TECHNIC INC
47 Molter Street
Cranston, Rhode Island 02910-1032
401-781-6100 • info@technic.com • www.technic.com

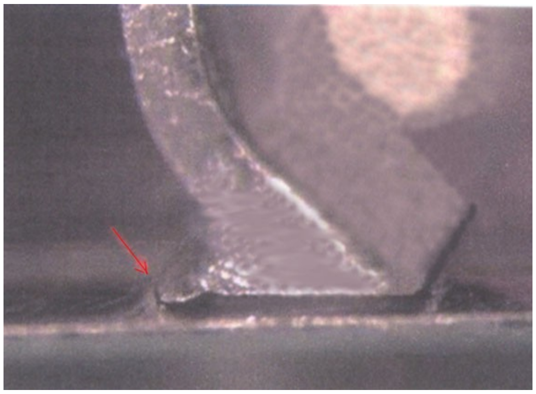
“Black Pad” - An Interfacial Surface Mount Solder Joint Failure on Electroless Nickel Immersion Gold (ENIG)

Deposits – Best Practice Recommendations

The continued shrinkage of hand held electronics, rapid expansion of surface mount component availability and the prospect of lead free solder assembly combine to drive PWB designers and manufactures toward organic solder preservatives, solderable immersion deposits of silver or tin and electroless nickel immersion gold (ENIG) as final finishes for surface mount assembly. Although all of the alternatives have demonstrated successful surface mount assembly, only ENIG provides the additional flexibility of reliable aluminum wedge wire bonding. This added compatibility with assembly alternatives has made ENIG the fastest growing SMT surface finish during the past five years. The increasing rate of adoption of flip chip assembly technology will accelerate the need for ENIG for under bump metallization. This rapid growth has changed what was the purview of a relatively few specialty contract service providers and large OEM’s into technology available to all but the smallest PWB manufacturers. The rapid introduction and adoption of ENIG technology has not been without problems.

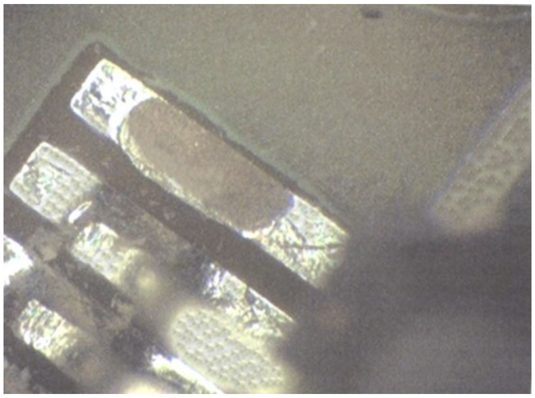
The application of electrolytic nickel and gold PWB edge contact surfaces has established that technology as capable and reliable. Thicknesses of 100 to 200 microinches of nickel on the PWB copper pad provide a solderable and bondable surface that protects against copper diffusion to the component solder joint. When followed by a thin sacrificial coating of precious metal, most typically gold, long shelf life is assured. The characteristically thin, 3 to 5 microinch, topcoat of gold protects the nickel layer from oxidation and degradation of solderability. When the gold layer reaches soldering temperature it dissolves into the bulk of the newly formed solder joint. The preferred solder connection actually occurs at the surface of the nickel on an intermetallic layer of nickel tin (Ni_3Sn_4) created during the solder joining assembly. Under normal operating conditions this intermetallic layer produces a thin, stable and highly adherent interface with good reliability. The black pad phenomenon represents an atypical nickel tin interface with unpredictable reliability characteristics.

The black pad problem is pernicious due to its low frequency of occurrence and difficulty of detection. The problem is manifested by a brittle fracture type failure of the solder joint at the foot of the component pad interface induced by thermal cycling.



Black Pad Brittle Fracture Failure

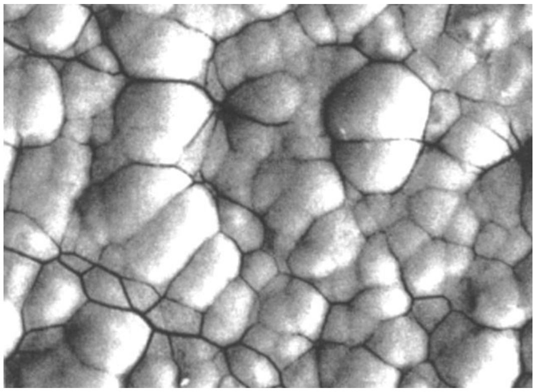
Upon detection and removal of the component lead the pad appears dark and depending on the lighting and intermetallic compounds present may be light gray, gray or black.



Black Pad Top View – After component lead removal

A complex mixture of nickel, gold and copper tin intermetallics with phosphorus characterizes surface analysis of the exposed pad surface. The intermetallic compounds take one of three general forms, M_6Sn_5, M_3Sn_2 or M_3Sn_4, where M is the metal nickel, gold or copper. The intermetallic compounds Ni_3Sn_4 and Ni_3Sn_2 tend to appear gray while those formed with gold appear white in color. The characteristic black layer that describes the pad appearance is due to the enrichment of phosphorous at the interface due to the consumption of nickel into the growing intermetallic layer. Those familiar with the typical color of an actively dissolving phosphorized copper anode will appreciate the surface enrichment of phosphorous and the resultant dark color.

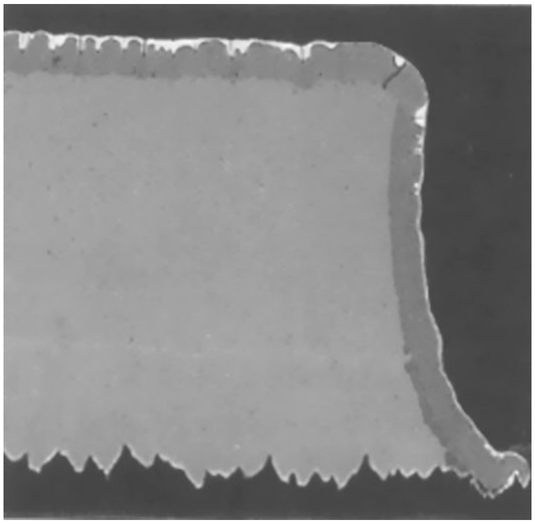
Due to the obvious accumulation of phosphorous, the electroless nickel deposit draws ones attention. When the surface gold layer on PWB's exhibiting the problem is stripped to reveal the nickel surface, it is usually characterized by a crazed or mud crack appearance.



Nickel Structure After Gold Strip

Upon further investigation, cross sections of the crazed nickel deposits reveal intergranular corrosion of the nickel. Closer examination also reveals that the preferred intermetallic formation is thin and or porous, a serious detriment to the reliability of the solder joint.

Poor solderability can also be manifested in formation of a laminar structure of alternating layers of nickel and gold. The formation of alternating layers is related to intermittent deposition of the immersion gold deposit. In the preferred reaction, the more noble metal; gold is reduced at the surface of nickel due to a displacement reaction that is based on the substantial difference of reaction is self-limiting in nature, as the gold initiates on the nickel surface and continues to reduce until the lack of available nickel inhibits the desired reaction. The formation of these laminar gold and nickel layers is responsible for the variety of nickel and gold intermetallics reported in various failure analyses. These intermetallics have relatively high melting points that retard the desired rapid dissolution of the preferred thin gold layer and result in unreliable cold joints.



Pad Cross Section Showing Gold Penetration

Board Design

Board design and circuit layout have been implicated in the occurrence of black pad failures. This theory is supported by observation that specific surface mount pads exhibit "repeater failures". Circuit designs with connections to internal ground planes or vias that connect to pads on external layers may bias surface electrical potentials. Non-uniform surface potentials may affect activation uniformity and create differential plating rates. Attempts to reproduce this effect in the laboratory have been inconclusive. Circuit design is typically not under the control of the ENIG service provider, except to the extent that panel surface area and loading rates affect plating rates and deposit thickness.

Cleaning and Activation

Uniform stripping of metallic etch resists, proper exposure and development of soldermask and bare copper activation are essential to uniform electroless deposition. Bare copper pads or vias impacted by soldermask or developer residue have been implicated in the intergranular corrosion of nickel. Clean copper surfaces promote uniform activation and rapid initiation of electroless nickel deposition. Developer residues have also been implicated in edge pull back of nickel deposits, an unrelated but frequently observed defect.

Nickel Deposition

Due to the characteristic color of the pad defect the phosphorous content of the nickel deposit has been frequently studied. Phosphorous levels in the mid range 5-9% are preferred and nominally high 7-8% is recommended. Nickel deposit morphology is related and non- uniform, thin or rough deposits should be avoided. Nickel deposit uniformity tends to improve with thickness and deposits of 120 to 160 micro inches minimum are recommended. Nickel bath formulation has been implicated to the extent that complexing agents and stabilizers affect initiation and deposition rates of the nickel deposit.

Gold Deposition

Thinner deposit of 2 to 5 micro inches are recommended except for the risk of meeting minimum thickness requirements on small isolated pads. Uniform initiation of the gold deposit is expected to limit the preferred reaction as the nickel surface is covered. Extending the exposure dwell time to meet thickness requirements is counter productive if the initial gold layer contains pores. The gold bath formulation has been implicated based on the observation that different complexers influence the rate of intergranular corrosion.