Electroplating Through Holes with Different Geometry -- A Novel and High Productivity Process for Through Hole Fill Plating

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INTRODUCTION

MICROFILL^{TM} THF Electrolytic Copper is a new process designed to offer outstanding through-hole fill (THF) particularly for substrates intended for use as core layers in build–up applications, producing planar, solid copper plugs in high volume production plating equipment. This technology is intended to replace resin or paste plugging, and offers many advantages, including improved reliability, higher electrical and thermal conductivity, increased productivity and reduced process costs.

This paper describes a novel copper through hole fill electroplating process designed for use with insoluble anodes and direct current (DC) rectification. The copper through hole fill chemistry is formulated to operate over a broad range of operating conditions, and offers end-users outstanding production flexibility in either panel or pattern plate operating mode.

The paper addresses electrolytic copper through hole filling performance for a variety of substrate thicknesses and hole diameters. The impact of hole formation method and hole quality on filling ratio and void formation will be discussed. In this work, production scale tests were performed on 100µm and 200µm thick substrates. The impacts of varying current density and solution flow on hole filling were examined. With optimized deposition conditions, including on-line additive analysis, void-free, highly planar through hole filling and excellent bottom-up blind micro via filling with low surface copper deposition thickness were demonstrated.

Portable consumer electronics has become the primary driver for the ever increasing circuit density of today's printed circuit designs. Based on the small dimensions of these devices, through hole and blind via diameters are typically in the 75µm to150µm range. Performance improvement and process cost reduction make through hole filling technology with copper an excellent approach, rather than the conventional plated through hole.

Prior to the development of electrolytic copper through hole filling, substrates for such applications were electroplated with a conventional through hole process, then plugged with an epoxy material. Following these steps, additional planarization, re-metallization and electrolytic copper capping processes were required before the build-up process steps could begin.

Used of electrolytic copper through hole filling eliminates several of these manufacturing steps and offers a number of additional advantages over the conventional build-up process by enhancing the thermal and electrical conductivity of the interconnections, and by reducing overall costs.

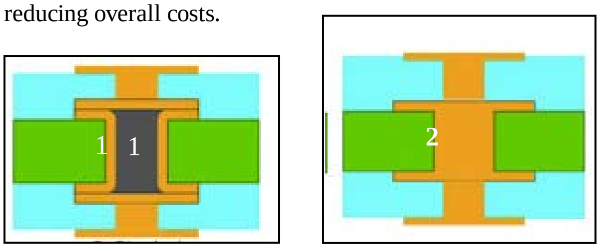


Figure 1: Through hole plug: Conventional (1) vs. New (2).

INORGANIC COMPONENTS

The vast majority of through hole fill electroplating baths are based on acid sulfate electrolytes, containing copper sulfate (the primary source of cupric ions), sulfuric acid (for solution conductivity) and chloride ion (as a co-suppressor). Of these components, sulfuric acid, typically at concentrations below 60 g/L, has the most significant effect on achieving good through hole filling. A plating solution with elevated acid concentration leads to conformal plating causing poor filling performance.

ORGANIC COMPONENTS

Acid copper sulfate system operated without additives typically yield deposits of poor physical properties. Organic additives, typically consisting of materials described as Suppressors, Brighteners, and Levelers, are therefore used to further refine deposit characteristics. Via fill plating systems such as the MICROFILL^{TM} EVF bath were not designed for through hole filling applications. The organic components and their respective concentrations used to achieve bottom-up filling in blind micro vias are less effective for initiating fill in the very different geometry of a through hole. Therefore, a novel organic package was developed specifically to favor the fill mode essential to completely plug the through hole with copper. While an accelerated bottom-up fill mechanism is the critical aspect of blind micro via filling, through hole filling requires initial creation of a "butterfly" structure, formed by rapid copper deposition at the center of the holes. This change in geometry is the critical first step in achieving good copper through hole filling.

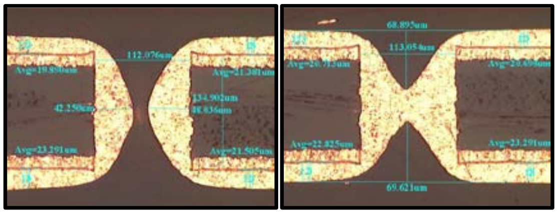


Figure 3: Butterfly structure leading to subsequent via formation

In theory, once the transition from cylindrical through hole to double blind via has taken place, a micro via fill system such as the MICROFILL™ EVF bath could be used to complete the filling. Although it is possible to use two different chemistries to achieve through hole fill, most printed wiring board manufacturers have chosen to adopt a single chemistry / one step approach to through hole fill, regardless of the hole shape. However, manufacturers may be forced to modify their approach as new challenges in hole size, planarity and void requirements emerge.

In order to appreciate all the aspects of the “single chemistry does it all” challenge, it is useful to discuss the effects of different through hole geometries on through holes fill.

THROUGH HOLE SHAPE

Currently blind vias, buried vias and though holes are used in the fabrication of high density interconnect designs. Mechanical drilling has been the conventional way to form holes and this process is still the basis for most printed circuit board manufacturing.

In addition, through holes can be formed using either one sided (OSLTH) or double sided laser drilling (DSLTH). The shape of such holes is not perfectly cylindrical, as shown in Figure 5 below. The tapered hole wall profiles make such holes somewhat easier to fill with copper than the more cylindrical mechanically drilled holes. As a result of this difference, mechanically drilled holes may show a highest tendency for seam void formation than double sided laser drilled through holes.

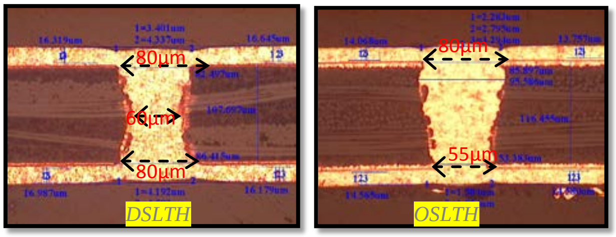


Figure 5: Double sided and one sided laser drilled holes

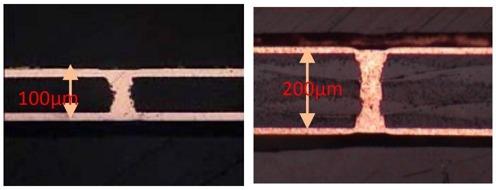


Figure 6: Double sided laser drilled through hole in 100µm and 200µm thick panels respectively

One sided laser drilled holes (OSLTH) can be prone to voiding due to the drilling process, which may cause excessive differences in hole diameter between the top and bottom of the panel.

Although panel thickness also has a major impact on the ability to achieve good fill without voiding, overall DSLTH are easier to fill and less prone to void formation.

CHEMISTRY DEVELOPMENT

To develop a new DC - based plating bath that can achieve good hole filling performance with minimal voiding, development efforts were directed towards the interaction of brightener and leveler additives. Levelers are preferentially adsorbed at areas of higher curvature such as the entrance of the hole, where mass transfer is enhanced, and thus filling behavior is strongly influenced by convection.

The competitive adsorption between brighteners and levelers result in a concentration gradient along the hole wall, with the leveler-rich corner effectively inhibited relative to the brightener rich center, resulting in the non-uniform plating rate required for through hole filling. Even with the use of a strong leveler, the leveler concentration has a huge impact on hole filling capabilities and on the deposit appearance and surface morphology (roughness and resistance to formation of nodules).

For instance, a low leveler concentration will lead to a lack of inhibition at the entrance of the holes, with the result being excessive plating rate at the knees, leading to formation of seam voids. An excessive leveler concentration will negate the ability to selectively inhibit only those areas with high curvature, resulting in a conformal deposit and increased risk of nodule formation. Electrochemical studies confirm that the adsorption of leveler on the hole openings and outer parts of the through hole walls are mass transfer dependent. Furthermore, both electrochemical and plating studies indicate that the inhibiting strengths of levelers are also dependant on the leveler concentrations as shown in Table 1 below.

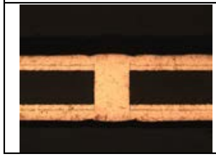
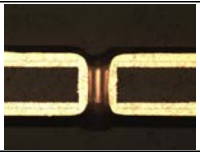
2.5 ml/L Leveler Optimized Concentration	7.5 ml/L Leveler Excessive Concentration
	

Table 1: Filling performance as a function of additive concentration

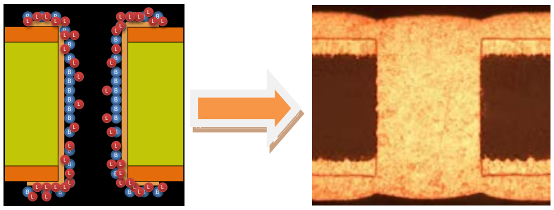


Figure 6: Optimized THF copper chemistry

After extensive research and development efforts, a well balanced additive package was developed to achieve the desired through hole filling performance.

This process was developed to work with solution jet impingement and insoluble anodes in both vertical batch mode and vertical in line and horizontal conveyorized plating equipment. A wide variety of equipment design features that further enhance though hole fill plating performance may be incorporated. These include the use of engineered fluid delivery devices such as eductors or nozzles designed to create optimized flow impingement on panel surfaces.

THROUGH HOLE FILL PERFORMANCE

Through hole fill plating performance, like blind micro via filling, may be characterized by the calculation of the dimple depth or bump height.

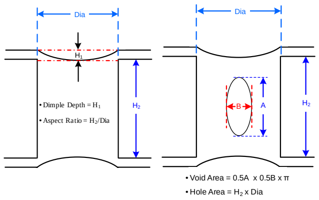


Figure 8: Dimple and void measurements

Dimple depth is the most commonly used metric to quantify both through hole and via plating performance. Depending on customer and application, void area (shown in Figure 8) may also need to be determined. Customer specifications for void area are typically expressed as % void, that is, Void Area / Hole Area.

IMPACT OF SUBSTRATE CONDITION AND PRETREATMENT

The thickness, coverage and surface condition of the electroless copper metallization layer applied to the panel prior to the through hole filling process has a profound impact on through hole filling and plating capability. Discontinuous or overly thin electroless copper deposits will not electroplate as reliably as thicker, more uniform deposits. Oxidation of electroless copper can also adversely affect filling performance. Internal data has shown that, in particular, aged electroless copper has an unfavorable impact on process consistency. Proper control of pretreatment processes also plays an important role in achieving good hole filling. A typical process sequence uses acid cleaner and acid dip steps to ensure that copper surfaces are completely wetted and free of contamination prior to the subsequent copper plating step.

Parameters	*(100µmx100µm)*
CD: 2 ASD **Cu: 25µm** **Electroless Thickness : 45 µinches**	
CD: 2 ASD **Cu: 25µm** **Electroless Thickness : 20 µinches**	

Parameters	*(100µmx100µm)*
CD: 2.5 ASD **Cu: 25µm** **Poor Coverage**	
CD: 2.5 ASD **Cu: 25µm** **Good Coverage**	

Figure 9: Plating performance as a function of electroless type and quality

IMPACT OF PROCESS AGITATION AND CURRENT DENSITY ON HOLE FILLING

Fluid delivery and flow agitation have a significant impact on hole filling performance, particularly in the presence of leveler components. To understand the effect of agitation on hole filling, solution flow rate was varied in a series of plating experiments performed in vertical continuous pilot plant plating equipment at Applied Equipment Limited (AEL) and NanYa (Taiwan).

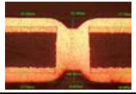
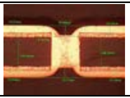
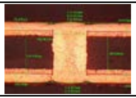
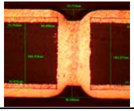
	High Flow	Medium Flow	Low Flow
100µm x100µm			
100µm x 200µm			

Table 2: Plating performance as a function of flow conditions

The effects of both these parameters on filling performance were significant, with the results showing that the impact of solution flow rate is the strongest. While lower levels of solution flow rates were found to improve hole filling performance; depending on application, this improvement sometimes came at the price of seam void formation. A flow ramp scheme, accompanied by good wetting during pre-cleaning, reduced void formation while maintaining good hole filling performance. It is imperative that agitation parameters be carefully chosen to match plating cell design and application. It is also important to note the positive value of current density ramp accompanied by flow ramp on reducing void formation. A similar test was then conducted in which current density (CD) was varied.

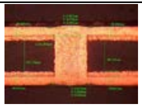
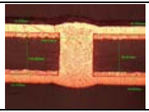
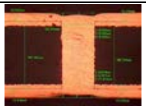
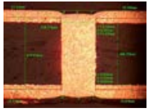
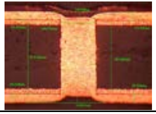
	CD= 1.5ASD	CD = 2ASD	CD = 2.5ASD
100µm x100µm			
100µm x200µm			

Table 3: Plating performance as a function of CD

The intention of this test was to demonstrate the broad capability of the process that has been developed. Table 3 shows the effect of current density on through hole filling performance. Consistent filling was achieved across a wide range of current density.

PROCESS PERFORMANCE

Applications using the finalized MICROFILL™ THF bath require excellent through hole filling performance combined with good surface appearance. These targets must be achieved and maintained as the bath is cycled. To evaluate aged bath performance, test panels were processed in a vertical batch pilot scale plating cell at bath ages from 0 to more than 100A.h/L. Consistent dimple depth of less than 10 µm was maintained with board thickness of 100µm and 200µm.

This process may be used in either panel or pattern plate processes. Table 4 demonstrates the capability of the process to fill through holes when used in a pattern plate mode.

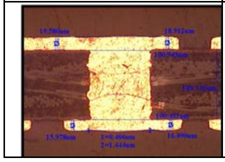
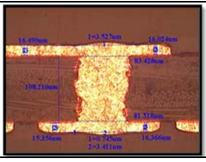
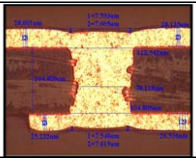
100µm x 100µm Mechanical Drilled Through Hole	**80µm x 100µm DSLTH**	**100µm x 100µm DSLTH**
		

Table 4: Pattern plate through hole fill.

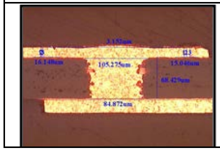
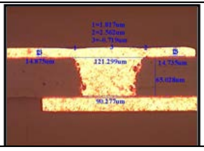
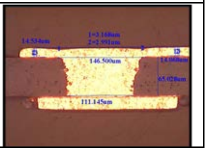
80µm x 65µm 1.5ASD / 15.0 µm	**100µm x 65µm 1.5ASD / 18.0 µm**	**125µm x 65µm 1.5ASD / 15.0 µm**
		

Table 5: BMV performance of MICROFILL™ THF bath

Table 5 also demonstrates that the bath can also be utilized for the metallization of Blind Micro Via (BMV) with surface copper thickness of less than 15 µm. Bump formation on top of the blind micro vias can be minimized by modifying such plating parameters as solution agitation and current density. Based on these results, this system may be utilized for BMV plating for Every Layer Interconnect (ELIC) HDI and IC substrate applications.

PROCESS RELIABILITY AND PHYSICAL PROPERTIES

To establish through hole fill reliability, cross sections were prepared after solder floating 6 times at 288°C per IPC procedure. The holes were then inspected. No cracks in the copper deposit or other defects were detected.

CD (ASD) / Panel Thickness	**Defects/ Total Holes Inspected**	**Cross Section**
2.5 / 100µm	**0 / 220**	
2.5 / 200µm	**0 / 220**	

Table 6: Filled through hole interconnect reliability

The MICROFILL™ THF [1] bath provides consistent deposit physical properties from a bath cycled up to 100 A.hr/L. Tensile strengths above 35 kpsi, and elongations in the range of 20-30%, were measured for deposits plated over a range of bath ages.

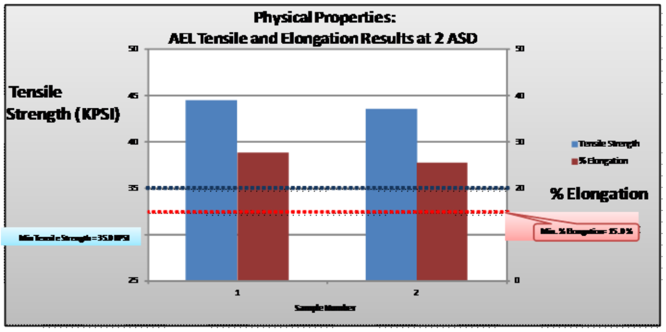


Figure 10: Deposit physical properties at 2 ASD.

SUMMARY

A novel DC through hole filling process was formulated for high volume HDI and substrate core layer metallization production. The process yields high quality results over a wide current density range.

The process has already been commercialized at a number of customers and it is anticipated that there will be substantial future growth in adoption of this technology to fill through holes. This "single chemistry does it all", in combination with optimized plating conditions and plating equipment is compatible with all though hole geometries. The plated copper has excellent physical and mechanical properties, with a bright and leveled surface. This formulation is intended to be used with either vertical or horizontal in-line jet impingement equipment in both panel and pattern modes. All organic additives can be monitored and controlled by conventional CVS analysis techniques.

Moreover, Dow Electronic Materials is currently working with ECI Technology and AEL to introduce the ECI's On-Line, Chemical Monitoring Systems. This will provide analysis capabilities for Front-End plating applications in high volume manufacturing fabs. This approach allows for drastically decreasing maintenance and waste generation, while increasing overall operational efficiency and reliability.

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