177a Non-Linear Analysis of Electromigration-Induced Surface Waves on Voids in Metallic Thin Films

Jaeseol Cho, M. Rauf Gungor, and Dimitrios Maroudas

Failure of metallic thin-film interconnects due to electromigration-driven void evolution has been a problem of major interest both as an important concern of interconnect reliability in microelectronics and as an intriguing nonlinear dynamical phenomenon of driven mass transport and microstructural evolution in materials. Recent theoretical work in this area has demonstrated an extremely rich electromigration-induced dynamics of void surfaces due to anisotropic surface diffusivity and current crowding effects. In this presentation, we focus on the analysis of electromigration-induced waves on the void surfaces and the implications of the corresponding void morphological evolution on the metallic line resistance.

The theoretical non-linear analysis is based on self-consistent numerical simulations of current-induced migration and morphological evolution of void surfaces in metallic thin films. Current crowding effects that become particularly important in narrow metallic films, as well as surface curvature effects that are particularly strong due to the strong anisotropy of adatom diffusion are accounted for rigorously in the simulations. The mass transport problem on the void surface is solved coupled with the electric field distribution in the conducting film that contains the morphologically evolving void. A two-dimensional (2D) implementation is followed in the xy-plane of a metallic film of finite width that extends infinitely in the x-direction; this 2D representation is based on the assumption that the void extends throughout the film thickness (in z), which is consistent with experimental observations.

The analysis predicts the onset of stable time-periodic states for the void surface morphological response as either the applied electric field strength, or the void size, or the strength of the diffusional anisotropy is increased over a critical value. For parameter values below the critical ones, morphological evolution leads to stable steady states for the void surface morphology; these steady states correspond to morphologically stable voids that translate along the metallic film at constant speeds (i.e., solitons). It is demonstrated that the different sequences of morphological transitions and instabilities as different operating conditions and system parameters are varied correspond to either supercritical or subcritical Hopf bifurcations. To compare our theoretical predictions with experimental data, the effects of void dynamics under electromigration conditions on the metallic film's electrical resistance, a readily accessible experimental parameter, are considered in metallic thin-film interconnects and the electrical resistance evolution is calculated. Changes in the metallic line resistance are found to depend strongly on electromigration-induced void morphological changes. In particular, propagation of stable time-periodic surface waves is found to give rise to stable time-periodic electrical resistance response. The theoretical results provide interpretations for experimental measurements that have demonstrated stable oscillatory dynamics in the electrical resistance evolution of metallic interconnect lines.