Printed circuit boards-Conductor finishes: nickel-gold

Introduction

Where a flatter surface finish is needed, many companies use ‘nickel/gold’, more properly referred to as ‘ENIG’ (Electroless Nickel, Immersion Gold), in which a 3–5μm layer of electroless nickel is given a thin gold ‘flash’ coating by immersion plating, an ion exchange process which coats the whole of the nickel surface.

A PCB finished with electroless nickel/immersion gold (ENIG)

Using gold

A gold coating does not oxidise, its excellent wettability by molten solder does not degrade with time, and a plated finish maintains the flat surface of the copper lands. For these reasons a gold finish fulfils the requirements for boards designed for fine-line printing. The plated film has, however, to meet strict specifications to ensure that the subsequent reflow solder process will be satisfactory.

It used to be thought beneficial to have a comparatively thick (1.3–2μm) deposit of gold. However, with an immersion process, because nickel and gold ions are exchanged, a thick deposit can only be achieved when the gold is sufficiently porous to allow the underlying nickel to sustain the chemical reaction. But porous gold provides less protection for the nickel, which has an adverse impact on assembly. Current immersion gold processes plate 0.8–1.3μm of gold and are self-limiting, with reduced porosity compared with the earlier coatings.

Gold readily dissolves in molten solder and will be present in the reflowed solder joint. Intermetallic gold-tin compounds formed cause joints to be brittle, and the gold film must therefore be thin (<<1μm) to minimise the amount of intermetallics.

However, thin gold plating is porous, and will not protect the underlying copper against oxidation. Oxidised spots at the base of pores are a cause of dewetting, and copper can also diffuse to the gold surface during heat treatments, where it can oxidise and thus impair wettability. To prevent this, an electroless nickel underlayer is first deposited, to act as a barrier to copper diffusion: thickness specifications vary, but are usually in the 2–6µm range.

The 'immersion gold' plating process self-limits at around 0.05–0.1µm. Not only is this beneficial from the cost point of view, but this also reduces the possibility[1] of gold embrittlement caused by the formation of a Au_4Sn intermetallic phase. [Note that this process is not the same as that used to electroplate 'gold finger' edge connections]

1 This embrittlement only occurs when at least 3–5% of gold is present in the joint. Typically the gold plate needs to be 1.5µm thick before this becomes a problem.

The nickel-barrier

Because the electroless nickel is between the component and the underlying copper foil pad, the nickel plays a significant role in the strength of the joint. The weak point within the joint in an ENIG surface is the nickel deposit, and Banerji reported a wide range of bond strengths, depending on the nickel used.

Another contributor to the variation in strength is that, when joints are being made, the solder has to be liquid long enough to form a true intermetallic bond to the base conductor. Since tin dissolves nickel far more slowly than copper, joints on gold finishes can have different amounts of intermetallic and different pull strengths compared with joints made on a HASL board. Intermittent faults on ENIG joints, particularly with BGA devices[2] , may be related to incorrect reflow profiling, which has reflowed the joint, but allowed insufficient time above liquidus.

2 Joint strength is particularly important with BGA packages, due to the differences in CTE between components and circuit board. As the devices get larger, the stress applied on the solder joints increases significantly, causing stress fractures on peripheral pads.

Quality issues

The ENIG process also continues to be a challenge to fabricators. The kind of problems which occur are extraneous plating and attack on liquid photoimageable solder mask[3] (LPISM), which may be lifted near plated pads or softened over covered traces. For this reason, a great deal of work has gone on to optimise the LPISM process for cure and adhesion of the solder mask. Similarly, much development has been expended on opening out the process window between over plating and skip plating.

3 Given the cost of gold, LPISM is normally applied before the ENIG process, in order to limit the plating area.

Three main problems have been reported in using nickel-gold finished boards:

poor solderability

gold embrittlement, with consequent weakening of the reflowed solder joint

very poor adhesion of components to the board.

All these may be avoided by correct specification and plating, but the quality and reliability of the assembled board will depend greatly on the processes used by the board manufacturer. The plating line should preferably be automated, as ENIG is very sensitive to process parameters.

A vital factor is the amount of phosphorus present in the electroless nickel plating bath, which should be controlled to the level recommended by the plating chemistry suppliers. This typically lies between 8% and 14%, but varies between suppliers

Care has to be taken to avoid 'skip plating', usually caused by carry-over of micro-etch into the nickel bath, most frequently occurring in small via holes which are difficult to rinse.

Black pad

In recent years, major concerns4 have arisen from a specific mode of premature joint failure on ENIG surfaces, referred to as either 'black pad' or 'black-line nickel'. The problem was first identified on BGA components, where open or fractured solder joints would appear on occasional pads. Why black pad? Because, after the component is removed, a very dark or 'black pad' with almost no solder is seen at the affected site. A black pad is not readily solderable, but can sometimes be repaired.

4 Fortunately black pad is a low level defect which has only slightly slowed the growth of ENIG from 2% in 1996 to an estimated 14% in 2000.

Black pad is associated with a weak intermetallic bond at the solder nickel interface, so that the joint is easily fractured by stress or shock, leaving an open circuit failure. Often the failures occur during later assembly, so may be picked up at electrical test, but others will reach the end user, which has a much worse impact.

The problem seems to happen most frequently on small pads, and with fine pitch components. Whilst black pad occurs on components such as QFPs, failures are much less frequent than with BGAs. This is because QFP leads are compliant, so that the solder joints do not experience as high a stress as with a BGA.

‘Black pad’ generally occurs at a very low level, but is batch-related and can unpredictably happen much more frequently, particularly with highly-stressed BGA joints. The most difficult aspects of the problem, which make it difficult to detect and eliminate are that:

Some joints are weaker than the normal joints which surround them

The effect is at a very low level, and occurs spasmodically, making it almost impossible to reproduce the defect consistently in an experimental situation.

Investigations have failed to determine a single root cause, but have indicated that:

The mechanism for creating black pad is accelerated corrosion of the nickel surface during immersion gold processing. Instead of there being just an exchange of nickel and gold atoms, it seems that the nickel surface becomes excessively depleted before the gold finally seals it

The problem lies in the nickel layer being susceptible to corrosion, rather than the gold plating process being unusually aggressive

Solder mask may be a contributory factor – panels manufactured without prior solder mask coating seem not to exhibit the problem

Board design has some bearing on the incidence of the defect – designs which are particularly susceptible to black pad tend to have defects at the same location from board to board

There appears to be some form of galvanic cell activity that allows a small pad to be attacked in preference to a larger pad that is electrically connected to it.

Analysis of black pad failures typically shows abnormally high phosphorus concentrations in the nickel, which led to an early theory that the problem was caused by excessive phosphorus co-deposition during electroless nickel plating. However, subsequent investigations showed that this apparent excess of phosphorus was actually due to the nickel being corroded away, and it has been argued that processes5 with a higher phosphorus content, which are less sensitive to other process fluctuations, offer the best protection against the effect. [It has also been suggested that replacing the gold with a silver, tin or palladium coating on a nickel base would offer better performance as regards black pad failure.]

5 Continuing work has shown the incidence of interfacial failure to have a complex interrelationship to the thickness and deposition rates of both nickel and gold, the highest failure rates being observed with high gold deposition rate, high nickel thickness, and low nickel deposition rate.

Recent work has also indicated a relationship between black pad and solder mask cure, where materials intentionally under-cured in order to make them more pliable may be extracted into the electroless nickel bath, acting as ‘stabilisers’ and directly affecting the rate, structure and composition of the nickel deposit. The materials which caused this effect can be reduced both by better cure of the solder mask, and by specific cleaning to remove the culprit materials from the solder mask at the beginning of the ENIG process.

Summary

Overall, the present advice is that, given sufficient attention to process selection and control, ENIG will give reliable joints, but undoubtedly black pad is an issue to be aware of and to follow in the literature in coming years.

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