Adhesion and Electromigration Performance of Barrier / Copper Interconnections in CMOS Technologies

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Introduction and Motivation

Electromigration (EM), the movement of metal atoms due to the flow of current, can cause failure in interconnects in complementary metal oxide semiconductor (CMOS) circuits. EM performance in copper (Cu) interconnect structures is largely related to the diffusion of copper atoms along the barrier layer interfaces. It has been shown that the mobility of copper atoms is closely related to the adhesive strength of this copper / barrier layer interface [1]. In the past these properties have usually been assessed separately.

Previously, Zhou et al. [2] reported that there was an increase in electromigration mean-time-to-failure as the interlayer adhesion increased. Lane et al. [1] showed that when the interface debonding energy of a copper / barrier layer is small, the void growth rate during EM is higher. This is presumably due to more mobile copper atoms. This again shows a connection between EM and adhesion.

In our work, we are developing a novel technique for characterizing EM performance and adhesion of a copper/barrier layer simultaneously. Once this technique is developed, it will provide a unique tool in optimizing EM performance in the next generation of integrated circuits and nanoelectronics. Using thin film fracture mechanics techniques, adhesion in copper / barrier film stacks was analyzed in the presence of electromigraton. The crack propagation rate or velocity, v, was measured versus applied strain release rate, G (which is a measure of adhesion). This was measured while different current densities were applied. X-ray photoelectron spectroscopy (XPS) was performed on the fracture surfaces to see if the failure does indeed occur at the Cu/barrier interface.

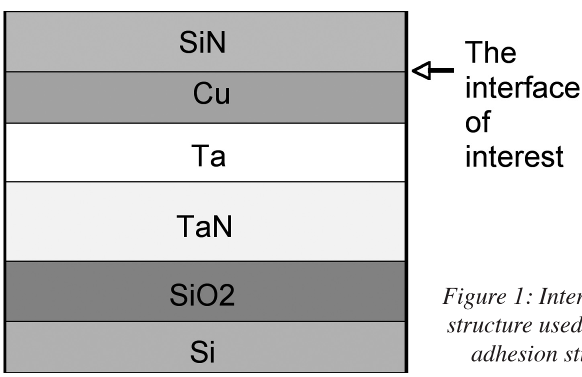

Figure 1: Interconnect structure used in EM/ adhesion studies

Experimental Method

Samples were obtained of typical multilayer interconnect structures, as shown in Figure 1. Copper was the main conducting layer and silicon nitride (SiN) was the barrier layer on top. The SiN layer was etched off at the ends in order to make contact areas. 85% aqueous phosphoric acid at room temperature was used. The resistance was measured every 5 minutes until the SiN was removed.

As shown in the schematic diagram in Figure 2, the crack propagation rate or velocity, v, was measured versus applied strain release rate, G (which is a measure of adhesion) by using standard subcritical double-cantilever beam fracture mechanics method. This was measured while different current densities were applied.

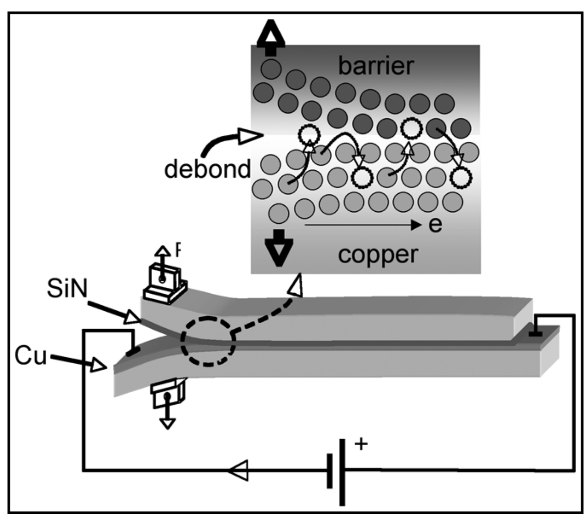

Figure 2: Schematic of samples used in standard subcritical double-cantilever beam fracture mechanics measurement, to measure crack velocity, v, versus adhesion, G, for different current densities.

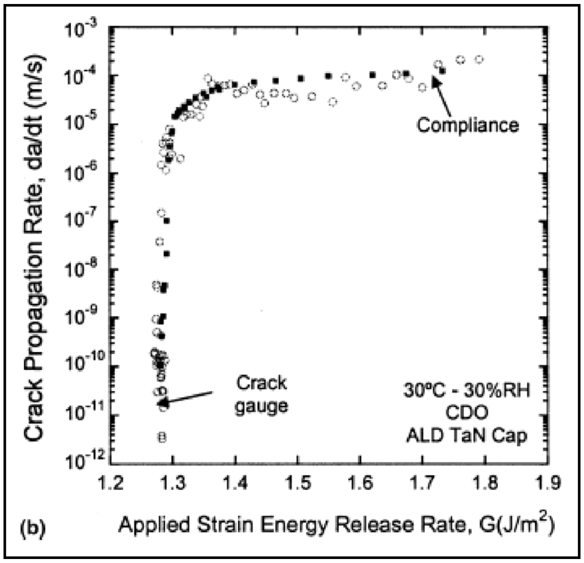

Figure 3: Previous results of our group measuring crack velocity versus adhesion without any current [3].

Results and Discussion

Figure 3 shows the results of previous work by our group [3]. This shows the relationship between crack velocity, v, versus the applied strain energy release rate, G (or driving force for cracking/debonding) for a copper/tantalum nitride interconnect without any current. In our present results, shown in Figure 4, we see v-G curves for two control specimens and two specimens with different current flow, J. Negative J represents electrons flowing opposite to the crack growth direction and positive J represents electrons flowing along the crack growth direction. We can see that these current densities are ~ 2 orders of magnitude below those used in standard electromigration tests, and there is no noticeable effect on crack growth at these low current densities.

XPS was done on the two surfaces exposed by the fracture in order to determine which interface of the structure failed. Table 1a shows XPS results of the top fracture surface (in Figure 2), indicating it is indeed a SiN layer. Table 1b shows XPS results of the bottom fracture surface (in Figure 2), indicating it is, in fact, a copper layer. From these results, we can conclude that the crack is indeed growing between the layer of Cu and the layer of SiN.

Si (2s)	34.6 %
N (1s)	24.1 %
Cu (3p)	0.5%
O (1s)	28.4 %
C (1s)	12.4 %

Cu (3p)	28.7 %
O (1s)	45.0 %
C (1s)	26.3 %

Conclusions

Using thin film fracture mechanics techniques, adhesion in copper / barrier film stacks was analyzed in the presence of electromigraton. Initial results at low current densities show no change in adhesion. X-ray photoelectron spectroscopy was performed on the fracture surfaces to show that the failure does occur at the Cu/barrier interface. Further measurements of crack propagation at higher current densities need to be done. Challenges that need to be overcome in the future are excessive Joule heating at these higher current densities, and enhanced oxidation for Cu and failure of solder joints at the higher temperatures due to the Joule heating.

Acknowledgments

I would like to thank Prof. Dauskardt for letting me work in his group, Michael Deal for being so helpful and for guiding me through the process, and Ryan Birringer for mentoring me, helping me out throughout the experiments and for answering all of my questions. Also I would like to thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program, CIS, and NSF for giving me this opportunity.

References

[1] Lane, M.W. et al, J. of Applied Physics, vol 93, p. 1417, 2003.
[2] Zhou, Ying, et al, AMC, 2004.
[3] Guyer, et al, J. Mater. Res., Vol. 19, No. 11, Nov 2004.

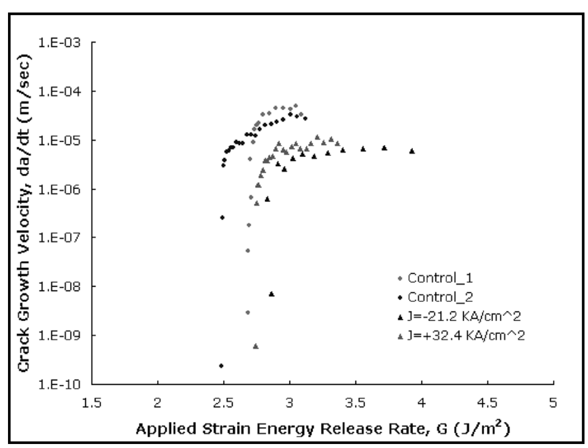

Figure 4, above: v-G curves for this work for two current densities, showing little effect on crack growth.

Table 1a, top left: XPS results of the bottom fracture surface (in Figure 2), indicating a copper layer.

Table 1b, bottom left: XPS results of the top fracture surface (in Figure 2), indicating an SiN layer.