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TiN metal hard mask removal with selectivity to tungsten and TiN liner

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Abstract

The challenge associated with titanium nitride (TiN) hard mask stripping in the presence of tungsten (W) has been reported[1]. It was pointed out that low-pH formulations utilizing oxidants other than hydrogen peroxide (H_2O_2) exhibit superior TiN selectivity toward Cu, W and dielectric films. The difficulty of an all wet TiN metal hard mask (MHM) removal further increases if a TiN barrier layer between the W and inter-level dielectric layer (ILD) is exposed during the stripping step. While this problem can be addressed through fundamental electrochemistry and proved out in laboratory testing, refining a chemical strip chemistry to meet needed performance criteria on integrated CMOS structures requires close collaboration between material supplier and device manufacturer. The goal of this study was to optimize formulations with TiN MHM etch rates ≥ 100 Å/min at temperatures $\leq 60^{o}$C, with compatibility to W, ultra-low k films, and the TiN liner. To facilitate this work a simple but novel patterned wafer test vehicle was developed.

Results

Electrochemical studies demonstrated the possibility for galvanic protection of the TiN liner within the integrated wafer structure (Figure 1). This galvanic advantage is one main factor allowing for the removal of TiN MHM while preserving any exposed TiN liner around the W contact. Note that with only minor compositional changes, the galvanic corrosion reaction can be tailored to better protect the TiN liner in the presence of W.

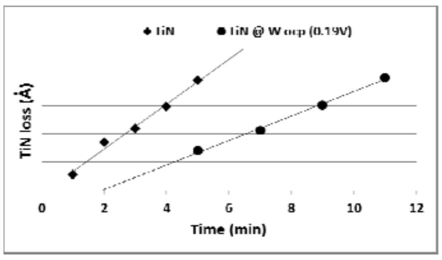

Figure 1 TiN etch rate reduction observed when system is held at W open circuit potential in TK10 chemistry.

Patterned shortflow wafer coupons were processed to validate etch rate results and an initial testing on fully integrated structures was run on a single wafer tool (SWT). Top down SEM and FIB-STEM on coupon wafers was sufficient to verify that TiN MHM removal was complete with no bulk damage to the W contact. However, TEM images on the fully integrated wafers showed minor damages to the W contact and/or TiN liner (Figure 2). Response on integrated wafers was not fully predicted by blanket wafer data and bulk film etch rates alone could not distinguish small differences in effect on W and the TiN liner. Even TEM data on fully integrated wafers was not sufficient due to small sample size and subjective interpretation. In principle, these small differences in impact to the W and TiN liner, while difficult to quantify with TEM, and not necessarily obvious even with inline electrical measurements, can have a large impact on product reliability.

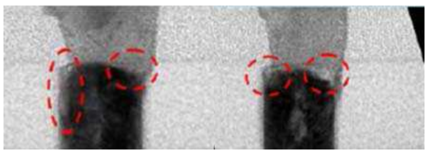

Figure 2 TEM of processed integrated structure at 60°C for 4 minutes. Suspected damage to TiN liner and W contact highlighted.

Identifying a method to minimize the risk of W or TiN liner damage prior to running electrical and reliability wafers was critical to finalizing a formulation. A test structure, referred to as a "W flop-down" wafer, was created to allow evaluation of the chemistry impact on both the W and TiN liner. Figure 3 shows the resulting top down SEM images after chemistry exposure for 30 minutes. In these images, the impact on W is much clearer than from FIB-STEM or TEM. Determining the optimal chemistry with the least damage to the TiN liner was also crucial, and thus the same test structure was used. Figure 4 shows FIB-STEM results after processing at 60°C for 60 minutes. Differences in the TiN liner impact between the chemistries can now be observed. Furthermore, FIB-STEM at these extended process times also increased visibility of more subtle damage of the W film.

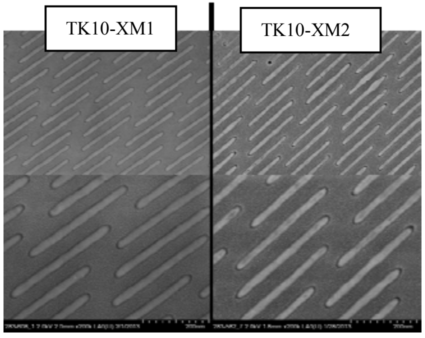

Figure 3 Top down SEM images of W flop-down wafer processed at 60°C for 30 minutes. Using this test vehicle damage to the W can be clearly observed in TK10-XM2.

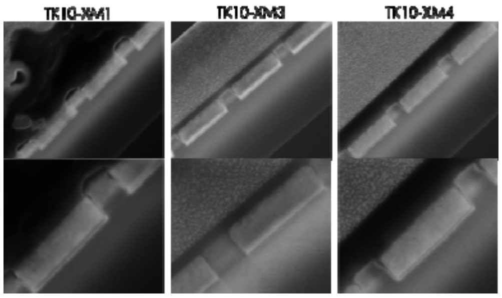

Figure 4 FIB-STEM images for W flopdown wafer processed at 60°C for 60 minutes. TiN liner damage and/or corner rounding of the W line for TK10-XM3 is visible.

Conclusion

TiN MHM removal formulations with removal rates ≥150 Å/min have been developed with excellent compatibility to both W and TiN liner. A combination of traditional development methodologies utilizing blanket wafer etch tests, electrochemical analysis, and standard structures for SEM was paired with a simple but novel test structure that improved the ability to resolve fine differences in formulation performance.

Acknowledgement

This work was performed by Alliance Teams at various IBM Research and Development Facilities.

[1] Emanuel Cooper, Rekha Rajaram, Makonnen Payne and Steven Lippy, Selective high-throughput TiN etching methods, UCPSS 2012.