出席國際學術會議心得報告

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會議時間地點	7 月 12 日至 7 月 14 日，2010/ Istanbul , Turkey
會議名稱	ASME 2010 工程系統設計與分析研討會
發表論文題目	Effect of Material Properties and Thickness of Die Attach on Delamination of Die Attach / Die Paddle Interface in Electronic Package

一、參加會議經過

2010 年 7 月 12 日至 7 月 14 日，經由香港至土耳其之伊斯坦堡參加 ASME 2010 Biennial Conference on Engineering Systems Design and Analysis，進行論文發表及參與相關學術交流。此研討會由 ASME 歐洲區分會主辦，每二年舉辦一次，此次會議選在土耳其舉辦，旨在更積極促進歐亞兩洲之學術交流，研討會之主題涵蓋各機械領域(熱流、固力、控制、製造、結構、材料等)，目的在促進國際學者對最近機械工程系統設計與分析發展的認識，增進彼此間的互動與交流，提升個人相關工程知識之累積。

二、與會心得

近年來新興發展國家積極投入工程領域研發，所參與的研討會場次，多篇論文來自中東地區的回教國家，論文利用電腦輔助工程分析的方法尋求機械結構的強度改進，新興國家在機械工程領域的發展，可期待較以往進步。研討會並有機會參觀土耳其 YediteRe 大學，其為土耳其成立不久的大學，位於伊斯坦堡的亞洲區，學校近年來積極舉辦國際研討會，與尋求國際研究合作，學校對國際合作與工程教育之重視，值得參考。

EFFECT OF MATERIAL PROPERTIES AND THICKNESS OF DIE ATTACH ON DELAMINATION OF DIE ATTACH/DIE PADDLE INTERFACE IN ELECTRONIC PACKAGE

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ABSTRACT

The electronic package is a multi-layered structure that is consisted of several materials. Under the temperature loadings, the interfacial stresses between layered components are generated due to the CTE (coefficient of thermal expansion) mismatch between different materials. In die bonding process, the void or defect might exist at the die attach/die paddle interface. The void cause further delamination on the interface during the encapsulation process. In this study, the finite element method is used to construct the model of electronic package with a void on the die attach/die paddle interface. The energy release rate based on J integration, which is calculated by the stress and strain around the tip of crack, is used as a damage parameter to predict the tendency of further delamination during encapsulation. Effect of material properties (Young's modulus and CTE) and die attach thickness on delamination of die attach/die paddle interface in package during encapsulation is studied.

Keywords: Delamination, Die Attach, Energy Release Rate, Finite Element

1. INTRODUCTION

The electronic package is a multi-layered structure, which consists of different materials. Thermal stresses are induced during processing steps, due to the fact that the silicon die , the die attach, the lead frame and the molding compound all have different coefficients of thermal expansion (CTE). The development of electronic package is toward lighter, thinner, shorter, smaller, and high performance. Under the minimization trend, the package stresses during assembly processes get more concerned. The stresses in package are important factor for the structural damage of package.

Delamination of interfaces in package during assembly processes is one of primary reliability problems for plastic package. The interfacial delamination of package can be predicted by interfacial stresses. The effects of material properties and geometrical dimensions of package components on interfacial stresses during processing steps have been extensively studied. Kelly et al. [1] used numerical simulation to study the effect of CTE mismatch between die and die attach on the interfacial stresses between die and die attach. Chang et al. [2] used finite element method to study the mechanisms of package delamination. The results show that the delaminations of die attach is caused by CTE mismatch between die attach and adjacent components and increasing the thickness of die attach can reduce the interfacial stresses of die attach. Lin et al. [3] constructed a finite element model of package to calculate the interfacial stresses of die paddle for both single and stacked die package during encapsulation. The principal stress is used as the damage parameter to predict the die paddle/molding compound delamination. Kapoor et al. [4] built a 3-D finite element model of package to simulate the interfacial stresses of die during the surface mount process. The interfacial shear stress of die is used to predict the die/molding compound delamination.

The interfaces between different materials in the package are the weakest area of package. If the stresses become excessive, the interfaces will tend to delaminate. However, the stresses at the sharp edge of die and die paddle are difficult to calculate accurately due to the singularity of geometric shape. Alternatively, a fracture mechanics approach was used to predict the interfacial delaminations in package. In using the fracture mechanics approach, a tiny crack is assumed at the edge of the crack-prone interface. Liu et al. [5] used fracture mechanics approach to analyze both pre-delamination and post-delamination of die attach of a SOIC package during reflow process. Tay [6] used numerical methods to calculate fracture mechanics parameters. Fracture mechanics methodology was applied to analyze the popcorn cracking failure of a plastic electronic package under solder reflows.

Delamination of die attach during encapsulation is one of the reliability problems for thin small outline package (TSOP). Die-attach delamination is caused by thermal deformation mismatch between die attach and adjacent materials acts on the initial void at die attach edge during thermal load. The void is generated owing to manufacturing faults or contaminations in die bonding process. In this study, finite element method is used to calculate package fracture parameters as energy release rate and mode mixity. Linear-elastic fracture mechanics approach is then applied to study the effect of material properties and thickness of die attach on delamination of die attach/die paddle interface in package during encapsulation.

2. STRAIN ENERGY RELEASE RATE

The energy release rate G and mode mixity (phase angle ψ) are widely used in the delamination analysis of electronic package. The interface will delaminate when the energy release rate exceeds the interface toughness. The J-integral is defined as an integral that measures the strength of the singular stresses and strains near a crack tip:

$$J = \int_\Gamma W dy - \int_\Gamma t_i \frac{\partial u_i}{\partial x} ds \qquad (1)$$

Where Γ is any path surrounding the crack tip; W is the strain energy density; t_i is the traction vector; u_i is the displacement vector; and s is the distance along the path Γ.

$$W = \frac{1}{2}\sigma_{ij}\varepsilon_{ij} \qquad (2)$$

Where σ_{ij} is the stress tensor; ε_{ij} is the infinitesimal tensor.

For a linear 2-D elastic material, the J-integral is related to stress intensity factor K and G as [8]:

$$J = G = \frac{1}{E^* \cosh^2(\pi\varepsilon)}(K_I^2 + K_{II}^2) \qquad (3)$$

Where K_{I} is Mode I (opening mode) stress intensity factor and K_{II} is Mode II (shearing mode) stress intensity factor; E^* is an effective Young's modulus, the formulation for bimaterial is as Eqn. (4); and ε is the oscillation index.

$$E^* = \frac{2E_1E_2}{E_1 + E_2} \qquad (4)$$

Where E_1 is Young's modulus for material 1 and E_2 is Young's modulus for material 2.

$$\varepsilon = \frac{1}{2\pi}\ln\left(\frac{1-\beta}{1+\beta}\right) \qquad (5)$$

Where β is the second Dundurs' parameter.

$$\beta = \frac{\mu_1(\kappa_2 - 1) - \mu_2(\kappa_1 - 1)}{\mu_1(\kappa_2 - 1) + \mu_2(\kappa_1 - 1)} \qquad (6)$$

Where μ stands for the shear modulus, κ is an index parameter for plain strain and plain stress.

Mode mixity $K_{\mathrm{II}}/K_{\mathrm{I}}$ can be calculated as:

$$\tan^{-1}\psi = \frac{K_{\mathrm{II}}}{K_{\mathrm{I}}} \qquad (7)$$

Where ψ is the phase angle.

In order to verify the numerical calculation of strain energy release rate by finite element method, a double cantilever beam with bimaterial [7] was built to perform the simulation. In the numerical simulation, the commercial code ANSYS 10.0 was used for all calculations. The model of a double cantilever beam subjected to a pair of loads at the free ends is shown in Fig. 1. The Young's modulus for material I is 11.9 GPa, and material Ⅱ is 169.54 GPa. The dimension for length L is 40 mm, half height H is 1 mm, width B is 1 mm, and crack length a is 20 mm.

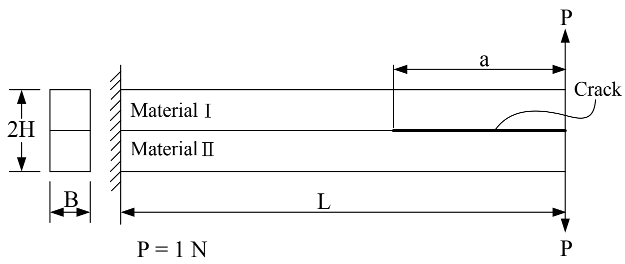


Fig1 Double cantilever beam model

In the finite element model, the materials are assumed to be isotropic and homogeneous. A collapsed triangle element (Plane 82 singular element) as shown in Fig. 2 is used to model the elements at the vicinity of crack tip. The rest of elements are constructed by four node element (Plane 42). The constructed 2-D finite element model (plane strain) of a double cantilever beam with bimaterial is shown in Fig. 3, where (a) is the global mesh model and (b) is the local mesh model with radius 0.4 mm and divisions 20 at the crack tip. Close up of the local model is magnified by 60. The sensitivity of element size on the calculated results was tested. In the test, the radius of enclosed circle at the crack tip is ranged from 0.1 mm to 0.5 mm and the division of radius is 10, 20, and 30, respectively. Considering the singular behavior of stresses and strain at the crack tip, the integral path of *J*-integral should disregard the singular elements. Form Fig. 4, the *J*-integral is almost converged for 20 divisions; however the radius 0.1 mm can obtain the closest calculation to the analytical result [7]. The energy release rate for the double cantilever beam with a bimaterial is given as

$$G = \frac{6P^2a^2}{B^2H^3}\left(\frac{1}{E_1}+\frac{1}{E_2}\right) \qquad (8)$$

Where *P* is concentrated load; *a* is crack length; *B* is width of the beam; *H* is half height of the beam, *E* is Young's modulus.

The energy release rate calculated by finite element method is 209(J/m^2), and the value estimated by Eqn. (8) is 216(J/m^2). The relative error is about 3.2%. The numerical simulation shows that the energy release rate predicted by finite element method can agree closely with the theoretical value.

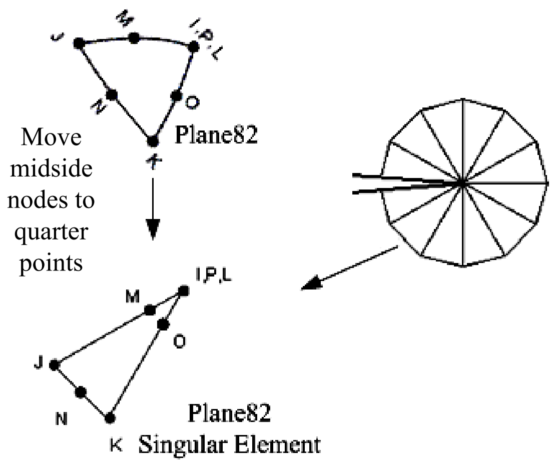
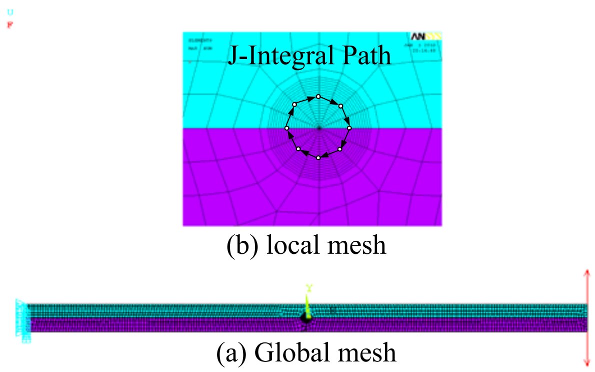


Fig. 2 2-D singular element



(b) local mesh

(a) Global mesh

Fig. 3 Finite element model of double cantilever beam

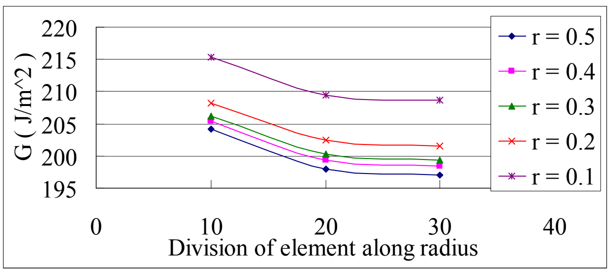


Fig4 Convergence test of double cantilever beam model

3. FINITE ELEMENT MODEL OF TSOP

A plastic 44-leaded TSOP package of dimensions 18.4×12×1 mm, die size of 5.10×3.97×0.28 mm, and die paddle size of 7.11×5.33×0.15 mm was selected for study. The generation of mesh model for TSOP with crack is similar to that for the double cantilever beam in previous section. The finite element mesh is shown in Fig. 5. In the figure, the die attach thickness is 0.0254 mm, and the mesh size of die attach is about 0.003 mm. The Young's modulus of die is 156.8 GPa, Poisson's ratio is 0.3, and CTE is 2.8 ppm/℃. The Young's modulus and Poisson's ratio of molding compound is 23.6 GPa and 0.3, respectively. The molding compound and die attach are polymer materials. The CTE of polymer material is a function of temperature. In this study, the effective CTE which considers both CTE below and above the glass transition temperature is used to represent the CTE of polymer materials. The effective CTE of molding compound is 35.9 ppm/℃. For leadframe (C7025), Young's modulus is 135 GPa, Poisson's ratio is 0.3, and CTE is17.3 ppm/℃. The impact of material properties and thickness of die attach on die attach-to-die paddle delamination was evaluated. The thickness is from 0.5 to 1.5 mil (10^{-3} in). The die attach properties is a combination of three Young's moduli and three effective CTE's. The studied failure behavior is the encapsulation process. Therefore the stress-free temperature is assumed to be the molding temperature, 175℃. When the package is cooled down to room temperature, 25℃, the energy release rate at the crack tip was calculated for different die attach materials and thicknesses.

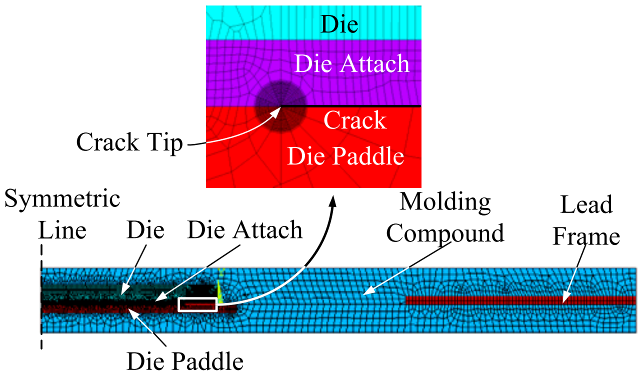


Fig. 5 Finite element mesh of TSOP with crack

4. RESULTS AND DISCUSSIONS

To evaluate the effect of material properties on delamination, the Young's modulus and CTE of the die attach are varied over different delamination length and die attach thickness. The range of material properties is chosen from the available die attach materials. The Young's modulus studied are 2.2, 3.3, and 4.5 GPa. The CTE's are 89.7, 131.3, and 172.8 ppm/℃. The delamination lengths studied are from 0.5 to 2 mm. For all the combinations, the energy release rate at the interfacial crack tip with die attach thickness 1.0 mil is calculated. The results of effect of Young's modulus of die attach on delamination are shown in Fig. 6 to Fig. 8 and the results of effect of CTE of die attach on delamination are shown in Fig. 9 to Fig. 11.

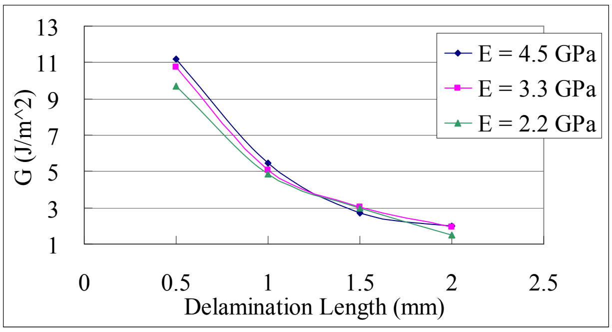


Fig. 6 Effect of Young's Modulus of Die Attach on Delamination (CTE = 172.8 ppm/℃)

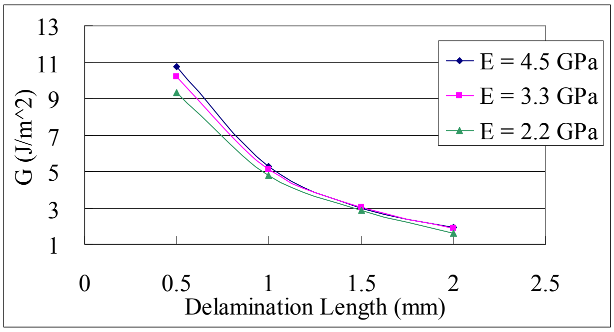


Fig. 7 Effect of Young's Modulus of Die Attach on Delamination (CTE = 131.3 ppm/℃)

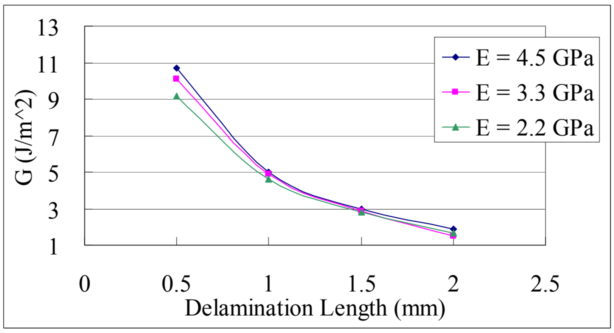


Fig. 8 Effect of Young's Modulus of Die Attach on Delamination (CTE = 89.7 ppm/℃)

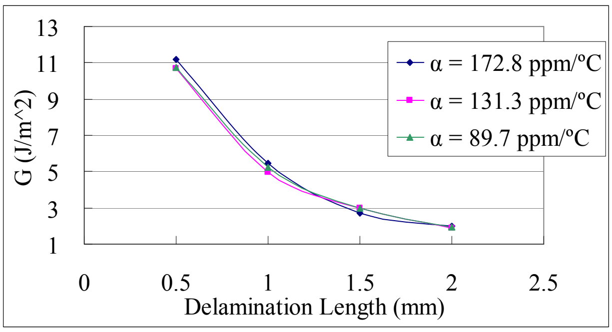


Fig. 9 Effect of CTE of Die Attach on Delamination (E = 4.5 GPa)

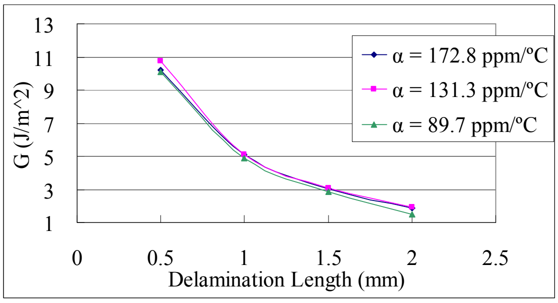


Fig. 10 Effect of CTE of Die Attach on Delamination (E = 3.3 GPa)

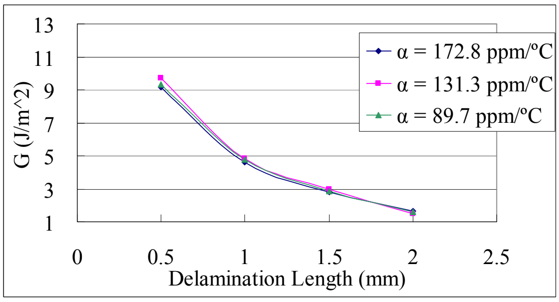


Fig. 11 Effect of CTE of Die Attach on Delamination (E = 2.2 GPa)

The figures indicate that the trend of energy release rate is increasing with increasing either Young's modulus or CTE. But the effect of Young's modulus is more significant than that of CTE. The results also show that the energy release rate is decreasing with increasing the delamination length. The stress distributions along the crack tip for different delamination lengths are shown in Fig. 12 to Fig. 14, where L_d is delamination length. The results show that von Mises stress along the crack tip is decreasing with increasing the delamination length. The effect of delamination length on the stress distribution is similar to the effect of delamination length on the energy release rate. For the studied die attach thicknesses, the energy release rate at the crack tip with Young's modulus 3.3 GPa and CTE 131.3 ppm/℃ is compared. The results are shown in Fig. 15. The figures show that the effect of die attach thickness on the energy release rate is not significant. But the energy release rate is slightly decreasing with increasing the die attach thickness for delamination length 0.5 mm.

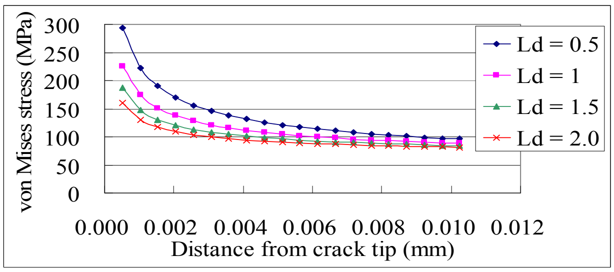


Fig. 12 Effect of Delamination Length on Stress Distribution along Crack Tip
(D/A thich. = 0.5 mil)

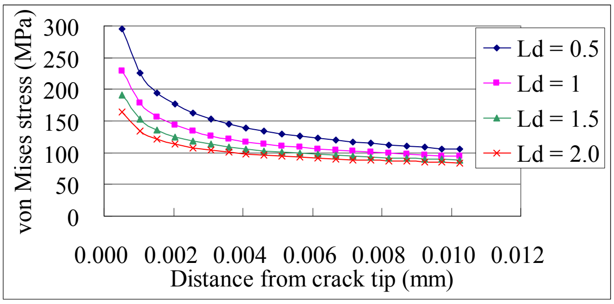


Fig. 13 Effect of Delamination Length on Stress Distribution along Crack Tip (D/A thich. = 1 mil)

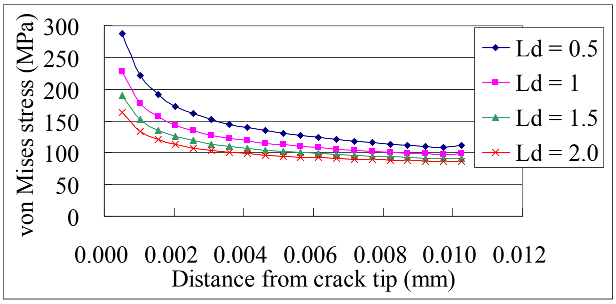


Fig. 14 Effect of Delamination Length on Stress Distribution along Crack Tip (D/A thich. = 1.5 mil)

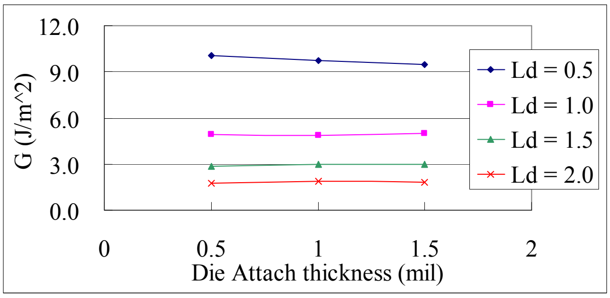


Fig. 15 Effect of Die Attach Thickness on Delamination

The interface will delaminate when the energy release rate exceeds the interface toughness. The toughness is a function of mode mixty. [6] The toughness has a minimum at $\psi = 0^\circ$ (pure Mode Ⅰ) and a maximum at $\psi = 90^\circ$ (pure Mode Ⅱ). Phase angle $\psi > 45^\circ$ stands for shear mode, while $\psi < 45^\circ$ corresponds opening mode. [5] The toughness is decreasing as the phase angle is decreasing. The Calculated mode mixity for different material combinations with die attach thickness 1.0 mil is shown in Fig. 16 to Fig. 18. The phase angle for the studied cases is between 62.5° to 72.5°. The results show that the trend for phase angle is increasing with increasing the delamination length. The effect of material properties of die attach on mode mixity is quite random. The effect of die attach thickness with Young's modulus 3.3 GPa and CTE 131.3 ppm/℃ is shown in Fig. 19. The results indicate that the phase angle is decreasing with increasing the die attach thickness.

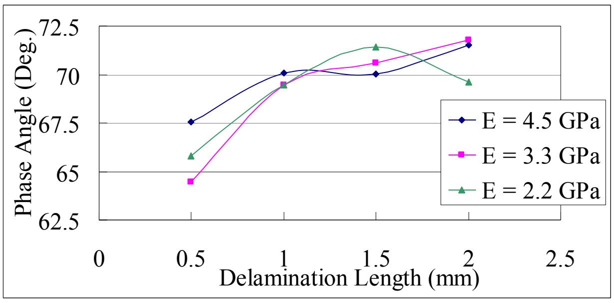


Fig. 16 Effect of Young's Modulus of Die Attach on Mode Mixity (CTE = 172.8 ppm/℃)

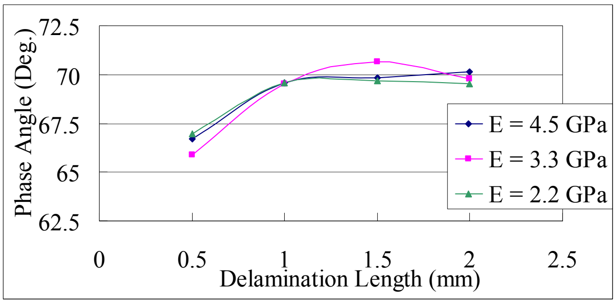


Fig. 17 Effect of Young's Modulus of Die Attach on Mode Mixity (CTE = 131.3 ppm/℃)

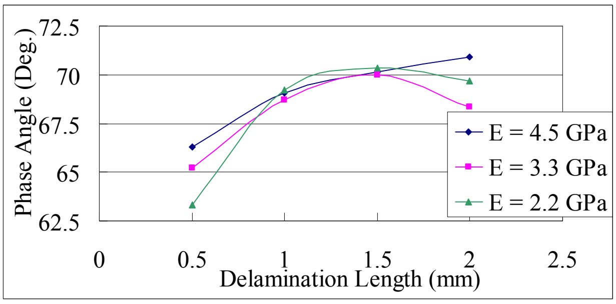


Fig. 18 Effect of Young's Modulus of Die Attach on Mode Mixity (CTE = 89.7 ppm/℃)

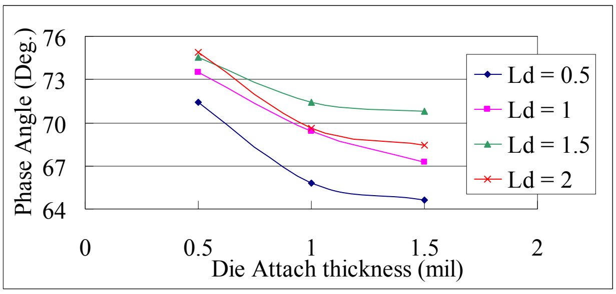


Fig. 19 Effect of Die Attach Thickness on Mode Mixity

5. CONCLUSION

In this to study, the fracture mechanic approach is used to study the effect of material properties and thickness of die attach on delamination of die attach/die paddle interface in TSOP under encapsulation. Energy release rate at the crack tip is increasing with increasing either Young's modulus or CTE of die attach. The effect of Young's modulus is more significant than that of CTE. For the studied cases, the effect of die attach thickness on energy release rate is insignificant. The phase angle is decreasing with increasing the die attach thickness. A good material design for die attach is low Young's modulus and low CTE. In the future, DOE (Design of Experiment) will be applied to obtain the optimal material properties and thickness of die attach to reduce the package delamination.

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