Mini Symposia: Mechanics of Next-Generation Nano Electronics and Power Electronics

Electromigration Induced Stress Analysis Using Fully Coupled Mechanical - Diffusion Equations With Non Linear Material Properties

Cemal Basaran* and Minghui Lin,

Electronic Packaging Laboratory,
Department of Civil, Structural and Environmental Engineering,
University at Buffalo, State University of New York, 212 Ketter Hall, Buffalo 14260, USA
cjb@buffalo.edu

Key Words: Electromigration, Thermomigration, Nanoelectronics, Damage Mechanics

Summary

Electromigration is a major road block in the pursuit of nanoelectronics. In the next generation nano electronics technology electrical current density is expected to exceed $10^7 A/cm^2$. In this paper an electromigration induced strain-current density model is proposed and implemented in finite element procedure for solution of boundary/initial value electromigration problems. Numerical simulations are compared with experimental data. Comparisons validate the model.

1. Introduction

Electromigration is a mass diffusion process as a result of an exchange of momentum between charge carriers and the thermally activated ions of the conductor. Electromigration became engineering interest since it was first observed as one of the primary failure mechanism in aluminum IC conductors. Due to insatiate demand for miniaturization of electronics, electromigration induced failure is becoming a concern for not only IC thin films but also for solder joints in microelectronic systems. Under high current density electromigration, vacancy diffusion is driven by four forces;

1) electrical current field forces, which is due to momentum exchange between moving electrons and host atoms,
2) Stress gradient, due to accumulation and depletion of mass,
3) Temperature gradient, due to Joule heating,
4) Vacancy concentration gradient.

Most of the published works ignored influence of third forces. Ye et al[5] was the first to observe that temperature gradient driving force can be as strong as other forces and under some instance dominant force.

It is shown that stress gradient can act as a counter force against electrical field driving force. As the mass moves from cathode side to anode side, compression on anode side and tension on cathode side will create a stress gradient.

Numerous experiments have already proved the existence of a strain gradient within the thin film conductor line using X-ray diffraction which can penetrate the passivation layer on top of thin film. Mechanical stress induced plastic deformation has been verified by the obvious evidence of whisker or hillock at the anode side of metal conductors. Plastic deformation also contributes to the main damage phenomenon, which is void nucleation at the cathode side. Plastic deformation by grain boundary sliding produces high stress localization when the slip band intersects with particles at grain boundary, which is in favor of void nucleation. Also when there is stress, void growth may occur within grains as it is governed by power law creep. Under high current density the damage is caused by several mechanisms including mechanical, thermal and electrical.

Physics literature is rich with empirical mean time to failure equations for thin films subject to electromigration. Yet these empirical and analytical equations can not be used for arbitrary boundary/initial value problems. Instead constitutive models that can be implemented in finite element method are needed. Models proposed in the literature do not consider plastic deformation during electromigration process which can't be neglected. Also real interaction of vacancy flux and stress, which exists concurrently, needs to be solved together and not by a sequential method as it is conventionally done in the literature, because of the coupled effect between stress evolution and atomic flux. In this paper, a fully coupled model for simulation of mechanical stress and vacancy diffusion with inelastic mechanical material property is proposed. The model accounts for vacancy flux due to electromigration, stress gradient, thermomigration and vacancy concentration gradient.