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Electromigration in Au Interconnects

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abstract

Electromigration in metal interconnects is the most pernicious failure mechanism in semiconductor integrated circuits (ICs). Early electromigration investigations were primarily focused on aluminum interconnects for silicon-based ICs. An alternative metallization compatible with gallium arsenide (GaAs) was required in the development of high powered radio frequency (RF) compound semiconductor devices operating at higher current densities and elevated temperatures. Gold-based metallization was implemented on GaAs devices because it uniquely forms a very low resistance ohmic contact and gold interconnects have superior electrical and thermal conductivity properties. Gold (Au) was also believed to have improved resistance to electromigration due to its higher melting temperature, yet electromigration reliability data on passivated Au interconnects is scarce and inadequate in the literature. Therefore, the objective of this research was to characterize the electromigration lifetimes of passivated Au interconnects under precisely controlled stress conditions with statistically relevant quantities to obtain accurate model parameters essential for extrapolation to normal operational conditions.

This research objective was accomplished through measurement of electromigration lifetimes of large quantities of passivated electroplated Au interconnects utilizing high resolution in-situ resistance monitoring equipment. Application of moderate accelerated stress conditions with a current density limited to 2 MA/cm^2 and oven temperatures in the range of 300°C to 375°C avoided electrical overstress and severe Joule-heated temperature gradients. Temperature coefficients of resistance (TCRs) were measured to determine accurate Joule-heated Au interconnect film temperatures.

A failure criterion of 50% resistance degradation was selected to prevent thermal runaway and catastrophic metal ruptures that are problematic of open circuit failure tests. Test structure design was optimized to reduce resistance variation and facilitate failure analysis. Characterization of the Au microstructure yielded a median grain size of 0.91 μm. All Au lifetime distributions followed log-normal distributions and Black's model was found to be applicable. An activation energy of 0.80 ± 0.05 eV was measured from constant current electromigration tests at multiple temperatures. A current density exponent of 1.91 was extracted from multiple current densities at a constant temperature. Electromigration-induced void morphology along with these model parameters indicated grain boundary diffusion is dominant and the void nucleation mechanism controlled the failure time.

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