

# HDI production using pulse plating with insoluble anodes

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## Abstract

A novel process for the production of HDI printed circuit boards using copper reverse pulse plating with dimensionally stable anodes.

The paper presents a production system incorporating reverse pulse plating of an acid copper electrolyte with dimensionally stable anodes. Hole to surface throwing power and surface distribution is as expected with pulse plating, results with micro-vias 75  $\mu\text{m}$  width and depth show equally good results. Through the use of insoluble anodes constant production conditions are achieved in the plating cell. This gives improvements in productivity and quality, the desired result is constant without the need for time consuming anode maintenance.

Anode debris is completely eliminated so enabling more effective filtration and ensuring roughness free high aspect ratio and HDI production. Copper concentration is held constant through the use of a novel technique to automatically control copper dissolution and replenishment.

Fine tuning of the InPulse process can be achieved using the Optipulse in situ measurement system. The pulse wave form is determined directly on the panel surface. A correlation between these measurements and the copper crystal structure will be documented.

## Introduction

The continuing trend of miniaturisation is driving printed circuit board design more and more in the direction of HDI. This means finer tracks, smaller holes and higher aspect ratios together with high frequency operation requiring controlled impedance. This trend is being pushed on the one hand by telecommunications, in particular mobile telephones and on the other by developments in networking and server applications.

This paper will present two methods for the production of HDI with insoluble anodes, the horizontal Uniplate system which has already achieved market acceptance and the alternative vertical Dyna-Plus system. The horizontal system is very well suited for the production of thinner materials and effective current densities of 8 to 10  $\text{A}/\text{dm}^2$  or the semi-panel plating of thicker materials followed by vertical processing. The vertical system however offers advantages in the full panel or pattern plating of thicker materials with aspect ratio of 10:1, where the horizontal plating system becomes less viable. This is due to the lower throughput achievable at lower current densities and therefore the low productivity in comparison to investment costs.

## Reverse pulse plating

The advantages of copper reverse pulse plating have been well documented (1,2,3), the process offers improvements in throwing

power particularly in high aspect ratio product and also in the surface distribution for vertical pattern plating. These advantages are achievable at similar or higher current densities compared to conventional DC in a vertical mode of operation and at a significantly higher current density in horizontal.

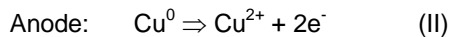
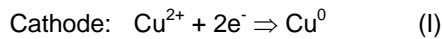
Reverse pulse plating has gained more acceptance partly due to the improved reliability of rectification but also to better understanding of the interplay between equipment and chemistry.

For HDI production reverse pulse plating offers the solution to higher aspect ratio and finer lines and spaces together with good copper throwing power into blind micro-vias. However a standard pulse plating system still has some disadvantages not least the need to stop production at frequent intervals to maintain anodes. The copper plating surface distribution, an important factor for impedance control, is very dependant on the condition of the anodes. When well maintained results are acceptable but with every minute plated the distribution suffers. This effect is most extreme at high current densities or in the pattern plating of an image with isolated track areas. Associated with anode maintenance is the danger of foreign particles being introduced into the plating solution. Copper anodes are frequently used as pellets or balls which produce particulate matter which must be filtered from the solution. The increased requirements of HDI demand that the plating solution remains free of such anode debris.

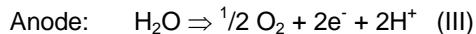
### The insoluble anode system

The answer to the difficulties with soluble anodes is to replace them with insoluble, dimensionally stable anodes. Parallel to this a system must be provided to replenish plated copper, with as an optimum the facility to maintain a constant copper concentration.

With standard copper plating either pulse or DC the anode material is phosphorised copper, the phosphorus content of between 0.02% to 0.08% is required to prevent anode polarisation during dissolution. The standard copper plating process can be described by the following reactions,



At the cathode, in this case the PCB, copper is deposited and at the anode copper is eroded. The copper anode can be directly replaced with an insoluble anode normally coated with platinum or other noble metal. In production systems the anode material used consists of a titanium mesh which has been coated with a mixed oxide layer of tantalum and iridium. At this insoluble anode the anodic reaction as described in (I), becomes,



This reaction shows the degradation of water in a conventional acid copper electrolyte leading to the evolution of oxygen.

This is the major problem associated with the use of insoluble anodes and the effects of this can be summarised as follows:

- High consumption of additives.
- Decreased anode lifetime.
- Anode passivation due to oxidation breakdown products.
- Gas bubbles causing surface defects on PCB for example pitting.
- Potential bubble entrapment in blind microvias causing poor copper coverage.

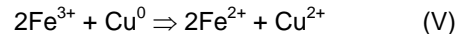
To overcome these problems the conventional copper sulphuric acid electrolyte has been modified to incorporate a redox system which prevents any oxygen evolution at the anodes. A further advantage of this redox system is that it allows the simple replenishment of copper. Iron II sulphate is added to the copper electrolyte and this changes the anode reaction as described under (III) to,



As can be seen the oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  prevents any oxygen evolution at the anode surface.

The solution from the anode area with a high concentration of  $\text{Fe}^{3+}$  is then pumped to an

external module containing a large area of copper pellets where the following reaction takes place,

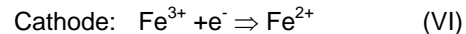


This reaction erodes copper in a quantity corresponding to the amount of  $\text{Fe}^{3+}$  produced in the plating reaction and so replenishes copper into the plating electrolyte.

A more detailed treatment of the theory of the redox system and associated anode design is given in (4).

The most important design factor in the insoluble anode system is the necessity to remove the  $\text{Fe}^{3+}$  rich electrolyte as rapidly as possible from the anode surface and to prevent this electrolyte from approaching the cathode.

If this electrolyte approaches the cathode then the following parasitic reaction will take place,



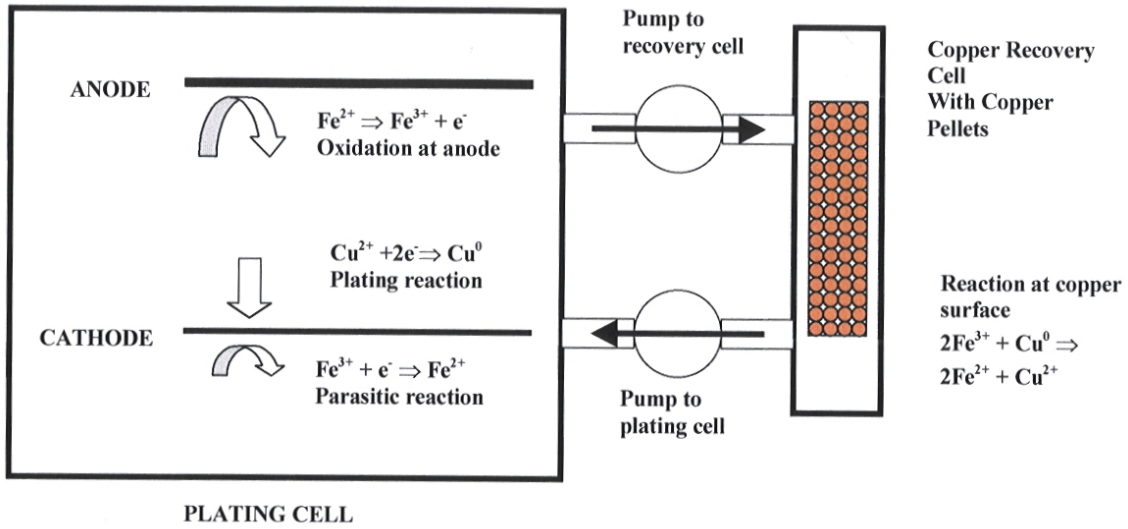
The consequence of this reaction is that the copper plating current efficiency, 100% with soluble anodes, will be reduced and less copper will be plated on the cathode. As well as this if not enough  $\text{Fe}^{2+}$  rich electrolyte is supplied to the anode then the anodic reaction as reaction (III) will begin and again oxygen will be generated at the anode with the associated problems described.

From this it can be seen that the successful use of the insoluble anode system as described is very dependant on the solution flow set up in the plating cell.

The solution to this problem as achieved with horizontal and vertical systems will be described separately.

A schematic representation of the general Inpulse system showing plating cell and copper recovery is given in Figure 1.

Figure 1: Acid copper plating with insoluble anodes showing general set up of plating system.



**Implementation in horizontal equipment**

The Uniplate Inpulse module solves the problem of separating anode and cathode areas by the use of pumps. The working electrolyte is forced towards the cathode from a sump area after passing through the copper regeneration. From the cathode area the solution flows towards the anodes and is then pumped rapidly from the anode area to the copper regeneration module so minimising any loss in current efficiency.

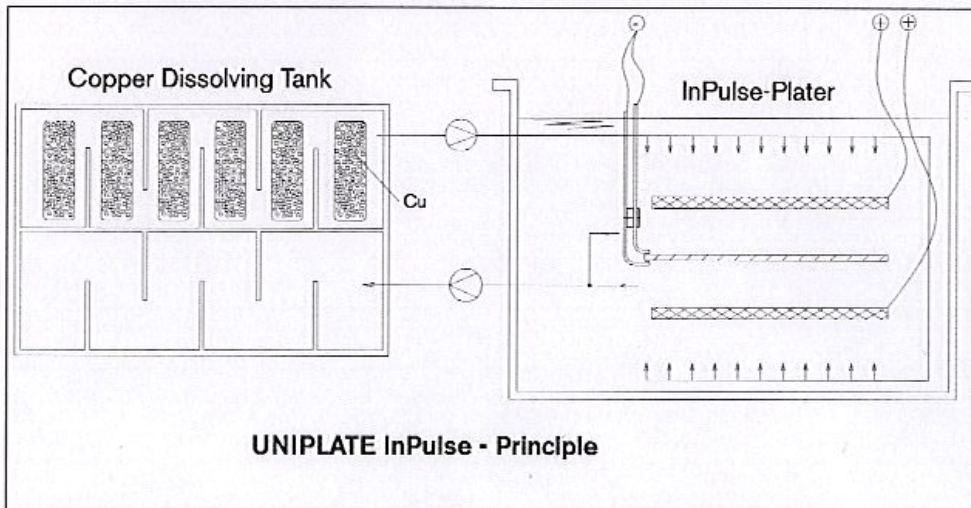
The insoluble anodes are installed horizontally and each anode is individually connected by

cable to an electronic pulse switch. This ensures identical pulse form at each anode and synchronisation of the pulse between all the anodes.

Printed circuit panels are conveyed through the module on guides and contacted by a clamp system on one side of the panel only. This has the advantage that a wide range in panel format can be processed in terms of panel size and also thickness. The minimum thickness which can be processed is down to 0.1 mm.

Figure 2 shows a cross section schematic of the horizontal module.

Figure 2: Cross section through Uniplate Inpulse



**Production results from horizontal installations**

There are currently more than 20 horizontal insoluble anode plating systems in full production world wide, some with more than one plating module. The following table gives an overview of results achieved in the full panel plate process.

Throwing Power Through Hole:

Panel Thickness mm	Hole Diameter mm	Throwing Power Effective	Effective Current Density A/dm <sup>2</sup>
1.0	0.2	90 %	9
1.0	0.3	≥100 %	9
1.6	0.2	55 %	9
1.6	0.3	75 %	9
1.6	1.0	≥100 %	9

Throwing Power in Micro-Vias:

Diameter	Depth	Throwing Power Effective	Effective Current Density A/dm <sup>2</sup>
120 μm	60 μm	≥100 %	6.5
100 μm	75 μm	≥100 %	6.5
75 μm	75 μm	90 %	5.1
Corresponding Throwing Power Through hole			
0.2	1.2	≥ 90%	6.5
0.3	1.2	≥ 100%	6.5
0.5	1.2	≥ 100%	6.5
1.0	1.2	≥ 100%	6.5

Corresponding micro-sections are enclosed in *Appendix I Microsection results from horizontal processing.*

**Implementation in vertical equipment**

The vertical system has been designed around existing technology for plating lines. This means that a retro-fit to install insoluble anodes is, at least in theory possible. The plating cell must be equipped with all standard features for high aspect ratio production such as adequate article agitation and efficient filtration. The differences to a standard plating cell are the replacement of the copper anodes with insoluble and the installation of the copper recovery system in the electrolyte circulation. To ensure separation of the electrolyte into anode and cathode areas diaphragms are necessary. These are made from standard polypropylene diaphragm material placed between anode and cathode. A circulation is installed similar to existing requirements, pumping solution from the anode area through the copper recovery and then back into the plating cell in the cathode area. The solution must be drawn evenly from both anode areas simultaneously and forced through the copper

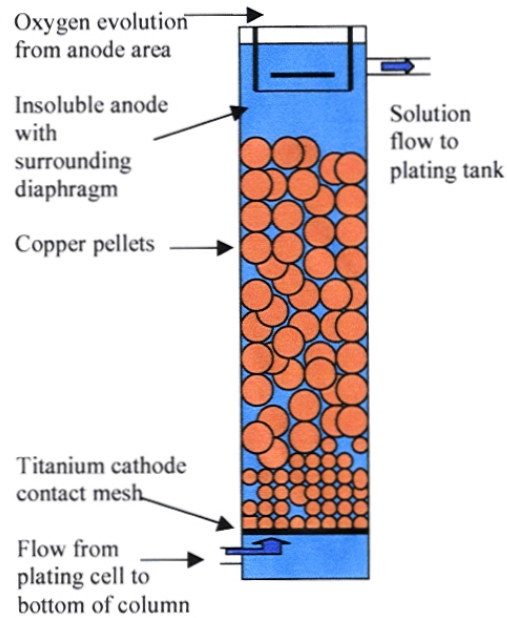
pellets with a turn over rate of about 3 times per hour. This rapid turn over ensures an efficient redox reaction and is important to maintain constant copper concentration, the circulation is simultaneously filtered.

The major problem with the system is not how to prevent the copper concentration falling but to prevent its increase. This increase is due to added oxidation of Fe<sup>2+</sup> in the electrolyte by the use of air agitation and also a slight increase caused by the pumping of warm copper electrolyte through a large copper area in the recovery column.

To prevent this copper increase and to give the possibility to fine tune the copper content a simple device has been employed. A potential is applied between the copper pellets in the recovery column and an insoluble anode at the top of the column. This DC potential can be varied and causes a deposition of copper directly onto the pellets and therefore lowers the copper concentration in the solution flow back to the plating cell.

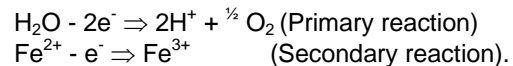
A schematic representation of the copper recovery column is given in Figure 3.

**Figure 3: Copper recovery column**

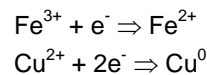


In the recovery column the following reactions take place:

At the anode:



At the cathode:



At the anode there is a strong evolution of oxygen due to a low solution circulation. This condition is deliberately set up to limit the secondary reaction which would otherwise introduce too much  $Fe^{3+}$  into the solution flow to the plating cell.

At the cathode two reactions are present, which reaction is dominant depends on the potential applied. In any case both reactions lead to a decrease in copper concentration in the working electrolyte. On the one hand copper is plated out of solution onto the pellets and on the other the  $Fe^{3+}$  concentration is reduced so limiting the dissolution reaction on the copper surface.

Although pure non-phosphorised copper pellets are used it is still necessary to filter the circulated electrolyte to prevent any particulate matter being carried into the plating cell.

The use of pure copper has other advantages, the anode surface is insoluble so dummy plating to build up an anode film is not required. Copper clippings can be used which are significantly cheaper than the copper balls as normally used in plating systems and there is the possibility to use recycled copper from a source within the printed circuit board production cycle.

The anodes in the vertical system are bolted onto a titanium covered copper bar and this bar is bolted to the standard copper anode rail. This ensures best possible contact and elimination of any resistance.

At the moment trials are being carried out in a pilot line using Eductors to provide solution movement in the cathode area. Using this technology air agitation is not necessary and so additional oxidation of  $Fe^{2+}$  may be prevented. Other benefits of Eductors such as more even solution flow and therefore improved throwing power are being assessed. Production results are given from experience under full scale production with a vertical plating line retro fitted with insoluble anodes.

### Production results from vertical installations

#### Throwing Power Through Hole:

Panel Thickness mm	Hole Diameter mm	Throwing Power Effective	Effective Current Density A/dm <sup>2</sup>
1.6	0.25	95 %	2.5
2.5	0.2	90 %	2.5
2.5	0.3	95 %	2.5
2.5	0.5	≥95 %	2.5

#### Throwing Power in Micro-Vias:

Panel Thickness mm	Hole Diameter mm	Throwing Power Effective	Effective Current Density A/dm <sup>2</sup>
75 μm	75 μm	70 %	2.0
80 μm	50 μm	90 %	2.0

Corresponding micro-sections are enclosed in *Appendix II Microsection results from vertical processing*.

### Optimisation of the pulse form

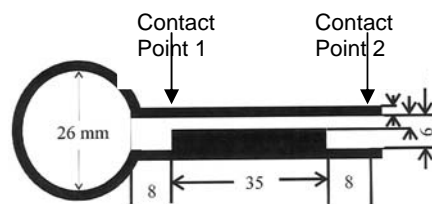
In pulse plating either with insoluble or soluble anodes the pulse form is all important in ensuring best results. The pulse form itself directly affects the copper crystal growth and final structure and is therefore responsible for the physical properties of the deposit and ultimately for the correct function of the final product.

By measuring the pulse form with a clamp tester some information can be obtained, an improvement on this however is to measure directly on the cathode itself. This can be done by measuring the pulse current using a modified test cathode connected to a current measuring device with sufficient sensitivity to resolve the pulse wave form. This test cathode or panel has a copper surface which is etched to form "islands" at several points. The points are then connected by shielded wires to an analogue to digital converter and the test signal is fed into a computer. The signal gives information on pulse timing and amplitude and simultaneously measures both sides of the panel at once.

The computer stores the data stream which can be run over a period of time limited only by the hard disk capacity. The data can be analysed and correlated to the physical characteristics of the deposit.

Figure 4 shows a schematic of one test island which is etched onto the surface of a panel.

Figure 4: Optipulse test island with dimensions



The copper track between the contact points takes the form of a shunt because of the defined copper etching. Shielded wires soldered to the contact points are used to measure the voltage drop and therefore the current flow to the island.

### Evaluation of the plated copper deposit

The deposit can be evaluated by standard light microscopy before and after thermal shock testing or cycle testing. However as already mentioned the most important feature of the deposit is the crystal structure. To directly assess this a scanning electron microscope must be used. This is done by making standard micro-sections of a plated copper layer and then electro-polishing to reveal the detail. The section must then be assessed using an SEM

with four quadrant back scattered electron detector (5), noise reduction techniques must often be used for best results.

Figure 5 shows an example of a poor pulse wave form as measured directly on a cathode with the corresponding crystal structure. As a comparison a wave form taken from a system with insoluble anodes directly connected to the rectifier is given.

**Figure 5: Pulse plate waveforms with corresponding crystal structures.**

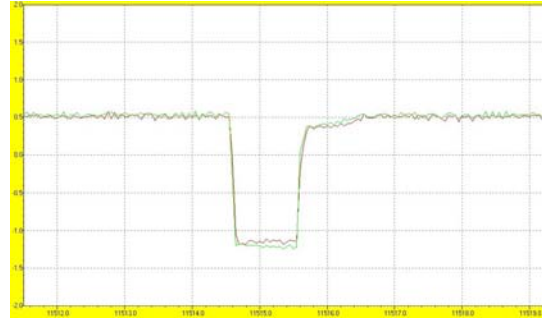
#### Poor pulse wave form.

Wave form with non-constant reverse current and strong positive overshoot.



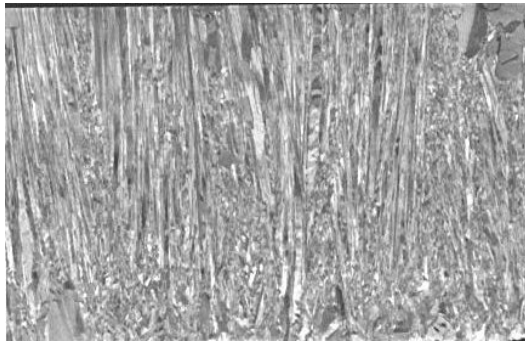
#### Optimal pulse wave form.

Constant reverse current with no positive overshoot or oscillation.



#### Poor crystal structure with strongly columnar deposition.

This copper structure exhibits poor physical properties



#### Ideal crystal structure showing regular polygonal growth.

This copper structure meets all physical test requirements.



### Summary

The use of insoluble anodes for HDI production gives obvious advantages in terms of gained production time. This can be as much as one full 8 hour shift per week which is otherwise necessary for anode maintenance and dummy plating.

Due to fixed contacts and direct wiring of anodes to power supply constant working conditions can be achieved. Working parameters can be set up and assessed and then fixed for constant production conditions.

This opens up the possibility to copper plate at high current densities particularly in the horizontal mode of operation where up to 10A/dm<sup>2</sup> is possible.

The working solution can be maintained in a cleaner condition because there is no possibility of any contamination with anode sludge.

Use of this system also opens up the chance to reduce waste water costs by re-cycling copper from etching processes.

For HDI production where the value of work in progress is constantly rising, the use of insoluble anodes is an important factor in maintaining constant product quality.

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