INITIATION OF INTERFACE CRACK AT FREE EDGE BETWEEN THIN FILMS IN AN ADVANCED LSI

T. Kitamura and H. Hirakata
Department of Engineering Physics and Mechanics, Kyoto University, Kyoto, Japan

ABSTRACT

The focus in this study is put on the delamination crack initiation from the interface edge between thin films, Cu/TiN, which is used in an advanced Large-Scale-Integrated circuit (LSI). A test method of delamination, where the mechanical stress is applied by an external load on the interface, is proposed. In the test, the crack is initiated at the interface edge, where the stress is intensified (effect of free edge). The internal stress of the films on the silicon substrate, which is introduced in the fabrication process, is measured before the mechanical test. The internal stress increases with the increase of film thickness and remarkably intensifies the stress near the edge in this case. On the other hand, the specimen with the thinner Cu film has apparently higher resistance against the cracking by the external load (the mechanical test). Superimposing the contributions of the external load and the internal stress, a good agreement is obtained in the normal stress intensity near the interface edge at the delamination independent of the Cu thickness. This signifies that the combination of intensified stresses due to the applied load and the internal stress governs the crack initiation at the interface edge.

1 INTRODUCTION

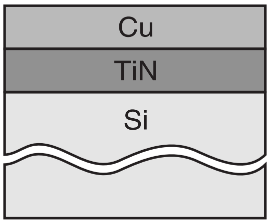
Multi-layered thin films, of which thickness is less than 1μm in each layer, are used for an advanced Large-Scale Integrated circuit (LSI). As metallic and/or inter-metallic films sometimes show poor adhesion, delamination takes place along the interface due to the deformation mismatch among the films and the substrate. Especially, the delamination from the interface edge, where the stress concentrates, becomes a critical issue in the manufacturing process of advanced LSI. In this study, the focus is put on the internal stress as well as the external load in the delamination mechanics between nano-films.

2 THIN FILMS ON SILICON SUBSTRATE TESTED AND INTERNAL STRESS

Figure 1 shows the structure of the multi-layered material tested. Copper (Cu) thin film, of which thickness is 50 nm (Material A) or 500 nm (Material B), is deposited by the vacuum evaporation method under the pressure of 1.3×10^{-3} Pa on a silicon (100) wafer (thickness: 650 μm) with a sputtered barrier layer of titanium nitride (thickness: 50 nm).

Considering the fabrication process, the internal stress of TiN scarcely influences on the Cu/TiN interface because the surface of the TiN film is stress free before the Cu film is deposited. Then, we carefully measured the internal stress of the Cu film. Si on the back surface of the rectangular Si/TiN coupon (5 mm x 45 mm) is carefully ground out until the thickness reaches 150 μm. The Cu thin film is deposited on the TiN film by the vacuum evaporation technique. The displacement of the coupon, δ, is measured, and the stresses in Si substrate, TiN film and Cu film, are inversely estimated using a finite element method. The internal stress is evaluated for the coupons with the Cu film of 50 nm thickness as well as of 500 nm thickness. Eight coupons are prepared for each material in order to check the scatter [1]. The results are summarized in

Table 1. The internal stress of epoxy, which is used in the mechanical test, is also measured and is tabulated.



	A	B
Metal film(Cu)	50nm	500nm
Barrier film(TiN)	50nm	50nm
Substrate(Si)	650μm	650μm

Figure 1: Multi-layerd thin films tested.

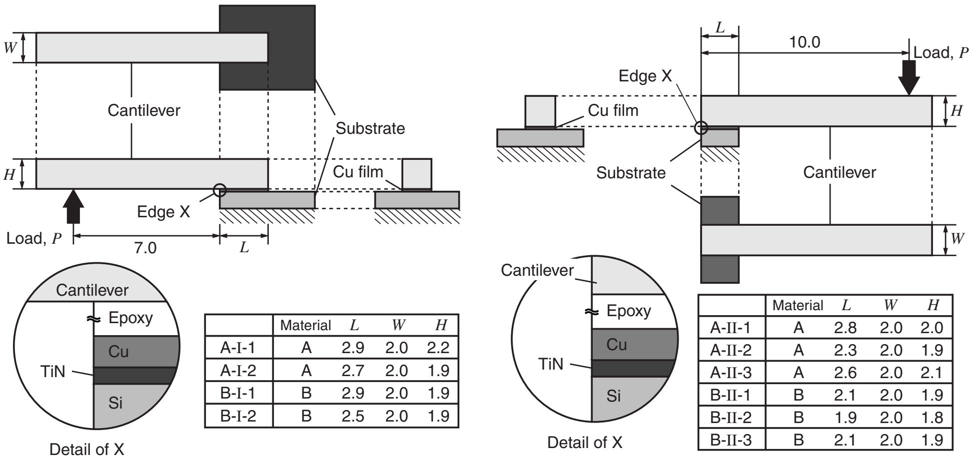
Table 1: Internal stress in thin film.

Material	Internal stress (MPa)
Cu film 50nm (Material A)	186 ± 69
Cu film 500nm (Material B)	250 ± 16
Epoxy 20μm	0.44 ± 0.35

3 MECHANICAL DELAMINATION TEST

3.1 Experimental Procedure

Rectangular coupons are cut from the multi-layered sample. Then, two types of specimen as shown in Figs.2 (a) and (b) are prepared in order to examine the effect of loading system on the crack initiation [2]. They are designated as “Type I” and “Type II”, respectively. The load, P, is applied on the thin film through a cantilever of stainless steel adhered on the test coupon so that the crack is expected to be initiated at the left end of interface. Since the cantilever as well as the Si substrate is relatively stiff as compared with the Cu film, the sandwich structure strictly restrains the plastic deformation of the Cu film. The Cu film outside the glue region is removed from the substrate before the test in order to avoid the effect of film fracture on the measured



	Material	L	W	H
A-I-1	A	2.9	2.0	2.2
A-I-2	A	2.7	2.0	1.9
B-I-1	B	2.9	2.0	1.9
B-I-2	B	2.5	2.0	1.9

(a) Type I

	Material	L	W	H
A-II-1	A	2.8	2.0	2.0
A-II-2	A	2.3	2.0	1.9
A-II-3	A	2.6	2.0	2.1
B-II-1	B	2.1	2.0	1.9
B-II-2	B	1.9	2.0	1.8
B-II-3	B	2.1	2.0	1.9

(b) Type II

Figure 2: Specimens and loading systems. All dimensions tabulated are on mm.

strength. The sizes of specimens are listed in Figs.2 (a) and (b), respectively. Analysis by a Boundary Element Method (BEM) revealed that Types I and II possess different stress distributions away from the edge along the Cu/TiN interface. The singular stress only governs near the interface edge, where the stress field, σ_y, is in the form,

$$\sigma_y = K\,x^{-\lambda}. \tag{1}$$

where K is the stress intensity factor, x is the distance from the edge, and λ is the parameter depending on the materials and the edge geometry [3]. Thus, the comparison between the results of Types I and II can clarify whether the singular field dominates the delamination or not. We carry out four kinds of tests in the combination of material, A (Cu thickness: 50 nm) and B (Cu thickness: 500 nm), and loading, Types I and II. Those are designated as "A-I", "A-II", "B-I", and "B-II", respectively. The experiments are conducted at room temperature in an air by means of a testing machine with an electro-magnetic actuator. The load, P, is applied at the cantilever edge with the constant rate of 0.2N/s. The displacement at the loading point, u_y, is continuously monitored during the tests. Several tests are carried out for each type, A-I, A-II, B-I and B-II in order to check the repeatability.

3.2 Experimental Results

The relation between load, P, and the displacement at the loading, u_y, point is linear up to the delamination, where the load sharply drops. The fracture surface indicates the brittle cracking along the Cu/TiN interface [1]. The elastic stress distribution near the edge at the delamination load, P_f, is numerically analyzed under the plane strain condition by a BEM. Because the singular stress field appears near the free edge of the interface due to the mismatch of deformation, the region is carefully divided into a fine mesh. The element length at the Cu/TiN interface edge is set to 1nm in order to reproduce precisely the stress field. Figure 3 shows the distribution of σ_y in a typical specimen for each Material, which possesses average delamination

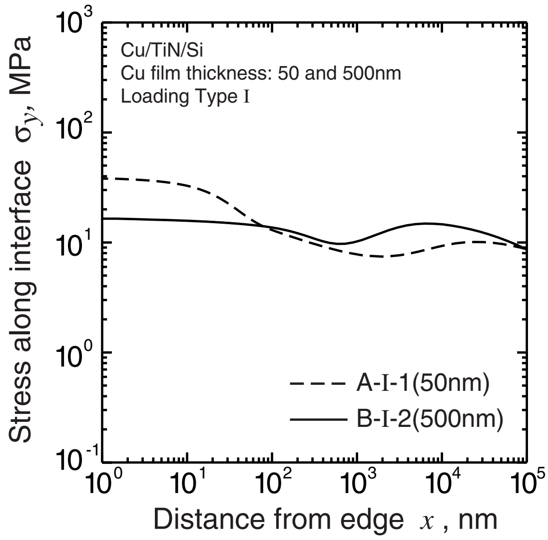


Figure 3: Distribution of normal stress along the interface near the edge.

stress intensity among the experiments. Attention must be paid to the fact that the stress near the interface edge is dependent on the Cu film thickness.

4 SUPERIMPOSE OF EXTERNAL AND INTERNAL STRESSES

Figure 4 shows the stress distribution near the Cu/TiN interface edge at the delamination obtained by the BEM superimposing the contributions of the internal stress and the applied load. The good agreement in the normal stress, σ_y, distribution regardless of the Materials A and B indicates that the crack initiation is governed by the intensified normal stress near the interface edge due to superimpose of external and internal stresses. Comparing the stress distributions shown in Figs.3 and 4, the contribution of the internal stress dominates the crack initiation. Strictly speaking, the power relationship between σ_y and x, eqn (1), does not exist. Figure 4 indicates, however, that the relationship approximately stands in this case. Since λ is nearly equal to 0.18, the stress intensity at the delamination, K_C, is evaluated as about 2.8 $\mathrm{MPam}^{0.18}$ independent of the Cu thickness.

ACKNOWLEGDEMENTS

This paper is supported in part by Center of Excellence for Research and Education on Complex Functional Mechanics (COE program of the Ministry of Education, Culture, Sports, Science and Technology, Japan).

REFERENCES

[1] Kitamura T, Hirakata H, Itsuji T, Eng. Fract. Mech., 2003, 70: 2089-2101

[2] Kitamura T, Shibutani T, Ueno T, Eng. Fract. Mech., 2002; 69: 1289-1299

[3] Bogy DB, Journal of Applied Mechanics, 1968; 35: 460-466

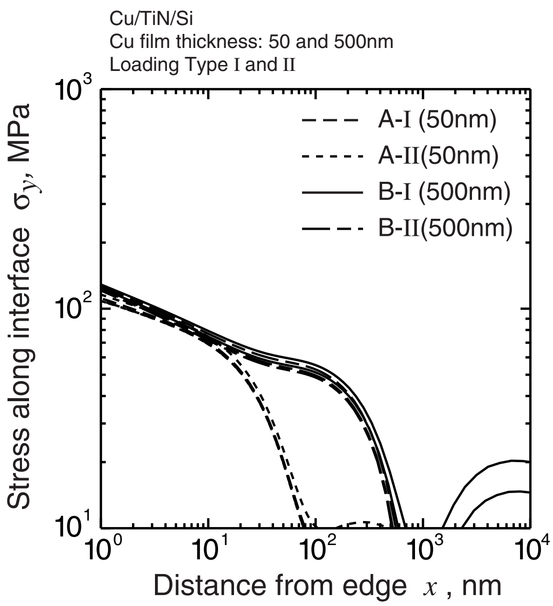


Figure 4: Distribution of superimposed stress along the interface near the edge.