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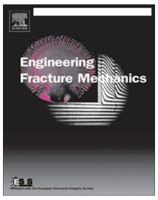

The evolution of void defects in metallic films based on a nonlocal phase field model

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ABSTRACT

In this paper, a nonlocal phase field method is presented to solve anisotropic diffusion-driven morphological evolution and migration of void defects in finite metallic film interconnects by utilizing a nonlocal phase field model considering a small scale effect. The nonlocal elastic theory is used to describe a small scale effect on the morphological evolution and migration of the void. In example calculations, the effects of the stress field, the electric field, and the anisotropic diffusion characteristic on the evolution of void defects in finite metallic film interconnects are described and discussed. The result in comparison with literature shows that the small scale effect based on nonlocal elastic model induces the migration diffusion of the crack tip to decrease.

1. Introduction

Over the past decades, as the size of microelectronics devices is miniaturized, the width of thin-film interconnection used in micro-electronic chips has been decreased. When thin film interconnects with smaller scale are processed and used, voids and defects are inevitably generated, which have detrimental influence on the performance and reliability of microelectronic devices [1–8]. The thin-film interconnects in chips are often subjected to severe residual stresses induced by thermal mismatch between the line and the surrounding matrix. The high current density also appears in thin-film interconnects due to the smaller scale of the thin-film interconnects. High residual stress, current density and temperature gradient in thin-film interconnect can induce the morphological evolution and migration of void defects, which often makes open circuit of the thin-film interconnects and reduces the life span of a micro-electronic device [9–11]. Thus, the investigation on the open circuit and reliability of thin-film interconnects has become more important as the size of micro-electronic device is gradually reduced. It is seen from Refs.[12–15] that the failure mechanism of thin-film interconnects is often associated with stress-migration (SM) and electromigration (EM) driven diffusion along the surfaces of void defects in the thin-film interconnects.

Gungor and Maroudas [16] presented a theoretical analysis for electromigration-induced failure of metallic thin films and predicted that prevention of failure is possible by adjusting the grain orientation with respect to the applied electric field. Using scanning electron microscopy, Arzt et al. [17] observed the characteristics of electromigration-induced voids in narrow, unpassivated interconnects and revealed that void nucleation, void growth and void shape changes can consume a major part of the lifetime of interconnects line. Based on numerical, Bhate et al. [18] presented a diffuse interface model

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Nomenclature

E_0	Young's modulus of thin-film interconnect
υ_0	Poisson's ratio of thin-film interconnect
ρ	an internal characteristic length (e.g., length of atom bond, lattice spacing, granular distance)
e_0	a constant appropriate to each material
a	the initially maximum characteristic length of void configuration
ϕ	the diffusion layer of void surface
ζ_0	the electric conductivities of thin-film interconnect
δ	the controlling parameter of the diffusion layer thickness of void surface
$W(\sigma_{ij}, \phi)$	the strain energy density based on the non-local elastic theory
Ω	the atomic volume
e	the charge of an electron
Z^*	the atom's phenomenological 'effective valence'
V	the electric potential exerted on interconnect film
$D(\phi)$	anisotropic diffusivity in the diffusion layer

for simulating electromigration and stress-induced void evolution in interconnect lines. Bower and Shankar [19] describe a two-dimensional finite element method to solve the nucleation, growth and evolution of voids in polycrystalline interconnects, where front tracking and adaptive mesh generation are used to follow changes in the grain structure and void shape.

In the previous investigations, numerical calculations are mainly either based on a sharp [5,20,21] or diffuse interface [18,22,23] models. However, in each case the stress-driven evolution characteristics of voids in thin-film interconnects are based on a classical elastic theory without considering the small scale effect of void defects. Because the width of a general thin-film interconnect is less than 0.5 μm, the dimension of initial void defect in thin-film interconnect should be much smaller, so that the investigation of the effect of small scale on the evolution characteristics of void defects could be significant. Liu et al. [24] present a scale effect on the evolution of a spherical cavity in a stressed grain. However, few investigations report the effect of small scale on the evolution characteristics of void defects in thin-film interconnect due to the complex expression of stress-driven force (strain energy density) in a phase diffusion layer near void.

In this paper, we present a non-local phase field model using a non-local physical relation between stress and strain [25] (Eringen) for the morphological evolution and migration of void defects in a finite scale interconnect. We discuss the effects of the stress field, the electric field, and the anisotropic surface diffusion on the evolution of the void. Results show that the effect of anisotropic diffusion parameter on the evolution of void depends on the loading strength, and the folding symmetry parameter.

2. Diffusive model of void morphology evolution based on nonlocal theory

A two-dimensional model is introduced to investigate the anisotropic diffusion-driven morphological evolution and migration of voids in finite thin-film interconnects, utilizing a nonlocal phase field method to consider a small scale effect. Here, a nonlocal elastic theory is used in the phase diffusion layer around void in finite thin-film interconnects. The representative interconnect with an elliptical void under electric field and stress field is shown in Fig. 1.

Based on the non-local elastic theory considering a small size parameter [25], the stress at a reference point r in the diffusion layer around void surface depends not only on the strains at the point r but also on strains at any other point around the r. Because the thickness of interconnect film is much less than the length and width of the film and the thickness direction of a single interconnect film is not constrained by other functional layers, the deforming model of the single interconnect film with void defects can be assumed as a state of plain stress, which is different from the plain strain model for interconnects covered with two functional layers [5]. For homogeneous and isotropic interconnect films in a two-

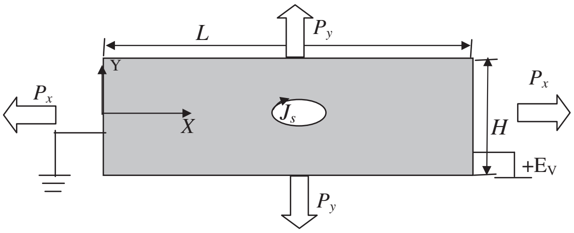

Fig. 1. Illustration of a void in thin-film interconnect under stress field and electric field.