# Integrated Metallization System for High Density Interconnects and Modified Semi Additive processing

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## Abstract

Printed circuit designers continually increase the technological complexity of their products. This includes more utilization of microvias and higher population densities via decreases in pitch. Many of these products will also require the application of thinner copper foils (< 17 microns) to resolve tighter lines and spaces. Building these more complex products often pushes the limits of capability in existing production processes and controls. Fabricators must investigate alternative methods to produce these highly functional devices while maintaining quality and low cost. This paper will detail a simple, highly automated metallization system that can enable the fabricator to consistently produce high quality, high density interconnect packages with high yields.

This integrated metallization system combines a horizontal desmear process, with a horizontal carbon technology, and a vertical continuous plating system. The production proven carbon system is well suited for modified semi additive processes (MSAP) when coupled with a newly developed copper etching technology. This innovative copper cleaning system completely removes carbon from the copper surfaces with a 0.2µm – 0.3µm etch rate, eliminating negative etch back and wedge voids due to excessive nail heading, while maintaining a highly conductive coating on the dielectric substrate.

In this paper, we will describe this integrated metallization system that produces HDI technology with the same or better performance as electroless copper while providing the added benefits of reduced costs, simpler process controls, and with a smaller equipment foot print than conventional horizontal electroless copper processes. Additionally, we compare this new copper cleaning process to the traditional sulfuric acid/persulfate microetch cleaning as it pertains to copper cleanliness, through hole integrity and microvia reliability. The low etch copper cleaning is adaptable to existing equipment sets with minimal or no modification.

## Introduction

Horizontal processing is well established in the PWB industry and the benefits are easy to quantify. Horizontal orientation enables improved solution exchange in the holes and blind vias through the application of ultrasonics for wetting and debris removal and the use of forced flood impingement systems. There are no rack effects common to batch type vertical processing and every panel sees the same conditions, improving consistency. While horizontal electroplating has advantages for transporting thin core substrates, the cost and the foot print required for a full panel plater, makes this option less appealing for high volume manufacture of standard thickness HDI. Vertical Continuous Platers (VCP) are capable of high volume through put in a limited amount of space, yield excellent micro/macrodistribution, possess the flexibility to run panel plating or pattern plate work, can be fitted with Direct Current (DC) or Period Pulse Reverse (PPR) rectification, and the equipment has a high degree of accessibility to the mechanicals (anode baskets, cathode bars, connections etc.). Integrating the benefits of horizontal primary metallization with the high productivity of vertical continuous plating, has produced a system that is a more cost effective for manufacturing HDI technology while maintaining high quality standards.

## Desmear

Laser and mechanical drilling operations can leave debris behind, either as lose material in the hole or as smear across interconnects. For best reliability, this debris/smear must be removed so subsequent metallization can adhere to the hole wall, capture pads of blind microvias and the copper interconnects. The standard process is to use an organic sweller that penetrates the resin and makes it more susceptible to subsequent attack by alkaline permanganate.

The proper temperature and time ratio between the sweller and the alkaline permanganate are crucial to ensure total removal of debris and drill smear and to produce a micro roughened resin surface for maximum adhesion.

Design of experiment methodology is used to optimize the desmear parameters. Contour graphs (figure 1) illustrate the effects in weight loss of different dwell times in the sweller and permanganate.

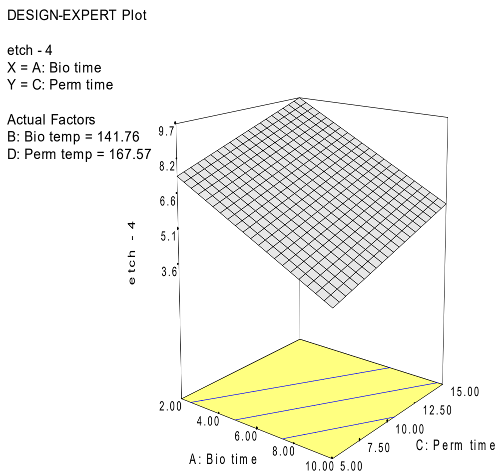


Figure 1

Once the weight loss cycle has been identified, slight variations of the cycle are used to process drilled samples and the hole walls are evaluated for micro roughening. (Figure 2)

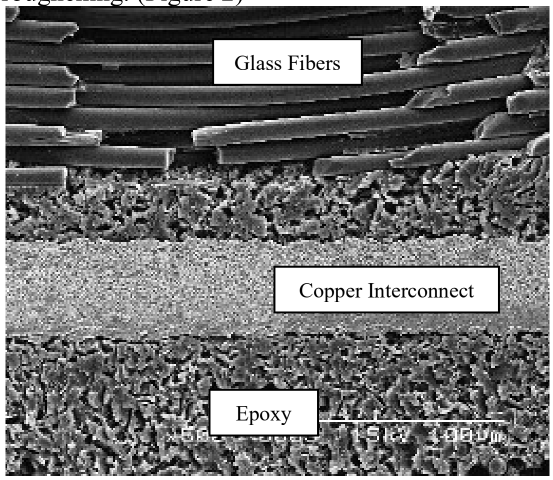


Figure 2

Clean copper interconnects are required for reliable electrical continuity while the roughened epoxy surface provides a base for excellent mechnical adhesion of subsequent metallization.

## Primary Metallization
## Carbon Technology

The current industry default for primary metallization is electroless copper. Electroless copper technology has been in use for 40+ years and is a known quantity. However, the downward price pressure on fabricators is exacerbated by increasing raw material costs, palladium (figure 3) and copper being the largest costs.

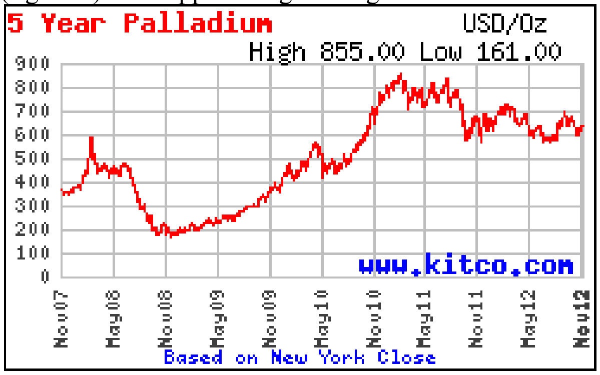


Figure 3

Additionally, environmental regulations are becoming more stringent as are water use restrictions, all adding to fabrication costs. Continuous cost reductions are unsustainable and it is unlikely that raw materials will decrease anytime soon.

A lower cost, horizontally integrated, production proven process is available. Figure 4 compares a standard electroless copper sequence to the carbon technology sequence.

| Step | Electroless Copper | Step | Carbon Technology |
|---|---|---|---|
| 1 | Clean/Condition | 1 | Clean/Condition |
| 2 | Rinse | 2 | Rinse |
| 3 | Microetch | 3 | Carbon-based Dispersion |
| 4 | Rinse | 4 | Dry |
| 5 | Predip | 5 | Microetch |
| 6 | Activation | 6 | Rinse |
| 7 | Rinse | 7 | Antitarnish |
| 8 | Acceleration | 8 | Rinse |
| 9 | Rinse | 9 | Dry |
| 10 | Electroless Copper | | |
| 11 | Rinse | | |
| 12 | Acid Dip | | |
| 13 | Rinse | | |
| 14 | Antitarnish | | |
| 15 | Rinse | | |
| 16 | Dry | | |

Figure 4

Chemical steps are reduced from 8 to 4 and rinse steps are reduced from 6 to 3. The space required for a carbon technology line is approximately 1/3 that of commercially available horizontal electroless copper lines, and the capital required for a carbon technology line is less than half the cost of horizontal electroless copper lines.

Factoring in that the carbon chemistry is non-dynamic (no breakdown upon idling), it is clear to see how this system reduces total cost of ownership. Additional advantages to the carbon system are its simplicity and environmental benefits. The carbon chemistry has no side reactions. The chemistry does not change as a function of time. There is no plate out, and no generation of hydrogen gas during application eliminating the possibility of bubble entrapment causing voids. The carbon process does not contain heavy metals or carcinogens and is completely RoHS compliant.

Performance of the carbon technology process is equivalent to or exceeds that of standard electroless copper processes, due to the direct bonding of electrolytic copper to the copper interconnections. This direct copper to copper bond is the strongest possible, with no intervening layers (such as palladium or porous electroless copper) that can cause weakness. The unique mechanism of the carbon technology exhibits reliability advantages over other direct metallization processes.

Unlike polymerizing types of direct plate systems, the carbon technology processes all materials types and constructions through the same set of parameters and the glass coverage is superior with the carbon based system. An area of concern for the carbon technology system has been the ability to process thin copper foils and innerlayers. Modified semi additive processing utilizes very thin surface foils to be able to resolve 30 micron line/space. 13 micron innerlayer foils are becoming more common, as is laser microvias to the backside of a core for substrate fabrication. The carbon system requires an etch as the final step.

The problem is that the direct metallization conductor (carbon) will be deposited on all surfaces, both dielectric and copper. After this deposition, a post copper etch must be used to fully remove the deposits from the copper surfaces. If the copper etch is too aggressive negative etch back or wedge voids at the innerlayers posts can occur. The typical defects that negative etch back can have with direct metallization is wedge voids (figure 5) and thinning of copper in high aspect ratio holes(figure 6).

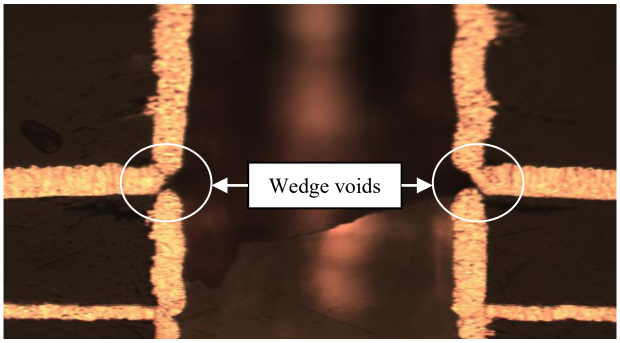


Figure 5

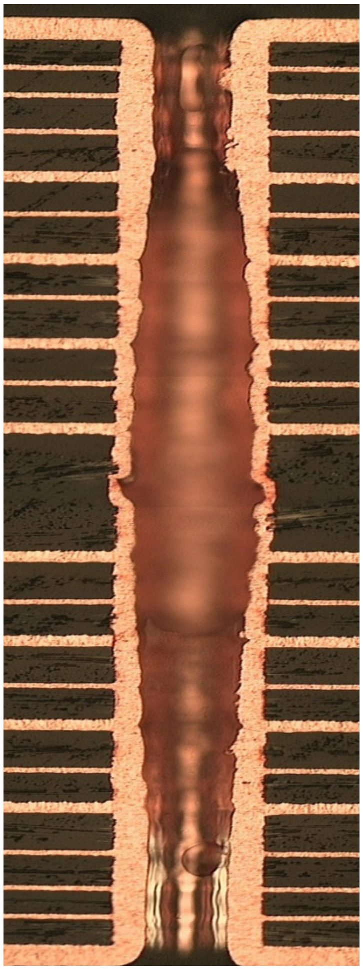


Figure 6

A new low etch system was developed to address these limitations in several ways. This system utilizes a preliminary sacrificial copper coating and a post etch incorporating novel organic additives that significantly reduce the etch rate without having to reduce contact time in the etch module. Maintaining proper contact time in the spray and flood impingement sections of the etch is critical in achieving fully clean copper surfaces. These organic additives also result in specific enhancements in removal of carbon dispersion residues from the copper surfaces, without any negative impact of the carbon deposit on the dielectric.

The first step of the new system is a cleaner that removes light oils/dirt from the substrate, wets the holes and applies a copper specific sacrificial coating. Figure 7 shows the IR spectra of the copper ran with the standard cleaner and the new cleaner.

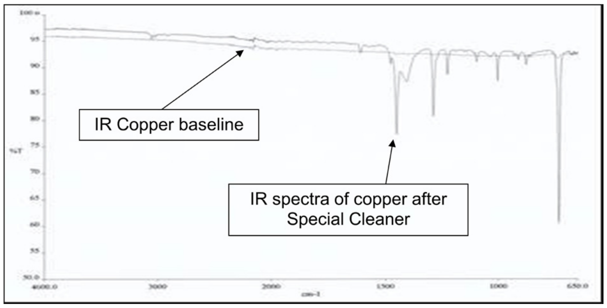


Figure 7

This sacrificial coating inhibits direct bonding of the carbon chemistry to the copper and enhances the cleaning ability of the new etch chemistry.

The final etch step, utilizing the organic additives, reduces the copper removal by >80% and yields very clean copper surfaces. The use of this new etch results in excellent propagation in high aspect ratio holes, eliminating the copper thinning in the middle of the hole (figure 8)

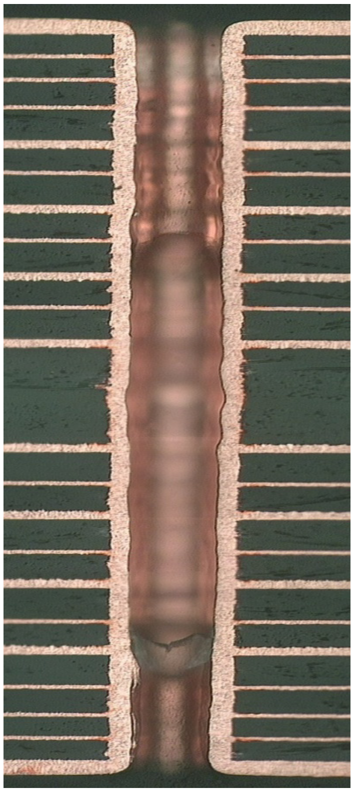


Figure 8

Even with the final etch reduced by >80%, the capture pads on the blind micro via constructions (HDI) are perfectly clean (figure 9).

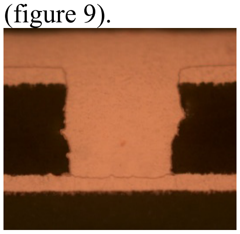


Figure 9

## Electrolytic Metallization

HDI technology calls for the ability to electrolytically plate the through holes and fill the blind microvias. Most commercially available chemistries require the filling of microvias, followed by a planarization step to remove some of the surface copper. These panels are then sent to mechanical drilling, PTH, and electrolytic copper plating in order to complete the process. These additional steps add cost and cycle time to the manufacturing process. The ability to take product directly from the carbon process, with all laser and mechanical drilling complete, and build up the required copper in the through holes and fill the microvias, without the need to planarize later, is a huge benefit in materials, cycle time and labor.

Plating through holes and filling vias without the need for subsequent planarization can be accomplished through chemical/mechanical design. MacDermid, a pioneer in the development of vertical continuous plating applications, continues to work with VCP equipment suppliers to optimize designs.

A cross sectional view of the plating cell is shown in figure 10.

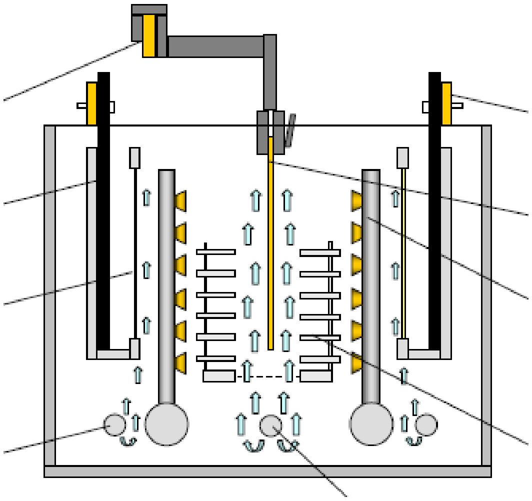
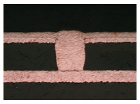


Figure 10

The design incorporates the use of eductors and air agitation. The anode type can be soluble (copper) or insoluble. The anode area is enclosed to prevent any particulate from the copper balls, (if using soluble anode) or the gas evolved at the anode (if insoluble anode) from mixing with the bulk solution.

The viafill chemistry was specifically designed for VCP plating. The additives have been balanced to work synergistically with the equipment to provide good through hole plating while simultaneously filling the microvias. The VCP / chemistry combination provides excellent macrodistribution across every panel (+/- 10%) while keeping the surface copper thickness 20 microns or less.

The plater incorporates an in line flash as the first electrolytic step. This flash section propagates copper through the holes and into the blind microvias and begins the filling process. A proprietary predip is used after the flash step to greatly enhance the bottom up filling mechanism. The final result is completely filled vias with minimum surface copper. The photos below shows the via filling capabilities.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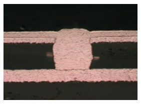
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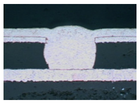
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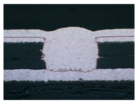
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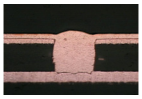
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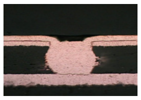
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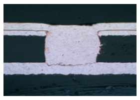
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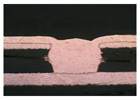
7x4

## Final product Reliability

With the elimination of negative etch back defects and the enhanced cleaning properties of the new etch, reliability is enhanced. Thermal cycling testing has demonstrated these benefits on both though hole and microvia barrels and interconnects.

On 22 layer IST test panels, the new direct metallization system demonstrated performance equivalent to or better than horizontal PTH. The comparative table (figure 11) shows IST cycles to failure after 6X precondition to 230°C and IST cycling to 150° C.

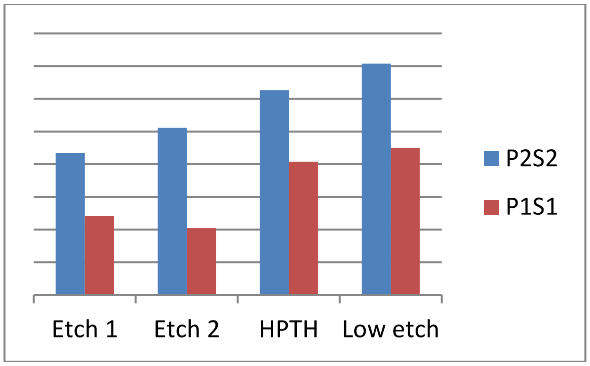

Figure 11

Microvia IST testing also demonstrated improved reliability. The test results below were generated using IST cycling specifically designed to monitor the capture pad electroplated copper interface. In this testing IST coupons were first preconditioned to 260° C using normal IST orientation. After preconditioning the microvia circuit (S2) was connected to POWER and a dummy, non heated, coupon was connected to SENSE. Then the microvia S2 circuits were IST cycled as POWER to 190° C (Figure 12). This methodology specifically monitors the quality of the copper plate capture pad interface.

| 4 mil mv - S2 POWER - dummy SENSE | | | |
|---|---|---|---|
| | IST-MV cycling to 190 C | | |
| | 4 mil mv ave. | | |
| Etch | P% | cycles | ST Dev |
| Etch 1 | 7.1 | 385 | 144 |
| Low Etch | 0.1 | 500 | 0 |
| Etch 2 | 11.0 | 122 | 23 |
| Low Etch | 0.4 | 500 | 0 |
| Etch 2 | 8.1 | 377 | 108 |
| Low Etch | 1.9 | 500 | 0 |
| Etch 1 | 4.8 | 462 | 65 |
| Low Etch | 0.3 | 500 | 0 |
| Etch 2 | 11.0 | 145 | 10 |

Figure 12

## Conclusion

The integrated process described in this paper achieves the goals of reduced costs, increased reliability, and addresses over etching concerns in regards to direct metallization. These enhancements allow for the production of much more difficult substrates including mixed constructions and very thin copper foils. With robust reliability, the described integrated metallization process offers a clear alternative to horizontal systems based around electroless copper, and guarantees significantly lower operating costs. Finally, the environmental benefits of reduced water and waste treatment volumes are substantial.