MECHANICAL STRESS EFFECTS ON ELECTROMIGRATION VOIDING IN A MEANDERING TEST STRIPE

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ABSTRACT

Earlier experimental findings concluded that electromigration voids in these meandering stripe test structures were not randomly distributed and that void nucleation frequently occurred sub-surface at the metal/thermal oxide interface. The data showed a strong correlation between void area, void growth rate and stripe segment length [1]. The influence of mechanical stress on electromigration damage in these test structures has been examined by applying tensile stresses to both passivated and unpassivated samples. The stress distributions are calculated using finite element analysis for each of the test conditions. The resulting impact on electromigration voiding, as well as mechanical stress voiding, and lateral hillock formation is discussed.

INTRODUCTION

The influence of mechanical stress on electromigration has been reported by many investigators [2-6]. The analysis of several experiments have suggested that vacancies created by the mechanical stress create an environment for void nucleation and subsequent growth [6-7]. Rome Laboratory conducted a thorough electromigration damage susceptibility evaluation on samples using a meandering test stripe. The analysis concluded that the majority of the electromigration voids nucleated on the metal edges at the metal/thermal oxide interface. Additionally, it was found that the void distribution was not random and occurred preferentially along the shorter length segments. These samples provided a well characterized vehicle for the mechanical stress/electromigration testing.

These experiments applied mechanical loads which altered the stress magnitude at the metal/thermal oxide interface along the shorter length segments of the stripe during the electromigration testing. 100%1 Al and Al/l% Si samples were tested, both passivated and unpassivated. Passivation is known to influence both electromigration behavior and mechanical stress in VLSI metallization [8].

EXPERIMENTAL

A 3 μn x 1690 μn meadering test stripe, shown in Figure 1, is used to perform the mechanical stress/electromigration tests. The test stripes are 0.8 μn thick, sputter deposited on 0.4 μn thermal SiO_2. These samples are identical to those used in the Rome Laboratory experiments. Four different sets of these test stripes are used, 100% Al and Al/l% Si, each unpassivated and passivated by 0.4 μn of SiO_2. Similar to the Rome experiments, all electromigration testing was conducted at a current density of 2 x 10^{-6} A/cm^2 and at a temperature of 150°C. A more complete description of the electromigration test setup is reported elsewhere [9].

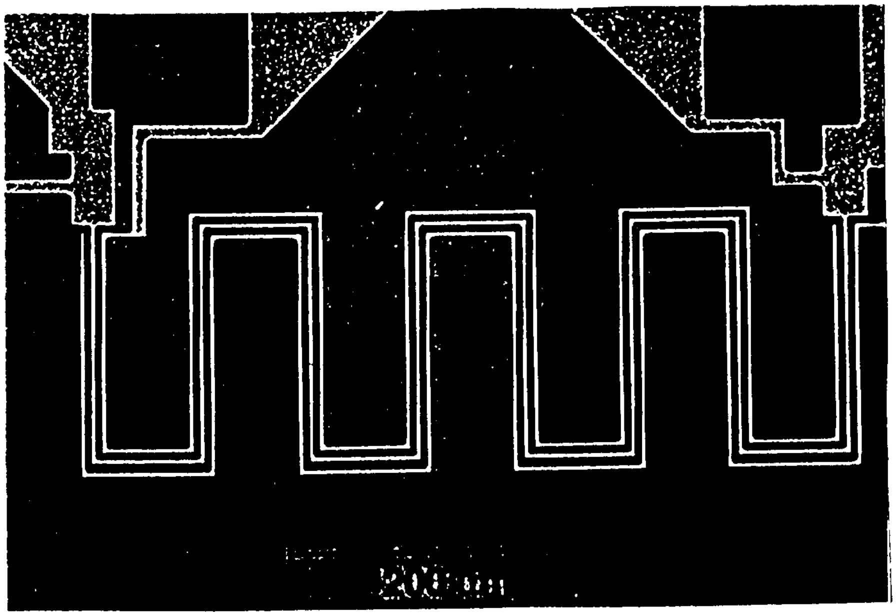


Figure 1. Meandering test stripe.

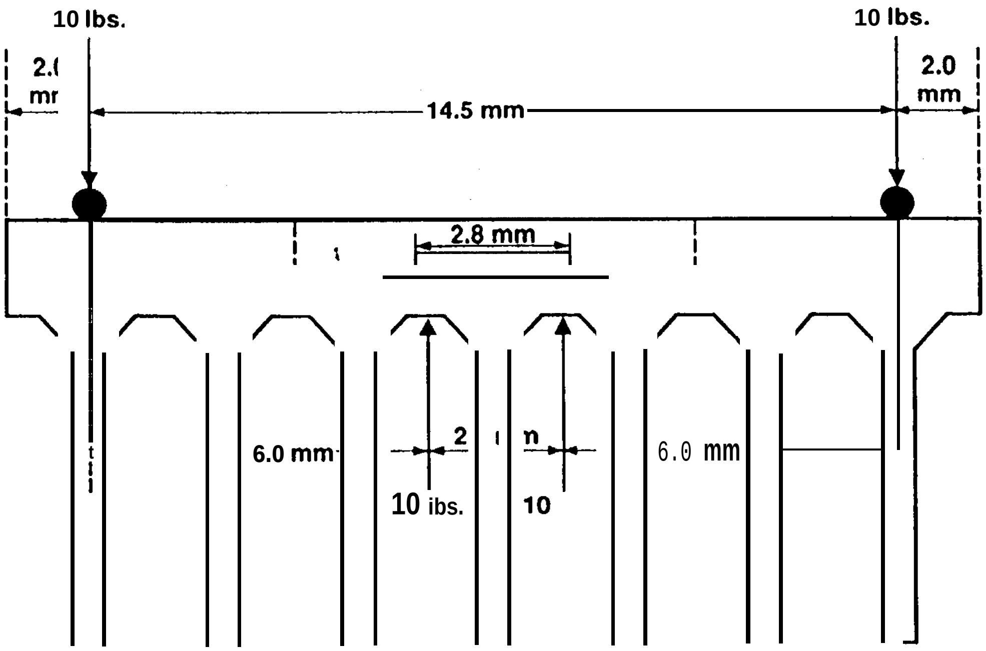


Figure 2. Mechanical stress/electromigration test setup.

Electromigration testing is performed only along the middle line of the test stripe. The outer guard stripes are used to detect mechanical damage as a result of the applied load.

Void examination was performed using an optical Leitz microscope equipped with a long working distance objective and a Cambridge Scanning Electron Microscope. The passivation was removed prior to examination using a buffered HF solution for four seconds.

All samples were mechanically loaded using a four-point load setup, as shown in Figure 2, in an Instron tensile test machine. The 20 lb. load was applied along the direction of the shorter line lengths of the test stripe. The dimensions of the test setup were chosen such that the fiber stress was uniformly distributed along the entire stripe length.

RESULTS AND DISCUSSION

A finite element analysis program [10] was used to analyze the stresses along the metal/thermal oxide interface and through the metal thickness for both the loaded and unloaded conditions. The stress distribution profiles were relatively the same for both cases. However, the magnitude of both the in-plane and out-of-plane stresses of the device in the loaded condition increased. Data generated through the metal thickness show that the highest tensile stresses in the plane of the device occur at the metal/thermal oxide interface for both passivated and unpassivated samples. Analysis along the metal/thermal oxide interface show that for the unpassivated samples, the highest in-plane tensile stresses occur at the edges of the stripes. However, for the passivated samples, the highest in-plane tensile stresses occur at the middle of the stripe. Additionally, for the unpassivated samples, the highest out-of-plane compressive stresses occur at the middle of the stripes, whereas in the passivated case, the highest out-of-plane compressive stresses occur at the edges of the stripes. It was also noted that the passivated samples have both higher in-plane and out-of-plane stresses than the unpassivated samples. These results are summarized in Figures 34.

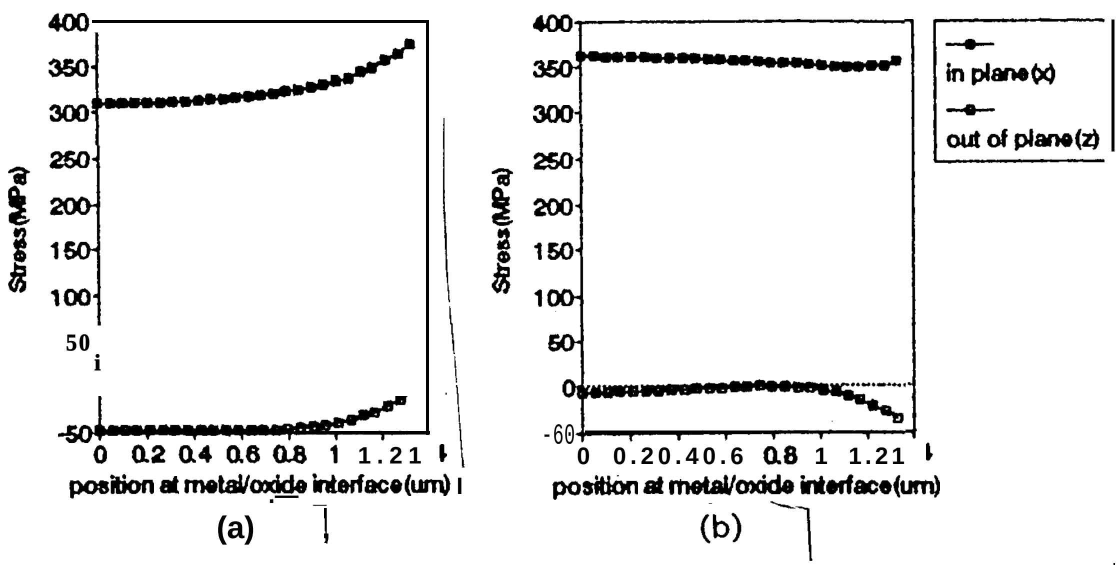


Figure 3. Finite element stress values for loaded (a) unpassivated and (b) passivated samples along metal/thermal oxide interface.

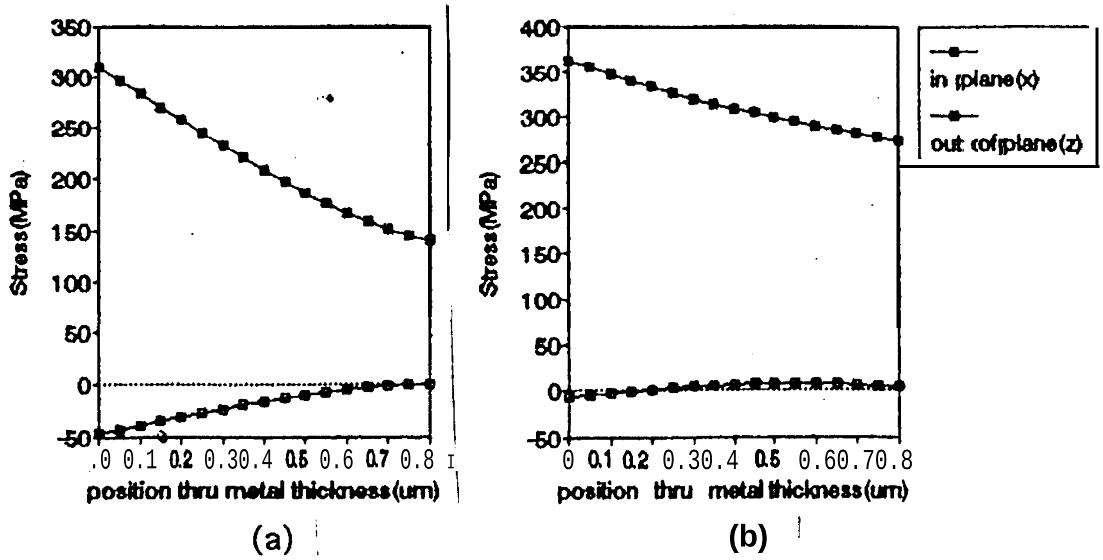


Figure 4. Finite element stress values for loaded (a) unpassivated and (b) passivated samples through metal thickness.

Based on the finite element analysis results and the assumption that higher in-plane tensile stresses would induce void nucleation, increased electromigration voiding was expected in all four sample types. Early void nucleation was predicted to occur along the metal/thermal oxide interface at the edges of the stripes in the unpassivated samples and at the centerline of the stripes in the passivated samples. Contrary to the model predictions, the results of the mechanical stress/electromigration tests showed void damage both on the edges and near the center of the metal stripes for both passivated and unpassivated samples, with no obvious preferred distribution. Figure 5 shows typical voiding in the electromigration stripe. The Al/l % Si samples were an exception, where no electromigration voiding was observed.

Stress voiding induced by mechanical damage in the guard stripes occurred only in the 100% Al passivated and unpassivated samples and only at the edges of the stripes. Additionally, lateral hillock formation was observed in the guard stripes of the 100% Al unpassivated samples. Figure 6 shows a transmission electron micrograph of a hillock microstructure and adjacent grain boundary in a guard stripe. Multiple grains with varying crystallographic orientations are evident.

The mechanical stress/electromigration tests showed significantly fewer voids than the Rome laboratory tests. This may be attributed to the differences in microscopy techniques, number of samples tested and the ability to detect sub-surface voids.

CONCLUSION

The intent of these experiments was to vary the magnitude of the tensile stress at the metal/thermal oxide interface and to observe the resulting impact on electromigration void nucleation. It was speculated that increased tensile stress would increase voiding and that early voiding would occur at preferential sites depending upon whether the lines were passivated. The experimental results did not support this model but seemed to suggest that electromigration voiding susceptibility was influenced more by metal composition than stress distribution.

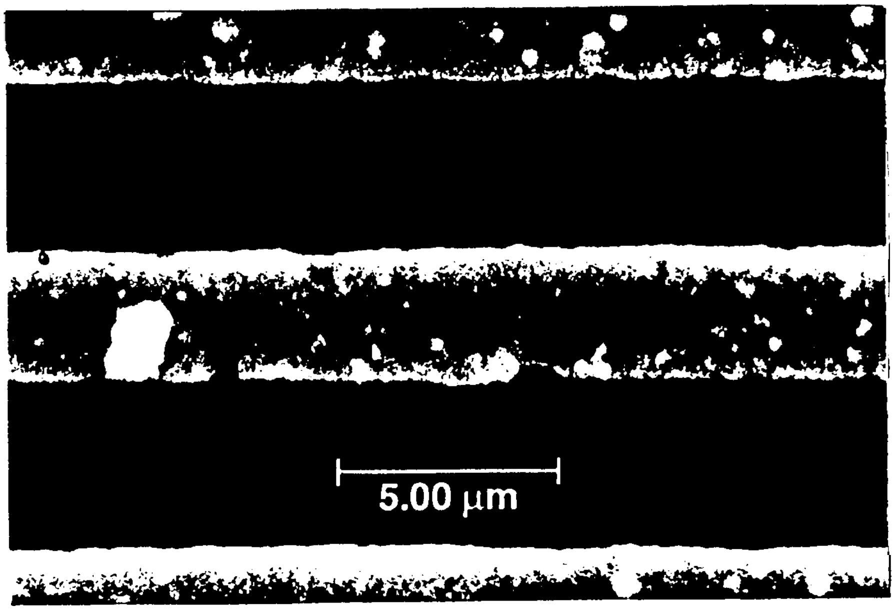
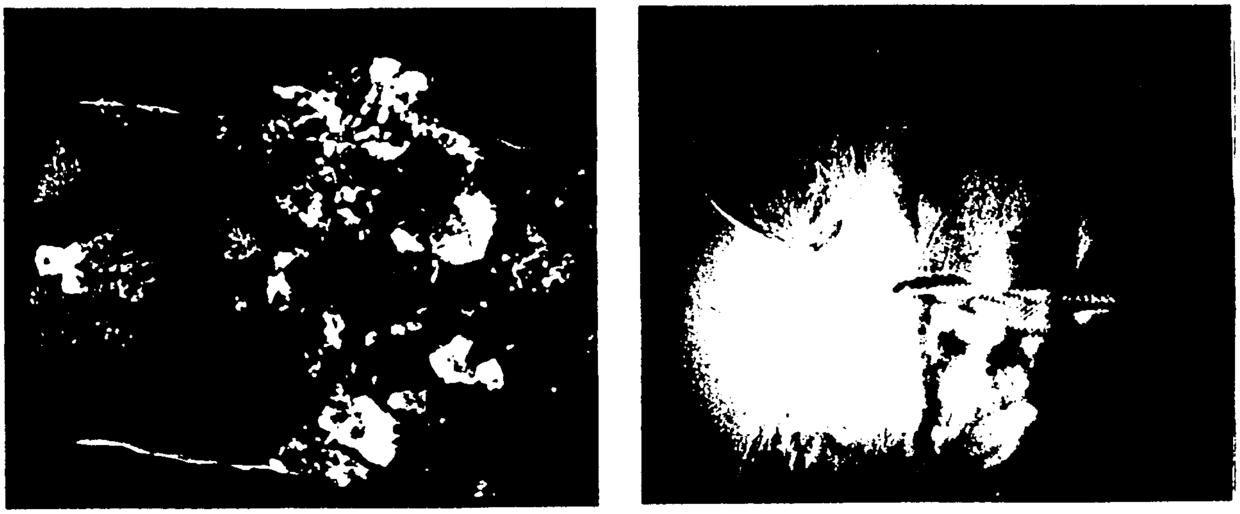


Figure 5. Scanning electron micrograph oftypical voiding inelectromigrated stripe.



(a) **(b)**

Figure 6. Transmission electron micrographs of (a) hillock microstructure and (b) adjacent grain boundary in guard stripe.

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