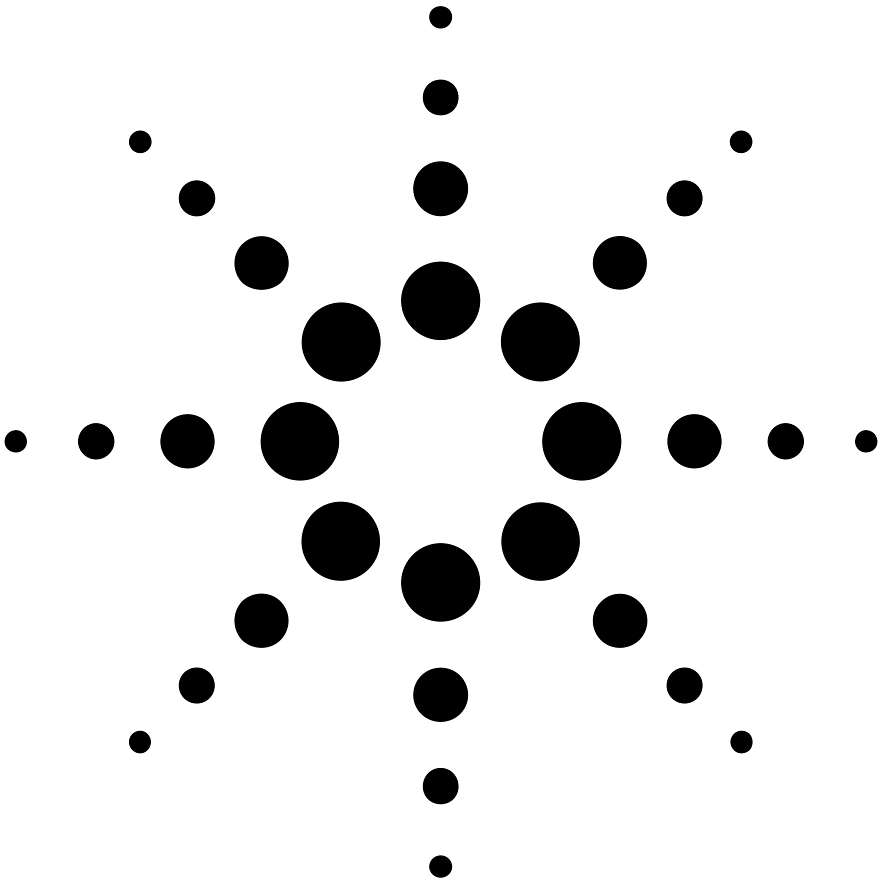
# Study and recommendations into using lead free printed circuit board finishes at manufacturing in circuit test stage

White Paper



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## Background

Historically, the test engineer has been primarily concerned with ensuring he has an effective test program that performs well in production. In-Circuit test is still a very effective method of detecting manufacturing defects.

More advanced In Circuit Test (ICT) systems can also add real value in configuring functionality at test by providing the means to program flash memory, PLD, FPGA and EEPROM. Agilent Technologies 3070 system is the market leader in ICT.

It is established that In-Circuit test still has plenty to offer to the manufacturing and testing of Printed Card Assemblies, (PCA), but how will the pursuit of a lead free PCB affect the ICT stage in the future?

The push for lead free solder techniques has led to many investigations into PCB finishes. These have been primarily based on the technology performance during the build process. The effects of various PCB finishes on the test phase have mostly been overlooked or focussed purely on contact resistance. This report will present details of the effects seen at ICT and the need to respond and understand these changes.

The purpose of this document is to share experiences and educate engineers regarding different PCB surface finishes and the specific changes required in the PCB build process to allow for ICT. This paper will address lead free PCB finish issues specifically at the ICT stage of manufacturing and show that successful testing of lead free finishes also relies on a positive contribution from the PCB build process.

Successful ICT testing always comes back to the physics of contact between the test probe on the bed of nails fixture and the test pad on the PCB.

When a sharp probe is brought to bear on a soldered test point, the solder will initially yield because the contact pressure of the probe is significantly higher than the yield strength of solder. As the solder yields, the probe breaks through any contaminants on the test pad surface. The uncontaminated solder beneath is now contacted by the probe allowing good contact to the test point. The depth that the probe penetrates is a direct function of the yield strength of the target material. The deeper the probe penetrates, the better the contact will be.

An 8oz probe can exert between 26,000 and 160,000 psi in contact pressure, depending on surface diameter. Since the yield strength of solder is around 5000psi the probe will make good contact into the comparatively soft solder.

## PCB Finish Alternatives

Before we look at cause and effect, it's important to describe the types of PCB surface finishes available and what they offer. All Printed Circuit Boards (PCB's) have copper finishes on their surface. If the copper finish is left unprotected the copper will oxidise and deteriorate,. There are various protective finishes available. The most prevalent are; Hot air solder levelling (HASL), Organic Solder Preservative (OSP), Electroless-Nickel Immersion Gold (ENIG), Immersion Silver and Immersion Tin.

### Hot air solder levelling (HASL)

HASL is the predominant 'leaded' surface finish used in the industry. The process consists of immersing circuit boards in a tin/lead alloy. The excess solder is then removed by 'air knives', which blow hot air across the surface of the board. For the printed circuit assembly (PCA) process, HASL has many advantages. It is the cheapest PCB available and the surface finish remains solderable through multiple reflow, wash and storage cycles. For ICT, HASL also provides automatic covering of the test pads and vias with solder However, the flatness, or co-planarity, of the surface is poor when comparing to available alternatives. There are some emerging lead free HASL alternatives, which are gaining in popularity due to the nature of being a 'drop-in' replacement. HASL has been working well for many years but with the advent of 'greener', more environmentally friendly processes, its days may be numbered. In addition to the lead free issues, the increased complexity of boards and finer pitches have exposed many limitations with the HASL finish.

**Pro's:** Lowest cost PCB's, remains solderable throughout manufacturing process, no negative effect at ICT

**Cons:** Mostly uses lead process, which is currently restricted and eventually eliminated by 2007. For fine lead pitches (<0.64mm) can lead to solder bridging and thickness issues. Unevenness of finish causes co-planarity problems in assembly process.

### Organic Solder Preservative (OSP)

OSP is designed to produce a thin, uniform, protective layer on the copper surface of the PCB's. This coating protects the circuitry from oxidization during storage and assembly operations. It has been around for quite a while but is only recently gaining popularity with the search for lead free techniques and fine pitch solutions.
For PCA assembly, it has superior capabilities over traditional HASL with regard to co-planarity and solderability, but requires significant process changes with the type of flux and number of heat cycles. Careful handling is needed as acidic fingerprints degrade the OSP and leave the copper susceptible to oxidization. Assemblers prefer to work with metal finishes that are more flexible and endure more heat cycles.
With OSP finish, if the test points are left unsoldered, this will cause major problems at ICT with the bed of nails fixture contact. Just changing to more aggressive probe styles to break through the OSP layer will only lead to damage and piercing of the PCA test vias or test pads. Studies have shown that changing to a higher probe force or style has little effect on yield results. Raw copper has a yield strength an order of magnitude higher than lead solder. The only result will be damage to the bare copper test pads. All testability guidelines strongly recommend against probing directly on bare copper. When using OSP a set of 'OSP' rules should be defined for the ICT stage. The most important rule requires opening up the stencil at the beginning of the PCB process to allow solder paste to be applied to those test pads and vias needed for ICT access.

**Pros:** Comparable per unit cost to HASL, excellent coplanarity, lead free process, improved solderability.

**Cons:** Significant changes needed to assembly process,
If probing raw copper - not ICT friendly, aggressive ICT fixture probes will damage the PCB, manual handling precautions needed, ICT limits and repeatability compromised.

### Electroless-Nickel Immersion Gold (ENIG)

These coatings have been used with great success on many boards despite the higher per unit cost. It has a flat surface and excellent solderability. The main drawback is that the electroless nickel layer is brittle and has been found to break up during mechanical stress. This effect is known in the industry as 'black pad' or 'mudflat cracking'. This has led to bad press for ENIG.
Pros: Excellent solderability, coplanar flat surface, excellent shelf life, withstands multiple reflows
Cons: Higher cost (approx 5x HASL), 'black pad' issue, manufacturing process uses cyanide and other unpleasant chemicals.

### Immersion Silver

Immersion Silver is a relatively recent addition to the PCB finish. It has been used mainly in Asia and is gaining popularity in North America and Europe. During the soldering process, the silver layer gets dissolved into the solder joint leaving a tin/lead/silver alloy on the copper which provides very reliable solder joints for BGA packages. The contrasting color makes it easy to inspect. It is also a drop in replacement for HASL for soldering operations. Immersion Silver is a very promising finish but as with all new finishes, end users are very conservative. Many manufacturers place this as 'under investigation', but it may well emerge as the best lead free alternative finish.

**Pros:** Good solderability, coplanar flat surface, 'drop in' replacement for HASLImmersion

**Cons:** Conservative approach means less information is available.

### Immersion Tin

Tin is a newer alternative surface finish with many similar characteristics to its silver counterpart. However, there are major health and safety issues to consider due to the precautions needed over the thiourea used in tin solution (a suspected carcinogen) during the PCB manufacture. There are also some concerns over Tin Migration ('Tin Whisker' effect) although anti-migration agents have had some success in limiting this problem.

**Pros:** Good solderability, flat surface, relatively low cost

**Cons:** Heath and safety concerns, limited number of heat cycles

### PCB Surface Finish Summary

These are the main alternatives for lead free PCB finish. HASL continues to be the most widely used PCB finish and in this case the test engineer will not see any differences. In some countries, HASL is already outlawed and alternatives are in place. With PCA manufacturing spread across a more diverse and global arena, the possibilities of seeing Lead Free finishes at In-Circuit test are increasing. Although OSP is not the natural replacement for HASL it has been one of the first alternate finishes that PCA manufacturers investigate. This has lead to real test reliability issues at ICT when the process is not changed to allow solder paste to be applied to test pads and vias.

The conclusion is that there is no 'holy grail' of PCB finish, each has its own set of issues that will need consideration. Some issues are worse than others, all of these Lead Free PCB finishes require adaptation during the process steps to prevent fixture contact reliability issues at ICT.

### HASL vs. OSP vs. Silver Considerations at In Circuit Test Stage

I want to now turn the focus to these surface technologies and how they impact performance at ICT. HASL finishes leave soft solder 'domes' on testpoints and unmasked vias that are a perfect target for ICT probes. What HASL does and OSP cannot is to absorb force. HASL is eutectic SnPB, which is extremely soft. This soft target does two things, it adapts to the probe and it absorbs energy.

For OSP PCB's there is no such soft target. Copper is a pretty hard surface in comparison and cannot absorb much energy. Therefore the immediate contact area for the probe to bite into is reduced. The copper plating on the outer layer is typically between 10 50um. Combine that with the OSP covering layer, and you can see that the probe that you used to probe the HASL boards is not going to perform on the OSP finish boards.

Studies show that during long transfer times between reflow and ICT, the OSP can create a hard 'crust' on test targets. Optimum transfer time to ICT is <24 hours. There are very many other process factors that can influence how much OSP will be a problem for the test engineer. Some of these factors are: OSP vendor type, number of times through reflow oven, whether the wave process been removed, nitrogen vs. air reflow and the types of analogue measurements being made at ICT.

Probing directly onto the copper surface combined with the higher probe force needed to break through the OSP layer,creates a real potential to break through that thin copper layer and cause internal shorts. Therefore, our recommendation is to never probe onto bare copper.

In recent cases it has been seen that a board via or testpoint may be pierced in between 5-10 actuations of the fixture.

OSP effects at ICT have been such a problem for some PCA manufacturers that they have totally outlawed its use. Others have learned to live with it and worked to a set of 'OSP rules' detailed below

'OSP Rules' for ICT fixture and programs

- Observe latest industry testability recommendations e.g. www.smta.org
- Always apply solder paste to test access points (testpad or via), never probe onto OSP coated bare copper. If you can't change the stencil, be prepared for:
  - Significant Impact to First Pass Yield (FPY)
  - May need to change fixture probes to higher force, e.g. 2N to 3N*
  - May need to change fixture probe styles for a sharper version*
  - May require a 'double hit' fixture actuation method or utilizing pneumatics, handlers*
  - Analog test program limits may need to be compromised, opened or even omitted*

* Studies have shown that these rules marked with * may have relatively little effect on yield and the only way to guarantee reliable test contact is to ensure that the test pads remain soldered.

OSP is seen by some to offer immediate cost savings and to be the first choice lead free replacement. However, some companies have recently made a u-turn and are re-examining their strategy when the real costs associated with manufacturing disruption and delays are considered.

### Immersion Silver

Immersion Silver is typically 0.4 to 0.8 um on top of the copper layer which offers some 'meat' for the test probe to bite into. Silver is not as widely used as HASL or OSP, but initial studies have shown it to be a 'drop in' replacement for HASL as far as the manufacturing process.
There have been some initial studies of reliability at ICT, and it has emerged that etch time (surface rough/shiny) and surface thickness are important considerations for repeatability. There have been no reported issues with Silver finish fixture contact reliability at ICT stage, therefore, no adjustments to fixtures, probes or test software should be required.
The etch rate is important to ICT testing as it determines whether the silver finish will be shiny or matte. During the silver deposition step, the silver takes to the contours of the copper surface. Therefore, the surface with increased roughness, hence area, presents a matte finish while the surface with minimal roughness presents a shiny finish.
There have been very limited studies of this finish but technically and commercially it would seem that this is the most promising. Recent experiences have shown that there are no issues with this finish at ICT. PCB manufacturers are now offering silver finish boards at the same cost as their HASL counterparts.

### Customer Studies - HASL to OSP conversion

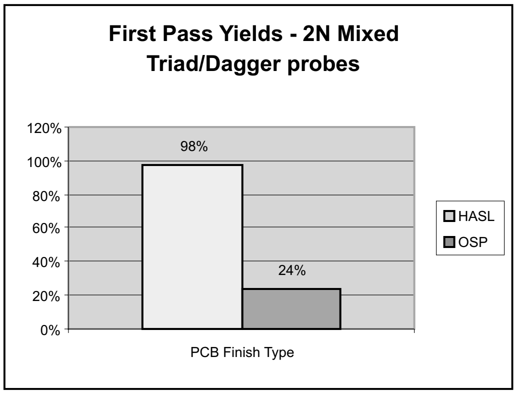
#### Study 1 OEM manufacturing site, Europe

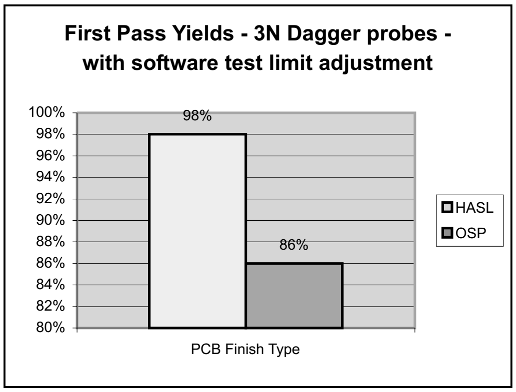
One set of data from OSP trial is shown below. This trial was initiated by a customer when they saw significant impact to yields when introducing OSP PCB finish as a trial lead free replacement on one of their product lines. These are independent results captured by the customer and are not influenced by Agilent in any way. The test equipment used was the market leader Agilent 3070 in circuit tester, which is widely accepted as being the most stable test platform in industry.

### OSP trial condition parameters

| Area | Parameter | Fixed or Variable | Comment |
|---|---|---|---|
| Test Dept | Probe force | Varied 2N- 3N | 2N sufficient for HASL |
| | Probe style | Varied | Daggers, Triads |
| | Probe Mfr | Fixed | Ingun |
| | Probe Maintenance | Fixed | Optimised |
| | Probe Age | Fixed | New Probes |
| | Probe Pitch | Fixed | Optimised |
| | Test Software | Fixed | Agilent 3070 ICT |
| Batch Size | 50 boards | | |
| Process | Post reflow delay | Variable | <24 hours |
| | Handling | Fixed | Gloves used |

### Yield results


First Pass Yields - 2N Mixed Triad/Dagger probes


First Pass Yields - 3N Dagger probes - with software test limit adjustment

The customer employed a recommended set of OSP rules and still saw a 12% impact to first pass yields. This customer's experience led to a reconsideration of OSP as a lead free finish.

**Study 2 - Contract Manufacturer Europe**

This contract manufacturer's study was driven by similar experiences to those of study 1, in that poor yield performances were seen at ICT. The study was an effort to identify root causes and provide feedback to the OEM.

The trial was split into 2 sub-sections. The first determined the effect that changing probe style and force had on probing on bare copper OSP test points. The second focussed on performance when testpoints were soldered.

During the first trial, the assemblies were stored in nitrogen before being passed to ICT to prevent oxidization. Three probe types were used, standard 7oz (2N), 7oz & 10oz (3N) e-type probes and finally twist probes.

The trial results found that there were no improvements in yield for the different probe types when probing onto bare copper OSP coating. On average, it took over 5 fixture actuations to 'break through' the OSP coating. Once the fixture pins contact test had passed, the remainder of the test program behaved normally and no changes to analog test limits were required. However, it was seen that by changing the probe force & style, the amount of damage to the PCB testpoints/vias also changed significantly. The conclusion from this trial was that unsoldered test points provide significant problems at ICT. Using greater force or more aggressive test probes will only cause damage to the PCB.

The second trial enabled a comparison between OSP boards with soldered test points and included a small sample of those that were pure OSP. The trial ran 86 boards, of which 77 were soldered and 9 were not.

During the trial the contract manufacturer made use of their global ICT fixture expert to examine the fixture. Several points arose from this trial, namely that the fixture compression and registration had been compromised and were not to the customer's specification. This highlights the fact that both incoming and current ICT fixture quality must always be monitored to ensure acceptable standards are met.

One other issue that the customer had to face was in the application of the solder paste to the board. They had small test targets of 30 thousands of an inch to apply and were limited to a maximum solder height restriction of >0.1mm in certain areas because of a conductive heatsink placement.

**Trial 2 results**

| | | **NUMBER OF ACTUATIONS** (required to achieve "pass") | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **NUMBER OF PASS UNITS** | **Soldered Test Points** | 28 | 25 | 14 | 5 | 1 | 1 | 3 | 0 |
| | **Unsoldered Test Points** | 0 | 0 | 0 | 2 | 3 | 1 | 2 | 1 |

| | **AVERAGE TEST LOOPS** | **FIRST PASS YIELD** | **SECOND PASS YIELD** |
|---|---|---|---|
| **Soldered test points** | 2.56 | 36% | 69% |
| **Unsoldered test points** | 5.67 | 0% | 0% |

The conclusion is that the performance at ICT is far improved when using the soldered test points. Taking into consideration some of the fixture and process issues, the customer remained confident that they could achieve first pass yields in the region of 80% to 90% once these issues had been addressed

## Summary

It seems that the trend in some companies is for OSP to be seen as a natural replacement for HASL. This decision is most probably derived from perceived unit cost savings. ICT engineers should be concerned at this trend as OSP coated PCB's will not perform as well as other alternative lead free finishes unless the test pads are covered with solder. What would seem to be an initial cost saving opportunity can be negated by the costs of changing fixture probes, fixture maintenance, adapting test software and scrap costs of damaged boards if process changes are not made. We have seen many recent reversals on OSP decisions. The advice for those customers who have not yet changed from leaded HASL is to make sure that the pro's and con's of all viable lead free PCB alternatives are considered and to ensure that all manufacturing stages are included in trials Including Test ! We do not have any definitive results available for Silver PCB finishes with respect to ICT. We have discussed with customers who are using Silver and they are not seeing any fixture contact issues when using this finish.

## Sources and Acknowledgements

Evaluation of Immersion Silver Finishes for automotive electronics: Robert Gordon, Susan Marr, Dongkai Shangguan Visteon Corporation
The Quest for the Ultimate Surface Finish: Luc Beauvillier Printed Circuit Design June 2002 edition
QA Technology Application note AN02, How probe tip geometry affects contact reliability

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