Options for Assembly using High Temperature Interconnection Technologies

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There is considerable interest in finding and replacing lead based solder alloys in high power environments and for existing high temperature operating environments[1]. The high power electronics market requires alloys that do not contain lead but perform equally as well[2]. With the increasing temperature requirements for harsh electronics in automotive and drilling applications the temperature these products require are increasing from 150ºC to 200ºC and equally need to consider alternatives.

This project compared solder joints consisting of existing lead-free and leaded solders produced with laser and robotic iron soldering on polyimide substrates. The soldering of through-hole connectors was used to examine the changes that take place during high temperature storage of different solder alloys. This part of the work was aimed at the existing high temperature organic level assembly market or those companies moving into that product environment. There currently is a dearth of published data in this area. The work reported here can be compared to sintered silver joining trials reported elsewhere [3].

Flux residues were considered in this work, particularly those from cored wire, where spitting and solder balling can be an issue. Robotic and laser soldering can achieve rapid heating of the solder with undesirable spitting of the flux as the result. We looked at the various approaches to solving this problem.

Introduction

Over the past few years there has been a lot of discussion on the need for higher temperature materials and expanding the use and knowledge of high temperature assembly techniques. When we start to talk about high temperature electronics it is not just the solder alloy but all of the materials that go to produce an electronic assembly. Substrates, components, connectors, cables and solder need to be examined; the needs of the assembly process also require careful consideration. Often due to the smaller volumes many companies who require high temperature capability have used manual soldering techniques particularly for through hole. Working at high temperature generally means operating between 150-200ºC; however, there are many applications that have to work at much higher levels, up to 300ºC. Typically the industries affected by these hostile working conditions include aerospace, automotive, petrochemical and military.

In this study we investigated the ability to solder with different alloys and board materials. Assemblies were manufactured using different techniques, and the quality characterised by visual and micro-sectioning examination.

The experimental approached is described by the following steps:

- Assemble through hole connectors
- Solder through hole joints using different solder alloys
- Undertake visual and X-ray inspection
- Microsection joints and measure the intermetallic thickness
- Expose additional samples to high temperature storage
- Microsection joints and measure the intermetallic thickness after ageing
- Visually inspect boards after ageing

In addition two other short exercises were conducted to make good use of the environmental test chamber time and to give an initial understanding of the impact of ageing on other materials which could be used during surface mount assembly. Six different conductive materials proposed for alternative die attachment were used to bond 1206 chip components to polyimide test substrates. The component joints were tested for shear strength before and after ageing for 1000hr at 200ºC. Sample bare boards were conformally coated to also look at the impact on two silicone and one Parylene coating after ageing at 200ºC.

The PCBs were typical of the high temperature materials currently available in the market.

Printed Circuit Boards

For high temperature operation up to 200ºC there is basically one option for traditional organic lamination. Polyimide laminate construction has been successfully used for many years for high temperature operation typically around 150-175ºC. The solder mask material and the solder finish also need to be considered for this high temperature post assembly environment. The most common surface finish selected for these applications is gold over nickel. In the case of the samples tested the solder mask was Sun Chemicals (Coats) XV501T. The laminate materials used during these trials are listed below.

A - MeteorWave
B - Nelco N7000 Polyimide
C - Ventec VT901 Polyimide
D - ISOLA P96 Polyimide

The test boards for assembly, thermal shock and peel testing were all produced by a PCB supplier in the UK. The PCB construction, for the assembly test board was a 1.6mm 4 layer polyimide build and is shown in Figure 1:

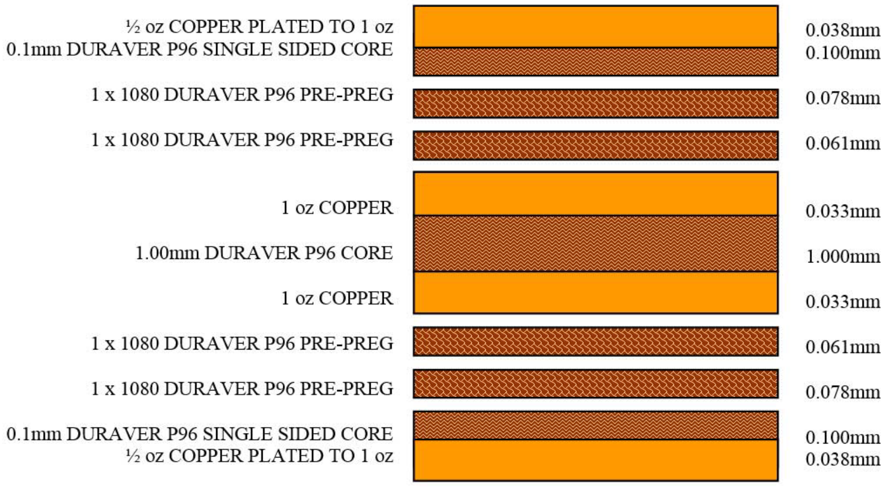
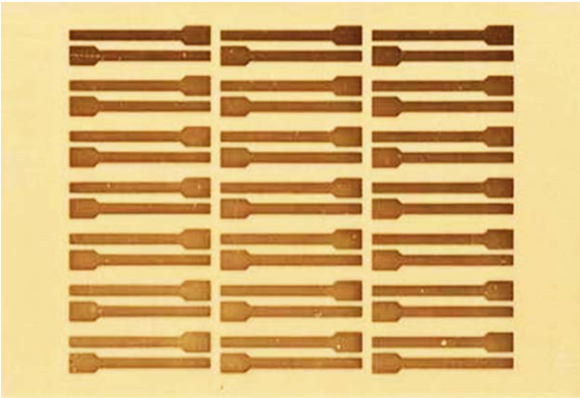
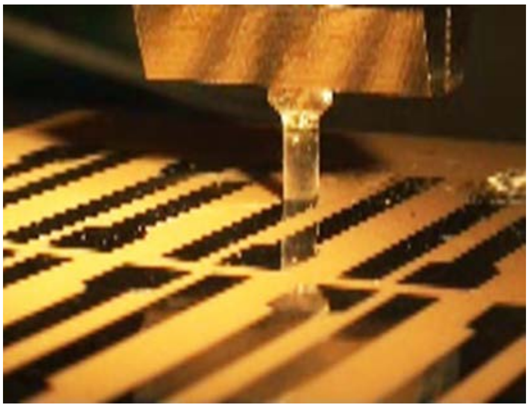


Figure 1: Typical board construction for the assembly board.

Two bare board tests, thermal shock and copper foil adhesion, were conducted on samples of the polyimide material, ISOLA P96. Testing was not conducted on all of the materials due to the size of the project and materials available. These were conducted on existing test patterns used at the PCB supplier. The adhesion testing was conducted on samples treated at 200ºC, after 0, 500 and 1000hr. Three surface finishes were included; lead-free solder level, gold over nickel and immersion silver. Adhesion testing was conducted using a production bond tester fitted with a peel test head and moving stage, and shown in Figure 2. The testing was conducted in line with IPC standards; however, the length of copper foil peeled during testing was 20mm rather than 25mm.



(a)



(b)

Figure 2: The PCB design used for the peel test (a), and a peel test in progress on the production tester (b)

Prior to testing the samples were partly peeled, starting at the wide section of the track, and then continuing to just beyond the point where the track necks down, hence allowing easy clamping in the machine jaws. After ageing it is more difficult to start the track peeling process on test boards. To avoid breaking tracks during sample preparation it would have been beneficial to modify the artwork to reduce the sharp transition between the track sizes. The results of peel testing are shown in Figure 3.

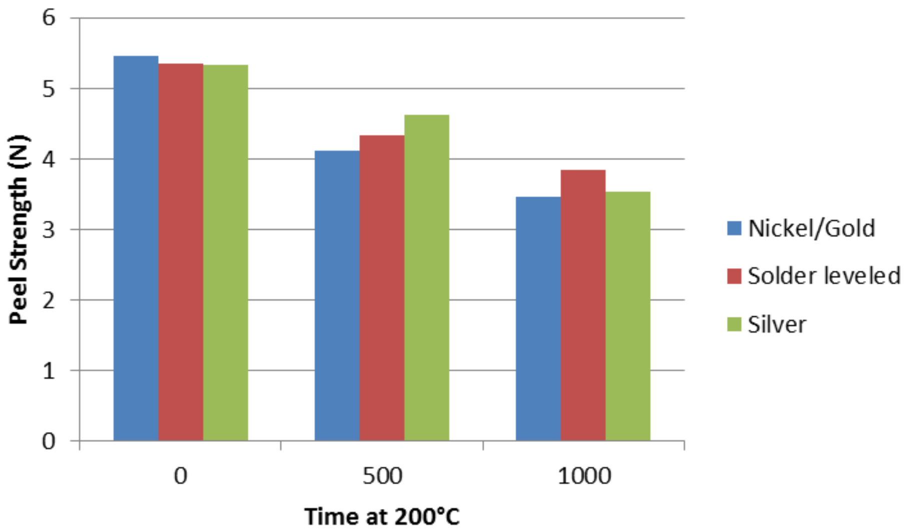
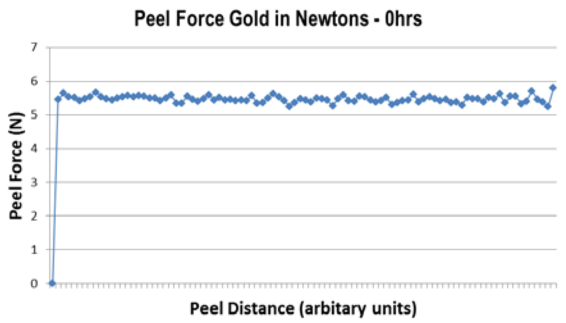
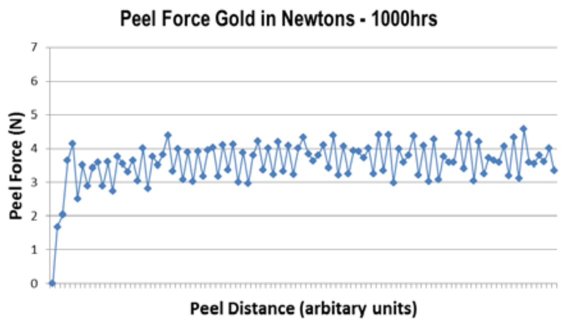


Figure 3: Peel test values at room temperature after ageing at 200ºC for different surface finishes

The results show satisfactory peel force values in line with existing standards. One observation was the distinct cracking noise heard during peel testing on nickel/gold samples. As the foil is peeled from the surface of the laminate the cracking of the nickel can always be heard. After ageing the tone of the cracking sound changes and with it the peak peel force fluctuates. The level of sound is noticeable due to the size of the track used on the test board and may not be detectable with typical track widths on production boards. Example peel force results are shown in Figure 4.



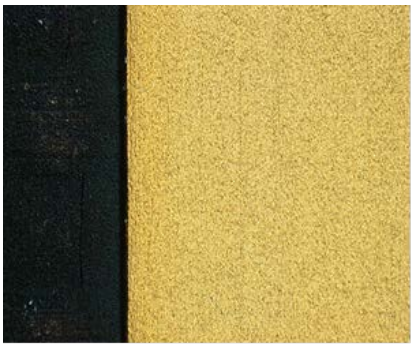
(a)



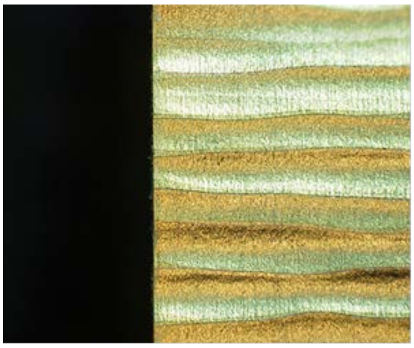
(b)

Figure 4: Peel force at 0 hours (a), and after 1000 hours ageing (b), for the gold over nickel tracks.

The appearance of the samples after testing was significantly modified as shown in Figure 5. Cracking is not unusual and is commonly seen when conducting mechanical tests on area array solder joints, such as with pad lifting during dye and pry testing. It can also be seen on pads where high speed shear testing is conducted and the pad peels from the laminate surface as the ball joint separates.



(a)



(b)

Figure 5: The images show: (a) the copper foil surface with nickel/gold before ageing, and (b) after ageing and then peeling

PCB Thermal Shock Testing

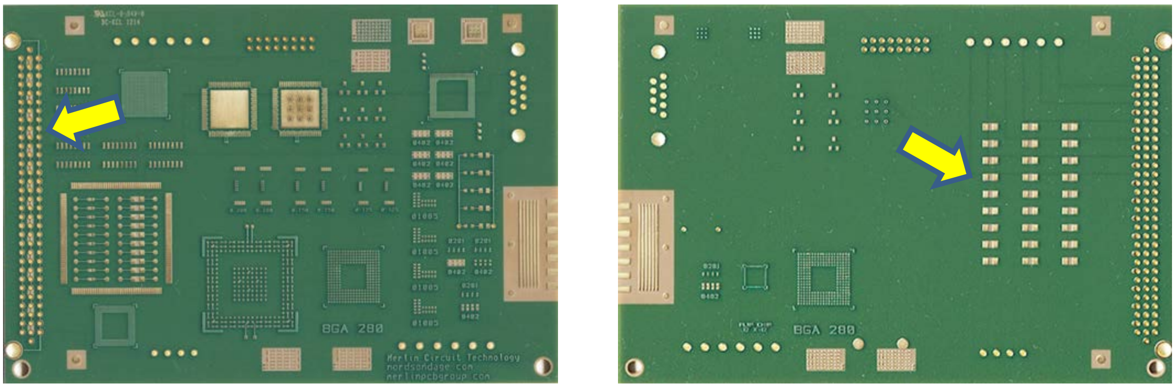
Thermal shock test coupons were subjected to immersion in water at ambient temperature then lowered into a fluidised sand bath at 260ºC. This procedure is conducted six times for each of the samples. The resistance change is measured continuously during the test; increases in resistance may indicate that cracking is occurring in one or more of the plated through hole samples. This would normally occur around the knee of the plated through hole or, in the case of multilayer boards, at one of the inner layer interfaces. This is more likely to occur on multilayer boards or with material that has a large Z expansion rate during soldering or temperature cycling. Resistance measurements did not exceed allowed during thermal cycling on any of the samples tested. Micro sections of the samples did not show any cracking on the highest stress points on the knee of the holes.

Polyimide Test Board and Assembly

In many cases the assembly of products for the high temperature applications are either small or medium volume and can be successfully produced using manual soldering for through hole applications. Automated point soldering or selective soldering may also be used if the quantity of products required are higher or a company wants to automate the process. In this project we have used manual soldering, selective, robotic tip and laser soldering to produce sample joints with different alloys.

The solder wire flux cores in existing high temperature products were formulated many years ago and are not necessarily optimised to leave a low volume of residue on the surface of the board. The materials do work successfully but they would not be considered low residue. Existing suppliers offering High Melting Point (HMP) alloys and silver antimony (Sn95 Sb5) leave a lot of flux residues. Normally in this case the flux residues would be removed for conformally coating the boards, but in the case of the trials it is also important to clean the boards prior to high temperature testing. If the residues are not removed, it becomes very difficult to achieve good adhesion with the epoxy used during micro section preparation.

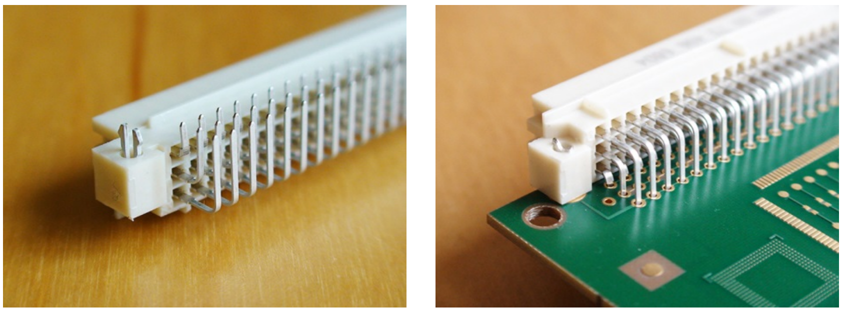
The printed circuit board design shown in Figure 6 was used for the soldering trials, only two components were mounted on this test board for these trials. Image (a) shows side one where the connector was positioned as indicated by the arrow, and image (b) shows side two used for soldering of 1206 chip resistors as indicated by the arrow. These PCBs were soldered using tin/copper, tin/silver/copper, HMP and Tin/Antimony solder wire.



(a) (b)

Figure 6: Test board design used for the core wire assembly trials

Sample boards from the trials were subjected to thermal cycling between -55 & 125ºC with visual examination of the boards and solder joints. As there was no electrical monitoring of the connections only visual examination was conducted on completion of 1000 cycles. Experience shows that it is very rare to have failure in plated through-hole and soldered connections. The results of these ongoing trials will be discussed in a future report.



(a) (b)

Figure 7: (a) the three row high connector, and (b) mounted in the PCB

Figure 7 shows the three row high temperature connector used here, and was manually inserted into the board for soldering. The example connector does have a barb hold down feature to retain the connector to the board prior to soldering. This provides mechanical support prior to soldering and then is not required.

One of the important things with through hole soldering is the lead to hole ratio; in this case it is based on the pin size. The finished hole size required on the PCB after plating and surface finishes like nickel/gold would be the pin size plus 0.010” to make manual or automated through hole assembly easy. Selective and wave soldering can tolerate some variation with little impact on the capillary fill of the hole. In the case of laser and robotic tip soldering the system computer needs to be programmed with the solder wire size and feed rate to achieve the desired through hole fill. If the connector pin or hole size changes there will be too little or two much solder. Some systems, however, are able to automatically calculate the volume size requirement then adjust the solder feed. Furthermore, with high melting point solders the fluidity and the ability to wet the terminations may change, requiring more energy in the process to achieve acceptable joints. Preheating may be necessary to achieve acceptable results.

Solder Alloys Used in the Production Trials

Alloy	Type	Melting point
Tin/Copper/Nickel	Sn-0.7Cu	227ºC
Lead/Tin/Silver	Pb93-Sn5-Ag2	296-300ºC
Tin/Silver	Sn-3.5Ag	221ºC
Tin/Silver/Copper	Sn-3.8Ag-0.7Cu	217-221ºC
Lead/Tin	Pb980-10Sn	268-302ºC

Manual Hand Soldering

The soldering and de-soldering process with higher melting point wires still follows standard good practice procedures, but at some point manual soldering cannot achieve the ideal joint. The first step is to consider pre-heating the product for either initial soldering or rework. These practices have already been successfully used with standard lead-free alloys like SnCu, SAC and lead based HMP solders. However, the high lead based alloys do need more care.

Selected soldering iron suppliers offer the use of nitrogen which is introduced around the soldering tip. This has been beneficial when using low residue products but may not be so beneficial with high solids cored wire. Nitrogen is either produced locally to the soldering iron with a small generator or provided from a company site facility. Suppliers have introduced nitrogen flowing around the heater before surrounding the soldering iron tip and joint. There is a benefit to the nitrogen being heated to avoid temperature fluctuation when introducing a cool stream of gas even at very low flow rates. Primarily the advantage is to reduce surface oxide formation on any surfaces, particularly when the temperature is higher. In the majority of cases de-soldering of high temperature joints cannot be achieved successfully without preheat and also one needs contact tools to reflow the solder prior to package removal.

In an automated soldering process where speed is important there is a benefit to preheating the joint area, also increasing the wetting characteristics of some surface finishes. Preheating can reduce solder wire spitting, another common problem where solder wire is fed direct to the tip or into the joint. Benefits have been seen with some soldering iron suppliers that have integrated their existing tools into robotic soldering cells. Set up and calibration can be achieved with special test boards and using thermal imaging cameras to compare temperature rise on the substrate with the degree in wetting.

Care needs to be taken with the soldering tips as inevitably they will have a shorter life due to the elevated temperature. In the past we have experienced the impact on soldering iron tips when the plating is damaged or poorly plated during manufacture. The core of the tip can be eroded by the tin if the plating on the tip is damaged. It is a difficult balance for tip producers to use the right balance of over plating and barrier coatings and not impact the heating capability and stability of temperature control at the soldering tip.

Selective Soldering

The selective soldering of sample boards was conducted in the traditional way using a production Selective Soldering machine with a 12mm nozzle. A wide soldering nozzle helped to maintain the heat of the two high temperature alloys as the solder progressively wicked up the barrel of the plated through holes. This may also be the best approach if thicker boards or denser connections are made on inner layers. The flux was applied with a drop jet nozzle for accurate, localised application.

It is important to use the minimum amount of flux to achieve the required hole fill. It is still possible to conformally coat boards in a no clean process. In many industries this has been standard practice for many years although cleaning is definitely increasing in popularity to give a high level of confidence in the reliability and a simplified material selection process. Soldering was conducted by bringing the 12mm nozzle up to the board and running the wave down the length of the connector. The soldering performance exceeded IPC 610 with very little flux residue left on the surface of the joints or solder mask. There was evidence of solder balling between pins adhering to the solder mask surface. This is not uncommon and the solder mask and flux combination could be reviewed in pre-production trials.

It is very common in manufacturing not to specify the solder mask material type used or conduct trials on compatibility between materials, which is poor engineering practice.

Sample boards were soldered using HMP Sn10Pb90 and Tin/Antimony Sn95Sb05 solder and a production liquid flux NC277. The dwell time for the joints was approximately 1-2 second with a nozzle speed of 229mm/min. The solder temperature for HMP was 360ºC and 340ºC for Tin/Antimony.

Selective Robotic Iron Soldering

The robotic iron soldering system is basically a fully automated soldering iron with computer controlled parameters, programmed manually or by importing PCB design files. The systems are either three or four axes robots with either proprietary soldering heads and wire feeder systems or units that have been integrated with commercially available heads. This can also be the case for laser systems. Robotic soldering has started to become more popular in recent years with high reliability and automotive manufacturers trying to reduce the use of manual soldering. It has also been used in high volume production where a small number of joints need to be produced on each assembly making it more viable than selective wave or jet soldering. It is clear that the sample board and connector used in this trial is more suited to a selective wave soldering process, but the speed of soldering was not necessarily part of this assessment.

As with any other printed board assembly a product should be designed for manufacture rather than adapted to suit a process. One of the key features is accurately and repeatedly locating the product for the soldering operation, even if some form of vision alignment is provided. Fixturing of the product for the soldering operation is very important for repeatability. If the product is a single board assembly then tooling or a fixture nest will be required for multiple boards if tip or laser soldering processes are to be used. If the boards are still in a multi-panel then standard tooling can be used but the panel must be supported to prevent sagging and inconsistent height. Some equipment has automatic height sensing to deal with sagging or warpage of boards.

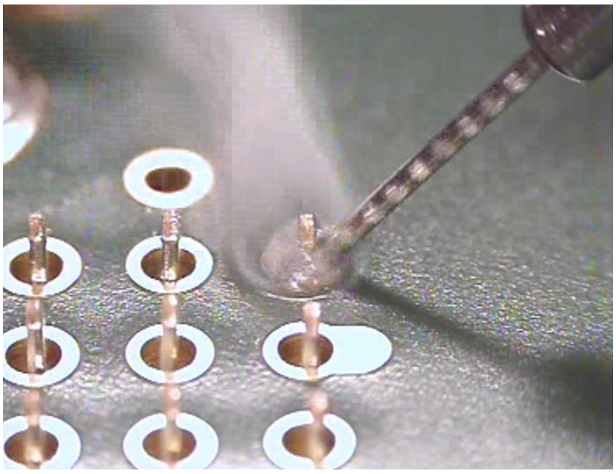


Figure 8: Shows a notched solder wire being feed to the joint zone, and heated by the laser.

Selective Laser Soldering

Particularly for high temperature solders, and limitation of access, laser soldering offers an attractive solution to delivering sufficient heat directly to the solder, and avoid over heating surrounding areas and delivering heat just to the joint zone. An example is shown in Figure 8.

Some machine suppliers are able to automatically calculate the amount of solder wire required to fill the hole and provide positive solder fillet during programming of their software. This is based on a simple calculation based on hole size, board thickness and pin size and the wire diameter. Some suppliers are able to do this automatically using vision systems which are also used for programming the equipment.

Soldering parameters

An example of the soldering set point parameters used in one trial are illustrated below and were determined by the equipment supplier to achieve satisfactory filling of the plated through holes with his equipment. The machine parameters are provided as an example only. It is very important to define the process parameters used for soldering and determine their repeatability during trials. Through hole fill is the key parameter in terms of inspection and in process quality control but inspection of the board, copper plating, laminate, pad and solder mask are also important.

Tip soldering	Laser Soldering
Soldering iron tip 2mm	60 watt single emitter 940nm wavelength
Solder iron temperature 385ºC	Minimum light diameter 0.5 – 0.8mm
Pre solder feed 0.4s	Preheat 0.0s with 0 watt
Pre heating 0.8s	Solder feed 0.6s with 25 watt
Solder feed 0.4s	Hold time 0.2s with 25 watt
Solder wire feed speed 75%	Solder wire pullback 0.1s
Solder wire pull back 0.1mm	Solder wire speed 100%

Laser and robotic soldering have the following benefits. Both processes can produce through hole solder joints with less energy and time per joint but still achieve successful through hole fill. Where high temperature solders are being used this capability can be a real advantage. Furthermore, both processes can benefit from local nitrogen supply to aid pre heat, prevent oxide formation and residue problems on the iron tip. Additionally with laser soldering it is possible to have different process parameters per termination without impacting throughput. With iron soldering the tip temperature cannot be changed per joint but the speed, dwell time and solder feed may be altered. The ability to tailor the soldering parameters per joint where heat load can be a sensitive issue is an important advantage. Where product reliability and traceability is important, such as in the automotive industry, the ability to automate each step in the assembly is a distinct advantage. Selected laser systems can capture temperature profiles and the soldering operation per joint for traceability.

Flux residues

Soldering individual solder joints with cored wire will leave residues. Depending on the number of solder joints in any one location the amount of residues will be more apparent; a good example of this is a connector. Depending on the pad size, hole size, hole to lead ratio and thickness of the board the amount of residue will increase or decrease. This is simply related to the amount of solder wire fed to create the joint.

If the board is to be cleaned after soldering, the volume of flux left on the surface of the board is less of an issue but the residues must be soluble in the cleaner to be used. The residues may be more or less difficult to remove based on the soldering process. Laser soldering residues may be easier to remove than iron soldering residues; and using nitrogen as opposed to air may also have an impact. As most products destined for the high temperature market will be conformally coated cleaning may be the normal situation.

As seen during the introduction of lead-free cored wires, there were generally two directions that suppliers followed. A residue that was still relatively soft after soldering or one which was brittle and easily cracked. This allowed test pins to make contact with the solder joints through the flux residues; however, both did still provide problems for the user. Where boards are conformally coated it is possible for the residues to expand and contract during thermal cycling which then leads to the coating separating or lifting. In turn allowing moisture to accumulate in those areas may cause corrosion or dendrites to form in the presence of an applied voltage. This may then not be a failure specific to activators from the flux but caused by lifting of the coating.

High temperature soldering can exacerbate flux residue problems. The lower wetting potential and the extended heat cycle for the higher temperatures can result in more residues, and those being more difficult to remove. Often assemblies being manufactured for harsh conditions will be conformally coated, and hence cleaning is required.

Flux Volatiles/Vapours

Each solder wire will have different characteristics depending on the supplier’s flux formulation and the volume of the flux included in the wire. During soldering the flux flows out from the wire aiding the soldering process. As previously stated there is a lot of flux left on the surface of the board and joints; however, it is the impact of the vapour potentially condensing on the optical systems used in the soldering systems that can also impact the process. Unfortunately this is often not noticed in small production runs or equipment trials. Higher temperatures and longer soldering times will exacerbate this effect.

Solder Wire Spitting

One of the potential problems, particularly with laser soldering, using cored wire is spitting from the flux which in turn can lead to solder balls on the surface of the board after soldering. Partly this a problem created by the end user as they try to optimise by speeding up the soldering process. By watching the soldering process closely or using video, you can see these problems happening in real time.

Although during the wire selection process an engineer can trial different products and different core sizes, other options have been used by different suppliers. During soldering the flux can explode from the wire as or before the solder reflows. For high temperature solder alloys there may be a limit to the range of products provided by suppliers including the size of wire and flux options. Some suppliers may not produce wires and rely on others to produce the products for them. An option to avoid spitting is to indent the wire decreasing the wall thickness, and this is shown in Figure 9. The theory is the pressure is released in a more controlled way. The indents in some cases are formed by the wire indexing wheel that is used to feed the solder through the nozzle for the soldering operation. Perhaps by making the shape of the feeder a specific design it allows two functions from a single operation. Scoring the wire is also an option that can also avoid undue pressure build-up of flux volatiles.

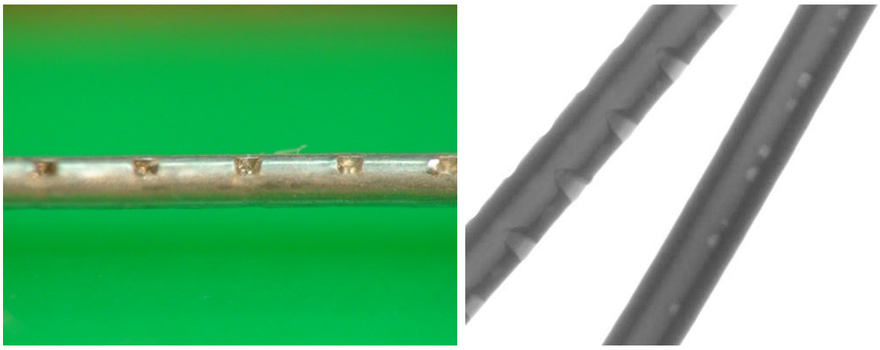


Figure 9: Cored solder wire with surface indentations after feeding, also shown in X-ray image

Very simple testing of different wires with and without indents or v-scoring has shown solder and flux being ejected from the solder surface. The tests involved feeding the cored wire onto a heated white ceramic tile. When the solder wire touches the surface reflow would take place; in most cases plain wire did result in spitting and scored or indented wire did not. Assessment can be made by simply checking the white tile surface for solder residues, this technique has been used successfully as an assessment tool and recorded on video.

Testing and observing the soldering characteristics of the wire during heating and reflow is very useful to compare products. The equipment supplier has used high speed video to show the difference in wires and the degree of solder balling. A video on their website shows the benefits of wire preparation prior to reflow. During this project we have also been able to control the flux volatile escape from the wire and, with it, spitting of solder balls. The images in Figure 10 show the various stages of heating a solder wire.

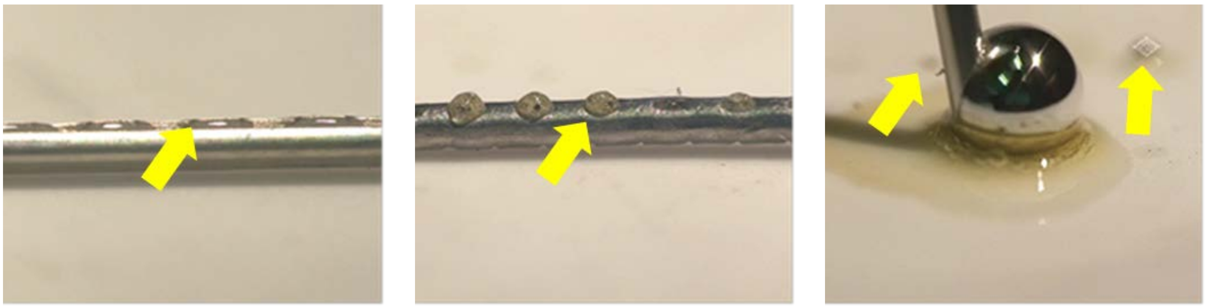


Figure 10: Images above left & centre show the point that flux escapes from the wire during heating.
On the right solder balls formed on a white ceramic tile when the wire was not prepared

Micro-sectioning of Joints

Sample joints were cut from the printed board for micro sectioning. The samples soldered with cored wire were cleaned prior to potting, due to the amount of flux remaining on the surface of the joints. In the past excess flux residues have reduced the support to the solder during the grinding and polishing stages. The samples selectively soldered were not cleaned prior to potting due to limited flux residues remaining on the surface of the board. Measurements of the intermetallic (IMC) thickness were taken on each of the samples. The majority of the samples prior to ageing provided IMC thicknesses of $\leq$ 1µm. One sample produced with laser using the tin/copper alloy had IMC thicknesses of 1-2µm, but this is not considered to be significant. After ageing at 200ºC for 1000 hours the IMC thickness was measured again and reported below:

Tin/Antimony	Hand Soldered	5.0µm
Tin/Antimony	Selective Soldered	10.5µm
HMP	Selective Soldered	16.0µm
SAC	Laser Soldered	8.5µm
SAC	Robotic Iron Soldered	8.1µm
Tin/Copper/nickel	Laser Soldered	9.2µm
Tin/Copper/nickel	Robotic Iron Soldered	8.4µm

Broadly, the IMC thickness was similar after ageing; although for the selective soldered samples the IMC thickness was ~50% thicker. Potentially this more energetic soldering process has an effect on the joint and the level of dissolved copper which may affect the future growth of IMC. From a reliability standpoint this level of IMC would not be considered to be problematic. Most failure and crack growth will propagate through the solder, but typically in a zone close to the IMC interface where there are higher stress levels. In this context the choice of alloy and soldering process and temperature is not affecting the IMC thickness, and any reliability issues will be more a function of the alloy composition.

Conclusions

There will be increasing interest in soldering with high temperature alloys in the future as applications demand locating electronic systems in harsh environments. Soldering at specific locations offers a route to manufacture that avoids overheating assemblies, and included techniques such as manual and robotic soldering, selective soldering and laser soldering. The ability to deliver heat just to the interconnect to be joined is a great advantage. With high temperature alloys that challenge fluidity of the solder and wetting, preheating of the PCB will definitely be beneficial. High temperature soldering also presents flux issues. Residues may be more copious, and more difficult to remove with high temperature processes. Solder cored wire is used with irons and laser soldering, and with the higher temperatures and the requirement to limit the high temperature exposure, solder spitting becomes an issue. Scoring and indenting the wire has been developed to release the flux as it liquefies and volatilises.

Acknowledgements

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Options for Assembly using High Temperature Interconnection Technologies

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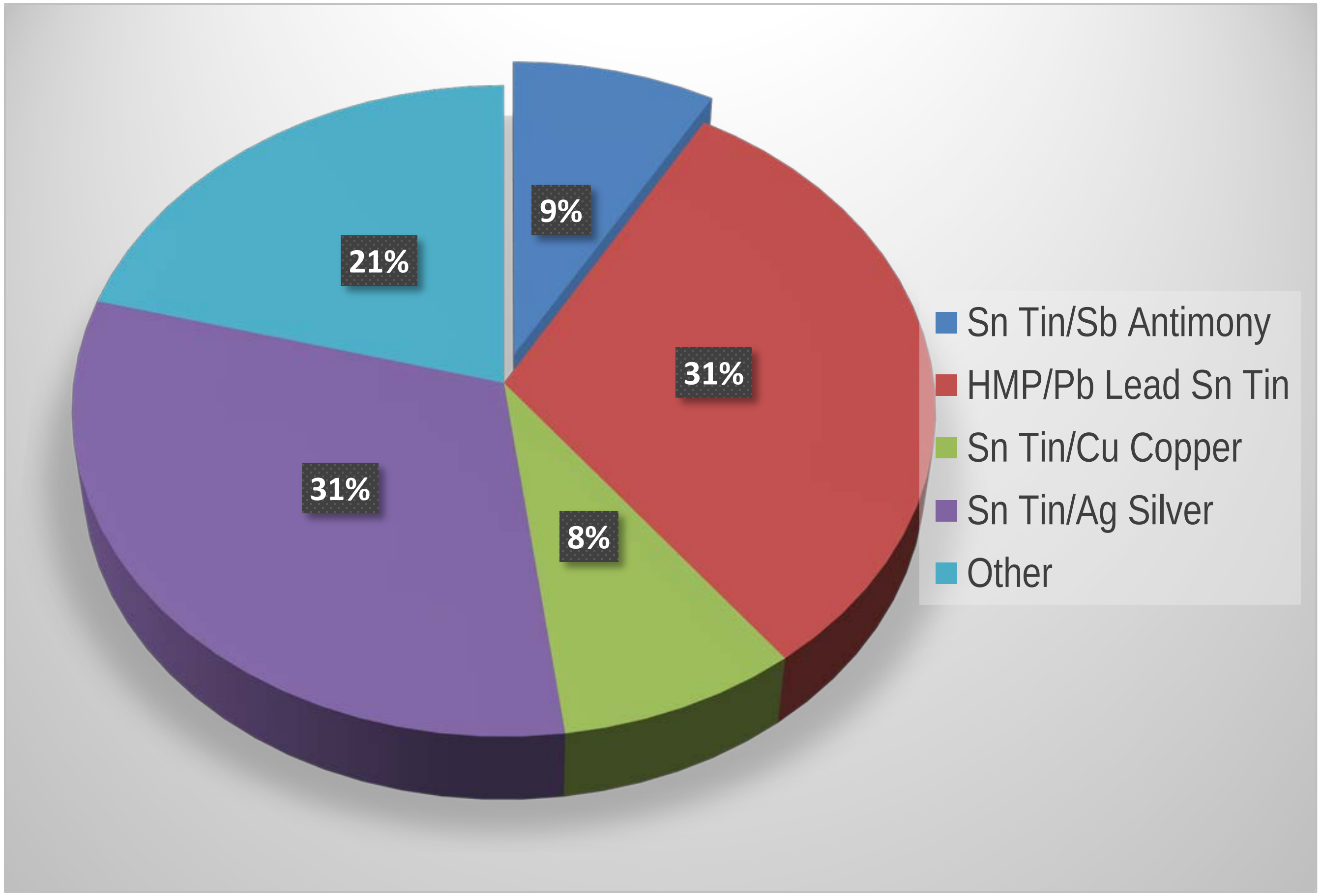
Project Aims

- Assemble polyimide board
- Selective solder, Robotic Laser & Iron soldering
- Different solder alloys – HMP, SnSb, SnCu & SnAg
- Static ageing at 200C for 1000hr
- Thermal shock and peel strength measurements

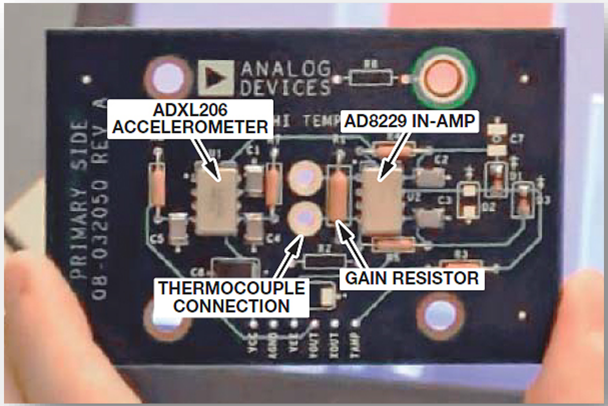
What solder alloy are being, used or considered, for High Temperature Assembly?



Component Packaging

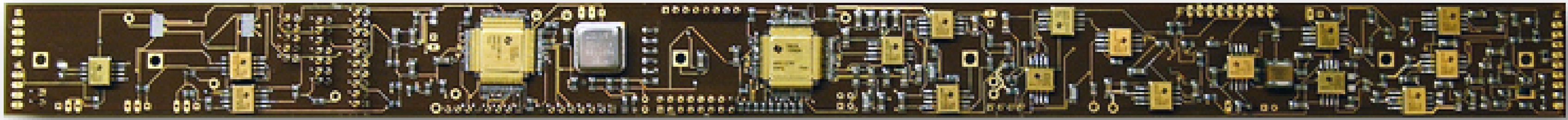
- Product Demonstration Boards
- Companies have produced working demonstrator boards to illustrate their components and operating capability. In both cases using polyimide as a base substrate

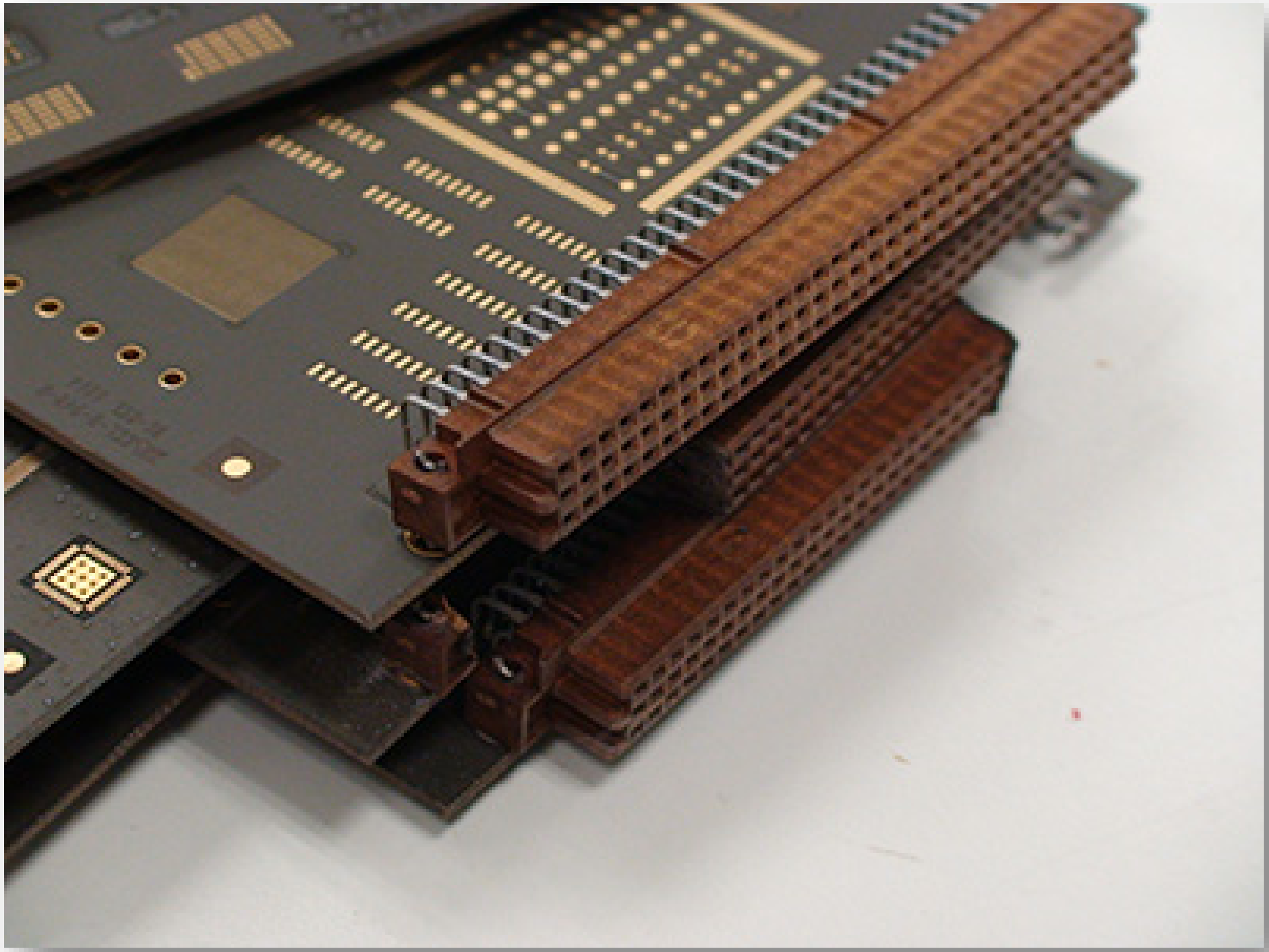
- Plastic parts 175C
- Ceramic components 210C
- Bare die 210C



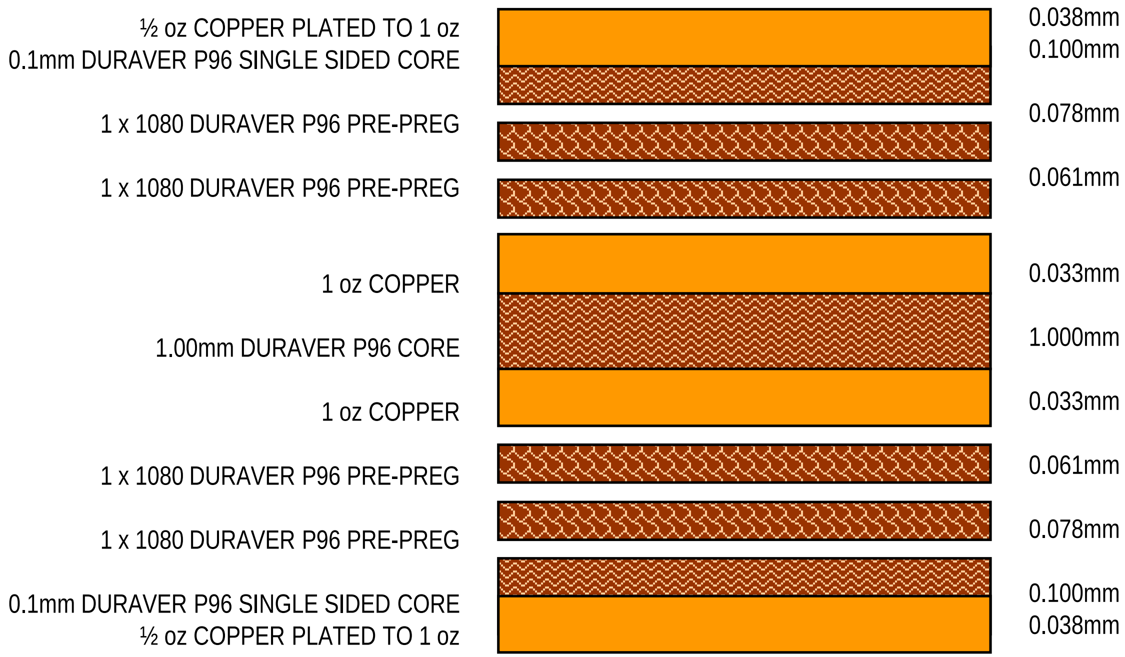
Reference: Texas Instruments

Reference: Analog Devices



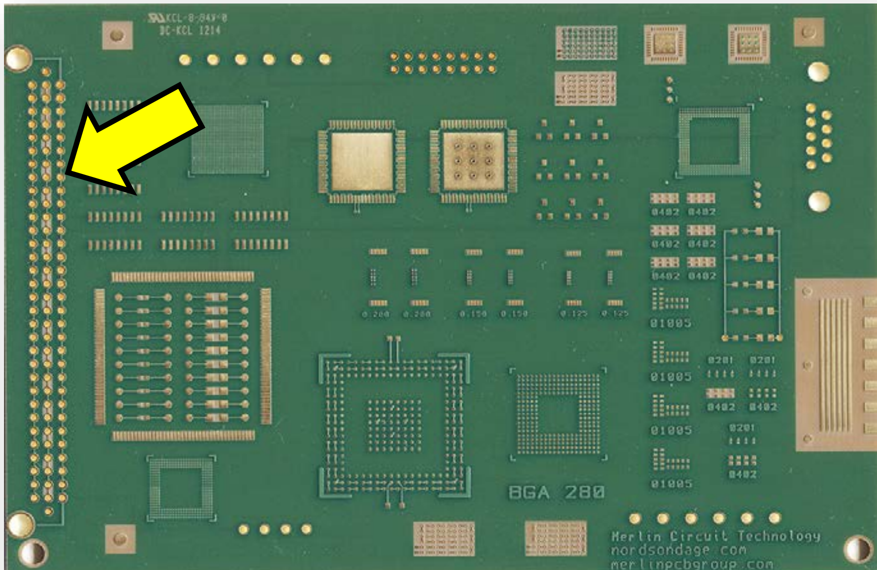


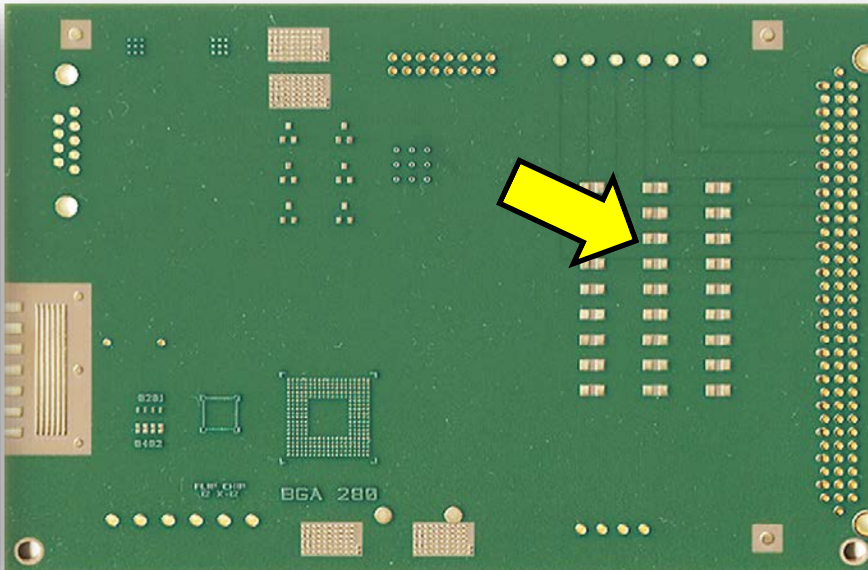
Boards and connectors do not look in perfect condition after 1000hrs at 200ºC



The test board was produced from four materials by a PCB supplier in the UK. The surface finish were all gold over nickel. The peel test boards were produced from one laminate but with three different surface finishes

Polyimide laminate types: MeteorWave laminate, Nelco N7000 Polyimide, Ventec VT901 Polyimide, ISOLA P96 Polyimide





- Standard test board design was used, PCB was 1.6mm thick with nickel/gold surface finish. The through hole highlighted were used for selective soldering of a high temperature connector. The connectors were rated at 260ºC for soldering but not for continuous high temperature storage at 200ºC. The 1206 chip resistors were used for a separate material test involving shear of the parts from the board
- All boards were subjected to 500-1000hrs at 200ºC in an air circulated oven

Soldering Processes for High Temperature

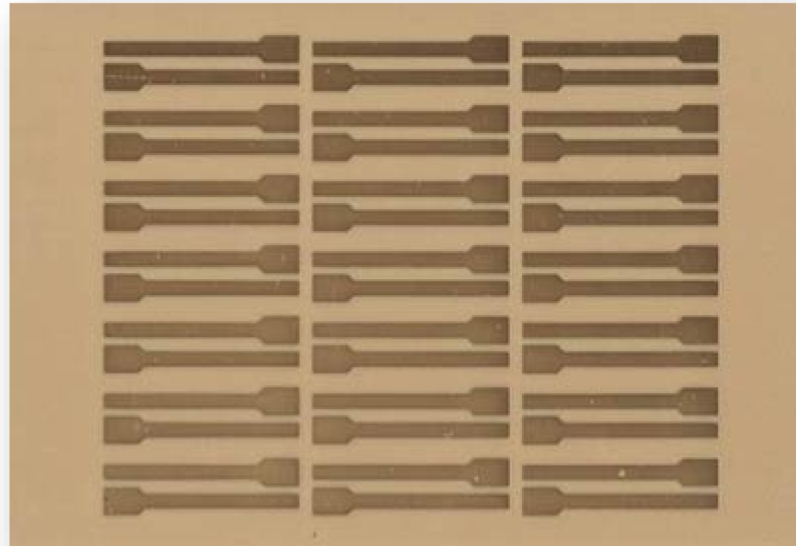
Assembly process is limited by the PCB and component temperature range

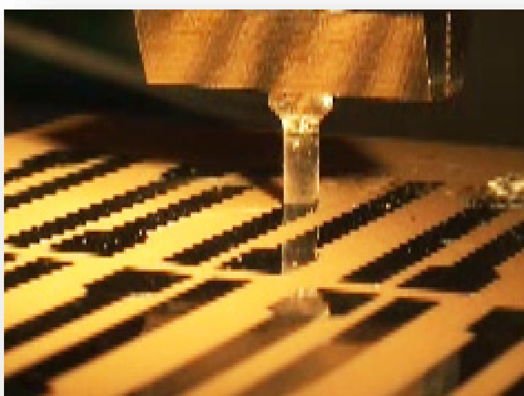
The temperature limit of the PCB and components must be able to withstand the peak temperature and continuous operation requirements

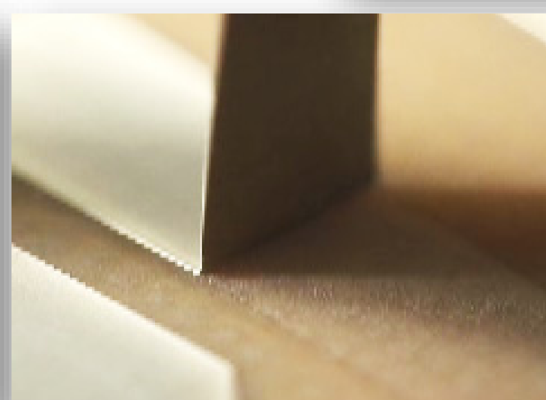
Some suppliers have re-qualified their high reliability parts to operate above 175^{o}C

Peel Conducted on a Production Bond Tester

Peel pattern in line with IPC & IEC standards for printed board quality control testing



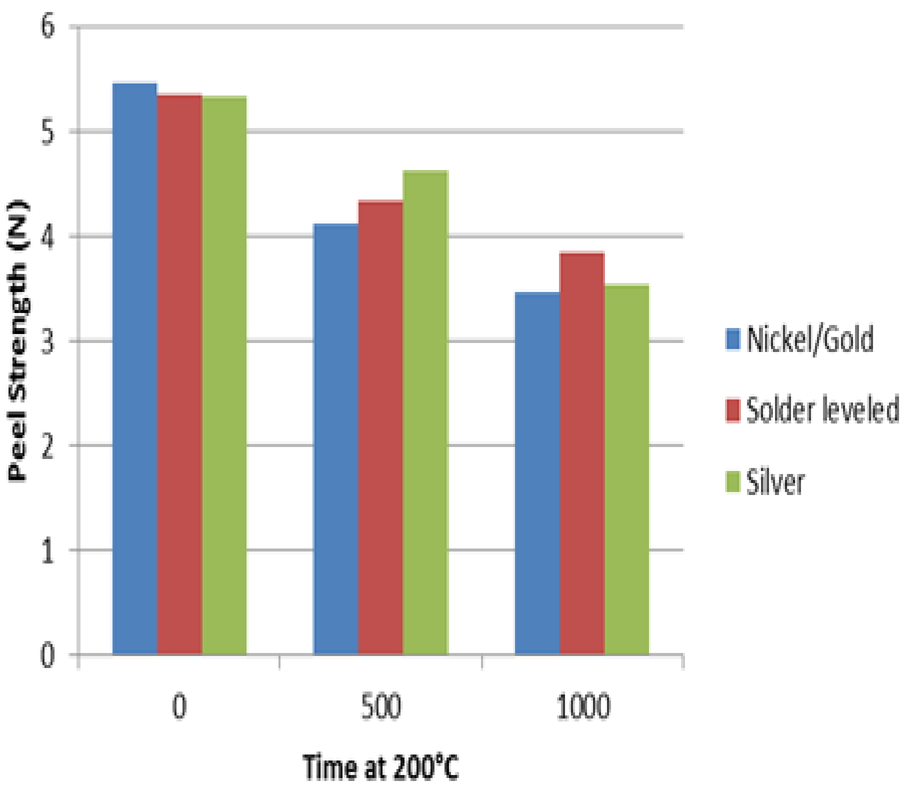


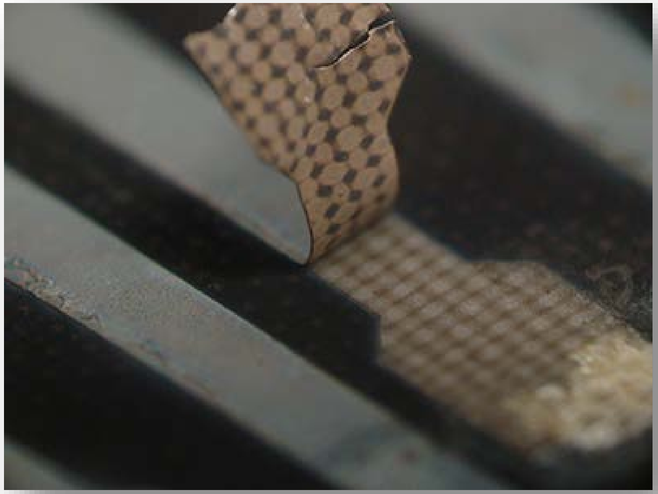


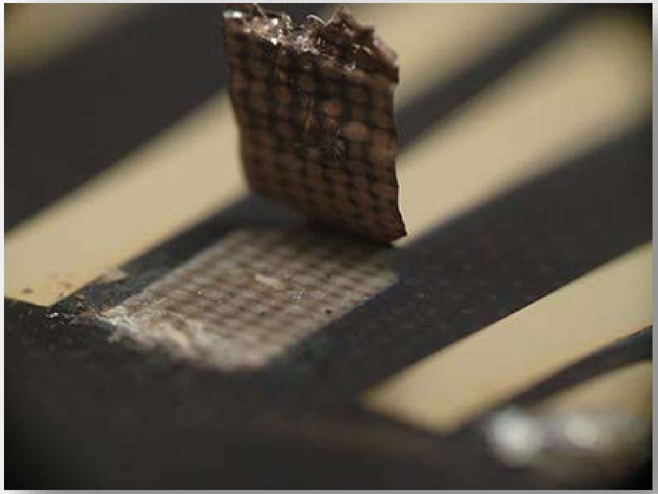
Tracks being peeled to show possible change in strength after ageing. Testing conducted at 0, 500 & 1000hrs at 200^{0}C

Video clip shows the test being conducted

Peel Conducted on a Production Bond Tester

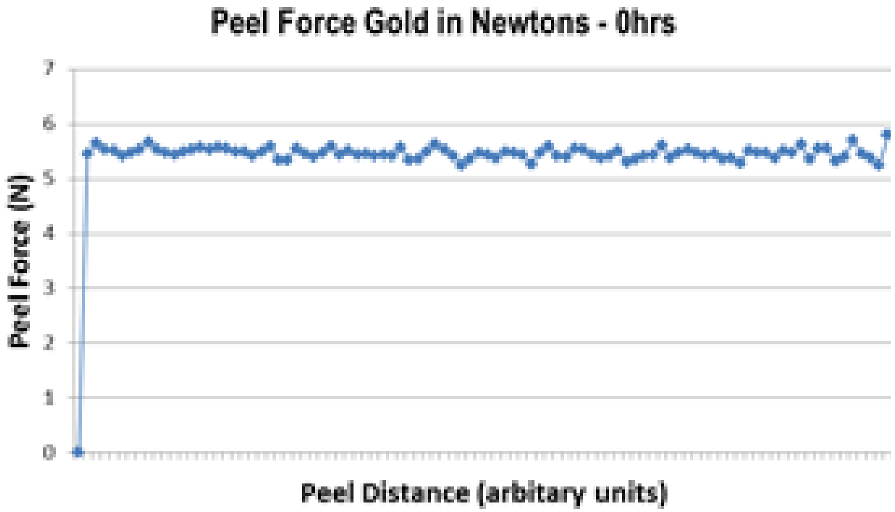


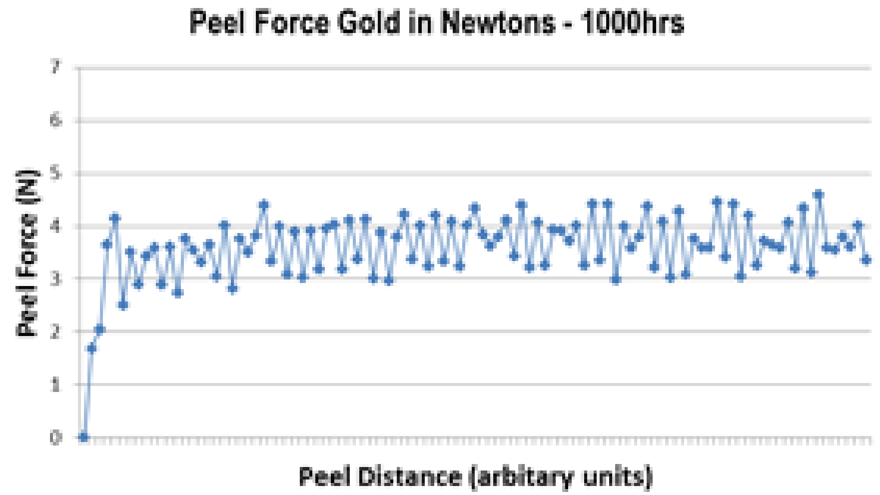




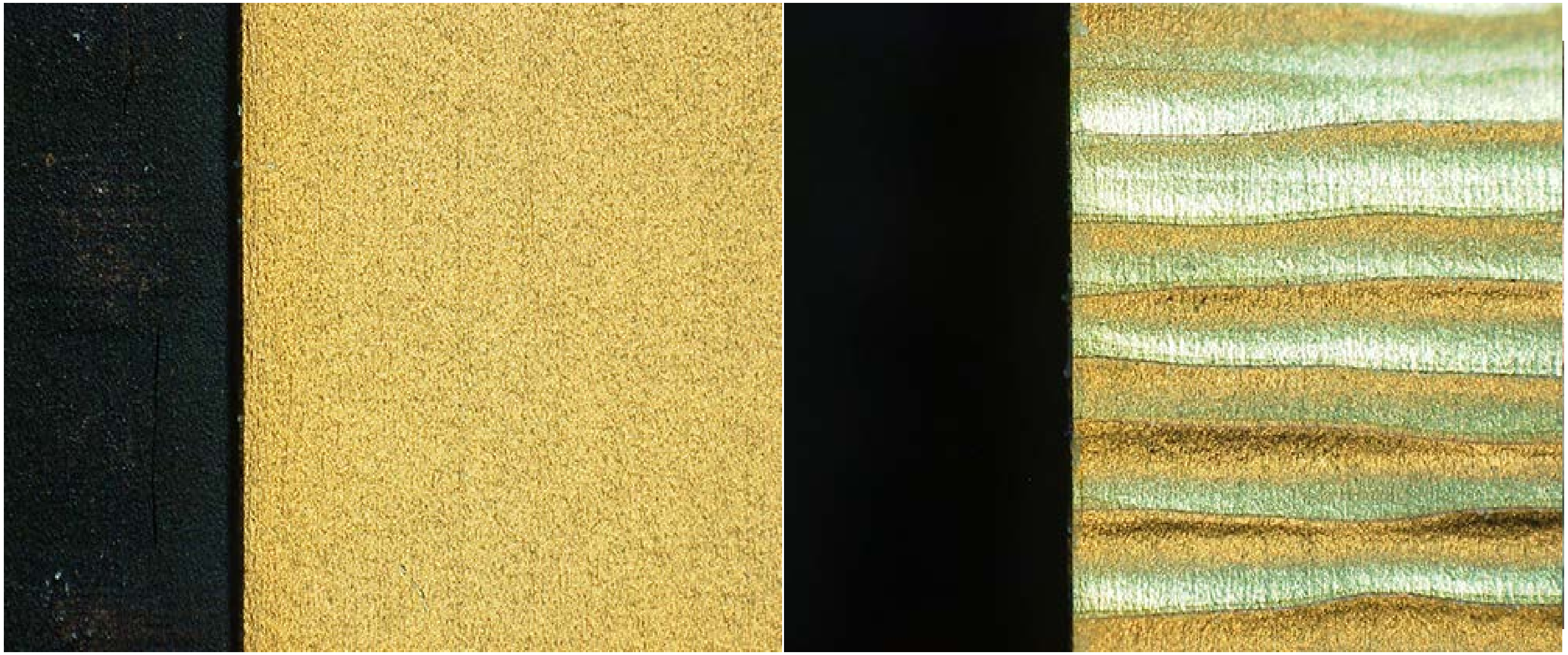
Change in the bond directly under the copper foil

Peel Force on High Temperature Laminate Before & After Ageing





The results of the peel test were satisfactory and in line with existing standards. One observation was the distinct cracking noise heard during peel testing on nickel gold samples. As the foil is peeled from the surface of the laminate the cracking of the nickel can always be heard. After ageing the tone of the cracking sound changes and with it measurement fluctuation on the peak of the graph. The level of sound is noticeable due to the size of the track used on the test board and may not be detectable with existing track width on production boards



Images above show the copper foil surface with nickel/gold before ageing (left) after ageing then peeling (right) from the surface of the laminate. The cracking in the nickel is not uncommon and is clearly seen on the surface of the image.

Close examination of BGA pads after dye & pry testing can often show the same cracking due to the peeling effect of the pad from the laminate surface

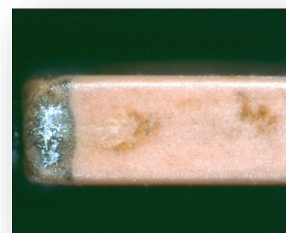
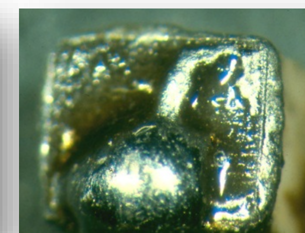
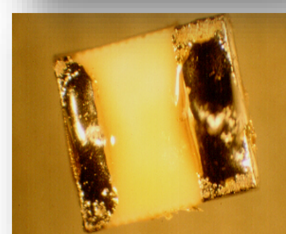
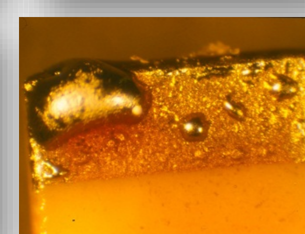
Soldering Processes for High Temperature

Name	Composition	Melting Point	Description
Sn63	Sn63 Pb37	182°C	Eutectic
Sn62 62/36/2	Sn62 Pb36 Ag2	(s)176°C (l)189°C	Limits Ag leaching
Sn42	Sn42 Bi58	138°C	Low Temperature
43-43-14	Pb43 Sn43 Bi14	(s)144°C (l)163°C	Low Temperature
Sn10 #159	Sn10 Pb90	(s)275°C (l)302°C	High Temperature

Solidus - This is where a solder alloy first starts to melt and go into a liquid state

Liquidus - This is where the solder alloy is completely in a liquid state

Eutectic - This is when a solder alloy does not have a pasty stage during its transition from solid to liquid or liquid to solid

Soldering Processes for High Temperature

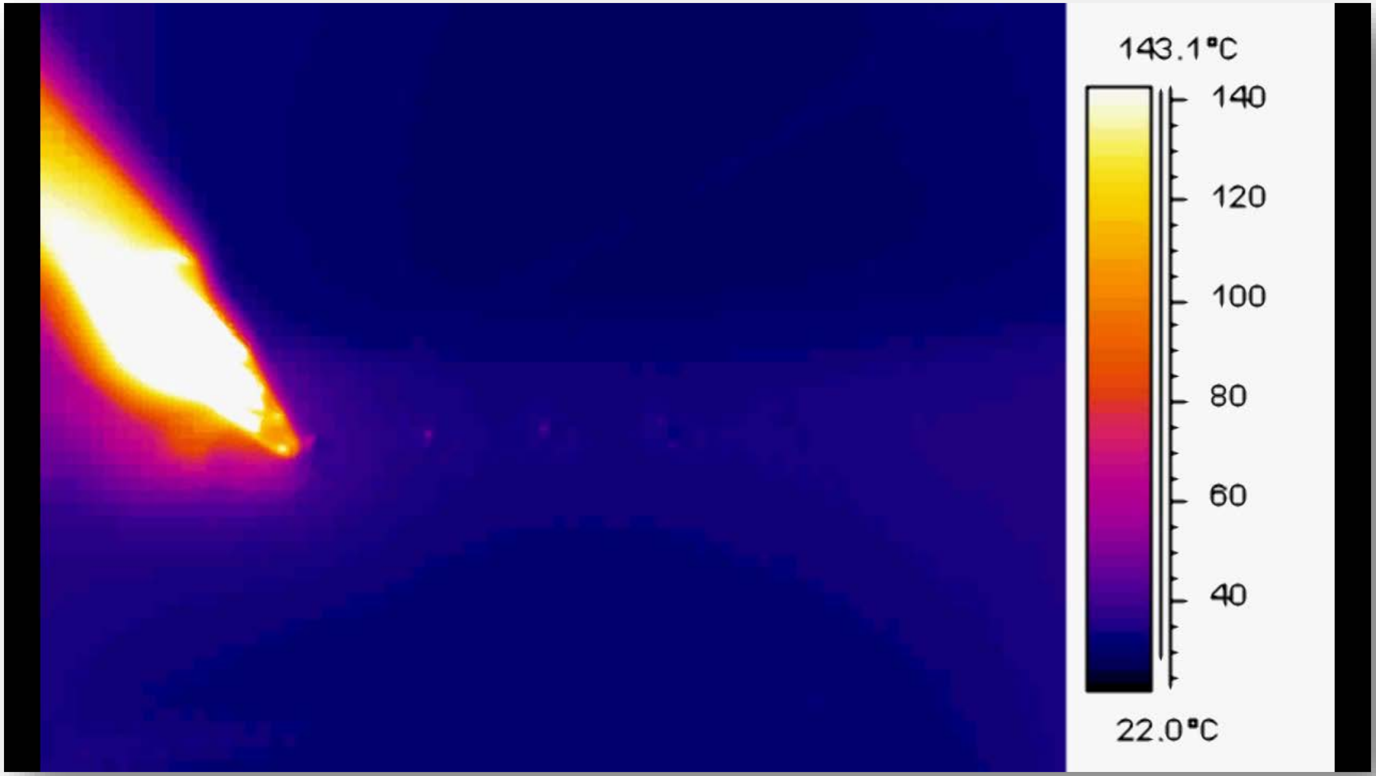
Solder Alloy	Melting Point o(C)
Sn-0.7Cu	227
Sn-3.5Ag	221
Sn-3.8Ag-0.7Cu	217-219
90Pb-10Sn	268-302
Sn-Cu-Ni-Ga	227
Sn95Sb5	232-240
Sn95/Ag5	221-240

There are many alloys available with PbSn contents above 90%, with melting points with a range up to 302C, and then PbAg alloys with melting points up to 365C

Soldering Processes for High Temperature

- Manual soldering
- Robotic iron soldering
- Laser soldering
- Selective soldering
- Vapour phase
- Nitrogen/reactive gas reflow

Manual Soldering



PCB temperature rise during manual soldering illustrated by thermal imaging with existing lead-free solder alloy on 2.8mm thick boards. Where there is a known difference in the design making heating difficult simply change the order of soldering. Skip the difficult one and come back to it as the other joints will have preheated the board!!

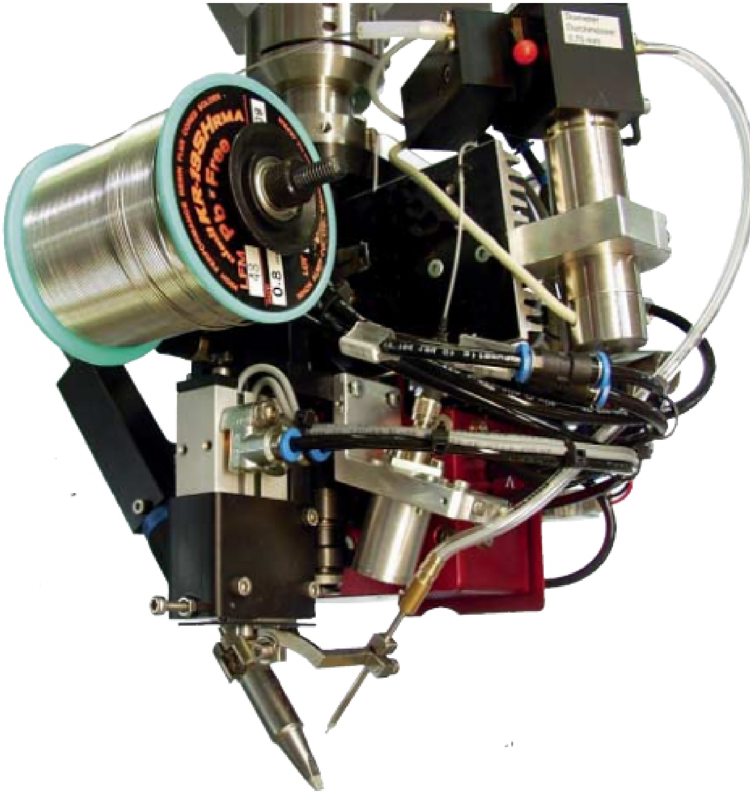
Robotic Soldering Systems

- Trials boards were processed with various suppliers.

Robotic Soldering

- Extremely flexible
- Define parameters per joint
- Different tip designs, point & drag soldering
- Cored wire feed
- Nitrogen support
- Improved tip control and temperature control

Accurate PCB tooling & component lead position



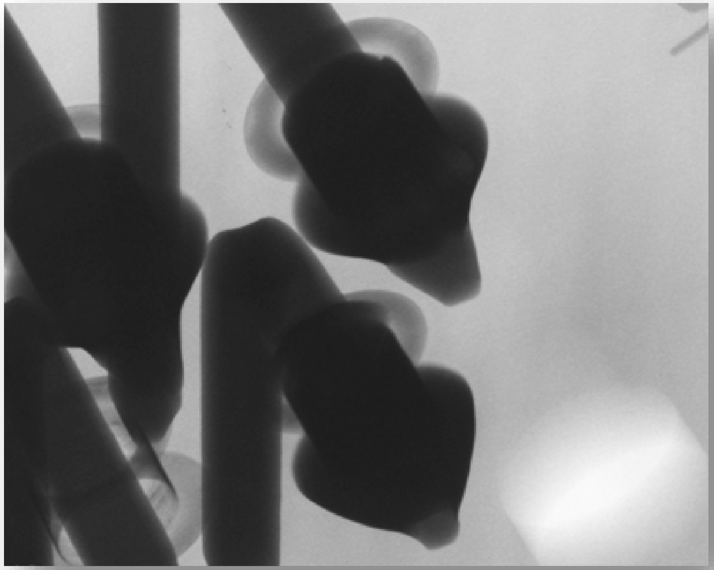
Laser Soldering

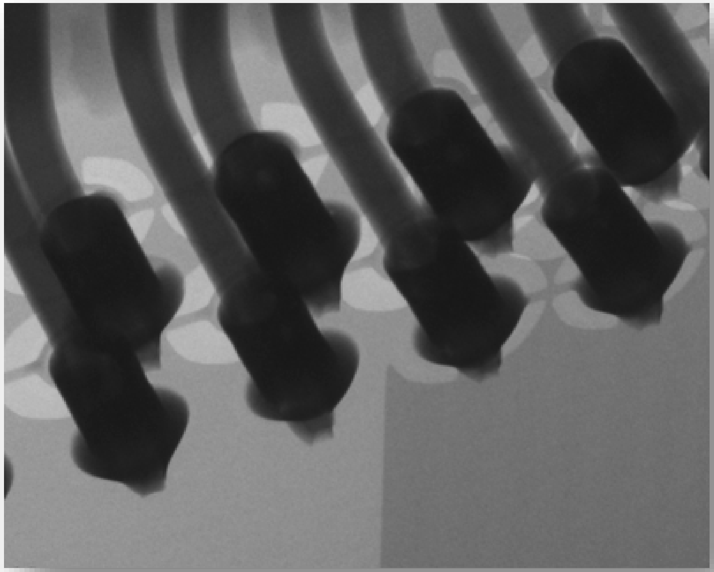
Laser normally 30-40watts

Focus spot size will be the PCB pad size or less

Pulse operation capability

Long working distance





Robotic Soldering Process

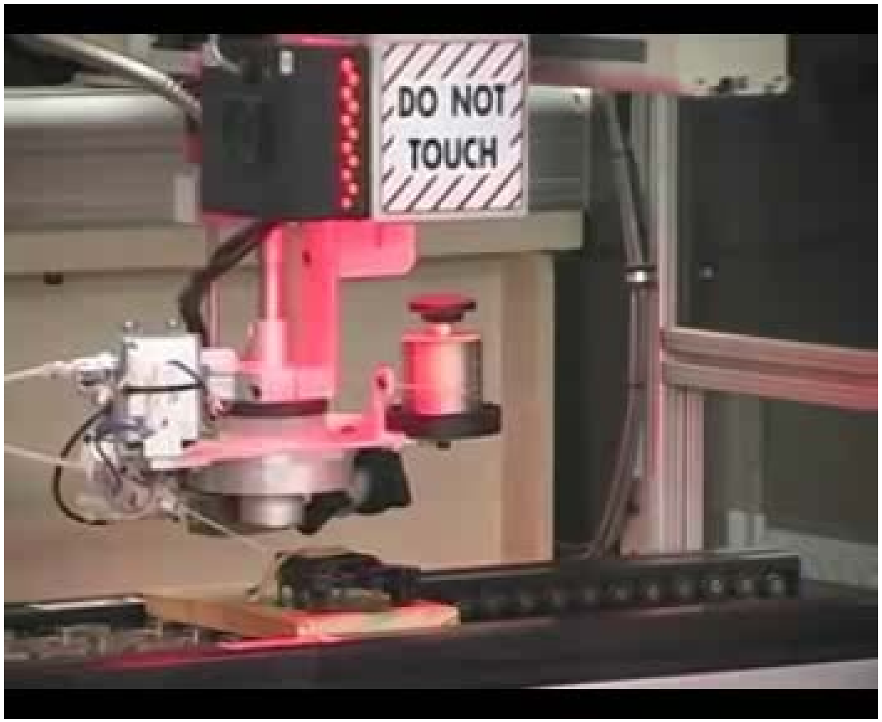
Tip soldering

Soldering iron tip 2mm
Solder iron temperature 385^{o}C
Pre solder feed 0.4s
Pre heating 0.8s
Solder feed 0.4s
Solder wire pull back 0.1mm

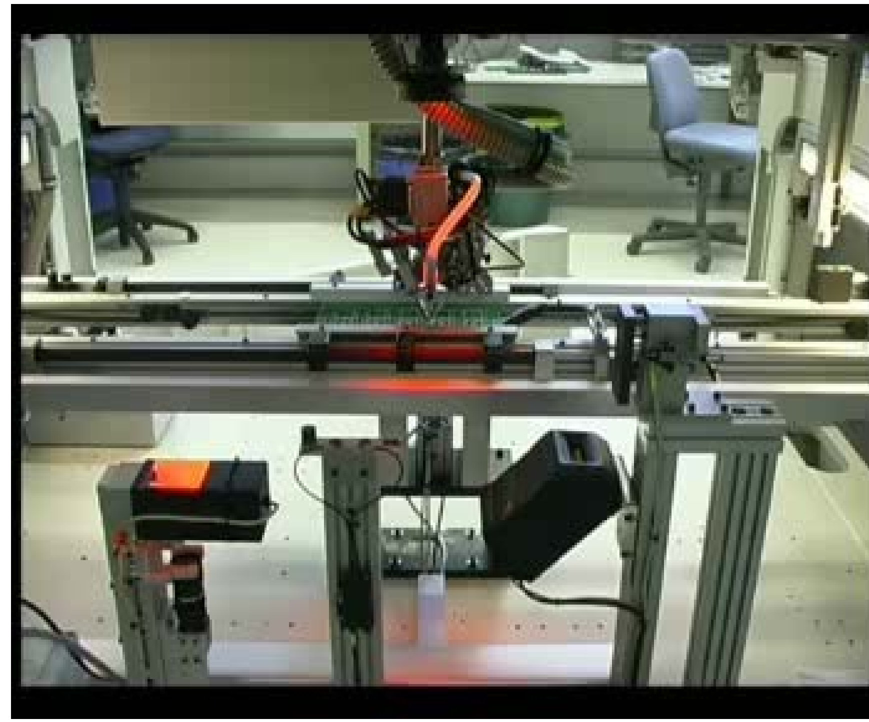
Laser Soldering

Minimum diameter 0.5 – 0.8mm
60w single emitter 940nm
Preheat 0.0s with 0 watt
Solder feed 0.6s with 25 watt
Hold time 0.2s with 25 watt
Solder wire pullback 0.1s

Robotic Soldering Process



Selective laser soldering

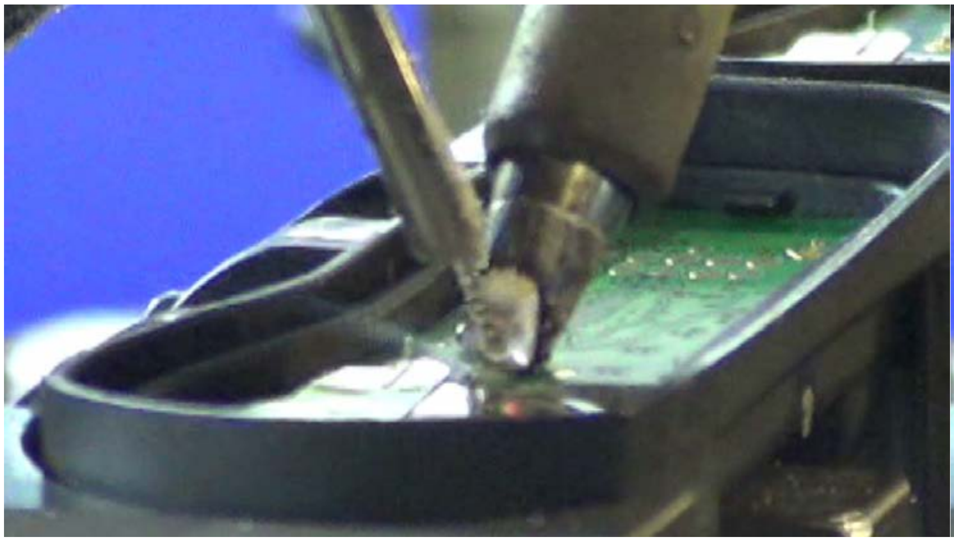


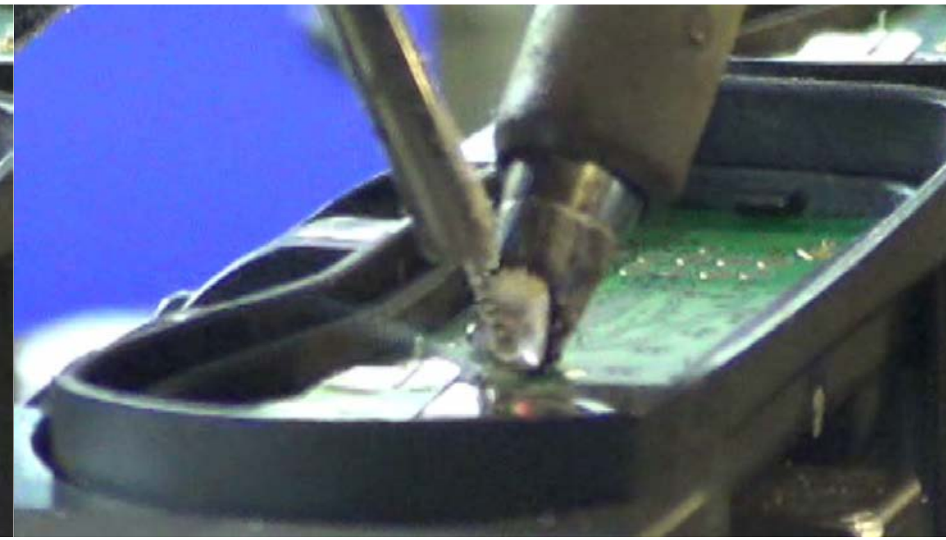
Robotic iron soldering

Any flow line assembly could incorporate preheat of the product prior to soldering

Reference www.wolf-produktionsystems.de

Robotic Iron Soldering





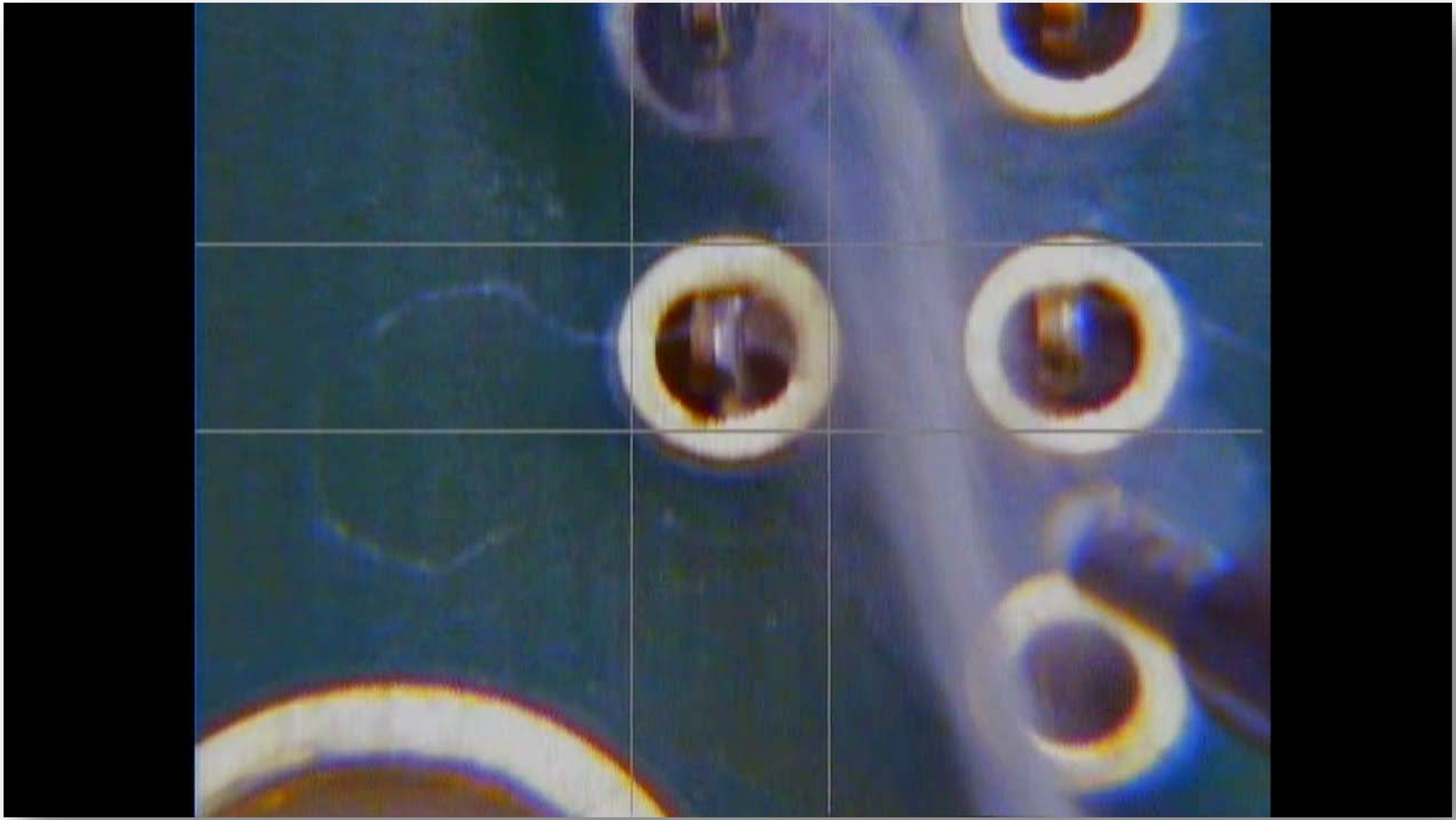
Example of customers soldering operation on surface mount module with through hole terminations. The second video is in slow motion to show the process steps more clearly

Reference: Apollo Seiko via HDSA www.hdsa.nl

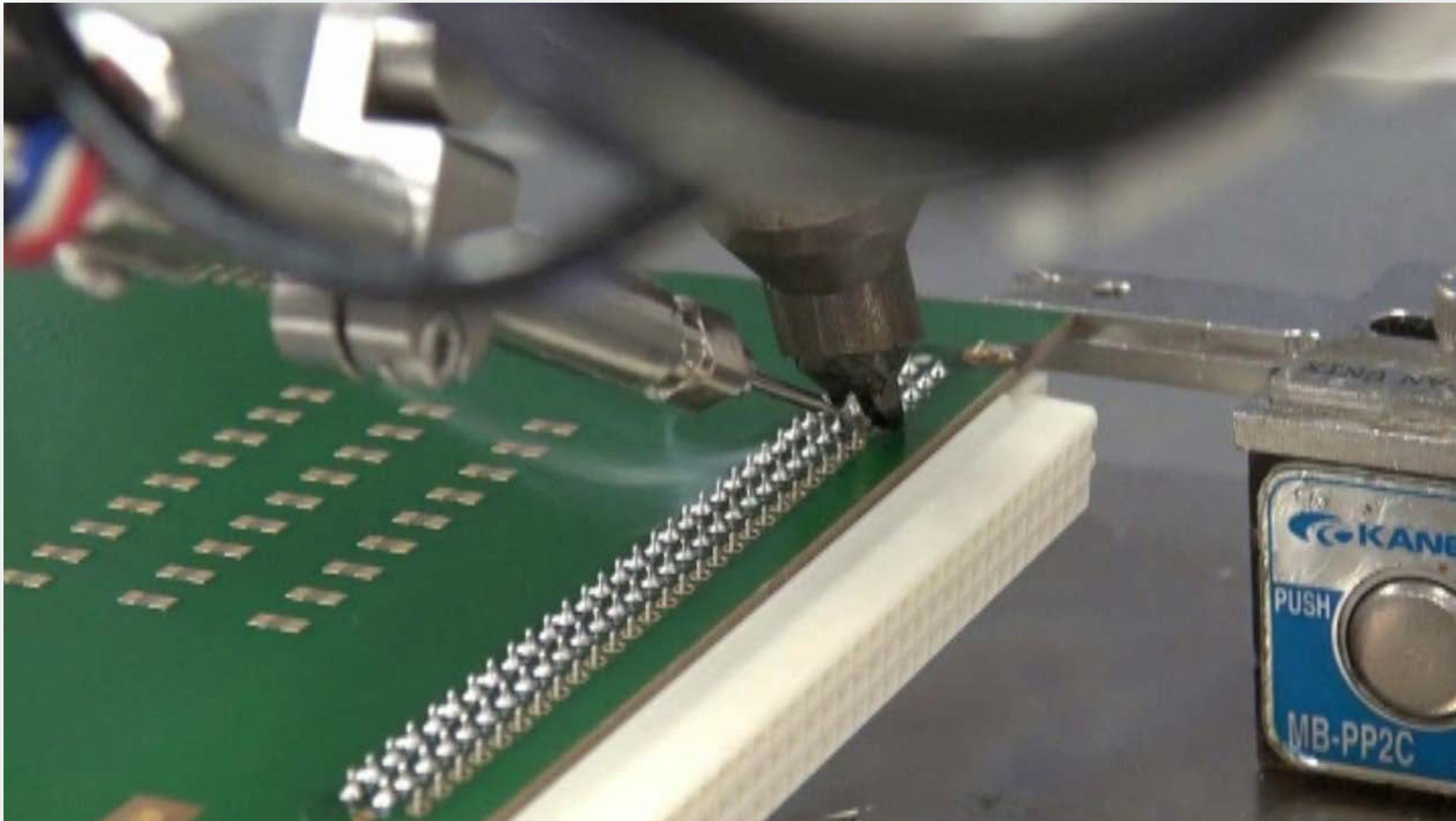
Laser Soldering

- Laser soldering trials, notice the indents on the cored solder wire which are important from a process optimisation point of view

Laser soldering system on test board.
Reference: mta

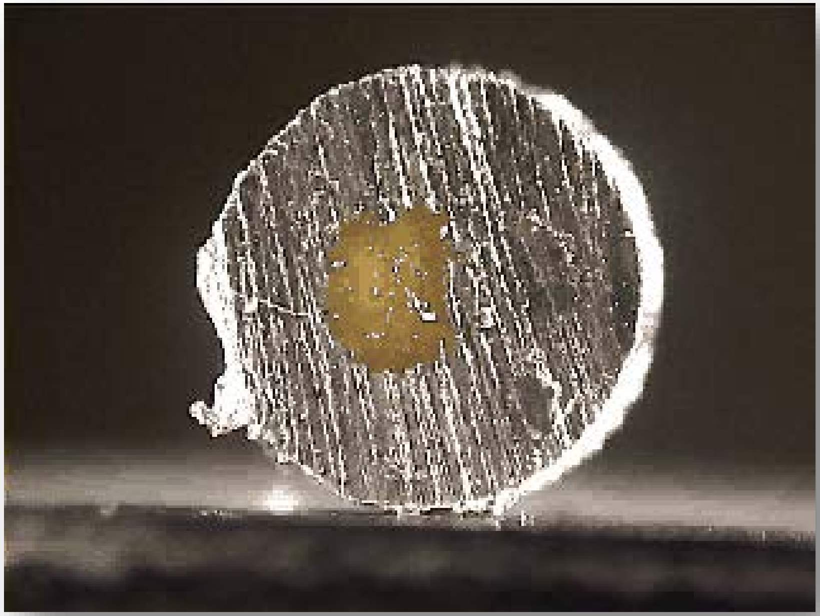


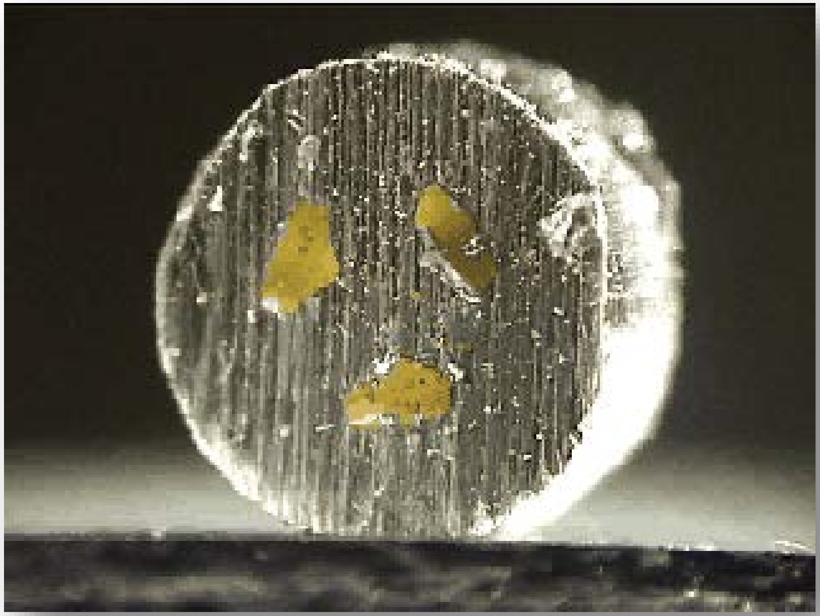
Laser soldering with tin/copper. Reference: Japan Unix



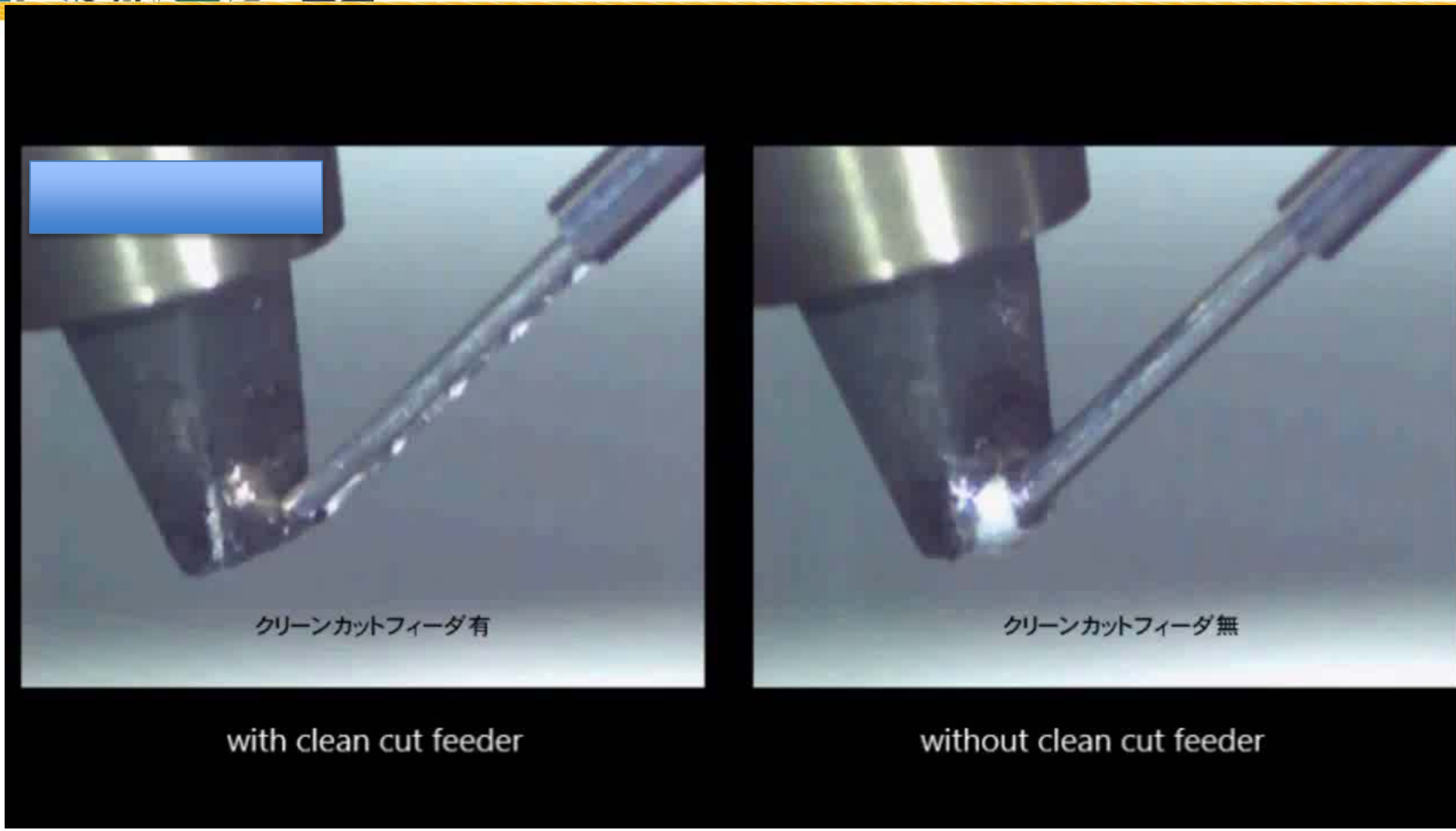
Iron drag soldering with tin/copper. Reference: Japan Unix

Cored Solder Wire

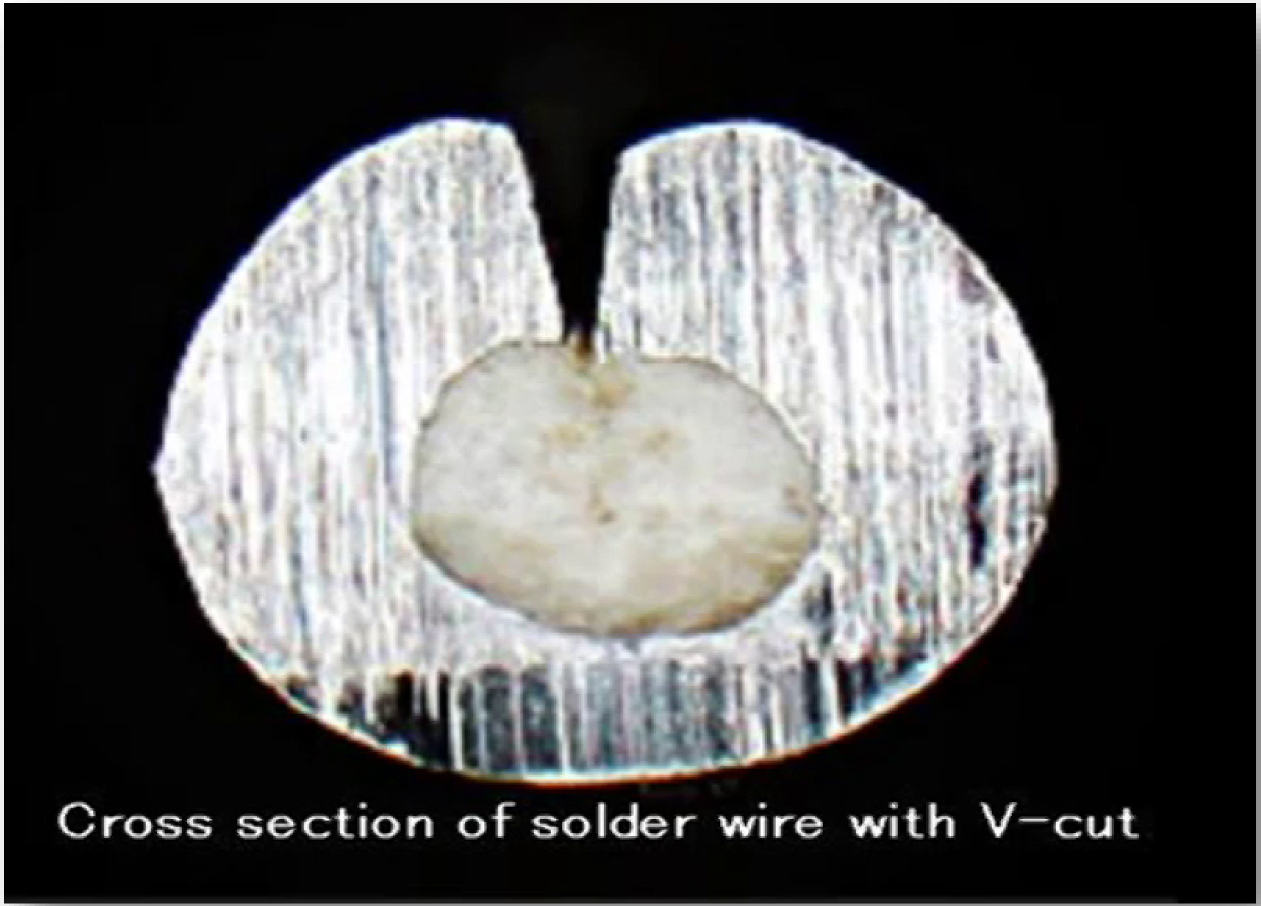




Examples of cored solder wire reflowing, first the flux flows out of the wire then the solder reflows to wet the surface to be joined. The design of the core can be supplier specific the key feature for automated soldering is no spitting of flux or solder particles. In laser and iron soldering the process is considerably faster

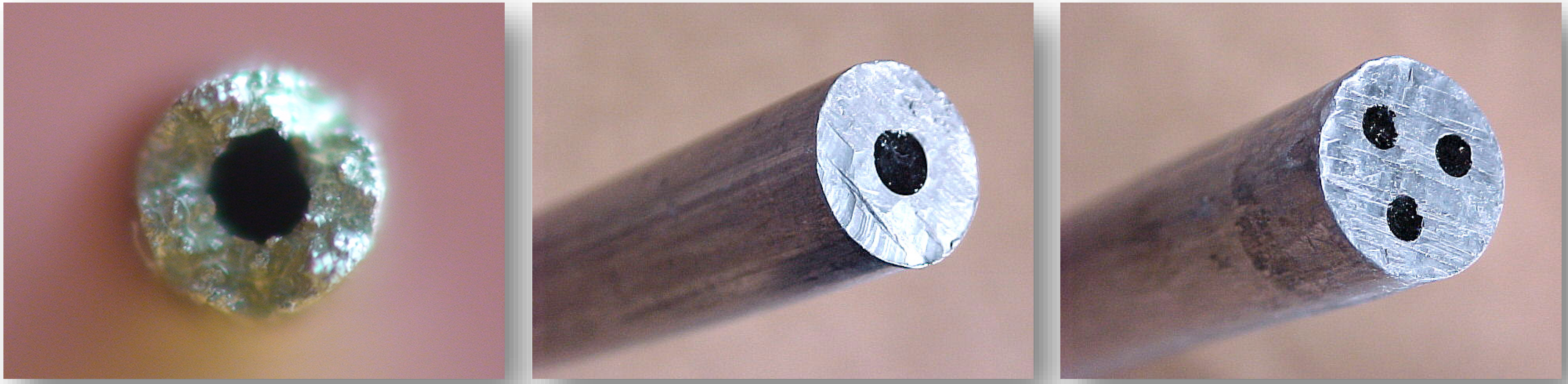


The impact of solder balls during automated soldering. You can slow down the process to reduce the fast temperature rise times but that impacts assembly times during soldering. Key feature is selecting material and reducing the percentage flux



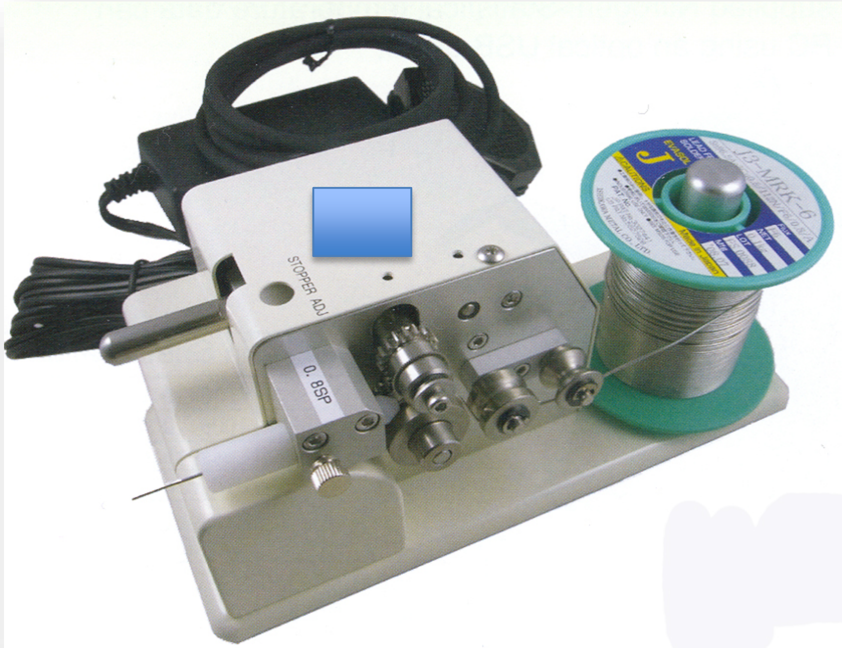
Example of cored wire cross section after feeding through a wire feed system
Reference: Japan Bonkote

Cored Solder Wire

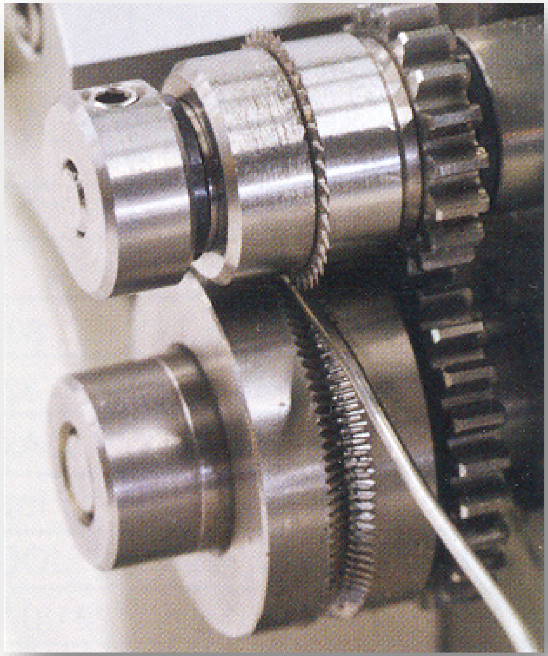


Another theoretical consideration is the type/shape of the flux core multiple cores may not benefit from scoring or indenting the wire?

Cored Solder Wire

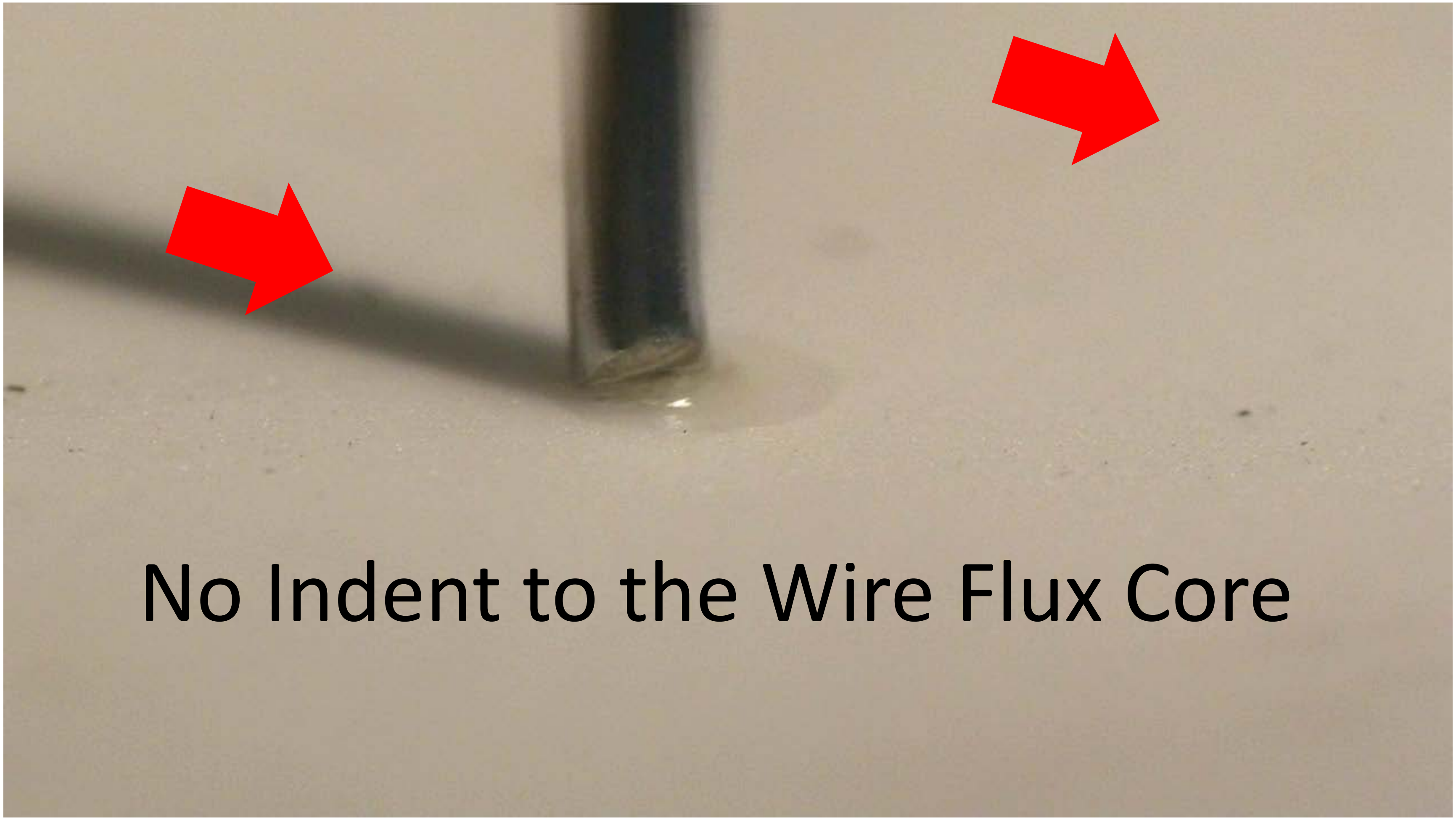


Wire feeder with indent tool

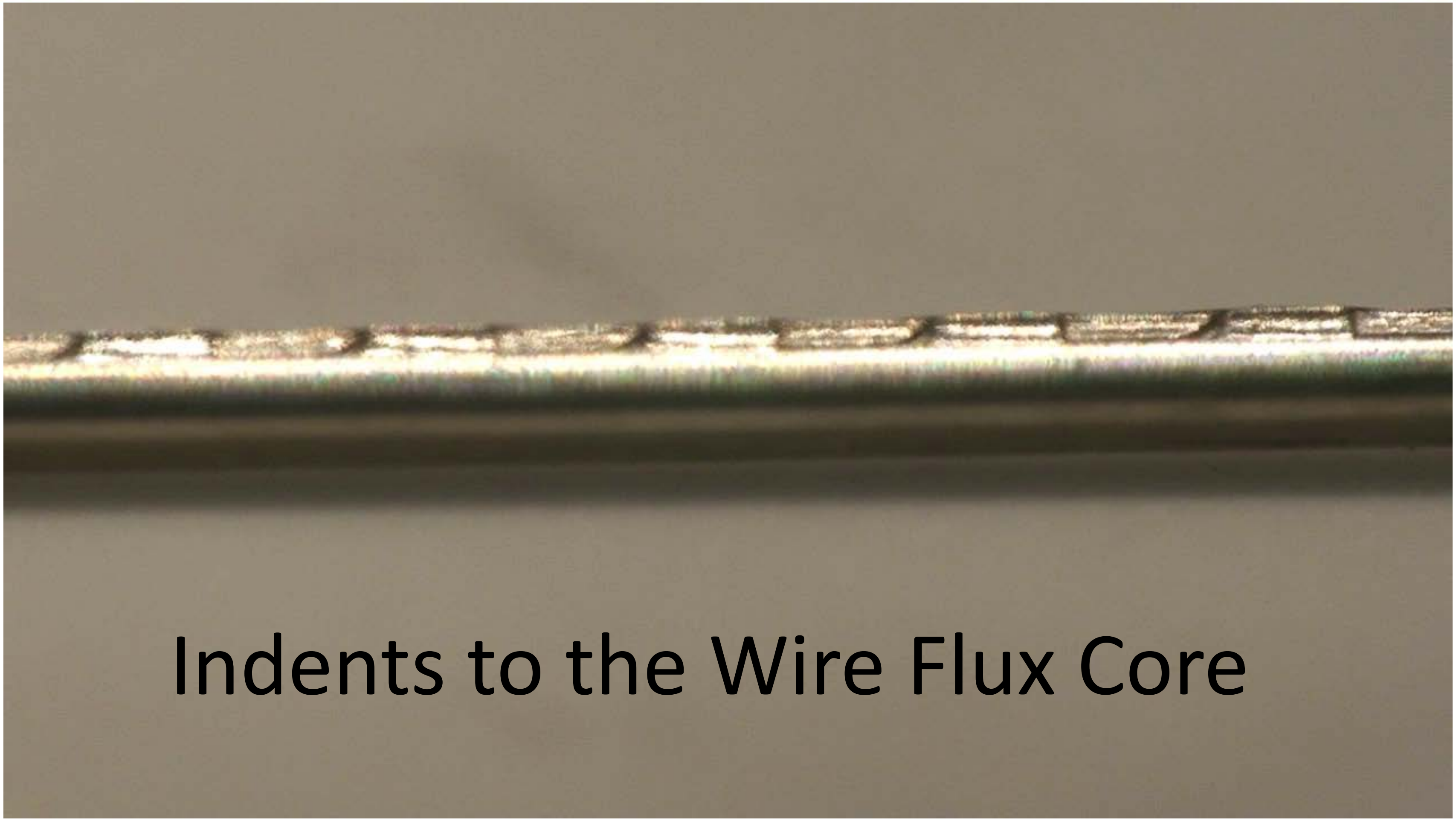


Wire feed indent tooling

Solder wire feed system used on Apollo Seiko robotic soldering system, the feed system indents the wire to reduce the possibility of solder balls caused by fast heating of the flux in the cored wire. This may be an advantage on both robotic iron or laser systems



Simple test reflowing the cored solder wire on a ceramic tile spitting and balls can be seen easily



Wire is not heated to reflow temperature in this demonstration to show the flux escape from the cored wire

Microsections of High Temperature Joints

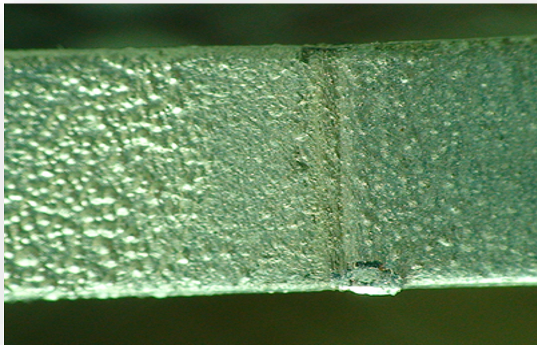
Average results of the IMC Thickness measurements are shown below, after 1000hrs, they ranged from 5um to 16um

Sample 1	Tin/Antimony	Hand Soldered	5um
Sample 2	Tin/Antimony	Selective Soldered	10.5um
Sample 3	HMP	Selective Soldered	16um
Sample 4	SAC	Laser Soldered	8.5um
Sample 5	SAC	Robotic Iron Soldered	8.1um
Sample 6	Tin/Copper/nickel	Laser Soldered	9.2um
Sample 7	Tin/Copper/nickel	Robotic Iron Soldered	8.4um

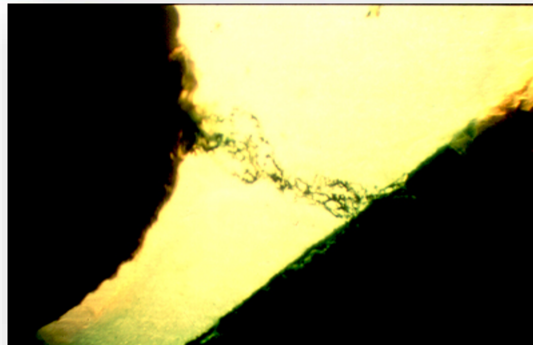
Sample test boards with selected solder alloys have been subjected to temperature cycling after soldering between -55C to +125C for 1000 plus cycles. The results of this work will be discussed in future presentations

High Temperature Application Defects

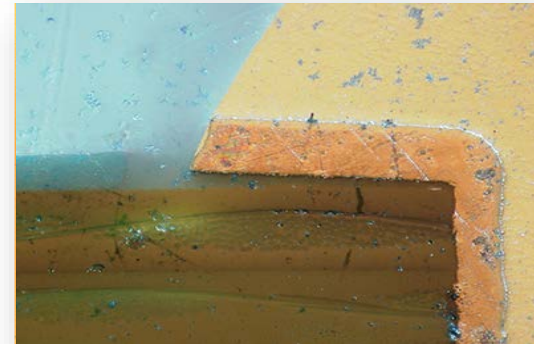
- Component plating flaking
- Surface corrosion
- Component damage
- Termination dissolution
- Sulphur corrosion
- Solder pin separation
- PCB delamination
- Plating separation
- Poor hole fill
- Solder shorts – migration in coatings



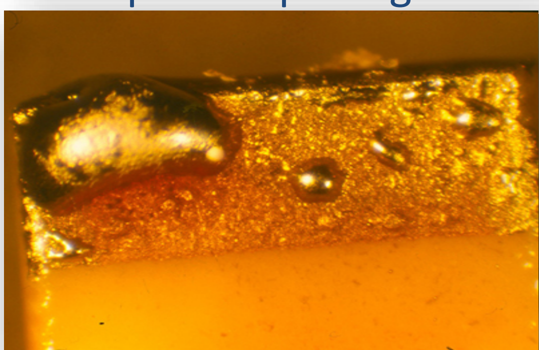
Component plating flake



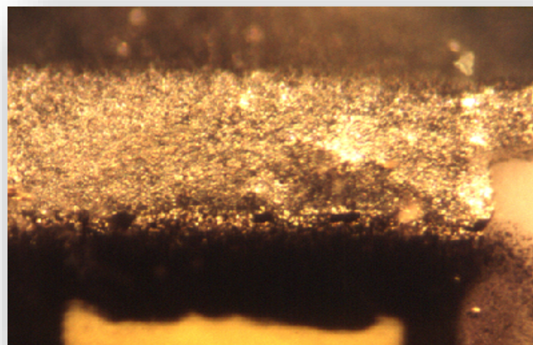
Surface corrosion



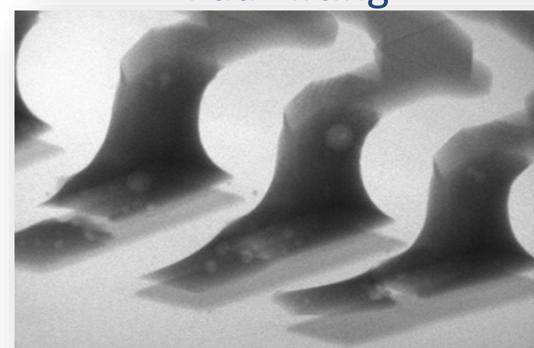
Pad Lifting



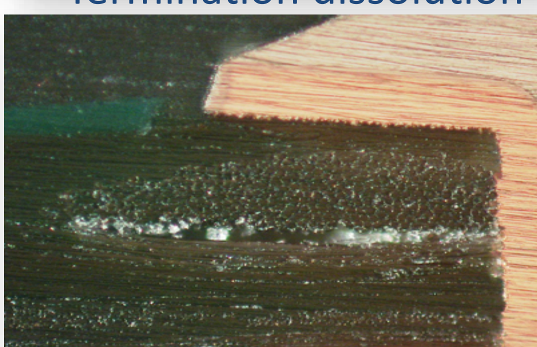
Termination dissolution



Sulphur corrosion

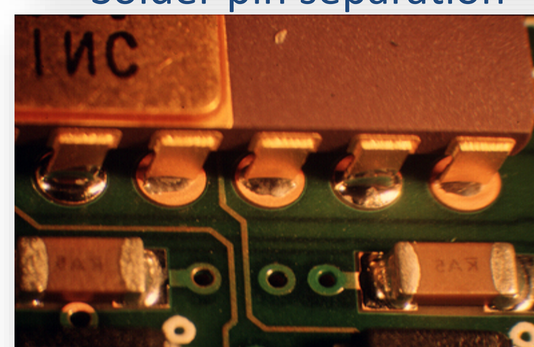


Solder pin separation

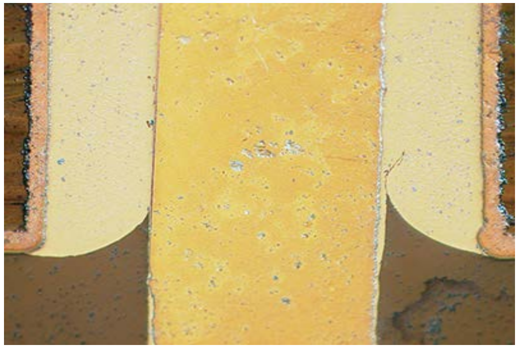


PCB delamination

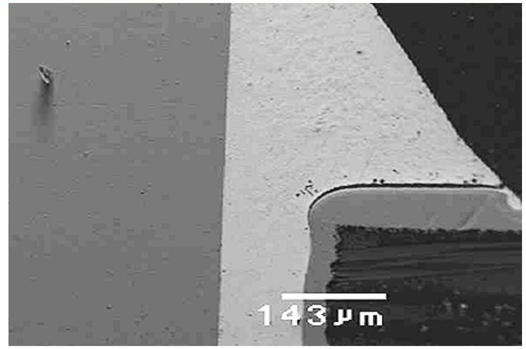
Plating separation



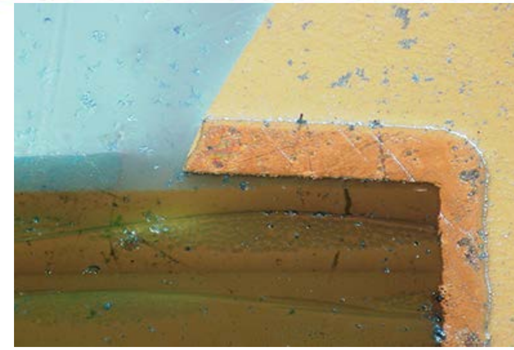
Poor hole fill



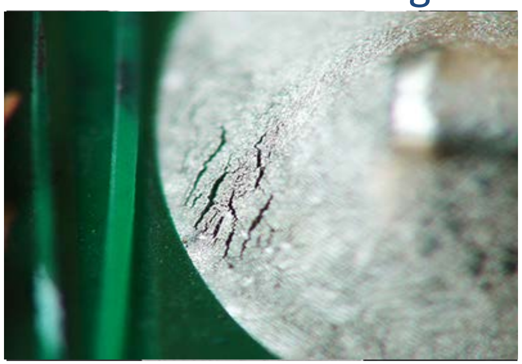
Poor tin wetting



Solder fillet lifting

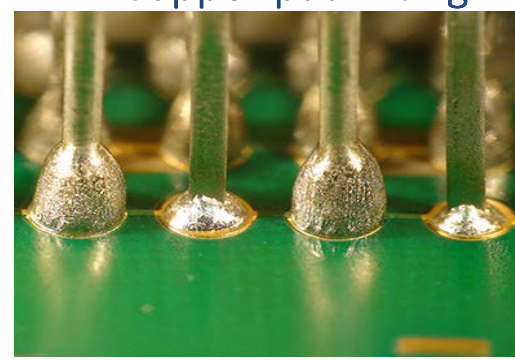


Copper pad lifting



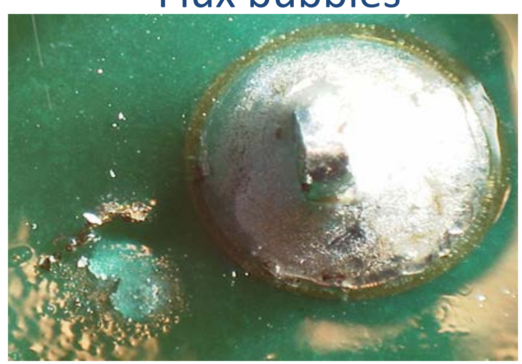
Solder/fillet tearing

Flux bubbles



Uneven solder fill

Copper barrel pull away



Solder mask damage

Pull out of copper barrel

Conclusions

- There is an increasing demand for locating electronic systems in harsh environments.
- Soldering at specific locations offers a route to manufacture that avoids overheating assemblies
  - The ability to deliver heat just to the interconnect to be joined is a great advantage.
  - With high temperature alloys that challenge fluidity of the solder and wetting, preheating of the PCB will definitely be beneficial. High temperature soldering also presents flux issues.
- Residues may be more copious, and more difficult to remove with high temperature processes.
- Solder cored wire can result is spitting issues.
  - Scoring and indenting the wire releases the flux as it liquefies and volatilises.

Acknowledgements

- This work was funded by the National Measurement Office of the UK Department of Business Innovation and Skills.
- The authors are also grateful to the following for providing materials, facilities or equipment to allow sample boards to be assembled and soldered: ACE Production Technologies, Harting Connectors, Merlin Circuit Technology Ltd, ISOLA Group, Lamar – Nelco, Ventec Europe, Park Electrochemical Corp, Henkel Ltd., Japan UNIX, MTA Automation Ag, Apollo Seiko LTD., DKL Metals Ltd., HumiSeal Europe, ParaTech Coating UK Ltd., Seica SpA, Wolf Produktionssysteme GmbH.

References

- Further information is available from the NPL Defect Database http://defectsdatabase.npl.co.uk/
  - NPL Report MAT64, *High temperatures solder replacement to meet RoHS*