Silver & Change
A Tale of Silver, Copper, Nickel and Gold

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Change is all around us. Change is inevitable. In the small, specialized world of PCB surface finishing, this axiom is especially true. Over the past ten years, the only predictability in circuit board finishing has been steady, evolving, persistent change. And similar to the coins that make-up history's pocket change, the metals defining the changes in PCB are Copper, Gold and Silver.

Within the modern generation of SMOBC, the first assault on Tin/Lead Hot Air Solder Level (HASL) came in the form of Copper – specifically Organic Solderability Preservatives (OSP's.) This change was embraced by fabricators as an inexpensive and user-friendly alternative to HASL. OEM's jumped on the OSP bandwagon as an easy path towards flat circuitry. For the assemblers, however, it was a different story. OSP meant incomplete solder coverage, "red-ring," lowered shelf-life, stricter handling, and new equipment to accommodate Nitrogen reflow environments. Still, the movement to Copper/OSP surfaces became a mass migration in the mid 1990's.

Figures 1a,b: Use of PCB Surface Finishes in 1995, 1997 (TMRC)[1]

The next assault on HASL was Electroless Nickel Immersion Gold (ENIG.) This time, the OEM's and assemblers teamed up to have their way with the PCB fabricators (with the assistance of the chemical suppliers, of course.) ENIG's wetting was far superior to OSP's; especially when samples were thermal stressed. Its shelf life was virtually unlimited, and it could be used for contacts, ICT, e-test, touchpads, and Aluminum wirebonding. The downside? The downside was, and continues to be, fabricator difficulty. For eight years, fabrication engineers have stationed themselves by the ENIG lines of the world trying to wrangle processes into a predictable system. They implemented automatic analyzers, replenishment schemes, and new QA testing techniques to conquer overplate, skips, and the dreaded black-line Nickel. The heroic efforts of engineers catapulted ENIG as the finish of choice for high tech boards. Showing the strengths of its advantages, ENIG commands a sizable share of today's PCB finishing market. Tragically, the Achilles named ENIG may be falling to injuries inflicted by fracturing solderjoints.

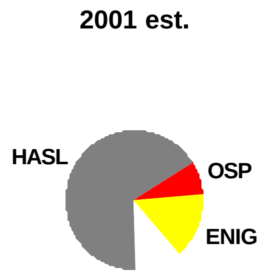
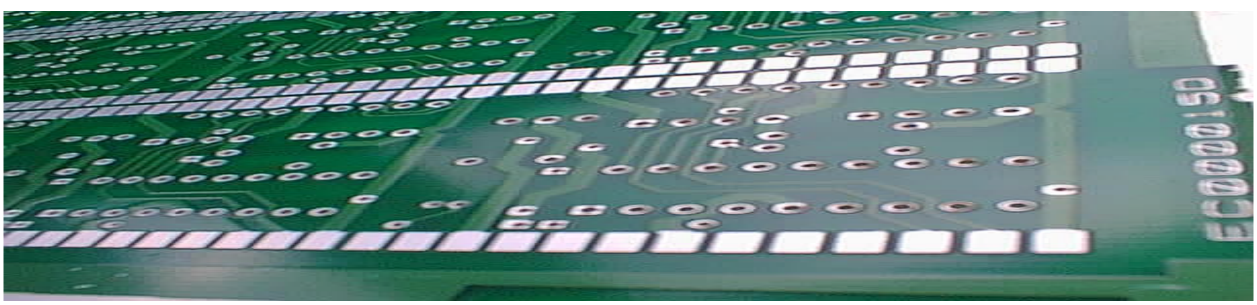


Figure 2: Use of PCB Surface Finishes in 2001est. (TMRC)[1]

Meanwhile, an alphabet soup of industry and government groups (ITRI, IPC, PMTEC, CCAMTF, US EPA, NCMS) were conspiring to find the "ultimate surface finish." Their goals: the ease and cost of OSP, the wetting and surface conductivity of ENIG. Yes to Al wirebonding. No to N_2 reflow. They found it. In test after test, Silver was a winner.[2,3,4,5,6] Members of these groups soon wrote Silver on their board's specifications. Some stories of this evolutionary change are given below.

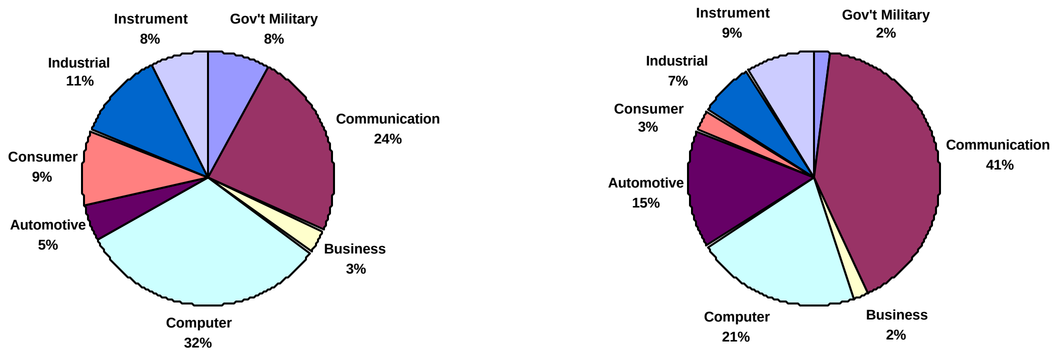
"Emerging" Silver

This article describes case histories of OEM's who have transferred specification to Silver. Each type of OEM has a unique set of reasons for spending the time to re-specify board finish. As the selection for Silver trickles down throughout the electronics supply chain, legions of engineers and procurement staff at every level become aware of this new technology. How's the surface contact? What kind of handling and storage should I expect? Have electromigration concerns been resolved? How thoroughly has Silver tarnish been studied? Is an adequate fabrication base available? Does Silver cover all bases, eliminating the need for all alternatives? (No. A variety of products should continue to demand functions suited for a variety of surface finishes.) Some experiences within the electronics industry are presented in this article. To save space, I've intentionally avoided the chemical mechanism and fabrication process details that have been previously presented.[8]



Segments of the Market

The IPC's Technology Marketing Research Council categorizes circuit board use into the industry segments detailed in Figure 2. Equipment in each segment relies on different functional performance. For example, mobile phones should have a conductive surface for keypads and strong solderjoints to accommodate phones dropping out of pocketbooks. As such, the use of certain finishes will dominate each equipment sector (ENIG has been the dominant finish in mobile phones.)



Figures 3a,b: Segments within the Electronics Industry; Equipment, Rigid Boards [7,1]

Telecommunications

The telecom sector was perhaps the first sector to really embrace Immersion Silver. Communications represented $284.2 Billion of the 2000 electronics equipment industry[1] and a staggering 41% of rigid boards in 2000. Of the top ten companies within the sector, seven have studied Silver to a significant degree. One large producer in particular has specified Silver on new products and has aggressively re-specified older board designs to take advantage of Silver's benefits. Priorities for telecom producers include bare board inspectability and signal integrity.[9]

Telecom:	Inspectability and Signal Integrity

Inspectability relates to the use of OSP in particular. In the past, a leading yield loss at assembly was non-wetting due to soldermask contamination. An extremely thin residue of mask on copper is invisible at bare board inspection, but is enough to prevent soldering. OSP does not change the color of the PCB, so boards with mask residue would fail at assembly. The use of Silver, however, changes the color of the Copper. Contaminated pads will not plate, showing up at fab as Copper "skips." Mask residue is now rejectable as a bare board rather than as a PCB assembly. Rejecting the board prior to assembly can save 90% of the cost of the rejected parts. This logic also applies to yield loss due to incomplete Tin removal.

Signal integrity is especially important in the telecom sector that was snake-bit by Silver electromigration in the 1950's[10]. In modern equipment, surfaces must pass Telcordia specifications. New immersion Silver is deposited at such a thickness and composition that exceeding Telcordia standards is easy. This issue has been thoroughly examined to the satisfaction of OEM's. Signal integrity also applies to the topic of insertion loss at high RF signal frequencies. As the best electrical conductor, Silver is attractive for next generation equipment that will operate into the high GHz.[11]

Overall, Immersion Silver has been well adopted by communications equipment manufacturers and has been used to manufacture billions of solderjoints successfully. Use by prominent companies has been a major driver toward worldwide use of Silver at fabrication. Each manufacturer may require a supply chain of 20 PCB fabricators or more.

Internet

A special case within the communications sector is the group of manufacturers that supply internet enabling equipment. In this quickly evolving field of technology, other functional needs are of higher importance. Major OEM's have been particularly reliant on ENIG for shielding, multiple reflow wettability, and overall flatness for fine-pitch devices (< 1.0 mm BGA). Use of ENIG on the extremely high-tech circuitry of the PCB's supplied into this sector became a problem with the increased detection of black-line Nickel failures. Internet equipment manufacturers needed an ENIG exit strategy that would provide flatness, low cost, and contacts for shielding. An adequate supply base of PCB fabricators offering Silver was an additional requirement.

Internet: Fix for Black-Line Nickel

Silver surfaces are not susceptible to black-line Nickel interfacial fractures. The solderjoints resulting from soldering to Silver are identical to those formed from well-soldered HASL or OSP; they are Copper-Tin intermetallic solderjoints. The Copper-tin solderjoint is preferred not only due to vast industry experience with the metallurgy; it is known to resist brittle fracture from tensile, shear, and shock.[2,12,13] Silver excelled in other stringent testing of shelf-life, conductivity, etc. Once a sufficient fab base was installed (now over 100 fabricators), some OEM specifications were re-written.[14]

Computer and Peripherals

The largest sector within electronics for the year 2000 was computer and peripherals. This segment comprised 32% or about $380 Billion. There are, of course, many various technical challenges directed at the surface finishes used by the numerous types of boards used within this sector. A key example is the motherboard used as the centerpiece of most systems. These boards are especially sensitive to two drivers: functionality and size. As such, microvias are included as a given part of standard motherboard designs. Silver is used to form a quality deposit with extremely good ionic cleanliness in these tiny structures. In addition, Silver must remain functional following the tenting operations subsequently performed on the boards. Silver is already used on less expensive product within the computer system. Use of Silver as a finish for motherboards is under investigation and may transition within one year.

Printers and data storage are examples in the computer peripherals segment. Disk drives are certainly affected by the forces of size, cost, and functional performance. Think about the growth in data storage capabilities during the past several years. My run of the mill laptop in 1995 came equipped with 500 MB of hard disk capacity. Today's units of similar price arrive equipped with 20 GB; an explosion of 40X. Functionality requires fine pitch; fine pitched components require a flat surface. Enhanced electrical processing requires double-sided assembly. Thin form factors require surface conductivity to replace soldered connectors. Low cost and durability in exposed environments are other demands.

Computer Peripheral: Long-Term Surface Contact, Low Cost

In one production case, the Silver coating was found to tarnish when exposed to accelerated age conditions. The surface was required to maintain its low contact resistance, so tarnish was a wake-up call. Overaggressive testing is a good way to proceed in these cases. The surfaces were exposed to mixed flowing gas for varying lengths of time to build a database comparing visible tarnish to contact resistance. If that wasn't tough enough, contact resistance was measured using extremely low force, non-penetrating probes. The Silver surfaces performed surprisingly well in maintaining sufficient surface conductivity. Full deployment of Silver on the parts within the peripherals sector is proceeding.

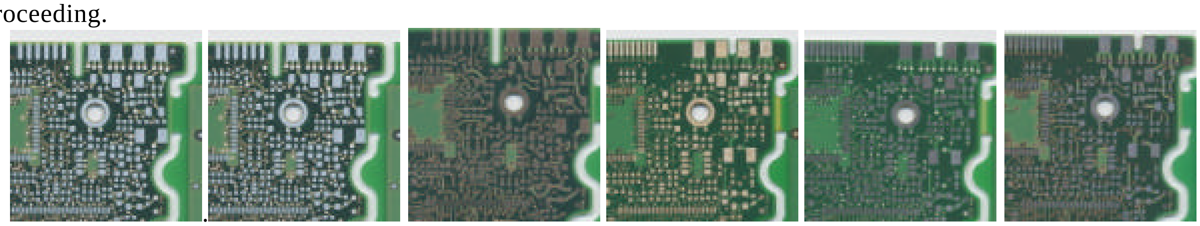


Figure 4: Silver as plated, and following 2 reflows, 3 months in plating room, ammonium sulfide, solid sulfur, mixed flowing gas (left to right)

Tarnish of Silver remains a concern for some. Others have studied the effects and have put the tarnish in perspective. For example, environments that tarnish Silver will render OSP non-functional even more quickly. Solderability of tarnished Silver is only affected once the tarnish is well visible; this is only achieved under aggressive environments. Tarnished Silver on non-soldered areas does not increase any tendency towards electromigration.[15] Perhaps most importantly, electrical contact remains quite good even on surfaces tarnished by mixed flowing gas.[16] Silver's performance rivals ENIG in contact and appearance after MFG.

Cost reduction is a major driver in any industry segment. Within computer equipment, the cost pinch may be most competitive. Due to the shear numbers of units produced every day, the effect of reduced costs is perceived most acutely in computers. Use of Silver is indeed a cost-saver. In a study conducted by the US Environmental Protection Agency, the overall cost of immersion Silver processes was determined to be lower than the cost of operating HASL.[5]

Automotive

The use of electronics within automobiles has a long history. Certainly, electronics are becoming more pervasive within today's vehicles as each function becomes automated and regulated. I understand that now there's even circuitry behind my side-view mirror to help it defrost. As the use of PCB's in autos climbs past 30/car, the market for automotive electronics should easily surpass 2000's share of $57 Billion. Already, 15% of rigid boards are used in automotive applications. The motivation at automotive companies to study surface finish alternatives includes functional and environmental planning. More than other industries in the USA, the automotive sector has embraced the push towards Lead-Free.

Automotive: Pb-Free, In-Circuit Testing

The huge volumes of product produced within the automotive sector warrants different levels of testing than other products. Liability is always a concern, so testing is especially extensive. Reports from experimentation with Silver date back to studies started at least five years ago. Research included mid-assembly soldering, ionic cleanliness, resistance to moisture, and surface conductivity. Conductivity is a central issue for production of large numbers of circuitry. Surface contact allows for more reliable in-circuit testing, which will maximize the yield of high running part numbers.[17] The excellent electrical conductivity of Silver was again demonstrated in this testing (see Figure 5.) A word of caution, however; parametric ICT may be sensitive to the extreme thinness of immersion Silver. Alternative probe tips may be required to accommodate the hardness of the underlying Copper substrate.

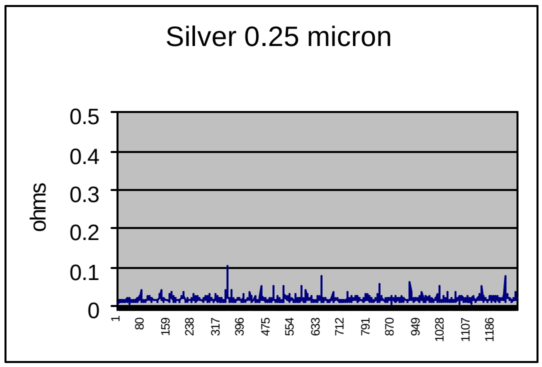


Figure 5: Surface Contact Resistance of Silver

Military

Military electronics spending during the past several years has been lower as a percentage than it had been in earlier years. Eight percent of electronic equipment ($91 Billion) was military in 2000. Tragically, recent events will most assuredly raise this measure in the short-term. As might be expected, solderjoint reliability is a serious issue within the military's electronic assemblies. In the arena of ICBM's, Humvees, and AWAC's, field failure is not an option – and the field can be somewhat strenuous. Industry groups comprised of military members have studied surface finishing extensively for many years. The series of reports resulting from these consortia has demonstrated the thoroughness of the test methods.[18] In many ways, the statistical treatment of the data has been most impressive.

Military: Solderjoint Reliability

Silver coatings endured a great deal of torture in military-type experimentation including exposure to nasty fluids, severe shock, and rigorous aging. Many tests were conducted under applied bias. Jim Reed's excellent summary of this work as printed in July 2000's PC Fab finishes with, "Immersion Silver and Immersion Gold on Palladium are 'drop-in' replacements for solder at assembly; though, the Silver process is more available."[19] This work was also very useful in answering the questions about dendrite formation. All finishes were corroded with dilute hydrochloric acid and allowed to form dendrites during this testing; "While some dendrites were found, there was no correlation to surface finish."

Mobile Telecommunications

No article discussing the segments of the electronics industry would be complete without some discussion of wireless phones. Mobile phones represent a huge number of boards produced each year; Dataquest reports production in excess of 400 million phones in 2000 and each phone may typically contain two PCB's. While mobile communication is dependent on the usual cost, yield and size drivers, phones pose a series of challenges specific to its industry segment. Of note is the ability of a solderjoint to withstand the high impact experienced when the consumer drops, throws, slams, or otherwise abuses the product. Joints made from Nickel-Tin intermetallic have been ubiquitous in the mobile phones due to the need for ENIG as a keypad surface. As previously referenced, studies confirm that the ENIG solderjoint is more brittle than the Copper-Tin solderjoint.

Mobile Phones: surface contact, copper/tin solderjoint

To answer the demand for sound solderjoints as well as surface contact functionality, most mobile phone producers have Silver well along into prototype programs. Already, Silver is used in production for equipment sensitive to high-frequency signals – cell base stations.

Immersion Silver is in the market. It is used at PCB fabricators and it is specified for production use at EMS and OEM. This latest evolution in metal finishing for electronics has been and will continue to be well studied. This article intended to gather the experiences of many engineers into one library of references. Yes, change is underway; but in every change, there's a Silver lining.

REFERENCES

1. IPC Technology Market Research Council, 2001 Program Volume 1, June 2001

2. B.Houghton, et al, "Alternative Metallic PWB Finishes; An Update on the ITRI/ October Project", IPC Expo Proceedings March 1998

3. W.Johnson, et al, "Evaluation of Solderability of Pb-Free PWB Finishes with Pb-Free Solders," Auburn University/ PMTEC, June 2001

4. R.Iman, et al, "Screening Test Results for Developing Guidelines for Conformal Coat Usage and for Evaluating Alternative Surface Finishes," CCAMTF Report, June 1998

5. D.Singh, et al, US EPA Design for the Environment – Pb Free Surface Finishes, Cleaner Technologies Substitutes Assessment; IPC Expo 2000 Proceedings

6. J.Kokas, et al, "Surface Finishes Team Final Report," NCMS, October 1996

7. W.Custer, "Global Electronics Industry - Electronic Equipment Production," September 2001

8. D.Cullen, "New Generation Metallic Solderability Preservatives: Immersion Silver Performance Results", IPC Works September, 1999

9. G.Wenger, R.Furrow, "Immersion Silver Surface Finish: Usage Requirement Test Results & Production Experience", AESF SurFin Proceedings June 2000

10. S.Chaikin, "Silver Migration in Printed Wiring." Industrial and Engineering Chemistry, March 1959

11. D.Cullen, et al, "Effects of Surface Finish on High Frequency Signal Loss using various Substrate Materials," IPC Expo 2001 Proceedings

12. D.Cullen, et al, A Study on Interfacial Fracture Phenomena of Solderjoints Formed using Electroless Nickel Immersion Gold Surface Finish," ITRI Core Team, IPC Works September 2000.

13. Z.Mei, et al, "Interfacial Fracture of BGA Packages on Electroless Ni Immersion Au and its Relation to Plating Process," IPC Summit on PWB Surface Finishes and Solderability, September 1997

14. News Update "Cisco Approves Immersion Silver and Tin," CircuiTree, August 2001

15. R.Michalkiewicz, "Report 48991 Bellcore GR-78 Core 13.2.7," Trace Laboratories East, March 2001

16. M.Peel, "Report 201274 Probe Test" Contech Research, May 2001

17. R.Gordon, et al, "Evaluation of Immersion Silver Finish for Automotive Applications," SMTA Int'l 2000 Proceedings

18. D.Hillman, “An Investigation of the Effects of Printed Wiring Board Surface Finish and Conformal Coating for BGA Assembly”, APEX 2000 Proceedings

19. J.Reed, “Risk Assessment of PCB Alternative Finishes”, PC Fabrication July, 2000