65NM YIELD DETRACTOR CAUSED BY M1 FILAMENT SHORTS AND SOLUTION

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Abstract

Device scaling has been implemented throughout the chip making industry as a means of increasing density and performance. This has imposed a lot of challenging tasks to develop new processes, improve process window and reduce defect density. In our fabrication of 65nm W contact to M1 scheme, we found severe metal 1 shorts after electrical testing, these shorts potentially causing drop in SRAM yield of ~ 40%. It is interesting to note that M1 shorts are induced by W CMP process. Detailed investigation showed that M1 shorts are related to post-W CMP topography and high-density of contact, which trap W-residues. This has subsequently affected M1 patterning processes. Electrical testing result shows the dependency of M1 failure rate on contact pattern density. In addition, cross-section TEM micrograph shows that adjacent metal lines are connected by filament, which contained Cu by EDX measurement. Base on our hypothesis, we have proposed the best ways to suppress this issue by optimizing W CMP platen 3 polishing time and DI water buffing time.

Keywords: W CMP, M1 shorts and Contact Pattern Density

Introduction

Chemical Mechanical Planarization (CMP) process has been widely used in the semiconductor industries [1-3]. In the complex world with stringent requirements (high planarity, low defectivity level and high device yield) of semiconductor device fabrication, any material that is part of the final device or makes contact with the wafer during processing must be qualified before being released for production. For Tungsten (W) CMP process, this may include incoming film composition, W and liner composition, pads, slurries and chemicals used in the post W CMP cleaning.

The tungsten CMP process is accomplished utilizing slurry that includes abrasive particles and a chemical reagent. Slurries for tungsten CMP utilize alumina (Al_2O_3) or silica (SiO_2) fine particles as an abrasive material in a harsh oxidizing environment. The choice of a preferred oxidizing agent depends on the overall scheme of slurry and the specific requirements of the tungsten CMP process. Oxide buff after W polish is always an alternative way to help in achieving better topography performance. Most CMP processes utilize a subsequent cleaning process referred to as post-CMP cleaning for removal of a contaminated layer on the substrate. The degree of contamination and damage to the wafer following a CMP process is a function of the polishing parameters and the set of consumables used in the process. Thus, this has imposed a lot of challenging tasks to develop new processes, improve process window and reduce defect density in W CMP process. In this aspect, we have deployed the BEOL CV® test chip [4] as the key vehicle to debug issues and optimize our 65nm W CMP process for world-class manufacturing,

The CV® test chip (Fig. 1) includes test structures to electrically quantify fail rate across many different design styles, minimum and sub design rules. In 65nm W contact to M1 scheme, different contact density varies from 0% to 12%, were designed underneath M1 snake comb structure, to evaluate the topography effect on subsequence processes. Through electrical testing, we found the dependency of M1 shorts on contact density. In this paper, we investigated the root causes of M1 shorts and based on our hypothesis, we have proposed solutions to solve the issue.

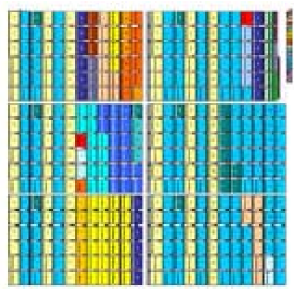


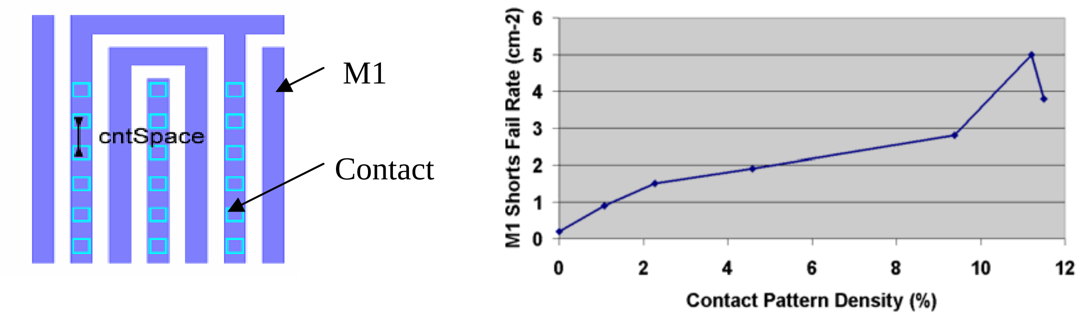
Figure 1. PDF Solutions' Back End of Liner Characterization Vehicle® test chip.

Experiment

The devices analyzed had 65nm design rules for the back-end-of-line metallization and the dielectric thickness. The device was fabricated by pre-metal dielectrics deposition, contact masking, contact etch, liner deposition, W fill and W CMP. M1 was processed using the single damascene approach. To address the issue, several splits were conducted at different W polishing time and DI water buffing time at platen 3 after W CMP. Electrical data of device was collected at M1 using PDF Solutions' Back End of Line Characterization Vehicle®. Atomic force microscopy (AFM) was used to measure the topography across the contact area after platen 3 W CMP. Finally, the wafers were optically scan to detect the presence of defect. Cross-section of the defects was characterized by transmission electron microscopy (TEM).

Results and Discussion

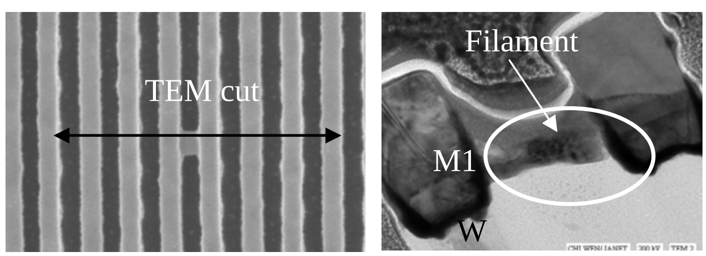
Figure 2a shows snake-comb structure with W contact designed in PDF Solutions' Back End of Line Characterization Vehicle® test chip, which is used to debug and improve process performance. Electrical testing result shows the dependency of M1 failure rate on contact pattern density as shown in Fig. 2b. It clearly indicates that M1 shorts increase with contact pattern density.



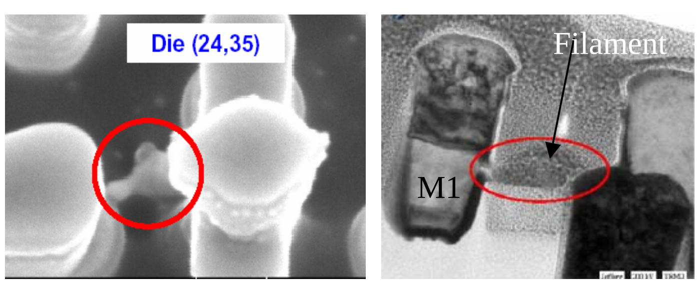
(a) (b)

Figure 2. (a) Snake-comb structure designed in CV® test chip with contact pattern underneath M1. (b) M1 electrical data shows M1 shorts increased with contact pattern density.

Further investigation was carried out using transmission electron microscopy on cross-section on the failure site as shown in Figure 3. Figure 3a shows SEM top view of M1 shorts. Cross-section TEM micrograph shows that adjacent metal lines are connected by filament, which contained Cu by EDX measurement. Another failure location shows CA to M1 shorts, as shown in Figure 3c and 3d. One common feature underlying these TEM results is the position of the filaments, which predominantly observed ontop of dielectric films after W CMP. Thus, we suspected that the root cause might not originate from M1 single damascene processes, but from the previous process steps. Hence, this narrowed down our inspection to W CMP processes.



a b



c d

Figure 3. a) SEM top -view on M1 to M1 shorts, b) TEM cross-section showing M1 to M1 shorts (filament), c) SEM top-view on CA to M1 shorts, d) TEM cross-section indicates CA to M1 shorts.

Further investigation was carried out using inline inspection after W CMP process. The SEM scan results showed that more than 50% of W-residues were randomly distributed and trapped in between W plugs as shown in Figure 4. This gets worse with higher contact density.

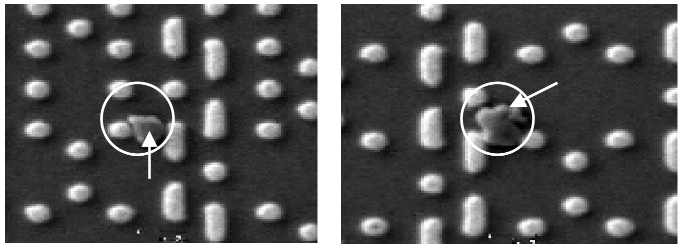


Figure 4. SEM scan picture showing W-residues trapped in between W plugs.

In addition, cross-section TEM results also show that the W plugs protrusion of 383Å as shown in Figure 5. These results suggested that the protrusion of the W plugs at high-density area would have high chances of trapping the residues. The next question is how these residues at post-W CMP caused M1 shorts? After detailed investigation and discussion, we come out a hypothesis as shown in Figure 6.

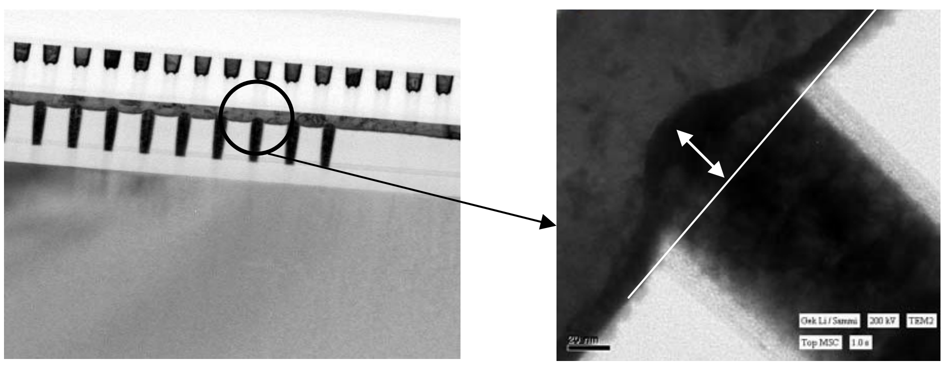


Figure 5. Cross-section TEM shows W plug protruded 383 Å, which has high chance of trapping W-residues.

Figure 6 represents the schematic of our hypothesis showing W-residues induced M1 shorts. If the patterning of M1 trench landed on W-residues as shown in Figure 6a, it will affect the M1 profile. During M1 trench etch, the difference in etch rate between the residues and dielectric causing notch formation at the sidewall as shown in Figure 6b. After wet clean, this notch will be aggravated as shown in Figure 6c. As a result, PVD liner is not able to deposit on the notch location as shown in Figure 6d. Thus, during electrochemical plating, Cu can fill in the notch and contribute to the filament formation as shown on Figure 6e, and thus cause M1 shorts.

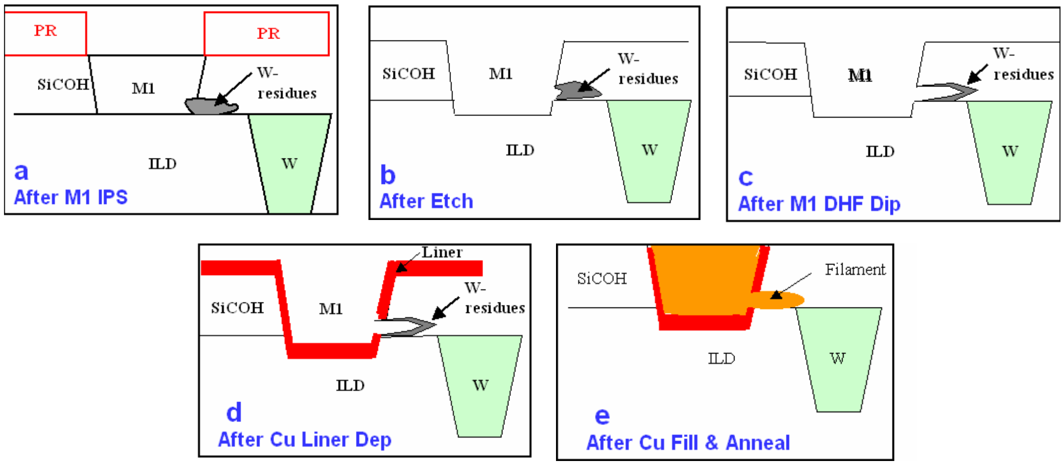


Figure 6. Schematic showing the hypothesis of CA induced M1 shorts. a) Residues from W CMP affect M1 patterning. b) Etch rate between SiCOH & residues could be different, inducing notch on sidewall. c) After wet clean, notch was aggravated. d) Liner unable to deposit on the notch. e) Cu will diffuse through the notch, and formed M1 filament.

Through these observation and understanding, we addressed the issue by optimizing our W CMP recipe to eliminate the W plugs protrusion and the trapped residues. Several splits were conducted at different platen 3 polishing time and DI water buffing time at platen 3 after W CMP to resolve W plugs protrusion issue and W residues removal respectively. Experimental results showed that by reducing W CMP platen 3 polishing time of process of record (POR), oxide loss was reduced. This reduced W plugs protrusion to less than 100Å as shown in AFM measurement in Figure 7.

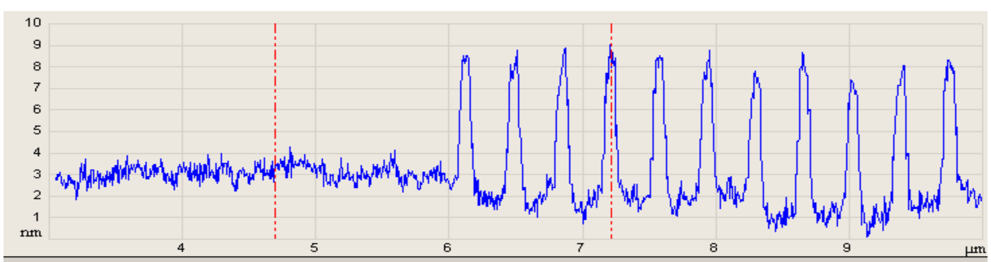


Figure 7. AFM profile scanned across contact area after platen 3 W CMP new recipe. It shows that W plugs protruded < 100 Å, which is much more less than that in Figure 4.

For the W residues removal, we have also investigated different DI water buffing time at platen 3 after W CMP. We found that too long buffing time would cause W recess. Through this investigation, the new optimized buff time, was effective in removing the W residues. With the above solutions, we found that M1 shorts were greatly reduced and it is now independent of contact pattern density as proved in electrical testing results as shown in Figure 8.

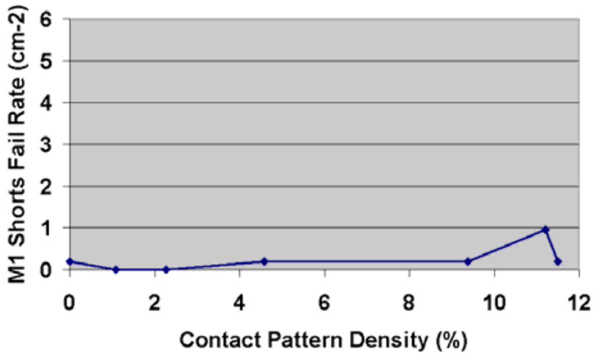


Figure 8. M1 shorts failure rate is greatly reduced and independent of contact pattern density with optimized platen 3 polishing time and DI water buff time.

Conclusions

Severe M1 to M1 shorts and CA to M1 shorts were found during the development stage of our 65nm device. Throughout detailed investigation, M1 shorts are found to be related to post-W CMP topography and high-density of contact, which trap W-residues. By optimizing the W CMP platen 3 polishing time and DI water buffing time, post-W CMP topography is flattened and the residues are effectively removed and hence improved M1 shorts.

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