

**A NATIONAL MEASUREMENT
GOOD PRACTICE GUIDE**

No. 110

Reduce Copper Dissolution
in Lead-Free Assembly

Measurement Good Practice Guide No. 110

Reduce Copper Dissolution in Lead-Free Assembly

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ABSTRACT

During a successful soldering operation to a copper surface, a small amount of copper is dissolved to form a reliable interconnection and is perfectly normal. During the soldering operation, copper is dissolved by tin to form a tin/copper intermetallic and the amount dissolved is dependent on the soldering process, solder alloy, surfaces to be joined, temperature, time and solder flow rate. Using lead-free alloys requires higher soldering temperatures and potentially longer contact times, and hence the propensity for higher dissolution of copper.

A typical intermetallic produced with a tin/lead solder can range between 1-3 μ m. In the case of lead-free soldering process this thickness can increase above 5 μ m. The intermetallics are themselves soluble in solder, and hence potentially the overall copper dissolution rate is greater. Dissolution during lead-free soldering does not just impact copper pads on printed boards, it can be a potential issue on thin copper wire, component terminations and hybrid metallisation. Examples of some typical problems previously experienced in industry are provided in this guide.

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What is copper dissolution ?

1

IN THIS CHAPTER

- Intermetallic formation in joints
- Copper dissolution rate of lead-free alloy

1.1 What is copper dissolution ?

Copper dissolution is not a new phenomenon, it has always occurred when a soldering operation is conducted on a clean copper surface. If copper were not dissolved to some extent a reliable connection would not be produced. The dissolution process at the interface of the solder and copper forms an intermetallic, and this is the bond between the solder and copper. The intermetallic itself is soluble in solder, and hence the copper dissolution process is a two-stage process with the copper forming an intermetallic, and then the intermetallic dissolving in the solder. Factors that change the intermetallic composition and morphology, will be dependent on composition of the solder and copper, as well as copper microstructure, and probably the soldering process and the heat delivery and solder flow mechanisms. Hence copper dissolution is dependent on many factors. Figure 1 shows typical through hole solder joints with a component pin in the hole.

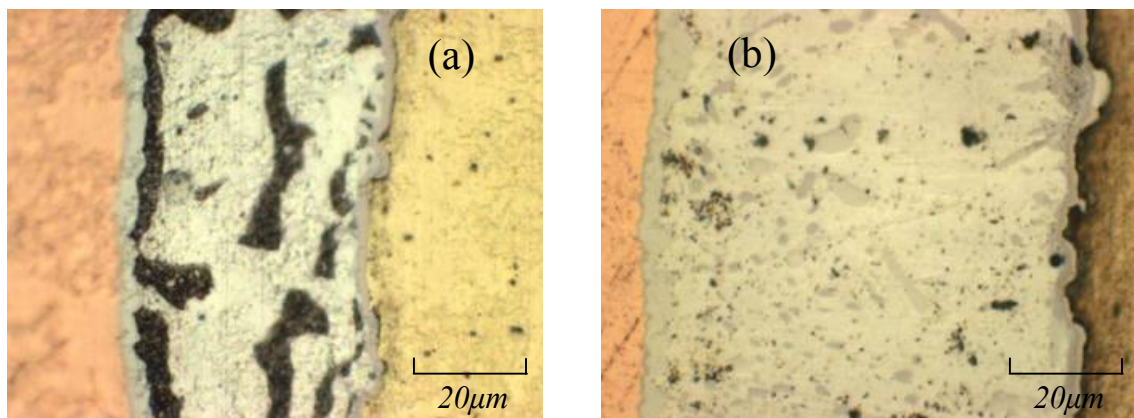


Figure 1: Microsections of typical solder joints formed between a copper plated through hole and a through hole pin. (a) tin/lead joint after soldering, (b) lead-free Tin/Silver/Copper joint after soldering. The grey boundary layers on both solders are intermetallic alloys, and the particles in the lead-free solder are also intermetallics.

Copper dissolution, when discussed in a lead-free context, refers to excessive copper loss; 10µm and above would be considered excessive hence the concern shown by industry. In Figure 2 the results of an experiment with copper wire show the different dissolution rates in three eutectic solders. This data clearly confirms the relative increase seen in dissolution with these simple lead-free alloys. Current commercial alloys are capable of achieving lower dissolution rates than seen in Figure 2, achieving rates as good as or better than SnPb, see NPL Report MAT26:

Measurements of Copper Dissolution in Lead-Free Solder Alloys. Improvements in resistance to copper dissolution have been achieved by alloying small fractions of key elements, the most notable of which is Ni, but Co has also been used and there are examples of others. The mechanism for this improvement is still the subject of research. Exposing a copper surface to such a modified alloy with these additions is hypothesised to stabilise the intermetallic. Hence a PCB finished in a HASL process with an alloy with a Ni addition can reduce copper erosion in subsequent processing irrespective of the solder alloy used subsequently.

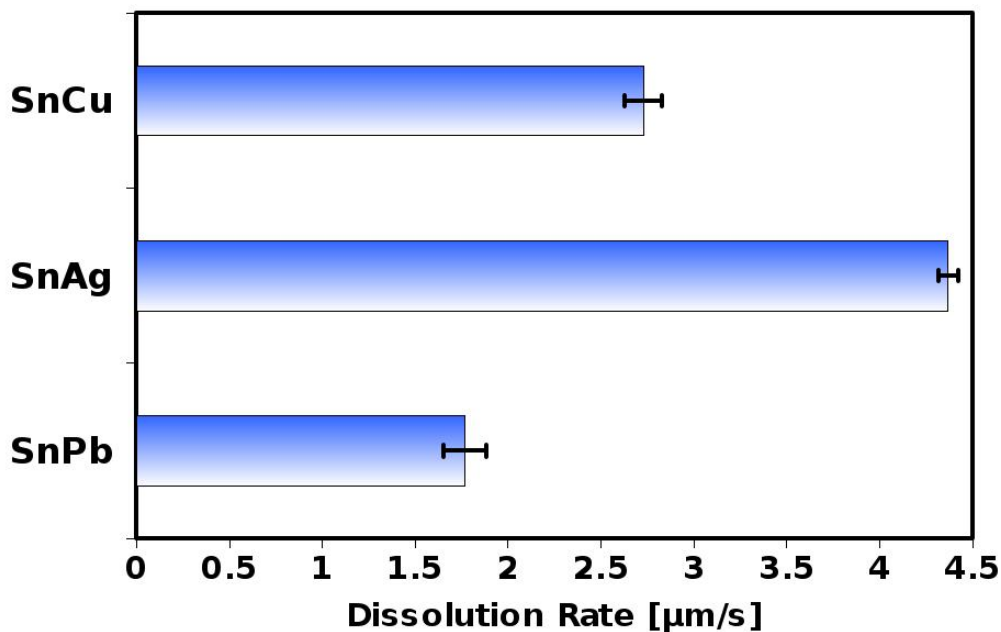


Figure 2: Dissolution rate of copper wires immersed in SnAg, SnCu and SnPb solder fountain at 275°C

Copper dissolution into the solder will also depend on the solubility of copper in the solder, and this will change as more copper dissolves into the solder. Hence as the number of boards processed increases, so will the copper dissolving into the solder decrease as the solubility limit is reached.

What is the impact to the user?

2

IN THIS CHAPTER

- Copper loss during production
- Dissolution of component terminations

2 What is the impact to the user?

Excessive copper dissolution can lead to intermittent or lack of electrical interconnection on copper tracks or through hole plating; in severe cases this will reduce reliability. To date most cases experienced in industry have been when excessive loss has occurred and is very obvious during inspection; however, other less obvious cases may have undoubtedly occurred and have not been noted.

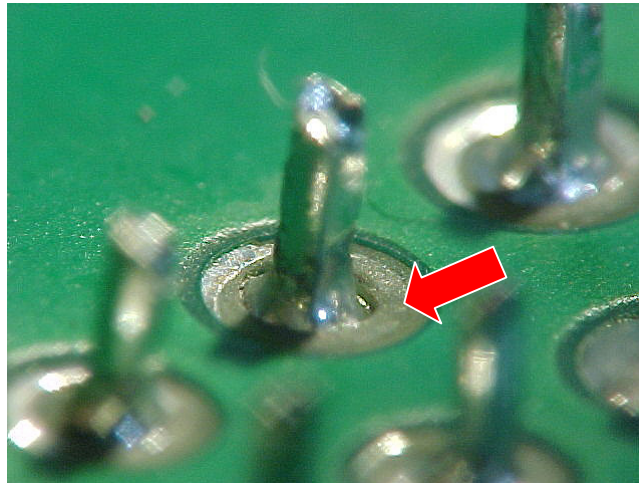


Figure 3: Examples of dissolution could be the failure of track connections to plated through holes or simply the loss of the copper pad. The printed board surface finish in this case was silver.



Figure 4: Loss of through hole connections where the knee/pad of the plated hole has been dissolved during selective soldering with a lead-free alloy. The surface pad finish on this board was copper Organic Solderable Preservative OSP.

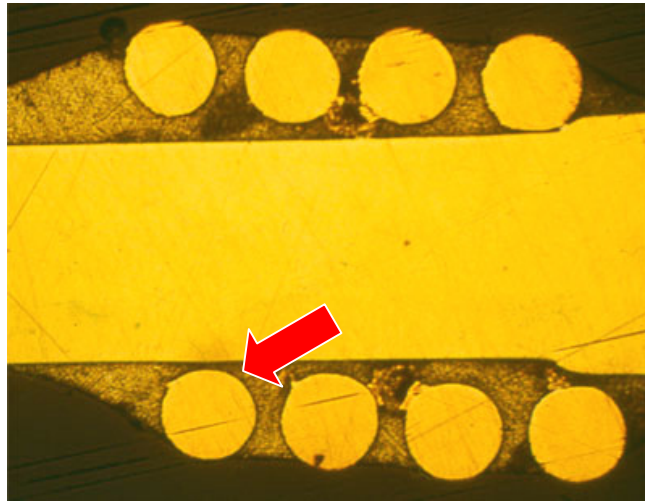


Figure 5: Reduction of cross-sectional area of thin copper wires. After changing from tin/lead to lead-free soldering dip soldering there was a noticeable reduction in the wire thickness

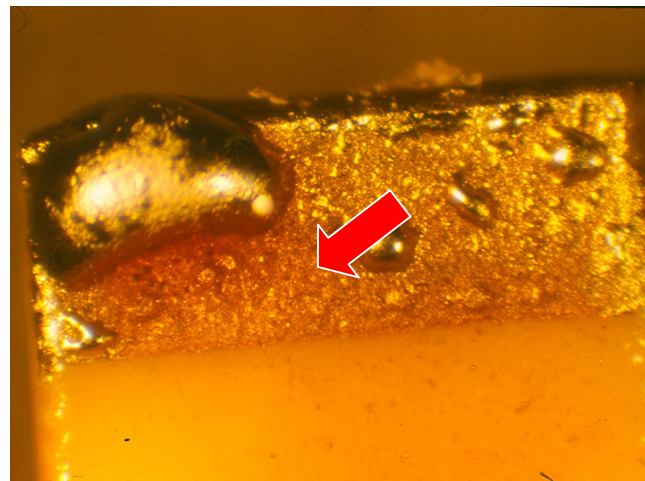


Figure 6: A related issue is the loss of chip component plating that could lead to intermittent joints. During soldering the chip capacitor metallisation has been leached from the surface of the ceramic. To avoid ensure the correct specification of the components.

3

How can PCB specification help ?

IN THIS CHAPTER

- Copper plating thickness control
- Updating specifications

3 How can PCB specification help?

Printed board specifications exist in the industry to cover the plated copper and original copper foil thickness for plated through hole and single sided boards. Documents from the IEC and IPC are available and are often supplemented by customer specific documents. Generally copper dissolution with lead-free alloy has not been addressed.

Currently minimum copper thickness in a plated through hole is 20µm, 18µm in a small via or blind via hole. Surface tracking or plated through holes would be most affected by the soldering process, via holes in standard assembly are less likely to be affected.

It is good practice to independently check the copper thickness on the PCB, using microsectioning for example. Microstructure can be important and this can be checked with a suitable etched section.

If the minimum copper thickness specified is to be increased then it needs to be discussed and agreed with the supplier. Industry experience suggests that copper thickness is not the only circuit board related issue, and engineers need to discuss the type of copper utilised if different suppliers are being used to supply printed circuit boards.

Copper dissolution will vary with different solder finishes like lead-free solder levelling, tin, silver and copper Organic Solder Preservative (OSP). In the case of nickel gold boards, copper dissolution should not be experienced, since during soldering, the joint is formed between the solder and the nickel layer, and not the copper. Nickel has a much slower dissolution rate in solder when compared to copper.

Copper can be found in at least three different forms on the PCB, electroplated, reverse plated and electrodeposited. These copper types have different dissolution rates. The work at NPL shows that electroplated copper suffers the highest dissolution rate, followed by reverse treated copper. Electrodeposited copper has the lowest dissolution rate.

Solder levelled boards using a lead-free alloy will have already experienced some copper loss during the levelling operation. The process, materials and any potential rework of panels during PCB manufacture should be discussed with the supplier.

4

Monitoring copper dissolution during fabrication and assembly

IN THIS CHAPTER

- Impact of assembly process
- Alloy, temperature and process flow rate

4 Monitoring copper dissolution during fabrication and assembly

All soldering processes can potentially reduce the amount of copper on the surface of the board or in the plated through holes. In such areas of thin copper the effects of dissolution will be worse.

Copper dissolution rates are affected by the following (see Figure 7):

Solder alloy used
Soldering temperature and time
Solder flow rate across copper surfaces
Copper type and surface coating

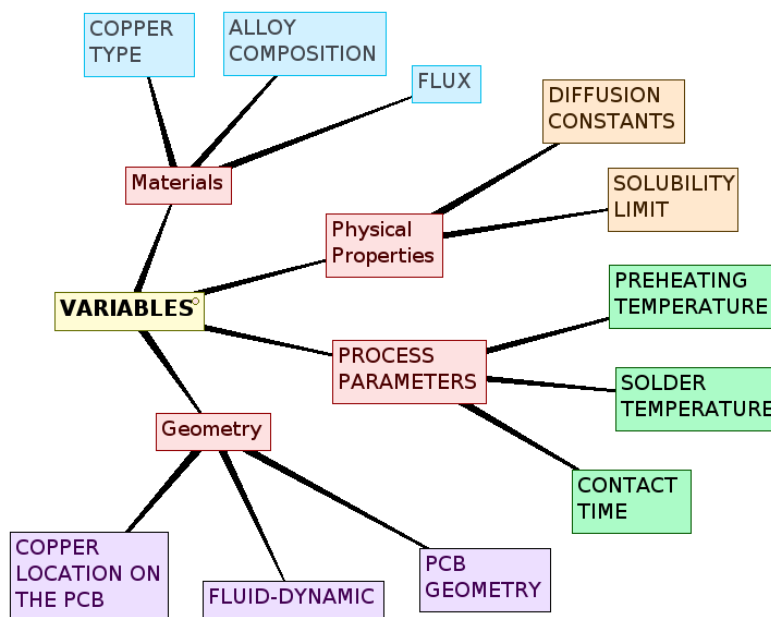


Figure 7 Main variables affecting the dissolution of copper in soldering processes.

Based on standard assembly and fabrication processes conducted with lead-free alloys and the typical parameters used in industry, the processes discussed below are most likely to have the greatest impact on copper dissolution rates.

As a general guide every attempt should be made to reduce the soldering temperature and soldering time. It is more difficult to reduce the soldering flow rate in processes like rework, selective soldering, levelling and wave soldering, as this is a fundamental part of the process to improve drainage and reduce short circuits. Every effort should be made to optimise pre-heating for each of these processes rather than use the solder energy as part of the pre-heating process, and hence reduce the solder contact time. Thermal profiling is recommended to optimise these soldering processes.

The most common assembly process steps are listed in order of potential copper dissolution rate, each process requires close monitoring during production. The first four processes normally have a significant volume of solder that moves quickly across exposed copper surfaces:

- Rework Solder Fountains
- Selective Soldering Processes
- Wave soldering
- PCB Solder levelling
- Manual soldering/de-soldering
- Reflow soldering

4.1 Rework solder fountain



Figure 8 Typical solder fountain equipment. *(Example image kindly provided by ZEVA)*

Solder fountains are used for reworking large through hole multi-pin components like connectors and sockets. A solder fountain is used so that all through hole terminations can be reflowed simultaneously, when the printed board and connector terminations are held in contact with the molten solder. When all solder joints are in a liquid state, the component can be removed from the printed board. This process is used as an alternative to a vacuum de-soldering iron, which de-solders each pin individually.

When a solder fountain is used, the plated through holes will still be blocked after removing the component terminations. The solder must be blown out of the holes when still in a liquid state or the board must be subjected to a second de-soldering operation. Most solder fountains used for rework do not have pre-heat. This will extend the solder contact times on thermally challenging boards. Some waves are pumped with a near static flow, some have faster flowing waves to increase heat transfer and maintain better control of the solder bath temperature. Generally the faster the flow-rate the higher the copper dissolution. The design of the nozzle and distribution of pressure across the ducting will also impact copper removal rates.

4.2 Selective soldering processes

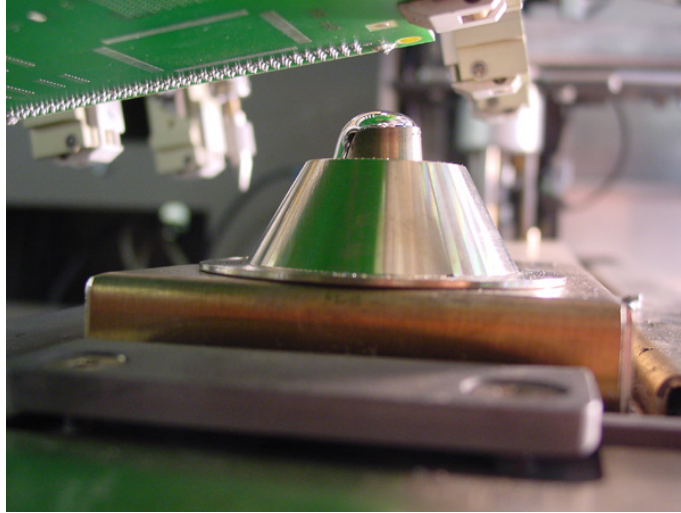


Figure 9 A fixed nozzle selective soldering machine

There are two types of selective soldering systems, a fixed nozzle where the board assembly/connections move through the flowing solder, or systems with a dedicated series of solder nozzles. The first type is the most popular for both small and medium volume users, and the second type are used in high volume dedicated equipment. The board assembly is lowered into contact with the solder, simultaneously soldering multiple connectors in one step. Prior to soldering, selected areas are fluxed and the board is pre-heated. On some systems, there is no pre-heat or the profiling of the board is not done correctly. This leads to the use of longer soldering times or engineers increasing solder temperature and contact time, both resulting in increased copper dissolution rates.

4.3 Wave soldering

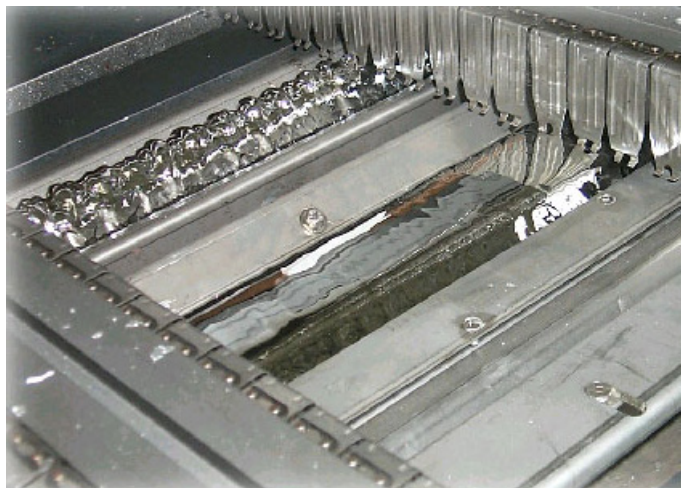


Figure 10 Wave soldering machine

Most wave soldering systems use a lambda shape wave, where the solder flows in the opposite direction to the board travel. When the board assembly contacts the wave, the solder also starts to

flow in both directions. Typically during wave soldering the board assembly is pre heated to 100-120°C measured on the topside of the board, the base of the board may be 20-30°C higher.

With the introduction of lead-free soldering typical conveyor speeds have decreased, increasing the solder contact times with all copper surfaces. Some suppliers have modified the design of the wave ducting to increase the potential contact time, thus avoiding a reduction in conveyor speed. The dissolution rate in wave soldering will therefore be associated with the wave temperature, conveyor speed and contact time.

4.4 PCB solder levelling

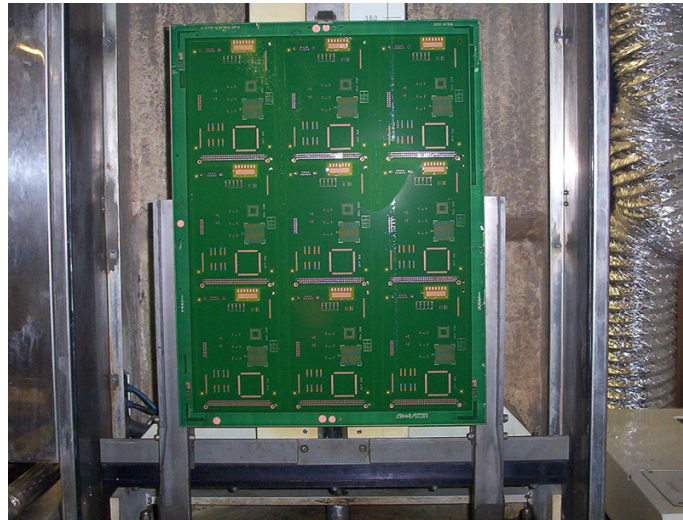


Figure 11: Application of lead-free solderable finish with a vertical solder levelling system

With the exception of electroless nickel immersion gold (ENIG), all board finishes like silver, tin, copper OSP and solder levelled board will experience some level of copper dissolution during assembly. The nickel in the ENIG finish has a much slower dissolution rate compared to copper and normally the 2-4µm of nickel under the gold will not be removed. Typically any solder levelling process will remove copper during application of a fresh coating of either tin/lead or lead-free solder. There may be more evidence of copper removal on a vertical levelling process as the bottom of the process panel will be in contact with the solder for a longer period of time than the top. On a horizontal system contact times will be the same across a panel, similar to the wave solder process. Solder temperature, dwell time, solder alloy, copper previously absorbed and flow rate will affect the amount of copper removed in a single pass.

In the early days of lead-free, it was common practice to double dip panels due to inadequate heat input or the performance of the flux. The use of this process was an attempt to improve the surface coverage and visual appearance, but can result in further copper removal. Today a double dip may be conducted for thermally demanding boards, however the total process time may be less than a single pass.

During solder levelling it is good practice to monitor the copper dissolution rates, the alloy contamination levels, alloy being used; users should make sure that this is being conducted during PCB evaluation or supplier audit.

4.5 Manual soldering/de-soldering



Figure 12 Soldering with a tip can cause copper dissolution

Manual soldering and de-soldering will dissolve copper from the exposed pad and through hole plating. The copper is dissolved as the solder flows across the surface of the copper during soldering, further copper can be removed when the solder is removed from the surface.

During manual soldering it is not common industry practice to pre-heat boards for either soldering or de-soldering, hence the soldering temperatures are higher and soldering times are longer than with other processes. Often manual soldering/de-soldering is used in rework after mass soldering and adds to any dissolution that has already occurred.

4.6 Reflow soldering

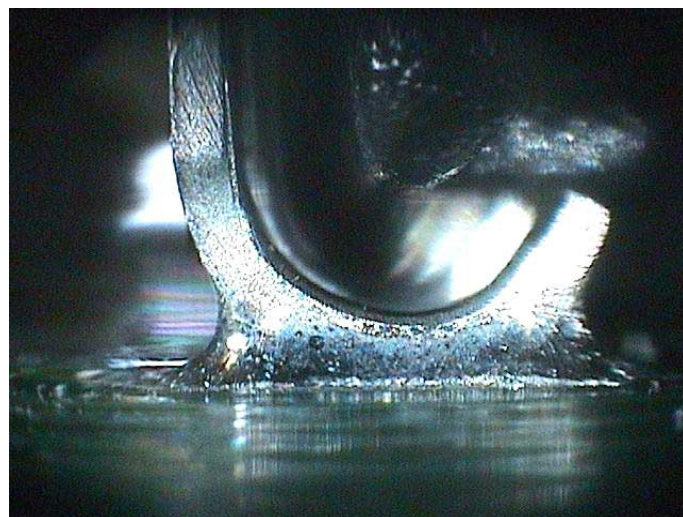


Figure 13 Typical reflow solder joint

Reflowing solder paste on pads for surface mount terminations or inside plated through holes for intrusive reflow of conventional leads, will dissolve copper as with any soldering process. The solder alloy, surface finish and temperature are the main factors affecting copper dissolution rates.

During reflow the flow rate of solder across the surface is minimal. Experience with lead-free solders already shows that wetting and flow are limited and less than with tin/lead solders. A typical surface mount joint experiencing one reflow cycle, may have a tin/copper intermetallic of 2-3 μm , and intrusive reflow joint in a through hole termination, may have 3-5 μm .

There is little experience of significant copper dissolution on reflow soldering. Copper intermetallic formation will vary based on soldering temperatures, time in a liquid state and the cooling time above liquidus. Reflow and multiple rework operations of joints may have a cumulative effect.

4.7 Copper dissolution, what do you look for?

The photographic examples are provided for reference to aid engineers and production staff to identify evidence of copper dissolution. Copper dissolution to the degree shown on the examples would be considered extreme but are being experienced in manufacture. Evidence of printed board assemblies featuring similar examples should be investigated urgently and the production process or materials reviewed.

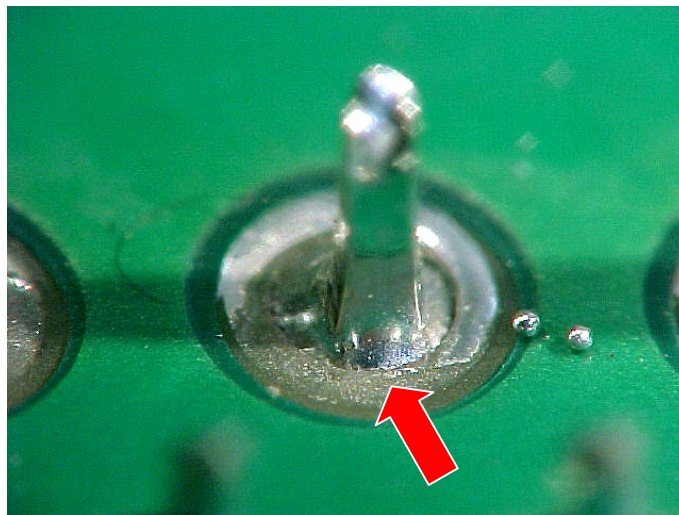


Figure 14 Solder pad dissolution leading to pad loss after selective soldering (in area indicated)

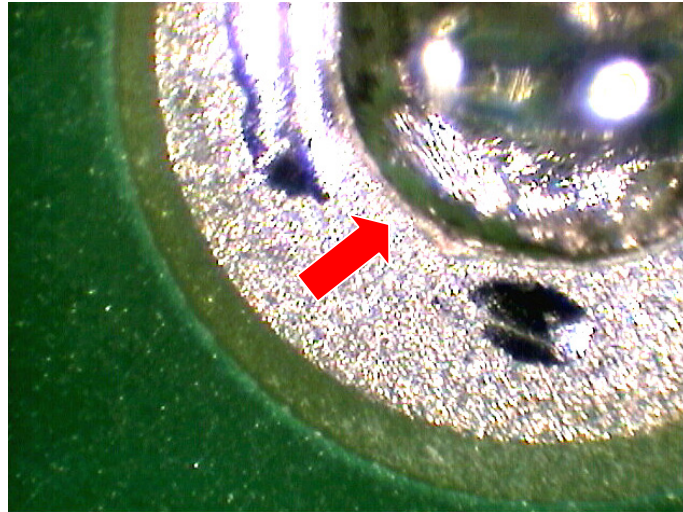


Figure 15 Solder dissolution of copper, has left limited copper pad and knee of the plated through hole after selective soldering on printed board with a silver finish

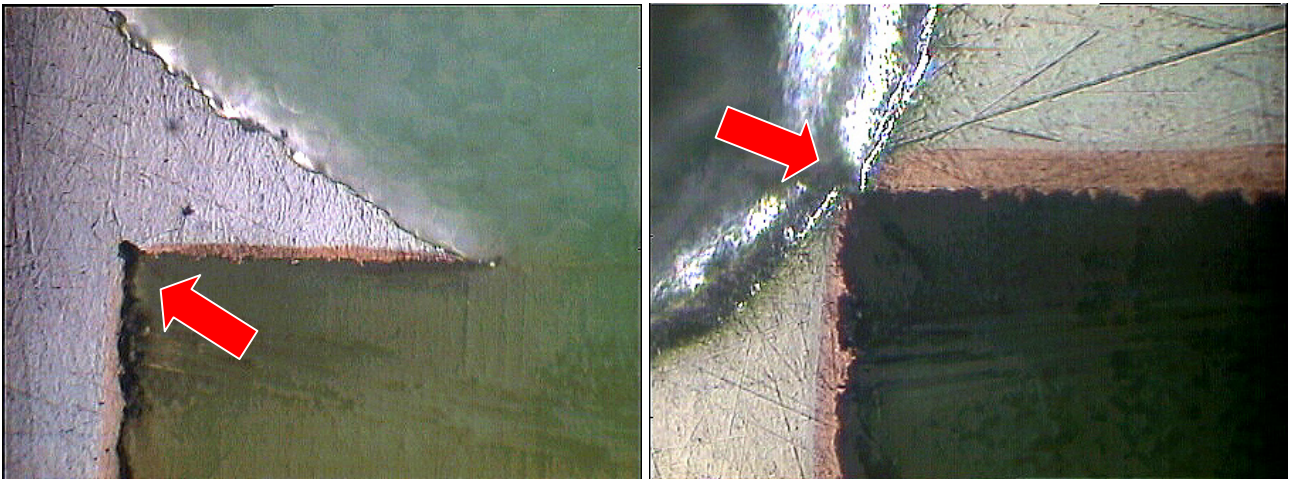


Figure 16 Microsection views of copper pad and knee area of a plated through hole showing evidence of dissolution

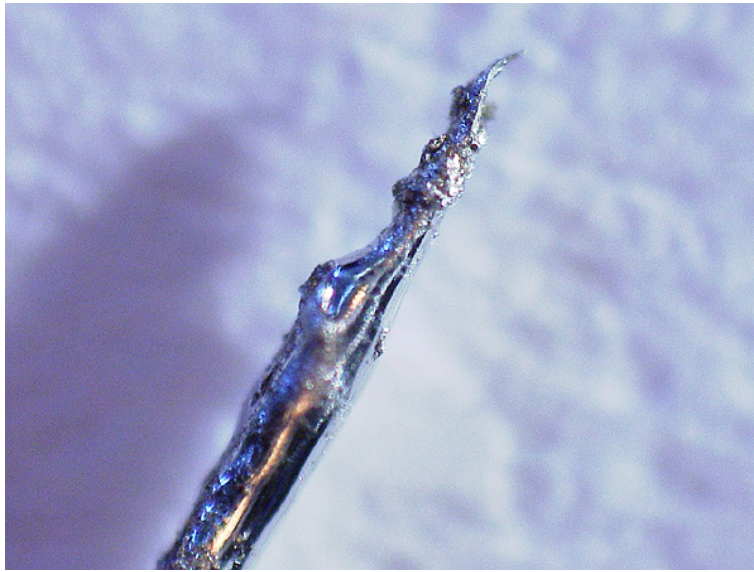


Figure 17 Thin copper wire reduction by lead-free solder

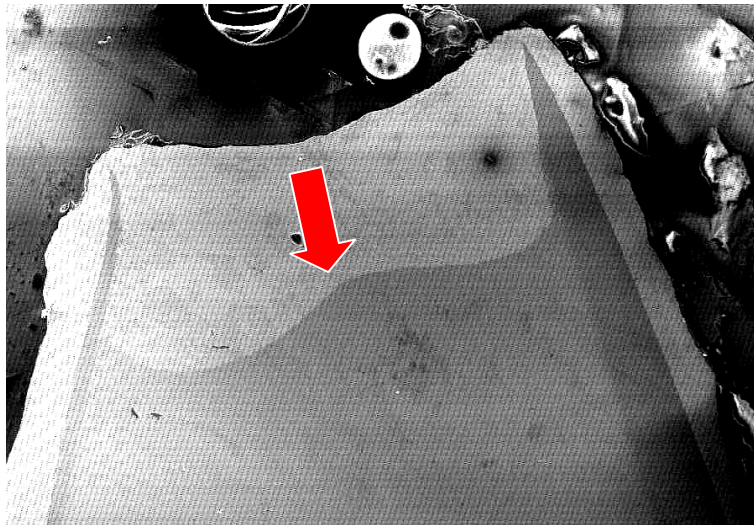


Figure 18 Copper dissolution on soldering iron tip. The copper core has been dissolved by lead-free solder after damage to tip outer plating

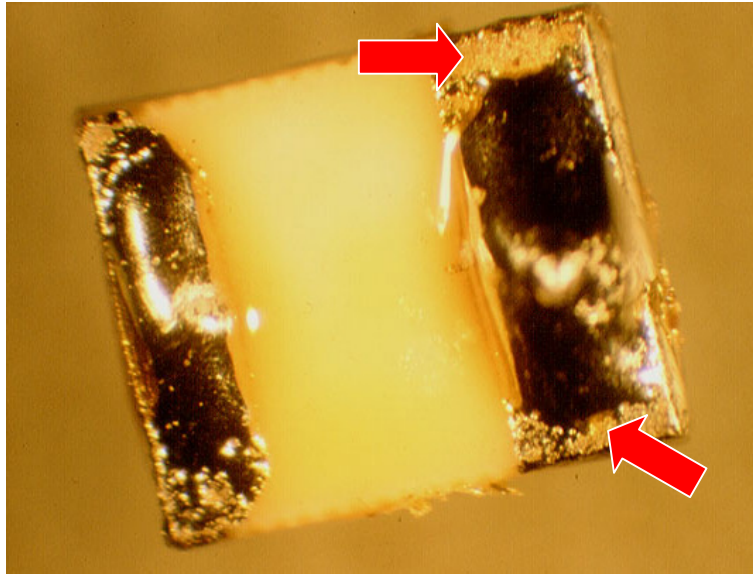


Figure 19: Related defect of dissolution of chip capacitor terminations referred to as leaching. The contact has been dissolved during soldering due to lack of a nickel barrier layer on the terminations



Figure 20: Copper dissolution of copper barrier layer on steel pin. Lack of a barrier layer on the base material has prevented a true bond forming on the surface of the steel surface. Copper or nickel barrier layers are often used to provide ease of soldering

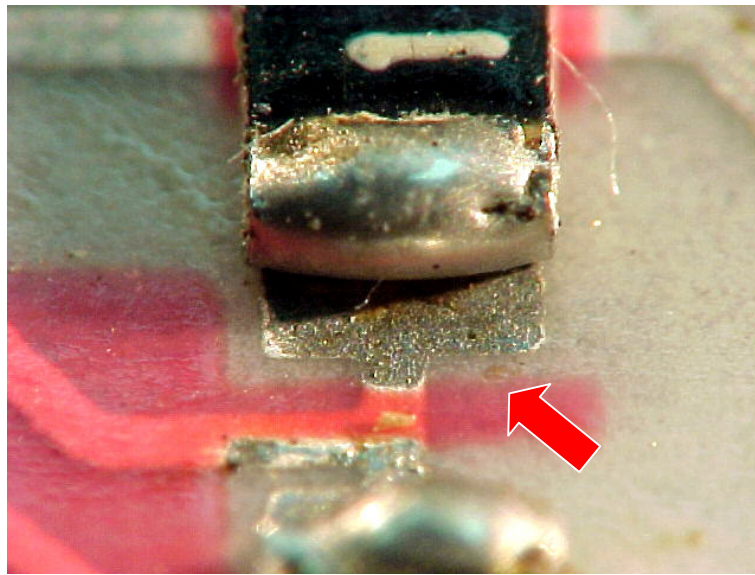


Figure 21: Hybrid circuit pad dissolution due to extended soldering times, the chip resistor shows satisfactory wetting with all the solder wicking up the resistor termination

Further information on copper dissolution is available from NPL in the form of a report on project work: NPL Report MAT26: Measurements of Copper Dissolution in Lead-Free Solder Alloys.

NPL on-Line Defect Database

5

IN THIS CHAPTER

- Solving production problems 24/7
- Defect types and solutions available online

5 NPL On-Line Defect Database

Excessive copper dissolution is just one of the new process issues experienced by industry and it is hoped that this best practice guide will go some way to assisting engineers reduce the possibility of excessive copper loss during manufacture. To further assist the continued introduction and improvement projects in lead-free, NPL have produced a free online resource.

With support from our industry partners, an interactive assembly and soldering defect database has been created, allowing engineers to search through a range of defects covering components, printed circuit boards and assembly problems. The aim is to add more process, material and environmental defects through online submissions by industry worldwide at <http://defectsdatabase.npl.co.uk/>

The interactive database will help engineers solve their problems and obtain practical advice day or night. A very practical benefit is its on-line global availability 24/7 to shop floor operators as a reference and training resource.

The screenshot shows the front page of the NPL Soldering Defects Database. The header includes the NPL logo and navigation links: About NPL, Products + Services, Working with NPL, News + Events, Reference, Publications, Networks, Careers, and Contact Us. The main content area is titled 'Soldering Defects Database' and features a search bar with a 'GO' button. Below the search bar, there are several drop-down menus for filtering results: Assembly Soldering Process, Solder Alloy Option, Defect Category, Defect Location, Product Volume, and Product Applications. Each menu has a default selection of 'Any'. To the left of these menus is a sidebar with categories: Science & Technology, Commercial, Educate & Explore, and Networks. Below the filters, there is a 'Free text search' field and 'Submit Query' and 'Reset' buttons. At the bottom, there is a table header with columns: Title, Defect Category, Assembly Soldering Process, and Image. The table currently shows 'No defects selected yet.' and a 'Print this page' link is visible at the bottom left. The footer contains links to Home, Help, Sitemap, Privacy Policy, Security Policy, Disclaimer, and Copyright.

Figure 22 Screen shot showing the front page of the NPL Defect Database

The screen shot shows the front page of the NPL Defect Database where engineers can query the database for soldering defects, assembly process, alloy type, production or field failure etc. Alternatively if the defect is not available then it's easy to submit a photograph for inclusion in the online database with feedback on defect causes and possible solutions.

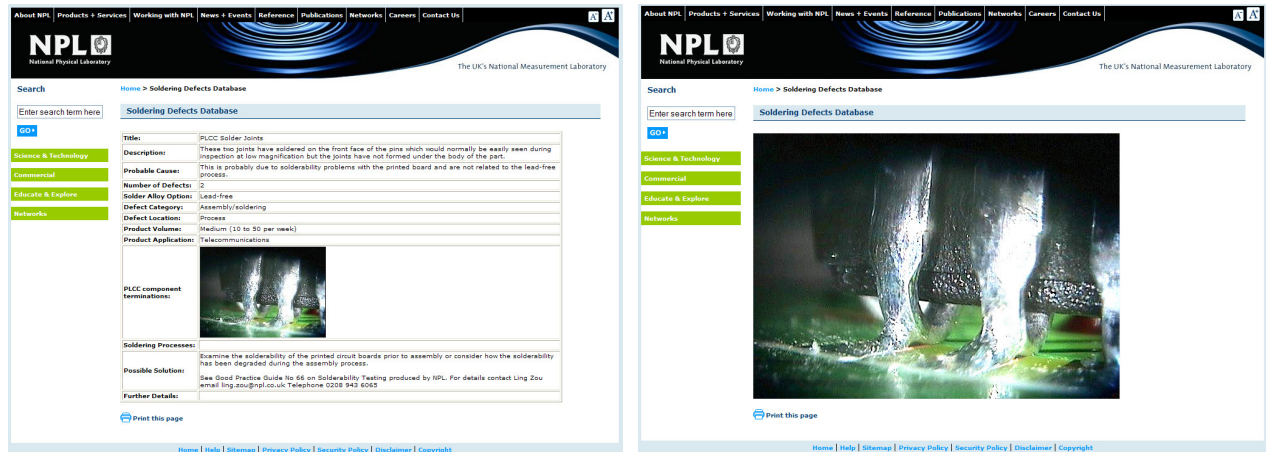


Figure 23 Screen shots shows an example of one soldering defect

The screen shots shows an example of one soldering defect found after a search of the database providing information on the defect, how it could have occurred and possible solutions. Selecting the defect image can provide a larger view of the defect, a second image, and the opportunity to print out the defect for shop floor staff reference or discussion with other departments or suppliers.

The NPL Defects Database is available to allow engineers to search for solutions to common problems or submit defects online with full details or requesting advice and a possible solution to the process issues or failures at <http://defectsdatabase.npl.co.uk/>

We would like to thank all our partners on the Copper Dissolution Studio project and the contributions to this best practice guide and the final report. Further details on the project and the final report can be obtained by contacting Ling Zou (email ling.zou@npl.co.uk, telephone 0208 943 6065).

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