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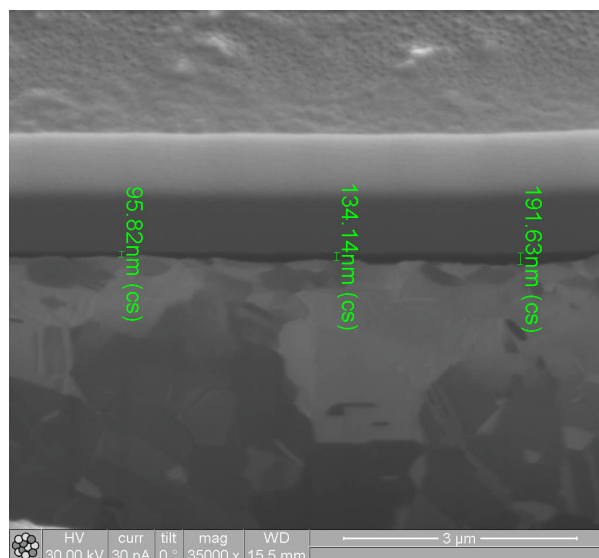
INTERCONNECT TECHNOLOGIES

Surface Finishes for Lead-Free Assembly

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Introduction

Strong and reliable solder joints are required to provide interconnections between components and PCB boards. With the shift to lead-free solder alloys, there has been a tremendous amount of research on solder joint reliability as a function of pad surface finishes (coating types and thicknesses) and solder alloy compositions of both the solder paste and the solder balls on components. These studies have explored performance through a wide variety of reliability test methods, including solder ball pull / ball shear force measurement, shear rate effects and failure mode analysis, bending tests, drop tests and thermal cycling testing. Intermetallic compound (IMC) formation and electro-migration effects have been studied as functions of reflow cycle conditions, thermal aging and applied current density. All of these efforts have been aimed at achieving industrial requirements for different applications.

Around the middle of 2006, when high volume lead free assembly in Asia began to expand rapidly, significant yield loss was encountered. Almost all assembly companies experienced issues during the transition period. By 2008~2009, after very substantial engineering and R&D efforts, including board re-design, assembly process parameter optimization, solder paste and flux re-formulation and modifications to PCB laminate materials and surface finishes, lead free assembly yields were much improved (although still often showing some degree of yield loss compared to SnPb).

One of the issues associated with the shift to lead-free assembly was a reduction in solder

joint formation process window. The differences in lead-free solder alloy behavior compared to eutectic tin-lead, in particular, reduced solder spread led to several problems, including pad coverage and hole-fill. Assemblers have addressed incomplete pad solder coverage by enlarging lead-free solder paste stencil apertures to give higher solder paste deposition volumes. Inadequate hole-fill with through-hole components in lead free wave soldering processes led to very high rework rates on pin assembly, especially using Organic Solderability Preservative (OSP). Modifications in reflow parameters and flux formulations were made to address this issue. Within through holes, very thin or etched out copper has been observed both after multiple lead-free wave solder operations and also after rework, due to higher copper dissolution rates associated with the combination of lead-free alloys and higher process temperatures. This problem has been reduced by ensuring that through hole plated thicknesses are sufficient to provide an appropriate safety margin for the anticipated assembly process flow.

However, the industry continues to seek new approaches to further improve the yield and process window of lead-free assembly by better understanding the interactions between surface finish, lead-free solder alloy and solder joint reliability.

In this article, we would like to discuss the influence of surface finishes in lead free assembly.

Technology Trends for Surface Finishes and Solder Joint Alloys

The most common surface finishes are ENIG (electroless nickel-immersion gold), OSP, Immersion Sn, Immersion Ag, HASL (hot air solder leveling) and the more recently introduced and widely evaluated ENEPIG (electroless nickel-electroless palladium- immersion gold). The specific

solder joint performance of these finishes has been compared for lead free solder pastes and lead free wave soldering. Applications and reliability requirements have driven the following surface finish technology migration.

Cost drivers have led to OSP finishes replacing almost all HASL on PC notebook/desktop mother boards for lead free solder joint

A need for a combination of high reliability in drop testing and key pad contact performance has led mobile phone and handset devices towards the use of selective ENIG (ENIG + OSP)

Both ENIG and OSP are used for flash memory providing acceptable joint reliability and plated pad flatness

Automotive and telecommunication boards are using a variety of finishes including ENIG, Immersion Sn, OSP and eutectic tin-lead HASL finishes. Some of these applications require press-fit or high durability in harsh environments and are struggling for suitable alternatives allowing a shift from eutectic SnPb to lead free solder

Immersion Sn and ENEPIG are being successfully used to replace ENIG in Flip Chip application

ENEPIG is being introduced to replace electrolytic Ni/Au surface finishes to provide

wire bonding and solderability in higher density designs, where bussing is not practical

While the most common solder alloy used after the shift to lead-free has been SAC305 (Sn 96.5wt%, Ag 3%, Cu 0.5%), studies of lead-free solder joint strength, long term reliability, and continuing cost pressures have led to evaluation of alternate alloys. Alloys with lower Ag content like doped SAC105+XY or SAC0307+XY have the potential to reduce solder costs while maintaining or even improving solder joint reliability.

As passive component dimensions shrink to 0201 or below, both pad size and solder joint size are also reduced, leading to new reliability issues and assembly challenges. Reductions in solder paste particle diameter from 25-45 μ m (Type 3) to 20-38 μ m (Type 4) combined with solder paste and flux optimization allow paste printing on pads for 0201 (0.6mm x 0.3mm) and 01005 (0.4mm x 0.2mm) passive devices.

The implementation of halogen-free flux adds yet another complication.

Interfacial Structure in Lead Free Solder Joint

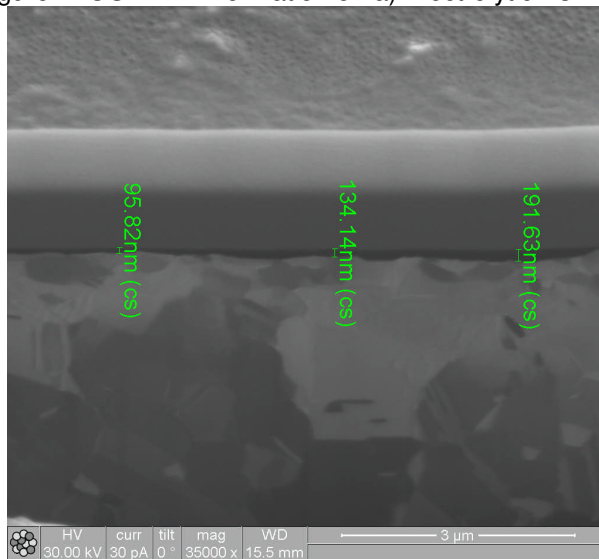
The variation in interfacial structure and IMC composition as a function of solder and surface finish composition provide valuable insights into the solder joint performance.

Organic Solderability Preservative

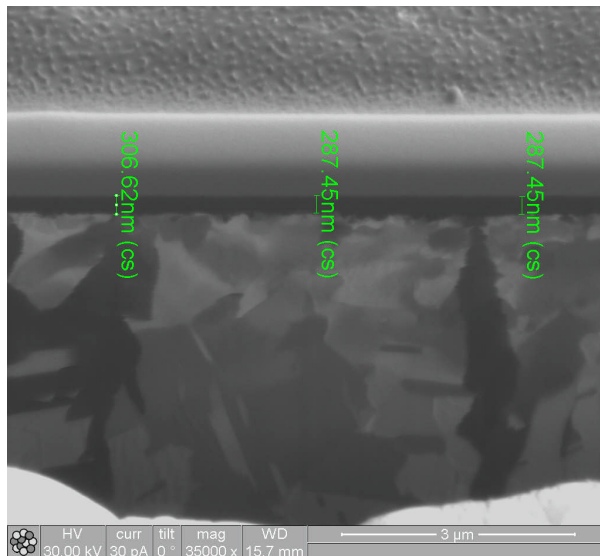
OSP functions as a barrier layer, preventing degradation of a copper metal surface until it comes into contact with solder. The OSP layer tends to level out surface non-uniformities, but this behavior may lead to local variations in the OSP layer thickness,

as shown in Figure 1. This variability may lead to uneven degrees of protection of the underlying copper. Areas with thinner OSP films may be more readily oxidized, while other areas with thicker films may also be more difficult to wet with solder, due to the difficulty of removing the film. Both of these conditions may inhibit complete wetting of the copper surface, particularly after exposure to the higher temperatures required for lead-free reflow cycles.

Figure 1. OSP Film Formation on a) Electrolytic As-Plated and b) Polished Copper Surfaces



a) Electrolytic Copper (as-plated)
- thinner and uneven OSP film



b) Polished Cu - thicker and more uniform OSP film

The primary intermetallic phase formed is Cu_6Sn_5 , over a thinner layer of Cu_3Sn at the copper-solder interface. The thicknesses of the intermetallic layers increases during aging, particularly at elevated temperatures and excessive thickness of IMC and formation of interfacial voiding, leading to brittle fracture at the interface can have an adverse effect on reliability.

In applications where the interconnection current densities are particularly high, it is possible for significant electromigration to occur and for voids to be formed at the

copper-solder joint interface. Possible approaches to limit the impacts of electromigration include substitution of alternate surface finishes and addition of trace components to solder alloys to reduce the rate of electromigration or suppress void forming. As an example, the additional of even a very thin nickel layer on a copper surface can change the structure of the IMC, by forming a ternary IMC $(\text{Cu, Ni})_6\text{Sn}_5$ layer compound which effectively reduces the rate of copper diffusion into a tin-rich solder joint (1).

Immersion Silver and Immersion Tin

IMC formation on both immersion silver and immersion tin is similar to that of OSP (2). Immersion silver encountered some early issues associated with micro-voiding at the copper-solder joint interface (referred to as champagne voids) with lead-free solder alloys. These problems have been associated with over-aggressive attack of the substrate and suppliers believe that they have been largely resolved by changes to process control and silver deposition thicknesses.

The immersion tin coating readily forms intermetallic compounds with the substrate copper at extended storage times or elevated temperatures. The changes in the deposit structure can lead to reductions in solder wettability. The typical shelf life of immersion tin is consequently significantly shorter than other finishes.

ENIG

ENIG finishes use a thin layer of immersion gold as a barrier to prevent oxidation of the underlying electroless nickel deposit. During the soldering process, the gold dissolves rapidly, allowing the electroless nickel and solder to react to form a reliable solder joint. Under equivalent reflow conditions, the rate of IMC formation on electroless nickel is slower than on copper, so care has to be taken to make sure that the assembly process is properly optimized. In the field, electroless nickel deposits with phosphorus contents between 6-10 wt% P are widely used for solder joint application. The effects of phosphorus content on IMC structure and solder joint reliability is a complex question,

with interactions with both the immersion gold process and the assembly parameters (particularly reflow profile and flux type). Electroless nickel deposits with higher phosphorus contents (11 - 12 wt%) shows good corrosion resistance, but show poorer solderability. However, such deposits have been used successfully as contact finishes, in applications where devices are used in environments that would normally cause corrosion damage to conventional ENIG surfaces. Evolution of electroless nickel formulations combined with improved immersion gold systems and optimized process control has allowed suppliers to continue to provide competitive options.

ENEPIG

ENEPIG is an excellent alternative to electrolytic nickel gold plating for wire bonding. In recent years, it has been qualified by a number of end-users and used successfully in multi-layer PCB boards. Flip chip BGA substrates are also using ENEPIG for solder joint applications.

Applications for wire bond BGA substrates as a replacement for electrolytic Ni/Au are also being commercialized. Use of suitable combinations of electroless palladium and immersion gold thicknesses provides a finish which is both bondable and solderable, while reduces the overall gold thickness

significantly (3). ENEPIG is protected from the risk of excessive electroless nickel attack in the immersion gold step, since the palladium deposit acts as a barrier.

ENEPIG can deliver good solder joint strength with SAC305 alloys during multiple reflow soldering. The thin electroless Pd layer, between the electroless nickel and gold layers, modifies the growth of the interfacial intermetallic phases. The ball shear tests show ENEPIG significantly higher solder joint strengths than ENIG after multiple reflow cycles (4).

Conclusion

Lead free solder joint technology continues to evolve, with a combination of innovative solder alloys, flux chemistries and surface

finish technologies offering improved solder joint performance.

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