# Copper Filling of Blind Micro Vias and Through Holes using Reverse Pulse Plating – Inclusion free filling of mechanical and laser drilled through holes

**This article describes the different techniques of via filling and their characteristics. It points out the advantages of reverse pulse plating and how the technology was modified to approach new market requirements such as thicker core substrates and laser drilling of through holes. The current capability of the system for inclusion free filling and the areas where development is ongoing are demonstrated.**

Laser drilling of blind micro vias (BMV's) and subsequent copper filling has become the standard manufacturing technique for high density interconnects. These copper filled BMV's are used in IC packaging in order to reach the required interconnect density and to provide the necessary surface for reliable solder attachment. For "smart phone" production, use of multiple lamination and typically 10 layers of stacked copper BMV filling is now the preferred technology, which is also known as the "Any Layer" filling process. To maintain the development in circuit miniaturization, together with the reduction in overall processing costs as expected by Moore's Law and to meet the demand for ever more filled BMV's on each plated layer, advances in filling processes are required.

## Via Filling Process

Copper Plating and Filling can be described as shown in figure 1.

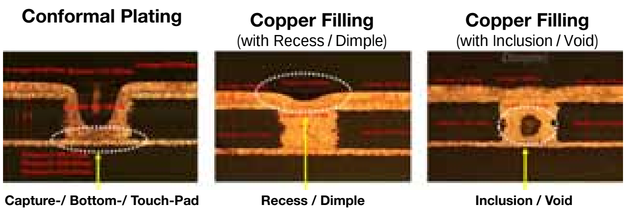


Figure 1: Description of technical terms for Via Filling.

A capture pad is the connection area of a surface feature to the inner layer beneath. Recess describes the remaining non-copper filled area on top of a copper-filled feature (trench, micro-via, through-hole) in relation to the copper plated on the board surface. Inclusions are non-copper filled voids within PCB features.

The filling of blind micro vias without additives ('normal deposition') will usually lead to the formation of a void (see figure 2a). Copper is deposited until the via is closed, but without additives less copper is deposited inside the BMV than on the surface and voids may occur.

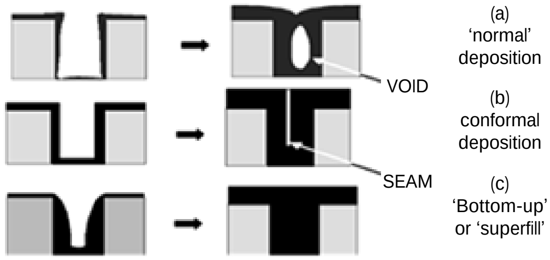


Figure 2: Schematic of BMV Filling Process.

Using organic additives that inhibit the deposition at the surface and increase plating into the BMV will lead to conformal deposition. However, by conformal plating the aspect ratio of the BMV is increased, limiting the solution exchange and mass transport into the BMV. The result can be a BMV with a "seam" in the center where copper deposition was not possible due to the increase in the aspect ratio (see figure 2b). The third way of BMV Filling is the bottom-up method where the copper is deposited preferentially onto the capture pad, ideally creating a low dimple combined with a minimum of plated surface copper (see figure 2c).

The filling of through holes is a bit different as there is no bottom area where copper plating can be increased. Therefore, basically two approaches are possible: The first one is to use slow DC plating and conformal copper growth on the side walls to fill the through holes. But similar to the conformal BMV filling method, this method tends to create a seam or inclusions. It also takes more time (less productivity) and needs more copper on the surface, as can be seen in figure 3.

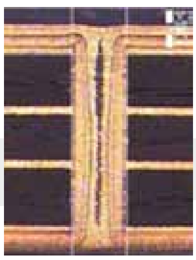

Figure 3: Seam in through hole filled in DC mode.

The other approach is to use conformal plating in the first step and then change to aggressive pulse plating in a second step in order to increase the amount of copper plated in the middle of the hole. The result is an X-shape in the hole built by two flat copper triangles on each hole wall. This X-profile can be seen as BMV's from both sides of the panel. These two BMV's are completely filled inclusion-free in the next step (see figure 4).

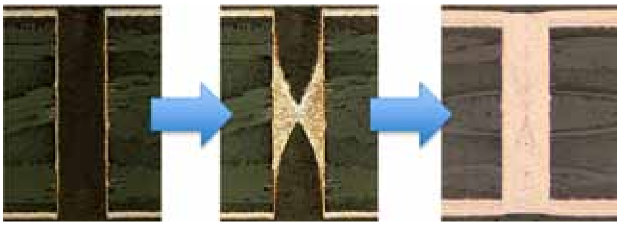

Figure 4: Steps of through hole filling by formation of "X".

Additionally, the formation of the "X-shape" or so called "bridge" offers the possibility to significantly reduce the Cu overburden. This is achieved by applying a combination of reverse pulse plating and etching in one electrolyte. The electrolyte contains not only Cu but also $Fe^{2+}$ and $Fe^{3+}$. This Inpulse system is schematically described in figure 5 for a better understanding.

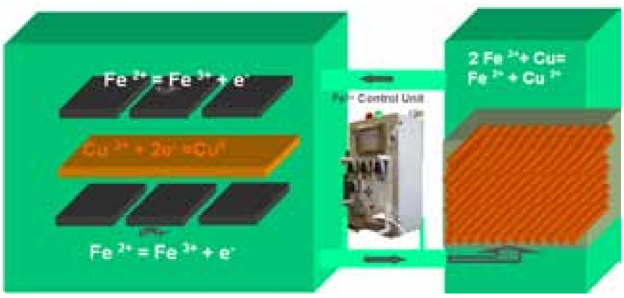


Figure 5: Inpulse Plating system containing Cu and Fe.

Cu is deposited as usual on the panel (cathode) whereas the $Fe^{2+}$ ions are used to carry the current at the dimensionally stable anodes and thus prevent oxidation of organic additives. The oxidation product $Fe^{3+}$ is used to dissolve the consumed Cu chemically, in a second chamber filled with pure Cu balls, and reduced again to $Fe^{2+}$. Moreover, the $Fe^{3+}$ cannot only be used to replenish Cu but also to reduce the plated Cu on the panel surface. The electrochemical reactions at the cathode in the Inpulse system with corresponding potential are given below (I) and (II) as measured against standard hydrogen electrode.

$$Cu^{2+} + 2e^{-} \rightarrow Cu \qquad E = 0.340\ mV\ (I)$$
$$2\ Fe^{3+} + 2e^{-} \rightarrow 2\ Fe^{2+} \qquad E = 0.771\ mV\ (II)$$

The electrochemical reaction (II) is favored against reaction (I). Thus the amount of $Fe^{3+}$ reduces and determines the amount of copper deposited onto the cathode (Panel). A $Fe^{3+}$-control unit (Ancolyser) between the plating and dissolving tank regulates the exchange between both compartments and controls the amount of $Fe^{3+}$ within a range of $\pm 0.1$ g/l. This online control is a precondition for a good process control and has been proven in production scale. The solution exchange on the surface is much stronger than in a hole, so the etching effect becomes effective mainly on the surface and not in vias and especially not in blind micro vias.
With this technology we were able to reduce the amount of Cu overburden for a 100 µm thick core from 50 µm down to now 13-15 µm (figure 6).

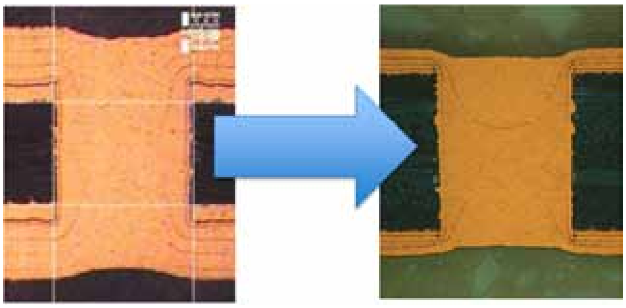

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Figure 6: Surface thickness reduction during through hole filling development.

Without this reduction actual production would not have been possible as the surface plated copper thickness determines the achievable lines and spaces. The reduction of surface thickness for filled BMV's allows the production of thinner stacked filled structures. As mentioned before, today typically 10 layers of stacked copper BMV filling is the preferred technology in smart phone production. It is one of the enabling production processes in the drive for miniaturization of consumer electronics following the expectation of innovation and invention given by Moore's Law.

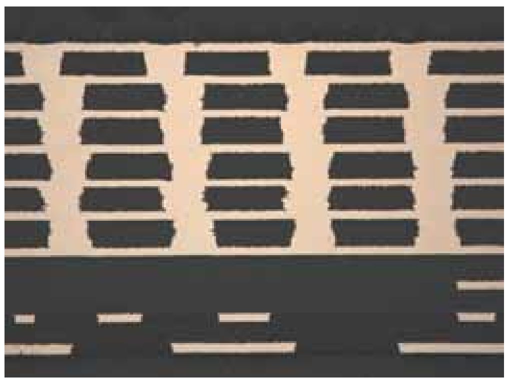


Figure 7: Filled stacked BMV, also called "Any Layer".

## New Challenges

The main core thickness for IC substrates is thicker than 100 µm; today's cores have a thickness of up to 400 µm or more. These are extremely difficult to fill without void formation and require a long plating time at a low plating current density. For up to 200 µm substrate thickness, the industry now moved from using mechanical drilling towards laser drilled through holes. Laser drilling causes new problems when it comes to drilling quality. Often, the time for the laser to vaporize the substrate is not sufficient to achieve smooth hole walls. Glass fiber protrusions occur, decreasing the diameter of the through hole, but not always in the center. During bridge plating the X-shape is made at the area where the diameter is at a minimum. When the gap is not closed at the center, one of the two resulting BMV's will have a very high aspect ratio, increasing the risk of inclusions (figure 8).

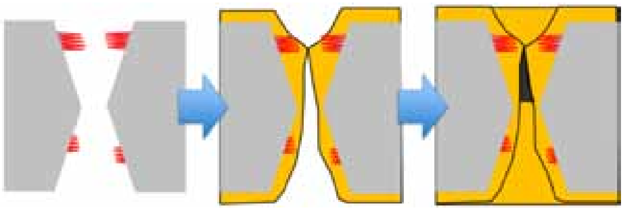


**Figure 8: Challenge for filling of laser drilled through holes.**

Therefore, a new test matrix was carried out in a small lab tool to determine which of the following parameters might have a significant influence; the results of these tests were then confirmed in a production tool:

- Brightener (accelerator)
- Leveller (inhibitor) concentration
- $Fe^{3+}$ concentration
- Cu concentration
- $Cl^{-}$ concentration
- Sulphuric acid concentration
- Temperature
- Electrolyte agitation
- Current density and pulse parameters

For this investigation we stopped plating after a certain time period and measured the thickness in the middle of the hole compared to the surface. Of course, the organic additives have a significant influence on the filling performance, but for the improvement of the X-formation a change of leveler and brightener ratio did not significantly show any benefit. During our studies we found out that the effect of $Fe^{3+}$ concentration is very strong. High ferric concentrations lead to very slow X-formation. Consequently, the control of ferric ions is extremely important for handling the process. Therefore, the online control unit between the plating and the dissolving tank is mandatory to keep the ferric ion concentration within $\pm$0.1 g/l (see figure 9) and assure bridge plating.

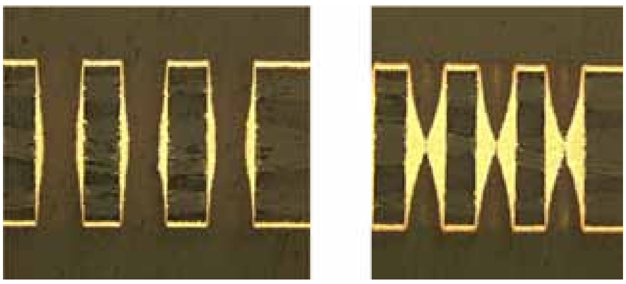
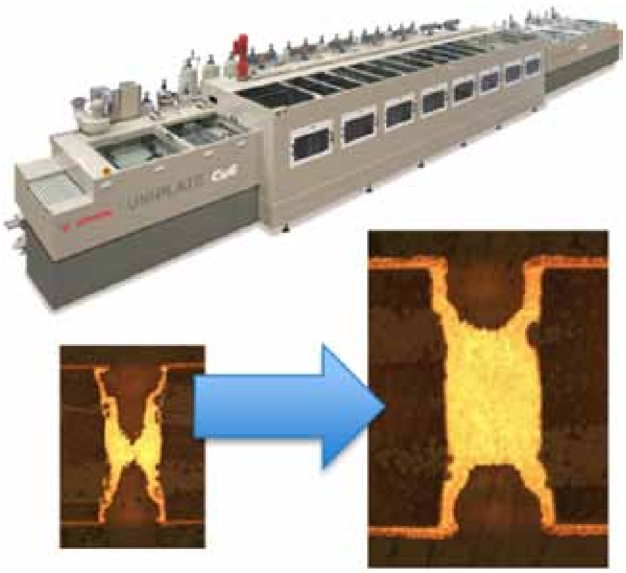


**Figure 9: Effect of ferric ions on the X-formation:**
**left 1.0 g/l** **right 0.5 g/l ferric**

Another interesting result is the effect of copper concentration on the X-formation. In contrast to the BMV filling process a lower Cu concentration turned out to be beneficial. Its influence is significant for the X-formation. Tests run with 18g/l and 32g/l Cu on very thick panels (3.2 mm with 0.3 mm hole diameter) confirmed this result. With the 18 g/l, we almost doubled the Cu thickness in the middle of the hole. For the Cl- concentration an increase up to 90 mg/l was beneficial, too. For the sulphuric acid concentration, we couldn't find a significant influence. The temperature influences the dimple performance in via filling, which depends on the adsorption/desorption ratio between accelerator and inhibitor. It turned out that the increase of temperature from 20°C to 40°C had a positive effect for the bridge plating. Besides temperature and chemical parameters, the equipment has a major influence in improving the filling performance. Therefore, the existing equipment was modified. Atotech introduced the Uniplate InPulse2 THF Advanced to meet and exceed these requirements.



**Result with standard system** **Result with advanced system**

**Figure 10: Bridging improvement by higher flow in advanced equipment.**

The pulse plating system, with its rectifiers, is well placed in the market, offering a high productivity for conformal and filling processes. To achieve the aggressive pulse parameters needed for creating the X-shape, the rectifier system was optimized. It is now capable of running very complex and aggressive current pulses. By that, we could proof that a strong reverse pulse (80 ms cathodic pulse at 5 ASD followed by a 4 ms anodic pulse at 50 ASD) for 15 minutes leads to reliable closure of the X-formation on 400 µm cores with 100 µm diameter. In our tests, the electrolyte flow direction onto the panel was at 90° angle towards the surface. Doubling the flow rate resulted in a consistent X-formation and centralized bridging (see figure 10). For this reason, we increased the pump capacity for the Uniplate InPulse2 THF Advanced. Moreover, a continuous flow control, in combination with frequency controlled pumps and automatic level control, grants a stable process performance.

## Summary and Outlook

Copper via filling is a critical process for the production of HDI panels and IC packages. The number of BMV's found on a typical substrate increases as well as the dimensions of through holes, which pushes the limits for the production process. Reverse pulse plating, in combination with the ferrous Uniplate InPulse2 THF Advanced system, offers a viable alternative to standard approaches as it is the only consistent inclusion free technology for the filling of mechanical as well as laser drilled through holes.

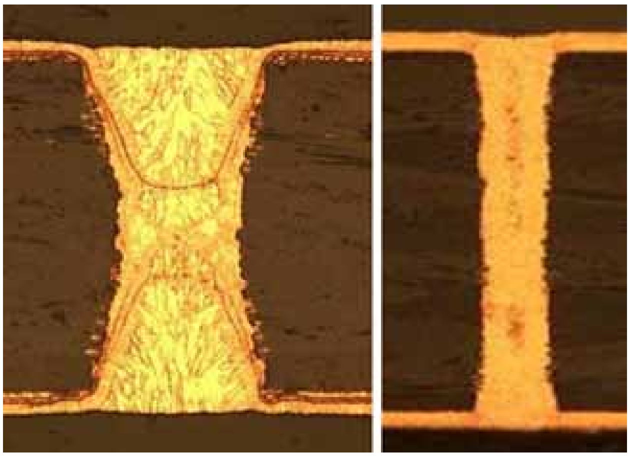


**Figure 11: Laser drilled through holes:**
**left: Inclusion free 200 µm x 100 µm**
**right: Minor inclusions 400 µm x 100 µm**

Flexible pulse shapes empower the system to plate the X-profile first and then fill the created BMV's with very low copper deposition on the surface with the same type of equipment. Solution exchange in the holes has a big impact on the results of through hole filling, a high exchange rate results in less inclusions. The Advanced system offers a supply of up to 20 $m^3/h$ at each anode, respectively 560 $m^3/h$ in one plater module, and can be setup to the optimized volume flow to meet complex requirements. Today, it is possible to fill mechanical drilled through holes up to a substrate thickness of 300 µm and a diameter of 100 µm inclusions free within 60 minutes. Laser drilled through holes of 100 µm x 100 µm can be filled inclusion free in less than 60 minutes, 200 µm thick substrates still need >60 minutes plating time to guarantee void free filling (figure 11). Further development aims at inclusion free filling of thicker substrates (>300 µm) and a further reduction of plating time.

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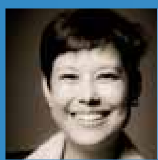


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