Next Generation Copper Electroplating for HDI Micro-Via Filling and Through Hole Plating

Nagarajan Jayaraju, Leon Barstad, Zukhra Niazimbetova, Maria Rzeznik, Marc Lin[+], Dennis Yee[§]

The Dow Chemical Company

455 Forest Street, Marlborough, MA 01752

[+] No. 6, Lane 280, Chung Shan North Road, Ta Yuan Industrial Zone, Ta Yung Hsiang, Taoyuan Hsien, Taiwan, R.O.C

[§]15 On Lok Mun Street, On Lok Tsuen, Fanling, Hong Kong SAR, China

njayaraju@dow.com

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INTRODUCTION

A next generation Electrolytic Copper product for filling blind micro vias can meet the demanding targets for High Density Interconnect (HDI) printed circuit board substrates intended for use as core layers in build–up applications. This product produces planar, solid copper fill in high volume production plating equipment. This technology offers many advantages including improved reliability, higher electrical and thermal conductivity, increased productivity, and reduced process costs.

This novel copper electroplating process was developed for use with insoluble anodes and direct current (DC) rectification to have excellent blind micro via fill and higher throwing power in through holes. The copper via 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.

Portable electronics have become the primary driver for the ever increasing circuit density of today's printed circuit designs. The required wiring density for products that continue to trend towards smaller, lighter and faster, includes a combination of filled blind microvias and build up technology. Based on the small dimensions of these devices, through hole and blind via diameters are typically on the order of 75 µm to150 µm.

This paper describes the performance of a new electrolytic copper process for micro via filling across several via dimensions. Currently blind vias, buried vias and though holes are used in the fabrication of high density interconnect designs. The HDI substrates used were 1mm thick with 0.15 mm and 0.25 mm wide through holes . The vias were 60 µm and 100 µm deep and the diameters varied from 75 to 150 µm. The impact of current density, solution flow and bath age on via filling were examined. Optimized deposition conditions with excellent bottom-up blind micro via filling with low surface copper thickness were demonstrated.

INORGANIC COMPONENTS

Via fill copper plating baths are composed of both inorganic and organic components. The inorganic components include copper sulfate (the primary source of cupric ions), sulfuric acid (for solution conductivity) and chloride ion (as a co-suppressor). The copper plating electrolyte typically contains sulfuric acid at concentrations between 60-100 g/L and copper sulfate at concentrations between 180-240 g/L. The chloride concentrations, very critical for the functioning of carrier and brighteners, are typically in the ppm range.

ORGANIC COMPONENTS

Electroplating acid copper sulfate systems[1-3] typically also contain of organic additives such as carriers, brighteners and levelers. These additives are used to achieve differential plating rates at the surface and inside the via enabling "bottom-up" void free fill as well as to further refine deposit characteristics. The carriers are large molecular weight polymers. The brighteners are smaller molecular weight sulfur containing molecules. Novel proprietary levelers are used. The organic components and their respective concentrations were optimized to achieve bottom-up filling in blind micro vias and achieve high through hole throwing power.

BOTTOM-UP FILL GROWTH

A DC copper electroplating process was developed to completely fill micro vias with copper and provide higher throwing power in through holes for HDI substrates. The via fill process was achieved through bottom-up plating within the vias by suppressing plating on the sidewalls while accelerating the plating at the bottom of the vias. Accelerated bottom-up growth prevents seam formation in vias and formation of voids.

The void free via filling process was achieved through a careful selection of concentrations of novel additives that are critical for controlled plating. A three component organic additive combination

was used for achieving void free fill. Carrier molecules, larger molecular weight polymers, are fast adsorbing but relatively slow diffusing. They form an inhibiting film on the copper surface slowing down the copper deposition kinetics. The accelerators, sulfur containing molecules, are slow adsorbing but fast diffusing inside the vias. Accelerators increase the copper deposition kinetics leading to higher plating rates inside the vias. The correct combination of carrier and brightener are critical for achieving bottom up fill. Levelers preferentially adsorbed at the entrance of the vias, preventing void and minimizing bump formation after the vias are filled.

The additive adsorption is convection dependent, with carrier and leveler adsorbing at high agitation regions such as the panel surface, while the brightener diffuses more at low agitation regions such as the via bottom. The competitive adsorption between brighteners and levelers in the via results in a concentration gradient along the via wall, with the leveler-rich corner effectively inhibiting relative to the brightener rich bottom, resulting in higher plating rates at the the bottom of the via compared to sidewalls.[4-7]

Figure 1 shows the via fill process for 60 and 100 µm deep vias as a function of surface copper thickness (0, 10, 16 and 21 µm) plated at 2.0 ASD. Plating was carried out in an R&D scale-up pilot line designed to simulate vertical in-line production. The plating initiated conformally during the initial stages of plating. This was followed by bottom-up fill with super-filling taking place during the later stages of plating leading to complete filling of the vias without voids.

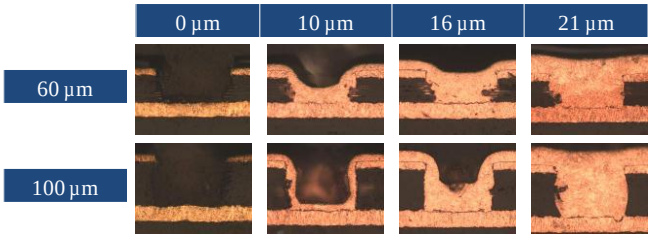


FIGURE 1. Plating performance as a function of surface copper thickness for 125 µm diameter vias

The concentration of additives also plays a critical role for via filling, particularly the leveler. A low leveler concentration will lead to a lack of inhibition at the entrance of the vias resulting in excessive plating rates at the knees leading to formation of seam voids. High leveler concentrations will result in a conformal deposit inside the vias.

After extensive research and development efforts, a well-balanced additive package was developed that achieved 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 via 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.

VIA FILL PERFORMANCE

Blind micro via filling performance can be characterized by the calculation of the %VF and dimple depth or bump height.

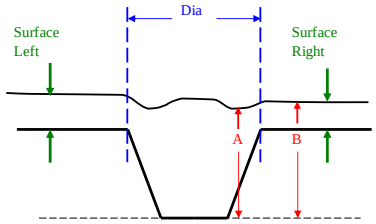


FIGURE 2. Dimple and void measurements

Dimple depth is the most commonly used metric to quantify both via fill (shown in Figure 2). Depending on the customer and application, void area may also need to be determined. Customer specifications for void area are typically expressed as % void, that is, Void Area / Hole Area.

EFFECT OF FLOW AND CURRENT DENSITY ON VIA FILLING

The via filling process can be affected by factors such as process chemistry, Cu metallization, mass transport and current density. Solution flow and current density play a significant role in the via filingl process. The effect of agitation on via filling was studied by plating at different flow rates (low, medium and high).

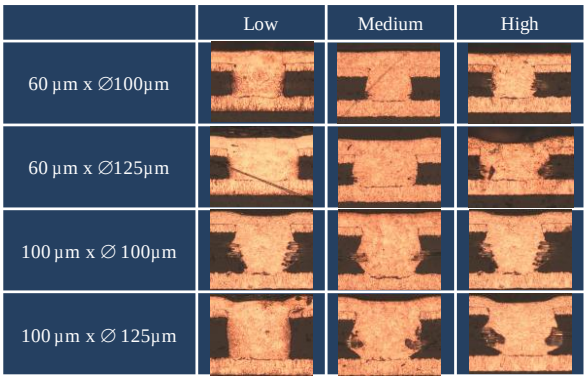


TABLE 1. Plating performance as a function of flow conditions at 21 µm surface copper thickness

Compared to current density, the solution flow has greater impact on via filling. Low to medium levels of solution flow rates were found to improve via filling performance although lower flow rate showed some seam void formation on the 75 µm diameter vias. Agitation parameters must be carefully chosen to match plating cell design and application. Higher flow rates resulted in larger dimples on the 100 µm and 125 µm diameter vias. Via filling performance as a function of flow is shown in Table 1. Medium flow rate was found to be optimal for achieving good via fill performance.

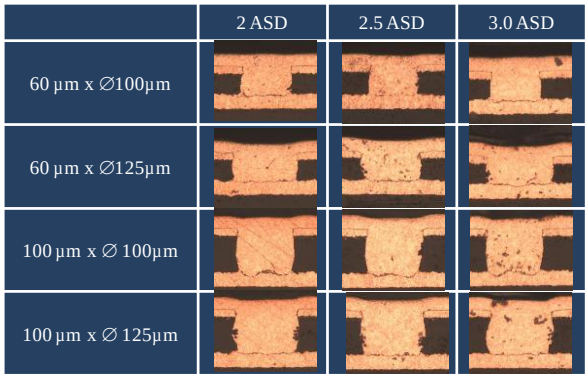


TABLE 2. Plating performance as a function of current density at 21 µm surface copper thickness

The effect of current density was studied at 2.0, 2.5 and 3.0 ASD. The resulting via filling performance as a function of current density is shown in Table 2. This next generation electrolytic copper plating process demonstrates consistent filling of micro-vias across a wide range of current densities.

Plating formulations optimized for via filling require high copper concentrations with low acid. Baths optimized for throwing power require low copper with high acid concentrations. Via filling baths that must also plate through holes are adjusted to achieve sufficient through hole throwing power while maintaining via filling performance.

PROCESS PERFORMANCE

This next generation Electrolytic Copper baths were formulated to achieve excellent via filling performance and high throwing power in through holes combined with mirror bright surface appearance free of nodules and flares. These targets were achieved and maintained throughout bath cycling from 0 to 100 Ah/L.

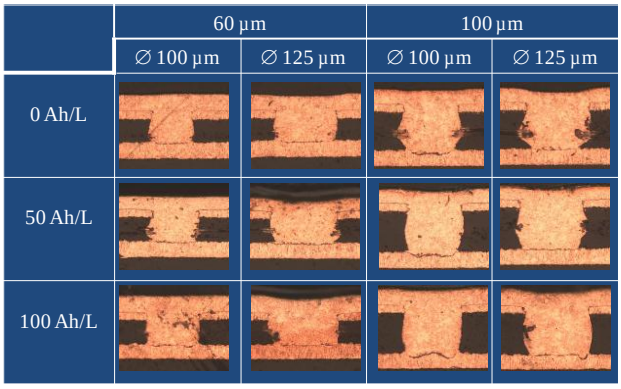


TABLE 3. BMV performance of next generation Electrolytic Copper plating bath at 21 µm surface copper thickness

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 100Ah/L. Consistent dimple depth of less than 10 µm was maintained for 100 µm x Ø 125 µm vias. Table 3 demonstrates the capability of the process to fill micro vias at 0, 50 and 100 Ah/L for 60 and 100 µm deep vias. Plating was carried out at 2.0 ASD.

Table 3 also demonstrates that the bath is stable at 100 Ah/L and consistent filling in the vias was achieved with an aged bath across a full range of microvia dimensions. Bump formation on top of the blind micro vias can be minimized by modifying plating parameters such as solution agitation and current density. This process may be used in either panel or pattern plate processes. Pretreatment processes ensure contamination-free Electroless copper surfaces to achieve consistent via filling.

THROUGH HOLE THROWING POWER

Filling blind micro via and maintaining high throwing power is very important for HDI applications. Throwing power (TP) is affected by solution conductivity, solution flow and hole geometry.

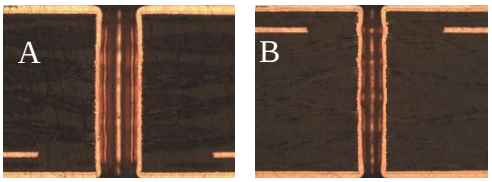


FIGURE 3. Through hole throwing power >80% for (A) 0.15mm and (B) 0.25mm diameter through holes.

Plating formulations were optimized to achieve a balance of via filling performance and high through hole throwing power. The throwing power data for the optimized plating formulation is shown in Figure 3. The hole throwing power for 0.15mm and 0.25mm diameter through holes are greater than 80%.

PROCESS RELIABILITY AND PHYSICAL PROPERTIES

Through hole and micro via interconnect reliability were evaluated by cross-section avalysis after solder floating 6 times at 288℃ as per IPC procedure.[8] No cracks or other defects were detected in the copper deposit (Table 4).

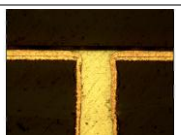
Current Density (ASD)	Panel TH ∅ (mm)	Cross Section
2.0	0.15	
2.0	0.25	

TABLE 4. Filled through hole interconnect reliability

The physical properties (Tensile Strength and Elongation) of this next generation Electrolytic Copper deposit were consistent when cycled up to 100 Ah/L. Tensile strengths above 40 kpsi, and elongation in the range of 20-30%, were measured for deposits plated over a range of bath ages and the results are shown in Figure 4.

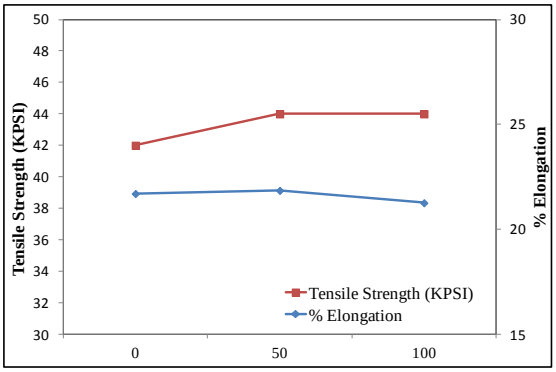


FIGURE 4. Deposit physical properties at 2 ASD.

SUMMARY

A novel DC blind micro via 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 will be commercialized and it is anticipated that there will be substantial future growth in adoption of this technology to fill blind micro vias. This new chemistry in combination with optimized plating conditions and plating equipment can fill blind micro vias of various geometries. The plated copper has excellent physical and mechanical properties with a mirror bright 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 easily monitored and controlled by conventional CVS analysis techniques.

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