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Departamento de Electrónica y Tecnología de Computadores

Surface Finishes Utilized in the PCB Industry

Curso 15-16

Printed Circuits Technologies

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4º Curso Grado en Ingeniería de Tecnologías de Telecomunicación

Contents

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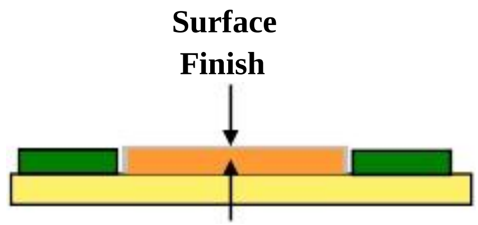
What is a Surface Finish?

A *surface finish* may be defined as a “coating” located at the outermost layer of a PCB
(which is dissolved into the solder paste upon reflow or wave soldering)

Two Main Types of Coatings

- Metallic
- Organic



Metal Plating

Note:

(Base) Metal Plating is typically copper (in most cases). But, in a few (like ENIG) the Nickel-phosphorous (5-12% P co-deposit) serves as the solderable surface.

Surface Finish Types

Metallic Coatings:

- *HASL (Hot Air Solder Level)*
- *ENIG (Electroless Nickel/Immersion Gold)*
- *Electrolytic Ni /Au (Electrolytic Nickel / Gold)*
- *Imm Ag (Immersion Silver)*
- *Imm Sn (Immersion Tin)*
- *Reflow Tin/Lead (Backpanels Only)*
- *Electroless Nickel/Palladium-Immersion Gold*
- *Selective Solder Strip (SSS)*
- *Sn Ni (Tin-Nickel)*
- *Unfused Tin/Lead*
- *Electroless Nickel-Immersion Palladium*

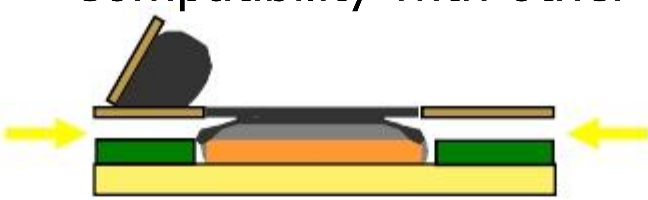
Not common

Organic Coatings:

- *OSP (Organic Solderability Preservative)*

Reasons for Finishes

- Coplanarity (See Below)
- Lead-Free (RoHS and WEEE) (RoHS 5 or RoHS 6)
- Contact Resistance (Compression Connection)
- Tarnish Resistance
- Press-fit Requirements
- Wear Resistance
- Hardness
- Chemical Resistance
- Wire Bonding (Au or Al?)
- Cost
- Compatibility with other Surface Finishes



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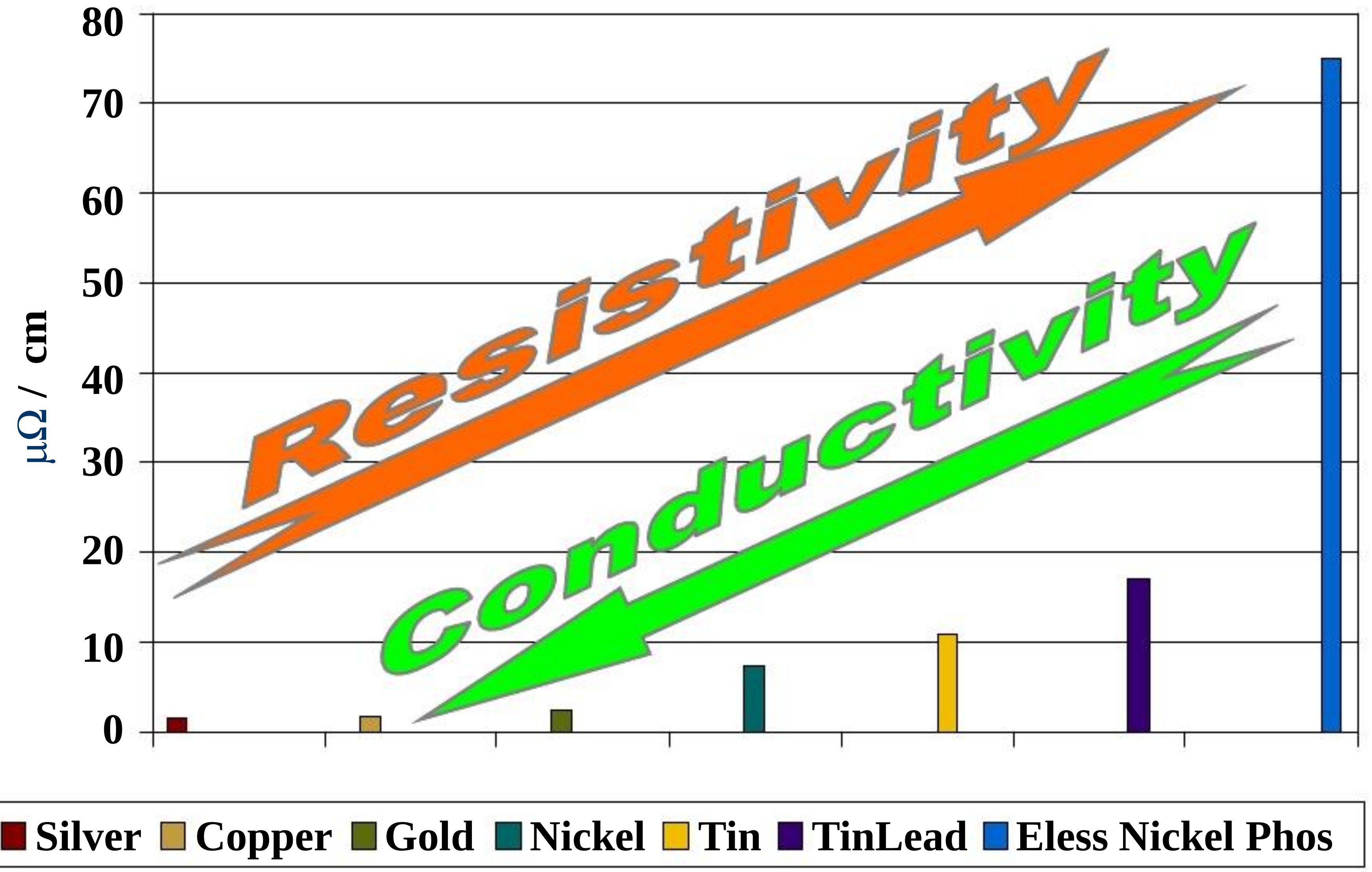
Resistivity of PCB Metals



Galvanic Series - Electromotive Force

Platinum
Iridium
Palladium
Silver + 0.80
Mercury
Ruthenium
Copper + 0.344
Bismuth
Antimony
Tungsten
Hydrogen 0.0 Volts
Lead
Tin
Molydenum
Nickel - 0.25

Group I	Group II	Group III	Group IV	Group V
Magnesium	Aluminum 2S	Lead-tin Solder	Copper-Nickel	Graphite
Zinc	Cadmium	Lead	Monel	Gold
Galvanic Steel	Aluminum 17ST	Nickel	Silver Solder	Platinum
	Steel	Brass	Nickel (passive)	
	Iron	Copper	Stainless Steel	

Metals can cause noise voltage due to a galvanic reaction between two metals. (Positive ions from one metal can be transferred to the other)

The farther apart the metals are in the series, the faster the rate of corrosion (fretting). When dissimilar metals must be combined, try to use metals from the same series group.

Electroless Plating (Only)

- **Process is nonelectrolytic**.

  (No electrical current applied)
- **Metal ions are reduced**

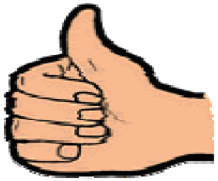
  by chemicals in the plating solutions.
- **A uniform coating**

  that can be applied on irregularly shaped features.
- **Applied by rack** (in a "batch" process).
- **Deposits are generally harder**, more brittle and more uniform than electroplated deposits.

Electroless Ni/ Electroless Gold

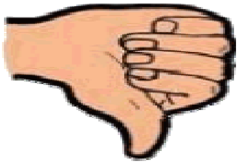
Typical Thickness:

0.25 – 1.3 µm (10 - 50 µ in) Electroless Gold over 3 – 6 µm (120 - 240 µ in) Electroless Nickel



ADVANTAGES

+ Gold Wire-Bondable
+ Planar Surface
+ Consistent Thicknesses
+ Multiple Thermal Cycles
+ Long Shelf Life
+ Solders Easily
+ Good for Fine Pitch Product



DISADVANTAGES

- Solder Joint Embrittlement Potential When Incorrectly Specified
- Difficult to Control
- Cannot be Reworked at PCB Fabricator
- Expensive
- Lab support extensive

The most common in the packaging industry

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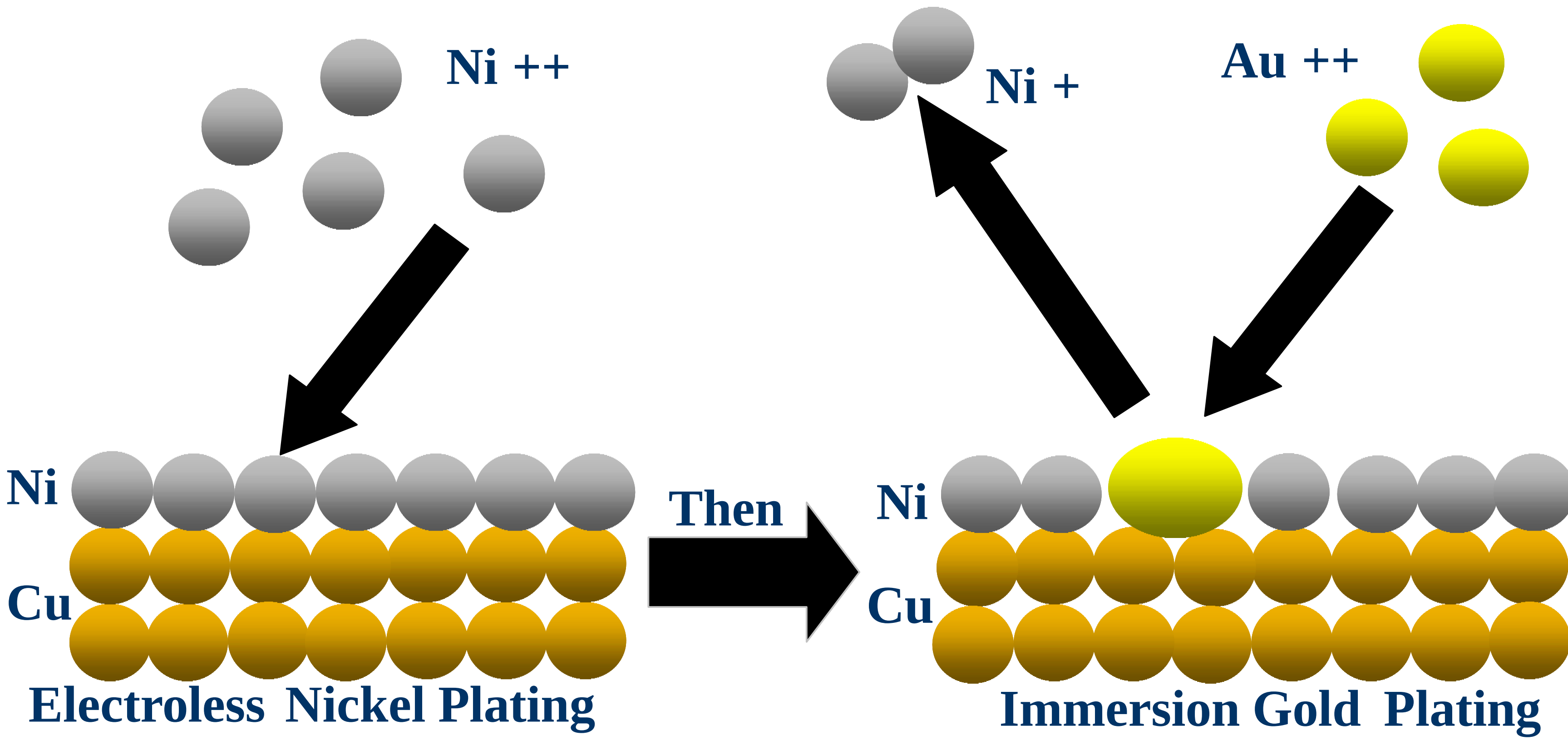
ENIG (Electroless and Immersion Plating)

Typical Equipment used for the Plating of ENIG

Automated ENIG Plating Line (PAL)

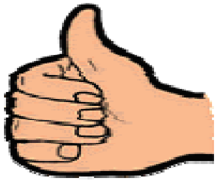
Electroless and Immersion Plating

- *ENIG (Depicted Below)*
- *Electroless Ni/Electroless Palladium-Immersion Gold*



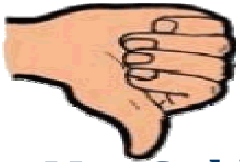
ENIG (Electroless Nickel/Immersion Gold)

Typical Thickness:
0.05 - 0.23 µm (2 - 9 µ in) Gold over
2.5 - 5.0 µm (100 – 200 µ in) Electroless Nickel



ADVANTAGES

- \+ Planar Surface
- \+ Consistent Thicknesses
- \+ Multiple Thermal Cycles
- \+ Long Shelf Life
- \+ Solders Easily
- \+ Good for Fine Pitch Product

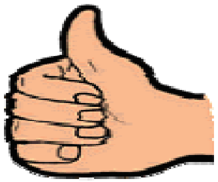


DISADVANTAGES

- \- Not Gold Wire-Bondable
- \- Expensive
- \- Should Not Be Used on ≤ 1.0mm Pitch; Black Pad Issues
- \- Waste Treatment of Nickel
- \- Cannot be Reworked at PCB Fabricator
- \- Nickel is a Suspected Carcinogen
- \- Not Optimal for Higher Speed Signals

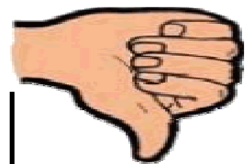
ENIPIG Electroless Ni/Palladium-Immersion Gold

Typical Thickness:
0.02 – 0.05 µm (1 - 2 µ in) Gold over
0.2 – 0.6 µm (8 - 24 µ in) Pd over 2.5 – 5 µm (100 - 200 µ in) Nickel



ADVANTAGES

+ Palladium Prevents Nickel from Passivating in the Presence of the “Porous”Gold Deposit
+ Aluminum Wire Bondable
+ Planar Surface
+ Good for Fine Pitch Product



DISADVANTAGES

- Additional Process Step for PCB Fabricator; Added Cost Results
- Dip Tank Process
- Evidence that Palladium Poisons the Solder Paste after Reflow
- Waste Treatment
- Expensive

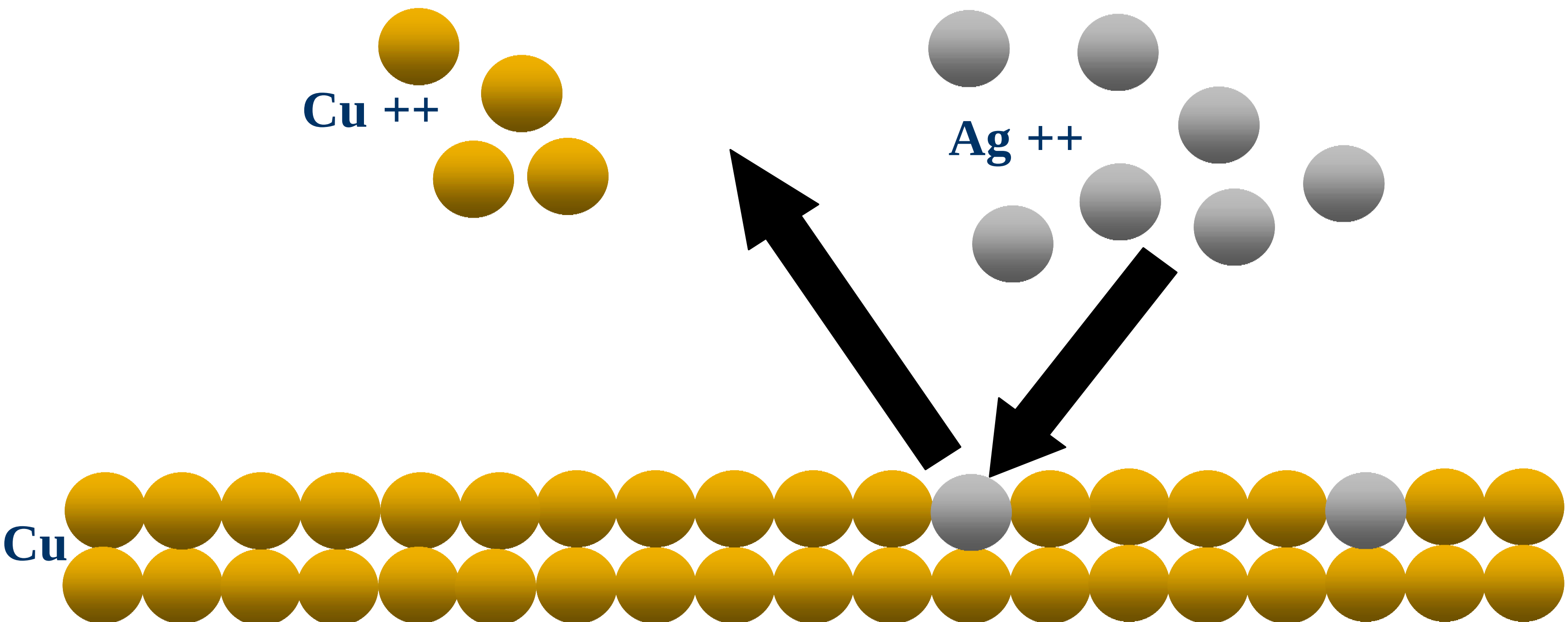
Immersion Plating

- ***Chemical reaction*** *is used to apply the coating.*
- ***Metal ions*** *are reduced by chemicals into the plating solutions.*
- *Then a* ***uniform coating*** *can then applied to irregularly shaped features.*
- ***Applied by a rack*** *(in a "batch" process).*

Immersion Plating

- *Silver (Depicted Below)*
- *Tin*
- *Gold Over Copper*

Galvanic Displacement- Simply an Exchange of Copper and Silver Atoms; No Reducing Agent Required



Base Foil + Plated Copper

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

Immersion Ag (Immersion Silver)

Typical Thickness:
0.15 – 0.45 µm (6 – 18 µ in).

ADVANTAGES

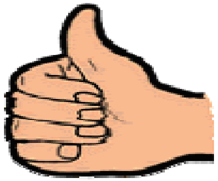
- \+ Good for Fine Pitch Product
- \+ Planar Surface
- \+ Inexpensive
- \+ Short, Easy Process Cycle
- \+ Eliminates Nickel
- \+ Doesn’t Affect Hole Size
- \+ Long Shelf-Life
- \+ Can be reworked/Re-Applied by the PCB Fabricator
- \+ OK for Multiple Insertions

DISADVANTAGES

- \- High Friction Coefficient; Not Suited for Compliant-Pin Insertion (Ni-Au Pins)
- \- Some Systems Cannot Throw Into Microvias with Aspect Ratios > 1:1
- \- Tarnishing Must be Controlled

Immersion Sn (Immersion Tin)

Typical Thickness: 2-5 µm (25-60 µin).



ADVANTAGES

+ Reliability Testing Results Comparable to ENIG
+ Good for Fine Pitch Product
+ Planar Surface
+ Eliminates Nickel
+ Can Substitute for Reflowed Solder
+ Inexpensive

DISADVANTAGES

- Handling Concerns
- Panels Must be Routed and Tested Prior to Coating
- Contains Thiourea, a Known Carcinogen
- Limited Rework Cycles at CM
- Horizontal Process Needs Nitrogen Blanket
- Too Viscous for Small Holes; Backpanels Only

Immersion Tin Plating

Typical Equipment used for the Immersion Tin Plating

Automated Immersion Tin Plating Line

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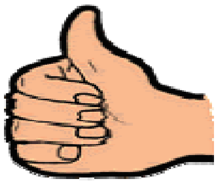
Immersion Pd (Palladium)

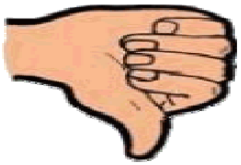
Typical Thickness:

0.1 µm – 10 µm (4 - 400 µ in)



ADVANTAGES

+ **Good Solderability**
+ **Cu/Sn Solderjoint**
+ **Used inAutomotive Sector**



DISADVANTAGES

- **Availability**
- **Possibly Issues with Solder Pot on Wave**
- **Handling Concerns**

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Electrolytic Plating

- ***Electrolytic plating*** *is achieved by passing an electric current through a solution containing dissolved metal ions.*

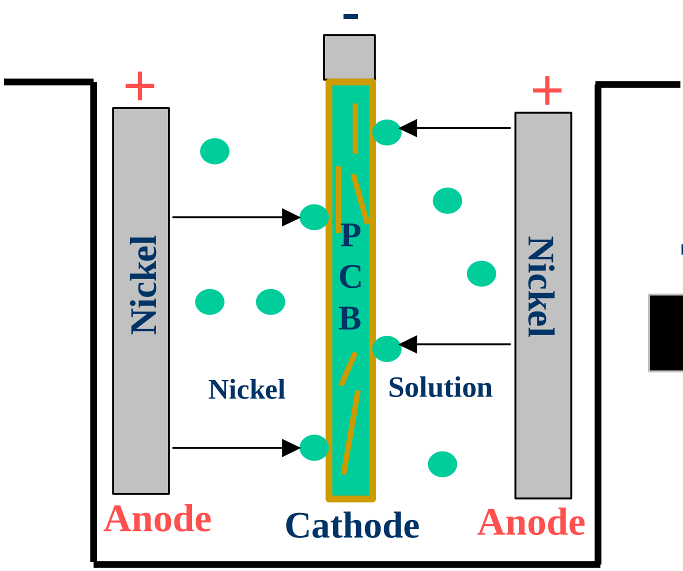
- *The PCB* ***panel then serves as the cathode*** *in an electrochemical cell, attracting the dissolved metal ions from the solution.*

- *The* ***process*** *includes* ***controlling*** *of plating parameters including* ***voltage and amperage, temperature, time, and purity of bath solutions****.*

- *Operators* ***rack panels*** *that carry the part from bath to bath (in a* ***"batch"*** *process).*

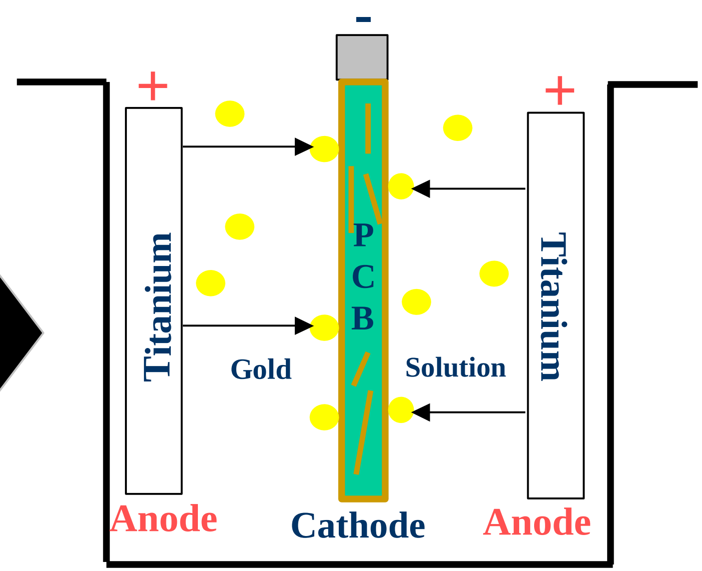
Electrolytic Plating

Electrolytic Nickel-Gold (Depicted Below)



Electrolytic Nickel Plating

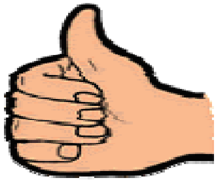
Then



Electrolytic Gold Plating (Over Nickel)

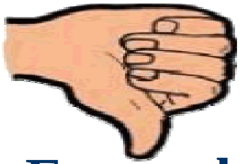
Electrolytic (Hard) Nickel/Gold

Typical SMT Thickness:
0.25 – 0.8 µm (10 - 30 µ in) Gold
over 2.5 – 8 µm (100 - 300 µ in) Nickel



ADVANTAGES

+ Plated Ni/Au Can be Used as an Etch Resist
+ Available for "Mixed Technology" Products
+ Au Wire-Bondable



DISADVANTAGES

- Exposed Cu Sidewalls
- Nickel Slivers Likely After S.E.S.
- Costly Process
- Excess Gold Easily Plated on Board Edges; Causes Poisoning of Solder Joints
- Poor throwing Power

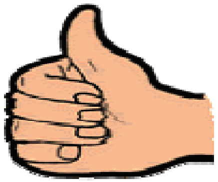
Electrolytic (Hard) Nickel/Gold

Typical Equipment used for the Electrolytic Plating of Nickel and Gold

Automated Nickel and Gold Plating g Line
PALand TAB Lines Shown

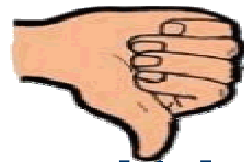
Selective Solder Strip (SSS)

Typical Thickness:
7 – 20 µm (300 - 800 µ in)



ADVANTAGES

+ **Hot Bar Reflow for TAB Devices**
+ **Viable Alternative to HASL on Thick Product**



DISADVANTAGES

- **Multiple Resist and Photo Cycles**
- **Difficulty in Controlling Plated Sn/Pb Thickness**
- **Overlap (Butt) Line Difficult to Control**
- **Expensive**

Selective Solder Strip (SSS)

Tthere are some parts that don’t lend themselves to an SMT package, such as **beepers**, **switches**, and **user access connectors**. Multi-image panels are utilized for many designs in order to maximize the efficiency of the PCB construction and assembly. This can create a situation where it is impossible to control co-planarity of the entire panel due to its overall width. All of these factors are driving the assembly industry to adopting “selective soldering” processes.

Selective soldering refers to the direct application of solder to specific areas of a PCB to form through-hole solder joints, rather than the “all or nothing” approach used in wave soldering.

There are a variety of processes that fall under the heading of selective soldering. These include robots that mimic hand soldering processes (a programmable solder iron and solder wire feeder), robots that use lasers and solder wire to form solder joints, programmable machines that precisely solder by moving a mini-wave solder pot or assembly to specific locations, and masking pallets that expose only specific locations of the board to a standard solder wave.

Selective Solder Strip (SSS)

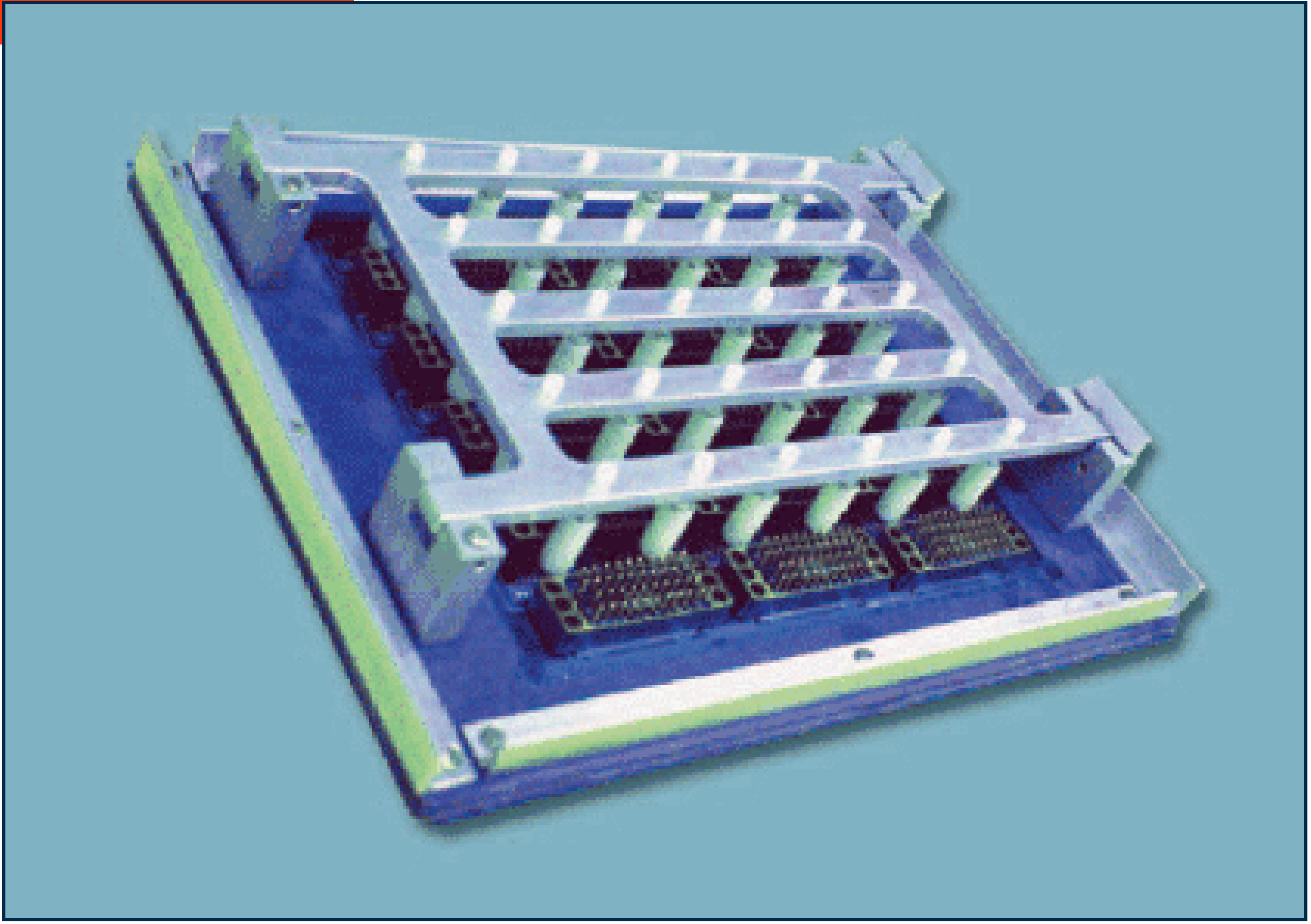


Figure 3-1: Masking pallet firmly holds the board in place from top side.

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Selective Solder Strip (SSS)

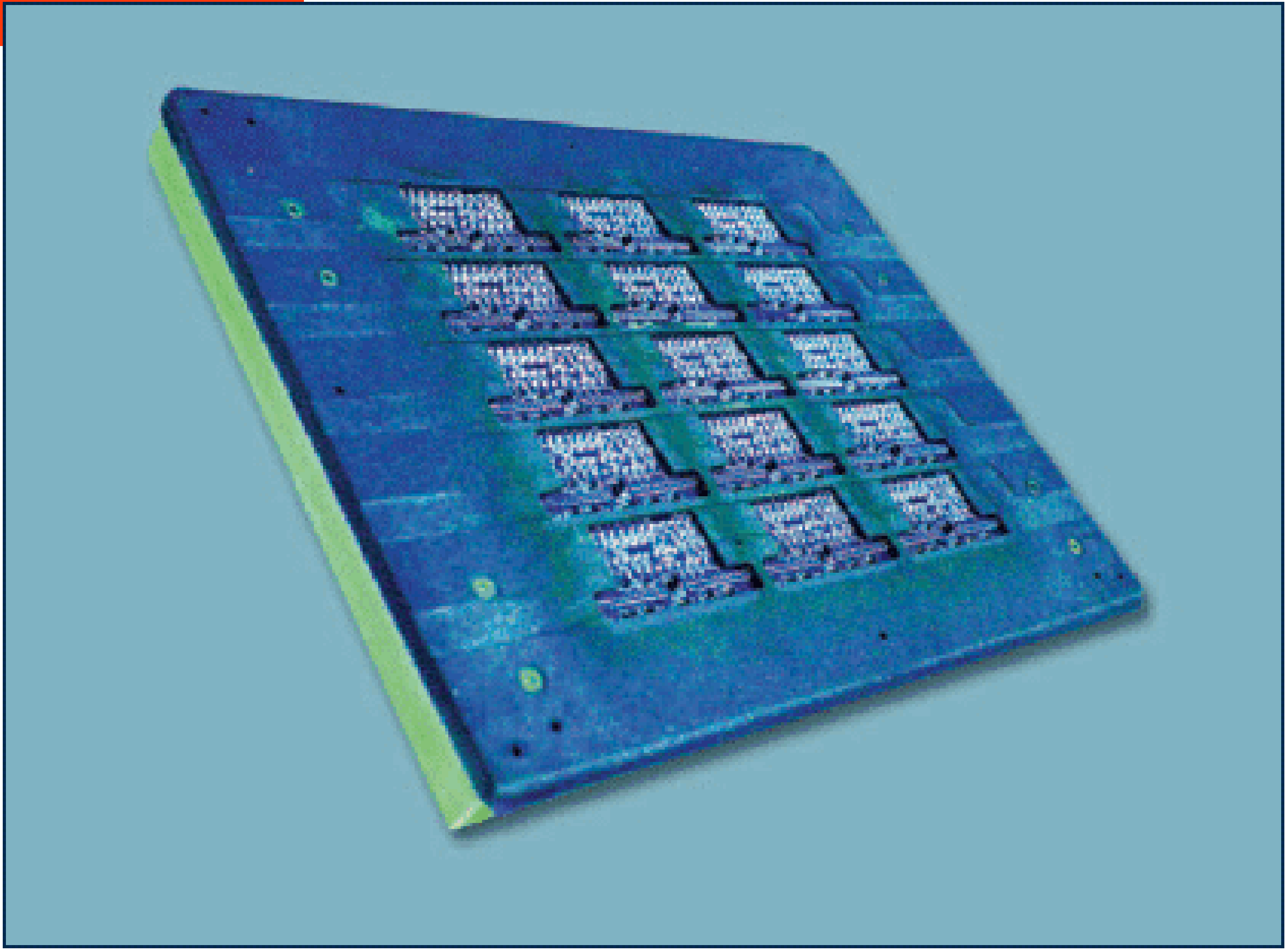

Figure 3-2: Bottom side of board is masked to only allow exposed pins to see the solder wave.

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Selective Solder Strip (SSS)

Typical Equipment used for the Solder Plating

Manual Tin-Lead Plating Line

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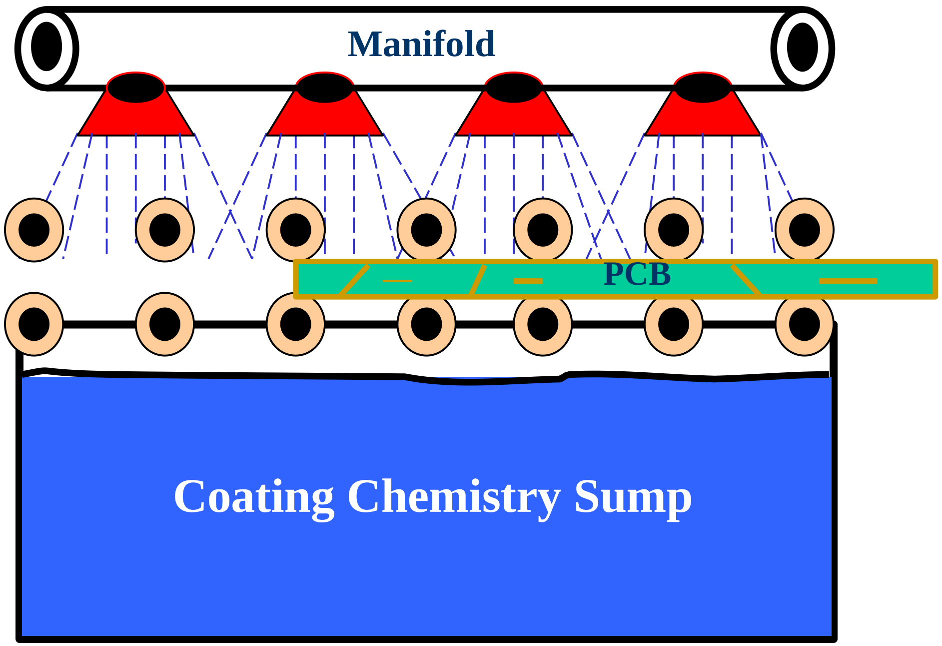
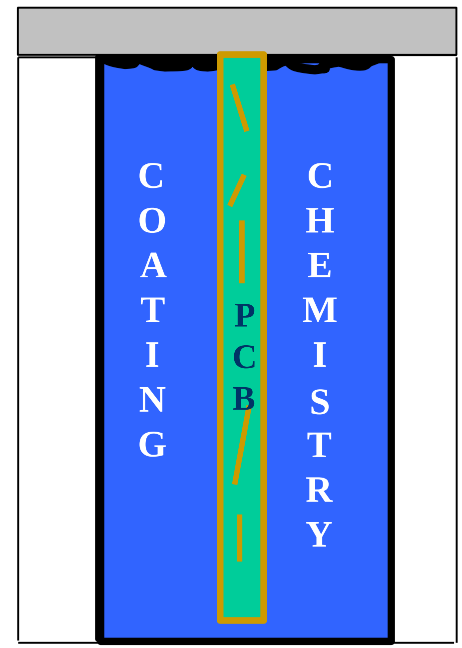
Dip Coatings

- *OSP (Organic Solderability Preservative)*
- *HASL (Hot Air Solder Level)*



Conveyorized Dip Module

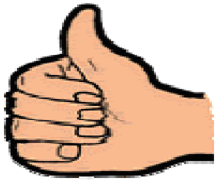
OR



Vertical Dip Tank

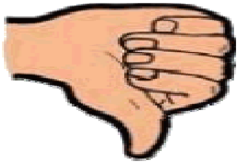
OSP (Organic Solderability Preservative)

Typical Thickness: 0.2 - 0.6 µm (8 - 24 µ in)



ADVANTAGES

+ Flat, Coplanar pads
+ Reworkable
  (at PCB Fabricator)
+ Doesn't Affect Finished
  Hole Size
+ Short, Easy Process
+ Low Cost
+ Benign to Soldermask
+ Cu/Sn Solderjoint

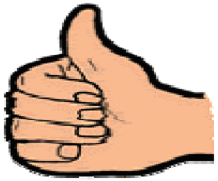


DISADVANTAGES

- Not a "Drop-In" Process
  (assy adjustments are required)
- Difficult to Inspect
- Questions Over Reliability of
  Exposed CopperAfterAssembly
- Limited Thermal Cycles
- Reworked at CM?; Sensitive to Some
  Solvents Used for Misprint Cleaning
- Limited Shelf life
- Panels Need to be Routed and Tested
  Prior to Coating (ET Probe Issue)
- Handling Concerns

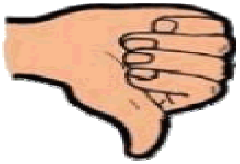
High Temp OSP
(Organic Solderability Preservative)

Typical Thickness: 0.2 - 0.6 µm (8 - 24 µ in)



ADVANTAGES

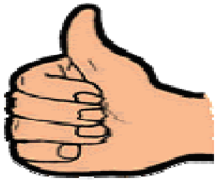
+ Flat, Coplanar pads
+ Reworkable (by Fabricator)
+ Short, Easy Process
+ Benign to Soldermask
+ Cu/Sn Solderjoint



DISADVANTAGES

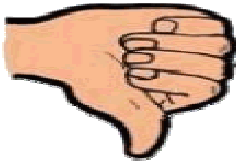
- Availability
- Not a "Drop-In" Process (assy adjustments are required)
- Difficult to Inspect
- Questions Over Reliability of Exposed CopperAfterAssembly
- Limited Thermal Cycles
- Reworked at CM?; Sensitive to Some Solvents Used for Misprint Cleaning
- Limited Shelf life
- Panels Need to be Routed and Tested Prior to Coating (ET Probe Issue)
- Copper Dissolution into Solder Volume
- Handling Concerns

OSP and Selective ENIG



ADVANTAGES

+ **Advantages of OSPfor SMT**
+ **Advantages of ENIG in through-holes**
+ **Cu/Sn Solderjoint**
+ **Can be used in Lead-Free**



DISADVANTAGES

- **Complex process for PCB suppliers**
- **Larger**

Currently being used in today's handheld portable products

(aka, Combi-Finish or SIT)

OSP (Organic Solderability Preservative)

Typical Equipment used for the Coating of OSP

Conveyorized Horizontal OSPand Pre-Flux Line

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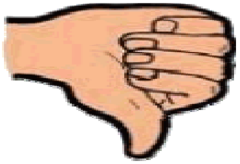
HASL (Hot Air Solder Level) LEADED Version

Typical Thickness: .65 - 50 µm (25 - 2000 µ in)

ADVANTAGES

+ "Nothing Solders Like Solder"
+ EasilyApplied
+ Lengthy Industry Experience
+ Easily Reworked
+ Multiple Thermal Excursions
+ Good Bond Strength
+ Long g Shelf Life
+ Easy Visual Inspection
+ Cu/Sn Solderjoint



DISADVANTAGES

- Co-Planarity Difference
  Potential Off-Contact Paste Printing
- Inconsistent Coating Thicknesses (on Varying Pad Sizes)
- Contains Lead
- Not Suited for HighAspect Ratios
- Not Suited for fine-pitch SMT and GridArray Packages
- PWB Dimensional Stability Issues
- Bridging Problems on Fine Pitch
- Subjects the PCB to High Temp

HASL (Hot Air Solder Level)

Typical Equipment used for the Coating of HASL

Vertical and
Horizontal HASL Equipment

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HASL (Hot Air Solder Level) UN-LEADED Version

iNEMI Test Panels:	Sn-0.3%Ag-0.7%Cu	2.61 - 14.2 µm
	Sn-3%Ag-0.5%Cu	1.0 - 12.3 µm
	Sn-0.7Cu + Ni	2.7 - 14.7 µm

ADVANTAGES

+ **EasilyApplied and Reworked**
+ **Familiar HALDynamics**
+ **Good Bond Strength**
+ **Long Shelf Life**
+ **Easy Visual Inspection (Wettability)**
+ **Cu/Sn Solderjoint**

DISADVANTAGES

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

LEADED-Free Solder Options

ALLOY SYSTEM	COMPOSITION	MELTING RANGE o (C)
Sn-Ag	**Sn-3.5Ag**	**221**
	Sn-2Ag	**221-226**
Sn-Cu	**Sn-0.7Cu**	**227**
Sn-Ag-Bi	**Sn-3.5Ag-3Bi**	**206-213**
	Sn-7.5Bi-2Ag	**207-212**
Sn-Ag-Cu EutecticEtti	**Sn-3.8Ag-0.7Cu**	**~217**
	Sn-4Ag-0.5CuS4A05C	**~217217**
	Sn-4.7Ag-1.7Cu	**~217**
SAC305	**Sn-3.0Ag-0.5Cu**	**218-219?**
SACX0307	**SnSn~00.9Cu9Cu~00.17Ag17Ag~00.1 4Bi14Bi**	**217-228217228**
Sn-Ag-Cu-Sb	**Sn-2Ag-0.8Cu-0.5Sb**	**216-222**
Sn-Zn-Bi	**Sn-7Zn-5Bi**	**170-190**

EUTECTIC ALLOYS

Process Parameters for Lead-Free HAL with Ni-Stabilized Sn-0.7Cu

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

ALLOY	MELTING POINT	PROCESS TEMPERATURE	PROCESS WINDOW
63/37 Sn/Pb	183° C	250° C(482)	67° C
Sn-0.7Cu+Ni	227° C	265° C(509)	38° C

*Source: Nihon Superior Co., LTD

LEAD-Free HAL running SN100C

There are now about 80+ shops operating lead-free HAL machines in Europe.

Running Lead free HAL machines in USA (Currently around 18 units)

(~400 in the World)

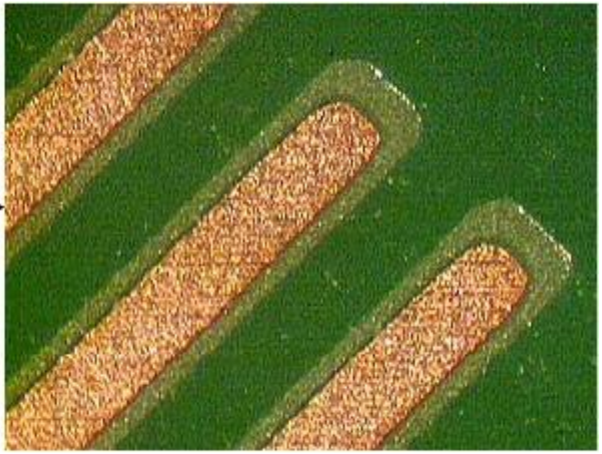
High Volume Production is determined by demand. **So proportionately, the need for lead-free boards is still relatively small.**

Source: Florida CirTech, I

EROSION OF COPPER PAD

Original Pad

18µm Copper



After 6 Passes over Wave Soldering Machine

105°C Preheat, 256°C Solder Temperature, 4 seconds contact time

Sn-37Pb

Sn-3.0Ag-0.5Cu

Sn-0.7Cu+Ni

Source: Florida CirTech, Inc.

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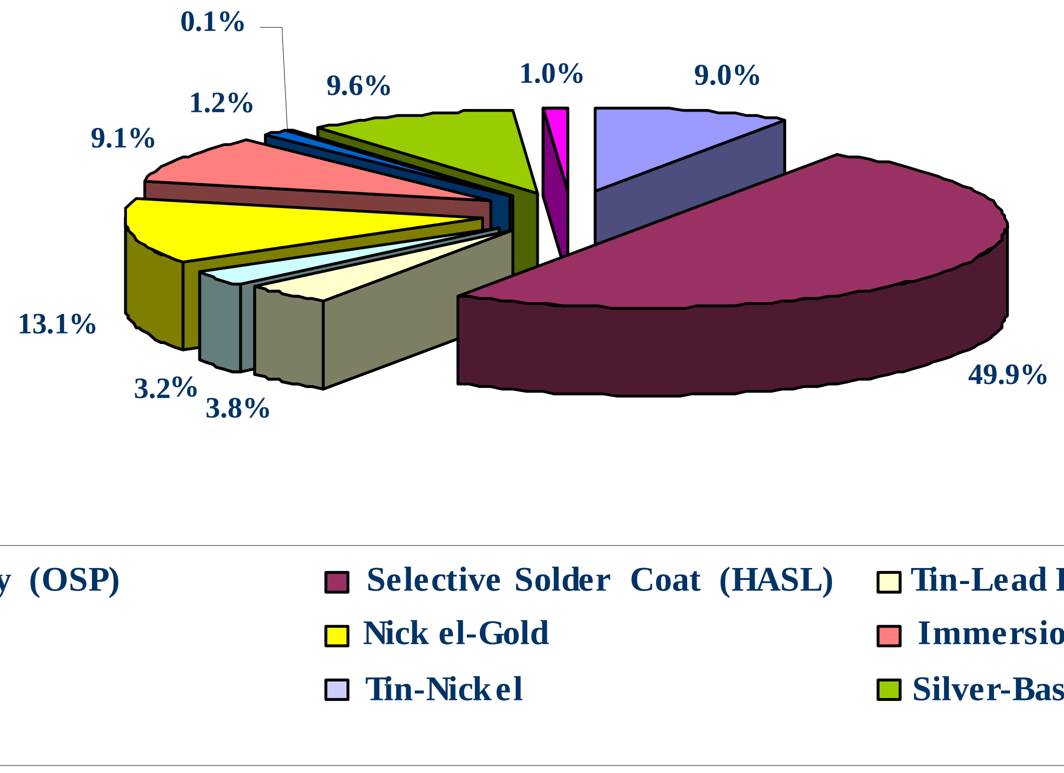
Industry-Wide Technology Trends

SURFACE FINISH	1998	1999	2000	2001	2002(Est.)
Copper Only (OSP)	19.1%	11.3%	10.0%	8.9%	9.0%
Selective Solder Coat	67.8%	67.1%	66.9%	53.4%	49.9%
Tin-Lead Plate and Reflow	2.7%	4.1%	4.2%	6.9%	3.8%
Tin	0.1%	0.1%	0.1%	2.2%	3.2%
Nickel-Gold	4.2%	4.1%	4.8%	11.4%	13.1%
Immersion Gold	4.1%	11.5%	12.2%	7.6%	9.1%
Palladiu	1.3%	0.6%	0.5%	0.9%	1.2%
Tin-Nickel	0.4%	0.2%	0.2%	0.1%	0.1%
Silver-Based	N/A	N/A	0.8%	7.3%	9.6%
Other	0.3%	1.0%	0.3%	1.3%	1.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

*Data Compiled Only For U.S. Companies

Technology Market Research Council Data

Estimated 2002 Surface Finish Utilization by U.S. PCB Fabricators



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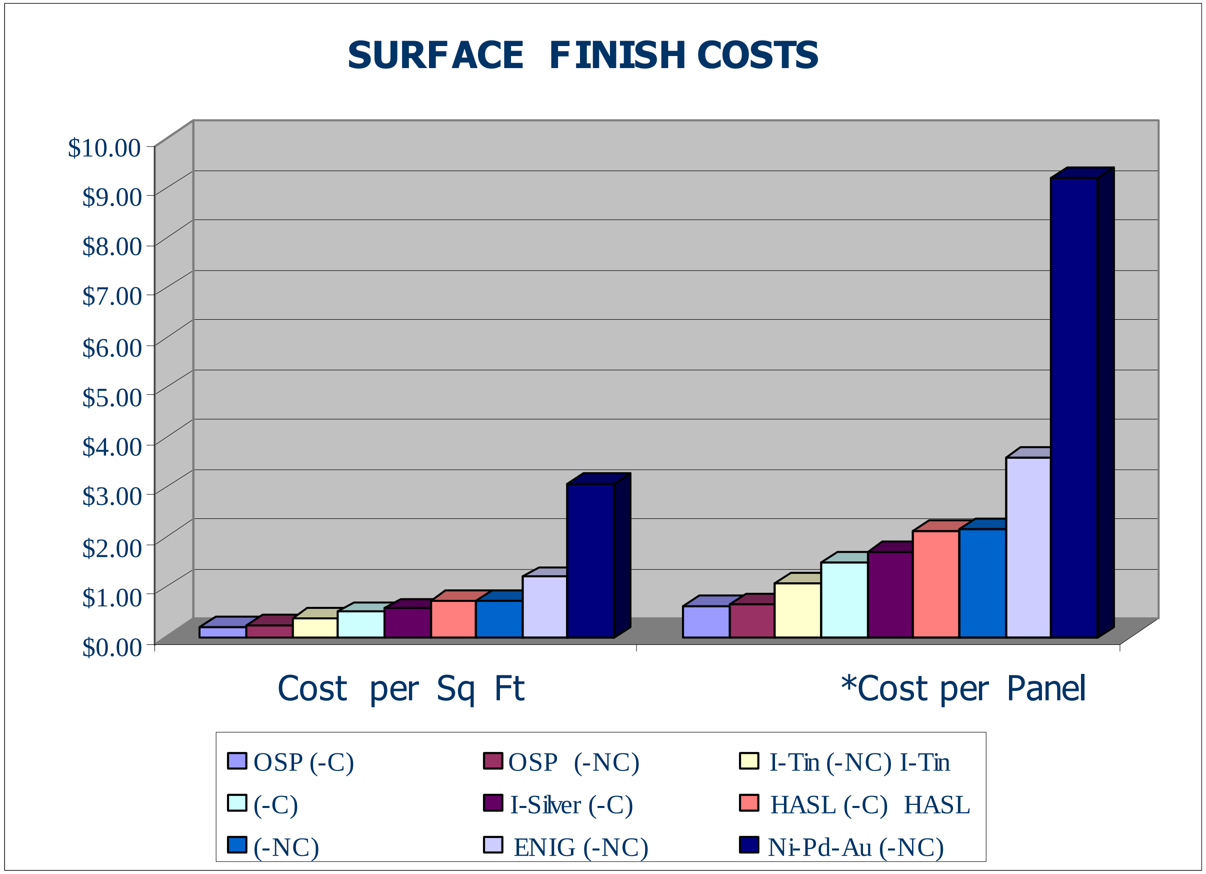
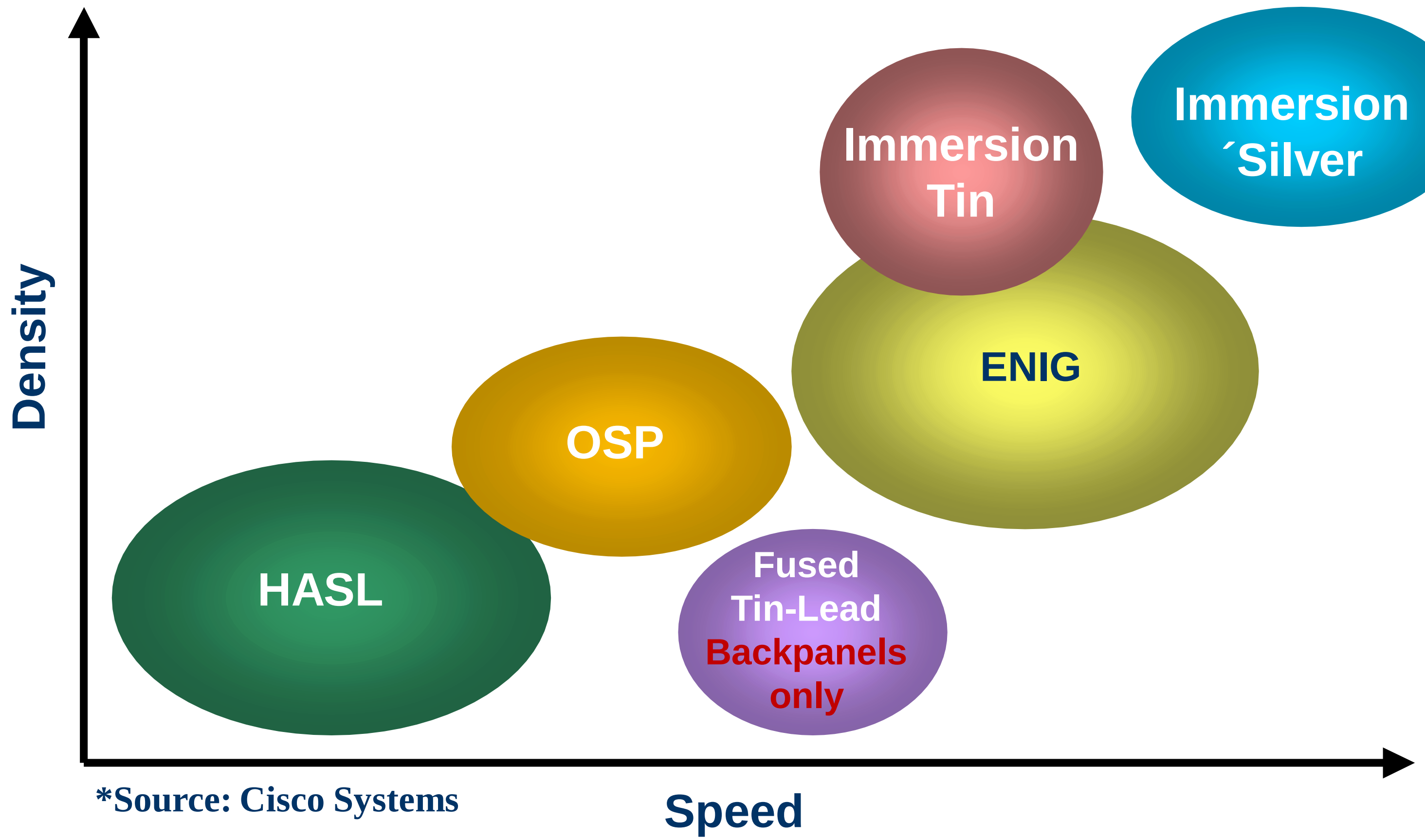
Surface Finish Cost Comparison



***Source: Cisco Systems**

-C: Conveyorized Process
-NC: Non-Conveyorized Process

Surface Finishes by Speed and Density



*Source: Cisco Systems

The Future of Surface Finishes

Among the New Surface Finishes Currently in Development are:

Tarnish-Free Immersion Silver / Immersion Silver for Backplane Applications

Direct Gold Plate over Copper

The Lead-Free Initiative and It's Impact on Surface Finishes

The European Union (EU) adopted The Restriction of Hazardous Substances (RoHS) directive, and it became law in February, 2003. This will effectively ban substances containing lead in tin/lead solders in some electronic equipment starting in July 2006.

As a result, lead-free solders will become more prevalent, and the effect on PCB surface finishes will have to be examined. For example, will the current/future finishes be compatible with the new lead-free (possibly tin/silver/copper alloy) solder? How many thermal excursions will the finishes be able to withstand?

These are questions which will have to be answered in the near future.

*Source: SMT June/2003

References

Surface Finishes Utilized in the PCB Industry Dan Slocum, Jr.

Cisco Systems

SMTONLINE *SMT Magazine*

Atotech

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Alternatives To HASL: Users Guide For Surface Finishes