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Novel rework techniques for electronic assemblies

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Novel Rework Techniques For Electronic Assemblies

A. D. Stennett and D. C. Whalley
Manufacturing Engineering Department, Loughborough University,
Loughborough, Leicestershire, UK.
email A.D.Stennett@lboro.ac.uk

Abstract

Soft soldering is the primary joining technology used in electronics assembly and is expected to remain so for the foreseeable future. Component removal for rework and repair is traditionally achieved by remelting of the solder, but the exposure of the assembly or its component parts to repeated soldering/desoldering cycles may cause both immediate damage and create a significant long term reliability hazard. Rework is also currently labour intensive and requires skilled operators. Area array components, such as ball grid arrays (BGAs), further increase the complexity of the rework process because of the number and inaccessibility of the solder joints and for some devices the necessity to remove and replace the solder balls before component replacement. There is also a growing requirement to recycle/reclaim electronic waste, creating the need for an effective process for dismantling of printed circuit board assemblies (PCBAs).

This paper will present a brief review of alternative non-thermal techniques for rework or dismantling of conventional soldered assemblies, including both chemical etchants and mechanical techniques. Results will then be presented on trials of chemical etchants, where rates of solder removal consistent with realistic times for component removal have been readily achieved using commercially available tin-lead strippers. Electrochemical techniques are also shown to be usable in specific applications, i.e. where electrical contact can be readily made to the solder joints to be removed and have the advantage of reclaiming the removed solder directly from the electrolyte.

Introduction

Dismantling of electronic assemblies for their repair, rework and recycling is a major issue for the electronic manufacturing industry. Complex, high value assemblies may require repair during their service life and despite continuing improvements in process technology, 100% manufacturing yields are unlikely to be achieved as companies use these improvements to enable the construction of ever more complex assemblies. Rework and repair are therefore certain to remain necessary, if highly undesirable, processes. In addition to these factors the issue of recycling and take back is being widely discussed and in the European Economic Community legislation on this could be in force as soon as 2001[1].

There are several techniques employed today in industry for the rework of PCBAs, all of which require localised heating of the PCB and component. Whether this heat is applied with a flow of hot air or by a heated probe, the PCB can be damaged by thermal stresses caused by temperature gradients across and through the board. These stresses can cause warping and delamination of the PCB as well as component lifting. At these elevated temperatures there is also accelerated intermetallic growth. For example, for tin-lead solder on a copper metalisation, an intermetallic

layer of 3 μ m will be formed in only 5 minutes at a temperature of 300°C, compared to 8 years at an operating temperature of 50°C[2]. It is well known that such intermetallics are brittle and can increase the risk of failure of PCBAs.

The problem of repeated high temperature exposure is even more acute for new package styles such as BGA's. These are generally high value parts such as microprocessors or application specific integrated circuits (ASICs), which if not defective must be re-used. These types of device rely on the component and/or substrate having a bump applied prior to assembly. Removal of the component will generally destroy this bump, requiring the remnants to be removed and then new solder balls placed. These two further cycles to the reflow temperature therefore result in potentially a total of four cycles to the reflow temperature during the complete component removal and replacement process. This will also be a major issue as chip-scale packages and flip-chip components become more widely accepted.

These process are also labour intensive and often require significant operator skill. Some attempts have been made to automate the reworking process [3,4] so that the level of skill required by the operator is reduced or the operator is removed completely, but these have proven to be expensive and impractical because of the level of intelligence and flexibility that would be required by the machine.

These factors have suggested the requirement for a non-thermal technique to enable components to be removed from PCBAs without damage to either and with the minimum of operator intervention.

Possible methods of non thermal rework

A number of potential techniques for non-thermal rework have been identified. These may be categorised as chemical methods and mechanical methods. Laser melting of solder has also been considered which, although not *per se* non-thermal, has large potential advantages since the very localised application of energy to the solder joints means that the temperature of the board and component is not increased greatly and the process can also be carried out very quickly. In terms of energy requirements, it has been shown that an energy in the order of 1J is required to heat the joint sufficiently[5]. If the laser power is too low (e.g. less than approximately 4W continuous wave (CW) for a PCBA) then the solder cannot be melted because of the heat conducted away into the assembly[6], however commercial lasers are readily available which can controllably deliver a high enough power to melt the solder within a fraction of a second. Drawbacks to this method are the high initial cost of the laser and delivery system, the difficulties in directing laser radiation underneath components such as BGAs and the necessity to maintain all of the joints in a molten state simultaneously as the component is removed.

Mechanical removal methods

Mechanical removal can be carried out in two alternative ways:

Firstly, the component can be removed from the board by a machining process such as milling the component from the board. This inevitably destroys the component, preventing its re-use, and is likely to scatter debris across the PCB. Once the component is completely removed the component pads on the PCB would then have to be reconditioned before another component can be attached. Control of such a machining process so that it completely removes the old component, but does not damage the PCB, is very difficult, particularly as components contain a mixture of often difficult to machine materials. Suitably fixturing the PCB to withstand the machining forces is also difficult.

Secondly, if either a shear or tensile force is applied to the component then the solder joints can be made to fracture, releasing the component. This process may be assisted by heating the assembly to reduce the strength of the solder, but without raising the temperature sufficiently to cause significant intermetallic growth. This process can however damage both the component and the PCB, but might be applicable to components that have no leads to distort and break, such as BGAs. This process will also leave a small quantity of solder attached to the PCB which might aid in reattachment of another component. Whilst this type of approach is sometimes used successfully in, for example, hybrid circuit repair, the risk of damage if used for PCBAs is considered too great.

Chemical removal methods

Chemical methods for material removal may be either purely chemical or electrochemical. Chemical etchants have long been used during the manufacture of PCBs for the removal of the tin-lead etch resists commonly used in plated through hole boards and have potential for component removal. Electrochemical plating of solder onto PCBs is also common place in industry, where solder is transferred from tin/lead anodes to the PCB which is connected as a cathode. If we visualise this process in reverse it is not difficult to see that it could be used to remove solder from a PCBA by simply connecting the PCBA as the anode. The chemicals used in these processes are therefore already established as compatible with the materials used in PCB manufacture. Both of these techniques are essentially isotropic when used on materials which have a polycrystalline microstructure, such as occurs in most solders, although the etching rates achieved and their uniformity will be affected by the extent of agitation and, for electrochemical methods, on the local current density.

Etchant based approaches were identified as having a number of potential benefits, which can be summarised as:

- No significant heat exposure or risk of mechanical damage during process;
- Intermetallic layer might be completely removable;
- Process chemistry compatible with the PCB;
- Possibility of a high degree of automation of component removal.

There are, however a number of potential issues with the use of etchants, such as the speed of operation and the delivery of the etchant to the solder joints to be removed. A

series of trials were therefore initiated to explore the potential of the approach.

Trials on chemical etchants

Commercial etchants for tin-lead are readily available for use in PCB manufacture and techniques for inhibiting the etching of copper during the process are well established. The trials reported here have used examples of the two most commonly used types of these off the shelf tin-lead strippers, i.e. a nitric acid based stripper (referred to as etchant A) and a peroxide based stripper (referred to as etchant B).

The nitric acid based stripper has ferric nitrate added and an organic corrosion inhibitor. The ferric nitrate acts to dissolve the tin/copper intermetallics and the purpose of the inhibitor is to slow the etching rate of the copper so as not to damage the PCB tracking (and in this application the component terminations). Etchant B was an ammonium hydrogendifluoride based etchant, also containing an inhibitor to stop the removal of the copper and activated with 7% by volume of hydrogen peroxide. During the trials the etchants were agitated either with a magnetic stirrer or ultrasonically.

Trials have been undertaken both to establish the etching rate under a variety of conditions and to remove components from PCB's, to demonstrate the feasibility of the approach.

The etching rate experiments were undertaken using FR4 test coupons covered on both sides with 15µm of copper. To one side of these coupons was applied either eutectic solder or 2% silver solder. The area of the board undergoing the test was approximately 6cm².

The samples were weighed after the solder had been applied and the flux removed. They were then immersed in etchant for an amount of time, quickly washed, dried and reweighed before returning to the etchant solution. From these reduction in mass measurements the etching rate in µm/min was calculated. At the end of each experiment the thickness of the copper plate remaining was also measured and recorded to establish whether the copper had been attacked. In all of the tests the etching of the copper was minimal, with a maximum rate of 0.3µm/min observed.

Etching rate results for chemical etchant A

Figure 1 shows the etching results from the experiments using etchant A. With agitation from a magnetic stirrer the average etching rates were 19.4µm/min for tin-lead eutectic solder respectively and 18.6µm/min for the 2% silver solder. By applying ultrasonic agitation these rates were greatly increased to an average etching rate of 55µm/min for the tin-lead eutectic solder and 50µm/min for the 2% silver solder. The initial rates of etch were approximately double the average rate, although the reasons for this are unclear.

Figure 2 shows an SEM of the solder surface shortly before all the solder had been removed. X-ray analysis of Area A showed a composition of 93% tin and 6% lead. The composition of Area B was 85% tin and 14% lead. These results indicate that the etchant is removing the lead rich phase in preference to the tin rich phase. Traces of copper are observed in the analysis of area B and this could indicate that

the etching process has nearly removed all the tin-lead so the copper layer beneath it is being detected.

Figure 1 Results for etching 2% Ag solder and eutectic SnPb solder with and without ultrasound agitation using etchant A

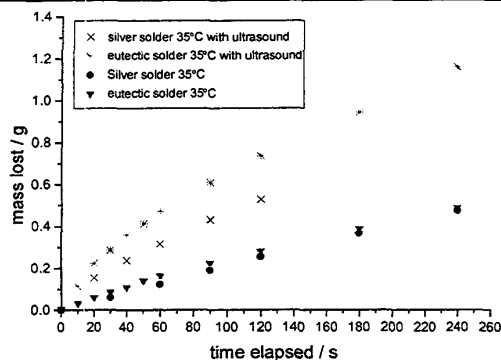


Figure 2 The surface of the eutectic SnPb solder not yet completely removed from the sample board.

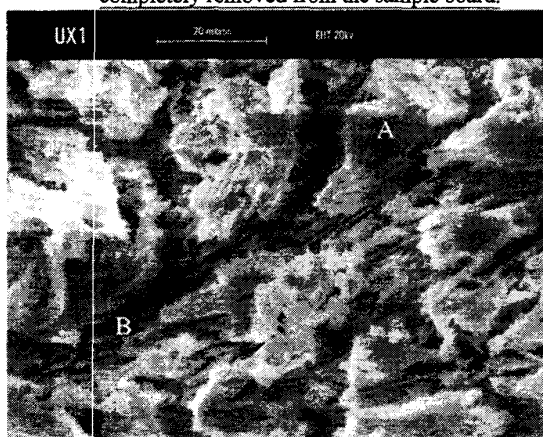
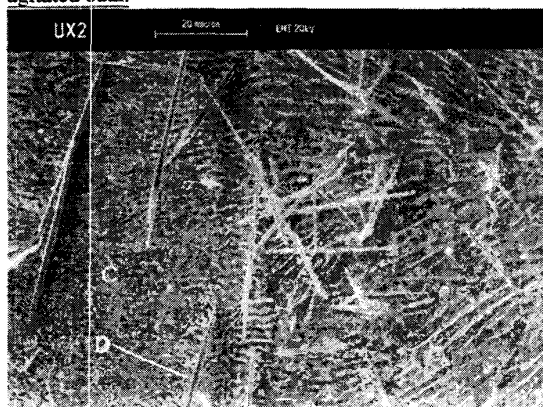


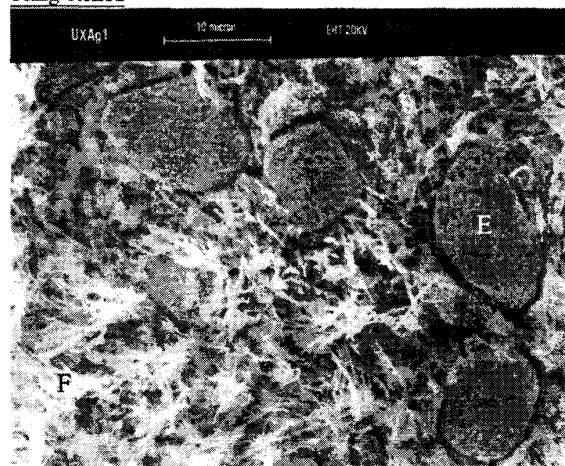
Figure 3 SEM picture of the etched copper surface after removal of eutectic SnPb solder using an ultrasonically agitated bath.



After all the solder had been removed there was still a dull grey veneer over the surface of the test coupon. Figure 3 shows an SEM of this surface. X-ray analysis showed that Zone C consisted of 58% copper and 41% tin with traces of other metals which is consistent with a Cu_6Sn_5 intermetallic. Zone D consisted of 41% copper, 51% tin and 7% lead. This suggests that there is a small amount of solder remaining attached to a tin-lead intermetallic fibre. Further immersion in the etchant caused the complete removal of the intermetallic layers revealing the clean copper surface beneath.

Examination of the surface of the 2% silver solder after etching indicated a possible problem with removing this type of solder. As can be seen in figure 4, the silver is not fully removed from the PCB during the etching process, instead it is remaining in certain areas as the solder is removed from around it. A commonly observed intermetallic in silver solder is Ag_3Sn but with such a small volume of silver present it would be unlikely for very much of this to be observed as the material is removed.

Figure 4 The surface of 2% silver solder in the process of being etched



The profile of the surface of the silver solder during etching shows two main features. The solid volumes (E) seen at the top and right of the picture consist of 53% tin, 26% lead, 16% silver and 5% copper. It would therefore appear that the tin and lead are being removed and the silver is remaining behind, becoming more concentrated. This situation is accentuated in the wiry looking areas (F) where there is 56% tin, 24% silver, 12% lead and 8% copper. The most likely assumption to make is that there are Ag_3Sn threads held in place by a lead depleted solder. This would account for the relatively high proportion of silver whilst still maintaining a high level of tin.

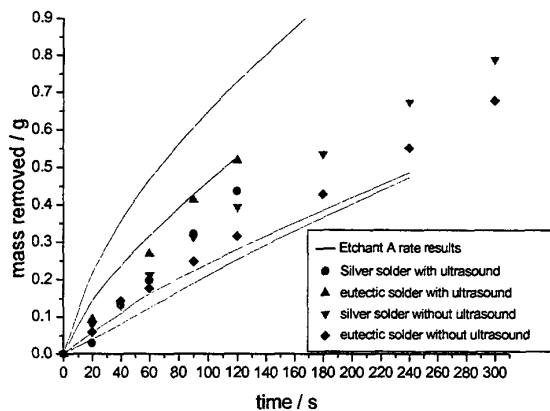
At the edges of the sample board where all the solder has been removed the analysis shows 64% copper, 33% tin and 3% silver. It is most probable that at this point, without the strength of the tin-lead to hold it in place the silver has been removed by the ultrasonic agitation and has become a suspension in the etchant solution as a small amount of precipitate is observed. The fact that the correct Cu_6Sn_5 ratio

has not been reached suggests that this intermetallic layer is being removed from the surface, exposing the copper underneath to the x-ray detectors.

Etching rate results for chemical etchant B

The rates of etching for etchant B are very similar to those achieved with etchant A except that the ultrasound agitation seems to be of less benefit. As can be seen in figure 5 the four different experiments have rates greater than that for magnetically stirred etchant A but less than that for etchant A with ultrasound which are indicated by black lines.

Figure 5 Results for etching 2% Ag solder and eutectic SnPb solder with and without ultrasound agitation using etchant B



During the removal of the 2% silver solder using etchant B a precipitate was seen to form. The precipitate was observed to be grey and increased in quantity as the etching progressed. The most likely cause of this precipitate would be oxides of the solder caused by the abundance of nascent oxygen in the solution.

Chemical etching of real components

Preliminary experiments have been carried out on BGAs and memory SIMMs using etchant A. Etching rates for the surface mount components on a memory SIMM were very encouraging. Each SIMM bore nine 18 pin J lead devices and these were all removed after between 12 and 14 minutes when agitated using only a magnetic stirrer. The rate of removal was increased by ultrasonic agitation such that the components were removed in 4 to 8 minutes. No significant damage occurred to the PCB or ICs.

It was observed that a fine pitch BGA device has a tendency to trap air underneath the component when immersed in etchant and this stops the etchant from reaching the inner balls until the outer layer of connections has been removed. This greatly reduces the speed of the component removal process as each "layer" of balls must be removed before the next can be attacked by the etchant. This also greatly increases the exposure to the etchant of the edge pads on the PCB and component, increasing the chance that the copper will be removed by the etchant along with solder. It is anticipated that by applying a spray of etchant with sufficient force to one or two sides of the component that this air will be

displaced from under the component and will allow the etchant to rapidly remove all the solder balls at the same time. As an example, if we assume a 2mm pitch BGA joint to be approximately 1mm in diameter, the etchant would have to remove approximately 500µm of solder which, with the highest etching rates achieved would require as little as 10 minutes. Smaller pitch devices would require significantly less time to etch depending on the lead type. A prototype spray etching apparatus is presently being constructed to test this approach.

Electrochemical etchants

As already mentioned commercial tin-lead plating solutions are available for use in PCB manufacture. These typically contain tin and lead fluoborate, fluoboric acid, boric acid and an additive to improve the solder deposition quality, although this additive would not be required for solder removal.

The primary advantage of this process is that the solder is retrieved from solution onto the cathode, so that there is no resultant tin lead loaded solution to dispose of. This may have environmental and cost benefits, although a more detailed analysis would be required to verify this. The process is also highly controllable as current density can easily be changed during the process, unlike the concentration of an etchant solution. More recently developed types of plating solutions allow higher current densities and this will increase the speed of the process.

The major disadvantage of this approach is the fact that electrical connections have to be made to every solder junction to be reworked. The immersion of the circuitry is not an extreme problem as the solution is not highly corrosive unlike the nitric acid based etchants, so it will not immediately attack the PCBA. Any solder joint that is directly connected to the plating supply will, however, be etched if it is immersed in the solution. Making electrical connections to every solder joint is possible for some components but for high lead count fine pitch devices this is extremely difficult and for BGAs may be impossible. The approach may however be useful for connectors, where connections may be made through the connector pins and for some other types of assembly where all component connections are brought out to a connector on the product, such as in computer memory modules.

Trials were performed with 9 chip single in-line memory modules (SIMMs). Each memory chip on these modules had 16 solder joints which were estimated to have a volume of approximately 0.1mm³. The time taken for each chip to be removed was recorded and these data are seen in figure 6 and table 1. Calculations of the ideal etching current show that at a recommended current density of 3Adm⁻² the ideal current for our process is approximately 200-300mA. Current densities in the range of approximately 1-30Adm⁻² have been investigated. When the higher currents, such as 1A and 2A, were used the process was found to cause significant damage to the chip and PCB. Table 1 shows the tabulated data for calculations of electrochemical etching rates for the different currents.

These samples were also examined using an SEM as seen in figures 7 and 8.

Figure 6 Etchant times for electrochemical removal of chips.

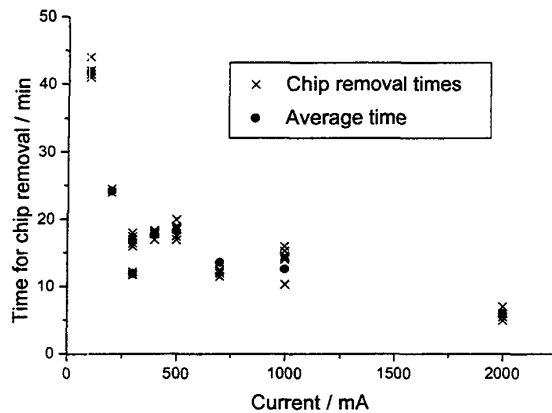
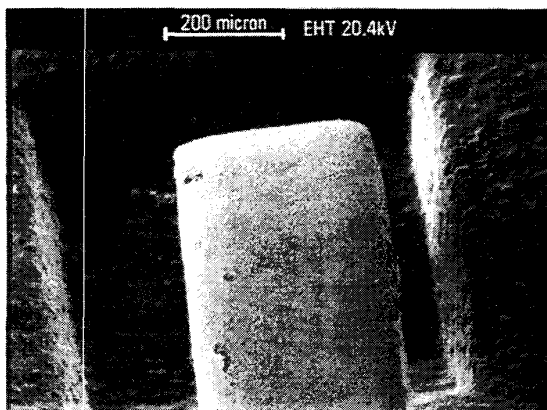


Table 1 Volume etchant rates for the electrochemical stripper.

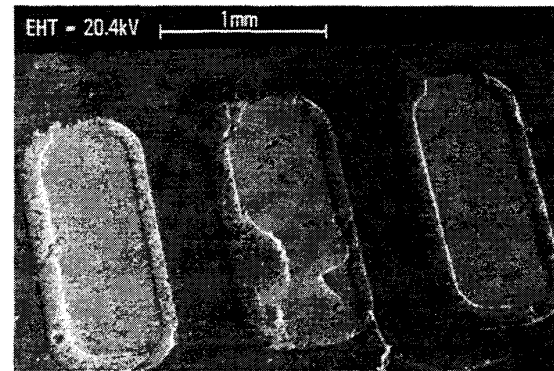
| Current (mA) | Average removal time (min) | Volume etching rate (mm ³ min ⁻¹) | Approximate etch speed (μm min ⁻¹) |
|--------------|----------------------------|--|--|
| 100 | 41.8 | 0.34 | 9.6 |
| 200 | 24.2 | 0.59 | 16.5 |
| 300 | 16.9 | 0.85 | 23.7 |
| 300 | 11.9 | 1.20 | 33.6 |
| 400 | 17.8 | 0.80 | 22.5 |
| 500 | 18.3 | 0.78 | 21.9 |
| 700 | 13.6 | 1.05 | 29.4 |
| 1000 | 12.6 | 1.13 | 31.7 |
| 2000 | 6.0 | 2.38 | 66.7 |

Figure 7 The component leg after electrochemical chip removal



This component leg is clean and undamaged by the removal process, although the lead has still retained the Cu₆Sn₅ intermetallic layer. It would however be possible to remove this layer with the ferric nitrate/organic inhibitor chemistry used in the chemical etchants.

Figure 8 Electrochemically desoldered PCB pads.



The pads of the PCB show some signs of damage having occurred. The central pad seems to have sustained the most damage but this could be because it might have been the last pad to be attached to the component and therefore experience a higher current density. This problem might be overcome through the use of more sophisticated plating current control or more effective inhibitors. As with the chip lead there is a residual Cu₆Sn₅ intermetallic layer on the pad, which again could be removed with the correct chemistry.

Conclusions

Both of these chemical etchant based approaches show promise for the removal of components for recycling as they can be used in bulk situations to remove large quantities of components without significant operator intervention. The process is relatively fast using off the shelf chemistry and it is possible that etchants optimised for this application will offer much higher component removal rates.

New etchants might require development for use with lead free solders should they begin to be widely adopted. Conformal coatings are also likely to hinder these processes and as such techniques for their removal or displacement will be required where these materials are used.

For the chemical only etchants the application of ultrasound to the etchant bath has been shown to greatly accelerate the etchant rate from approximately 20μm/min to a peak rate of in excess of 100μm/min, which has been seen with real components to halve the time required to remove the component. For rework, an etchant delivery system would also be required to allow selective removal of components. It may be possible to combine ultrasonic agitation with this delivery system to accelerate the etching rate of the tin-lead solder.

The problem of making electrical connections hinders the electrochemical removal of components, but some assemblies are ideally suited to this process. Memory SIMMs, backplanes, connectors and bus controllers all tend to have readily accessible electrical connections, which would allow this process to work, but for most assemblies the difficulty of forming electrical connections is likely to preclude the use of this technique.

It is anticipated that these processes can be refined to improve speed, selectivity, and ease of use for the operator

providing a controllable, non-thermal method of rework, reducing the damage caused to PCBAs and simplifying the task of rework or recycling in the industrial environment.

Acknowledgements

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