PCB Surface Finishes: A General Review

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Introduction

Surface finishing is an integral part of any Printed Circuit Board (PCB) or Printed Wiring Boards (PWB) fabrication. It is generally applied to exposed Cu connectors and conductors on the PCB. Surface finishing has numerous important functions. It serves as a protective layer for the Cu connectors during storage. The surface finish helps minimize or reduce tarnish of the Cu substrate. Additionally, since it is the layer that comes into contact with other components during assembly, it ensures good solderability between the PCB and the component during assembly. Furthermore after assembly, the finish helps prolong the integrity of the solder joint during use.

What is a Surface Finish?

A surface finish is a material that is deposited onto the conductor surface of a PCB or PWB (Cu is the most common conductor). It is typically a metal or an alloy but there are also surface finishes that are organic polymer. Depending on the finish of choice, the deposition entails unique steps and specialized equipment. Here we will review the most commonly used surface finishes in the industry.

Common Surface Finishes

This section discusses the most commonly used surface finishes in the PCB industry. Each has its own unique features and processing challenges. There are other less common surface finishes such as electrolytic, and even plasma, but we will limit the discussion to the list below.

- Hot Air Solder Leveling (HASL)
- Organic Solderability Preservative (OSP)
- Immersion Tin (ImSn)
- Immersion Silver (ImAg)
- Electroless Nickel/Immersion Gold (ENIG)
- Electroless Nickel/Electroless Pd/Immersion Gold (ENEPIG)

As far as utilization of surface finishes, they are found in a wide range of applications. Ranging from consumer electronics to more sophisticated high reliability electronics. The choice of a surface finish will depend on balancing different factors such as performance, reliability and cost.

Figure 1 shows the 2014 surface finish market in terms of sold chemistry in millions of US dollars (1). The largest share is by ENIG at about $210 million followed by OSP at $83 million. Immersion tin as a surface finish is gaining wider use as it is being utilized more and more in automotive applications. The rest of the surface finishes are much smaller with about $26 million each for immersion silver and HASL.

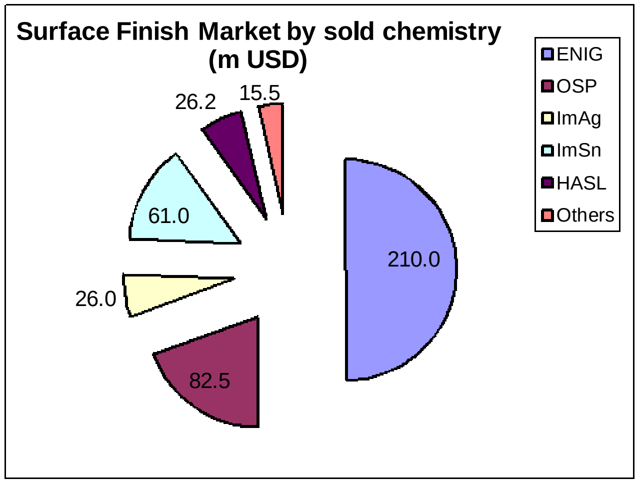

Figure 1. Surface finish market in terms of sold chemistry (2014, in millions of USD)

Immersion Process

In general, a surface finish is directly deposited onto the Cu substrate surface. However, for surface finishes that utilize an immersion approach such as immersion silver and immersion tin, the deposit is applied via a displacement mechanism. It's worthwhile to differentiate an immersion process from the conventional coating process. In a conventional coating process, the material of choice is deposited via an additive approach. In other words, it is applied on top of the substrate surface. Whereas in an immersion process, the material to be deposited is added at the expense of the substrate surface. Figure 2 depicts a simple schematic of the immersion process wherein the deposit (gray) is formed on the surface by displacing substrate material. This cycle keeps repeating itself until there is no more accessible substrate material available to be displaced by the deposit material. Hence immersion processes are considered self-limiting unlike autocatalytic process which could go on indefinitely.

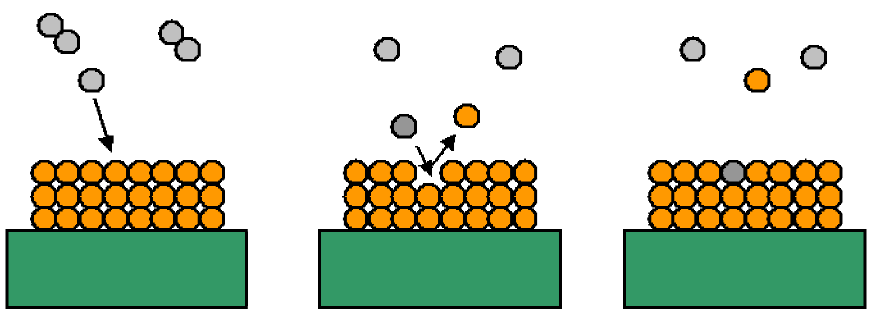

Figure 2. Schematic of an immersion process

Comparison of Surface Finishes

As mentioned above, the choice of surface finish depends on numerous factors. Each with its own pros and cons. The next section will discuss and differentiate the common surface finishes used in the industry.

Process Comparison

Table 1 illustrates the processing steps for the different surface finishes. The substrate preparation steps are generally similar typically starting with a chemical cleaning of the PCB followed by microetching of the Cu substrate. The initial cleaning step is often overlook but it is considerably important. The cleaner prepares the board by removing grease, debris particulates and even soldermask residues on the surface. Following the cleaner step is Cu etching. The microetch prepares the Cu substrate for the desired morphology, and texture. Additionally providing further cleaning of the Cu surface.

Right after the substrate preparation steps are the specific chemical treatment steps depending on the finish of choice. The processing times and cost varies for each and shown in the table for comparison purposes.

Table 1. Processing comparison of the different PCB surface finishes

HASL	OSP	ImSn	ImAg	ENIG	ENEPIG
Cleaner	Cleaner	Cleaner	Cleaner	Cleaner	Cleaner
Rinse	rinse	rinse	rinse	rinse	rinse
Microetch	Microetch	Microetch	Microetch	Microetch	Microetch
Rinse	rinse	rinse	rinse	rinse	rinse
Flux	Pre-dip	Pre-dip	Pre-dip	Catalyst	Catalyst
Solder	OSP	Immersion Tin	Immersion Silver	rinse	rinse
Air Knife	rinse	rinse	rinse	Post-acid	Post-acid
Cleaner				rinse	rinse
Rinse				Electroless Nickel	Electroless Nickel
				rinse	rinse
				Immersion Gold	Palladium
				rinse	rinse
					Immersion Gold
					Rinse
$	$	$$	$$	$$$	$$$$
	~ 10 to 15 min	~ 25 to 30 min	~ 15 to 20 min	~ 60 min	~ 65 to 75 min

Hot Air Solder Leveling

Hot air solder leveling or HASL for short, is one of the earlier type of finish still being used today. It's relatively inexpensive and simple to apply. The PCB is dipped into molten solder and drawn up. During this draw up, hot air knives would clean off any excess solder to leave behind only a thin layer. The solder itself protects the underlying Cu conductor/connector. Common HASL material include SnPb, SnCu or even SnAgCu alloys. The thickness of an HASL finish can vary from 0.2 to 50 um.

One of the best features of HASL is that it readily solders. After all, the Sn based alloy is the same material used in soldering which allows for a good joint. This finish is also widely available. Furthermore, it can be reworked by removing the solder finish. The downsides of HASL are its limited capability for fine pitch dimensions. It's also not a flat finish which could complicate assembly. Its application simplicity is also one of the drawbacks. Because it is dipped into molten solder, the entire PCB is subjected to a very high temperature which is not good for the board material itself.

Organic Solderability Preservative

The only surface finish in this list that is not a metal or alloy is the Organic Solderability Preservative (OSP) finish. The active compound is normally a thermally stable organic molecule based from a substituted phenylimidazoles, or benzimidazoles and their derivatives. The OSP coating is formed when the active molecule is allowed to network with Cu ions on the surface of the substrate. Figure 3 shows a simple schematic of the OSP coating. The normal thickness of an OSP coating is from 0.1 to 0.3 um. Due to the organic nature of this finish, it appears as a transparent colorless coating.

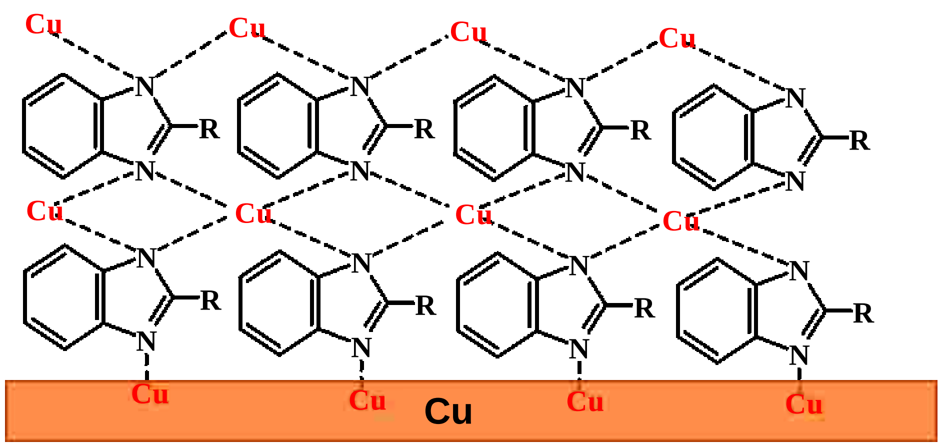

Figure 3. Schematic of an OSP coating

The application of an OSP coating is considerably inexpensive. It is simple to apply and easily reworkable by stripping off the organic coating without much damage to the PCB. Another nice feature of the OSP is that it yields a flat finish. Despite the nice qualities of OSP, it does have its own set of disadvantages. The organic nature of this finish makes it more sensitive to handling issues (i.e. oils in fingers, etc). At the same time, the organic molecule can withstand fewer number of thermal reflow cycles compared to metallic finishes before it starts to deteriorate. This finish is also more challenging for inspection because of its clear, transparent appearance. Furthermore, it's not electrically conductive so electrical testing is not easily done.

Immersion Tin

As explained in the earlier section, immersion tin (ImmSn) is applied via a displacement mechanism wherein the metallic Sn is deposited by replacing the surface Cu atoms on the PCB. The finish itself is not a pure Sn metal but rather include traces of metal additive in the deposit. Thickness of ImmSn can range from 0.8 to 1.2 um. However, the plating rate dramatically slows down at higher thickness due to the self-limiting nature of the immersion process.

Immersion tin as a finish is gaining more market share due to growing adaptation particularly in the automotive segments. It's not a cost prohibitive finish while giving fine pitch and flat plating capabilities. This finish also exhibit excellent solderability. The one major disadvantage of ImmSn as a surface finish is its susceptibility to tin whisker defect. This defect is the result of internal stress that developed in the deposit. The only way to relieve this internal stress is that some material is 'pushed' out of the structure hence forming very fine whiskers (see Figure 4). These whiskers grow outward and could eventually cause shorting when it becomes dislodge or comes into contact with another adjacent connection. One way to minimize is by incorporating metal additive to alter and reduce the internal stress. An additional challenge for ImmSn is that most formulation contains thiourea which is a suspected carcinogen. So health considerations should be taken when using this finish.

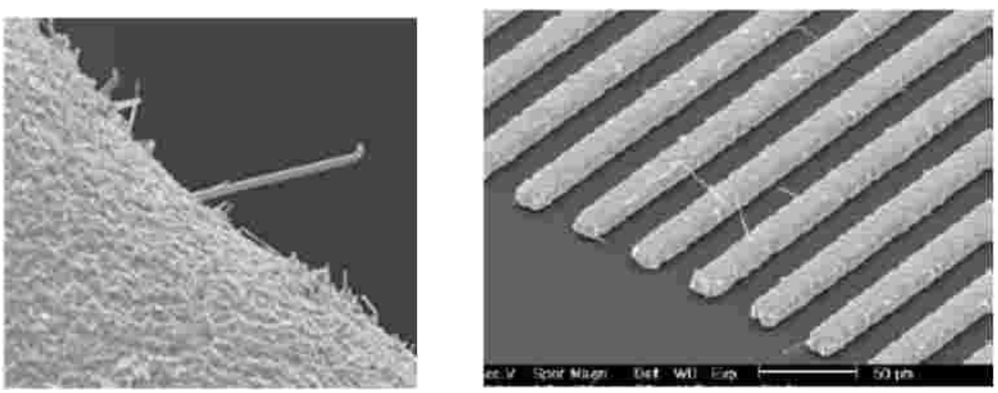

Figure 4. Tin whisker defect

Immersion Silver

Another immersion based surface finish is immersion silver (ImmAg). This process is also self-limiting, with typical plating thickness in the range 0.1 to 0.4 um. The finish is about 99% Ag metal with small traces of organic material. The coating is relatively simple and straight forward to apply.

Immersion silver exhibits very good solderability aside from depositing a flat finish. Furthermore it is useful for fine pitch dimensions. Despite silver being a precious metal, the lower thickness target make it a cost effective finish. The major disadvantage of ImmAg is it's propensity for corrosion attack from sulfur and chloride bearing environment. As seen in Figure 5a, creep corrosion is one example of such corrosion wherein at elevated humidity and temperature, the ImmAg finish will form metal sulfide dendrites that can continue to grow and eventually cause shorting problems. To mitigate this problem, a thin organic top coat can be applied to reduce the creep corrosion by providing an additional barrier (Figure 5b).

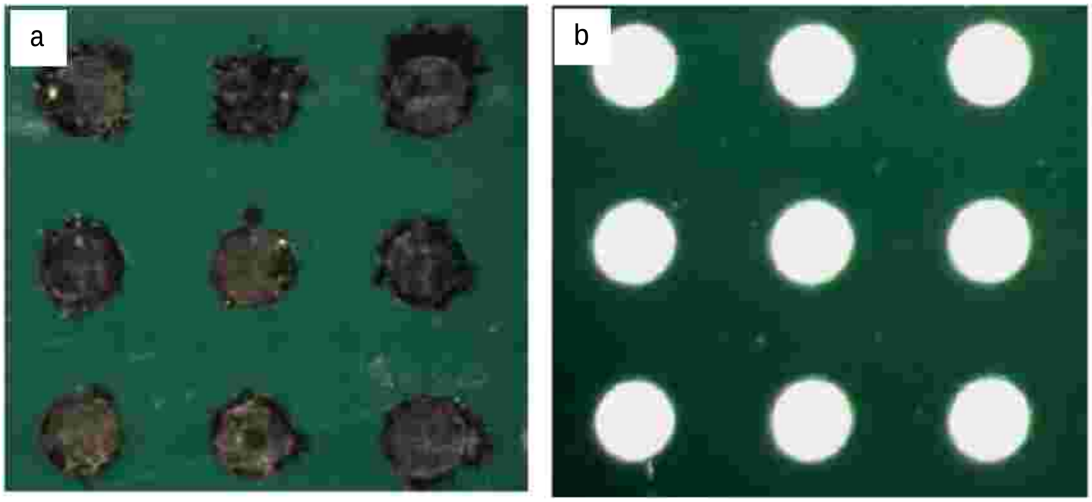

Figure 5. (a) Creep corrosion on an Immersion silver finish (b) reduced corrosion when top coat is applied

Electroless Nickel/Immersion Gold

The electroless nickel/immersion gold (ENIG) finish has the largest market share among the surface finish in terms of sold chemistry in USD. It's considerably more expensive than OSP and the immersion type finishes. Not to mention that the steps are also longer and more complex since the finish comprise of two distinct layers of metals: nickel and gold.

The electroless nickel (EN) layer is deposited via the autocatalytic mechanism. This approach utilizes a chemical reducing agent to reduce the Ni ions in the plating bath. Depending on the formulation and type of reducing agent; certain ingredients will also be co-deposited together with the Ni forming a Ni alloy. Prior to Ni deposition, the Cu surface will need to be activated first. Activation is typically achieved by catalyzing the surface with a precious metal to lower the activation energy for the chemical reduction step. After Ni is deposited, gold is then plated via an immersion process. This time, the gold is plated by replacing the Ni atoms in the EN layer. Figure 6 depicts an ENIG finish. The EN layer is considerably thick with thickness from 3 to 6 um followed by a thin layer of ImmAu (i.e. 0.05 um).

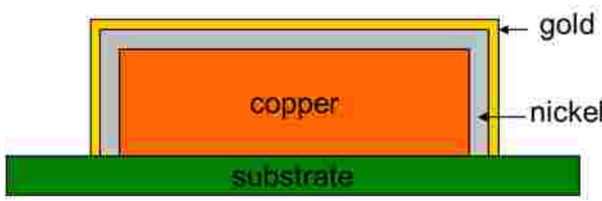

Figure 6. An illustration of the ENIG surface finish

An ENIG finish has excellent solderability due to the good solubility of the gold layer with solder. This finish has a very long shelf life as well because the gold has very good tarnish resistance. Besides the gold, the EN layer is a good Cu diffusion barrier which helps allow for multiple reflow capabilities. The plating also provides for a flat finish. Disadvantages of ENIG include increased cost and complexity of processing owing to the 2 metallic layers. The EN processing requires a good understanding and proper control of the operating parameters in order to obtain a good EN deposit. Otherwise, the EN layer can be inferior and susceptible to issues such as corrosion attack, overplate and premature bath decomposition. Plating mistakes with ENIG is almost impossible to rework. Stripping off the ENIG finish will almost always result in some form of damage to the board surface. It's also worthwhile to point out that most EN plating are done at elevated temperatures in the range of 80+ °C which is a high enough temperature to cause problems with certain soldermask type. So a proper soldermask is needed when plating with ENIG.

One major disadvantage of ENIG is its susceptibility to black pad corrosion (2). This corrosion occurs during the ENIG process more specifically during the deposition of gold. Since gold is deposited via the immersion mechanism, Ni atoms are displaced by the gold atoms being deposited. Ideally, the corrosion is controlled and uniformly distributed along the entire EN surface. This would limit the corrosion to just a top shallow layer. But in practice, black pad attack are localized corrosion wherein the attack on the EN layer can extend throughout the entire thickness as seen in Figure 7. Black pad attack are more commonly seen in irregular topography like deep crevices or grain boundary regions. These localized corrosion spots are detrimental because they are much more concentrated resulting in significant damage to the EN layer which would reduce the joint integrity leading to solder failure. It is also for this reason that proper EN plating is paramount, otherwise an inferior EN foundation layer will be obtained.

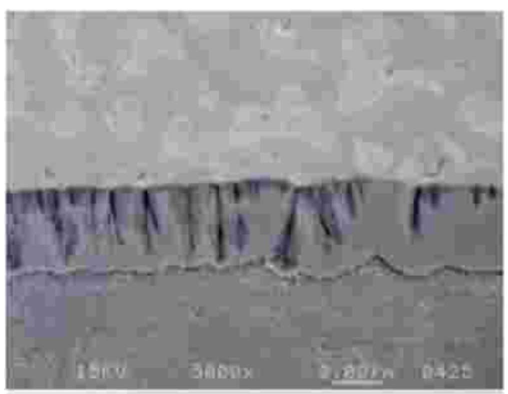

Figure 7. Black pad corrosion on ENIG

Electroless Nickel/Electroless Palladium/Immersion Gold

Electroless Nickel/Electroless Palladium/Immersion Gold or ENEPIG for short is one of the more durable surface finishes. As the name implies, this coating utilizes 3 distinct metallic layers (see Figure 8). Similar to ENIG, an EN layer serves as the foundation for this coating. Thickness for the EN layer is between 3 to 6 um followed by a thin layer of electroless palladium (EPd) which can be between 0.2 to 0.5 um thick. The EPd layer is deposited with the use of a reducing agent so it's not achieved by displacement reaction. Because the EPd is coated by using autocatalytic means, there is very minimal damage to the EN layer since Ni is not displaced in order for Pd to deposit. Lastly, the top most layer is the immersion gold. The gold layer in ENEPIG can be thinner than the gold layer in ENIG. In ENEPIG finishes, the gold can be from

0.025 to 0.05 um thick. Since the gold layer is not in direct contact with the EN layer, the damage from black pad corrosion is also much reduced and mitigated.

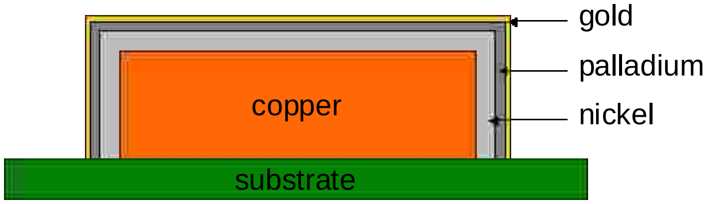

Figure 8. An illustration of the ENEPIG surface finish

The ENEPIG finish is a very corrosion resistant surface finish allowing for a very long shelf life. It plates considerably flat and is coplanar which makes it suitable for fine pitch dimensions. Among the surface finishes, it is compatible with a wide variety of wire bond assembly methods not to mention it has very good solderability as well. On the other hand, because of its multiple metallic layers, the process of ENEPIG is much more complicated requiring the maintenance of 3 different plating chemistries (i.e. EN, EPd, and ImmAu). This complexity would increase the processing cost further together with the cost of using 2 precious metals (Pd and Au). This finish is also not easily reworked.

Summary

Surface finishes play several important roles in the electronics and PCB industry. Though there are numerous different surface finishes available, each has its own unique advantages and disadvantages. Hence it is important to correctly choose the appropriate surface finish that would meet the requirements of the targeted application.

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