High-Speed Bondtesting: Understanding the Technology

A comprehensive knowledge of bond strength, force displacement and energy measurement of solder ball bonds is critical for the detection of brittle fracture failures within semiconductor packages. This article discusses the interrelationship between these parameters since this correlation is critical to the identification of the brittle fracture failure mode.

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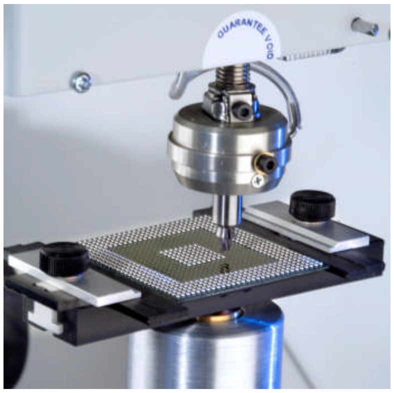

High-speed bondtesting can detect the presence of brittle fracture failure within a BGA device, a defect that typically cannot be identified with traditional shear testing.

The increased use of lead-free solder in ball grid array (BGA) or micro-BGA packaged semiconductor devices, widely used in portable devices, makes them susceptible to brittle fracture failures at the solder ball to pad interfaces when subjected to mechanical shock. Brittle fracture failure can occur after device packaging, during board assembly, or throughout the end use of the product. Traditionally, bond strength force has been considered when testing solder ball bonds. Knowing the value and limitations of this test parameter is essential when testing bond integrity.

Bond Strength

The region between the bulk of a solder ball and the device or circuit board pad that it has been soldered to is referred to as the bond. Its strength is the load it can support before failing such that the solder ball separates from the pad. The load can be shear, tensile or pull, bending or a combination of these forces. Bending normally exists as a result of a shear load applied above the bond plane, resulting in a combination of shear and bending forces upon the bond. Combinations of shear and pull are rare in bondtester applications but are common in end use, thermal or bend tests.

There are intermetallic compound (IMC) layers within a bond but compared to the ball size their total thickness is relatively small. The location within these layers that a bond fails defines the failure mode but providing the failure occurs in this region it is referred to as a bond failure. As such, this differentiates bond strength from solder failures in the bulk solder of the ball or pad failures of the substrate. Bond strength is of interest as it is often the failure mode that occurs during device manufacture or end use.

Force Displacement

When a test load is applied to a solder ball extremely small but measurable deflections occur. A force displacement (FD) of the test load can be plotted against the corresponding deflection. (Figure 1 shows a typical force displacement graph with solder ball deformation.)

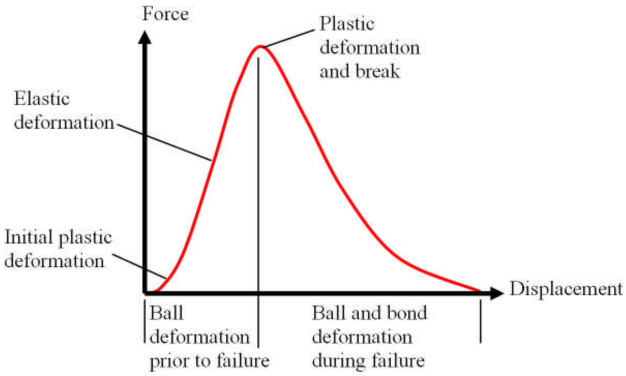

Figure 1. Force displacement graph showing solder ball deformation

Since high-speed bond testing is typically done at a constant velocity a force time graph can be used as a very similar alternative to the force displacement graph but it is the force displacement graph that is most useful. On such a graph the displacement can be directly related to the bond geometry and the area of the graph represents the energy absorbed by the bond.

Energy measurement

At traditional test speeds of less than 1 millimeter/second (1mm/s), bond strength is typically measured in units of force. An alternative measure of strength is the energy absorbed by the sample or bond interface during the test. Energy is very commonly used in impact testing because it is relatively easy to measure and highlights the transition from ductile to brittle fracture.

Energy Measurement Techniques

Some test systems measure energy directly by swinging a pendulum into the sample. Historically these systems have always been shear tests. The change in height of the pendulum center of gravity before and after the test is proportional to the loss of potential energy, transferred from the pendulum and absorbed by the sample. The product of the change in height, pendulum mass and gravitational constant is the absorbed energy. Although the test may be completed in fractions of a millisecond this simple method accurately measures the energy absorbed.

Two common material testing methods based on this concept are the Izod and Charpy test. (Figure 2 shows a schematic of the Izod test.) Typically the test sample is notched to create a stress concentration reducing the amount of energy required to cause a failure. The Charpy test is similar but clamps the test sample at both ends in a beam arrangement rather than a cantilever.

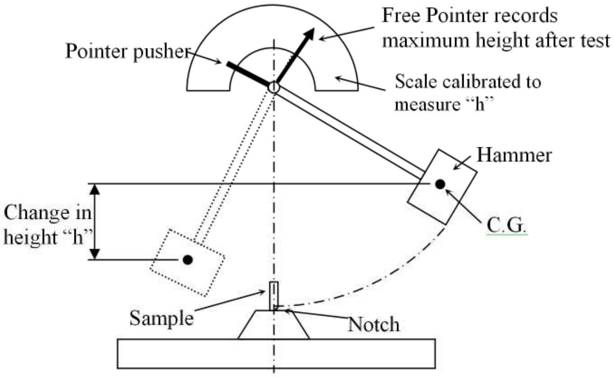

Figure 2. Izod impact tester

The Izod and Charpy test are commonly used to study what is referred to as "temper brittleness." This is understandable since as the hardness of a material is increased its strength or resistance to loading increases. For ductile failure a sample will bend, as the hardness is increased the peak load and the energy absorbed will increase. If the hardness is increased to the point of brittle fracture the peak force will have still increased but the energy will be much less. This is because with brittle fracture the deflection of a sample is much less.

Energy is the product of force and distance. In an impact test if the deflection is much smaller but the force remains at a similar order of magnitude, the energy will be less. Energy can also be measured by integrating the force on the impactor against its distance traveled, relative to the sample. (Figure 3 shows energy as the area defined by a force displacement curve.)

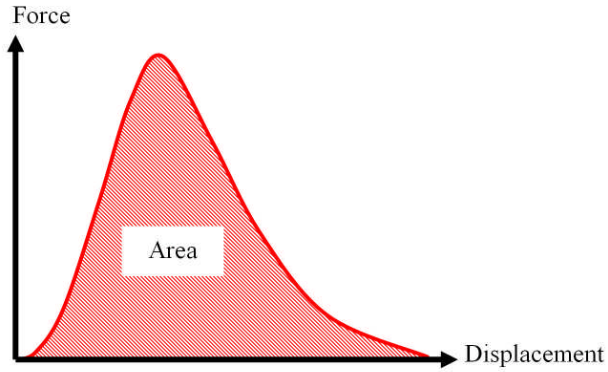

Figure 3. Typical force displacement graph

Energy levels are much harder to measure this way, as it requires accurate force measurement during the impact event lasting only fractions of a millisecond. This requires a force transducer and data acquisition system with a very high bandwidth. A significant advantage of this method is that it also provides the peak force and the shape of the force deflection profile. Another advantage is that the test can be conducted at constant velocity as energy is measure by integrating force through distance rather than by loss of potential or kinetic energy as in a pendulum test.

Force Measurement

In any high-speed bond test, shear or pull, the load is applied to the solder ball in a very different manner to the events that are to be simulated. For example, in a shear test the ball is loaded on its side causing deformation at the point of contact. This may simulate a shear load at the bond due to the drop testing or thermal expansion but it does not simulate the load condition on the ball. (Figure 4 shows solder ball load conditions during shear and pull testing.)

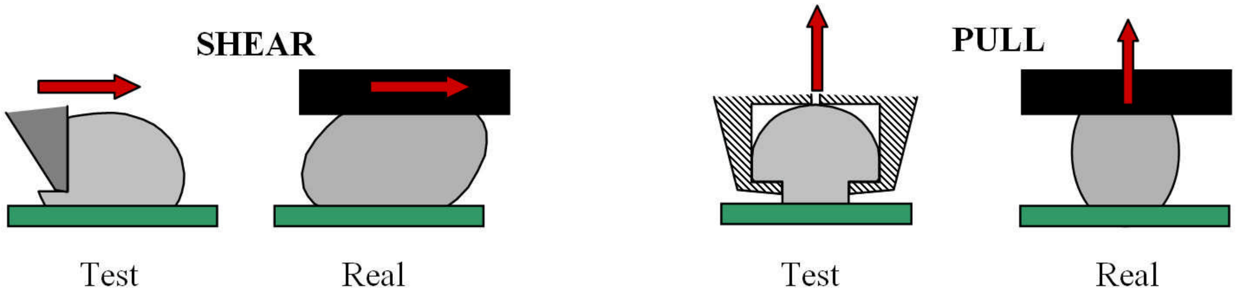

Figure 4. Illustration of shear and pull testing of BGA solder balls

A typical intermetallic bond is very thin, only several microns. Since it is so thin it can only deform a minute amount before its yield strain is reached. Therefore the energy and displacement in the bond are also very small. Most of the displacement and therefore the energy in a typical solder ball test results from the ball and substrate pad. These metrics are then a measure of the solder ball and substrate pad, and not the bond. This is not true for force measurement however. Although the force is transmitted via the ball it remains an accurate measurement of the force upon the bond. A similar argument is true for thermal loading, as again the displacement at the bond is extremely small.

Force measurement is more difficult to measure and instrument but is the only metric relevant to the accurate measurement of bond strength. Knowledge of this force defines the bond strength and enables it to be measured and maximized.

Value of Energy Measurement

As was explained previously, energy is mainly a metric of the solder ball and substrate deformation. It is these parts of the bond interface system that absorb the energy of a shock load. The more compliant they are the more energy they can absorb and this in turn reduces the force upon the bond. This is very similar to the compliant crumple zones in an automobile minimizing the forces on the passengers.

Maximizing the energy that the system can absorb will then reduce the possibility of bond failures just as maximizing bond strength and force does. The difference is that energy is affected by the solder ball and substrate and bond strength is affected by bond metallurgy. Knowledge of energy and bond strength enables the system compliance and bond strength to be optimized independently.

For force measurement the deformation of the solder ball during a test is immaterial. This is not true though for energy measurement. Energy absorption is directly affected by deformation and so an energy test ideally simulates the deformations that occur when the bond is subjected to mechanical shock. This requires the sample to be prepared into tokens, enabling the device substrate and package to be loaded such that the ball deformation is more typical of what the device will encounter during real life. (Figure 5 shows solder ball preparation for shear and pull testing.)

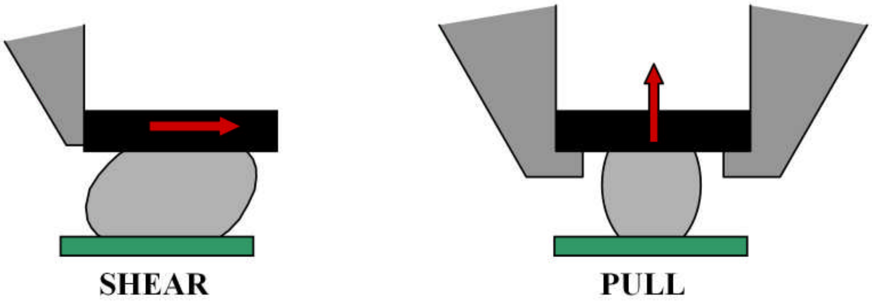

Figure 5. Illustration of solder ball deformation during shear and pull testing

Although ideal, manufacturing tokens are difficult and time consuming to prepare. This being the case conventional shear and pull tooling may be used on actual BGA and micro-BGA devices accepting that the deformations may be somewhat different than sample tokens. The basis for this is that a compliant ball will deform more in any test and even if the deformation is different it may provide an indication of relative performance.

Importance of Failure Mode

It is known that at low strain rates solder is relatively soft. This is why at traditional test speeds solder yield and solder ball failures are dominant. It can be assumed that the same is true for a bond in service within an area array device where low strain rate events result in plastic deformation of the solder ball before the bond fails. At high rates of strain the reverse is true. The solder is often harder and will transmit greater loads than the bond strength before it deforms itself. So in a drop test the bonds are subjected to higher loads and fail as in a high-speed shear and pull test. (Figure 6 shows examples of solder shear, brittle fracture failure and corresponding force displacement curves.)

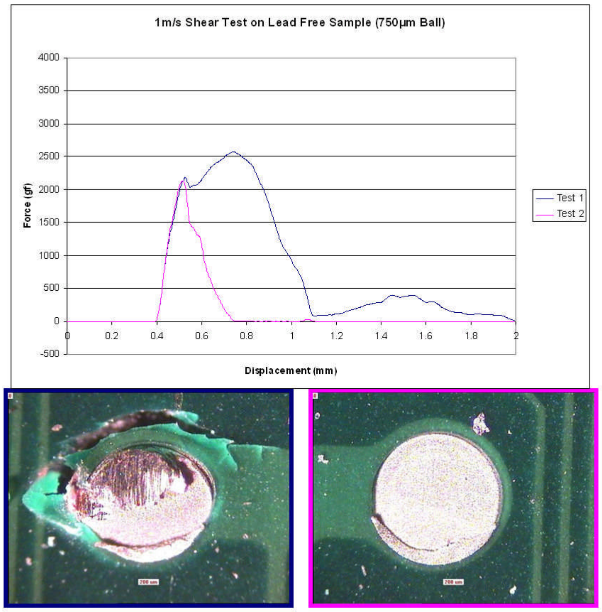

Figure 6. Results from 3G shear transducer and digital signal processing

It is these force displacement curves captured using an ultra high bandwidth force transducer and data acquisition system with high-speed bondtesting technology that can identify bulk solder failure, interfacial and failure and mixed mode failures.

Conclusion

The presence of bond failures is evidence of high loading on the bond and high strain rates. If however the bonds are weak or of poor quality, they can fail even at low forces that can be transmitted by the solder at low strain rates. The key is to determine what force and energy they fail at. To be able to cover the full range of possible failure modes, for both good and bad bonds, the ability to test and measure force at low and high strain rates is required. This is the reasoning behind high-speed bondtesting technology.

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About Dage

With international headquarters in Aylesbury, UK, Dage Precision Industries Ltd. is a unit of the Nordson Corporation and manufactures and supports a complete range of award winning digital x-ray inspection systems and bond test equipment for the printed circuit board assembly and semiconductor industries. For more information, visit www.dage-group.com.

About Nordson

Nordson Corporation is one of the world's leading producers of precision dispensing equipment that applies adhesives, sealants and coatings to a broad range of consumer and industrial products during manufacturing operations. The company also manufactures equipment used in the testing and inspection of electronic components as well as technology-based systems used for curing and surface treatment processes. Headquartered in Westlake, Ohio, Nordson Corporation has more than 4,100 employees worldwide, and direct operations and sales support offices in 34 countries.