# New Concepts for Production of High Aspect Ratio Printed Circuit Boards

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## Introduction

The production of high aspect ratio printed circuit boards for example so called back panels poses well known problems for good quality electrolytic copper metallisation. The panels can be from 3mm and up to 10 mm thick with aspect ratios of typically 10 to 1, however there is a current trend requiring even thicker panels and with aspect ratio up to 15 to 1. Such panels typically can be larger than “normal” production panels which gives added problems in handling due to their weight. One of the limiting factors in copper deposition is the mass transport of ions into the high aspect ratio holes. Achieving the required copper thickness in the hole without over plating the surface causing resist over plating with pattern plate or poor line definition with panel plate is the main problem in the production of high aspect ratio panels. A further factor with back panels is the difficulty of component mounting using the press fit technique when the copper deposit distribution is poor. To overcome throwing power problems low electroplating current densities have been used which obviously have a negative impact on productivity. As a solution to these problems reverse pulse plating can allow the use of higher current densities with improved surface distribution and throwing power in the through holes. However pulse plating does not eliminate mass transport limitations, to achieve good plating results an adequate electrolyte agitation must be ensured.

## Experimental work in analysing electrolyte flow in through holes

In a joint project with the Kurt Schwabe Institute the flow dynamics of copper deposition were investigated [1], the influences on copper deposition in blind micro-vias has been documented as part of these experiments [2]. In the project further experiments have been carried out to investigate the influences on through hole plating particularly in high aspect ratio holes. The following table gives a summary of electrolyte exchange mechanism considered and also the influencing factors.

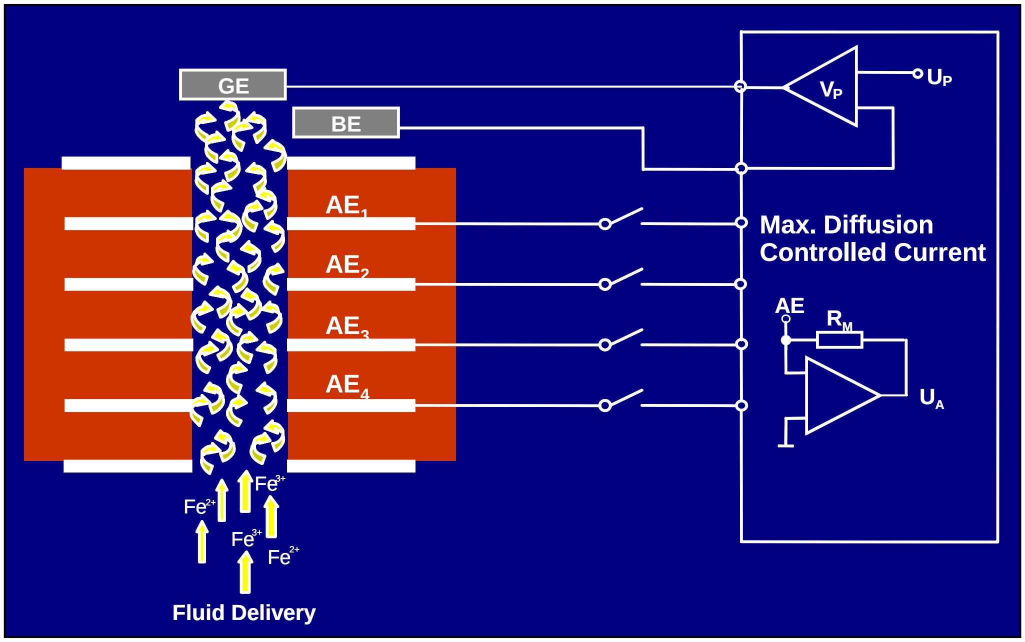
**Table 1: Electrolyte exchange mechanisms and influencing factors.**

| Electrolyte exchange by | Influencing factors |
|---|---|
| • Diffusion<br>• Migration<br>• Natural Convection<br>• Artificial Convection | • Concentration<br>• Temperature<br>• Surface Tension<br>• Viscosity<br>• Density |

The influencing parameters were held constant as far as possible and the artificial convection by means of forced flooding was investigated.

A specially designed multilayer printed circuit board with electrochemical flow sensor was used as part of these investigations a schematic of one hole on the test board is shown in figure 1.

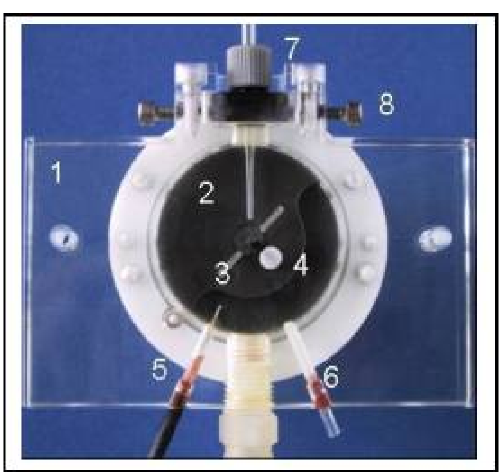
**Figure 1: Schematic of test hole in circuit board showing micro electrode array.**




The test board was placed in a test chamber which allowed the variation of key parameters as follows,

- Diameter of nozzle.
- Angle.
- Distance.
- Lateral flow.
- Pressure / flow.
- Density.
- Pulse pumping.

**Figure 2: Test chamber for hydrodynamic studies.**




1. Housing.
2. Adjustable disc.
3. Test PCB.
4. Stopper.
5. Counter electrode.
6. Reference electrode.
7. Nozzle.
8. Lateral nozzle adjustment.

Figure 3 shows a Microsection through one test coupon showing the inner layer electrode connections, results from one experiment is given in figure 4.

**Figure 3: Microsection through test coupon showing inner layer connections**

Test coupon with hole diameter 0.2 mm showing inner layer electrode connections

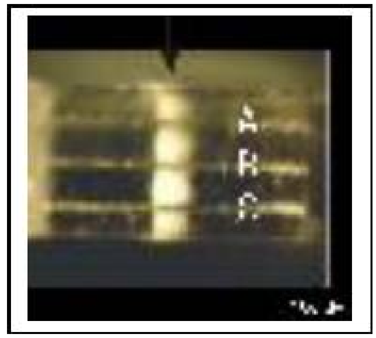
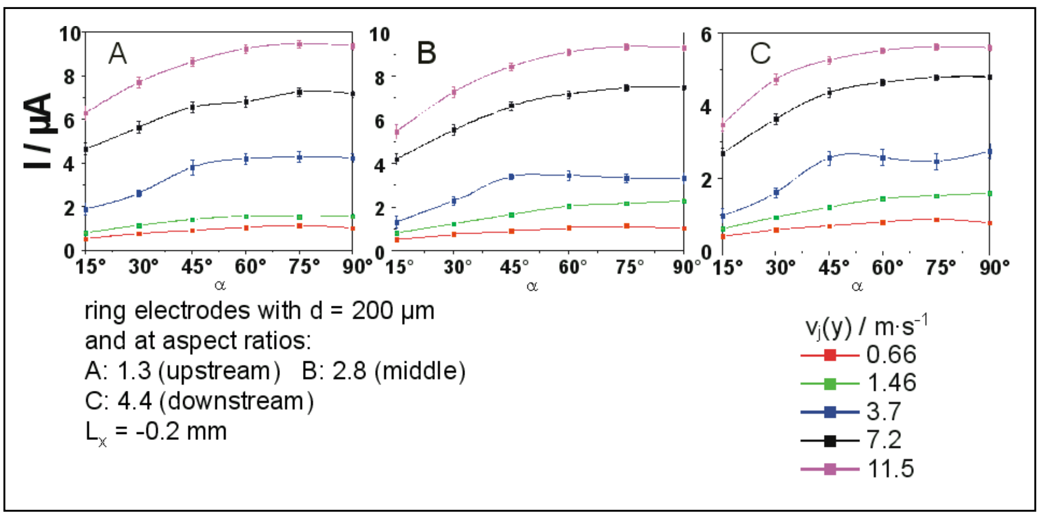



**Figure 4: Results of investigation of fluid velocity and spray angle.**



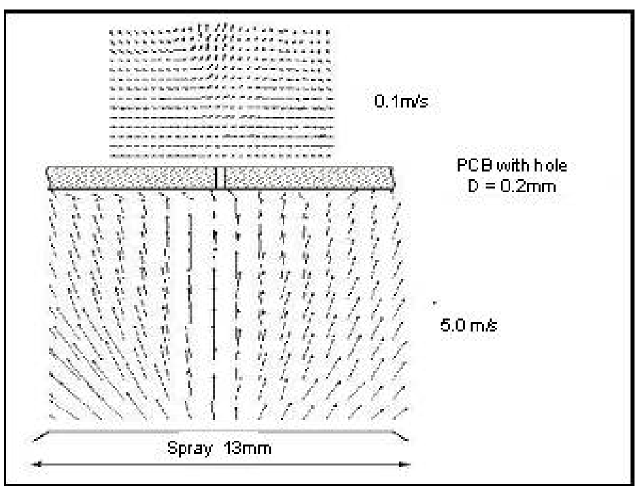

The results show that a maximum diffusion current is achieved at a flow angle of 90° and of course with the highest impingement velocity.

In larger scale tests the technique of particle image velocimetry (PIV) was used to image the flow of electrolyte through a high aspect ratio panel. Figure 5 shows the experimental set up used to carry out the tests. In this a dynamic system is illuminated by two laser beams and the resulting interference pattern information is recorded on a camera.

**Figure 5: Particle image velocimetry apparatus.**

The data from one of the flow experiments through a high aspect ratio panel is shown in figure 6.

**Figure 6: PIV measurement of vertical solution flow through high aspect ratio panel.**




The results from the experiments have enabled modifications to made to the Uniplate Inpulse system to improve the production of blind micro-vias as reported.

### Horizontal Application

The high aspect ratio throwing power in Uniplate systems has been a restriction to their use for the production of thicker panels. Even for panels thicker than 1.6 mm the copper throwing power has not been fully acceptable depending on the aspect ratio. The reasons for this have been because of the emphasis on the production of thinner material at higher current densities with blind micro-vias. The high current density, in the order of 10 A/dm² average and the requirement to produce blind micro-vias under such conditions has required the use of relatively high copper concentrations at above 35g/l, both of these factors have not enabled the best throwing power in high aspect ratio panels. Trials have been made to improve the throwing power in standard Inpulse equipment but these have only given a marginal improvement, these trials were limited by the pulse parameters which are available with the standard Inpulse system.

The standard Inpulse module has a spray bar to cathode separation of 95 mm and an anode to cathode separation of 75 mm. In the Inpulse 2 both the spray bar and the anode is set much closer to the cathode at 15 mm and 8 mm for the anode. This enables a more intense electrolyte flow towards the panel and also as an added advantage making the use of anode shielding unnecessary whilst retaining excellent surface distribution. Also the spray system itself has been modified to give a more directed agitation towards the panel, these changes were made primarily to enable the more efficient flooding of blind micro-vias. Using this system experiments were made to investigate the optimal electrolyte composition and pulse plating parameters to achieve best throwing power in 3,2 mm thick panels with aspect ratio 10:1. The results have shown that primarily the pulse wave form set up and the electrolyte adjustment are critical in giving throwing power improvement. The best electrolyte composition was found to be as follows,

Copper 20 g/l
Sulphuric acid 270 g/l
Chloride ions 40 mg/l
Iron(II) 7 g/l
Iron(III) 1 g/l
Leveller Inpulse H6 1.7 – 2.0 ml/l
Brightener Inpulse 4.0 – 5.5 ml/l

The additive concentrations are more typical of electrolytes adjusted to produce high aspect ratio panels, in particular the copper concentration is 15 – 20 g/l lower than in a standard Inpulse electrolyte.

The pulse plating parameters were varied from DC plating conditions at 4 A/dm² to pulse plating with forwards 250 ms and reverse 25 ms, a selection of the parameters used together with the throwing power achieved is shown in the following table.

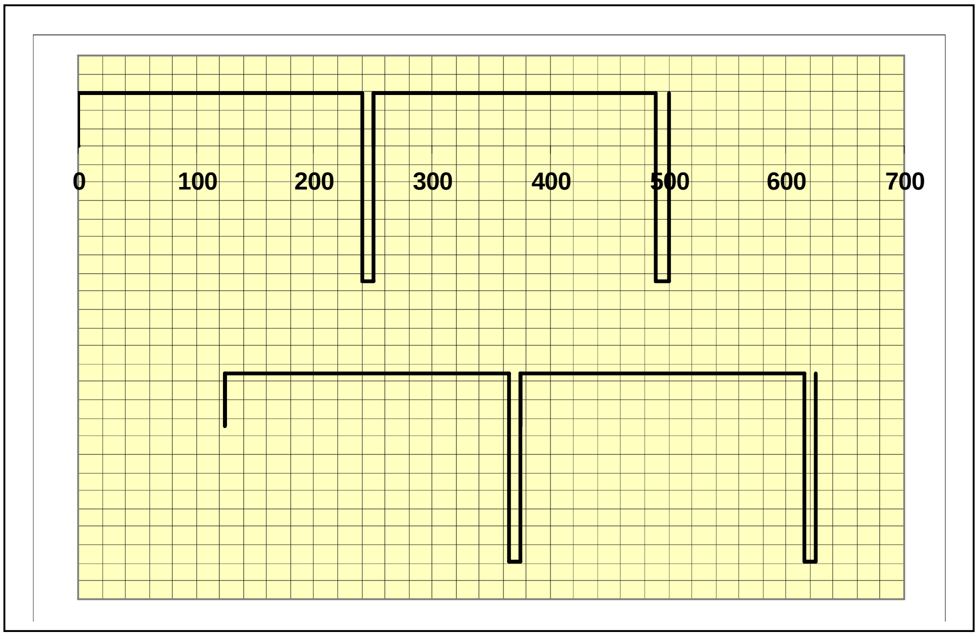
**Table 2: Test conditions for Inpulse 2 trials for 3.2 mm thick panels.**

| Test | I average / I reverse in A/dm² | Pulse Parameters in ms Forward / Reverse | Phase Shift in° | Pulse Rise Time Factor | Surface Finish | Throwing Power min. in % |
|---|---|---|---|---|---|---|
| 1 | 4 DC | DC | - | - | Good | 32 |
| 2 | 4 / 4 | 240 / 20 | 180 | 1.2 | Good | 53 |
| 3 | 4 / 16 | 80 / 4 | 180 | 1.2 | Good | 49 |
| 4 | 4 / 16 | 80 / 6 | 180 | 1.2 | Rough | 55 |
| 5 | 4 / 16 | 250 / 25 | 180 | 1.2 | Rough | 54 |
| 6 | 5 / 15 | 240 / 10 | 180 | 1.2 | Good | 67 |

The best throwing power results were achieved with forwards 240 ms at average current density 5 A/dm² and reverse 10 ms at current density 10 A/dm². In all tests a phase shift in

pulse parameter of 180°C was used, this means that the reverse pulse was applied to the anodes on one side of the test panel at the same time that the forwards pulse was applied to the anodes on the other side, the schematic in figure 7 illustrates this setting.
The pulse rise time factor was set at 1.2 in these experiments, this parameter can be adjusted in the Inpulse 2 system, the effects on plating results are currently being investigated.

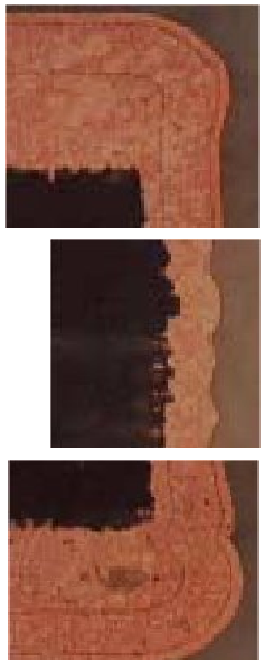
**Figure 7: Pulse wave form schematic showing phase shift between top and bottom anodes.**




Microsection photographs of the panel produced in test 6 are shown in figure 8. The reinforcement of this panel was made at 5 A/dm² under DC conditions and as can be seen at the centre of the hole the thickness achieved is very low, the panel plate with the Inpulse 2 system has a throwing power of approx. 67%.

As a comparison with similar panels, a throwing power of only 30 % would be achieved at 3 A/dm² with horizontal DC and at 2 A/dm² a throwing power of 55 % under vertical conditions in DC. Only with pulse plating under standard vertical conditions with air agitation is a throwing power of 90% achieved but this is at a current density of 2 A/dm². Using forced agitation improved throwing power is possible as discussed in the next section but even this is not at such a high current density.

**Figure 8: Microsection of 10:1 aspect ratio panel under test conditions 6.**



Panel thickness 3.0 mm

hole diameter 0.3 mm

Panel plate reinforcement DC horizontal

Panel plate full build up approx. 67%

### Vertical application

In vertical systems the electrolyte agitation is usually made with a combination of air agitation in the electrolyte itself and a mechanical agitation of the circuit board being plated. This mechanical agitation must ensue that the panels are moved evenly and remain vertical in the electrolyte otherwise solution flow will not be uniform through all the holes in the panel. To ensure this cathode movement systems are used which clamp the panel securely and which are also used to supply current to the panel. These agitation systems, air in the electrolyte and movement of the panel can lead to uneven fluid transport due to the non defined air agitation and the movement of the panel through the agitation bubbles, to overcome these problems the use of Eductors is becoming more common.

Eductors use the venturi principle allow small pumps to circulate larger volumes of liquid, the kinetic energy of one solution will cause the flow of another. Typically the use of Eductors can give a 4 to 6 times increase in volume of solution movement when compared to the volume pumped, this increased volume is however at a lower pressure than the directly pumped solution. Figure 9 shows two sizes of commonly used Eductors in electrolytic copper plating systems.

**Figure 9: Eductors commonly used.**

The smaller Eductor will pump a lower volume but will allow more Eductors to be placed on one pipe so giving a more even flow.

Currently the method of installation in a vertical plating tank is on the floor underneath the cathode as shown in figure 10.

**Figure 10: Installation of Eductors in vertical Inpulse line.**

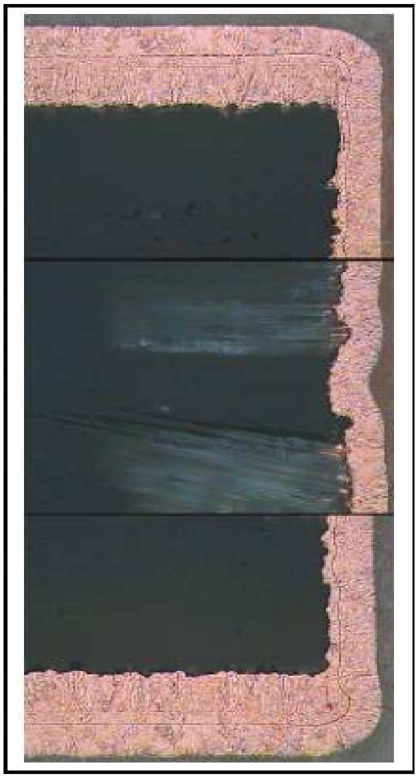
This installation is with two pipes placed one on each side below the cathode with the Eductors adjustable pointing upwards towards or away from the cathode. There are similar installations with the Eductors mounted on a single pipe running directly below the cathode, the Eductors mounted at a fixed angle pointing alternately away from the panel. The disadvantages with this set up is that the electrolyte flow uniformity depends on the positioning of the Eductors and also the distance between nozzle and the panel.

To give a more uniform flow the Eductors can be positioned between the anodes in the plating cell pointing directly towards the cathode. This set up has the advantage of giving a more direct flow of electrolyte towards the panel and is show in figure 11. The disadvantage of all Eductor installations is that the solution flow can never be completely uniform over the panel surface. A compromise must be made between the number of Eductors installed and the flow uniformity.

**Figure 11: Eductors installed with flow directly towards the cathode.**

To overcome the limitations of flow uniformity by the use of Eductors a moving spray system has been developed and is being tested in a trial tank in laboratory conditions. The system consists of a spray head which moves regularly over the surface of the cathode and produces an intensive forced flooding of the panel and the through holes at the point of spraying. The head moves in a plane between anode and cathode but is so dimensioned that it does not interfere with the electro deposition process. Initial results with high aspect ratio panels have show a significant improvement in throwing power when compared to standard air agitation and a more uniform deposit in comparison to Eductor agitated equipment on the same scale. Figure 12 shows plating results from a 3.2 mm panel with 0.3 mm hole.

**Figure 12: Microsection of 10:1 aspect ratio panel plated with moveable spray system.**



Panel thickness 3.0mm
hole diameter 0.3 mm.
Average current density 2 A/dm²
Throwing power 90- 95%
Reinforcement plated by DC horizontal at 5 A/dm²

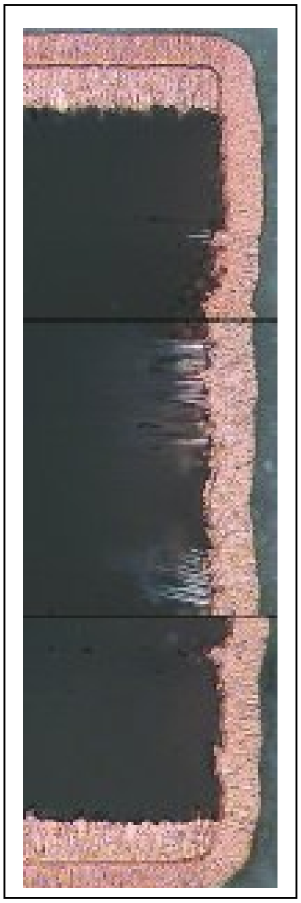
Investigations are ongoing in the use of so called batch plating parameters to improve throwing power particularly in panels thicker than 5mm. During the plating cycle the pulse parameters are varied, normally at the start of the cycle a strong reverse charge is used to give a good throwing power followed by a lower reverse charge at the end of the plating cycle to give a good surface finish. An example of such a plating sequence is given in table 3.

**Table 3: Pulse plating batch sequence for thick panel trials**

| Sequence | Exposure time mins. | A/dm² Ratio Forward to reverse | Pulse timing ms |
|---|---|---|---|
| 1 | 100 | 1:3 | 30:1.5 |
| 2 | 15 | 1:2.5 | 20:1 |
| 3 | 5 | 1:1.1 | 20:1 |

Figure 13 shows plating results from a 5.0 mm panel with 0.5 mm hole using a pulse plating sequence together with the moveable spray system to give optimal electrolyte exchange.

**Figure 13: Microsection of 10:1 aspect ratio panel plated with modified pulse parameters**



Panel thickness 5.0mm
hole diameter 0.5 mm.
Average current density 1.7 A/dm²
Throwing power 95- 100%

Use of both optimised pulse parameters as well as electrolyte agitation gives significant improvements in throwing power in trial line experiments.

### Summary and outlook

Experiments in basic electrochemistry have shown a strong influence of electrolyte agitation on copper electroplating characteristics. Modifications to horizontal Inpulse equipment together with optimised plating parameters show improved throwing power under experimental conditions however the influence of improved solution flow appears to be limited in first investigations. This could be due to the essentially optimal electrolyte agitation in the Inpulse system in comparison to a vertical set up.

In vertical equipment use of Eductors to improve agitation is becoming a standard for new equipment. However implementation of agitation systems to give as good an agitation in vertical systems as in horizontal has not yet been achieved. The use of a moving spray flood system shows advantages in the trial line scale, this must be confirmed in full scale production equipment as a next step.

Use of varying pulse parameters over the copper deposition time have shown the possibility to improve throwing power with aggressive parameters whilst retaining optimal surface finish using milder pulse parameters at the end of the processing time.

## References

[1] B. Reents, A. Thies, P. Langheinrich, Atotech GmbH, J. Zosel Kurt Schwabe Institute für Mess und Sensor Technik e.V. „Online measurement of flow and mass transfer in micro-holes with PIV and an electrochemical sensor array". Proceedings ISE symposium 2002, Düsseldorf, Germany.

[2] B. Reents and S. Kenny "The influence of fluid dynamics on plating electrolyte for the successful production of blind micro-vias" IPC Expo 2002 Proceedings of the Technical Conference IPC Northbrook, Illinois, USA, (2002).