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Board Finishes for the EMS Provider

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Abstract

Some new alternative PWB surface finishes have been entering the industry over the past few years. In order for any new board surface finish to be accepted for general use, it must be approved by the OEM as well as the EMS provider. This approval process begins with the chemical suppliers performing their own initial trials and tests. The supplier must approach potential EMS and OEM users to determine their interest in the finish. The EMS providers must run some trials to determine the advantages and disadvantages of the finish, compared to existing finishes. The OEM must determine if the finish is suitable for and compatible with any particular product application. This assessment must consider such items as whether the product requires: single reflow or multiple reflow assembly processes, precious metal contact, EMI shielding, press fit connection to a particular metallurgy, operation in a particular environment, etc. The board finish must be able to provide the EMS provider with a consistent assembly process that has a very high assembly yield. The resulting interconnections must provide a long term, reliable product for the OEM and end customer.

What is the EMS provider looking for in an ideal board finish? A single board finish that is consistent, predictable, very solderable, reliable and suitable for all applications. The ideal finish is one that

- Both SMT solder pastes and Wave Solder solders will quickly wet to
- Will be compatible with either no-clean or water soluble pastes and fluxes
- Will be compatible with SMT and wire bonding
- Will be compatible with EMI shield materials
- Will be compatible with soft touch membrane switch contacts
- Will be compatible with surface compression contact connectors and components, such as HDI connectors
- Will be suitable for edge tab contacts
- Will be compatible with press fit connectors
- Solder will form a strong intermetallic bond under static, dynamic and shock loads
- Will consistently result in a given amount of solder remaining on the board surface to create a defined solder joint
- Will withstand general warehouse storage for at least one year
- Will still be solderable through at least three soldering process steps, spread out over one week
- Will be solderable in either a nitrogen or ambient environment
- The presence of the finish can be verified visually
- The quality level of the finish can be determined visually
- Will strengthen the reliability of via and pin-through-hole barrels
- Will prevent the dissolution of copper from the board surface and barrels during rework
- Will meet all the requirements of both tin/lead and Lead-Free soldering initiatives
- Will minimize total system cost

Obviously the entire list of desires cannot be met with any single surface finish. Changes in technology may introduce new requirements for surface finishes which sometimes necessitate multiple finishes on the same board. These multiple board surface finishes add to the complexity of manufacturing the board and add to the board cost. A single board finish would be advantageous for both the board fabricator and the EMS provider.

The board surface finish debate is further complicated by the fact that all chemistries for any particular finish do not always yield the same assembly results. Process equipment for application of the board finish varies considerably and these differences can affect the quality of the surface finish. Some finishes can be applied either vertically using tanks with overhead hoists or horizontally using in-line process equipment. The solderability of the finish from these different processes is not necessarily the same. Even the assembly processes can differ between assemblers, which can affect the yield of the finished product, such as using different fluxes, reflow profiles, use of nitrogen and ppm of oxygen left, etc.

The above list has the qualities that the EMS provider desires in a board finish. However, what are the issues that the EMS provider experiences with the different board finishes that affect their process and or yield? The following discussion covers some general issues with each finish and then a summary of some of the advantages and disadvantages of each finish.

OSP (Organic Solderable Preservative) Finishes

Thin OPS Coating

The use of thin OSP finishes goes back over 20 years, and some are still used today. A thin OSP is typically an imidazole or benzotriazole type of chemistry, one molecule thick, in the range of 30 to 50 Angstroms. One cannot readily see if the OSP finish, and only the OSP finish, is on every surface that is to be soldered. If there is any very thin contaminant, such as soldermask residue, on a pad, the pad may visually look acceptable, but solder will not wet to the pad on the board but will only wet to the component lead. When this happens on a BGA device, the component fails test with an open and must be removed. The affected pad must be cleaned and manually soldered, then a new BGA device replaced. This is very time consuming and costly. See Table 1.

Table 1 – Thin OPS Coating

Advantages	Disadvantages
Good planar surface	Very narrow process Window for multi-pass assembly
Most inexpensive finish	Difficult getting adequate hole fill
No intermetallic formed before assembly	Probing and grounding issues through Cu oxides
Strongest solder joints to copper	Handling concerns – etch finger prints in Cu
Does not stain gold tabs	Short shelf life
	Can't detect soldermask residue on Cu
	Incomplete pad wetting

Thick OPS Coating

Thick OSP coatings are typically substituted benzimidazole chemistry. The finish is many molecules thick, in the range of 1500 to 5000 Angstroms, depending on the chemistry. The thick OSP coating has the same risk as thin OSP. Board fabricators do not apply the finish until after electrical test due to the difficulty of probing through the finish. It is more difficult to electrically probe through most thick OSP finishes, compared to thin OSP finish, on unsoldered features, after assembly. See Table 2.

Table 2 - Thick OPS Coating

Advantages	Disadvantages
Good planar surface	Narrow process window for multiple passes
Inexpensive finish	'Plus' coatings deposit film on gold
No intermetallic Formed before assembly	Some 'Plus' coatings stain gold
Strongest solder joints to copper	Difficult getting adequate hole fill
Withstands multiple assembly reflow steps	Probing and grounding Issues through hard OSP
	Handling concerns
	Can't detect soldermask residue on Cu
	Incomplete pad wetting

HASL (Hot Air Solder Level) Finishes

There is too much solder thickness variation from pad to pad, board to board, lot to lot. As high technology boards become thicker, it is becoming impossible to adequately blow solder out of the high aspect ratio via holes while leaving enough free solder on the knee of holes for pin-through-hole components and on large SMT pads to retain a solderable surface. The EMS provider needs a consistent, thin layer of solder on every soldered surface on every board. Ideally we would like to receive between 100 and 250 micro inches on every solder pad and in every soldered barrel. See Table 3.

Table 3 – HASL Finish

Advantages	Disadvantages
Excellent Solderability	A 1 sigma process in a 6 sigma world
"Nothing solders like solder"	Wide thickness variation: Pad to pad
Good shelf life	board to board, lot to lot
Good electrical probe surface	Non planar surface for SMT
Withstands multiple process steps	Intermetallic formed before assembly
	Risk of no free solder after multiple Pass
	High thermal stress process to Board
	Solder plugged holes or hole size Reduction
	Will be phased out with Lead-free Initiative

Selective Solder Strip or Selective Reflowed Tin-Lead or Fused Solder

Selective solder strip reduces some of the problems with thickness variations from HASL, since the tin-lead is plated on the board and the thickness variations are greatly reduced. However, the plating process must be done early in the process before soldermask. The solder must be stripped off the circuit lines so that soldermask is applied over bare copper. Tolerance buildup between the registration of the solder striping process and the soldermask features can create very narrow soldermask dams with good adhesion around BGA devices. The adhesion of the BGA soldermask dam is a critical feature, which prevents solder from wicking away from the BGA pad and escaping down the adjacent via hole. See Table 4.

Table 4 - Selective Solder Strip Finish

Advantages	Disadvantages
Excellent Solderability	Limited and decreasing availability
Fairly consistent surface for SMT	Environmental issues with tin-lead stripping
Good electrical probe surface	Additional high stress process to board
Withstands multiple process steps	Risk of via hole plug
Minimal handling issues	Insufficient registration tolerances for BGA soldermask
Long time military standard finish	May be phased out with Lead free initiative

ENIG (Electroless Nickel/Immersion Gold) Finish

ENIG has many of the properties that the EMS provider desires. However, the finish is susceptible to a defect called Interfacial Fracture (IFF), Black Line nickel or Black Pad. Certain board designs are far more susceptible than others to having this interfacial fracture occur. ITRI (Interconnect Technology Research Institute) had worked on this interfacial fracture problem for four years.[1] Some of the chemical suppliers have made improvements to their chemistries and process guidelines. Some board fabricators have made improvements to their equipment and processes to reduce the occurrence of the problem, but there are no guarantees that a design will not be impacted by IFF. In general, the average defect level for IFF failure is a low ppm defect level. However, for the particular design that is impacted with IFF failures, the defect level can be a significant percent. See Table 5.

Table 5 - ENIG Finish

Advantages	Disadvantages
Excellent Solderability	Low ppm joint cracking / 'black pad' problem
Consistent flat surface for SMT	Different chemistries – Process differences
Good electrical probe surface	Moderately expensive
Good surface for EMI shield contact	Not available from all suppliers – subcontract
Withstands multiple process steps	Incompatible with some soldermasks
No holes plugged	Multiple board finishes difficult
Minimal handling issues	
Increased barrel and via reliability	

Electrolytic Nickel Gold (Ni/Au)Finish

Electrolytic Ni/Au finish eliminates the interfacial fracture problem associated with ENIG. However, the Ni/Au must be applied early in the plating process, after copper plating, similar to selective solder. This Ni/Au finish is then covered with soldermask and the soldermask is stripped from the solder features. There is a risk of soldermask residue being left on solder features. Similar to OSP finishes, if there remains a bit of soldermask residue on a pad, that pad will not wet. The Ni/Au is also exposed to a number of chemical baths after it has been applied, which can degrade the solderability of the finish. Soldermask has very poor adhesion to the gold compared to copper and therefore BGA soldermask dams are readily damaged or broken. The throwing power of Ni/Au is poor, so there is a risk of getting sufficient nickel in high aspect ratio holes. Since the Ni/Au is the etch resist, thin nickel or nickel voids can lead to copper etch voids in vias and opens after assembly reflow. Gold thickness varies considerably across the board surface and can result in gold embrittlement. See Table 6.

Table 6 - Electrolytic Nickel Gold finish

Advantages	Disadvantages
Excellent Solderability	Applied after pattern plate
Consistent flat surface for SMT	Risk later surface contamination (soldermask etc.)
Good electrical probe surface	Poor solder mask adhesion to gold
Withstands multiple process steps	Poor Ni/Au throwing power into high aspect ratio holes.
No holes plugged	Risk of weak barrel strength
Minimal handling issues	Difficult to control gold thickness across board
No 'Black Pad' issue	Ni/Au is etch resist, causes undercut of base Cu

Electroless Nickel/Electroless Palladium / Immersion Gold (ENi/EPd/IAu) finish

ENi/EPd/IAu is possibly the closest to the 'Ideal' surface finish. It can be applied after soldermask in the fabrication process. The palladium layer acts as a buffer between the nickel and gold to prevent immersion gold attack of the nickel, and therefore does not have IFF failures. However, palladium is very expensive and its availability, mainly from Russia, is sometimes questionable. This finish is not readily available. My test results with this finish have always been very good and very consistent.[2] See Table 7.

Table 7 - Electroless Nickel/Electroless Palladium / Immersion Gold Finish

Advantages	Disadvantages
Excellent Solderability	Different chemistries – Process definition
Possibly the 'Ultimate High-end finish'	Palladium cost and availability
SMT, Wave, Au & Al Wire Bond, Press fit	Still new – Unknowns as a board finish
Consistent flat surface for SMT	
Good electrical probe & contact surface	
Withstands multiple process steps	
Minimal handling issues	
More process development potential	
Avoids ENIG Interfacial Fracture	

Immersion Silver (IAg) Finish

Immersion Silver (IAg) and Immersion Tin (ISn) are the two new board surfaces to challenge the industry. IAg appears to be more popular in North America and ISn appears to be more popular in Europe at this time. The use of both finishes appears to be growing in the Far East. Like OSP, IAg is applied at the end of the board fabrication process. George Wenger, formerly from Lucent, describes IAg as a 'metallic OSP'. The IAg protects the copper from oxidizing, like an OSP finish. The silver dissolved into the bulk solder and the strong solder joint is formed to the underlying copper. See Table 8.

Table 8 - Immersion Silver Finish

Advantages	Disadvantages
Excellent Solderability	Not available from all suppliers – subcontract
Wets faster than OSP	Multiple board finishes difficult
Consistent flat surface for SMT	Long term use as electrical contact unknown?
Good electrical probe surface	Long term storage Issues unknown?
Withstands multiple process steps	2 year production use
No holes plugged	Possible unknowns as a board finish
Visual inspect if silver has deposited on pads	Possible compatibility problem with via plug
Compatible with Lead-free processes	

Immersion Tin (ISn) Finish

Like OSP and IAg, ISn is applied at the end of the board fabrication process. The ISn protects the copper from oxidizing, like an OSP finish. However, the tin process can be very aggressive against soldermask and can lift it. Tin also readily dissolves into copper, slowly at room temperature and quickly at reflow temperatures. A concern to the EMS provider is that there may not be enough free tin to provide solderability through all assembly processes for boards that must be processed through multiple assembly processes. See Table 9.

Table 9 - Immersion Tin Finish

Advantages	Disadvantages
Excellent Solderability when new	Not available from all suppliers – subcontract
Consistent flat surface for SMT	Multiple board finishes difficult
Good initial electrical probe surface	Short shelf life – dissolves into Cu in storage
Good for press fit connectors	Can have poor hole fill after double side SMT
No holes plugged	Handling issues unknown
	Still new – Unknowns as a board finish
	Possible compatibility problem with via plug

Conclusions

Both the board fabricators and EMS providers would like to have fewer board finishes to work with. As the IAg and ISn board finishes grow in acceptance, I anticipate that they will gradually replace OSP and HASL finishes. The transition to Lead-free processes should finally see the end of HASL. Lead-free HAL is very stressful on the board and hopefully will not gain acceptance.

My own testing of board finishes over the past few years has provided consistent results with the different finishes. My latest tensile testing of BGA solder joints using different surface finishes gave equal tensile strength results with OSP, HASL, ENi/EPd/IAu, Ag and most Sn finishes.[2] Since the cost of the silver or tin finishes, in volume production, will be very close to, or cheaper than HASL, I expect considerable growth in the use of these finishes.

For those that have product that must perform in a harsh military environment, they should monitor the testing of some of the alternate finishes that has also been conducted by a CCAMTF (Circuit Card Assembly and Material Task Force) consortium.[3]

I would like to see more testing by the OEMs on ENi/EPd/IAg as a potential replacement for ENIG or electroplated Ni/Au for high-end boards. Solderability and solder joint strength have been very good.[2] This ENi/EPd/IAg finish could be a universal, high end finish that could eliminate the necessity for two surface finishes on some complex product.

References

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