Evaluation of thin film interfacial properties using single nanoindentation testing

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1. Introduction

Delamination of thin-coating films on substrates has become a critical issue for the reliability of micro- and nanoelectronic devices. Since failures of the interface may eventually lead to total system failure, evaluation of the interface between its film and substrate becomes an important problem and several testing methods such as a scratch test, pull-off test and peel test have been proposed. However, these conventional tests have limitations as a universal test methods because of limitations of the film characteristics and requirements such as specially designed specimen[1].

In this study, nanoindentation test was developed to overcome the limitations of conventional test methods. In general, nanoindentation testing has been widely applied to evaluate the mechanical properties of thin films such as hardness and elastic modulus at small scale. It was initially used only to evaluate hardness and elastic modulus from the loading/unloading curve of the indentation testing, but has now been extended to evaluate residual stress, tensile, fracture properties and so on. The nanoindentation test has the advantage that local and thin-film properties can be evaluated through only a single indentation, and no specially designed specimen is needed.

When indentation is made in nanoindentation testing, the amount of elastic-plastic deformation beneath the indent increases as the indentation load increases. In addition, in the case of a thin film, which is a bond-type heterogeneous material, the total amount of work involved in indentation testing can be expressed as the sum of the work in the film, work in the substrate, and work at the interface. The work at the interface generated by indentation testing can be defined as the resistance to interaction between the film and the substrate, which can be expressed as adhesion at the interface. As a result, in order to evaluate the adhesive force at the interface, the work at the interface is evaluated by a quantitative evaluation of the work in the composite film-substrate structure and the work occurring in the film and the substrate in an independent situation.

2. Interfacial constraint effect

The amount of work in the indentation test with no interfacial effects can be expressed as:

$$W_{total} = W_{film} + W_{substrate} \quad (1)$$

where W_{total} is the total amount of work, W_{film} is the work done by film and $W_{substrate}$ is the work done by substrate. But in actual indentation testing, there are not only the effects from the substrate but also interfacial work is present, so that the total work at depths greater than 10% in the indentation test is the sum of the work done by film, the substrate and the interface:

$$W_{total} = W_{film} + W_{substrate} + W_{adhesion} \quad (2)$$

$W_{adhesion}$ is a virtual value representing the work done by the interface. Because it is impossible to distinguish work by the film, substrate and interfacial work experimentally, theoretical modeling is used to develop the formula.

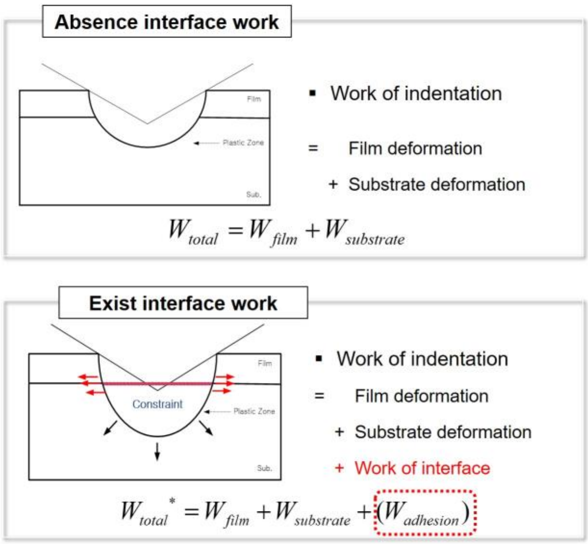

Fig. 1 Work of interface

Constraint of film/substrate system can be classified by hardness and plastic zone size as shown below[2]. The quantity of constraint can be expressed using an interface parameter, and thus the energy at the interface can be evaluated using the indentation parameter.

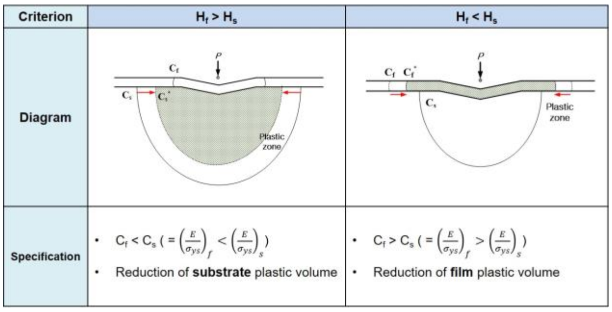

Fig. 1 Classification

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