Creep of Al Underlayer Determined by Channel Cracking of Topical Si₃N₄ Film

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This paper presents the results of channel cracking experiments performed on a multilayered structure. Room temperature creep behavior of a metallic underlayer was studied by using a newly developed channel cracking method. By the analysis of a channel crack propagating under tensile load in an elastic Si₃N₄ topical layer, the creep properties of an aluminum underlayer were determined. The experimental results were compared with the results of room temperature creep studies performed on commercial Al and Al–Mg micro-wires. As expected, the viscosity of pure Al underlayer is less than that of these materials. It is about 50% of the viscosity attributable to the primary creep region of commercial Al micro-wires. Compared to the viscosity of a harder alloy, the viscosity of the pure Al underlayer is about 20% of that attributable to the primary creep region of Al–Mg micro-wires. The growing cracks are observed to terminate at surface flaws that relieve their stress fields.

Keywords Channel cracking; Crack growth; Creep; Multilayer structure; SiN; Thin films.

INTRODUCTION

The reliability of microelectronics and microdevices used in various applications including computers, automotive industry and biomedical fields greatly depend on the mechanical properties of the materials [1–3]. Since mechanical behavior of small structures used in microelectronic and microelectromechanical devices (MEMS) differ from those of bulk materials, it is necessary to conduct micro-mechanical tests on these materials in their final geometries [4–7]. Room-temperature creep of metallic layers in microelectronics and metallic components in MEMS can lead to unexpected failure of these devices [8, 9].

Channel cracking [9–15] has been developed to study and compute [10, 16] the steady state energy release rate of channeling cracks in thin films. The application of this method is important in the prediction of the fracture behavior of multilayered structures that are under residual stress developed during the fabrication process. In the presence of a sharp corner or a microcrack, the stress field intensifies at the interface between dissimilar materials.

Residual stress is not the only component that affects the failure of structures. Other parameters such as thickness of the layers will play an important role in the failure process. The successful application of multilayered structure relies on designs that optimize processing variables. These involve: residual stresses, the thickness of the individual layers, as well as the type of the materials used in each layer.

In multilayered structures consisting of dissimilar materials, cracking of one layer may lead to the plastic deformation of another. Consider crack extension in an elastic Si₃N₄ layer deposited on an Al thin film, which, in turn, is deposited on Si. Crack propagation in the topical Si₃N₄ layer can reach a steady state, which is dictated by two parameters: the rate of decohesion at the crack tip and the rate of creep of the Al layer.

Shear lag models have been used to study cracking of brittle films deposited on viscous [9, 11, 14]. Liang et al. [11] developed a shear lag model that approximates the fracture process in an elastic film blanketing a metal underlayer. The creep properties of the underlayer and the fracture toughness of the topical inelastic layer are interrelated such that if one is known the other one can be calculated. Ma et al. [12, 13] studied channel cracking in brittle Si₃N₄ films deposited on Al [12] and on Si [13] substrates. They reported two different values for the fracture toughness of Si₃N₄, as will be discussed later.

Under bending loads, both Al and Si₃N₄ layers are under tension. At high stress levels, beyond the yield point of Al, the Si₃N₄ layer experiences elastic strains while the Al underlayer undergoes plastic deformation. The system remains in equilibrium if no cracking occurs. However, once a crack is initiated in the Si₃N₄ layer, the stress intensity in the vicinity of the crack tip causes further deformation of the Al underlayer. This additional strain accumulated in the Al film can be attributed to the presence of excess stress at the crack tip.

In this paper, the approach of Liang et al. [11, 15, 16] has been adopted to study the room-temperature time-dependent deformation of an Al layer undergoing creep concurrent with the propagation of crack in its Si₃N₄ overlayer. The information obtained here will be complementary to the mechanical properties of bulk Al and Al alloys [17–19] on micron scale. These include room temperature creep properties [20, 21] obtained for thin aluminum micro-wires.

Theory

This section presents an overview of the underlying theory that was used to extract the creep viscosity. For brevity,