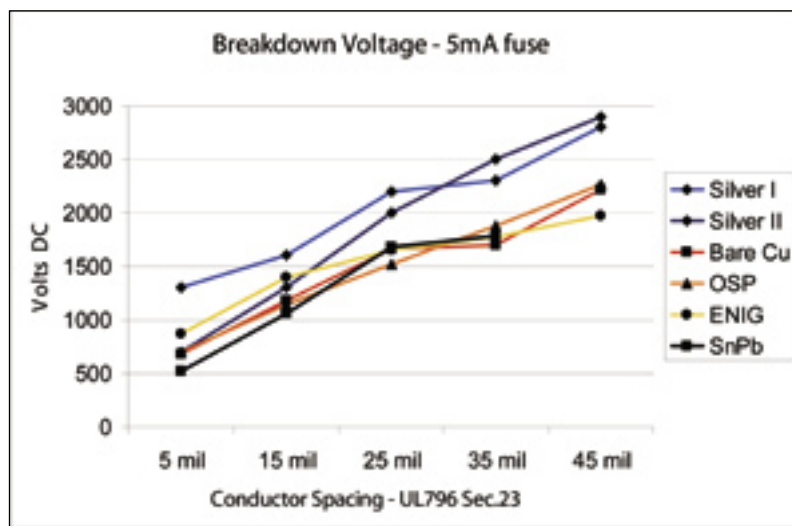


# Underwriters Labs Compliance Of Immersion Silver PCB Finish

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The transition in the use of Circuit Board surface finishes has been one of the most dramatic in the history of PCB manufacturing. The use of Hot Air Solder Level (HASL) to replace reflowed Tin-lead was a major transition in the 1980's. During the 1990's, the use of OSP grew to more than 25% of the market. Electroless Nickel Immersion Gold (ENIG) was chosen increasingly in the late 1990's, reaching more than 20% of board finishing. Another transition is now under-way. During the past two years, the use of Immersion Silver has grown dramatically to the current level of about 8%.



Figures 2 - Dielectric withstand test results

More than 40 years ago, there were failures in the electronics industry attributed to the use of Silver as a conductor material. Failure was due to a phenomenon known as 'electrochemical migration' or 'dendrite formation.' As a result of that experience, some safety and specification groups wrote specifications restricting the use of Silver in circuitry. Underwriters Laboratories, concerned with the prevention of fire and shock hazards, included text in UL's documents concerned with the manufacture of printed circuit boards. The principal document affected was UL 796, UL Standard for Printed Wiring Boards. This document refers to

the use of Silver in sections 7.2 and 9.1.6c, and provides a migration test method for the use of Silver in section 23.

## Silver finish

Silver is the only PCB surface finish with specific testing requirements. The unique specification for recognition of Silver by Underwriters Laboratories (UL) is being addressed by the IPC 3-11g program. IPC 3-11g is a group of circuit board manufacturers, OEM's, chemical suppliers, and testing labs that convened in order to assist UL in updating their standards. The

goal of this team is to determine if Silver still poses a unique dendrite risk, update the test methods employed by UL, and determine if UL restrictions on the use of Silver are still appropriate. The industry group working on this issue began as an Ad Hoc committee under a broader UL/IPC umbrella. In late November 2002, IPC proposed to recognise the group officially as IPC's 3-11g Metal Finishes Data Acquisition Task Group within the IPC 3-10 Printed Board Base Materials Committee.

## Brief History of IPC-3-11g

The goal of the team is to remove the restriction on immersion Silver from UL documentation. The members of the team feel that immersion Silver is safe based on at least eight years of experience as a PCB board finish. There are now hundreds of millions of electronic devices in use made using immersion Silver. No case of immersion Silver-induced electrochemical migration failure has been documented. Since 2001, the team has worked with special-



Figure 1 - a) High-voltage source used in withstand voltage test and b) test pattern after electric arc

ists at UL to explain the testing and performance of board finishes. The 3-11g team has updated their test methods, and are now working to show that immersion Silver performs exactly the same as all other board finishes from the perspective of electrochemical migration.

### Underwriters Laboratories

In the area of electrical systems, UL is primarily concerned with the prevention of two hazards, fire and shock. UL maintains a core document, UL-796 Standard for Printed Wiring Boards, to describe the testing and safety requirements regarding the manufacture and use of rigid circuit boards containing the testing methodology specific to Silver. At first, UL only required the "Silver Migration" test for PCB's to be used in non-LVLE applications. Low Voltage Limited Energy (LVLE) devices were not subject to specific migration testing. However, the various UL groups associated with different end-use segments differed in setting the limits defining LVLE. UL itself began to find difficulty administering the LVLE classification. During 2002, UL decided to eliminate the LVLE designation. It was recognised that many PCB designs would be easily served by the simpler recognition category termed "flammability only." With the transition of LVLE to the flammability-only rating system, UL effectively required Silver migration testing only on designs requiring recognition higher than flammability-only. This transition did seem to ease the interpretation among end-use groups as to which products classified as LVLE. However, there was still ambiguity within the OEM decision-makers as to whether specific part numbers should require flammability-only recognition, or a more rigorous full-recognition designation.

### Electrochemical migration

Metals subjected to humidity and

Test vehicle standard spacing:	12 mils (0.3 mm)
Other test vehicle spacing:	fabricator's choice
Withstand voltage (proof test):	40 volts/mil (1.6 kV/mm); 1000V max
Conditioning chamber temperature:	35°C +/- 2°C
Conditioning chamber relative humidity:	87.5 +/- 2.5% RH
Time in chamber:	56 days (1344 hours)
Electrical bias in chamber:	requested voltage rating

Table 1 - Conditions for Silver migration test in UL 796, Section 23

electrical bias will form dendritic growth in the presence of corrosive electrolyte. Conducting ions within the electrolyte may derive from corrosion of the metal conductors, or from improperly cleaned circuit board substrates. Contamination may derive from the manufacturing of the bare PCB, subsequent handling, or from the application of corrosive fluxes without adequate cleaning. Studies have determined that failure due to electrochemical migration is based primarily on the cleanliness of the parts. In fact, during the transition to so-called 'no-clean' assembly for environmental reasons during the 1980's and 1990's, the topic of electrochemical migration was thoroughly investigated.

New coatings for protecting the solderability of the boards (PCB surface finishes) have been tested according to the migration and SIR test methodologies to ensure compliance. In addition, new immersion Silver processes are designed to overcome the threats to repeating the dendrite formation.

For clarification purposes, the phenomenon of dendrite formation is different from whisker formation and conductive anodic filament (CAF) formation, although the three defects are frequently confused. The occurrence known as whiskering is linked to intermetallic formation and the deposit's crystal stress. Stress results in movement, and as the metal grain boundaries slide, they force single-crystal whiskers up to 200 microns from the surface. The concern is that whiskers can act to short-circuit closely spaced conductors, change impedance values, or act as RF antennas. Whiskers seem to appear only in Tin and Zinc, whereas

dendrite formation can occur with any metal. In the future, as a separate project, the 3-11g committee plans to review restrictions applied to Tin by Telcordia and other organisations. Conductive anodic filament formation involves a growth of conductive metal salts, usually along capillary-like fractures with-

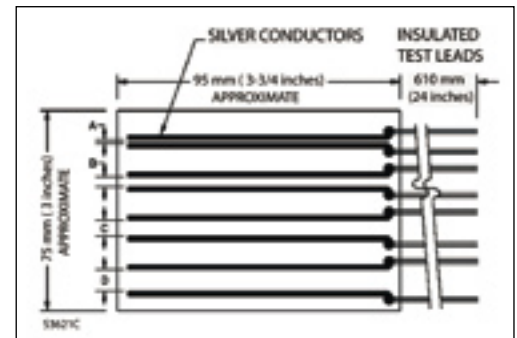


Figure 4 - Schematic design guide for test boards as described in UL 796

in PCB substrate materials. CAF formation is largely dependent on substrate material and drilling parameters. Interestingly, some of the early literature reporting electrochemical migration was actually what would now be termed CAF. The inferior substrate materials of the time, such as paper phenolic boards, were vulnerable to CAF formation.

### Circuit board surface finishes

With new circuitry designs, the electrical and surface contact properties of the coating may become the highest priority when selecting a board finish. Immersion Silver consists of a very thin (0.15-0.55 micron) coating of nearly pure Silver. In this aspect, immersion Silver is 100x thinner than traditional electroplated Silver deposits. A slight amount of organic material is typically deposited within the

immersion Silver intended to prevent tarnish and electromigration. The metal coating is deposited via a relatively simple conveyorised or vertical chemical process. Benefits of immersion Silver include flatness, Pb-free, inspectability at assembly, lack of soldermask attack, and surface contact functionality. Relative to other PCB coatings, immersion Silver does not suffer from the black-pad interfacial fracture phenomenon, Tin-Copper intermetallic shelf-life reduction, whisker formation, or sensitivity to weak fluxes. For these reasons, OEM's fabricators and assemblers have increasingly used and specified immersion Silver during the past 10 years.

Environmental Protection Agency worked with Raytheon to study new Pb-free finishes, Silver was compared to HASL, ENIG, OSP, reflowed Tin/Lead, and immersion Tin. In this study, all finishes were corroded with dilute acid and allowed to form dendrites during this testing; "While some dendrites were found, there was no correlation to surface finish." Dendrites will form on any surface as long as there are residual ions, electrical bias, and condensing environments. As a consequence of this extensive testing, immersion Silver is now chosen by military board suppliers in the avionics, navigation, and space equipment fields. Many other OEM's have had similar results in testing migration of various board finishes.

bridged the air gap. Figure 2 clearly demonstrates that the withstand voltage of a pair of parallel conductors is purely a function of conductor spacing, not surface finish. Following the demonstration, UL acted quickly to modify the withstanding voltage to a more realistic 40 volts/mil (1000V max). UL later modified the specification for environmental conditioning from 95-100% RH to 87.5% +/- 2.5% relative humidity. In this way, condensation of water on the test sample, and therefore certain failure, was avoided in the test protocol. UL acted on the humidity requirements following the testimony of industry experts, in addition to demonstration tests conducted at Microtek Labs.

#### Current method for UL recognition

Before discussing the latest progress within 3-11g, it is probably wise to review the UL Silver recognition method as of January 2004. Many fabricators and OEM's are unsure as how best to achieve UL compliance. The following steps may provide helpful direction. Be aware that as the 3-11g committee interacts with UL, the procedures are generally becoming less complicated. In fact, the Silver migration test may not be required at all for immersion Silver PCB finishes:

- A PCB fabrication company that uses immersion Silver as a board finish should contact its regional UL representative.
- The first step is to inform UL of the fabricator's use of immersion Silver.
- At this step, the UL engineer will ask the fabricator whether the application is for flammability-only or full-recognition parts.
- The fabricator should then de-

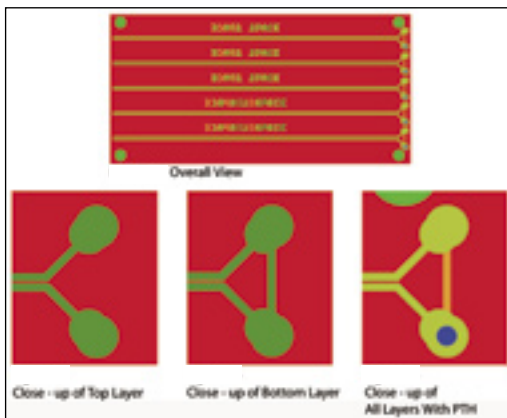


Figure 3 - Test board design recommendation for use in submission to a UL-certified lab

#### Electrochemical migration testing of immersion Silver

Environmental stress testing of Silver coatings has included exposure to corrosive fluids, severe shock, and rigorous aging. Many tests were conducted under applied bias. These studies were very useful in answering the questions about dendrite formation. When the USA

#### UL's withstand voltage test method

UL's 796 Section 23 details a procedure to be used for testing migration of Silver used in PCB's. Basically, the procedure as presented in the 8th edition involved: 1) withstand voltage test, 2) environmental conditioning at 23°C/ 95-100% RH energised at the maximum voltage, 3) follow-up withstand voltage test, and 4) visual inspection for dendrites. The method as given in this document was difficult to pass when applied to modern PCB line spacings. In December of 2001, the 3-11g committee demonstrated the withstand voltage test at a conference: in all cases, the applied voltage formed an electrical arc through the air between the conductors. The method did not test for electrochemical migration or result in any dendritic growth. Figures 1a and 1b depicts the test equipment used and a magnified view of the test coupon after an electrical arc

Table 2 - Conditions for 3-11g Silver migration test comparisons; proposed (left) and actual (right)

Parallel	12/4		12/12		Comb	
	12/4	12/12	4/4	6/6	12/12	25/50
1V/mil	4V	12V	4V	0.7V	12V	50V
20V/mil	80V	240V	80V	80V	240V	96V
10V fixed	10V	10V	10V	10V	10V	10V

Parallel	12/4		12/12		Comb	
	12/4	12/12	4/4	6/6	12/12	25/50
1V/mil	4V	12V	4V	6V	12V	50V
20V/mil	80V	240V	80V	120V	240V	1000V
10V fixed	10V	10V	10V	10V	10V	10V



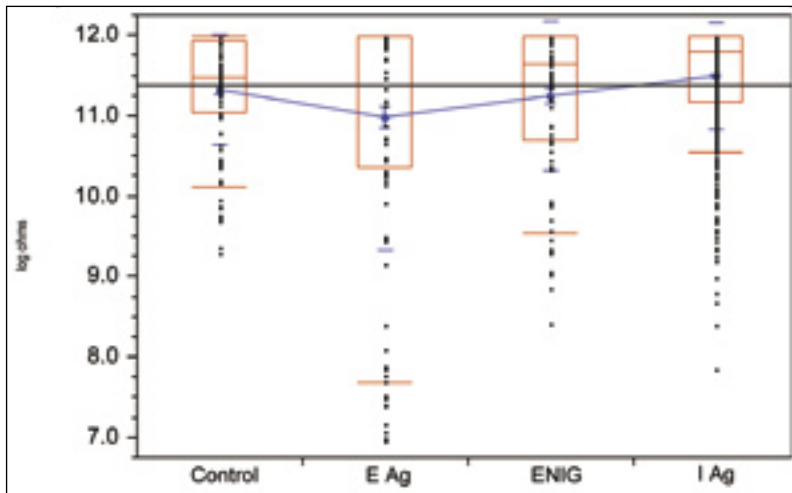


Figure 5 - SIR test results at 96 hours

termine from its OEM customers whether or not any boards require recognition higher than “flammability only.”

- For “full recognition” boards, the fabricator will need to certify with UL for producing such product.
- Submitting samples for UL testing. The fabricator has the option of also submitting a control finish such as OSP or bare Copper.
- The test requires a dielectric withstand “proof” test, 56 days in a humidity chamber energised at the maximum desired voltage, a follow-up dielectric “proof” test, and visual inspection. The PCB shop will be certified according to the minimum spacing and maximum voltage that passed test requirements. These notes will be added to the company’s UL file. As of January 2004, details of the modifications UL has made to the updated test method are not included in older versions of UL 796. Updated conditions are given in Table 1. Test vehicle specifics are shown in Figures 3 and 4.

#### Recent 3-11g electrochemical migration testing

A central goal of the industry members of the 3-11g committee was the elimination of testing that specifically applied to immersion Silver and did not apply to other PCB surface finishes. It was the team’s sentiment that there was no performance difference between com-

monly used surface finishes with respect to migration and dendrite formation, so special requirements for Silver were arbitrary and discriminatory. The industry members presented various sets of data to UL in support this claim. The data sets, however, did not form a seamless, convincing story, due to the numerous authors, test methods, and controls. Table 2 summarises the voltage and line spacing conditions tested in the 3-11g experiment. The team decided to test the standard UL method, the standard IPC method, and a set of conditions which adopted parameters from both methods. For example, the IPC method calls for 596 hours under temp/humidity; in the 3-11g test, the samples were measured after 596 hours as well as the 1344 hours typical of the UL methodology. The applied voltages

were selected to cover all possibilities, but were somewhat restricted by the actual equipment available.

Surface finishes:

- Bare Copper (control)
- Electroless Nickel Immersion Gold (ENIG)
- Electrolytic Silver
- Immersion Silver (four vendors)

Test methods:

1) UL 796 Section 23:

- withstand voltage test at 40V/mil;
- environmental conditioning at 35°C/ 87.5% RH for 1344 hours under applied bias applied voltage to be determined by fabricator according to desired rating, 1/8 amp fuse;
- repeat withstand voltage test at 40V/mil;
- visual inspection at 10x for dendrites;
- UL 796 Figure 23.1 test pattern (parallel conductors modified for spacing).

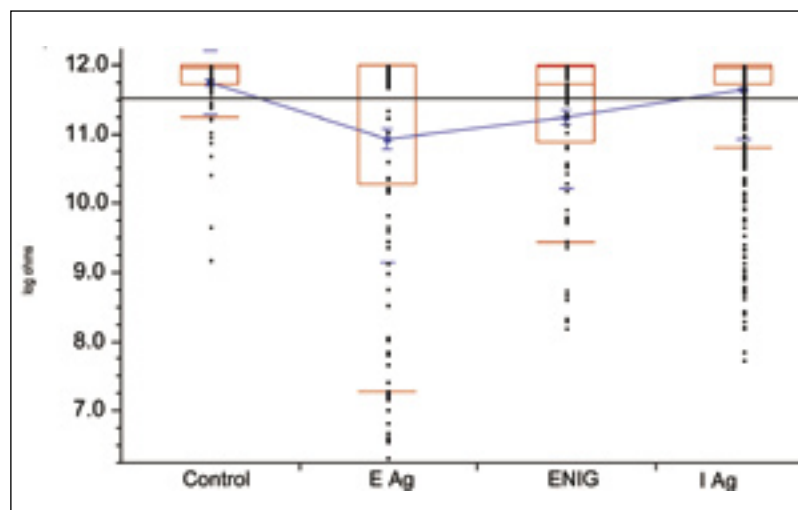
2) IPC TM-650 2.6.14.1

- 96 hours at 35°C/ 85% RH, measure SIR;
- 500 hours at 35°C/ 85% RH under 10V applied bias, measure SIR;
- visual inspection for dendrites;
- IPC-B-25A test coupon (comb pattern modified for spacing), 1Meg. current limiting resistor.

The experimentation was conducted according to the following project goals:

- Determine if immersion Silver is any more vulnerable to electrochemical migration relative to oth-

Figure 6 - Electrochemical migration test results at 596 hours



er finishes.

- Determine if the IPC (Telcordia) method is more/less rigorous than the UL method for electrochemical migration testing.
- Identify the utility of all new finishes to resist electrochemical migration.
- Institute an exception for immersion Silver within UL-796 so that no special testing is required by fabricators using the finish.

Figure 5 shows the measured insulation resistance of all finishes after three-day stabilisation in the temperature and humidity environment without applied electri-

cal bias. faster formation of dendrites in theory, but higher voltages may also lead to the destruction of those dendrites once formed.

All data presented so far represents measurements taken using the IPC test method. The UL test method did not provide any failures or information for graphical representation. Each of the sets of parallel patterns on the test vehicle (Figure 8) passed the initial dielectric withstand test and passed the final dielectric withstand test. None of the 1/8 amp fuses was tripped during the 1344 hours under temp/humidity/bias.

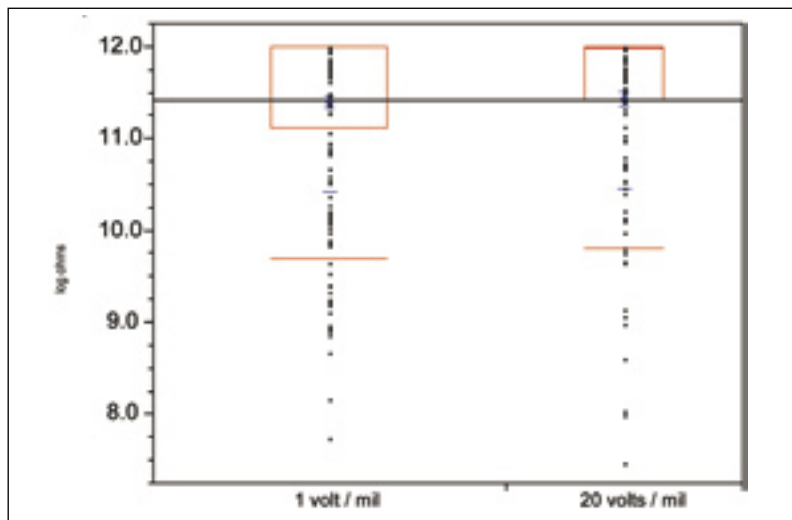


Figure 7 - Electrochemical migration test results at 1344 hours

cal bias. There was no substantial difference among the bare Copper, electroless Nickel, immersion Gold, and immersion Silver finishes. There was an overall lowered resistance value for electrolytic Silver, labelled E-Ag in the following figures. Figure 6 shows the same data for the samples following environmental conditioning under electrical bias for 500 additional hours. In addition to the typical 10V applied bias, these summary charts include all voltage settings tested: 1V/mil and 20 V/mil.

Figure 7 shows a comparison of results obtained using different applied voltages, 1V/mil and 20 V/mil. The results support the hypothesis that higher voltages do not lead to a higher failure rate. Higher voltages may lead to the

### Beyond immersion Silver

Due to historical concerns over the electrochemical migration failures of thick, pure, electrodeposited Sil-

ver, Underwriters Laboratories implemented a restriction on the use of Silver in high-energy electronics. A group of industry members with a stake in the implication of UL's procedures formed an Ad Hoc committee to investigate the situation. The group later became the IPC-3-11g Metal Finishes Data Acquisition Task Group. IPC 3-11g worked closely with UL starting in late 2001 to review, revise, and recommend the procedures used in UL-796 to test for electrochemical migration. The teamwork of the committee with UL proved to be a very positive experience, resulting in numerous interim adjustments to the test methods. The group eventually conducted extensive testing and produced data supporting the hypothesis that immersion Silver has no increased tendency to exhibit dendrite formation. With supporting test results, UL engineers will propose an exemption for immersion Silver that would allow full recognition of fabricators using immersion Silver without additional costly testing (all non-related recognition procedures, such as substrate and soldermask testing, is unaffected by the proposal.) Nearing the conclusion of this successful and intensive project, the 3-11g committee is refocusing its efforts on other projects, such as the use of Silver-filled conductive adhesives, Pb-free solders, and Tin according to various regulatory groups.

*This article is based on a paper originally presented at the IPC Printed Circuits Expo, APEX and Designer Summit 2004*

Figure 8 - Test vehicle used in 3-11g Silver migration test comparisons

