APRIL 2008

SolidState TECHNOLOGY®

THE INTERNATIONAL MAGAZINE FOR SEMICONDUCTOR MANUFACTURING

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Full-wafer post-via wet clean

non-visual defect inspection

EXECUTIVE OVERVIEW The optimization of wet clean and surface preparation processes is an industry challenge, due in part to the lack of adequate inspection techniques to detect non-visual defects (NVD). This article describes how a novel, nonoptical inspection technique was used to optimize an existing post-via wet clean process. A scanning differential work function technique detects submonolayer NVDs, allowing for an increase in die yield due to the elimination of residual cleaning media, and a reduction in cost through shorter rinse times and lower water consumption.

Optimization of manufacturing processes and development of new unit processes must consider three important factors: performance, cost effectiveness, and environmental performance. In many cases, these three factors are tightly coupled and therefore inseparable. Performance is essential to enable the manufacturing of advanced devices, and to ensure acceptable line yields from a defect perspective and fab yields from a device perspective. To maximize profits, cost effectiveness must be considered using variables such as cycle time, throughput, media usage, and yield. Finally, environmental considerations include water usage, chemical waste, and airborne emissions.

The time required to develop or optimize a unit process can be significantly shortened by using metrology and inspection. However, in some cases, the metrology and inspection may not be adequate enough to provide true feedback on a given performance metric. In the case of wet clean and surface preparation processes, traditional inspection systems using optical or e-beam techniques cannot detect critical yield-limiting NVDs.

Non-visual defect detection

According to the *International Technology Roadmap for Semiconductors* (*ITRS*), "Defects that cause electrical failure, but do not leave behind a physical remnant that can be affordably detected with today's detection techniques, are called non-visual defects. As circuit design becomes more complex, more circuit failures will be caused by defects that leave no detectable physical remnant" [1] based on the use of traditional defect inspection techniques. This new class of defects comprises mostly submonolayer residues that do not scatter light, thus making them invisible to optical scattering inspection techniques.

As shown in the **table**, these submonolayer residues may consist of organic residues, inorganic residues, trace-level metallics, water marks, and other yield-limiting surface chemical defects. NVDs are commonly associated with wet clean and surface preparation processes because they have a higher tendency for leaving submonolayer chemical residues on the surface due to rinse efficiency issues and surface interaction dynamics.

It is therefore critical that advanced inspection techniques be developed for the detection of these NVDs in order to provide fast, inline inspection for both process optimization and inline process monitoring. Previous work has been presented on using a scanning differential work function technique for the detection of submonolayer NVDs [2, 3], which is commercially available in the ChemetriQ inspection system from Qcept Technologies.

Post-via etch wet clean process

The process challenges associated with the post-via wet clean process are, among other things, driven by the need to remove etch residues from via structures while at the same time ensuring the complete removal of the cleaning chemical and associated reactants. **Figure 1** illustrates the post-etch condition where etch residue is present on the via surfaces.

Wet cleaning chemicals for backend-of-line (BEOL) cleaning can be composed of dilute acids, amines, surfactants, corrosion inhibitors, buffers, chelating agents, and numerous other additives. In some cases, the solutions can be as simple as a single dilute acid in water. Ultimately, the compositions of the residual etch polymers and the selectivity of the cleaning media to the interconnect materials will dictate the chemical to be used.

Sub-monolayer residues: Defect examples and available techniques

	Defect examples	Available inspection techniques	Available review/ classification techniques
Physical defects	Particles Scratches Pits Bridging	Laser scattering, optical imaging, e-beam	Optical microscope, SEM/EDX
Non-visual defects (NVDs)	Trace metallics Organic/inorganic residues Watermarks Charging	Scanning differential work function (ChemetriQ)	Analytical tools such as TXRF, TOF-SIMS, ICPMS

Since the polymers are composed of the very materials that are present in the device, the components of the cleaning chemistry used can—in the worst case scenario—degrade those materials if prolonged contact occurs. If there is a residual amount of the chemical left in the via, then out-gassing can occur (**Fig. 2**). It is therefore critical that the rinsing process following a wet chemical clean process be highly efficient and effective.

In the continuing effort to reduce process time and cycle time, and to increase the throughput of process tools, it is desirable to spend as little time executing a given recipe step as is practical. As such, minimizing rinse and dry time is important to unit process time reductions. The criteria for establishing what constitutes the minimum rinse time can be elusive due to the prevalence of NVDs, leaving the user with the possibility of a process that is prone to yield-loss excursions.

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Reprinted with revisions to format, from the April 2008 edition of **SOLID STATE TECHNOLOGY**

Via structures are basically capillaries, and as such are very sensitive to diffusion mechanics at the surface and within the via.

Most commercial cleaning media are designed to be highly miscible in water, thereby facilitating the efficient and rapid removal of the media from via structures. Dilute acidic and basic chemistries are also generally miscible in water, but can also leave trace residues if not completely diluted and removed from the structure. Complete removal is difficult to detect and often is only measurable through end-of-line electrical testing of device structures, and in some cases using subsequent inspection with TEM or SEM.

Vapor diffusion in via structures

While detailed discussion of vapor diffusion in via structures is beyond the scope of this article, general principles suffice to provide a picture of the phenomena involved. First, it is assumed that the vapor molecules in the via adhere to the sidewall of the via until they release or are struck by another molecule. Figure 2 illustrates the condition whereby residual liquid media is present in the via in the form of vapor and molecules adhering to the surfaces.

After via formation, the wafer exits the process chamber to atmospheric pressure with air as the ambient medium. The diffusion regime can be approximated by examining the relationship between mean free path and critical dimension. For example, if a via has a diameter of 65nm, and considering the properties of air at atmospheric pressure with a molecular mean free path of ~60 nm, a dimensionless number (the Knudsen number, Kn) representing the ratio of molecular mean free path to the physical critical dimension of the feature, would be approximately:

$$Kn = \lambda/d = 60/65 \sim 1$$

A Kn of 1 suggests the frequency of vapor molecule collisions between other molecules and via side walls will be the same. This sets up the condition whereby diffusion of vapor molecules out of the via can take place in the transient molecular flow regime without a velocity gradient. In the present study, the critical dimension of the via structure on the test wafers is 130nm, giving a Kn of ~ 0.5, which is also within the transient molecular flow regime.

Once a molecule exits to the air above the wafer, it will be subject to collision forces associated with the gas molecules and with electrostatic potentials. In the case of a dense via structure, or via chains, there are potentially thousands of capillaries, and therefore the flux of molecular species into the air adjacent to the wafer can be significant. **Figure 3** illustrates how molecular contamination from within a via could outgas and deposit adjacent to the via opening. Where the media in the via is well rinsed, no significant source of contamination is left.

Rinsing and drying of chemical media from via structures must be performed in an effective manner so as to provide a concentration gradient to promote diffusion of chemical species from the via, and to introduce boundary layer turbulence to increase diffusion through the addition of the turbulent diffusivity component to the overall diffusion. Spray rinsing is an effective means of removing chemicals, but narrow via structures require more attention to optimization.

For spin processes, the effective boundary layer velocity increases with wafer radius. Vias closer to the center can experience less overall diffusivity than those in the outer radii. As such, adjusting rinse and dry parameters to maximize the diffusion of chemical species from the vias in the center region of the wafer is important. Some cleaning chemical media contain a variety of chemical species such as fluorine, amines, surfactants, and various other materials that, if not completely removed, can be reactive with materials in the via such as barrier layers and copper contact surfaces or potentially deposit on the surface of the wafer as an outgassing event.

Inline detection of NVD trace molecular residues is therefore critical for providing faster feedback and lower cost alternatives for the optimization of the wet clean processes. In this study, wafers were processed on a Semitool single wafer clean system using a viscous chemistry from ATMI using a best known methods (BKM) process. The wafers were then inspected using the ChemetriQ inspection system for detection of NVDs, including trace molecular residues resulting from via outgassing events.

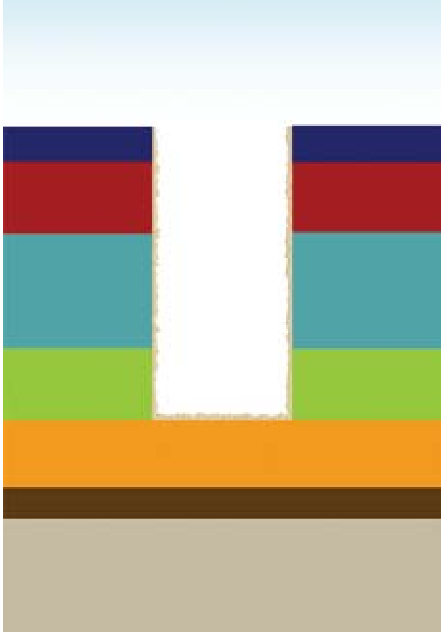


Figure 1. Illustration of a via structure following etching, with etch residue on sidewalls and floor of via.

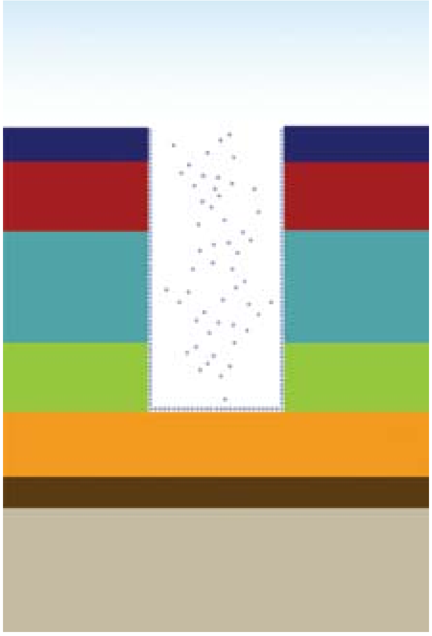
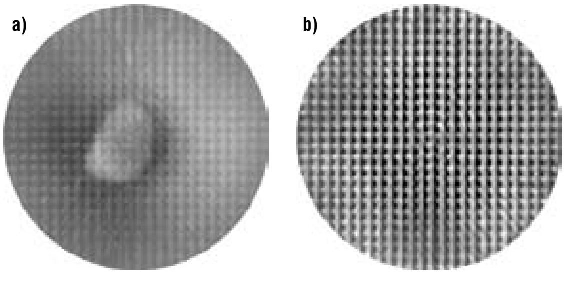


Figure 2. A post-clean via shows the presence of a monolayer of media and vapor that may be present in the via.

Figure 3. The scenario whereby residual media in the via "outgases" and deposits on the wafer surfaces adjacent to the via.

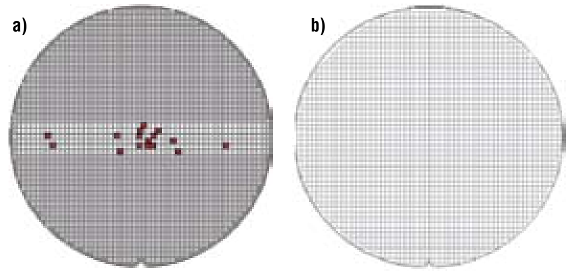
Experiment and results

For this study, patterned low-*k* wafers were processed and inspected to determine if NVDs were present after the post-via wet clean step. The via structures used in this study were 130nm in diameter with an aspect ratio of ~2.5-to-1. The wafers were processed using ATMI ST250, rinsed with DI water, and spin dried with an IPA/N_2 process. The wafers were then inspected on the ChemetriQ system 1) immediately after processing; and 2) after the wafers had been stored in a clean, sealed wafer box for 24 hours to allow further outgassing of potential residues trapped within the via structures. The most interesting results were obtained on the wafers stored for 24 hours.



Unoptimized Optimized

Figure 4. ChemetriQ results of stationary nozzle rinse condition wafer showing **a)** NVDs attributed to the via outgassing phenomenon, and **b)** results of sweep nozzle rinse condition wafer showing elimination of the NVDs.



Unoptimized Optimized

Figure 5. Probe yield maps showing **a)** defective die regions potentially influenced by trace residual media left behind by nonoptimized rinse process, and **b)** elimination of defective die with optimized rinse process derived from use of NVR analysis.

Wafers stored in a box experience very little circulation of air, since there is generally a lack of thermal and mass gradients present to promote circulation. However, on a microscale, if via outgassing does occur, the presence of the species gradient may create micro circulation and resulting diffusion and deposition of the outgassed species on the surface of the wafer.

In the case of trace amounts of pure deionized water, one would expect water vapor to completely diffuse into the air in the wafer box, and show nothing in the way of an NVD. However, if trace chemical media is present in the via, the assumption is that once outgassed from the via the small amount of mass would deposit on the wafer adjacent to the via, forming the NVD trace molecular residue that could then be detected by the ChemetriQ technique.

For this experiment, rinsing was accomplished using two different rinse configurations: 1) a stationary nozzle positioned at 5mm off center; and 2) a sweep nozzle translated across the center of the wafer to disrupt the boundary layer of liquid and introduce more turbulence to increase the turbulent diffusivity at the via surfaces.

As shown in **Fig. 4a**, ChemetriQ results for the stationary nozzle rinse condition clearly exhibit an NVD covering a large area at the center of the wafer, which was attributed to the via outgassing phenomenon. This clearly indicates that the rinse and dry process using the stationary nozzle is not fully optimized. In comparison, the effect of translating the water dispense nozzle through the center of the wafer during the rinse step resulted in a clean wafer surface (**Fig. 4b**). There is no apparent outgassing even after the 24 hours of queue time. Thus, the sweep nozzle rinse process completely removed the chemical media from the vias and should result in a higher yielding process.

The experiment's final step was to implement the improved BKM process at a customer fab site to study the correlation of the via outgassing signature to actual yield results. The production fab for this study was making vias with 90nm critical dimensions and aspect ratios of ~2-to-1. **Figure 5** shows a comparison of the stationary nozzle rinse vs. the sweep nozzle rinse, indicating a clear yield advantage to the latter.

The probe yield map in **Fig. 5a** using the stationary nozzle highlights a yield loss mechanism for die at the wafer center, which corresponds to the location of the NVD via outgassing events detected during the previous work done with ChemetriQ inspection. In comparison, the probe yield map shown in **Fig. 5b** using the sweep rinse had zero yield loss at the wafer center, indicating the optimized process was effective at removing the trace residues from the vias. Furthermore, the optimized sweep rinse used a shorter rinse time, resulting in reduced overall costs through shorter cycle time and reduced DI water consumption. Rinse time was reduced by 30%, which corresponds to a water use reduction of ~625 ml/wafer and a platform throughput increase of 10 wafers/hour.

Conclusion

We have presented a methodology to inspect for NVD patterns on a post-via wet clean process. This enabled the inspection and optimization of a post-via wet clean process that was then correlated to an actual increase in device yield at a 90nm production fab. Along with the yield increase, there was a reduction in cost through shorter cycle times and reduced DI water consumption using the optimized rinse conditions. ■

Acknowledgments

ChemetriQ is a registered trademark of Qcept Technologies. This article is based on a paper that was presented at the 2008 Sematech Surface Preparation and Cleaning Conference (SPCC).

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