FAILURE DUE TO COUPLED CREEP FLOW, DIFFUSION, AND ELECTROMIGRATION

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Void evolution in interconnects induced by electromigration has significant effect on the reliability of integrated circuits. Interconnects are thin wires of copper or aluminum alloy, which make electrical contact between devices on a chip. The continuous scaling down in the dimensions of typical integrated circuits leads to increasing electric current density in interconnect lines. As a result, current induced directional mass transport causes nucleation of voids. Nucleated voids in interconnects change their shape and sometimes cause an open circuit as a result of the small dimensions, intense currents, and elevated temperatures. This phenomenon has largely limited further device miniaturization.

While diffusion has been investigated as a mass transport mechanism in electromigration, recent studies suggest that creep can play an important role. This paper studies void evolution driven by electromigration in a small scale interconnect. The high electric current density induces high temperature, high pressure gradient and low viscosity, where creep flow has a significant effect. A study considering concurrent kinetics and small interconnect size is necessary to respond to new demands of nanoscale devices. When the size of an interconnect is reduced below the grain size, the grain boundaries no longer connect into a continuous diffusion path. Thus we focus on void evolution process inside the grain rather than at the grain boundary. In fact, slit voids were commonly observed inside grains even in a micro-scale interconnect. We aim to reveal the dynamic void evolution process in interconnects by studying the interplay of the electron wind, surface energy, surface diffusion and creep. A three-dimensional model capable to describe the rich dynamics is developed in this paper, which can provide more realistic simulation beyond existing two-dimensional diffusion models. To overcome the computational complexity due to evolving interfaces, multiple energetics and kinetics, a diffuse interface approach is adopted. Similar approach has been applied in previous studies and demonstrated its reliability and effectiveness [1, 2]. In contrast to interface tracking methods such as the boundary element method, the interfaces are not modeled explicitly but given implicitly by a concentration field, where an interface is represented by a thin continuous transition region. Consequently, complex interface changes, such as void breaking or coalescence, will not cause any additional computational difficulty.

A series of simulations have been performed to study the effect of creep flow, electric field strength, interconnect line thickness and initial void geometry. An approximate estimation of mass transport suggests that whether creep or diffusion dominates is determined by mobility, viscosity, interconnect thickness, and void radius. The simulations show that different dominating kinetics lead to quite different morphologies. A void shape stable with surface diffusion can be unstable with creep. This suggests that considering the coupled mechanism may be necessary for some problems to provide more reliable prediction.

References

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