THE ROLE OF MICROMECHANICAL TESTING IN MICROELECTRONICS

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ABSTRACT

The development of new materials e.g. lead-free solders and advanced high density packaging designs e.g. flipchip, has significantly increased the demand for more accurate measurement of the mechanical properties of materials and systems used in microelectronics devices.

This paper outlines the areas in which a detailed knowledge of the mechanical properties is required in order to ensure good process yields and reliable products. The different types of mechanical test available, at the scale level of microelectronic components, are reviewed and compared. The desirable characteristics of micromechanical test instruments and fixtures are critically examined with reference to an example of current "state of the art" equipment.

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1. Introduction

In the last few years there has been a dramatic 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 typical high-density package known as a BGA (Ball Grid Array) is shown in Figure 1.

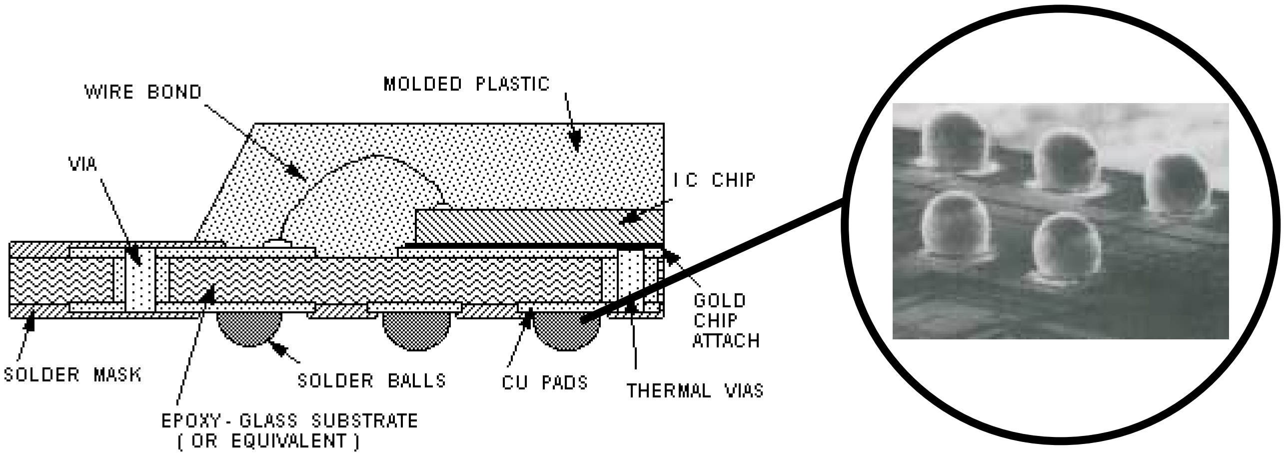

Figure 1. Cross section of a BGA package showing key features (Inset shows solder balls)

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 mechanical testing is required in order to provide accurate materials and interfacial properties data for design and modelling (FEM) and for design verification.

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 it is ill-suited to the short product and process development cycles associated with the fast moving world of microelectronics. 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. The Role of Mechanical Testing

In device development mechanical testing can shorten packaging development time by providing accurate materials data for use in simulation and modelling. Typically this mechanical 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 properties would also be required.

Testing on prototype devices or elements of devices would then be used to validate the model and provide rapid pre-qualification tests - this testing could include pull or shear testing of adhesive bonds and fatigue testing of solder joints.

More routine types of mechanical testing would then be used to monitor the production process once the device was in volume production with the more sophisticated mechanical testing used, if required, to improve process yields or investigate failures and/or improve device reliability.

3. Types of Micromechanical Test used in Microelectronics Industry

3.1 Small Scale Versions of Conventional Mechanical Tests

Many of the tests used in the Microelectronics industry are essentially the same as those used in traditional mechanical testing, however the samples being tested and the associated test fixtures are on a smaller scale (Figure 2). Because of the small size of the samples the forces and extensions are relatively low requiring a low capacity load cells and very high position resolution. NOTE: Because of the small specimen sizes and variety of shape it is generally difficult to use a conventional extensometer to achieve the required displacement resolution.

Figure 2. – “Micro” Test Fixtures (1-10mm Bend Fixture and 10N Pneumatic Grips)

An aspect of testing electronic devices and assemblies is that it is often possible to monitor the electrical characteristics (e.g. the resistance of a conductor or joint) of the device or assembly in order to detect failure.

3.2 Specialised Tests for Microelectronics

In order to meet the special needs of microelectronic device testing a number of specialised tests have been developed. Examples of some of these tests each from a different area are presented here.

3.2.1 Solder Joint Fatigue Test

The development of lead free solders and packaging techniques which subject soldered joints to high levels of shear strain has generated a considerable interest in the fatigue reliability of solders and soldered joints. Traditionally thermal cycling has been used to perform fatigue testing of soldered joints - however this method is very slow. Mechanical testing can be used to simulate the effects of thermal fatigue on solders and soldered joints reducing the test time dramatically. For example; while a typical thermal cycle will take several minutes, a mechanical test could, easily, be conducted at several cycles per second, reducing the total test times from week or months to hours.

A typical test set up for a solder joint fatigue test is shown in Figure 3. It should be noted that this configuration allows a number of joints to be tested in parallel (as would be the case for a thermal fatigue test). The integrity of the joints can be monitored electrically.

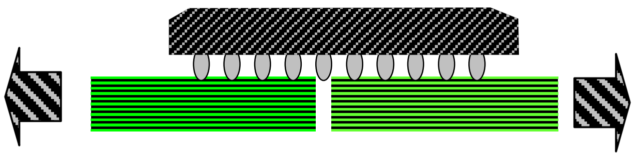

Figure 3. Fatigue Test on Solder Joint

Since this test is simulating thermal strains on small components the displacements are generally small of the order of a few tens of microns, thus the test requires high position resolution and very precise and stable position control. An extensometer can be used to monitor the displacements, however this complicate the fixtures and can be a problem if the test is being carried out in an environmental cabinet (to achieve low/high temperatures or high humidity environment).

3.2.2 Adhesion Characterization

The SEMI G69-0996 Standard describes a test method for measurement of adhesive strength between lead-frames and moulding compounds in semiconductor packages. A sample is prepared by moulding a moulding compound onto the surface of a lead frame sample such that part of the lead frame is free of moulding compound adherence (Figure 4).

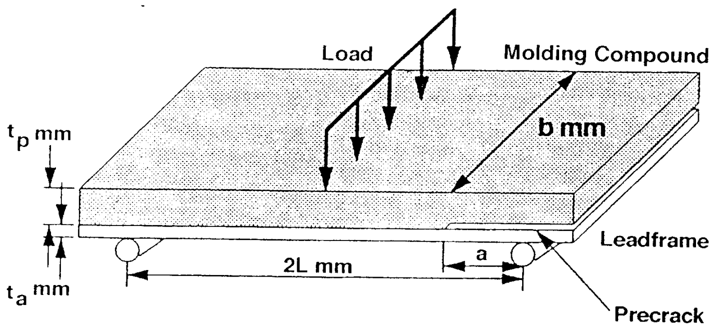

Figure 4. SEMI G69-0996 Test for adhesive strength between lead-frames and moulding compounds

A three-point bend test is then performed on the sample from which apparent and true adhesive strengths can be calculated (Figure 5).

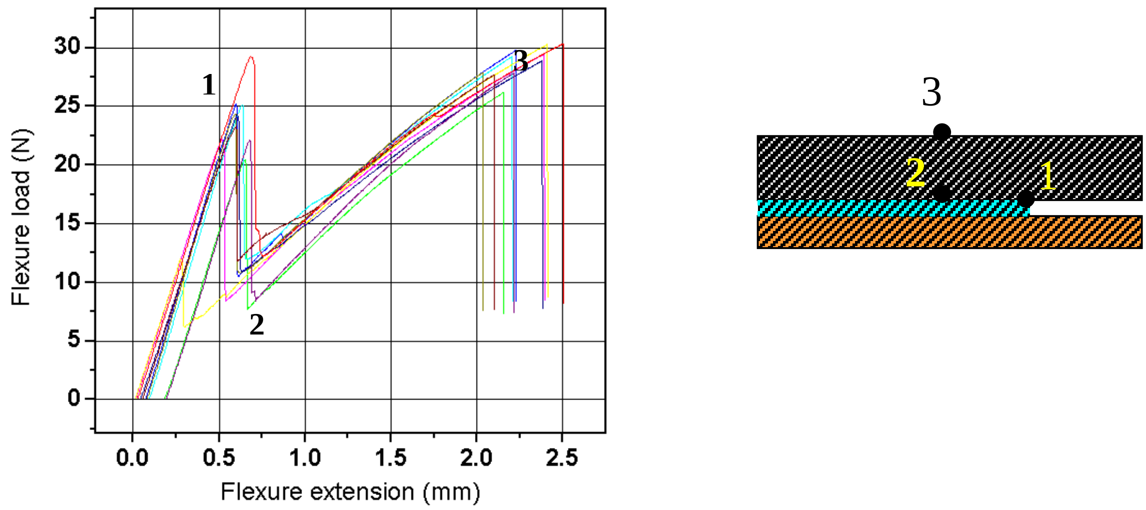

Figure 5. Results of SEMI G69-0996 Test for adhesive strength between lead-frames and moulding compounds

3.2.3 Die Shear Test

The Die Shear test is used to evaluate the bond strength between a semiconductor die and a substrate. Usually the bond is made with an epoxy adhesive. The basic test configuration is shown in Figure 6.

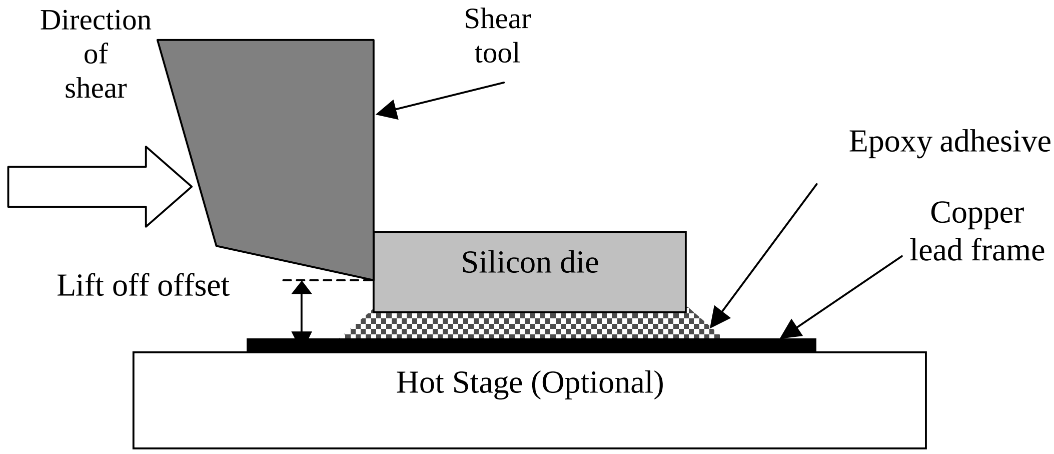

Figure 6. - Die Shear Test

The test is usually carried out at ambient temperature, however it may be performed at elevated temperature and in this case the sample is usually placed on a heated stage. Good test results require careful control of the parallelism of the tool and the "Lift-off" distance. The problem of poor parallelism is shown in Figure 7. The adverse effects of poor parallelism are premature cracking of the die leading to wasted tests and a general lack of reproducibility in the failure forces. Poor parallelism will show up in the force deflection curve as non-linear behaviour at the start of the test (Figure 7). Allowing the specimen stage to have rotational freedom allows the sample to self-align with the tool and this ensures good parallelism.

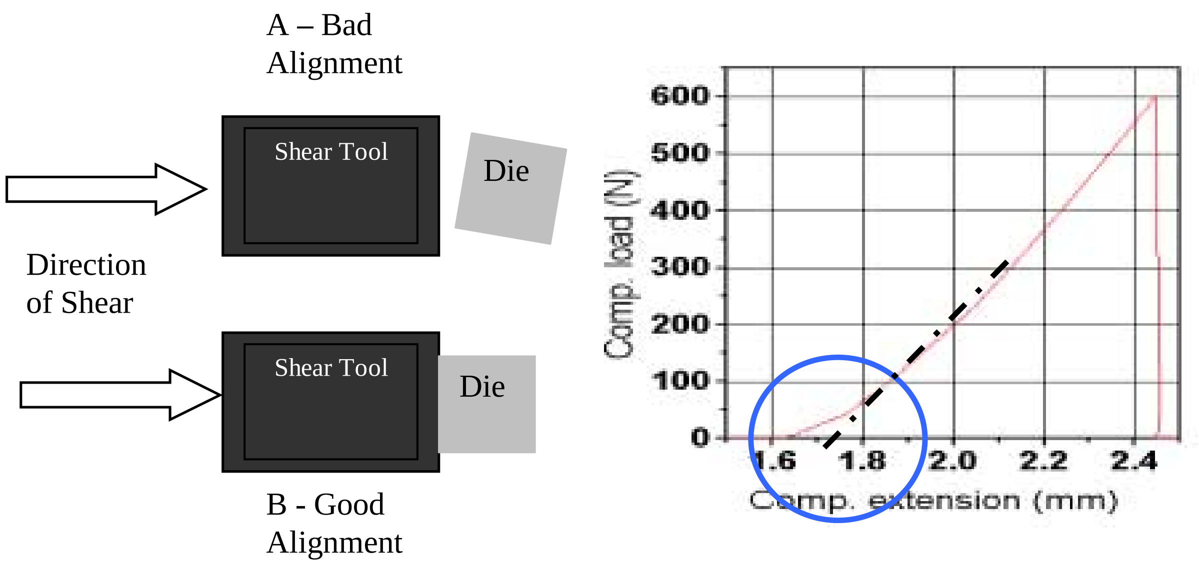

Figure 7. Die Shear Test – Tool alignment

Figure 8. Illustrates the effects of an incorrect lift-off distance. The substrate is normally used as the datum to set the lift off distance, however, as the underfill thickness is difficult to control, it is hard to achieve a clean & good shear and in many cases a crack initiates at the underfill (Figure 8 A). A

notch tool as shown in Figure 8 B is designed to resolve the problem by using the die as the datum since its thickness is well controlled.

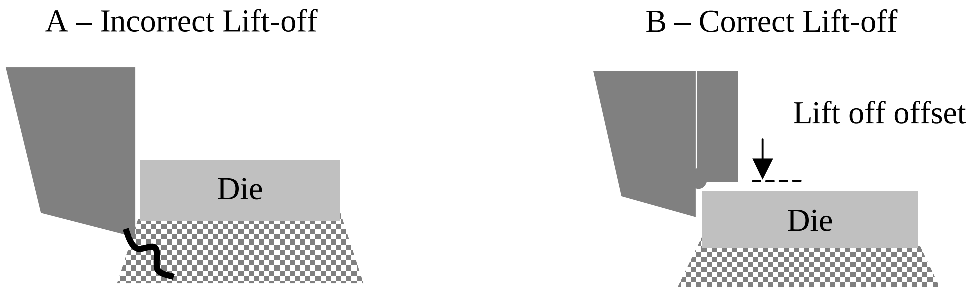

Figure 8. Die Shear Test – Effect of incorrect lift-off Distance

It is difficult to use the Die shear test on larger dies, due to cracking of the die, in this case the solution is either to use a hot-stage to soften the adhesive or to use a stud pull test (in which the test force is applied in a direction normal to the bond).

4. R&D Equipment for Micromechanical Testing of Microelectronics Devices

4.1 Mechanical Test System

In order to satisfy the likely needs of Microelectronics R&D a Micromechanical test system is required which has characteristics which are distinct from both the traditional materials testing machine and from the dedicated wire pull and bond testers widely used for QC work within the microelectronics industry.

The system needs to offer a high degree of mechanical adaptability (e.g. vertical and horizontal orientation) and flexibility (e.g. the ability to accept a wide range of test fixtures). For many applications an X/Y/Rotation stage along with an optical or video microscope is required in order to be able to position the component prior to a test.

The system needs to offer a combination of very high position resolution/control precision (it is often difficult to use an extensometer) and dynamic performance (for fatigue testing). It should be possible to control in either position or force feedback control in order to be able to simulate the appropriate test conditions. The control electronics and software needs to provide flexible test control and data acquisition – it must be able to record a full force extension curve. It is very desirable for the software to have an open architecture to allow the researcher complete freedom to program tests and integrate other channels of data collection (e.g. electrical resistance monitors).

Finally in many cases the system must be compatible with a clean room environment (e.g. the equipment cannot use hydraulic power).

4.2 Environmental control

In order to simulate service or processing conditions many of the mechanical tests performed on Microelectronic devices need to be conducted at a specific temperature and possibly also at a specific humidity level. Temperatures in the range of –70 to +250 deg C are common.

Some tests, requiring accurate positioning of samples and fixtures, (e.g. Die or Ball Shear, wire pull testing) are best performed at temperatures above or below ambient using a hot/cold stage. The use a hot/cold stage allows unimpeded operator access to the test area (often working through a microscope) and allows complex fixtures to remain at ambient temperature. The use of a hot/cold stage does result in a less uniform temperature distribution across the sample, however a correctly positioned thermocouple can be used to achieve the desired temperature in the region of interest.

In many cases the optimum way of achieving the desired environmental conditions will be using a temperature cabinet and this is the only way to be able to control humidity.

5. References

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