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Delamination crack initiation from copper/silicon nitride interface edge with nanoscale singular stress field

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ABSTRACT

In order to investigate delamination crack initiation from an interfacial edge in nanoscale component with the singular stress field, we conduct mechanical experiments using four kinds of cantilever specimens with the nanoscale singular stress field at the copper/silicon nitride interface. The results reveal that regardless of the specimen dimensions, the critical magnitude of the plastic stress intensity parameter, $K_{\text{interface edge (C)}}$, is constant (112 MPa $m^{0.179}$) within the singular stress field range of approximately 25 nm. This indicates that in the nano-sized component, a delamination crack initiation is dominated by a nanoscale singular stress field near the interface edge.

1. Introduction

In multilayered components, stress is concentrated at the interface under load due to the deformation mismatch of dissimilar materials [1–3]. In particular, the singular stress field often appears near an interface edge where the interface meets a surface (Free edge effect) [4,5]. Therefore, the interface edge is one of the potential crack initiation sites. Once a delamination crack is initiated in the nano-sized component, it immediately leads to malfunction or facture. Thus, it is important to investigate the criterion for the delamination crack initiation from the interface edge.

In a bulk material, it is well known that the stress intensity factor K can be applied to the criterion for the interfacial crack propagation [6–9]. At the interface edge, the singular stress field is governed by the stress intensity parameter, $K_{\text{interface edge}}$, and the delamination crack is initiated at a critical magnitude of $K_{\text{interface edge}}$ in bulk materials [10–13]. These concepts are based on the continuum mechanics where the singular stress field contains of sufficient number of atoms. As the component size shrinks, the singular stress region near the interface edge is reduced to a nanometer scale [14,15], which correspond to about several dozen to hundred atoms. In this case, it is not experimentally investigated well whether the delamination crack initiation is governed by the nanoscale singular stress field near the interface edge or not.

The aim of this search is to investigate the criterion for the delamination crack initiation from the Cu/SiN interface edge in nanoscale component on the basis of *in situ* experimental observation.

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Nomenclature

C_{11}, C_{12}, C_{44}	elastic constants for Si
$P_{\text{crack initiation}}$	crack initiation load
Λ_K	magnitude of singular stress field
$K_{\text{interface edge}}$	stress intensity parameter
$K_{\text{interface edge (C)}}$	critical magnitude of plastic stress intensity parameter
σ	von Mises stress
ε	von Mises strain
λ	order of the stress singularity
TEM	transmission electron microscopy
FEM	finite element method
SEM	scanning electron microscopy
FIB	focused ion beam

2. Experiment and analysis

2.1. Specimen

The material is multilayered (Ti/Cu/SiN) thin films formed on a silicon substrate. Titanium (Ti) is deposited up to a thickness of a few nanometers at the rate of 20 nm/min on Si wafer with (1 0 0) oriented before a Cu layer is deposited up to a thickness of 200 nm at the rate of 25 nm/min by magnetron sputtering. A silicon nitride (SiN) layer is sequentially deposited up to a thickness of 900 nm at the rate of 11 nm/min by magnetron sputtering without breaking the vacuum. As the interfacial strength between Si and Cu is increased by deposing the thin Ti layer, the delamination crack appears at the Cu/SiN interface.

Fig. 1 illustrates the preparation procedure of the nanoscale cantilever specimens. A 10 μm × 10 μm × 10 μm block is cut from the multilayered material (Fig. 1(a)) and is picked up by a probe manipulator (Fig. 1(b)). After the block is mounted on the top of a gold (Au) wire (φ0.25 mm) with a flat top using an wolfram (W) deposition (Fig. 1(c)), the block is thinned in *z* direction (Fig. 1(d)) and the cantilever specimen containing the Si/Ti/Cu/SiN interfaces is processed by a focused ion beam (FIB: FB-2100FIB system (HITACHI)) (Fig. 1(e)). The gallium (Ga) ion beam energy is 40 kV, and the beam current is changed from 10 pA to 10 nA depending on the fabrication precision.

Fig. 2 schematically shows illustration (a) and dimensions (b) of the cantilever-specimen, along with the loading scheme for the investigation of cracking behavior at the Cu/SiN interface edge. Four specimens (Specimens 1, 2, 3, and 4) of different sizes, as summarized in Table 1, are prepared.

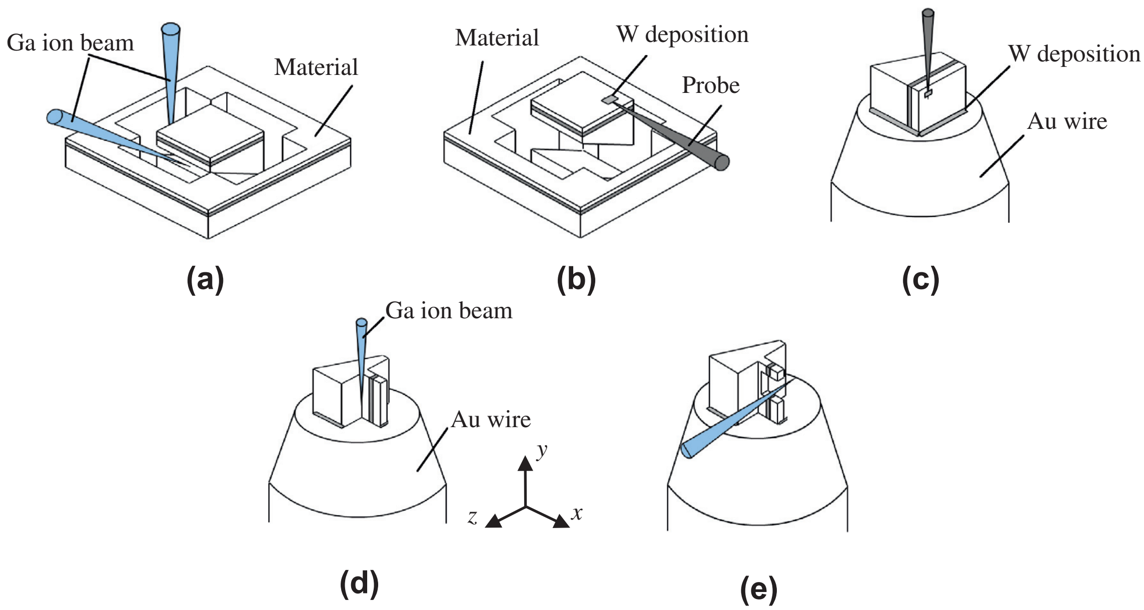

Fig. 1. Schematic illustration of preparation procedure of the nanoscale cantilever specimen.