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A Nano-Cantilever Method for Crack Initiation at the Free Edge of the Cu/Si Interface in Nanoscale Components**

Xiaoyuan Wang[1] **Yabin Yan**[1*] **Qiang Wan**[1] **Takashi Sumigawa**[2] **Takayuki Kitamura**[2]

([1] *Institute of Systems Engineering, China Academy of Engineering Physics, Mianyang* 621900, *China*)
([2] *Department of Mechanical Engineering and Science, Kyoto University, Kyoto-daigaku-katsura, Nishikyo-ku Kyoto* 615-8246, *Japan*)

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ABSTRACT Straight and Bent nano-cantilever specimens are respectively proposed to investigate the single-mode and mixed-mode crack initiation at the Cu/Si interface edge in nanoscale components. With a minute loading apparatus, all nanoscale samples are *in situ* loaded and observed. Numerical analysis is employed to acquire the critical interfacial stress distributions during crack initiation. The stress concentration regions near the edge of Cu/Si interface in all specimens are within the scale of 100 nm, and the critical normal and shear stresses have a circular relation in nanoscale components, which represents the fracture criterion of the interface in nanoscale components.

KEY WORDS nanoscale, cantilever, interface, crack initiation, mixed mode, thin film

I. Introduction

Micro- and nano-mechanical systems and electronic devices consist of dissimilar components, the sizes of which are in nanometer scale. Since the intrinsic bi-material interfaces are inevitably introduced into these devices, deformation mismatch between the dissimilar materials induces a stress concentration on the interface. Thus, the interface is one of the potential sites of fracture[1–4]. The delamination of interfaces may lead to the failure of all nanoscale components and even of the whole micro-system. Thus, to ensure the reliability of these systems, it is necessary to investigate the cracking behavior of interfaces in nanoscale components.

At nanoscale, crack initiation at the free edge of interface is a prominent problem for the interface delamination in low-dimensional tiny components. In such small materials, the failure at a minute area usually causes the malfunction of the entire system. In particular, at the free edge of interface, where the interface meets the free surface of component, the concentrated stress field induced by deformation mismatch makes the interfacial crack liable to initiate at this region[5]. Therefore, it is important to conduct experimental study on the crack initiation at interface edge in nanoscale components, and to obtain the corresponding mechanical criterion for the evaluation of cracking behavior of interface.

Different from traditional experiment methods for macroscale materials, the extremely small volume of nano-materials induces a series of experimental difficulties, such as the grip of specimen, load appli-

* Corresponding author. E-mail: yanyain@gmail.com

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cation on the interfaces inside the specimen, and precise measurement of minute mechanical quantities. Several experimental methods have been proposed to investigate the interface cracking in multilayered thin films since 1980s[6,7]. Typical methods include the pull test[8], peeling test[9], bulge test[10], scratch test[11], indentation test[12], and bending test[13]. So far the cracking behavior and the bonding strength of interfaces in different types of thin films have been widely studied by these experiments. However, it should be noted that for a thin film specimen, only the size along the thickness-direction is in the nanoscale and sizes in other directions are still in the macroscale. Thus, specimens adopted in the above experiments are actually macroscale materials, and the obtained experimental results only represent the macroscale mechanical properties instead of the nanoscale ones.

Usually, in practice, the three-dimensional geometric sizes of the components in micro-systems are all in the nanoscale, where the size effect and the surface effect are significant, making the mechanical properties of nano-materials obviously different from those of macro-materials[14]. Thus, to precisely investigate the crack initiation at interface edge in nano-materials, it is necessary to develop a suitable experimental method to investigate the interface fractures of nanoscale components.

In this study, a nano-cantilever method is developed and used to perform crack initiation experiments on the interface between a 20-nm-thick copper (Cu) film and a silicon (Si) substrate.

II. Experimental Procedures

2.1. Material

The nano-cantilever specimen is cut from a multi-layered material, *i.e.*, silicon/copper/silicon nitride (Si/Cu/SiN). After cleaning a Si (100) wafer surface by means of inverse sputtering, a Cu layer is deposited up to a thickness of 20 nm by means of radio-frequency (RF) magnetron sputtering. A SiN layer is subsequently deposited up to a thickness of 1000 nm using the same method without breaking the vacuum. This study focuses on the interface between the Cu layer and the Si substrate.

2.2. Straight nano-cantilever specimen

Figure 1 shows a straight nano-cantilever specimen used to investigate the single-mode crack initiation at the edge of Cu/Si interface. Load is applied on the SiN layer with a diamond loading tip, and the Cu/Si interface is stressed with a bending moment. Three specimens with different sizes are prepared and their scales are summarized in Table 1.

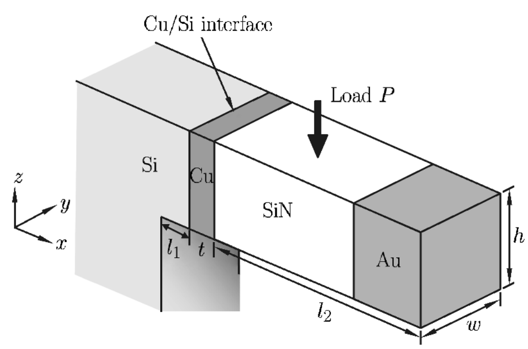

Fig. 1. Schematic illustration of a straight nano-cantilever specimen and its loading method.

Table 1. **Dimensions of straight nano-cantilever specimens**

Specimen	t(nm)	l_1(nm)	l_2(nm)	w (nm)	h(nm)
S1	20	220	715	434	250
S2	20	84	767	415	642
S3	20	120	700	308	233