DEVELOPMENT OF A CU POLISH PROCESS FOR THE SPEEDFAM AURIGA C

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Abstract:

In 2002, FAB25 began preparations to convert its BEOL from aluminum to copper. During this process, a large number of SpeedFam Auriga C’s running ILD and W polish processes would be idled. A project was initiated to develop a new Cu polishing process for these tools so that some of them could be redeployed. There were a number of economic motives for embarking on this work. These tools were already installed and nearly depreciated. Engineering, maintenance, and operations staffs were already familiar with the tools and could leverage existing proficiencies. By developing a process on this legacy toolset, the team hoped to avoid the considerable costs and disruption of removing, storing, and selling off the used equipment and buying and installing new tools. To bring the process into production, staff had to screen a variety of copper and barrier slurries, optimize process settings, and surmount unique tool limitations. The team overcame a variety of challenging defect issues. Engineering collaborated with vendors to develop customized equipment software and an integrated residual copper detection system. Using a Mirra-Mesa Cu Polishing process for benchmarking, the team succeeded in demonstrating a lower cost of ownership and equivalent yield with the SpeedFam Auriga C Cu polishing process.

Background:

Spansion, Inc. engineers at FAB25 (Austin, TX) initiated a conversion from aluminum to copper metallization in 2002. In the Polish module, this would mean decommissioning the majority of the SpeedFam Auriga C’s that supported running upper layer ILD and W polish processes. The technical leader of Polish proposed developing a copper polish process on the Auriga C for a number of economic and logistical reasons. The obvious first rationale for this strategy was the existence of a large existing installed base of fully depreciated tools, some of which could be immediately deployed for development work. Engineers, maintenance personnel, and operators were familiar with the tools and its capabilities. In particular, FAB25 manufacturing engineers had developed all of the existing processes in house and therefore felt comfortable with taking on these additional responsibilities. Advanced process control, a consumable and spare parts supply chain, and IT systems were already in place. The five-head SpeedFams had also proven to be very effective and efficient producers; FAB25 had consistently lead SEMATECH benchmarking for Polish productivity and cost of ownership for many years. Finally, if FAB25 did decommission its SpeedFams it would have the significant expense of removing, storing, and selling off its used equipment and the heavy burden of purchasing and facilitizing new Cu Polishers.

Keys to Success

There were three main reasons that Spansion succeeded in developing a Cu polishing process on its legacy toolsets:(1) hard engineering work, (2) management support, and (3) strong vendor support. Process development went through nearly four generations of refinement before it was ready for high volume manufacturing. The first version attempted to adapt an existing Mirra-Mesa process to the SpeedFam. Continuous improvement through optimization of the SpeedFam process knobs and equipment modification followed in the second. The third generation focused on slurry improvements such as adding a selectivity additive to the copper slurry and qualifying an improved buff slurry. A final unsuccessful attempt was made during the fourth cycle to develop a lower cost, higher throughput single platen process. This paper will discuss some of the work that went into building Spansion's patent-pending process.

Some Background on the Auriga C:

The Auriga-C was brought to market by SpeedFam International, Inc. over ten years ago. The tool offers complete dry-in/dry-out capability employing the same five-head, two-table architecture found on SpeedFam's first-generation CMP-V. At the time, the tool was popular because of its high-throughput. Its integrated multiple-process control systems enabled multi-tasking of tool automation and control. SpeedFam Auriga C's have been sold to a wide variety of integrated circuit manufacturers throughout the world such as Samsung, National Semiconductor, and Siemens Semiconductor Group. A diagram and photograph of a SpeedFam Auriga C can be found in Figures 1 and 2, respectively.

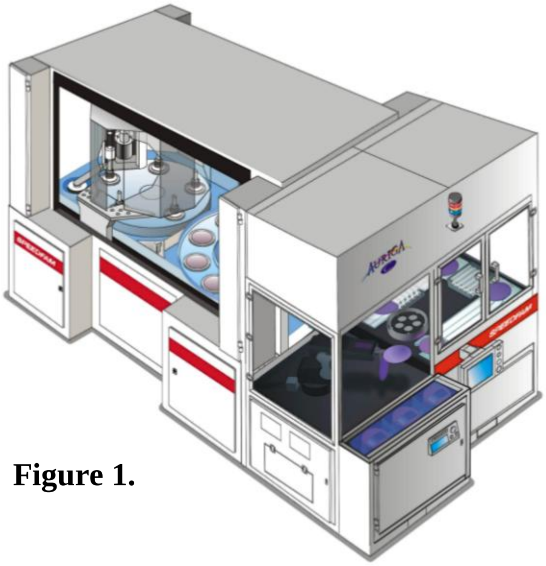

Figure 1.

Figure 2.

In Figure 2, the tool's index table is shown with wafers in the load and unload cups. The tool's final table is visible in the center of the index table. The multihead is above the main platen.

The SpeedFam has two polishing platens: (1) a 32" main table and (2) a 22" final table. In conventional ILD or W polishing, the main table is used as the "work" table where the bulk of material polishing is performed. The final table is typically used for reducing defectivity via a buff process. The small final platen is encircled by an index table possessing ten cups which are typically immersed in water; every other cup is dedicated for either the loading or unloading of wafers. Individual wafers are loaded via a Motoman robot or unloaded by a simple flipper robot. The large multi-head transport assembly slides on rails back and forth to access the two platens. Five wafers are processed in parallel on five independent arms on the same platen. This gives the tool a significant throughput advantage and reduces consumable waste (pads and slurry). To fit the confines of the index table, the final platen is very small and as a result the polishing heads can not oscillate and/or hang off the platen. An additional challenge is that the final table lacks a conditioner.

Consumable Identification

To reduce the time to develop a new Cu Polish process, most of the development cycle focused on copper and dielectric polishing slurries leveraging existing pads, conditioning rings, and carriers. Early on, it was decided that to achieve maximum throughput, the wafers would need to be jettisoned through the tool's onboard scrubber and dry station as quickly as possible. As a result, existing OnTrak scrubbers, formerly used for ILD and W processes, were redeployed as post Cu polish scrubbers. Both scrubber systems employed the same proprietary cleaning chemistries.

Spansion's R&D division, the Sub-Micron Development Center (SDC), had developed a copper polish process using the Mirra-Mesa. During initial development, the same slurries were used on the Auriga C, but as testing proceeded it became obvious that the existing slurries would not work effectively on the SpeedFam. To meet the tighter sheet resistance requirements at the 90 and 65 nm nodes, the team evaluated a variety of new copper and buff slurries. The initial criteria used to judge the slurries were blanket test wafer performance (both TEOS and Cu): (1) removal rate, (2) nominal removal profile, (3) removal profile tunability via recipe parameter windowing, and (4) defectivity. Unlike the Mirra-Mesa, the Auriga C has basic process knobs: (1) carrier speed, (2) table speed, (3) downforce, (4) carrier position, and (5) main table carrier oscillation. The carriers are of a simple design lacking zone pressure controls. Slurries that performed well on the blanket experiments advanced to short loop, patterned wafer tests. The proprietary frictional endpoint system that FAB25 engineers had co-developed with Momentum Technical Consulting for SpeedFam tungsten polishing was reused and found to be perfectly amenable to copper CMP. These patterned wafer tests were used to study product removal rate behavior, endpoint detection, and overpolish window. A significant amount of time was spent adjusting recipe parameters to eliminate residual copper (especially at the wafer's edge) and to achieve uniform and reasonable dishing and erosion performance.

Vendor Support

FAB25's internal polishing engineering staff was augmented with exceptional support from several local Austin companies. Together FAB25 engineers developed proprietary and patent-pending technologies to enhance the Auriga C's performance. Although not directly involved in the Cu Polish process, Momentum Technical Consulting's endpoint system was critical for identifying copper/tantalum to TEOS breakthrough. To improve the tool's performance, Atomic Medium upgraded the tool's operation software eliminating bugs and adding additional functionality. Graftek Imaging, Inc. worked closely with Spansion process and equipment engineers to develop a Residual Detection System (RDS) to promptly identify incomplete copper polish issues. Taking advantage of the Auriga C's configurable Motoman robot, engineering added an extra motion to the unload sequence so that an unloaded wafer is momentarily held underneath a camera system wired to a computer that scans the wafers for any residual copper. If any is detected, Spansion's control system logs the tool down. Images of the offending wafers can be examined for troubleshooting. Prior to the development of this system, operators had the laborious task of performing wafer-level inspections. When photo-induced corrosion issues were discovered, ChemWest provided complete customized retrofit kits to black out all Cu polishers and scrubbers. Spansion also benefited from strong relationships with its pads and conditioning ring suppliers. Perhaps most important of all were the numerous relationships that developed with various slurry vendors who provided an invaluable education into copper process development.

Defect Issues

During process development, Spansion engineers encountered several defect related issues. Some issues like **photo-induced corrosion** were resolved quickly after some technical research. There were three others that took more troubleshooting: **(1) residual copper, (2) final table microscratching, and (3) the so-called copper "rip-out" defect**.

The presence of gross residual copper is an obvious yield killer. Due to the limited knobs on the SpeedFam to adjust the tool's removal profile, Cu polish engineers worked closely with Cu plate engineers to produce custom film depositions based on SpeedFam requirements. As mentioned previously, an integrated residual detection system was designed to catch residual copper excursions.

With copper residual effectively eliminated, the next major technical challenge was microscratching. The original transferred buff slurry used fumed silica. This slurry could function without issues on a tool with an integrated brush conditioner such as the Mirra-Mesa. On the other hand, because the SpeedFam lacked a final table conditioner, its soft pad would become progressively more and more embedded with slurry, effectively becoming fine sandpaper. This caused excessive microscratching of the copper which required pulling the buff pad early in lifetime. While microscratching in of itself was not a significant yield concern, the saturation of defect scans masked true killer defects and therefore was unacceptable. To solve this problem, a completely different slurry employing colloidal silica and other proprietary components was tested and qualified. The new slurry eliminated the silica embedding problem entirely and as a result pad lifetime increased more than ten times which reduced consumable and test wafer expenses and dramatically increased tool availability.

One of the most challenging defectivity problems the team overcame was the "rip-out" defect which required significant troubleshooting. During defect review, engineering would find "U" shaped swaths of defects made up of hundreds of holes in a variety of damascened copper features. The edges of the holes were cut clean down to the spotless, underlying barrier metal. Sample SEM micrographs of this defect type are shown in Figure 3 and 4.

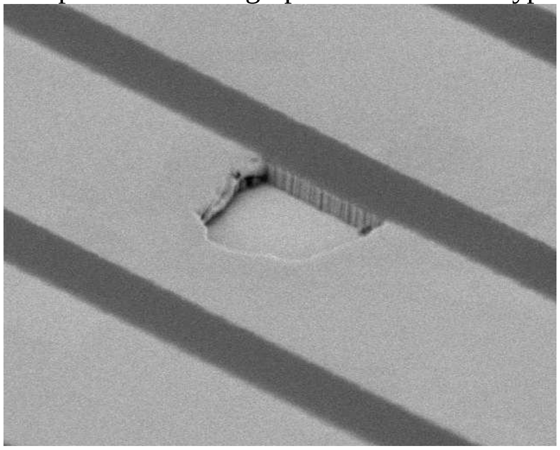

Figure 3. "Rip-out Defect"

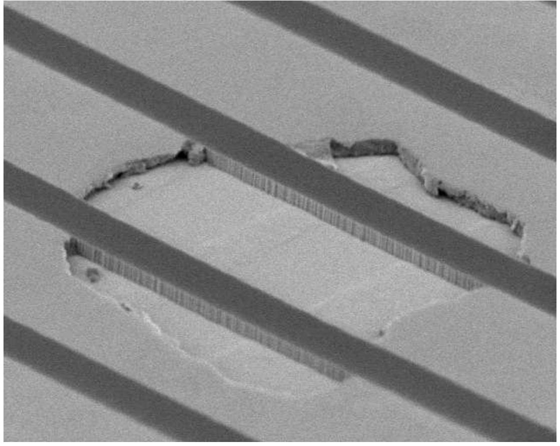

Figure 4. Three Cu lines ripped out

The defect density was directly correlated to the amount of processing that had occurred on the tool. For example, when a 25-wafer lot of copper blanks was processed on an idle tool, the first 5-wafer run would have hardly any defects, then the next 5-wafer run would have more of these "rip-outs", and the next run even more, and so on. If the tool was permitted to idle for an hour and the experiment was rerun, the same results were observed indicating the defect generator was accumulating or dissipating depending on whether the tool was operating or not.

One initial theory was that organic particles were being deposited onto the polished surface during the index unloading sequence. It was theorized that the particles were being sandwiched between the unload cup and the face of the wafer. When this interface was broken, the weakest bond was the copper-tantalum interface resulting in the cleanly ripped out area. This is the origin of the “rip-out” defect name. The index table is continuously replenished with fresh ultra pure water and so over time contaminants in the bath would be depleted.

During the investigation, it was discovered that polishing table fluids were being drawn into the carriers’s vacuum lines during normal operation. Slurry and other debris was being sucked between the wafer and the carrier film backing and then up through the carrier’s vacuum pin-holes into the carrier’s vacuum line. During the normal unload segment, wafers are ejected from the carrier with the assistance of water forced through these same vacuum lines and pin-holes. This was causing a blend of slurry, polishing byproducts, and potentially reacted materials or other contaminants from within the line to be dispensed into the water filled index table cross contaminating the loaded and unloading wafers. To further study this problem, Spansion engineers partitioned the process, removing wafers during various stages of processing. This work revealed that the damage was being done to only the unloaded wafers and not the wafers waiting to be polished in the same index table. Defect scans and reviews revealed these wafers were being covered with a combination of (1) randomly distributed spherical organic defects and (2) swath clusters of these same organic defects that had been pancaked flat on the wafers surface. These flattened “scabs” were then catalyzing an etching reaction into the copper. During normal processing, all of the copper beneath the defect would have been cleanly removed leaving the sharply delineated side walls and a pristine underlying tantalum surface. Figure 5 and 6 show two examples of organic catalyzed reactions halted early in the reaction. These defects have partially “melted” into the copper structures.

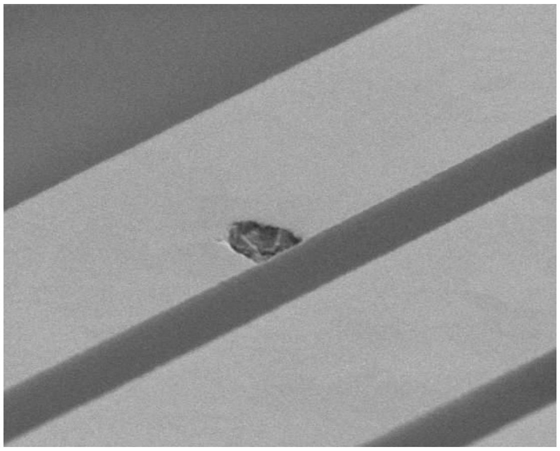

Figure 5. Organic catalyzed etch

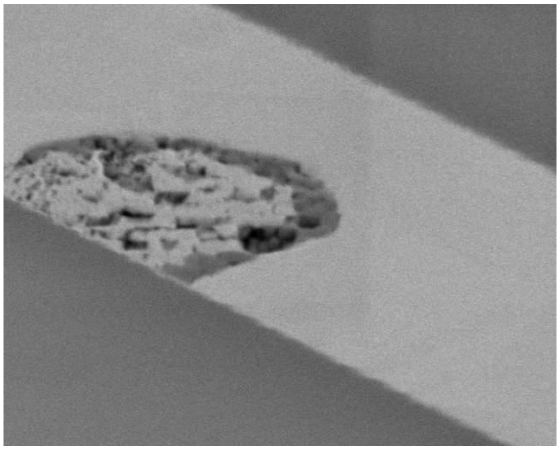

Figure 6. Uneven organic attack

Since the “rip-outs” were usually devoid of foreign material, it was assumed that the particles were removed during one of the two post Cu polish scrub processes. The engineering and maintenance team did not have an easy fix for preventing the fluids transfer problem. It was ultimately decided to spike the index table with the same passivation chemistry used during the final table process. This solution effectively neutralized the copper surface and prevented this surface particle catalyzed etching reaction, eliminating the problem.

SpeedFam v4.0

One of the last stages of development on the SpeedFam was a project to develop a single-platen copper and barrier polishing process. Although this work was ultimately not successful, it highlights some of the challenges in pursuing this type of strategy. The motivation for this work was to dramatically boost the throughput from 33 WPH to approximately 60 WPH and to further cut process expense. Several slurry vendors were tapped to provide very high removal rate, selective copper slurries capable of producing reasonable dishing and erosion at high downforce. To maximize throughput, the new process would have two components (1) each five wafer run would have no more than 185 seconds dedicated to main platen processing and (2) 115 seconds of wafer loading / unloading while ex-situ conditioning occurred on the main table. The total process time for each five wafer run would be limited to a total of 300 seconds (5 minutes) or an average of 1 wafer per minute. The final platen process would be entirely eliminated. The main platen time was selected because it was observed that the bottleneck in the tool was the 180 seconds required by the Motoman robot to fill the load cups. The copper polishing component of this work was surprisingly good. Two vendors were able to provide slurries that produced extremely impressive erosion and defectivity. Because of the high downforces employed to achieve a flat removal profile, dishing on large pads tended to suffer regardless of the slurry used. On the other hand, erosion tended to be quite reasonable. Perhaps most impressive of all was the erosion uniformity which when measured by High Resolution Profilometry (HRP) from center to edge, could be consistently achieved at less than 20 A! The biggest obstacle in a single-platen process was cross contamination between the copper and the barrier/dielectric slurry. Due to tool limitations such as the lack of in-situ conditioning and the ability to lift the carriers mid-process, residual copper slurry and polishing byproducts on the pad contaminated the buff process producing low removal rate and unacceptable removal profiles.

Benchmarking Performance

For initial qualification and benchmarking, FAB25 installed and setup the transferred BKM copper polishing process on an Applied Materials Mirra-Mesa. To bring the SpeedFam into production, SpeedFam Cu Polish engineers in FAB25 needed to demonstrate equivalent or better yield between the two competing tools. After extensive electrical and yield testing, the SpeedFam process was fully approved. Although several more Cu Polishing Mirra-Mesas have been added to FAB25's Polish module to allow for ramping of 90 & 65nm copper BEOL wafer starts, the majority of FAB25 Cu polishing capacity remains SpeedFam Auriga C. Sample yield comparisons between the tools have consistently demonstrated that SpeedFam performance is equivalent to Mirra-Mesa and both processes have similar tool throughputs. The SpeedFam Auriga C consumable costs (slurries, pads, conditioners, etc.) are 17% less per wafer pass than the competing Mirra-Mesa process. Obviously, eliminating the need for new capital equipment and related installation and facilitization expenses have helped to keep manufacturing costs down.

Conclusion:

Engineers at Spansion developed a copper polishing process using a legacy toolset most would have retired. Despite the tool's many limitations, the engineering staff successfully delivered an integrated process capable of producing equivalent yield at substantially lower costs over the best alternative method. There were undoubtedly challenges along the way, only a fraction of which have been described in this paper. By leveraging an existing deep reservoir of engineering, maintenance, and operational talent, an existing and efficient supply chain, and the outstanding support of numerous vendors, FAB25's Polish module was able to realize its goal of making efficient use of its assets to achieve a competitive advantage.