Plating Showerhead System for Improved Backside Wafer Plating

Jens Riege, Heather Knoedler, Shiban Tiku, Nercy Ebrahimi

Skyworks Solutions, Inc.
2427 West Hillcrest Drive, Newbury Park, CA
jens.riege@skyworksinc.com (805-480-4434)

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Abstract

Plating thickness uniformity can become increasingly difficult to control when migrating from four inch to six inch wafers, especially when plating through-wafer vias with non-cyanide gold bath solution. The standard tooling provided on our four inch plating equipment did not scale adequately for the larger wafer size and still maintain good process control. The solution implemented at Skyworks changes the plating solution delivery to the wafer surface to provide better process control and better plating uniformity. This process qualification was part of a Six Sigma team effort to help ensure timely project success.

INTRODUCTION

When electroplating through-wafer vias **(**TWVs) on a Semitool Equinox® plating tool, the negative terminal of the power supply is connected to the wafer to make it the cathode and the positive terminal is connected to a metal disk parallel to the wafer to make it the anode. Gold plating uniformity is determined by the electrical contact made at the wafer perimeter, the electrical field from the anode disk parallel to the wafer, and the availability of gold ions when the wafer and anode are submerged in the plating bath solution. Our four inch wafer plating anode is attached at the top of an anode post (See Fig 1a).

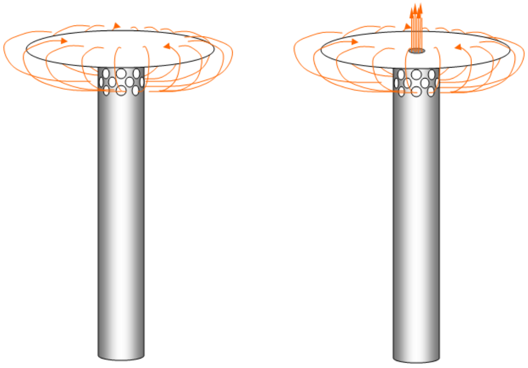

Fig 1a, b: Standard 4" Plating Anode on top of anode post, Modified 4" Wafer Plating Anode With Added Center Hole.

Before plating starts the wafer is lowered into the plating solution, parallel to the anode, and it begins to rotate. When the plating current is initiated, gold ions are consumed from the plating solution, and additional solution from a plating tank is supplied through holes in the anode post under the anode. As our 4" plating bath aged, the conducting salt concentration increased and the center of the four inch wafer did not plate fully at the bottom of the vias. At higher conducting salt concentrations, the bath density increases and the larger, heavier gold ions cannot flow as freely into the vias. Since the wafer rotates during plating, plating solution is pulled away from the center due to centrifugal force. By drilling a hole in the center of the anode and the anode post more fresh plating solution is delivered to the center of the wafer (see Fig 1b). This solution delayed the onset of thinner plating in vias at the center of the wafer as the bath aged and allowed us to extend our plating bath life. Our challenge was to find a way to maintain the plating thickness uniformity as we increased our wafer size from four inch wafers to six inch wafers.

UPGRADE TO PLATE SIX INCH WAFERS

When Skyworks decided to upgrade to six inch wafers, it became clear that the prior solution for four inch plating may not scale properly for the larger wafer diameter. Six inch wafers have a higher centrifugal force at the wafer edge when rotating at the same RPM, and the radius is fifty percent larger. To prevent a potential plating uniformity problem during tool qualification a new plating showerhead design was fabricated in parallel with the standard four inch anode design modified for six inch plating. The showerhead

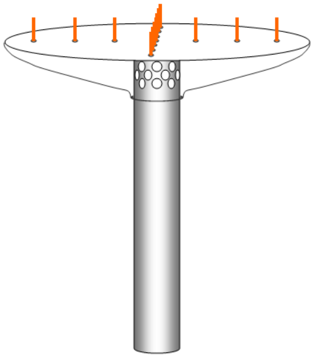

Fig 2: New 6" Showerhead Plating Design: Showerhead Cup and Modified Anode.

design was compatible with the existing plating chamber and just required a new showerhead cup and modifications to the anode plate and anode post. The showerhead cup is tapered at the narrow contact around the anode post and gradually widens to reach the edges of the anode plate. The shape was designed to prevent eddy current formation as the solution leaves the anode post and travels to the openings in the anode. The cup is sealed at the edges of the anode plate to generate pressure behind the anode. The direct flow from our modified four inch wafer plating anode provided a single wide low pressure spray source at the center of the wafer. The six inch anode uses multiple smaller holes to provide a spray at several locations across a wafer. By confining the plating solution in the showerhead cup, the flow rate at the wafer surface can be set by selecting the number of holes and the size of the holes in the anode and the initial flow rate from the pump. Using the flow conservation equation for an incompressible fluid from fluid dynamics,

$$\upsilon_1 A_1 = \upsilon_2 A_2$$

it is possible to determine the relative flow for various hole sizes and varying number of holes (see figure 3).

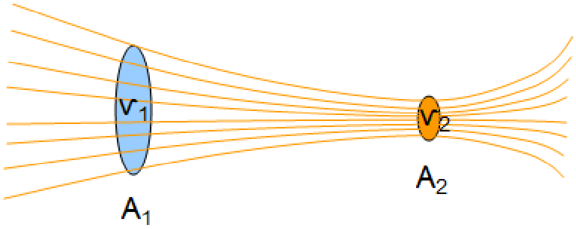

Fig 3: Fluid flow conservation for a constrained fluid. (υ = flow rate, A = cross-sectional area)

In this equation, the new flow, υ_2, is determined by the initial flow provided by the pump, υ_1, multiplied by the ratio of the total area of all hole openings in the anode post to the total area for all holes in the anode, or $\upsilon_2 = \upsilon_1 * A_1/A_2$. It is therefore possible to design an anode that provides a relative flow at the wafer surface that is greater than what the pump can provide using the conventional anode design.

BOUNDARY LAYER REDUCTION

Above a via opening during plating, gold metal ions are transported into the via. As the gold ions are removed from the plating solution they leave behind a thin volume of plating solution with fewer gold ions next to the via wall. New gold ions must be transported into this region and diffuse through the boundary layer to allow plating to continue. If the layer is thick, it takes time for new ions to diffuse through this barrier and the plating rate will be reduced. Since the wafer rotates the boundary layer is likely to be thinned on the backside by the centrifugal force causing solution flow. However with the conventional anode, there is little to no agitation inside the vias to reduce this layer. The showerhead spray reduces the boundary layer inside the vias by spraying plating solution with a high flow rate perpendicular to the wafer surface several times a second.

MEASURING BACKSIDE PLATING UNIFORMITY

In addition to plating chemistry and bath flow rate, the wafer-to-anode separation distance plays a very important role in maintaining plating uniformity. If the wafer is too far away from the anode, the electric field between the wafer and anode is non-uniform and plating is thicker at the edge of the wafer than the center. The sheet resistance profile plots the inverse of the thickness as a convex pattern. As the wafer is moved closer to the anode, this profile flattens. If the wafer is moved too close to the anode the resistance profile becomes concave due to thicker plating at the wafer center and thinner plating at the edge. We use a four point resistance measurement at 225 sites on a 6 inch test wafer. The relatively large number of sites allows us to plot a three dimensional resistance profile with sufficient resolution to see small differences in anode designs. It is possible to use a simple algorithm to optimize the backside plating uniformity: a technician enters the plating head position, the sheet resistance percent uniformity, and the resistance profile shape (concave or convex) and a spreadsheet calculation provides the head adjustment required to optimize the plating uniformity. Since the plating profile is radial, the number of measurement sites can be reduced by measuring only along the diameter of the wafer.

PLATING ANODE OPTIMIZATION – BACKSIDE PLATING

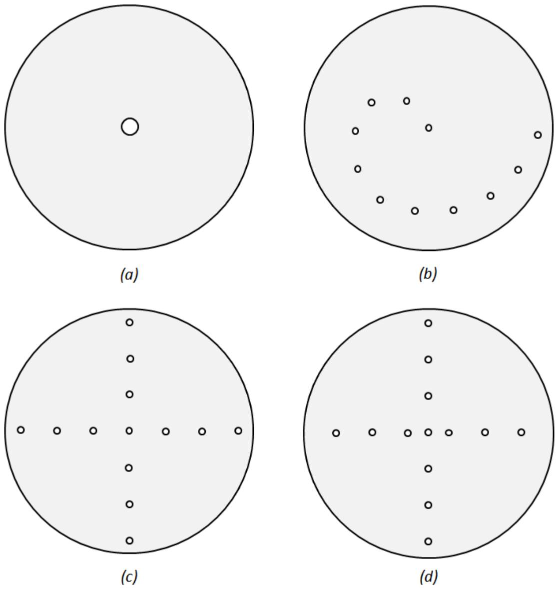

Fig 4a,b,c,d: 6" Plating Anode Designs Evaluated 4" anode design, sprial anode, cross anode with evenly space holes, cross anode with one axis of holes inset

Our experience has shown that if backside plating thickness uniformity is poor, plating inside the vias is also poor. While the inverse is not automatically true, optimized backside plating uniformity provides the best starting point for optimizing plating inside the vias. We evaluated several anode designs to find one that provided equal or better backside plating uniformity than our four inch wafer plating process, targeted at less than four percent sheet resistance variation across a wafer surface (See Fig 4).
The initial goal was to identify which of the three anode designs (Figs. 4a, 4b, and 4c) offered the best backside plating uniformity. Of these three designs using large holes, the cross pattern anode design (Figs 4c, 5c) gave the best uniformity at 5.4%.

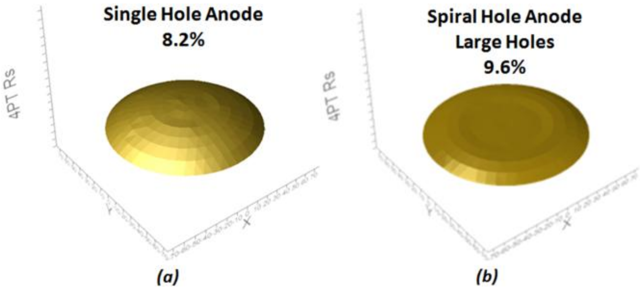

Fig 5a: Sheet Resistance using 4" Anode Design on 6" Anode (single hole in center). Best Uniformity = 8.2%; Fig5b: Sheet Resistance on 6" Spiral Pattern Anode with Large Holes. Best Uniformity = 9.6%.

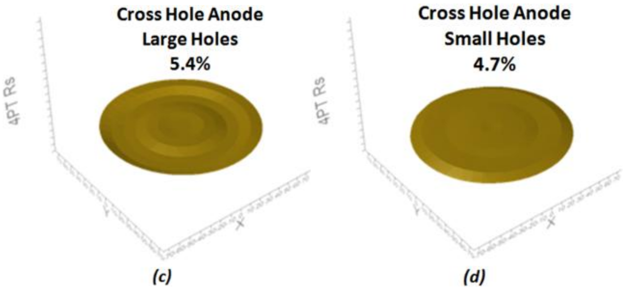

Fig5c: Sheet Resistance on 6" Cross Pattern Anode with Large Holes. Best Uniformity = 5.4%; Fig5d: Sheet Resistance on 6" Cross Pattern Anode with Small Holes. Best Uniformity = 4.7%.

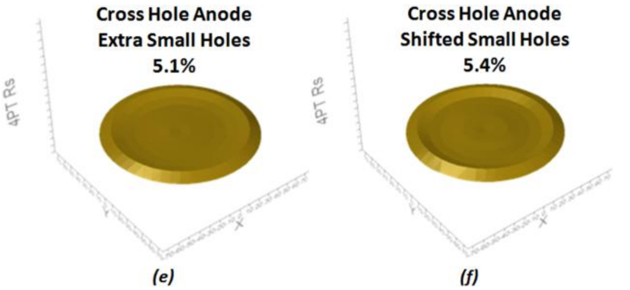

Fig 5e: Sheet Resistance on 6" Cross Pattern Anode with Extra Small Holes. Best Uniformity = 5.1%.; Fig 5f: Sheet Resistance on 6" Cross Pattern Anode with Shifted Small Holes. Best Uniformity = 5.4%.

To improve the uniformity further, we evaluated adjustments to plating head height, plating solution flow rate, and wafer rotation speed. The single hole anode design (Fig 4a, 5a), generated a domed resistance profile with a uniformity at 8.2%, even when the head height was optimized. The best uniformity achieved for the spiral pattern anode with large holes (Fig 4b, 5b) was 9.6%, and any slight deviation in head position worsened the uniformity considerably. Experiments with wafer rotation (10 RPM – 140 RPM) revealed that rotation speed had to be cut in half from four inch wafer processes settings to optimize uniformity on six inch wafers. Backside plating uniformity worsened for both higher and lower rotation speeds.

Plating Anode Optimization – Plating Inside the Vias

Plating thickness is the thickest on the wafer backside and decreases inside vias closest to the wafer frontside because of limited access to fresh plating solution. We use a focused ion beam to open a small hole from the front of the wafer to inspect the plating thickness at the bottom of the via (see Fig 6). Plating thickness variation inside vias is affected by via etch profiles and via size since larger and shallower sloped vias permit plating solution to enter more readily.

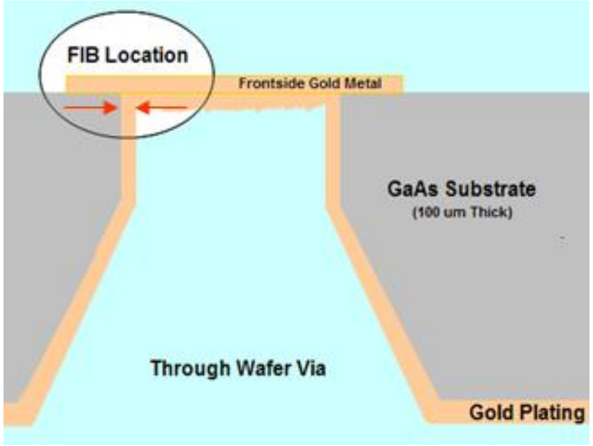

Fig 6: PlatingThickness Measurement Location Inside Vias

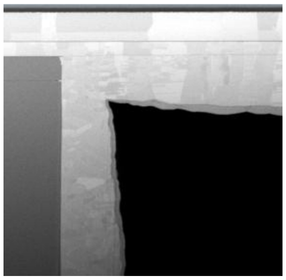

Fig 7: Gold plating is thinnest at the bottom corner of a via. (Cross Pattern Anode Design with Small Holes)

Experiments with plating solution flow rate using the spiral and cross large hole anodes indicated the bath pump had to run at its maximum flow rate, near five gallons/minute, to provide the thickest plating and best plating uniformity inside vias (Fig 8).

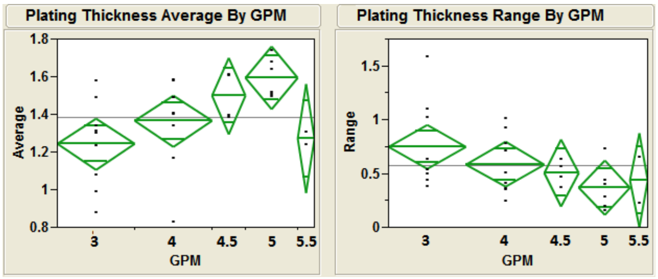

Fig 8: PlatingThickness vs. Plating Solution Flow Rate for Large Hole Anode Designs

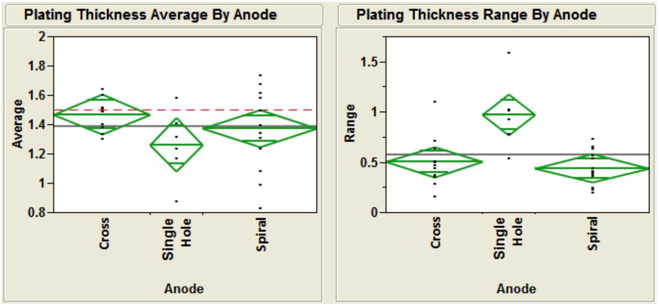

Fig 9: Plating Thickness Average and Range Measurements Inside Vias for for Single Hole Anode and Cross and Spiral Pattern Anode with Large Holes

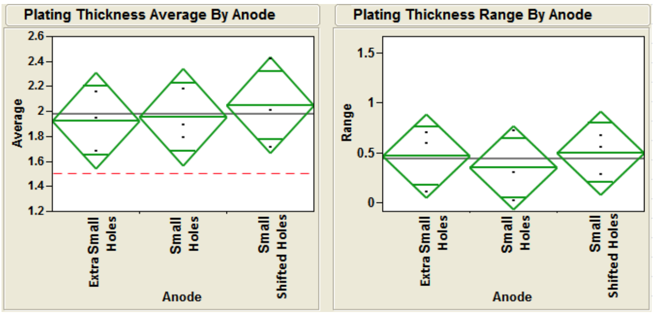

Fig 10: Plating Thickness Average and Range Measurements Inside Vias for for Single Hole Anode and Cross and Spiral Pattern Anode with Small Holes

To increase the effective flow to the wafer we experimented with smaller hole sizes and different hole positions. This improved the backside plating uniformity further, but more importantly, improved the plating thickness inside vias. The cross pattern anode with large holes provided better plating thickness in the via than the spiral anode with large holes (see Figs 9). However, both large hole anode designs did not plate vias as thick as our four inch wafer process. The process goal was to plate at least 1.5 um inside the vias. When switching to the smaller hole anode designs (see Figs. 5d, 5e, 5f) via fill was considerably better (see Fig 10). This improvement confirmed that the large hole designs do not generate sufficient agitation to replenish the plating solution inside the vias. For this reason, we did not evaluate large hole anode designs further. The results for the single hole anode also had the worst plating thickness uniformity inside the via and had the lowest plating thickness.

With the design selection narrowed to the cross pattern anode, we evaluated variations of this design. One anode design shifted one pair of holes so that they would not overlap the spray other pair of holes during wafer rotation (Fig 4d). The best uniformity with this pattern was 5.4%. The backside resistance profile showed slightly increased concentric rings, and did not offer better plating uniformity inside the via. Another design decreased the anode hole size further. The extra small hole design also gave comparable results to the shifted hole design for both backside and inner via plating thickness uniformity. This design could be a suitable alternate to the small hole anode design. All three designs generated plating thicknesses well above the minimum 1.5 um threshold. Additional experiments evaluated higher plating rate (+10%, +25%) and plating bath age (new vs. old). Plating thickness decreased inside the vias with an older bath, and with higher plating rate. We therefore selected the cross pattern anode design and a plating current that balanced the minimum 1.5 um plating thickness required for the full plating bath life, and provided sufficient throughput for production needs.

CONCLUSIONS

With the showerhead anode designs in production for more than two years, our six inch wafer plating resistance uniformity is now a stable plating process. Our ability to adjust plating head height to flatten our resistance profile often results in plating resistance uniformity near 2%. This would not have been possible had we simply upgraded our equipment using the conventional anode designs. The increased agitation from the showerhead spray provides rapid replenishment of gold ions inside the vias and creates a plating process that is easy to control.

ACKNOWLEDGEMENTS

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ACRONYMS

TWV: Through-Wafer Via
RPM: Revolutions per minute
GPM: Gallons per minute