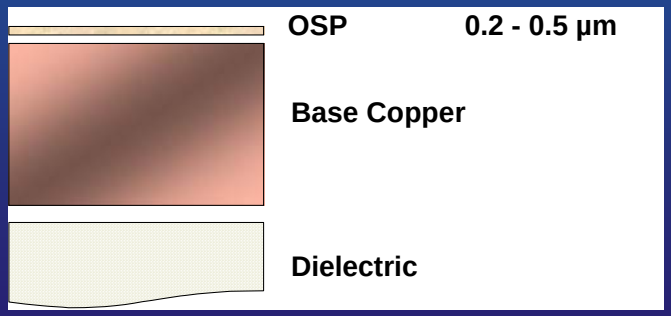
- can withstand the demands of Pb-free assembly
- development of high-temperature OSPs
- used for consumer, telecommunications and automotive electronics

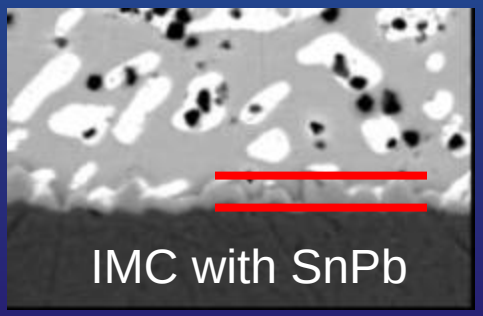
Selective Finishing

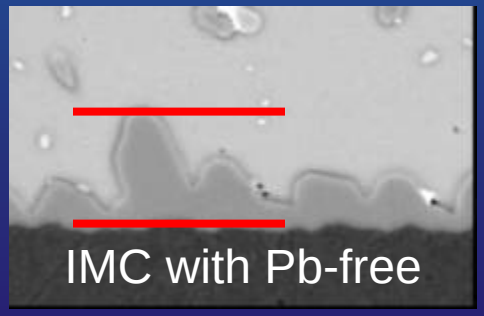
Pb-free surface finishes
Organic solder preservative

Deposit characteristics

- thickness range 0.2- 0.5µm
- reflow in air will oxidize copper underneath
- decomposition temperature for Pb-free versions 290°C (vs. 260°C)
- creates a thicker IMC during Pb-free reflow temperature
- higher copper dissolution rates into solder (high tin ~95% vs 60%)







Selective Finishing

Pb-free surface finishes
Organic solder preservative

Benefits

+ simple process
+ suitable for horizontal application
+ suitable for Pb-free soldering
+ good planarity
+ shelf life of 6-12 months (with proper storage)
+ relatively easy to rework
+ suitable for mixed technologies (e.g., ENIG)
+ low-cost deposit
+ environmentally friendly

Selective Finishing

Pb-free surface finishes
Organic solder preservative

Concerns & limitations

- thermal excursion (multiple reflows, dry heat)
- storage conditions
- compliant pin (press-fit)
- visual inspection (lack of color contrast)
- ICT inspection
- not wire-bondable
- requires N_2 atmosphere (reflow / wave soldering)
- removal of solder paste misprints may remove coating

Selective Finishing

Pb-free surface finishes

Immersion Silver (IAg)

Selective Finishing

Pb-free surface finishes
Immersion Silver

- immersion / displacement reaction (copper is exchanged by silver)
- during soldering the molten alloy solves the silver into the solder joint
- bonding / IMC formation occurs with the substrate copper
- UL (Underwriters Laboratory) exemption, allowing immersion silver as PCB finish without additional tests (restrictions, based on 1950s experience with electroplated silver could not be confirmed)

Continues attention

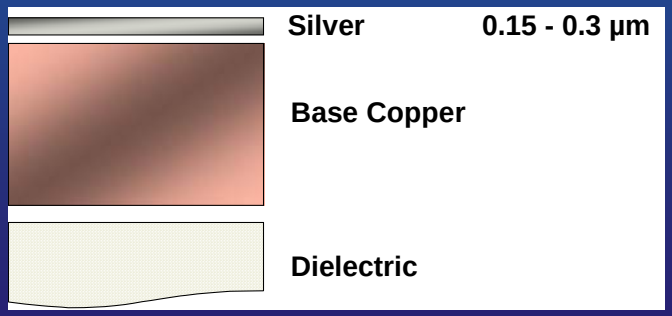
- focusing on champagne voids' or planar 'micro voids'
- tarnishing of the surface
- dendritic growth in harsh automotive environment
- 'etch defect' reducing copper track dimensions underneath soldermask

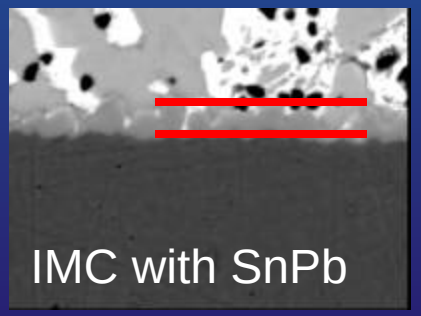
Selective Finishing

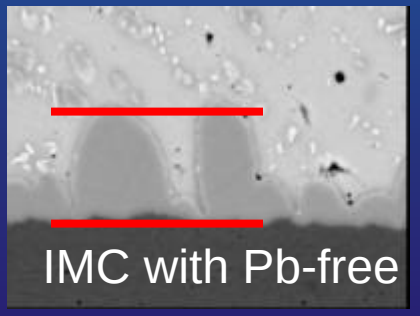
Pb-free surface finishes
Immersion Silver

Deposit characteristics

- very dependent on supplier and process
- thickness between 0.10- 0.15µm and 0.15- 0.40µm
- with or without co-deposited organic, either as bath ingredient or as subsequent step
- creates a thicker IMC during Pb-free reflow temperature
- higher copper dissolution rates into solder (high tin ~95% vs 60%)







Selective Finishing

Pb-free surface finishes
Immersion Silver

Benefits

+ Simple process
+ Suitable for Pb-free soldering
+ Good planarity
+ Shelf life of minimum 12 months (with proper storage)
+ Suitable for fine-pitch applications
+ Relatively low-cost deposit
+ Aluminum wire bondable (with proper sealing avoiding humidity)

Selective Finishing

Pb-free surface finishes
Immersion Silver

Concerns & limitations

- Tarnishing or staining
  (usually caused by reaction with airborne oxygen, chlorine or sulfur)
- Storage conditions required to maintain solderability
- Micro-voiding in solder joint (with thicker silver deposits)
- Potential for electromigration on exposed silver pads
- Potential for galvanic reaction with copper under solder mask
- Copper dissolution with additional soldering operations
  or high-temperature applications
- Suitability for press-fit applications

Selective Finishing

Pb-free surface finishes

Immersion Tin (ISn)

Selective Finishing

Pb-free surface finishes
Immersion Tin

- immersion / displacement reaction (copper is exchanged by tin)
- bonding / IMC formation occurs with the substrate copper
- used for soldering, press fit connections, zero-insertion-force edge connections and thick Al-wire bond application

Ongoing attention

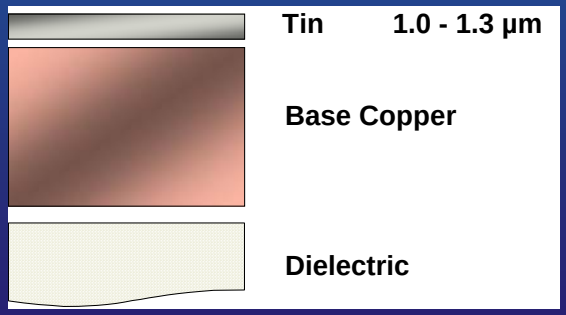
- whisker formation
- copper diffusion through the tin layer (creating Cu_3Sn and Cu_6Sn_5) impacting shelf life and soldering performance
- ionic contamination for automotive applications
- Pb-free soldering in air atmosphere

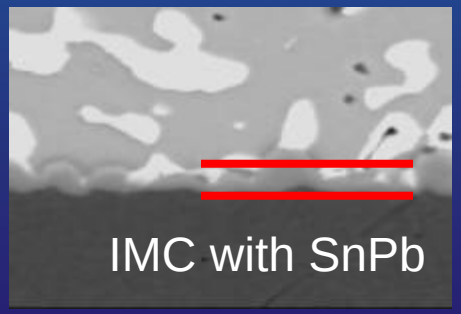
Selective Finishing

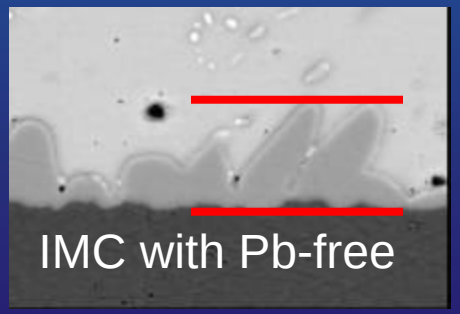
Pb-free surface finishes
Immersion Tin

Deposit characteristics

- very dependent on applied tin thickness
- thickness between 0.80- 1.20µm
- with or without whisker reducing additives
- creates a thicker IMC during Pb-free reflow temperature
- higher copper dissolution rates into solder (high tin ~95% vs 60%)







Selective Finishing

Pb-free surface finishes
Immersion Tin

Benefits

+ Simple process
+ Suitable for horizontal application
+ Shelf life > 12 months (with proper storage conditions and deposit thickness)
+ Suitable for Pb-free soldering
+ Good planarity for surface mount device applications
+ Suitable for fine-pitch applications
+ Suitable for thick Al-wire bonding
+ Suitable for compliant pin (press-fit) connections
+ Relatively low-cost deposit

Selective Finishing

Pb-free Board surface finishes
Immersion Tin

Concerns & limitations

- Control for tin whisker growth
- IMC growth and effect on tin thickness
- Soldermask compatibility
- Sn(IV) concentration in horizontal working solution
- Thiourea in working bath
- Not suitable for contact switching applications

Selective Finishing

Pb-free surface finishes

Electroless Nickel Immersion Gold (ENIG)

Selective Finishing

Pb-free surface finishes
Electroless Nickel Immersion Gold

- dual metal finish (nickel/phosphorous & gold)
- since early 1990s one of the most versatile finishes
- diffusion barrier between substrate copper and solder alloy
- during soldering the molten alloy solves the gold into the solder joint
- bonding / IMC formation occurs with the nickel layer
- requires copper activation for nickel reaction to start
- nickel layer adds strength to plated-through holes and vias
- increasing wear resistance through its hardness

Recent attention

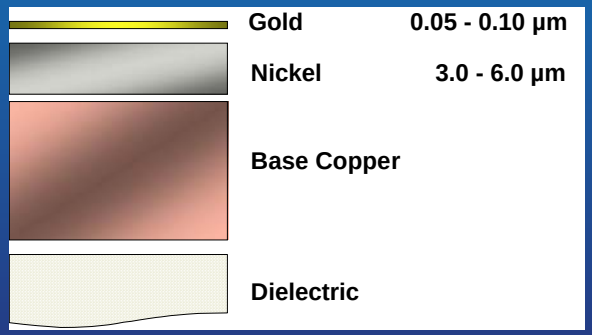
- as corrosion resistant final finish for harsh environments
- dummy plating free process operation after idle time
- Pb-free soldering in air atmosphere

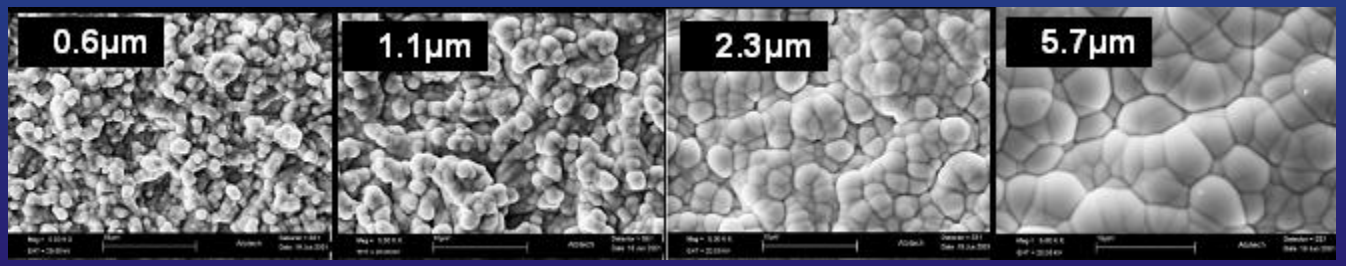
Selective Finishing

Pb-free surface finishes
Electroless Nickel Immersion Gold

Deposit characteristics

- to be classified into low / medium / high P systems (<7;7-10;>10%P)
- thicknesses between 3- 6µm NiP and 0.05- 0.12µm Au
- autocatalytic nickel deposit
- gold protects nickel layer from oxidation
- reliable finish for Al-wire bonding





Growth of nickel phosphorus deposit on activated copper surface

Selective Finishing

Pb-free surface finishes
Electroless Nickel Immersion Gold

Benefits

+ Suitable for multiple Pb-free soldering (even air atmosphere)
+ Planarity for surface mount device applications
+ Barrier layer (nickel) to stop dissolution of copper
+ Good shelf life (>12 months)
+ Good surface for ICT probability
+ Suitable for contact switching applications
+ Good resistance in corrosive environments
+ Suitable for aluminum wire bonding applications
+ Suitable for high aspect ratio through holes

Selective Finishing

Pb-free surface finishes
Electroless Nickel Immersion Gold

Concerns & limitations

- Cost of precious metal
- Potential brittleness of nickel-tin IMC (if no copper in solder joint)
- Corrosion of nickel by immersion gold solution
- Process operating window; requires tight control
- Not suitable for gold wire bonding applications
- higher level of maintenance
- Requires special solder masks
- Extraneous nickel plating

Selective Finishing

Pb-free surface finishes

Electroless Nickel / Electroless Palladium / Immersion Gold (NiPdAu)

Selective Finishing

Pb-free surface finishes
Electroless Nickel / Electroless Palladium / Immersion Gold

- since mid 1990s
- for Al-wire, Au-wire and soldering on the same surface
- same process as for medium P ENIG is used
- no risk of 'black pad' as palladium is electroless not immersion

Received attention

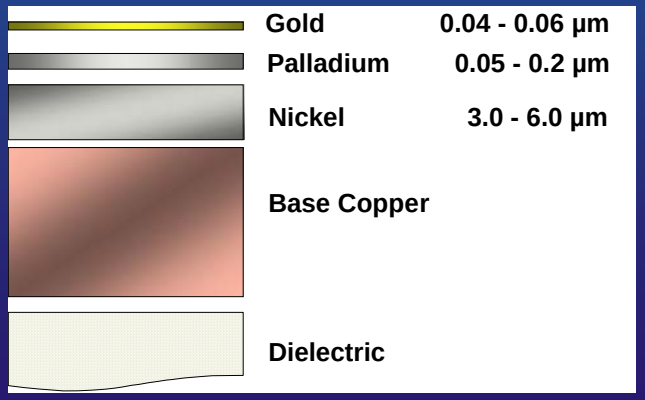
- 'under the hood' automotive applications for low-temperature co-fired ceramics (LTCC)
- for higher level of solder joint reliability for IC-substrates
- use as gold wire bond surface

Selective Finishing

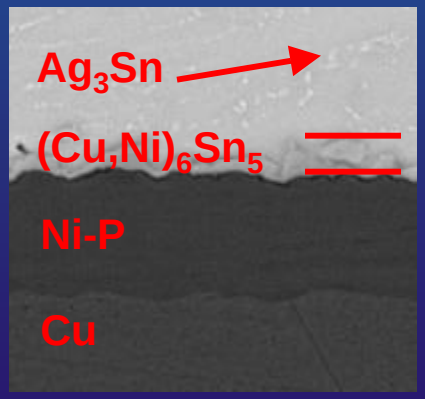
Pb-free surface finishes
Electroless Nickel / Electroless Palladium / Immersion Gold

Deposit characteristics

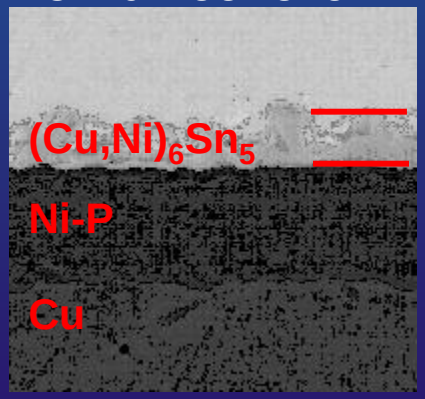
- nickel thickness 5- 7µm, palladium 0.05- 0.20µm, gold 30- 60nm
- to be classified into zero and 1-3% palladium P systems
- autocatalytic palladium deposit
- IMC formation occurs with the nickel layer
- wire bonding occurs with the palladium layer



1 Pb-free reflow



5 Pb-free reflow



Selective Finishing

Pb-free surface finishes
Electroless Nickel / Electroless Palladium / Immersion Gold

Benefits

+ Suitable for multiple Pb-free soldering (even air atmosphere)
+ Shelf life > 12 months
+ Palladium layer reduces formation of brittle Ni-Sn IMC
+ Reduced incidence of “corrosion” effect (associated with ENIG)
+ Good planarity for surface mount device applications
+ Barrier (nickel) to stop dissolution of copper
+ Suitable for gold and aluminum wire bonding applications
+ Good surface for ICT probability
+ Suitable for contact switching applications
+ "low-cost" alternative for gold wire bonding (vs. electrolytic Ni/Au)

Selective Finishing

Pb-free surface finishes
Electroless Nickel / Electroless Palladium / Immersion Gold

Concerns & limitations

- Relatively high cost if only used for soldering
- Relatively complex process (more process steps)
- Potential brittleness of nickel-tin IMC (eutectic SnPb solder)
- Potential for solder joint embrittlement due to excess Pd (if ≥0.3µm)
- Process operating window; requires tight control
- Requires special solder masks
- Relatively unknown process with little PCB history

Selective Finishing

Pb-free surface finishes

Electrolytic Nickel / Electrolytic Gold (E-Au)

Selective Finishing

Pb-free surface finishes
Electrolytic Nickel / Electrolytic Gold

- classified as either “hard” or “soft” gold
- hard gold is typically used for tabs or “fingers” (connection purposes)
- soft gold or “pure” gold is primarily used for gold wire bonding
- nickel serves as a barrier to prevent copper / gold IMC
- requires an applied current and a bus connection

Recent attention

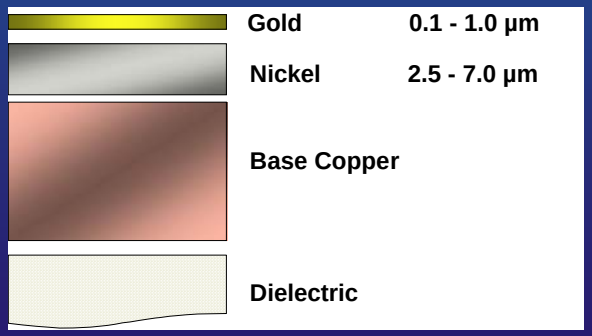
- limitation for soldering when using small solder depots ($AuSn_4$ IMC)
- limitation for IC-substrates as a bus connection needs to be incorporated into the circuit design

Selective Finishing

Pb-free surface finishes
Electrolytic Nickel / Electrolytic Gold

Deposit characteristics

- nickel (pure) thickness 2.5- 7µm, gold 0.1- 2.5µm
  (gold thickness is very application dependent)
- hard gold
  1.25-2.5µm, extremely good for repeated insertion/removal
  0.10-0.5µm, corrosion resistance and soldering
- soft gold 0.5-1.0µm for Au-wire bonding



Selective Finishing

Pb-free surface finishes
Electrolytic Nickel / Electrolytic Gold

Benefits

+ Suitable for multiple Pb-free soldering
+ Long shelf life (> 12 months)
+ Barrier (nickel) to stop dissolution of copper
+ Suitable for contact switching applications
+ Suitable for gold wire bonding applications
+ Good surface for ICT probability
+ Suitable for corrosion protection

Selective Finishing

Pb-free surface finishes
Electrolytic Nickel / Electrolytic Gold

Concerns & limitations

- High cost of deposit (gold thickness)
- Requires electrical continuity within PCB (i.e. bussing)
- Excess gold in solder joint can cause embrittlement
- Potential brittleness of nickel-tin IMC
- Plating surface distribution issues
- Exposed copper on sidewalls of traces and features
- No Al-wire bonding

Selective Finishing

Pb-free surface finishes

Custom Finishes
(e.g. SIT (OSP & ENIG))

Selective Finishing

Pb-free surface finishes
SIT (OSP & ENIG)

Recent attention

- OSP and ENIG on a PCB
- requires a second photo resist imaging process
  (SIT, secondary image technology)
- OSP for soldering
- ENIG for contact switching and corrosion resistance
- nearly every cell phone is build with this technology

Deposit characteristics

- as standard ENIG
- as standard OSP

Selective Finishing

Pb-free surface finishes
Immersion Gold (over copper)

Typical Process sequence

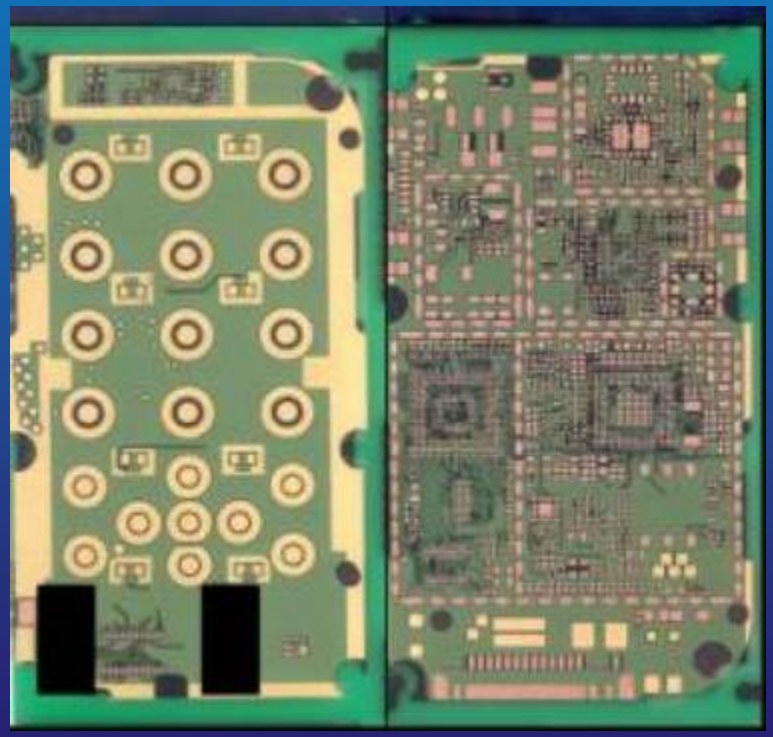
Soldermask Application

Photo Imaging

Aurotech SIT Process

Dry Film Stripping

OSP Application



Selective Finishing

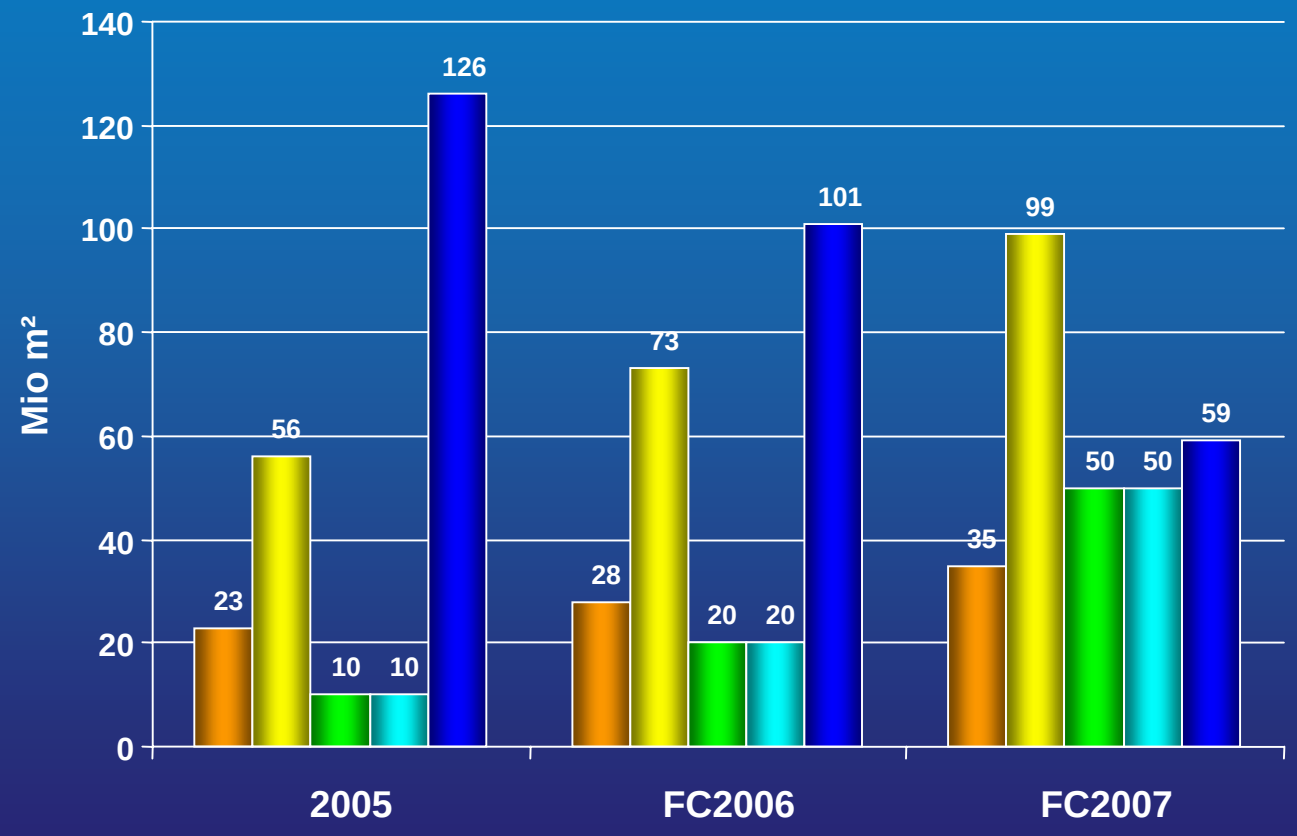
Pb-free surface finishes
Immersion Gold (over copper)

Trends / Forecast

Selective Finishing

Pb-free surface finishes

Forecast of Surface Finishes Area / Global Market*



Growth 05 / 07

- ENIG (50%) ↗
- OSP (75%) ↑
- Immersion Tin (500%) ↑↑
- Immersion Ag (500%) ↑↑
- HASL+Electrolytic ↓↓

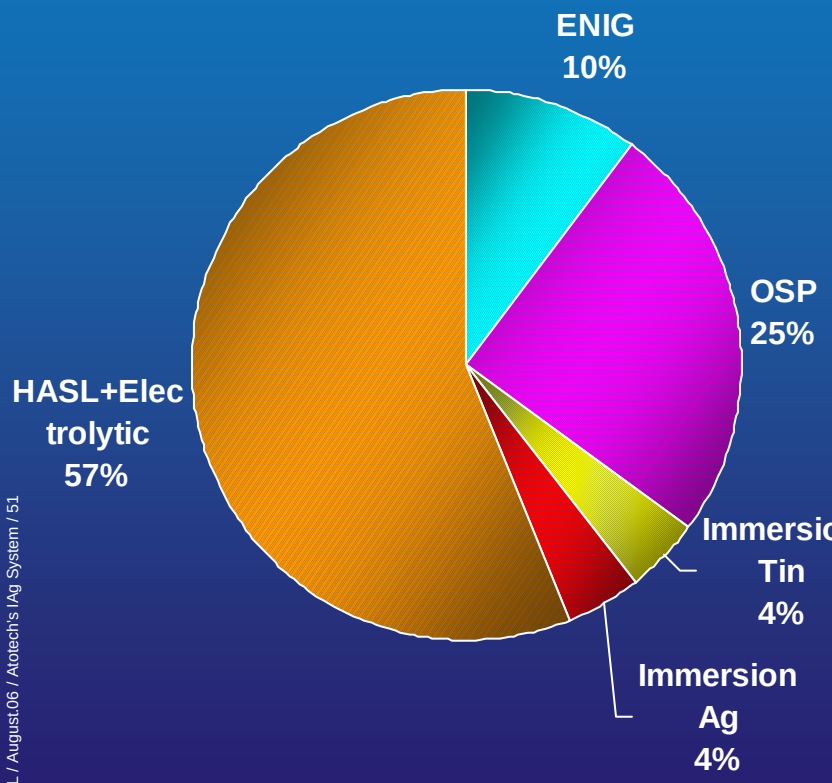
Suffers from RoHS 1st.Jul.06 & technical limitations

*** Based on supplier data collected by Data4PCB (~70% of market) and Atotech estimation for forecast.**

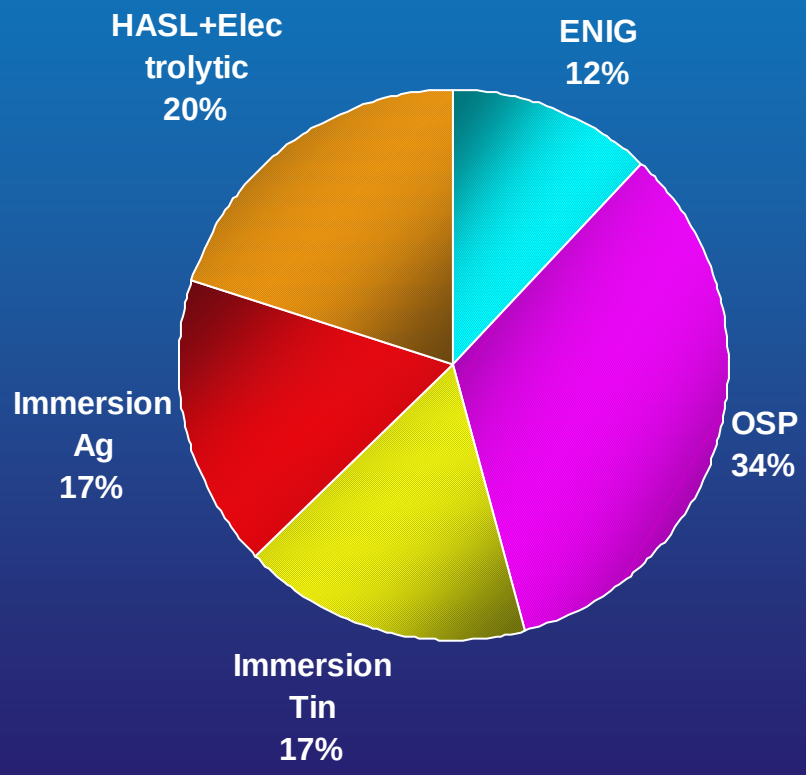
Selective Finishing

Pb-free surface finishes
Share of Finishes for 2005 and 2007

2005



FC 2007



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Selective Finishing

Pb-free Board surface finishes Summary

- For PCB surface finishes fabricators have many options and nearly all will work for Pb-free assemblies
- Choice of finish is dependent on the application and preference
- Pb-free HASL, OSP, IAg, ISn, ENIG have all been used successfully in Pb-free assemblies
- Feature dimensions continue to decrease, performance and functional reliability become even greater concerns
- Selection of the proper surface finish will become more critical with increasing demands, particularly in the never-ending drive to reduce costs

Selective Finishing

Pb-free surface finishes
Summary

As a result, each finish must be examined

and evaluated based on its recognized functional capabilities

and known potential weaknesses

Selective Finishing

Pb-free surface finishes

Thank you for your attention

Nigel White

European Product Marketing Manager SF

Tel 00447721716530