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Yield Improvement Using Cryogenic Aerosol for BEOL Defect Removal

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A dry, cryogenic aerosol has been integrated into an advanced copper low k dielectric process flow for defect removal. The cryogenic aerosol is able to remove particulate defects from the exposed substrate materials without etching, charging or altering the conducting or insulating properties of the exposed materials. In this work, the cryogenic aerosol is composed of a mixture of argon and nitrogen. The results have confirmed high defect removal efficiency ultimately resulting in a yield increase. The application of a wet clean was not possible without adverse, yield decreasing side effects. Three BEOL processing steps will be covered in this work. The three steps are defect removal after via etch, film deposition, and in-line electrical probe.

Introduction

BEOL features containing copper and low k dielectrics have provided increasingly difficult cleaning challenges as the feature sizes and low k values decrease. Maintaining the integrity of the materials during the cleaning process is essential for optimum device performance but is difficult especially with wet chemical cleans. Copper corrosion, low k value degradation due to moisture absorption, insufficient drying in high aspect ratio features and drying marks due to mixed hydrophobicity are concerns with wet cleans. In response to this, several leading IC manufacturers have implemented a dry cleaning approach for defect removal for BEOL processes where sensitive features and materials are exposed.

The ability of a dry cryogenic aerosol to remove particulate defects without altering the substrate properties is well established (1, 2). This is the differentiating factor for the use of the cryogenic cleaning technology with the majority of the insertion points occurring in the BEOL. The same cryogenic aerosol advantages also are beneficial for FEOL processing and have been implemented for defect removal with exposed poly silicon gates (3).

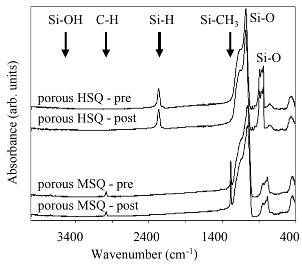

Figure 1. FTIR of porous low k before and after (post) exposure to a cryogenic aerosol. No observable change in the FTIR was detected confirming no moisture absorption occurred during processing which would result in degradation of the dielectric constant (1, 2).

Experimental

All work was performed on 300mm substrates in a 65nm logic production line. The wafers were processed in commercially available systems with a cryogenic aerosol generated from a mixture of argon and nitrogen gases (4). The gases are cooled as they pass through a liquid nitrogen dewar resulting in a mixture of cryogenic liquid and gas (Figure 2). The resulting mixture is delivered to the process chamber held at reduced pressure and exits through a nozzle located above the substrate. The nozzle contains a fixed number of orifices across the length to form the solid cryogenic aerosol clusters. The cryogenic liquid goes through a region of rapid expansion as it exits the orifices in the nozzle resulting in liquid droplets that freeze to form solid aerosol clusters. These solid aerosol clusters impact the substrate and dislodge the defects by momentum transfer. Thermophoresis and a laminar flow of nitrogen across the wafer surface combine to remove the dislodged contaminants and solid aerosol clusters from the process chamber.

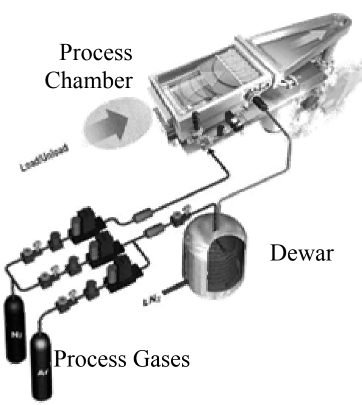

Figure 2. A schematic of the hardware for forming the cryogenic aerosol. The solid cryogenic aerosol clusters are formed when exiting through the nozzle located in the process chamber.

Results

Particle Removal Efficiency

An evaluation of particle removal efficiency (PRE) on blanket wafers was the initial metric to gauge the effectiveness of the cryogenic aerosol clean. The silicon nitride particles were deposited with a commercially available MSP deposition system and aged for greater than 72 hours before processing. The results of four, two process chamber tools are shown in Figure 3. For all particle sizes measured, PRE was greater than 99%.

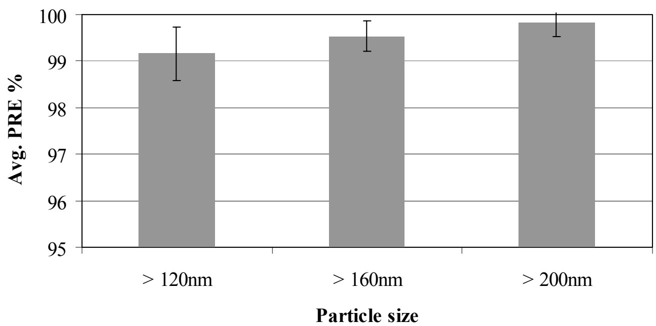

Figure 3. PRE of MSP deposited Si_3N_4 on blanket Si wafers. Greater than 99% PRE was achieved for all particle sizes measured without any material loss or modification of the substrate.

While the PRE is an important metric on the blanket test wafers, the ending defect count on a device wafer after processing is equally or more important. Using the PRE values on blanket wafers as a guide, the average remaining defect count on the device wafer surface can be expected to be less than two at greater than 0.12µm. As will be seen with the data presented below, this number was not realized due to all particulate, surface and underlying defects being included in the defect count.

Particle adder data has also confirmed the low defect counts possible with the cryogenic aerosol. On site process optimization reduced the particle adders compared to the previous process of record resulting in average adder counts in the single digits at greater than 0.12µm particle size. This level of particle performance is possible on hydrophilic, hydrophobic and mixed hydrophobicity surfaces with the dry cryogenic aerosol.

Post Via Cryogenic Aerosol Clean

At this application point, defects are present on the substrate surface after via etch and ash. A wet chemical approach to remove the defects is not desired due to the high aspect ratio of the vias and the inability to dry inside these features. Figure 4 contains SEM images of the defects present. The defects typically range from the smaller size of 150µm up to greater than 2µm.

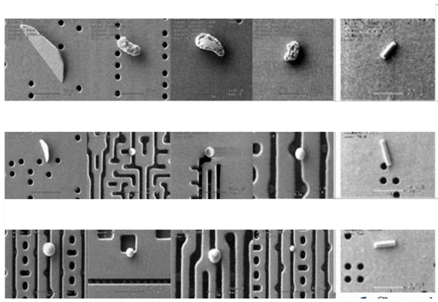

Figure 4. SEM images of the defects of interest after via etch that are removed by the cryogenic aerosol. Defects range in size from ~0.150µm to greater than 2µm. Energy Dispersive X-ray spectroscopy (EDX) indicated the defects are mainly composed of silicon.

All detected defects, particulate, surface and underlying defects, are included on the wafers maps and graphs in the following two figures. A typical patterned wafer map before and after processing with the cryogenic aerosol clean is presented in Figure 5. Removal of these types of defects with the cryogenic aerosol is significant.

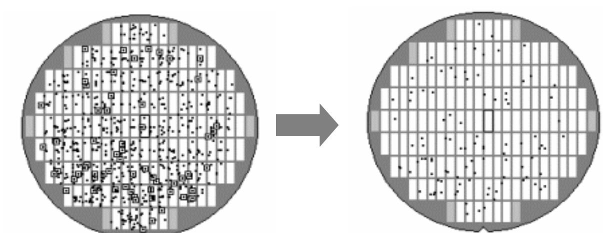

Figure 5. Patterned defect wafer maps before and after a cryogenic aerosol clean. Significant defect reduction is observed after the cryogenic aerosol clean. All particulate, surface and underlying defects are shown.

Figure 6 quantifies the defect reduction monitored over 38 lots processed with the cryogenic aerosol. Again, it is important to note all particulate, surface and underlying defect counts are reported. The true defect removal rate will increase when only the particulate defects are considered but the average defect count was reduced from 242 ± 197 to 55 ± 40 defects with a cryogenic aerosol clean. It is also important to note the highest defect counts are reduced very efficiently with the cryogenic aerosol.

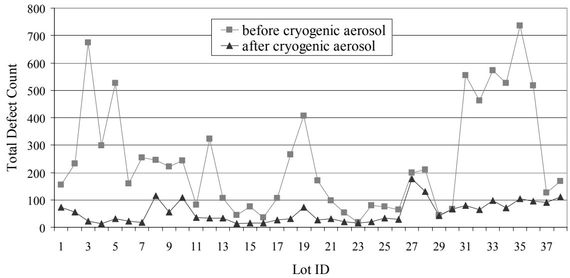

Figure 6. Total defect count after via etch (before cryogenic aerosol) and after a cryogenic aerosol clean. Total defects were reduced from an average of 242 ± 197 after via etch to an average of 55 ± 40 after the cryogenic aerosol clean. All particulate, surface and underlying defects are included in the defect count.

Post Film Deposition Cryogenic Aerosol Clean

Even very small defects left on the surface at this process step can be magnified by subsequent film deposition processes. The films deposited include TEOS, SiN, or SiCOH which vary in their surface hydrophobicity but they all require cleaning without material modification, loss or residue left behind in the form of watermarks or particle adders. Again, the cryogenic aerosol is very effective at removing the defects after film deposition determined to be silicon and oxygen by EDX shown in Figure 7.

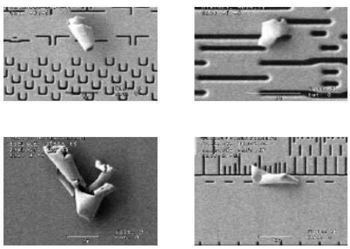

Figure 7. SEM of the defects present after film deposition. Defects sizes range from ~0.50µm to greater than 2µm and are composed of silicon and oxygen. These defects are effectively removed by the cryogenic aerosol.

Figure 8 contains a wafer map of all detected defects after film deposition and after a cryogenic aerosol clean.

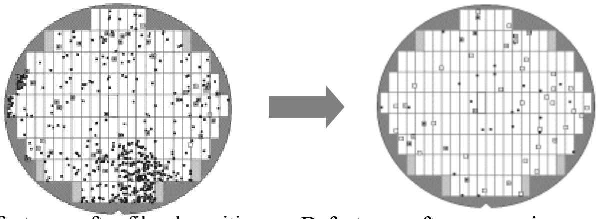

Figure 8. Patterned defect wafer maps before and after a cryogenic aerosol clean. All particulate, surface and underlying defects are shown in the wafer maps.

Post In-line Electrical Cryogenic Aerosol Clean

The particulate defects created from the physical contact of the in-line electrical probe parametric testing at metal 1 and metal 2 are also removed with the cryogenic aerosol. The ability to remove defects after in-line probe is especially critical to allow the collection of valuable parametric data without sacrificing yield (5). Probing is done on a planar surface with regions of copper exposed as well as dielectric material. Copper corrosion concerns and difficulty in drying the patterned wafer surface after a wet chemical exposure are the main drivers for using a dry cryogenic aerosol clean for defect removal at this insertion point. Figure 9 shows SEM images of the particulate defects created after the in-line electrical probe test.

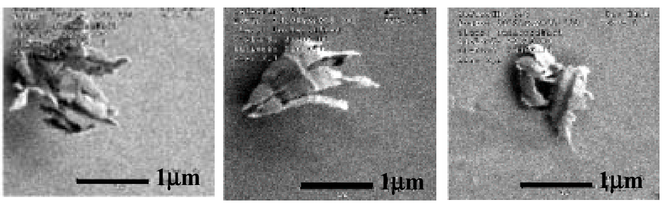

Figure 9. SEM images of the particulate defects created by the physical contact of the probe during in-line electrical testing removed by the cryogenic aerosol.

The particulate defects generated by the in-line electrical probe are removed with the cryogenic aerosol. This ability to remove defects without any surface modification is critical for returning the in-line electric probe wafers for further processing.

Summary

Dry cryogenic aerosol is being used in production at three process insertion points in copper BEOL integration. By implementing the cryogenic aerosol a significant yield improvement has been achieved. Wet cleans were not considered as a viable solution at these insertion points due to material incompatibility with either the chemical processing (copper corrosion, material modification) or drying (watermarks or high aspect ratio features). Evaluations continue to expand the application insertion points to other areas in the BEOL and the FEOL. Specific areas under investigation include structures sensitive to damage and material loss.

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