# Fine line through hole copper filling in VCP for next generation packaging

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**ABSTRACT**

This paper presents the complete through hole filling for cores using a Cu electroplating process for IC Package production, especially for FC-BGA and FC-CSP. There are two main objectives for this application: technological aspects and productivity. The only state-of-the-art through hole filling in panel plating providing inclusion-free performance is available for horizontal conveyorised systems with pulse plating since 2005[1] and already used in full mass production. When it comes to pattern through hole filling the process presented hereafter has been designed for vertical continuous plating (VCP) equipment. In order to meet the technological requirements for next generation packaging, parameters such as pattern plating with excellent within-unit distribution and inclusion-less filling performance are of utmost importance. From a productivity standpoint high current densities and reduced plated thickness are the preferred two ways to follow. This paper focusses on technological aspects and on difficulties to fill through holes of various dimensions and sizes that exist in the market. The fluctuating drilling tolerances/ qualities (protruding glass fibres, laser drilling asymmetry) give indications how to minimise the inclusion rate. In detail the influence of electrolyte agitation, current density, inorganic and organic concentrations on the filling performance are described and discussed. The result of our investigations is a process with improved TH filling capability at low void occurrence and excellent within-unit distribution. The new process has shown improved capability to fill though holes in cores of up to 200 µm, while further investigation continues.

Key words: Through hole filling, VCP, horizontal systems, IC packaging.

**INTRODUCTION**

A wide range of via filling processes are currently being offered based on conventional electrolytic copper technology. This consists of a system in DC mode and using soluble or insoluble anodes and organic additives. The function of the additives is to give a stable operating electrolyte which will fill the vias with minimum of copper uniform plated onto the surface. Insoluble anodes offer many advantages such as less maintenance, higher applicable current densities and uniform constant surface distribution. Parallel to development work in vertical via filling, the use of horizontal equipment using pulse plating and insoluble anodes with iron redox copper replenishment offers additional benefits in contrast to conventional vertical systems. It has been seen that the electrolytes used in insoluble systems do not show the typical lifetime restriction as in soluble anode systems. And the in general higher copper concentration in horizontal systems with iron redox copper replenishment improves the mass transport of copper into the vias. Sophisticated fluid devices and frequency controlled pumps support the electrolyte exchange especially in blind micro vias. The use of special pulse plating parameters in horizontal applications allowed increased throwing power in through holes. These parameters can be modified to enhance the plating in the centre of through holes with the effect to allow through hole filling inclusion free. This patented two-step process starts with a very strong reverse pulse plating parameter set which leads to formation of bumps in the middle of the through holes until they finally merge together. The resulting two blind micro vias are then preferably filled with minimum plated copper on the surface. This excessive bump plating is not possible with DC mode and the way to achieve inclusion-free though hole filling. This process is now the industry standard for inclusion-free through hole filling in panel mode and used in mass production at customer worldwide.

**THROUGH HOLE FILLING**

**Dimensions of through holes**

Various dimension of through holes exist in the market for FC-CSP, SiP and FC-BGA design. The most common thicknesses of the plated boards varies from 60 µm up to 200 µm and the through holes are either mechanical drilled or laser drilled, resulting in different hole shapes with different requirements for the filling process. The market is very versatile and all specifications are changing frequently.

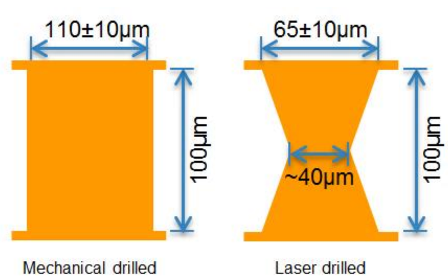


**Figure 1:** Dimensions of typical filled through holes of 100 µm thickness

A major challenge for the filling is the quality of the drilling, especially for the laser drilling as mechanical drilled boards show lower tendency for drilling defects. For laser drilling of through holes usually a laser beam is applied from both sides of the substrate leading to an X-shape of the through hole. The formation of an X-shape allows through hole filling in DC mode with reduced inclusion rate, as the bump in the middle of the hole right from the beginning of plating supports the closure of the hole in the middle even in DC mode. Nevertheless critical parameters for the laser drilling of through holes are:

- Positioning of the laser,
- Energy of the laser.

If there is an offset in the position of the lasers asymmetric drilling may occur. Too weak laser energy will result in glass fibre protrusions and too strong laser energy will cause a kind of belly in the centre of the trough hole. All this may lead to larger inclusions in the copper filling step.

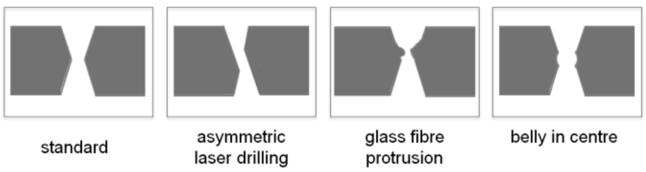


**Figure 2.** Different shapes of laser drilled through holes

**State-of-the-art inclusion free through hole filling process for panel plating mode**

| Parameter | Bridge plating | Via fill |
|---|---|---|
| Pulse Parameter | Strong reverse | Strong reverse |
| Overall current density | 3-4 ASD | 3-4 ASD |
| Temperature | 40°C | 35-40°C |
| $Cu^{2+}$ | Low 20-30 g/l | High > 40 g/l |
| $Fe^{3+}$ | Very low 0.5g/l | > 1.5 g/l |
| Electrolyte agitation | Strong | Low |
| Time | Approx 15 min | 40-60 min |

**Table 1:** Example of process parameters for “bridge plating” and remaining via fill

A well accepted and competitive technology to fill laser through hole inclusion free in panel mode is available for horizontal conveyorised systems with pulse plating and iron redox system[2]. Use of adapted pulse parameters and electrolyte settings (see table 1) gives not only a clear technical advantage as inclusion-free through hole filling for cores with thickness up to 300 µm but as well a significant advantage in terms of productivity. The process consists of 2 steps: The first one merges both centre of the through hole walls in order to form a so-called bridge in its centre (figure 3). In a second step the two remaining blind micro vias will be filled at lower copper thickness and high speed to give a result as shown on figure 4.

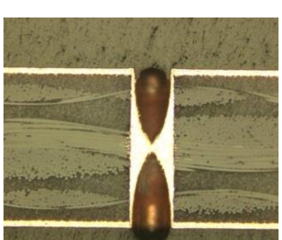

**Figure 3:** Example of X-plating in the centre of the through hole

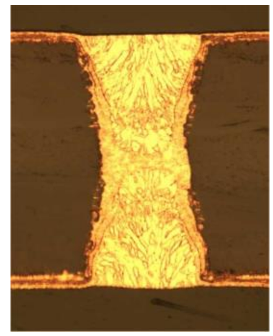

**Figure 4:** Example of filled 200µm through holes with reduced copper thickness in panel plating mode.

**Fine line requirements**

The ever evolving trend in circuit miniaturization calls for finer lines and spaces. Together with the requirement of inclusion-free filling with minimum dimple to allow stacked filled structures and a minimum of surface plated copper this demands new solutions. The accessible fine line resolution is, by rule of thumb, about twice that of the overall copper thickness. For line and space requirements of SAP and amSAP this means a reduction in plated thickness is necessary together with usage of pattern plating. With the move from panel to pattern plating the requirement of plating uniformity becomes critical. Especially the within-unit distribution (WUD) is of highest importance for the development of organic additives, as the organic additives have a big influence on the WUD. In contrast to that the panel uniformity can mainly be influenced by equipment parameters, for example usage of insoluble anodes improves the distribution as well as the fluid dynamics in the plating system.

**Figure 5:** Pattern plating for fine line application: the challenge of within unit distribution and inclusion free filling

**DEVELOPMENT OF A NEW FILLING PROCESS**

When it comes to amSAP or SAP application (pattern plating application) the main objectives of the development are to maximize via filling ability in through holes while minimizing thickness variation across the substrate surface. Filling ability, expressed in term of recess (“dimple”), shape and dimension of possible void formation within the filled hole and metal distribution on the pattern art work (within-unit distribution) are quantifiable measures used to describe the effectiveness of the process. Those points will be discussed hereafter.

**Through hole dimension**

Filling of double sided laser ablated through holes has been mainly investigated on amSAP test vehicles on following through hole dimension:

- 0.15mm thick core through hole diameters ranging from 70 to 80 µm at the entrance.
- 0.2mm thick core with though hole diameter ranging from 70 to 80µm at the entrance.

This range of through holes mostly covers the typical bulk of geometries currently utilized on IC Substrate production basis.

**Through hole filling**

It is apparent that for the achievement of a proper filling process the plating rate within the blind micro via should be higher than on the surface and as such the copper electrolyte characteristics are of fundamental importance in creating such differential plating rates. For this purpose the development of present process focused on the use of proprietary organic additives in a sulphate acid copper system, which typically consists of cupric ions (copper sulphate is the first ion source in the solution), sulfuric acid and chloride. The balanced interaction between the additives gives rise to remarkable deposit characteristic, such as grain refinement, levelling and brightening, and plays a key role in the mechanism of accelerated filling process in direct current plating.

A large number of parameters including chemical parameters (organics / inorganics concentrations) and physical parameters (current density, flow, temperature) will have a certain degree of influence on the filling performance.

- Cu concentration
- *$Cl^-$ concentration*
- *Sulfuric acid concentration*
- Brightener (accelerator) concentration
- Leveller (suppressor) concentration
- *Correction (inhibitor) concentration*
- Current density
- Temperature
- Electrolyte flow

After identifying key parameters responsible of best performance in small laboratory equipment (see presented in italic above) we started a series of experiments to confirm the observation on full panel level scale.

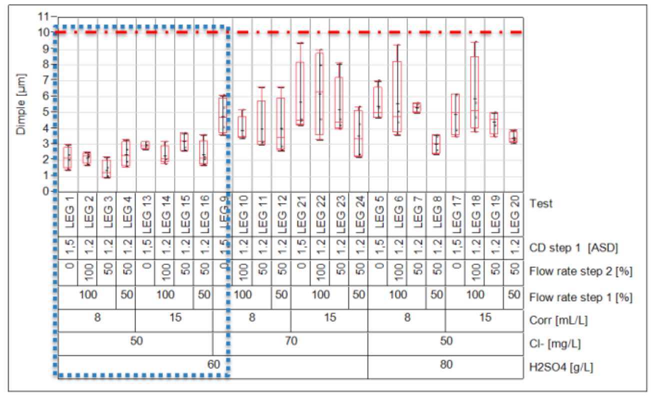


**Figure 6:** Example of filling performance on individual unit. Behaviour of one organic additive operated in a wide working range versus different acid and chloride concentration and physical parameters

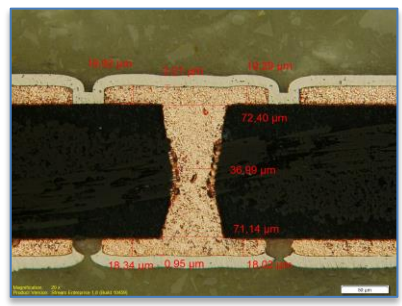

**Figure 7:** Example of filled 0.15mm thick through hole

The applicability of a wide additive working range in an electrolyte containing different acid and chloride concentrations at different physical parameters, as current density and solution agitation, has also been studied; the relationship of each these and the principal effects are presented in figure 6, from the evaluation optimum process parameters can be derived.

In general, it can be seen that lower sulfuric acid and/or lower chloride concentrations promote more effective filling performance both in the 150 and 200 µm deep through hole, whereas a loss of fill capability is manifest at higher acid and chloride concentration. In lower acid and chloride concentration range the inherent variation of laser drilling quality (asymmetric drilling, extent of protruding glass fibre, overhang) can be overcome, as discernible by comparing the data spread between lower and higher acid and chloride concentration. In contrast physical parameters like electrolyte flow and current density do not significantly influence the filling performance

**Inclusion occurrence**

Along achieving a good filling performance inclusion-free filling is usually desired. Similar to the pulse induced bridge as presented above the optimized approach would be in this case to enable organic induced bridge plating in the centre of the through hole. As for the filling process the key parameters influencing inclusion are listed below.

- Cu concentration
- $Cl^-$ concentration
- Sulfuric acid concentration
- Brightener (accelerator) concentration
- Leveller (suppressor) concentration
- *Correction (inhibitor) concentration*
- *Current density*
- Temperature
- *Electrolyte flow*

Solution agitation (flow directed towards the panel) and step-process (variation of flow rate, current density and plated copper thickness in two steps) do show significant and beneficial effect in reducing amount and size of void in the 0.15mm thick core material (figure 8).

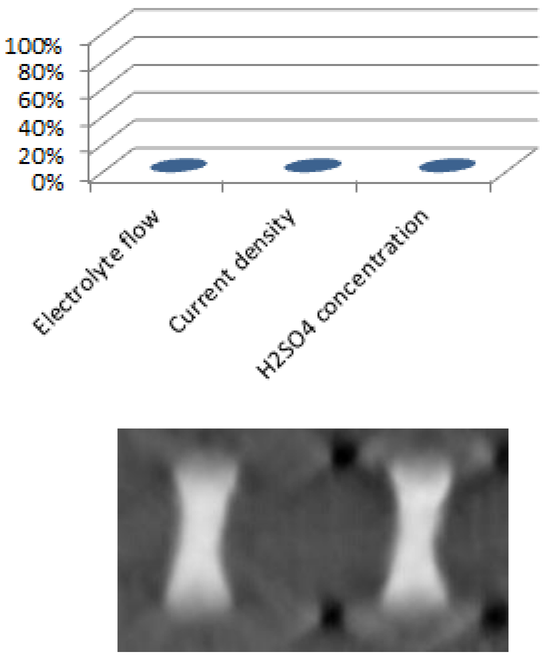


**Figure 8:** Example of inclusion occurrence for 0.15mm thick core and corresponding X-ray detection

In contrast the 0.2mm thick core material mostly present inclusion occurrence (figure 9). Even though the size and amount of inclusion can be reduced with optimized physical and chemical plating parameters it becomes obvious that the shape and the drilling quality of those 0.2mm thick core will have a significant impact on the inclusion occurrence. As mentioned previously if an offset in the position of the lasers asymmetric drilling may occur. Too weak laser energy will result in glass fibre protrusions and too strong laser energy will cause a kind of belly in the centre of the trough hole. All this may lead to larger inclusions in the copper filling step.

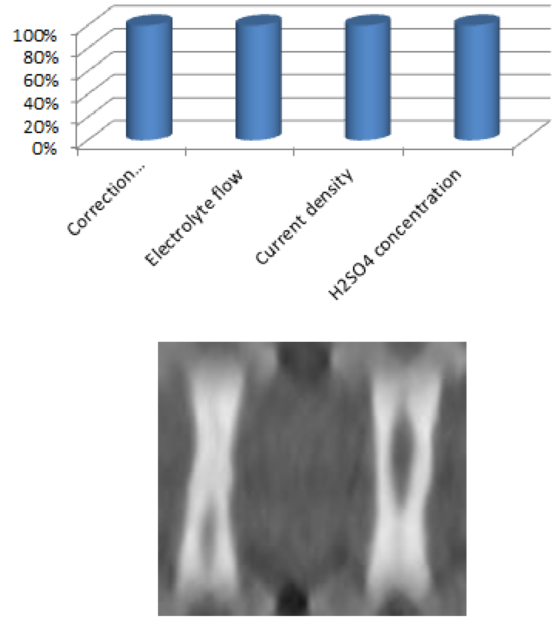


**Figure 9:** Example of inclusion occurrence for 0.2mm thick core and corresponding X-ray detection

**Within-unit distribution**

The metal distribution on the specific pattern layout is within the defined working window not affected. This is illustrated in figure 10: The range on unit is defined as difference between maximum and minimum copper thickness in predefined locations on each individual units, and has be found to be almost lower than 3 µm across all test conditions.

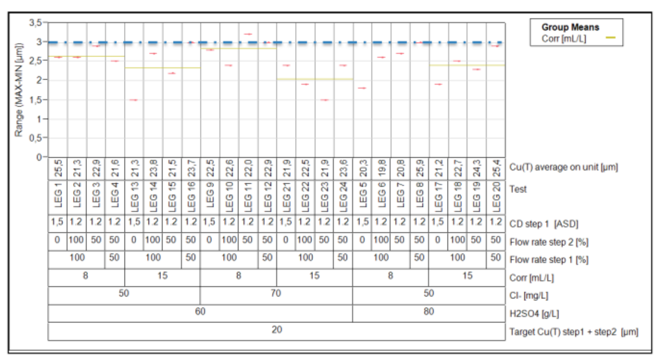


**Figure 10:** Example of metal distribution on individual unit. Behaviour of one organic additive operated in a wide working range versus different acid and chloride concentration and physical parameters.

**INCLUSION-FREE THROUGH HOLE FILLING IN DC MODE**

As previously shown, inclusion free though hole filling can be achieved using adapted plating parameters and conditions; however principally the size, shape and drilling quality of the laser ablated though hole will dramatically impact the plating performance in terms of inclusion occurrence. In order to close the gap for inclusion free though hole filling principally induced by organics in direct current (DC) mode we have performed extensive studies on small volume laboratory equipment. The though hole used were even more challenging than previously in terms of dimension nevertheless they are of high relevance and importance for core application:

- 0.2 mm thick core with through-hole dimension ranging from 90 to 110 µm at the entrance

Among many challenges offered by this through-hole type the higher volume to fill, the presence of two glass fibers, the higher wall to wall distance in the through hole center combined with the absence of X-shape (figure 11) and the non-negligible interaction between type of electroless seed layer and subsequent electrolytic plating process are the principal ones.

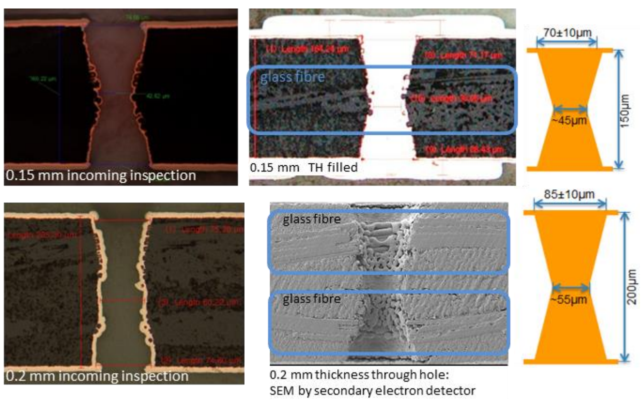


**Figure 11:** 0.15 mm thick through-hole with one centred glass fibre showing beneficial X-shape in the centre. 0.2 mm thickness through-hole with two glass fibres.

Besides standard chemical parameters (inorganics / organics type and concentration) as well as physical parameters (current density, electrolyte agitation, temperature) more disruptive approaches with respect to traditional printed circuit board production have been studied and their impact on inclusion occurrence are listed in table 2.

| **Parameter** | **Impact** |
|---|---|
| Inorganic concentrations in plating bath | Low |
| Organic type and concentrations in plating bath | High |
| Current density | High |
| Electrolyte agitation | Medium |
| Temperature | Low |
| Type of seed layer | High |
| Pre-treatment type | High |
| Conditioning of plating sample | Low |

**Table 2:** Impact of different process step (from pre-treatment to plating conditions) on inclusion occurrence

Using the best conditions as suitable organic type, low current density, optimized electrolyte agitation and pre-treatment type leads to outstanding inclusion-free through-hole filling. We could achieve a complete filling of those 0.2 mm thick through-holes at ~5 µm copper thickness on the surface under DC mode in 100 minutes plating time as shown in figure 12.

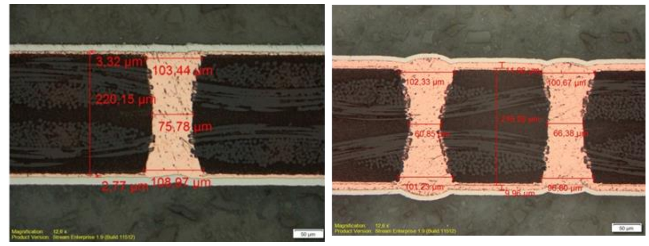


**Figure 12:** Example of optimized inclusion-free through-hole filling obtained at reduced copper thickness ~3-11 µm

This technology is still at an early stage and those results have been obtained on small scale equipment in which the plating conditions are optimised. Further work is still required to enhance the robustness of the process as well as to implement it to universal and production relevant equipment. Nonetheless those more than promising results open the door to new perspectives with respect to outstanding through-hole filling performance induced by organics under DC mode.

**CONCLUSION/ SUMMARY**

Filling through holes is a well-accepted technology by the industry. While an inclusion-free process for panel plating is in mass production for many years, the demand for fine line pattern plating requires new solutions. The variation of existing dimensions and drilling quality of through holes makes this development even more complicated. Too high power drilling, misalignment of top/down drilling and glass fibre protrusions are the main drilling factors to make the filling more difficult. The introduced through hole filling process using pattern plating technology in conveyorised systems showed its capability to fill common through hole quality for SAP and amSAP production with diameter 75 µm to 100 µm and with substrate thickness 150 µm and up to 200 µm. Intensive investigations were carried out to find best inorganic and additive and physical parameters for reliable filling. By that parameters were found to achieve very positive results in terms of reliable filling capability, reduced amount and size of voids and consistent and low within-unit distribution. The process meets the current production specifications, however further optimisation is ongoing. Our latest development shows very promising results regarding vertical DC filling of 0.2 mm through holes. Inclusion-free through hole filling could be achieved at very low plated thickness. However these are only first results in small scale equipment and more investigation work is needed until this process will be applicable for use in full scale production.

## ACKNOWLEDGEMENT

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