Blind Micro Via and Through Hole Filling in Horizontal Conveyorised Production System

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Abstract
This paper presents a novel electrolytic copper panel plate system incorporating equipment and specially developed electrolyte which enables filling of blind micro vias with a minimum of surface plated copper.

The system utilises Uniplate plating equipment which may be combined into a wet to wet metallisation and copper plating line. The InPulse2 electrolytic copper plating module uses insoluble anodes for uniform plating conditions together with a special clamping system for electrical contact to the substrate which also enables production of material with thin copper foil down to 3 µm. Such material is becoming more common in HDI production but requires special techniques to ensure optimum surface distribution at high production current densities. The insoluble anodes are segmented and each anode segment has an individually controlled rectifier to ensure uniform blind micro via filling over the whole substrate.

Blind micro vias typically seen in hand held devices with 70 µm depth and 100 µm diameter can be easily filled with this system with only 15 µm copper deposited on the surface, this offers the possibility to meet the requirement for 2 MIL line and space with panel plating techniques. Also due to the low thickness of plated copper, savings in materials are very significant particularly in copper metal but also in solder mask and etching chemistry. This process has already reached a high acceptance in the mass production of HDI circuit boards particularly for hand held devices.

Development results showing the system capability also for through hole filling of substrates is shown together with discussion of possible application areas for this new technology.

Introduction
The filling of the micro-vias with copper enables a high degree of miniaturisation utilising via in pad and stacked via designs and has advantages over other filling methods.

1. The filling of micro-vias by use of conductive pastes becomes difficult with decrease in their dimension, in contrast to this filling is easier and more reliable with copper plating.
2. The electrical and also thermal conductivity of copper filled micro-vias is higher than that achieved with conductive pastes.
3. Air inclusion in micro-vias during solder mask coating will give possible component failures due to out-gassing during thermal excursion. If the micro-vias are even only 50% filled then the danger of air inclusion is minimised.
4. Copper filled micro-vias can be used to conduct heat generated at components to a heat sink possibly incorporated as an inner layer. This thermal conductivity may also be used to improve soldering of BGA substrates.

The advantages of the copper filling process can best be shown by considering the solder mounted component as in figure 1.

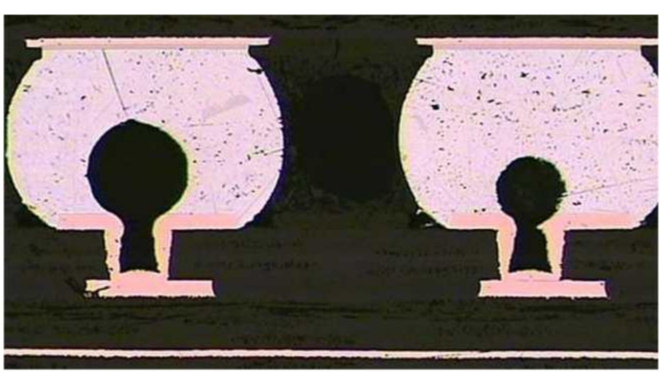

Figure 1 – Air Voiding in BGA after Component Mounting

The component mounting onto the non-filled blind micro vias has resulted in air voids within the solder joint. This can have serious consequences for the reliability of the joint not least that initially the joint will show good functionality but which may cause subsequent in service failure.

Blind micro-via filling with copper plating is the standard process used in IC substrate production where generally no through vias are present. In this technology micro vias with dimensions of the order of 75 µm diameter and 35 µm depth are filled, typical line and space requirements for this application are of the order of 25 µm to 40 µm, an example of a build up substrate is shown in the microsection in figure 2. The laser vias to be filled are produced in a homogeneous material without any copper foil; this makes the demands on the copper filling process relatively simple in comparison to those for the filling in other HDI applications.

Figure 2 – IC Substrate with Copper Filled Build-Up Layers.

This copper filling technique is now applied for the production of hand held devices with micro via dimensions in the order of 100 µm diameter and 65 µm depth. In this application typical line and space requirements are 100 µm to 150 µm and through vias may also be present. Figure 3 shows a microsection through a stacked filled structure where the dielectric is a glass reinforced material.

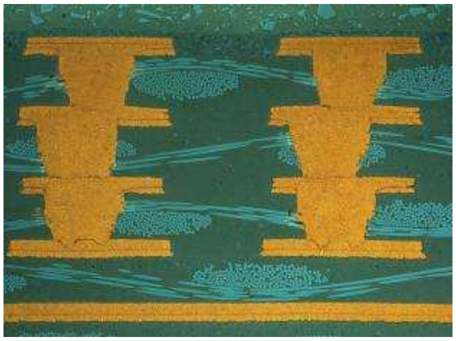

Figure 3 – Stacked Filled Blind Micro Vias

Such blind micro vias are more demanding on the copper plating process, this is due to the fact that the laser drilling is more difficult and the drilled vias produced are less uniform. The substrate to be drilled is glass reinforced and thus non homogeneous also copper foil is present and current production methods require direct drilling of this copper which can lead to a significant copper overhang on the drilled via. Figure 4 shows an example of such a filled blind micro via with copper foil overhang and protruding glass in the via wall.

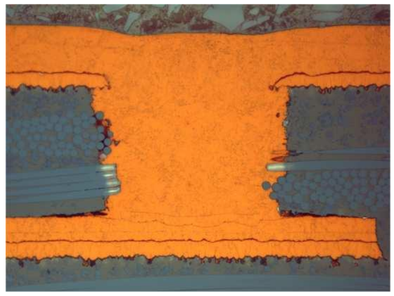

Figure 4 – Filled BMV with Copper Overhang and Protruding Glass

Generally to fill such blind micro vias production processes are chosen to use lower current densities and also to deposit a thicker copper layer to give void free filling. This has the disadvantages that the production process becomes longer, determined by the slow copper deposition and also the cost will increase due to the greater consumption of copper. Also thicker deposits of copper in panel plating mode cannot be etched for fine line applications, this means that normally pattern plating processes will be used. This production method utilising vertical copper plating equipment can produce fine line structures but the plated track uniformity cannot match that of panel plating, this track uniformity is an important consideration where circuitry for high frequency and impedance control applications is produced. Horizontal copper plating equipment using insoluble anodes offers a high performance alternative to conventional vertical systems, higher current densities give increased productivity and filling with lower copper thickness reduces cost.

Discussion of Methodology

The use of horizontal plating with insoluble anodes has achieved considerable industry acceptance for the production in particular of thin base materials with blind micro-vias and through holes. The system gives a good surface distribution in panel plate mode at high plating current densities important for good productivity. Copper replenishment is made by either addition of copper salts for example copper oxide or by the use of an iron redox system, this paper describes use of the iron redox system to give blind micro via and also through hole filling. The system is inherently very suitable for the production of filled blind micro vias for the following reasons,

- Copper concentration 35 – 40 g/l.
- Normal working temperature 40°C.
- Strong solution flow towards panel.
- Optimised panel plate surface distribution.

The high copper concentration together with the high temperature and solution flow are critical to ensure adequate mass transport into the blind micro vias for uniform filling. Special flooding devices and spray designs as reported in reference[1], together with use of frequency controlled pump systems ensure best possible working conditions. Figure 5 shows a semi-dismantled view of a copper plating module where the top flood bar assembly and anodes have been removed to show the lower anodes and also the clamping system.

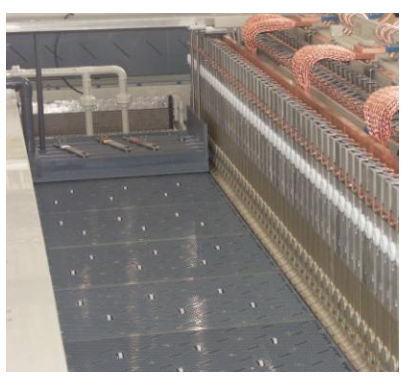

Figure 5 – Open View of Horizontal Conveyorised Copper Plating Module

The clamp system is non-coated but has an integrated shield to maintain copper plated surface distribution; the contact area is extended to ensure low resistance to the plated substrate. The clamp design is made so the plating can be made without any “crimping” or distortion of thin material which would otherwise be fixed into the substrate, all clamps are also accurately positioned in the plane of the material to be plated to ensure smooth transport. Thin material with copper foil at 3 µm can be produced in this system; also reel to reel production applications are possible using special winding equipment for load and unload. Copper plated distribution is also dependant on the anode configuration; this is shown in figure 6 where the segmented structure can be seen.

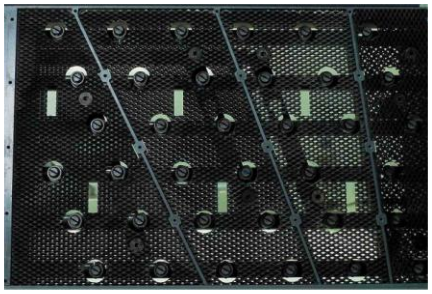

Figure 6 – Insoluble Anode with Four Individually Controlled Segments

Each segment of the anode is individually controlled and including a separate rectifier to ensure the correct plating parameter is applied. This is important to ensure copper surface distribution as the thin conducting layer has a specific resistance which can cause thicker deposit at the clamped side of the panel in comparison to the non-clamped side.

An important consideration in the copper plating module is the working level of the electrolyte; this is determined by the rate of flow of the pumps and also by the return flow to the holding chamber. For certain applications for example to ensure good electrolyte exchange in high aspect ration vias, a high pump flow is required. Alternatively for example with 25 µm thick cores a reduced pump flow is necessary to prevent any mechanical distortion of the material caused by the high electrolyte flow. In both these cases a constant electrolyte working level can be set by the control of the electrolyte flow using a pneumatic valve system as shown in figure 7. This valve is placed in the return pipe to the holding tank and restricts the flow depending on the constriction caused by the applied air pressure.

Figure 7 – Pneumatic Valve System for Level Control

These valves are controlled by the equipment systems and can be set depending on the characteristics of the base material which can be registered as relevant data for each production run.

The electrolytic copper plating module may be combined also with a horizontal pre-treatment line to give a combined metallisation and electrolytic copper production plating system. This combination gives the advantages of a wet to wet continuous processing which ensures reliable copper deposition and decreases production costs. As is described the use of insoluble anodes gives the advantages of uniform deposition of copper over the entire cathode area. Accurately defined pulse plating parameters may be set up due to the use of the individually controlled rectifiers for each anode segment. The choice of the pulse plating parameters together with electrolyte settings allows the deposition of copper and also the etching of copper simultaneously during the plating cycle. This innovative process combination allows the filling of structures on a substrate with a minimum of surface plated copper and may be also used to fill laser ablated trenches in a substrate as reported[2]. In comparison to conventional filling processes the amount of copper required can be reduced by over 40% and can also achieve an overall better filling result. Figure 8 shows an example of a copper filled blind micro via with diameter

140 µm and depth 115 µm filled with only 16 µm of surface plated copper, the residual dimple after plating is less than 10 µm.

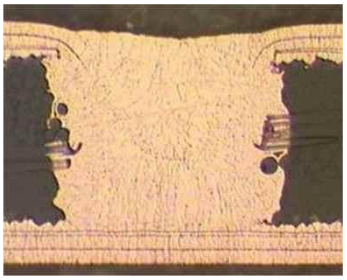

Figure 8 - Blind micro via diameter 140 µm and 115 µm depth filled with 16 µm surface plated copper.

This process is currently used in full scale production in HDI applications particularly for hand held devices; figure 9 shows a microsection of stacked, filled blind micro vias and the associated attached component from such an application. The advantages of the copper filling can be clearly seen, the first filled blind micro via provides the planar copper surface ideal for the following stacked, filled blind micro via. Without copper filling, soldering onto the BGA could be expected to have significant voiding due to entrapped air, this copper filling process has in the meantime become an industry standard for the production of HDI for certain mobile phone applications.

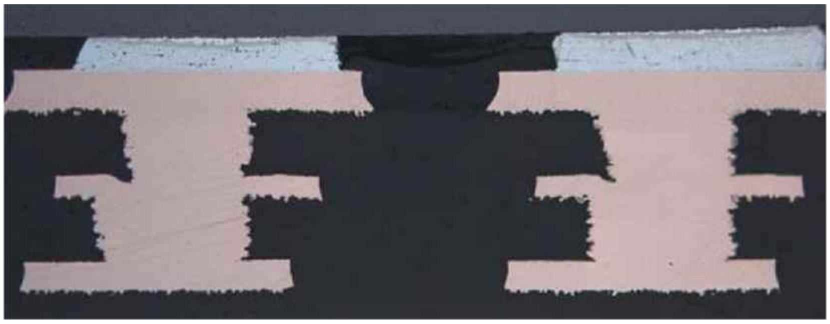

Figure 9 – Filled Stacked Blind Micro Vias in Hand Held Device Application

The filling capability with low surface plated copper has obvious cost saving advantages in the use of less copper raw material and technical advantages in that the thin copper plating may be etched to form the fine line features. The profile of the etched features is more uniform than with other production techniques due to the excellent plated uniformity of the copper layer. Further cost savings are also possible in etching processes and also solder mask as the surface plated copper is thinner than is usual.

As part of a development project the pulse plating parameters and electrolyte have been optimised to allow the filling of through holes as shown in figure 10. The target of the development work has been to utilise the advantages of the horizontal plating system to produce uniformly filled through holes with a minimum surface plated copper. The through hole plating is made as a two stage process, first the centre of the hole has to be filled with special reverse pulse plating parameters followed by the filling of the two “micro vias” produced to give a smooth filled substrate.

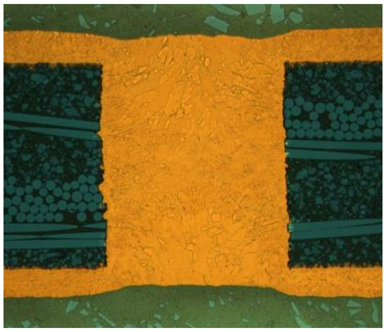

Figure 10 - Filled Through Hole 120 µm thick, 100 µm Diameter with Total Surface Plated Copper 13 µm.

A possible application of the through hole filling process is for the production of plated cores for IC substrate applications, in figure 11 a prototype substrate has been produced with a copper filled core. This core has then been further processed to produce the blind micro vias which have then in their turn been filled using the horizontal electrolytic copper plating process.

Figure 11 - Core filled with electrolytic copper followed by filled BMV with minimum surface plated copper.

This technology may be used to improve the reliability of a through hole filled substrate, the plated copper may replace resin or paste plugging. Copper has technical advantages due the much higher thermal conductivity in comparison to resin materials and also a much lower CTE. The target for the development in through hole filling is to optimise the electrolytic copper plating process to allow reliable filling of thicker substrates with higher aspect ratio through vias and with a minimum of surface plated copper. Currently in the development project a 0.4 mm substrate with 100 µm diameter via can be filled with only 19 µm of surface plated copper, this result is shown below.

Figure 12 - Copper Filled Through Hole Panel Thickness 0.4 mm Hole Diameter 100 µm. Surface Plated Copper 19µm.

The through hole filling process is also compatible with production in a complete horizontal wet to wet processing line. This means that the drilled substrate is processed in one production equipment comprising metallisation and electrolytic copper plating. Conventional plugging processes in comparison are made in separate equipment after initial metallisation and require also curing and mechanical brushing which are labour intensive and add additional cost to the process. For future applications with thin core materials any mechanical treatment will have to be avoided due to the demands of dimensional stability for registration.

Summary

Filling of blind micro vias with electroplated copper is the production standard process for IC substrates and also for other HDI applications in particular for hand held devices. Increasing miniaturization can be expected to demand further use of this technology in combination with via in pad interconnect. Use of copper filled blind micro vias gives improved reliability and eliminates the danger of solder joint voids. Fully integrated conveyorised production equipment is required to meet the production demands of this technology. Higher aspect ratio blind micro vias are most efficiently processed by the use of specially designed force flooding during copper plating.

Pure copper is also the obvious material for the filling of through holes to give improved reliability. Copper filled through holes give a more efficient thermal and electrical conductive path in a substrate and can allow potentially smaller vias with good thermal characteristics which could release space on a substrate for active circuit pathways. The production process for through hole filling is significantly shorter and less labor intensive than the conventional plugging technology used for cores prior to sequential build up production.

References

[1] B. Reents, S. Kenny, “Influence of Fluid Dynamics on Plating Electrolyte for the Successful Production of Blind Micro Vias”. IPC, 2002.

[2] R. Huemoeller, S. Rusli, Amkor, S. Chiang, T. Y. Chen, Unimicron, D. Baron, L. Brandt, B. Roelfs, Atotech “Unveiling the Next Generation in Substrate Technology”. Proceedings of the Pan Pacific Microelectronics Symposium, 2007.

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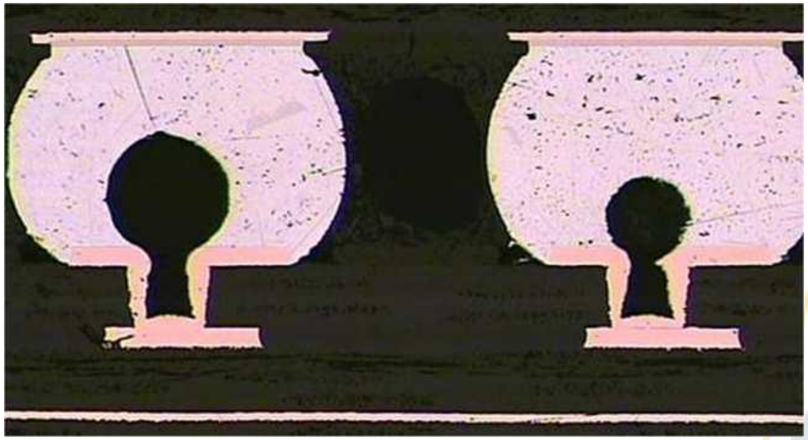
Process Reliability with BMV Filling

- Air inclusion in solder joint eliminated
- Electrical and thermal conductivity of copper is higher than with conductive pastes
- Production process is simplified with wet to wet metallisation and electrolytic copper filling

Solder Joint Reliability? with Conformal Plated BMV

- Air voiding in BGA solder joint
- Reliability problems due to non uniform solder joint

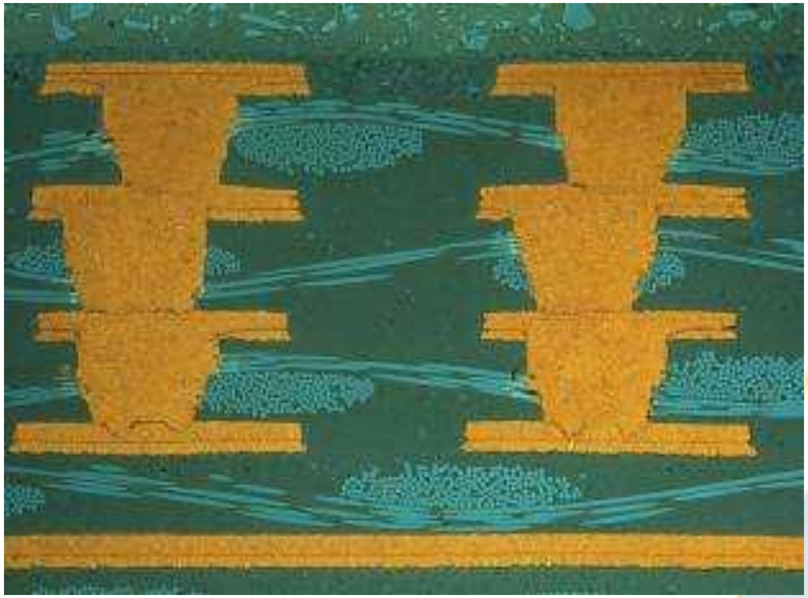


IC Substrate BMV Filling

- BMV diameter approx 75 µm, depth approx 35 µm
- Homogenous base material
- Uniform “V” shape BMV
- No copper foil

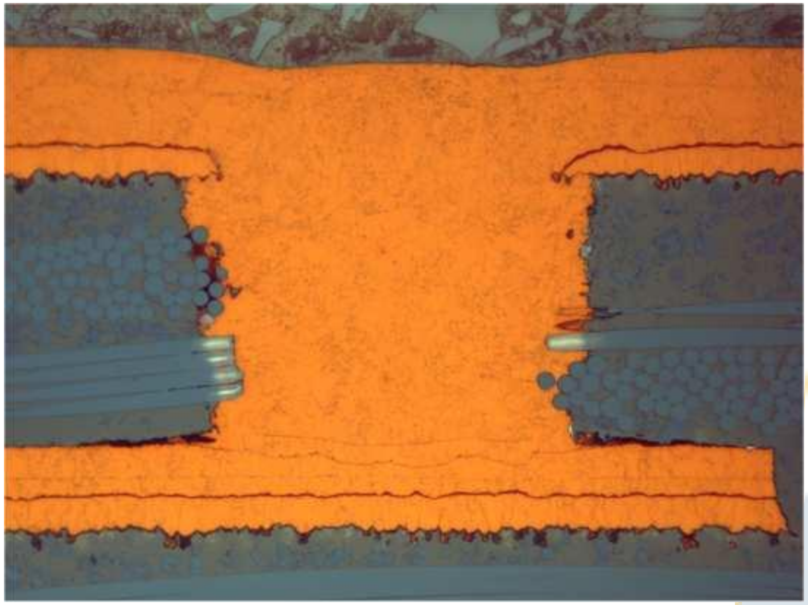
Filled Stacked BMV

- Stacked BMV structure
- Produced in multiple pass electrolytic copper filling process



Conventional BMV Filling

- Filled BMV with 30µm plated copper
- Base material with glass fibre reinforcement

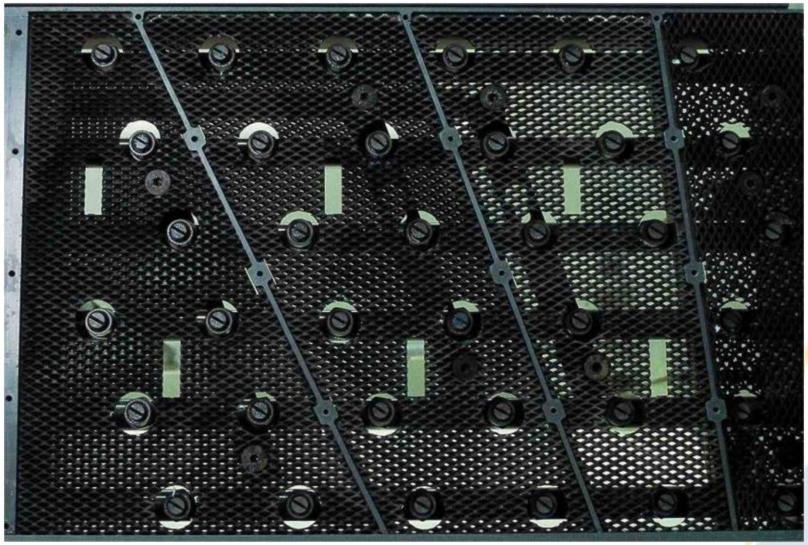


Horizontal Copper Plating Module

- Top view shows clamp transport system
- Foil guides
- Electrolyte spray system

Segmented Insoluble Anodes

- Anode with 4 segments
- Each segment with individual rectifier control

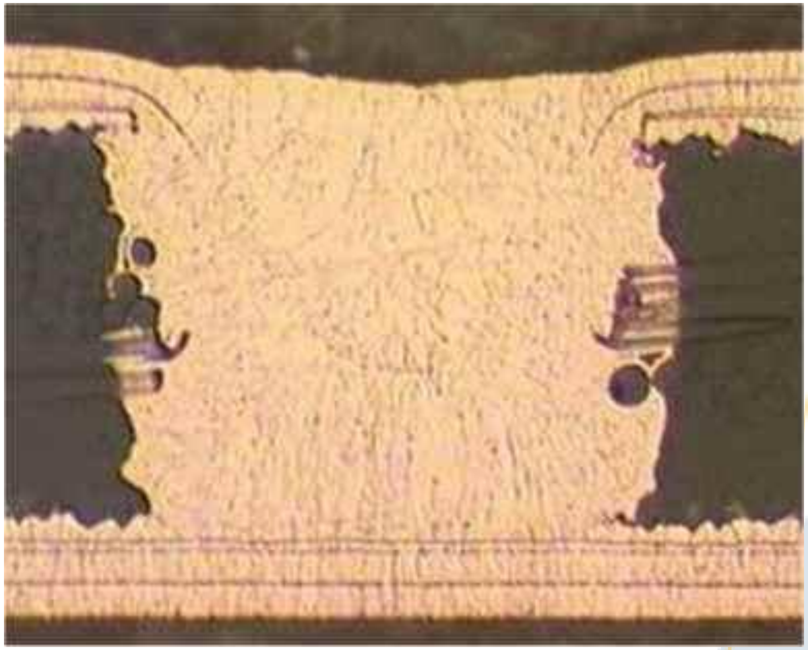


Automatic Level Control

- Pneumatic valve system to allow automatic level control
- Electrolyte flow return to equipment sump regulated

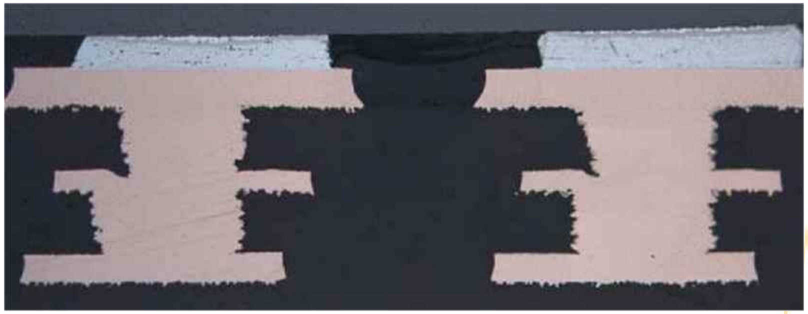
BMV Filling with Minimum Surface Copper

- BMV diameter 140µm
- Depth 115µm
- Surface plated copper 16µm
- Dimple < 10µm



Hand Held Device Production

- Filled stacked BMV
- Processed in horizontal desmear, electroless copper and electrolytic copper BMV filling



Through Hole Filling Process

- **Conventional Process**

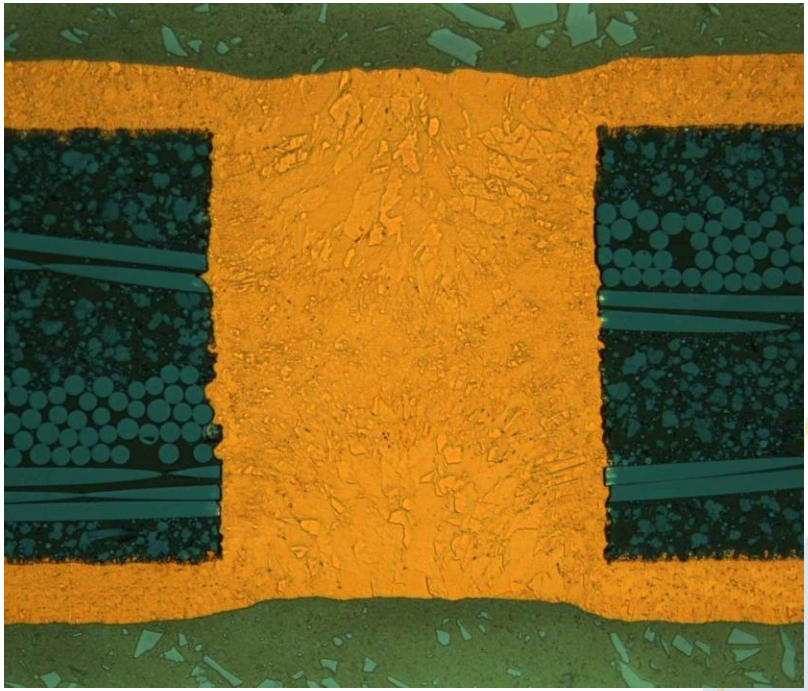
1. Through hole drill
2. PTH
3. Panel plate 25 µm
4. Resin plug
5. Cure
6. Brush
7. PTH
8. Panel plate 25 µm
9. Dry film

- **Horizontal Cu Filling**

1. Through hole drill
2. PTH
3. Panel plate 3 µm
4. Through hole fill 12µm – 20µm
5. Dry film

Through Hole Filling

- Panel thickness 120µm
- Hole diameter 100µm
- Copper foil 3µm
- Surface plated copper 13µm
- Dimple < 10µm



IC Substrate Production

- Customer qualification
- Core through hole filled
- Subsequent BMV filling

Copper Filled Through Holes

- Panel thickness 0.4 mm
- Hole diameter 100 µm
- Production development for copper through hole filling process

Copper Through Hole Filling

- Reliable plugging / filling technology
- Improved dimensional stability of substrate
- Higher thermal conductivity
- Improvement of CTE matching
- In line production process
- Increased yields
- Reduced processing costs

Via Filling Summary

- Increasing miniaturisation in HDI also requires copper filling of BMV to ensure reliability
- Integrated horizontal processing of metallisation and copper plating simplifies production
- Increase in yields and reduction of costs

Thank you for your attention.
Any questions?

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