Post Etch Residue Removal: Novel Dry Clean Technology Using Densified Fluid Cleaning (DFC)

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Abstract
A novel dry cleaning technology has been developed by GaSonics, which was successfully applied to post etch residue removal. Densified Fluid Cleaning (DFC) is a dry source, liquid mode cleaning technology. It is based on application of densified gases at elevated pressures and low temperatures. When used together with microwave downstream plasma treatments, DFC enables the damage-free removal of heavy post etch residues, containing Al, Ti or Cu, not readily affected by other wafer cleaning methods.

Introduction
Post etch residue removal is one of the most challenging problems IC manufacturing face today. High density plasma sources, new (and smaller) device structure and a higher degree of overetch required, contribute to the formation of stubborn polymeric veils surrounding the patterned features. These metal containing residues (Al, Ti or Cu) can not be removed by conventional oxygen plasma used for photoresist removal, and often persist after expensive liquid cleaning.

GaSonics has developed a novel dry cleaning method, which has shown successful results when applied to post etch residue removal (1,2). Densified Fluid Cleaning (DFC) can be described as a dry source, liquid mode cleaning technology. It is based on applying densified gases at elevated pressures (20 – 25 atm) and low temperatures (20 – 60^{o}C) to the wafer surface. The gas of choice is ammonia. The liquid (or liquid like) layer formed on the wafer surface performs the cleaning action in a way similar to liquid cleaning methods. At the same time, DFC has all the advantages of dry, gas based methods: lower cost, improved safety and reduced environmental and health impact (3, 4). A megasonic enhancement is also used to improve cleaning efficiency.

DFC was successfully used for removal of stubborn polymeric residues formed during via etch (2) and metal etch, when used together with microwave downstream plasma treatments. Different via types were cleaned applying this method: straight, tapered, high aspect ratio, and unlanded vias. The residue removal was characterized visually by SEM and by performing electrical tests (via chain resistance, flat-band voltage shift). Ammonia is an excellent solvent for a broad variety of organic and inorganic substances. This dual affinity leads to strong interaction between ammonia and the metal-containing sidewall polymer. It was confirmed that DFC is not damaging typical materials used in manufacturing of IC devices: Si (by measuring roughening changes by AFM), oxides and different types of SOG materials (thickness and refractive index changes), metals – Al, Ti, TiN (sheet resistance changes), and coatings – Cr, SiON, TaSi, TaSiN (morphological changes measured by AFM).

Experimental
<u>DFC process</u>: The wafer is placed in the DFC reactor on a rotating platen, which is kept at a lower temperature (20^{o}C) than the reactor walls. Hot pressurized ammonia vapor is introduced into the reactor, and condense preferably on the wafer surface. The pressure in the reactor is kept at 20 - 25 atm. A megasonic device enhances the ammonia action on the post etch residues and particles by transferring additional mechanical energy to the wafer through the densified layer formed on the wafer. At the end of this process (time controlled) the reactor pressure is released, the ammonia evaporates from the wafer surface and the wafer emerged dry from the DFC tool.
<u>Integrated Cleaning</u>: The post etch via wafers were cleaned by applying GaSonics "Integrated Clean^{TM}" technology, which in this case indicates a combination of Microwave Downstream Plasma (MWD) and DFC treatment. MWD-plasma refers to low temperature, fluorine containing plasma (O_2/NF_3).
The wafers were processed first by MWD plasma, followed by the DFC step. The MWD clean parameters (gases ratio, flow rates, temperature, pressure) needed to

be adjusted for the plasma clean step in order to obtain an effective process without damaging the oxide, ARC and metal layers.

The MWD plasma step was performed in GaSonics PEP clean tool, equipped with End-of-Process (EOP) Controller (Luxtron, Model 1015). Hitachi S-4200 SEM was used for evaluating the wafer cleanliness.

Results and Discussion

Post via etch residue removal:

Fig.1 shows an example of a two-step DFC-based cleaning technology of vias, where the etch stopped on the Al/Si/Cu layer, with a high degree of overetch. The wafers were etched on Lam 4500 tool with fluorine containing chemistry. As-received wafers can be seen in Fig. 1(a), with heavy residues in the via bottom and sidewall, and “crust” layer on top of the photoresist. The first step, low temperature MWD-plasma (O_2/NF_3), removes the photoresist layer and most of the hard polymeric crust on top of it and causes partial breakdown of the polymeric via residues (Fig. 1(b)). The fluorine containing chemistry generates porosity in the residues, and converts it to a form that can be completely removed by the following DFC step. The final results can be observed in Fig. 1 (c, d). After the DFC step, the polymeric residues were completely removed from the bottom and sidewalls of the vias, as well as from the wafer surface. The ammonia extract organometallics from the residue, and causes further fragmentation. Densified ammonia causes detachment of the residues from the via walls by inducing mechanical stresses resulting from mechanical and chemical interactions between ammonia and organometallic polymers. This action is enhanced by the megasonic device. Due to its physical properties (surface tension, viscosity) ammonia is able to penetrate into high aspect ratio vias, and affect the upper, lower and bottom part of the via residues.

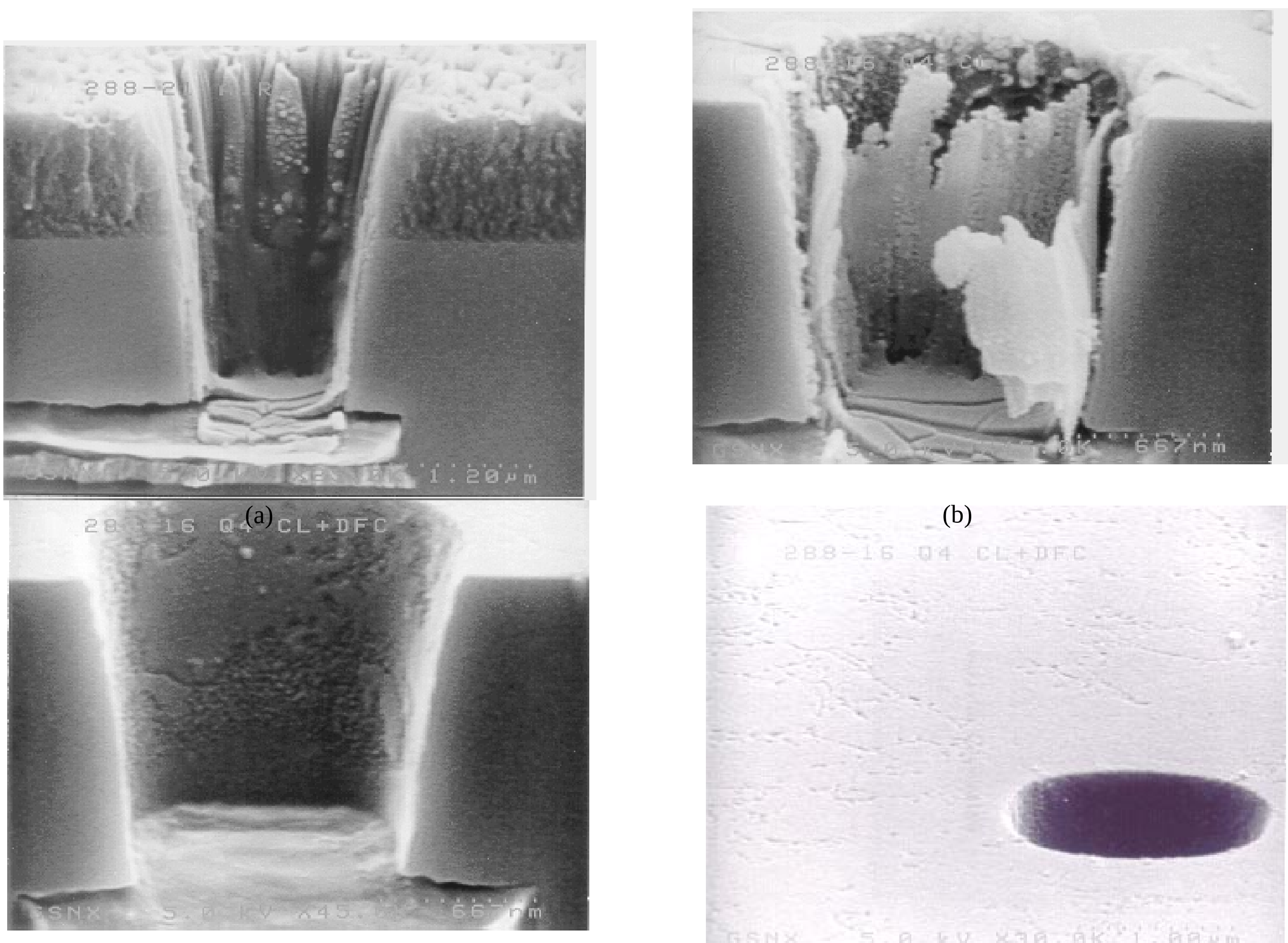

Figure 1: Post via etch residue removal by DFC technology: (a) as-received wafers (x80 k magnification) ; (b) via residue after MWD-plasma treatment (x70 k) ; (c, d) clean via, after MWD-plasma + DFC 2-step process (x70 k, x100 k).

(c) (d)

<u>Post metal etch residue removal:</u>

Two-step cleaning technology for post metal etch wafers, based on MWD-plasma followed by DFC, is illustrated in Fig. 2 . As-received samples, with photoresist on top of a thin SiON layer can be observed in Fig. 2(a). After the first MWD-plasma step (O_2/NF_3 chemistry) the photoresist layer was removed, but polymeric residues can clearly be observed on the sidewall of the Al metal lines. These organometallic residues are completely removed by the following DFC step.

Conclusions

DFC is an innovative, non damaging, dry, low temperature wafer cleaning technology. Combined with the appropriate MWD-plasma treatment, post via etch and post metal etch residues can be completely removed by applying a two-step cleaning process. We have demonstrated the absence of any adverse effect of the DFC with respect to typical IC device materials and their electrical properties.

References

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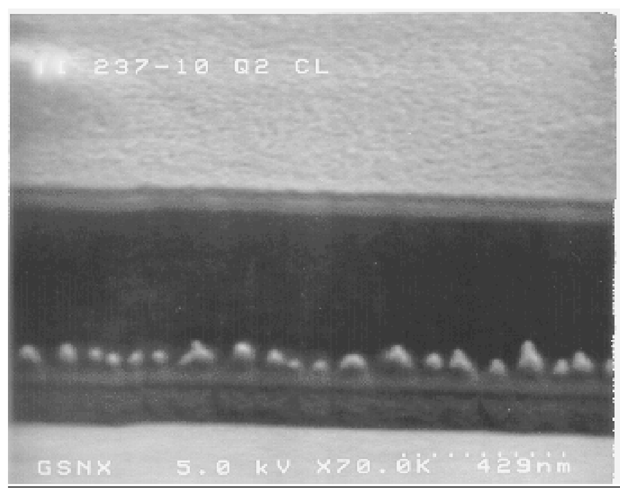
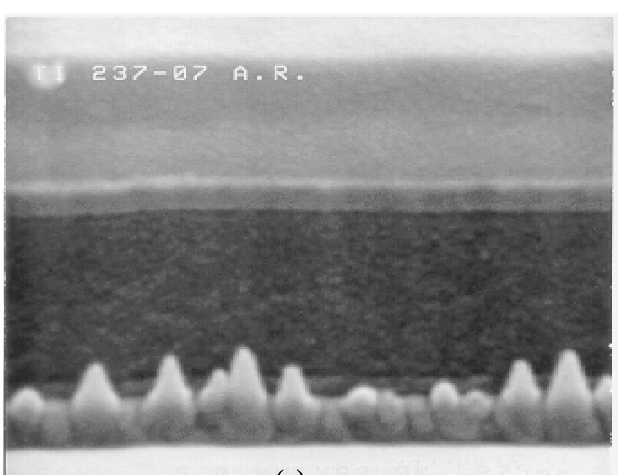
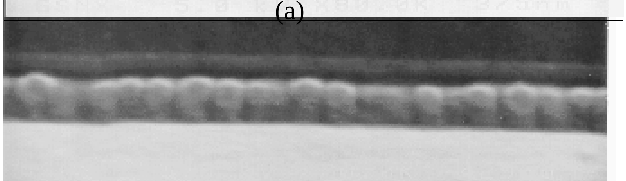
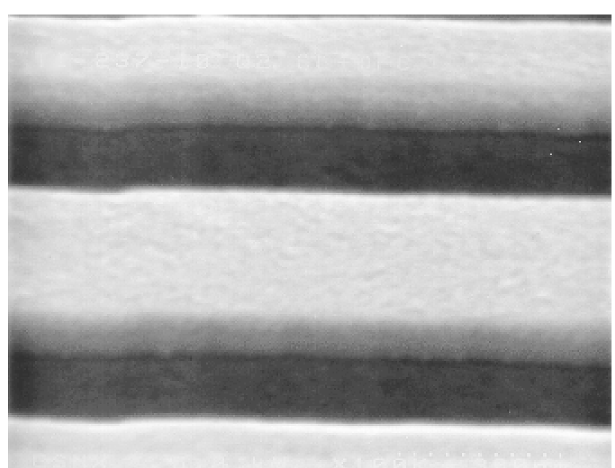


(b)



(a)





(d)