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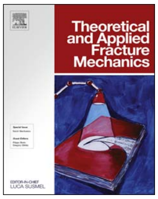

Mixed mode interfacial crack energy estimation of glass interposer and SiNx coatings by using fracture mechanics based computer methods and experimental validations

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ABSTRACT

Glass-based interposer is a promising candidate for novel 3D-IC integrations because of its characteristics, such as low cost, low coefficient of thermal expansion, smooth surface quality, and large size fabrication. However, an inherent behavior of brittle material such as glass is its low fracture toughness, which easily induces both interfacial delamination and fracture failure modes, particularly for bonds with neighboring passivation coating of silicon nitride (SiN_x). Accordingly, this research proposes a simulated methodology based on the index of interfacial strain energy released rate (G-value) to estimate the glass/SiN_x interface using a J-integral approach and modified virtual crack closure technique. Adhesion measurement of glass/SiN_x was also implemented by means of four-point bending architecture to validate the predicted accuracy. The results show that a 17.95 J/m^2 of G-value for aforementioned interface is obtained. A higher modulus of SiN_x coating as determined by different deposited conditions utilized at the concerned glass/SiN_x interface also had an effect on the critical fracture energy of the crack after it begins to advance.

1. Introduction

Interposer technology has been widely developed and adopted in chip stacking and three-dimensional integrated circuits (3D-ICs) packaging because it satisfies the requirements of high performance, stacking size miniaturization, and cost consideration. In selecting the substance of the interposer, a glass-based carrier has low coefficient of thermal expansion (CTE) as compared with the traditional silicon one. Consequently, glass interposers deposited with multi wire-redistributed coatings are regarded as a promising candidate for diminishing the stress impact resulting from CTE mismatch among 3D-ICs packages. However, many urgent reliability issues need to be addressed, such as thermo-mechanical stress, thermal management, micro-bump fatigue life, and delamination of multi-stacked coatings [1–8]. The thickness of the stacking components within an interposer scaled down to the scope of several micro and nanometers has resulted in the common occurrence of interfacial fracture, which has become one of the major concerns. The interfacial fracture is inspected facilely during the manufacturing process. Another concern is the poor adhesive characteristics of a bi-coating system. Hence, in addition to experimental implements, the fracture-based finite element analysis (FEA) is also utilized as a capable approach to demonstrate and explain the interfacial fracture mechanism of dissimilar stacked coatings with nano-scaled thickness [9,10]. Lai et al. investigated the delamination growth behavior in the packaging structure under a load of fatigue temperature cycling [11]. The numerical analysis of peeling test was performed to evaluate the interfacial characteristics of a laminated glass [12]. The interfacial adhesion of an a-Si_3N_4/Si bi-layered system was predicated through the utilization of the molecular dynamics simulation, which can describe the fracture phenomenon of interfacial crack [13]. A similar approach is used to improve the related mechanical stability and reliability of multi-layered advanced packaging [14]. On the other hand, the pressure-sensitive adhesives (PSA) are widely adopted in applications of package and electric products. The mechanical properties and responses of PSA on its adhesion, peel, and shear behaviors are summarized and reported by Sun et al. [15]. The modeling of peeling mechanism for PSA adhered on flexible substrate has also developed [16,17]. To enhance the peel resistance, the effect of substrate in term of stainless steel, poly methyl methacrylate, polycarbonate, polyethylene, polypropylene, and polytetrafluoroethylene, are considered and demonstrated, respectively [18]. Moreover, the bonded strength of PSA applied to mobile devices under a dropped load is analyzed in detail [19].

However, previous technical literatures have focused rarely on the adhesive properties of concerned glass interposer and the adjacent thin

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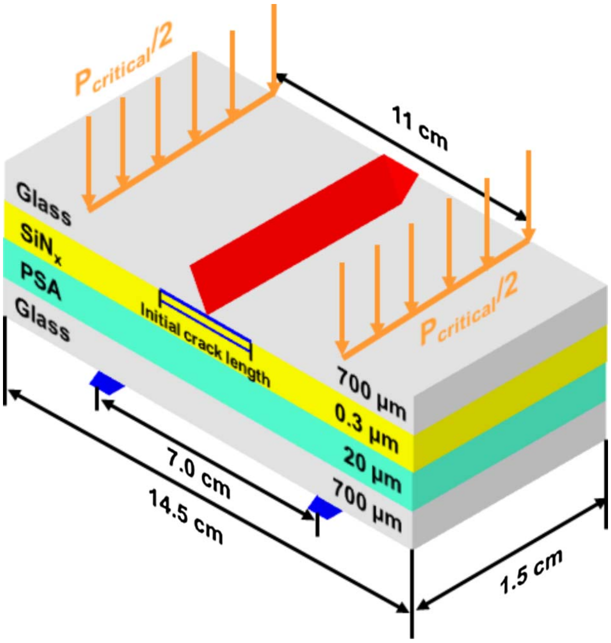

Fig. 1. A schematic diagram of the stacked coatings specimen composed of the interfacial crack between the glass interposer and SiN_x passivated layer performed in 4-PBTs.

coating, and a significant scale mismatch among them exists. For this reason, the fracture-based FEA combined with the experimental measurements of four-point bending tests (4-PBTs) were performed to extract and optimize the adhesive strength of glass interposer/silicon nitride (SiN_x) passivation, as shown in Fig. 1.

2. Fracture-based numerical analysis and theory

From the viewpoint of fracture mechanics, the adhesive properties of dissimilar materials are difficult to investigate using specific stress components because of the complexity of the driving force for cracking extension with mixed failure mode. Hence, several energy-based methodologies have been developed and subsequently demonstrated to examine the interfacial fracture behavior of concerned heterogeneous interface. In this research, two well-known approaches, J-integral approach and modified virtual crack closure technique (MVCCT) are adopted separately to estimate the strain energy release rate (G-value) of glass/SiN_x interface. The detailed explanation of the above-mentioned numerical theories can be found in the following sections.

2.1. J-integral approach for interfacial cracking energy estimation of dissimilar stacked coatings

The energy-based J-integral approach is demonstrated to be suitable for calculating the G-value under the elasto-plastic condition. When the considered medium is pure elastic, the estimation acquired from the J-integral approach is identical to the same magnitude of G-value. The normal formula can be expressed as follows [20]:

$$J = \int \Gamma \left(W dy - T \frac{\partial u}{\partial x} ds \right) \tag{1}$$

where W refers to the strain energy density per unit capacity and T and u represent the surface traction and displacement vectors alongside Γ curve, respectively. Moreover, Γ is an arbitrary contour path around the crack tip and ds is an infinitesimal section of the contour length along Γ. The decent selection of integral path is necessary for the calculation of interfacial adhesive strength on the interface included in the FEA model. Consequently, a robust J-Integral path with a rectangular shape is clarified in FEA when the ratio of Track 2 divided by Track 1 revealed in Fig. 2 is approximately infinity [21].

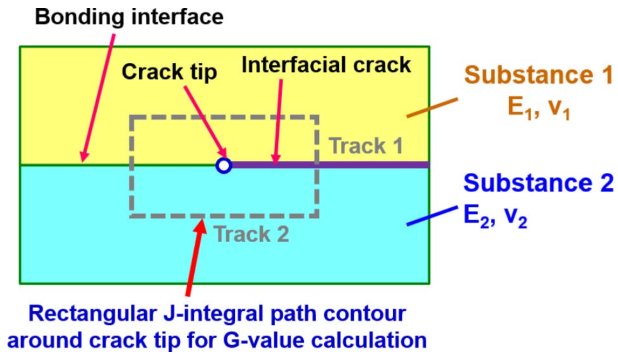

Fig. 2. A sketched explanation of the extraction of interfacial cracking energy using the J-integral approach with integral contour of a rectangular path.

2.2. Modified virtual crack closure technique (MVCCT)

Among the predicted approaches of interfacial adhesions, MVCCT is regarded as one of the most uncomplicated methods, because it requires only one step for the G-value calculation. Moreover, MVCCT is also beneficial in clarifying detailed information on whether the magnitude of cracking energy belongs to each fracture mode and the related mixed level of fracture vectors at the crack tip. Take the example of a two-dimensional situation, two main fracture modes composed of peeling-dominated fracture mode (G_I) and shearing-dominated fracture mode (G_{II}) can be described mathematically. The formulas for the type of four-nodal element are written separately as follows and graphed in Fig. 3 [22].

$$G_I = \frac{1}{2\Delta A}\left(\sum_n F_z^{(j_1)}\delta_z^{(i_1,i_2)}\right) \tag{2}$$

$$G_{II} = \frac{1}{2\Delta A}\left(\sum_n F_x^{(j_1)}\delta_x^{(i_1,i_2)}\right) \tag{3}$$

where ΔA denotes the element length multiplied by a unit width adopted in FEA model, and n refers to the numbers of nodes alongside the crack front direction. $F_z^{(j1)}$ and $F_x^{(j1)}$ refer to the nodal forces exerted individually at node j_1 along the orientations of z and x axes. The relative displacements between nodes i_1 and i_2 along the directions of z and x axes are labeled separately as δ_z and δ_x.

3. Finite element modeling of dissimilar stacked coatings and 4-PBT testing apparatus

In accordance with the testing scheme of stacked coatings shown in Fig. 1, the half symmetry of FEA model for 4-PBT specimens during the testing process needs to be constructed. The related geometrical

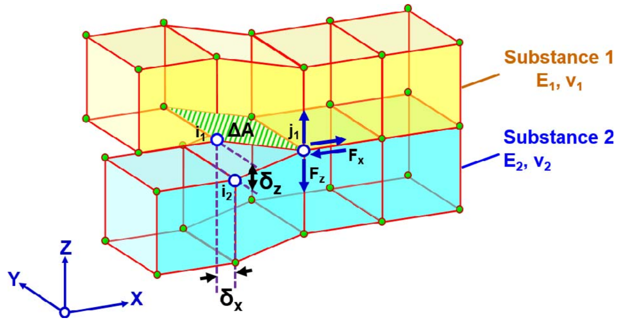

Fig. 3. Description of delaminated energy components with regard to MVCCT utilized in FEA simulation for in-plane peeling (G_I) and shearing (G_{II}) fractured modes.