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Novel Plating Cell Geometry for Uniform Metal Deposition

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Faraday Technology, Inc. has developed a number of novel processing cells based on an innovative cell geometry that results in high levels of processing uniformity. This geometry is comprised of a number of unique attributes for the uniform electrodeposition or electroetching of metals across large planar substrates as well as fine features that are utilized for printed circuit board (PCB) and electronic packaging applications. The cell has been characterized with a 457 mm x 610 mm substrate. A coefficient of variation of 5.3% was achieved in FARADAYIC® ElectroCell over a 457 mm x 610 mm substrate; these values were compared to a commercial system. This cell design has been applied to a number of industrial processes, including electroplating of copper, trivalent chromium and platinum and electroetching of copper for interlayer circuit board applications. The current work outlines the importance of various cell components and resulting uniformity.

Introduction

The need for smaller and faster electronic circuits is driving the design of PCB interconnects in the direction of finer pitch transmission lines, smaller diameter through holes and vias, and thicker boards with higher layer counts to provide increased circuit densities (1,2). With the advent of HDI, the number of electronic devices on a single chip is continuously increasing, and in the interest of smaller devices, so is the need for multilevel interconnect (3). Increasing utilization of multilevel interconnections, or z-interconnects, increases the importance of uniformity and desirable mechanical properties of the z-interconnect. Any voids and non-uniformities of the copper in the z-interconnects may result in deposit fatigue and deposit cracking, which may result in short circuiting and product failure (4, 5).

Electroplating is the standard fabrication technique for the metallization of z-interconnects (3). However, technological advances in circuit board and HDI technologies are in general limited by the plating process in PCB shops (4). Generally, the edges/corners of the features are metallized at a faster rate than the barrel due to the uneven localized current distribution, and thickness distribution is non-linear along the barrel wall especially as the aspect ratio of the feature increases (5). Lower applied current densities, pulse/pulse reverse plating and chemical additives are methods to improve throwing power in high aspect ratio z-interconnects. However, if electrolyte is inaccessible to the center of the z-interconnect due to poor electrolyte flow, then these methods will not address metallization of high aspect ratio z-interconnects. Plating cell geometry on the other hand defines the characteristics of the boundary layer, which controls the primary current distribution. The FARADAYIC® ElectroCell has been engineered to provide a uniform boundary layer across a 457 mm x 610 mm substrate.

Agitation is an important aspect of any electroplating process. Agitation is necessary to provide a constant supply of electrolyte to the workpiece, facilitating deposition. Agitation also has the following secondary functions: removal of hydrogen from the workpiece, aid in the dissolution of anodic species, removal of particulates or precipitates from the workpiece surface, aiding in filtration, and reduction of electrodeposit burning in high current density areas, commonly experienced at the edges of the panel. Traditionally, agitation was achieved through air sparging. However, air sparging results in plating thickness non-uniformity as a direct result of non-uniform electrolyte flow. Traditional air sparging agitation gave rise to eductor agitation, though both are currently used in commercial plating cell geometries. Eductor flow is achieved with any number of plating cell geometries, however, the configuration may adversely impact plating performance in poorly utilized eductor schemes (6).

The FARADAYIC® ElectroCell

The FARADAYIC® ElectroCell, engineered and built by Faraday Technology, utilizes eductor flow as the primary solution agitation mechanism, however, unlike other plating tank geometries, the eductor flow is directed past the workpiece surface in a laminar manner through distinct flow channels. This concept is illustrated schematically in Figure 1.

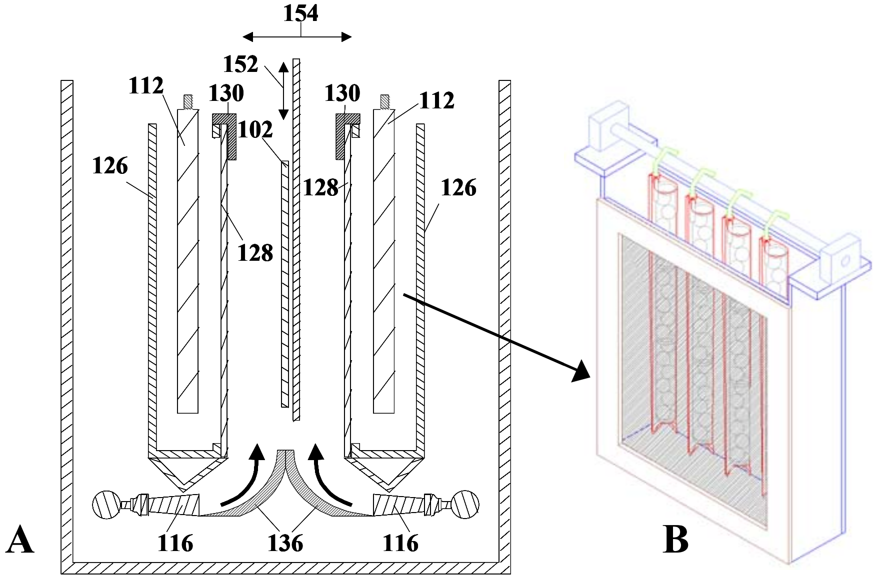

Figure 1. A) Schematic of the patented FARADAYIC® ElectroCell, identifying specific cell components, and B) illustration of anode chamber with polymeric cloth.

Plating electrolyte is pumped into the eductor system (116), located below each anode chamber (126) in a perpendicular orientation (individual titanium anode baskets with copper balls are noted as 112). The electrolyte leaves the eductor nozzle and is directed in a laminar fashion to the cathode (102) by dampening elements (136) adjacent to the eductors. The anode chambers, including a porous polymeric cloth (128, shown in Figure

1B), form distinct channels with the cathode, maintaining a uniform laminar flow across the entire surface of a workpiece.

In addition to laminar flow and channeling effects, the cell also incorporates other features that enhance plating uniformity. The cell has insulating shields (130) to minimize edge effects; these shields are easily installed and changed to accommodate any size workpiece. In order to address feature uniformity, the cell is capable of lateral oscillation (154, range 6-63 cycles/min) and vertical vibration (152, range 0-2170 cycles/min) and alternating flow schemes. The cell utilizes two 300 L/min pumps for continuous electrolyte circulation and a heating/cooling system to maintain desired plating temperature. The cell has been extensively characterized and optimized to deliver 5.3-8.7% variation across a 457 mm x 610 mm panel.

Experimental

The aim of this work is to explore plating thickness uniformity as a function of cell geometry. Additionally, the present work also presents the mechanical properties of copper deposits prepared in the FARADAYIC® ElectroCell with pulse/pulse reverse plating parameters in the absence of difficult to control organic additives. The experimental conditions for both uniformity studies and evaluation of mechanical properties are given in Table I. Thickness uniformity was tested with a flat stainless steel panel, copper plated to a thickness of 25 μm. The resulting copper foil was removed from the substrate and measured according to the schematic given in Figure 2. As shown in Figure 2, there are two separate measurement areas, one in which the 36 equispaced measurement points begin 25.4 mm from the edges and the second in which the 36 equispaced measurement points begin 38.1 mm from the edges. The extent of uniformity is expressed as a coefficient of variation, which is simply the standard deviation divided by the average thickness, expressed as a percentage. The lower the CV, the more uniform the deposit thickness. CVs lower than 10% are sought in industry and generally translate into a more robust product.

TABLE I. Experimental Conditions for Thickness Uniformity and Mechanical Property Characterization Tests.

	Current Density	**E-Field**	**Cu (g/L)**	**H_2SO_4 (g/L)**	**PEG (g/L)**	**Cl^- (g/L)**	**Substrate Type**
Thickness Uniformity Characterization	20, 25 ASF	Direct Current	24.7	206	70	350	Stainless Steel
Mechanical Properties Characterization	18 ASF	Sequenced Waveform	23.9	205	62	350	Stainless Steel

A photograph of the test panel used for mechanical property evaluation is given in Figure 3. The front side of the panel is masked to yield 10 vertical test strips and the back of the panel is masked to yield 10 horizontal test strips. The ultimate tensile strength and percent elongation were tested according to IPC-TM-650, Number 2.4.18.1, *Tensile Strength and Elongation, In House Plating*. Faraday plated the test panel in the FARADAYIC® ElectroCell with the electrolyte given in Table I and a sequence of waveforms proven to uniformly metallize high aspect ratio z-interconnects Since this sequence of waveforms is used to address high aspect ratio z-interconnect metallization for PCB fabrication, Faraday deemed it relevant to test the mechanical properties of deposits prepared under these conditions. For comparison purposes, another board was plated at a PCB facility in commercial tank geometry, with different waveform sequence and different plating electrolyte containing organic additives. The tests conducted at Faraday utilized a lateral oscillation rate of 26 cycles/min and vertical vibration frequency of 1400 cycles/min. The comparison tests were conducted with a lateral oscillation rate of 12 cycles/min, a knife-edge agitation rate of 12 cycles/min and vibration, which were the standard operating conditions used at that PCB facility.

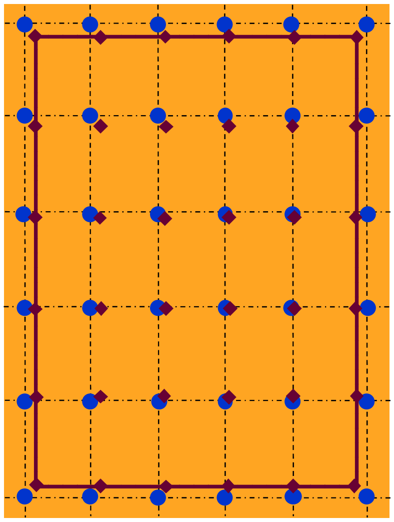

Figure 2. Measurement protocol for thickness uniformity experiments.

Figure 3. Photograph of test vehicle used for mechanical tests.

Results and Discussion

Thickness Uniformity Studies

The anode basket spacing and configuration were evaluated in terms of plating thickness uniformity. For these tests, the FARADAYIC® ElectroCell was used in its standard configuration, as outlined in Figure 1, at 20 ASF with 300 L/min flow per side. Copper foils were measured according to the 25.4 mm measurement scheme illustrated in Figure 3. The results of these tests are given in Table II. As seen in Table II, the effect of anode basket spacing and configuration is small. For the remainder of the tests, the anode configuration utilizing 76 mm basket spacing on-center with cathode and a current density of 25 ASF were used.

TABLE II. Anode Basket Parameters for Thickness Characterization Tests.

Number of Baskets	Basket Spacing	Basket Orientation	CV (1-inch)
3	114 mm	On-Center with Cathode	11.7%
4	152 mm	On-Center with Cathode	13.1%
4	152 mm	Off-Center with Cathode	10.7%
4	76 mm	On-Center with Cathode	10.7%

The impact of various FARADAYIC® ElectroCell components was evaluated in the current study in terms of copper thickness uniformity. As such, the cell was altered from its optimized configuration, shown in Figure 1, to assess the impacts of anode chamber, polymeric cloth and anode configuration/basket spacing as a function of flow rate. Copper foils from this set of experiments (at 25 ASF) were measured according to the protocol given in Figure 3 for both 25.4 mm and 38.1 mm measuring schemes.

First, the anode chambers (including polymeric cloth and insulating shields) were removed from the cell, leaving the cathode between the anode baskets (4 titanium baskets containing soluble copper anodes on either side of the cathode, illustrated schematically in Figure 4). Generally the FARADAYIC® ElectroCell is operated at a maximum flow of 300 L/min per side. Without the anode chambers in place, the electrolyte flow was too high and resulted in splashing. Therefore, for this test, the electrolyte flow was reduced to approximately 50% (150 L/min flow per side). Under the 25.4 mm measurement protocol, this test resulted in a CV of 17.8% and under 38.1 mm protocol was 14.4%. Next, the anode chambers and insulating shields were reinstalled without the polymeric cloth and retested for thickness uniformity distribution. Both flow rates of 50% (150 L/min, CV of 7.1 - 7.7%) and 100% (300 L/min, CV of 9.2 – 9.5%) were tested. The polymeric cloth was reinstalled and characterization was conducted at 50% flow (150 L/min, CV of 8.3 – 9.3%) and 100% (300 L/min, CV of 5.3 – 8.7%). These results are summarized in Table III.

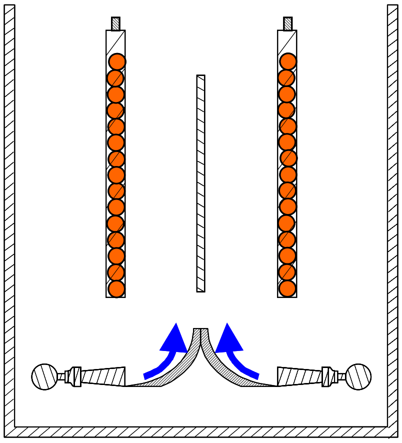

Figure 4. Schematic view of the FARADAYIC® ElectroCell without anode chamber, porous polymeric cloth and insulating shields.

TABLE III. Cell Configuration Parameters for Thickness Characterization Tests.

Flow Rate	Anode Chamber	Insulating Shields	Polymeric Cloth	CV (25.4 mm)	CV (38.1 mm)
150 L/min	N	N	N	17.8	14.4
150 L/min	Y	Y	N	7.7	7.1
300 L/min	Y	Y	N	9.5	9.2
150 L/min	Y	Y	Y	9.3	8.3
300 L/min	Y	Y	Y	8.7	5.3

Mechanical Property Characterization

The panel for tensile/elongation tests was plated in the FARADAYIC® ElectroCell with 300 L/min flow, a sequenced waveform, and electrolyte containing minimal organic additives (PEG-Cl^- system). Baseline comparison tests were conducted with the same type of board, with a commercially available cell geometry and plating electrolyte containing organic additives. The comparison process utilized a sequence of waveforms, though different than that utilized by Faraday. Five strips from each side of each panel were tested for ultimate tensile strength and percent elongation. The data for average ultimate tensile strength and average percent elongation is presented in Tables IV. The data from Faraday's board is plotted in Figure 5 and the data from the comparison board is plotted in Figure 6. According to IPC-6012B Paragraph 3.2.6.8 (August 2004), the ultimate tensile strength for electrodeposited copper should not be less than 36,000 psi and percent elongation should not be less than 12%; according to this standard, both processes exceed the standard requirements for mechanical strength.

TABLE IV. Mechanical Property Data for Faraday Process and Comparison Process.

Process	Ultimate Tensile Strength (psi)	Average Percent Elongation
Comparison Board: Vertical Strips	42730 ± 1023	27.62 ± 6.5
Faraday Board: Vertical Strips	41392 ± 430	27.85 ± 1.8
Comparison Board: Horizontal Strips	43133 ± 596	28.40 ± 5.9
Faraday Board: Horizontal Strips	42041 ± 726	29.85 ± 1.8

From Table IV, it is noted that the samples submitted by Faraday in general show a lower standard deviation than the comparison process, with the exception of the ultimate tensile strength from Faraday's horizontal test strips. While the average ultimate tensile strength and average percent elongation values are comparable between Faraday's process and the comparison process, it is apparent from Figures 5 and 6, that the processes are not equivalent in terms of reproducibility. Faraday's process demonstrates a tighter tolerance in ultimate tensile strength/percent elongation as opposed to the comparison process, though both processes clearly pass the mechanical strength standards defined in IPC-6012B Paragraph 3.2.6.8 for all samples evaluated.

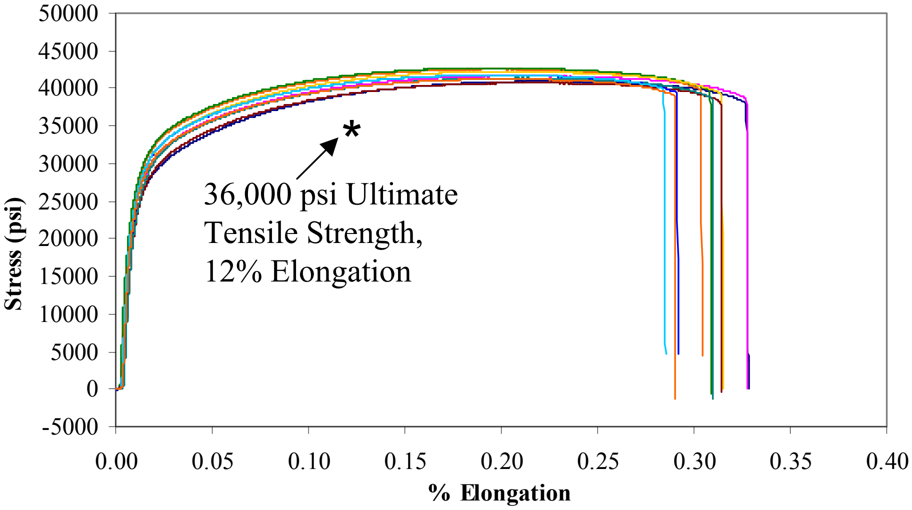

Figure 5: Ultimate tensile strength and percent elongation for copper deposits prepared in the FARADAYIC® ElectroCell with simple chemistry and sequenced waveform.

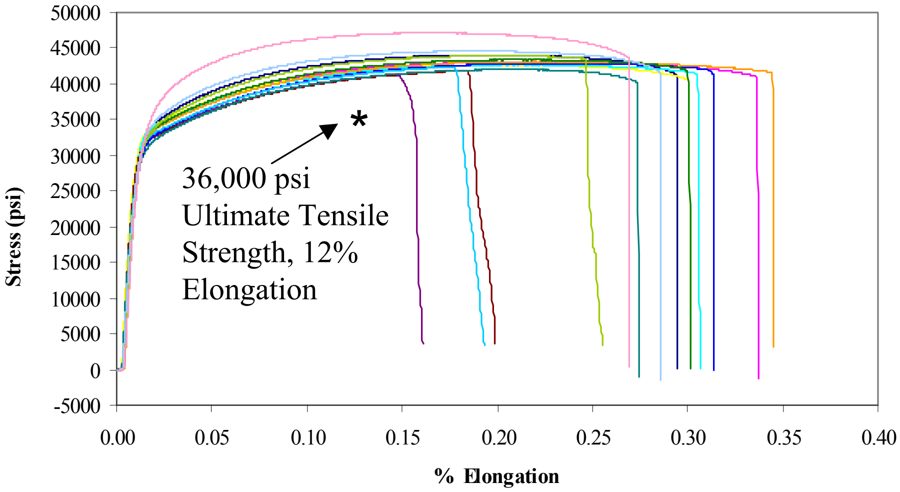

Figure 6. Ultimate tensile strength and percent elongation for comparison process, which utilizes different cell design, different copper chemistry and different sequenced waveform as compared to the samples submitted by Faraday Technology.

Conclusions

The FARADAYIC® ElectroCell has been engineered to deliver uniform electrolyte flow to a workpiece, resulting in uniform thickness distribution. The current work demonstrates the importance of ElectroCell components, namely the anode chamber, porous polymeric cloth and insulating shields, on the thickness distribution over a 457 mm x 610 mm workpiece. This is attributed to the formation of distinct channels with the workpiece. Delivery of uniform electrolyte flow over the workpiece provides a uniform current distribution that allows a simplified chemistry when using pulse and pulse reverse waveforms. Lack of organic inclusions in Faraday's copper deposits may account for the higher reproducibility in mechanical properties of the Faraday deposit when evaluated with the comparison deposit. Though the higher reproducibility may also be a consequence of uniform thickness distribution; previous studies indicate that the FARADAYIC® ElectroCell tank geometry provides a higher level of thickness uniformity when evaluated against this comparison tank (8.7% CV as compared to 19% CV, (7)). Furthermore, the ElectroCell geometry has been proven effective for the uniform filling of high aspect ratio z-interconnects. The ElectroCell technology has been applied to both deposition and etching industrial processes and is easily retrofitted for any direct current or pulse/pulse reverse electrochemical process.

Acknowledgments

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