Microelectronic Engineering 137 (2015) 59–63

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Effect of 4-point bending test procedure on crack propagation in thin film stacks

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ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 12 September 2014
Accepted 15 September 2014
Available online 27 September 2014

Keywords:
4 point bending
FEM modeling
Symmetric/asymmetric crack propagation
G_c variation
Cohesive/adhesive failure
Crack path variation

ABSTRACT

An in-depth study of 4-point bending (4PB) test method had been conducted in order to determine the influence of test parameters on measured critical energy release rate G_c and fracture location. Force loading speed proved to have an influence not only on measured G_c values, but also on quality of force–displacement curve plateau, as did the loading pin distance. While the 4PB technique is used to determine the adhesion strength of a material, a study of notch depth had also been conducted in order to determine whether it is possible to trigger the cohesive failure of the tested low-*k*. In addition to the experimental work, the influence of crack propagation path within the sample (symmetric and asymmetric propagation) on measured force plateau was assessed using a Finite Element Method (FEM) modeling. Assuming same interfaces triggered, crack propagation path was shown to have no influence on the value of force plateau. The FEM simulation also showed good correlation with analytical results found in literature in regards to crack opening.

1. Introduction

In order to meet the ever increasing demands for improved performance of ICs, new ultra low-*k* dielectrics have been introduced with the goal of reducing the RC delay of the interconnect layer. However, this improvement of performance comes at the cost of reduced mechanical integrity. Adhesion properties of the ultralow-*k* films play a critical role in mechanical integrity of the Back-End-Of-Line (BEOL). The 4-point bending (4PB) test method has been widely used to quantify the adhesion energy of interfaces in multilayer thin film stacks [1]. However, there is no standardized specimen preparation method or 4-point bending test procedure, which leads to a possibility of having different results with the same low-*k* material. The goal of this paper is to investigate the influence of various test setups on measured critical adhesion energy.

2. Experimental details and sample description

The interface adhesion strength is commonly characterized by the critical energy release rate, G_c. The 4PB test is a powerful, commonly used technique to quantitatively measure G_c and is therefore suitable to study the effect of a wide range of factors, such as effect of cure/bake temperature [2], on thin film adhesion. A high precision micro-mechanical test system (DTS Company) was used to perform 4PB tests using sandwiched beam specimens containing the films of interest. Three displacement rates (0.5 µm/s, 1 µm/s, 5 µm/s) were used during the tests. The system includes an actuator that provides linear motion with a submicron resolution. To produce specimens for 4PB tests, specific film stacks were prepared on 300 mm Si wafers with thickness of 775 µm. Three different film stacks were prepared and tested. First film stack consisted of 200 nm thick spin-on glass (SOG) dielectric film with *k*-value close to 2.2 which was first deposited onto the wafer, followed by a 5 nm thick TaN/Ta physical vapor deposition (PVD) metal barrier, 60 nm PVD Cu seed and 500 nm electroplated Cu. Sec-

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http://dx.doi.org/10.1016/j.mee.2014.09.006
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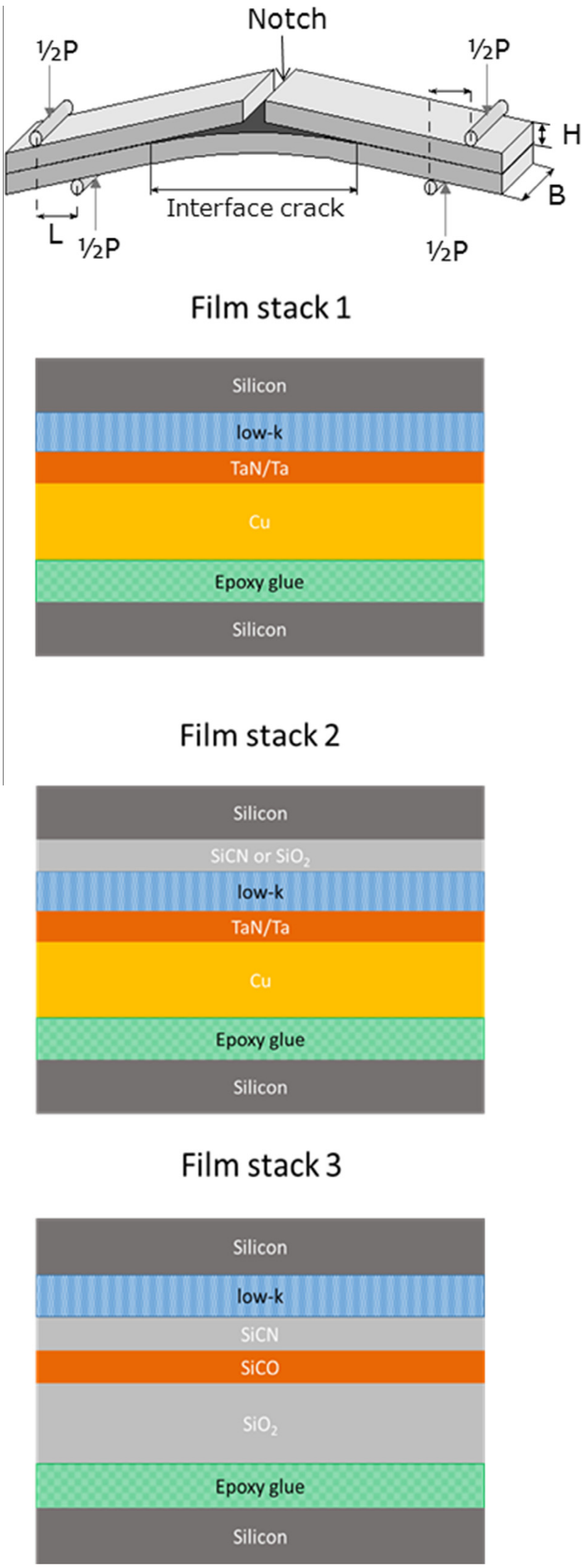

Fig. 1. 4PB test layout and tested film stacks.

Table 1
Tested film stacks.

Film stack 1	Film stack 2	Film stack 3
SOG 2.2 low-*k*	SOG 2.2 low-*k*	PECVD OSG 2.2 low-*k*
5 nm TaN/Ta PVD barrier	30 nm SiCN or 100 nm SiO_2	5 nm SiCN
60 nm Cu PVD barrier	5 nm TaN/Ta PVD barrier	25 nm SiCO
500 nm electroplated Cu	60 nm Cu PVD barrier	1000 nm SiO_2
	500 nm electroplated Cu	

ond stack was identical to the first, with only difference being additional 30 nm SiCN or 100 nm SiO_2 layer, deposited below the low-*k*. Third stack consisted of plasma enhanced chemical vapor deposition organosilicate glass (PECVD OSG) dielectric film with *k*-value close to 2.2, followed by a 5 nm thick SiCN, 25 nm SiCO and finally 1000 nm SiO_2 layer. All three stacks are then sandwiched in between Si substrates using an epoxy and curing it at 125 °C for 120 min. Stack layouts and layer thicknesses can be seen in Fig. 1 and Table 1. After this, the samples were diced into rectangular pieces of sizes 60×5 mm^2 and centrally notched [2]. During 4PB testing, at certain maximum load (peak load), a crack is initiated at the notch and propagates into specific location in the film stack. At critical load *P*, the crack then propagates in a steady state manner. The critical energy release can then be calculated from the plateau load *P*, as followed

$$G_c = \frac{21}{16}\frac{(1 - v^2_{\text{substrate}})P^2L^2}{E_{\text{substrate}}B^2H^3} \tag{1}$$

where *E* and *v* are Young's modulus and Poisson's ratio of the substrates, and parameters *L*, *B*, and *H* are as defined in Fig. 1.

To study the influence of notch the depth, the individual 4PB samples were notched at four different depths, namely 630 µm, 560 µm, 540 µm and 480 µm. This notch was diced at the substrate on which the film stack was deposited.

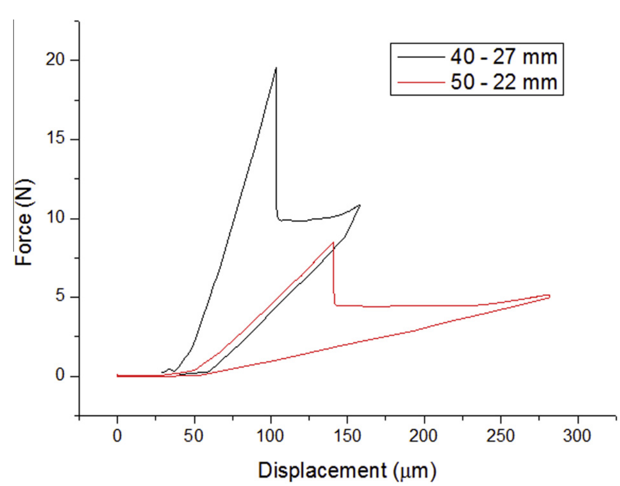

Fig. 2. Force plateaus for 40–27 mm and 50–22 mm configurations.