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Pre-cracking technique for fracture mechanics experiments along interface between thin film and substrate

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Abstract

Utilizing the difference in interface strength due to fabrication process, a technique for producing a sharp pre-crack between a thin film and a substrate is proposed. A cracked specimen for examining fracture toughness of interface between a sputtered copper (Cu) thin film and silicon (Si) is made by the method. A vacuum-evaporated Cu thin film, which has poor adhesion to Si, is inserted between the sputtered Cu thin film and the Si substrate as a release layer. The release layer debonds from the Si substrate at very low load, and the sharp pre-crack is successfully introduced along the interface. Using the pre-cracked specimen, the interface fracture toughness test is conducted and the critical J-integral, J_C, is evaluated as about 1 J/m^2 for the sputtered Cu/Si interface.
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1. Introduction

Interface is the most probable cracking site in a component of micro-electronics and micro-mechanical devices. Then, it is significant for keeping the high reliability to understand precisely the interface toughness. Poor adhesion sometimes causes delamination among multiple thin films on a substrate. However, it is not easy to examine experimentally the interface strength because of the thinness of films. Although a lot of methods [1–19] have been proposed to measure the adhesion strength, few ones can precisely evaluate it based on fracture mechanics. Main reason is the difficulty in introducing a well-controlled sharp pre-crack along the interface. The attempts have been conducted by etching of interface (Fig. 1(a)) and by insert

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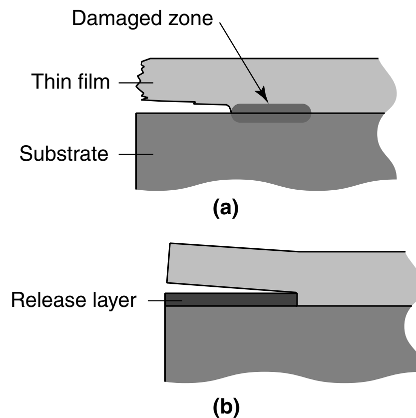

Fig. 1. Examples of methods for introducing pre-crack along interface (a) interface etching, (b) inserting heterogeneous release layer.

of a release layer which has poor adhesion (Fig. 1(b)). However, in the former, the interface toughness is influenced by the chemical reaction area formed ahead of the pre-crack front. In the latter, the strength is sensitive to the sharpness of crack tip, which is dependent on the thickness of the release layer. These influences can be avoided when the crack propagates far from the pre-crack tip. Although a few studies [17–19] are conducted for the propagated crack, it is difficult to take crack path long enough for minute materials. Therefore, it is necessary to develop a new method which can introduce a sharp crack and produces no damages near the crack front.

In this study, a technique for producing a sharp pre-crack between a thin film and a substrate is proposed and is applied to a sputtered copper (Cu) thin film on a silicon (Si) substrate. Then, the interface fracture toughness is evaluated using the cracked specimen.

2. Experimental procedure

2.1. Idea of proposed method

The idea for introducing a pre-crack proposed here is schematically illustrated in Fig. 2. Interface strength between a thin film and a substrate depends on the deposition method. Then, the film/substrate interface, which consists of strong and weak parts, can be produced by using two different deposition methods. After a very thin film is partly deposited by a method (Fig. 2(a)), the identical material is deposited by a different method which produces a stronger interface than the former method does (Fig. 2(b)). Only the weak interface is separated by applying an adequate load, and the sharp interface pre-crack is introduced (Fig. 2(c)). The boundary (dashed line) in the thin film is stronger than the bi-material boundary since the deposited materials are identical. This method can be applied to any materials which can be deposited by two different methods.

2.2. Dependence of interface strength on deposition method

The Cu film with the thickness of 200 nm is deposited on the (100) surface of the Si substrate of thickness 550 μm by two methods such as sputtering in Argon (Ar) gas environment (6.7×10^{-6} Pa) and evaporation in vacuum (1.3×10^{-3} Pa) at room temperature (see Table 1). Copper deposited by the methods are

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