

# **CHARACTERISATION OF INTERFACIAL CRACKING IN MICROELECTRONIC PACKAGING**

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## **ABSTRACT**

The development of advanced package designs, including the Ball Grid Array (BGA) and Flip-chip packaging, has significantly increased the demand for more accurate measurement of mechanical properties of materials. Microelectronic packages and assemblies contain many layers of different materials, where amongst the many properties of interest; the adhesion of these layers is of primary concern. Delamination at any of the interfaces e.g. Die/Leadframe, Molding Compound/Leadframe, Underfill/PCB, solder ball/PCB will almost certainly lead to device failure. Predicting the performance of new packages and processes with Finite Element Modelling techniques requires accurate and comprehensive data on the materials and their interfaces.

This paper first reviews established methods of mechanical bond strength testing and then looks at new fracture based test methodologies proposed and under development for measurement of interfacial properties. The new techniques based on Fracture Mechanics principles for properties in mode I, II and mixed mode fracture offer the ability to determine the fundamental materials and interfacial properties needed to properly model package designs. These new techniques offer tremendous promise, but in practice difficulties exist due to the small sizes of the test samples used, which results in greater demands from the test instrumentation compared to traditional strength testing.

# 1. INTRODUCTION

## 1.1 Mechanics of Microelectronic Packaging

In the last few years there has been a significant increase in the use of mechanical testing in the microelectronics industry. Historically, much of the mechanical evaluation done has focused on simple techniques such as wire pull testing with simple pass/fail criteria based on the failure force. Designers of microelectronics devices had little need to concern themselves with structural failures and manufacturing quality control requirements drove the need for mechanical testing. However the continued drive towards ever smaller, faster and cheaper microelectronic devices driven by the market for products such as mobile phones, computers, PDA's and MP3 players has lead to the development of very high density packages. At the same time environmental legislation is driving changes in some of the established materials e.g. lead free solders and process redesign to reduce process waste. A cross section of a typical high-density BGA package is shown in Figure 1 and an example of delamination and subsequent cracking in a typical microelectronic package is shown in Figure 2.

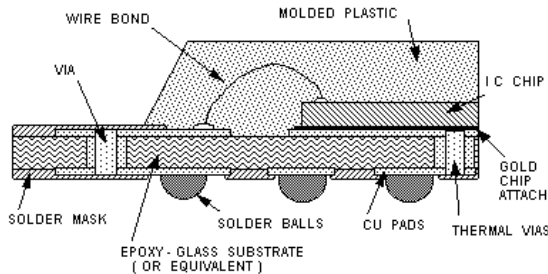


Figure 1 - Cross section of BGA package showing interfaces between dissimilar

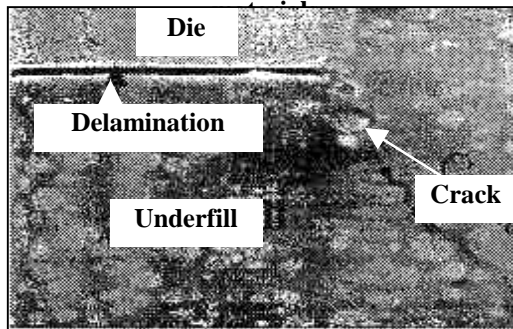


Figure 2 - Cross section of Flip-chip showing delamination of die and cracking of the Underfill

## 1.2 The Role of Mechanical Testing in Microelectronics

As will be clear from Figure 1 the level of the structural complexity (high stiffness, mix of materials with differing thermal expansion coefficients etc.) of BGA and other high-density packages means that predicting reliability is a complex matter involving; sophisticated design and modelling, design verification and accelerated life testing. Mechanical testing is required in order to provide accurate materials and interfacial properties data for design and modelling, design verification (strength testing) and for accelerated life testing (fatigue testing).

Typically the materials data would include tensile properties (elastic, yield, fracture), time dependent properties such as

creep and stress relaxation and fatigue for materials along with interfacial properties. Other data such as the thermal and hygrothermal (e.g. volume change due to moisture absorption) properties would also be required.

Traditionally one of the key methods of evaluating the reliability of an electronic component or assembly has been thermal cycling, however the nature of this method means that it is very time consuming and is ill-suited to the short product and process development cycles associated with the fast moving world of microelectronics. Various types of mechanical test e.g. cyclic fatigue and creep-fatigue on solder joints and assemblies can be used to augment or even replace thermal testing.

In many ways mechanical testing and design in the Microelectronics Industry is now emulating the path taken by traditional mechanical engineering activities in terms of development of materials data bases and accelerated service life testing of components, subject to thermally generated strains, by means of a mechanical fatigue test.

## 2. Measurement of Interface and Bond strengths

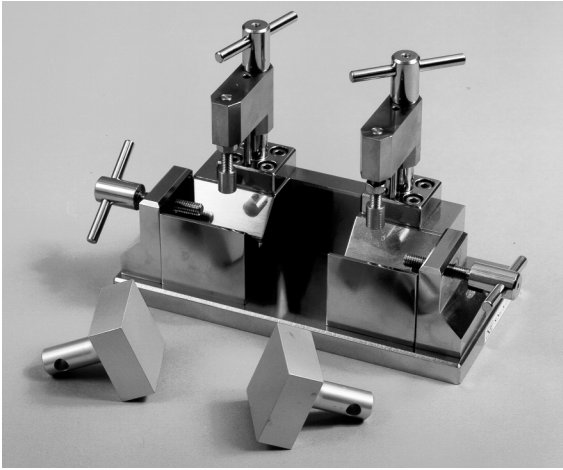
There are a number of common mechanical test methods, used to determine the comparative strengths of bonds and interfaces found in microelectronics packaging. These methods are in widespread use in QC, reliability and failure analysis areas, and are suitable for monitoring and comparing bond strengths but they are not capable of determining materials and/or interfacial properties.

### 2.1 Pull Tests

In a stud-pull test the strength of a bonded assembly (e.g. a die/substrate, a BGA Integrated circuit/PCB) is determined by bonding an actuator to the component or assembly under test and then loading the assembly until it fails (Figure 3).



Figure 3 - Stud Pull Fixture Mounted in a Testing Machine



**Figure 4 - Stud Pull Assembly Jig**

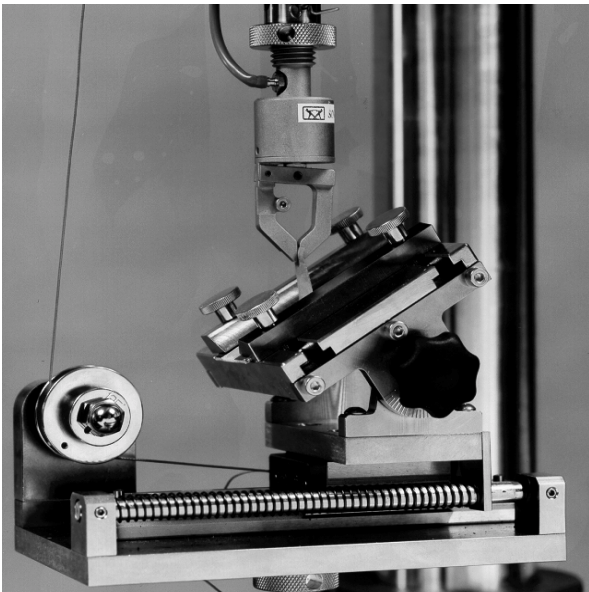
Care must be taken to ensure that misalignment between the two halves of the component and the loading axis is minimised in order to prevent uneven loading and uncontrolled bending moments. The bonding of the sample under test to the studs used to apply the test force, should take place in a jig in order to ensure good alignment (Figure 4). In general, the stud-pull method is easy to apply and provided care is taken will give repeatable results.

The SEMI standard G69-0996 “Test method for measurement of adhesive strength between leadframes and molding compounds” describes a method for determining adhesive strength using a pull out method. In this test the Adhesive Strength is determined from the force required to pull apart a sample of leadframe material molded into a block of molding compound using a tensile test.

Both the pull test methods described are effective for quality control of packages and assemblies and for some comparative testing, however neither method can be used to extract basic interfacial properties.

### 2.2 Peel Testing

Peel tests are suitable for determining the strengths of interfaces, in which, one of the layers is sufficiently flexible to allow it to be peeled off the substrate (e.g. copper foil coating on FR4 substrate).

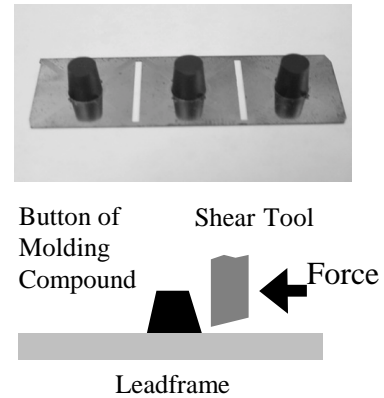


**Figure 5 - Variable Angle Peel Test**

The simplest type of peel test is the 90° Peel test, where the layer being peeled of the substrate is subject to large amount of plastic deformation and the force required to produce this deformation influences the test result. By performing a peel test at a number of different peel angles, using a variable angle peel fixture (Figure 5), it is possible to correct for the effects of plastic deformation and obtain a true measure of the adhesive strength.

### 2.3 Button Shear Test

SEMI Standard G69-0996 “Test method for measurement of adhesive strength between leadframes and molding compounds” describes a button shear test. In this test a specially prepared test sample consisting of a “button” of molding compound on the surface of a leadframe is prepared (Figure 6a). The sample is then mounted in a testing machine configured for shear testing (Figure 6b) and the force required to shear off the molding compound from the surface of the leadframe is recorded. This test method is a good technique for quality control and comparative adhesive strength measurements but residual stresses and the shear tool lift-off distance influence the results obtained, hence the values obtained are not fundamental materials properties.

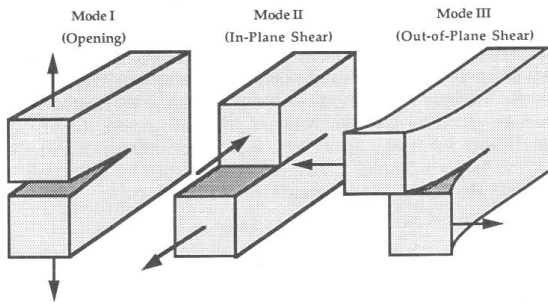


**Figure – 6 a) Test Sample Molding Compound Buttons on Leadframe, b) Test Configuration**

## 3. Fracture Mechanics and Determination of Interfacial Properties

### 3.1 Fracture Mechanics concepts

The methods described so far are effective for Quality control and comparative testing purposes, however they are not able to determine the materials and interfacial properties data that are needed for modelling purposes. In order to be able to predict the fracture behaviour of an interface requires the determination of parameters like the Fracture Toughness ( $G$ ) – the energy absorbed in making a unit area of crack and the associated critical stress intensity ( $K_{Ic}$ ) – these numbers are *materials properties*, independent of sample shape and size. It should be noted that materials and interfaces have 3 different values of  $G$  and  $K_{Ic}$  each associated with one of the 3 different modes of fracture (figure 7). The different values are designated with a subscript denoting the mode (e.g.  $K_{Ic}$ ,  $G_{Iic}$ ).

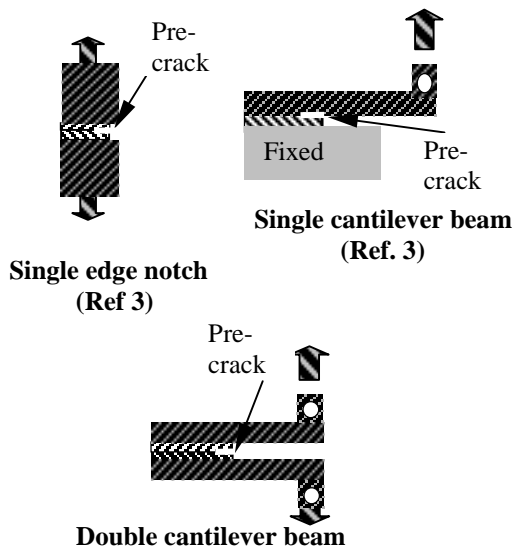


**Figure 7 - Various Fracture Modes**

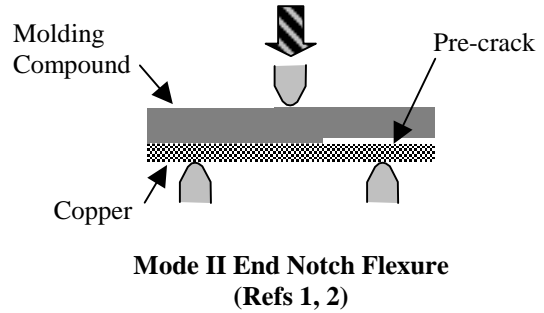
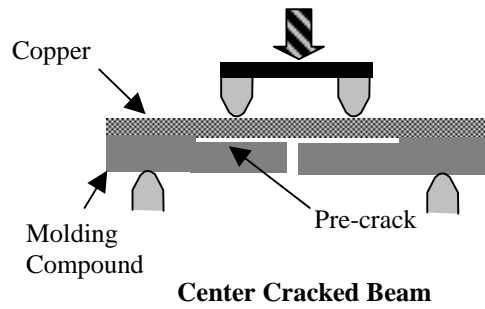
Referring to Figure 7. Mode II (In-plane shear) is the most common situation encountered in microelectronics packages where the strains are generated by mismatches in thermal expansion coefficients.

**3.2 Fracture Mechanics Testing for Microelectronics**

Several fracture mechanics based tests, suitable for microelectronics, have been receiving attention in the literature. For Mode I fracture these include Single Edge Notch, Single or Double Cantilever Beam (SCB or DCB), see Figure 8. For Mode II fracture they include the Centre Cracked Beam Bend (CCBB) and End Notch Flexure, see Figure 9.



**Figure 8 - Mode I Fracture Test Configurations**

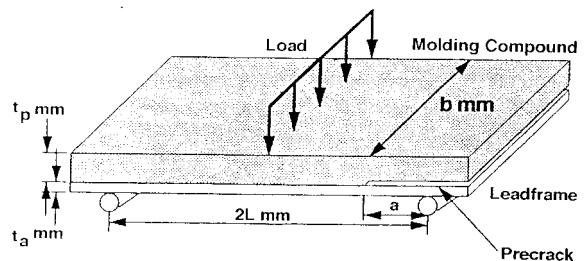


**Figure 9 - Mode II Fracture Test Configurations**

**3.3 Mode II Fracture Mechanics Testing using End Notch Flexure Configuration**

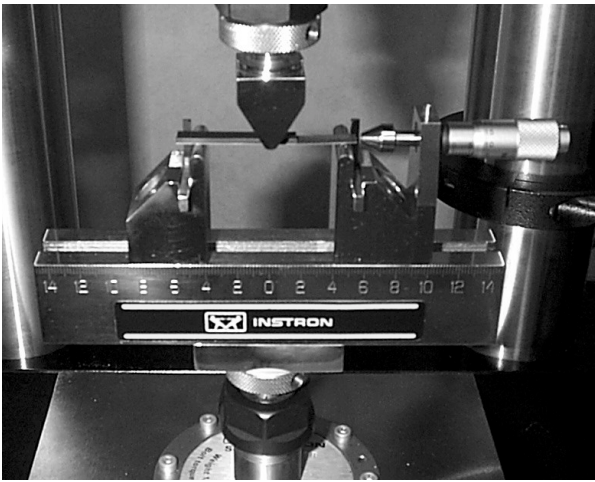
**3.3.1 SEMI G69-0996 Mode II Three Point Bend test for determination of Adhesive Strength**

SEMI Standard G69-0996 “Test method for measurement of adhesive strength between leadframes and molding compounds” describes a test method for determining the Fracture Toughness and Adhesive strength of an interface in Mode II Fracture using a three point bend specimen containing a pre-crack (figure 10, 11). This method is based on work by Nishimura et al (Ref. 1). In this method a specimen is deformed until the crack propagates and the peak force recorded, the test is then repeated on a second specimen but this specimen is located upside down relative to the first one. The apparent adhesive strength (i.e. not corrected for the effects of residual stress) can be calculated for each test and the True Adhesive Strength can be determined by taking the average of the apparent adhesive stress values.



**Figure 10 - Bend Test to SEMI G69-0996**

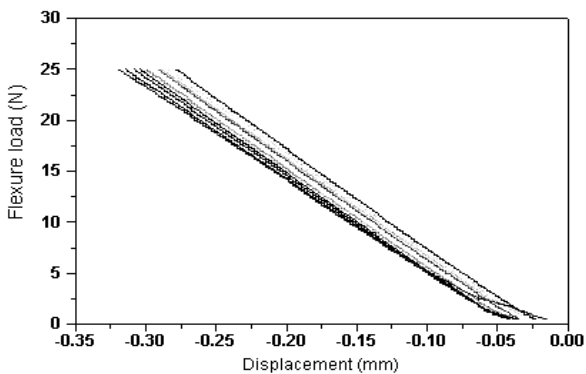




**Figure 11 - Bend Test set up to SEMI G69-0996**

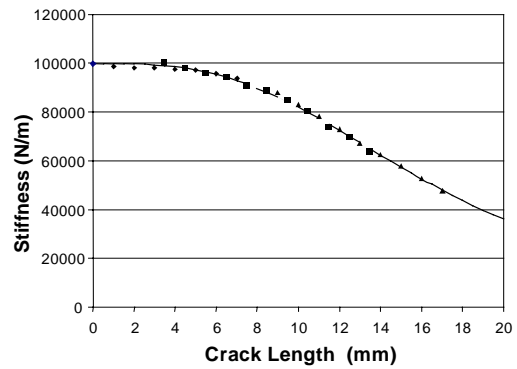
### 3.3.2 Improvements to SEMI G69-0996 Three-point bend test method

One of the complexities of performing the three-point bend test to the method described above is the problem of measuring crack length. Nishimura and the standard both recommend the use of ultrasound to scan the specimen and determine the location of the crack. The added complication is that this should not be done by immersing the specimen in water but that the specimens be properly sealed first. The specimen must then be accurately positioned with respect to the 3-point bend anvil as the crack length is defined as the distance from the crack front to the bend anvil – not to the edge of the specimen. A more effective way would be if the crack length could be measured in-situ, as part of the test. Work by Tsai (Ref. 5) has shown that it is possible to use a test machine with a very high displacement resolution to determine the crack length of the specimen by monitoring the specimen stiffness (figure 12a and 12b).



**Figure 12a - Load displacement plots for various crack lengths**

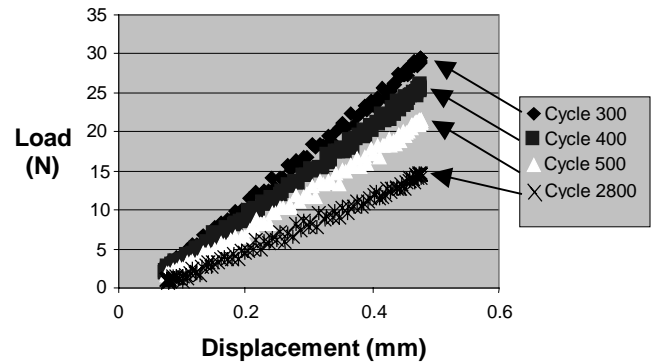
The results shown demonstrate clearly that the idea of using compliance to simplify the experimental protocol by eliminating the need for a separate measurement of the crack length is viable.



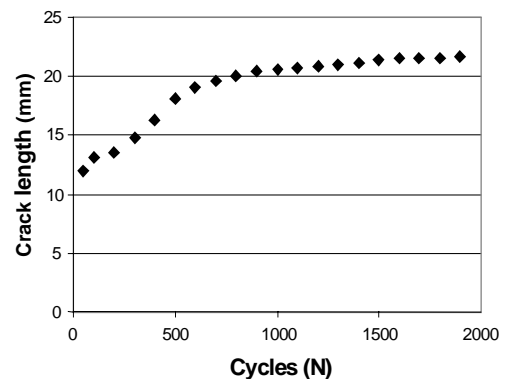
**Figure 12b - Stiffness change with crack length (black line is theoretical)**

### 3.3.3 Mode II Interfacial Fatigue Crack Growth

Tsai (Ref. 5) has also shown that the compliance method for measuring crack length can be applied to fatigue crack growth. Using the same Mode II three point bend specimen and test set up as used in SEMI G69-0996, a cyclic, displacement amplitude of 200microns was applied. Under these conditions the crack grew in a stable manner. Figure 13 shows the compliance change as seen in the load - displacement plots for different test cycles (the noise seen in these plots was attributed to the friction between moulding compound and lead frame). The stable development of the crack is seen in figure 14.



**Figure - 13 Force v Displacement for various crack lengths during cyclic loading**



**Figure 14 - Crack Length v Cycles**

#### 4. Conclusions

Mechanical testing is a powerful tool not only for QC and comparative testing but also for determining the fundamental properties of materials and interfaces.

This paper has highlighted the differences between bond and adhesion strength measurement for Quality Control and materials property measurements for design and modelling with reference to the fracture properties of interfaces.

The example quoted in this paper shows that it is possible to use ultra high precision, low force test systems to determine crack length in-situ by measuring the compliance on End Notched three point bend specimens to the SEMI G69-0996 standard thus avoiding the need for a separate crack length measurement.

The examples also show that it is possible to use the end notched three-point test configuration of SEMI G69-0996 to grow a stable fatigue crack under Mode II loading conditions and to monitor crack growth by measuring specimen compliance.

#### References

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- 4) J W Hutchinson and Z Suo, "Mixed Mode Cracking in Layered Materials", Advances in Applied Mechanics, Vol. 29, pp63-191
- 5) K T Tsai, "New Developments in Testing for Microelectronics" Proceedings of the 13<sup>th</sup> Conference on Mechanical Behavior of Materials (Reliability assessment of electronic component materials) Korea 5/6<sup>th</sup> November 1999 (Korean Institute of Metals and Materials).
- 6) I. McEnteggart "The Role of Micromechanical Testing in Microelectronics" Materialprüfung in Produktion Forschung und Entwicklung (SVMT November 2000)