Designation: F459 – 13

Standard Test Methods for Measuring Pull Strength of Microelectronic Wire Bonds[1]

This standard is issued under the fixed designation F459; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods cover tests to determine the pull strength of a series of wire bonds. Instructions are provided to modify the methods for use as a referee method. The methods can be used for wire bonds made with wire having a diameter of from 0.0007 to 0.003 in. (18 to 76 µm).

NOTE 1—Common usage at the present time considers the term "wire bond" to include the entire interconnection: both welds and the intervening wire span.

1.2 These test methods can be used only when the loop height of the wire bond is large enough to allow a suitable hook for pulling (see Fig. 1) to be placed under the wire.

1.3 The precision of these methods has been evaluated for aluminum ultra-sonic wedge bonds; however, these methods can be used for gold and copper wedge or ball bonds.[2]

1.4 These methods are destructive. They are appropriate for use in process development or, with a proper sampling plan, for process control or quality assurance.

1.5 A nondestructive procedure is described in Practice F458.

1.6 The values in SI units are to be regarded as standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

F458 Practice for Nondestructive Pull Testing of Wire Bonds

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 For the purposes of these test methods the following failure points are defined:

3.1.2 *bond-wire junction failure*—a rupture in the wire within two wire diameters of the bond and in which more than 25 % of the bonded area is left on the pad after the pull test has been applied.

3.1.3 *weld interface failure*—a rupture in which less than 25 % of the bonded area is left on the pad after the pull test has been applied. See pad lifting in 6.6.

3.1.4 *wire span failure*—a rupture in the wire other than *(1)* at a point within two wire diameters of either bond, or *(2)* at the point at which the hook contacted the wire.

4. Summary of Test Methods

4.1 The microelectronic device with the wire bond to be tested is held firmly in an appropriate fixture. A hook is positioned under the wire midway between the two bonds. The hook is then raised until the wire bond breaks. The force applied to the hook in order to cause failure of the wire bond is recorded. The point of failure is observed and recorded. In the referee method, the force in the wire on breaking is calculated.

5. Significance and Use

5.1 Failure of microelectronic devices is often due to failure of an interconnection bond. A common type of interconnection bond is a wire bond. These methods can assist in maintaining

[1] These test methods are under the jurisdiction of ASTM Committee F01 on Electronics and are the direct responsibility of Subcommittee F01.03 on Metallic Materials, Wire Bonding, and Flip Chip.

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[2] Harman, G. G., "Microelectronic Ultrasonic Bonding," *NBS Special Publication* 400-2, pp. 94-95 and "Wire Bonding in Microelectronics," Third Edition, McGraw Hill, 2010. Also Microelectronics Reliability 51 (2011), Special Issue on Copper bonding.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

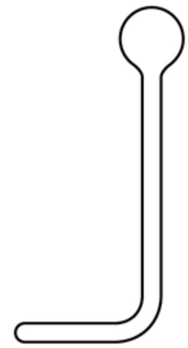

FIG. 1 Suggested Configuration for a Pulling Hook

control of the process of making wire bonds. They can be used to distinguish between weak, nonadherent wire bonds and acceptably strong wire bonds. The methods are destructive.

5.2 These test methods are appropriate for on-line use for process control, for purchase specifications, and for research in support of improved yield or reliability. The referee method should be used for quantitative comparison of pull strengths of wire bonds.

6. Interferences

6.1 Failure to center the hook along the loop between the two bonds or pulling in a direction not lying in the plane containing the undisturbed loop may invalidate the test since an unbalanced distribution of forces between the two bonds may result.

6.2 Slippage of the hook along the wire span during pulling may invalidate the test because an unbalanced distribution of forces between the two bonds may result.

6.3 Careless insertion of the hook may damage either bond or wire and thus invalidate the test.

6.4 The presence of vibration or mechanical shock may cause the application of an extraneous force and thus invalidate the test.

6.5 Measured bond-pull force is strongly dependent on the height of the loop ($H + h$, as defined in 11.1.1) and the bond-to-bond spacing (d, as defined in 11.1.1).

6.6 For fine pitch ball bonds (<60 µm pitch), the bond pad may tear and lift during pull testing. Current practice is to accept this if the pull force is acceptably high under agreed upon requirements, but note it as appropriate. In some cases of bad peeling, it is necessary to move the pulling hook directly over the top of the ball bond. This should be noted.

7. Apparatus

7.1 *Bond-Pulling Machine*—Apparatus for measuring wire-bond pull strength with the following components:

7.1.1 *Hook*—Pulling hook made from a rigid wire such as tungsten. The diameter of that part of the hook that contacts the wire loop should be approximately 2.5 times the diameter of the wire used to make the wire bond. A suggested hook configuration is shown in Fig. 1. The hook should appear under visual inspection to have a smooth polished surface with no sharp edges in any part of the hook that contacts the wire loop. The hook should be rigidly mounted in the pulling apparatus.

7.1.2 *Lifting-and-Gaging Mechanism* —Mechanism for applying a measured vertical force to the hook. The mechanism shall incorporate a means for recording the maximum force applied and shall be capable of applying force at a rate constant to within 2 gf/s (20 mN/s) in the range from 1 to 30 gf/s (10 to 290 mN/s) inclusive. A mechanism with a single fixed scale shall have a maximum scale reading no greater than three times the nominal bond pull strength anticipated.

NOTE 2—Mechanisms of the dynamometer type known as "gram gages" have been found satisfactory, but currently, electronic gauges (properly calibrated using the manufacturers' procedures) are more common.

7.1.3 *Microscope with Light Source* —Zoom microscope with light source with a magnification range of approximately 14× to 60× with the eyepiece not to exceed 10×, for viewing the device under test.

7.1.4 *Device Holder*— Mechanism for holding the device under test *(1)* in a horizontal position, for Method A, or *(2)* in either a horizontal or a tipped position so that both bonds are in the same horizontal plane, for Method B. For the referee Method C, the device holder should provide a measurement, to within 2°, of the angle from the horizontal (which may be zero) through which the device has been tipped.

7.1.5 *Calibration Masses*—At least five masses (weights) with mass values known to within 0.5 % sized to cover the lifting-and-gaging mechanism range of force measurement, and suitably configured so that they may be supported by the pulling mechanism for calibration.

8. Sampling

8.1 Since the pull-test method is destructive, it shall be performed on a sampling basis. The sample selected should be representative of the wire bonds of interest. The size of the sample and the method of selection shall be agreed upon by the parties to the test.

9. Calibration

9.1 Calibrate the bond-pulling machine at the beginning of each series of tests, or daily if a series spans more than one day.

9.2 Assemble the bond-pulling machine in the same configuration to be used to perform the wire-bond pull test.

9.3 Calibrate the lifting-and-gaging mechanism.

9.3.1 For mechanisms incorporating a calibration adjustment, either calibrate the mechanism in accordance with the manufacturer's instructions or in accordance with the procedure of 9.3.2.

9.3.2 For mechanisms without a calibration adjustment, use the following procedure:

9.3.2.1 Select masses that will provide at least five calibration points over the mechanism range.

9.3.2.2 Attach a selected calibration mass to the lifting-and-gaging mechanism. If a lever-arm mechanism (dynamometer or gram gage) is used, rotate the body of the gage in a manner that maintains the arm (carrying the hook) in a horizontal orientation.

9.3.2.3 Observe and record the measured force in grams-force (millinewtons).

9.3.2.4 Repeat 9.3.2.2 and 9.3.2.3 for each calibration mass (or electronic scale) selected.

9.3.2.5 Plot the measured force values as a function of the forces applied by the masses. Use these results to construct a calibration curve.

10. Procedures

10.1 *Method A—Device in Horizontal Plane:*

10.1.1 Place the device having the wire bond to be tested in the device holder so that the plane of the device is horizontal, as judged visually.

10.1.2 Position the microscope and light source and focus the microscope so that the wire bond to be tested is clearly seen in the microscope field.

10.1.3 Position the device holder so that the wire forming the loop of the wire bond to be tested is under the rigidly mounted pulling hook.

10.1.4 While viewing the wire bond through the microscope, maneuver the hook so that it is under the wire loop to be pulled, and adjust the hook so that it is midway between the two bonds and contacting the wire loop, as judged by eye.

10.1.5 Activate the pulling mechanism while observing the wire bond and hook through the microscope. Continue pulling until there is failure.

10.1.6 If the wire fails at the point of contact with the hook, record the test for that bond as invalid.

10.1.7 Measure and record the force required for breaking the wire bond. Determine and record the corrected force from the calibration curve if the calibration procedure of 9.3.2 was used. Record the identification of the wire bond and the identification of the device (substrate).

10.1.8 Examine the remaining parts of the bonds and the wire span at appropriate magnification to determine the nature and location of the failure.

10.1.9 Record the failure location as being one of the following:

10.1.9.1 First bond at the weld interface,

10.1.9.2 First bond at the bond-wire junction,

10.1.9.3 In the wire span,

10.1.9.4 Second bond at the weld interface,

10.1.9.5 Second bond at the bond-wire junction, or

10.1.9.6 Other (describe: for example, pad lift-off (see 6.6)).

NOTE 3—The operator will normally be supplied information as to which is the first bond and which is the second bond.

NOTE 4—If the tester is electronic with optical placement control, then all hook placement/positioning is set up during the initial machine calibration. However, failure mode determination will be evaluated by the operator.

10.2 *Method B—Device in Tipped Plane:*

10.2.1 Place the device having the wire bond to be tested in a device holder capable of tipping.

10.2.2 Perform steps 10.1.2 and 10.1.3.

10.2.3 Tip the holder (if required) until both bonds appear to be in sharp focus as viewed through the microscope.

NOTE 5—Care should be taken not to tip the wire bond about the bond-line axis. However, a judgment by eye through the microscope is adequate, as an error of a few degrees will not significantly alter the measured pull strength. This tipped-plane method is not considered applicable to an optical-electronic or other automatic pull tester.

10.2.4 Perform steps 10.1.4 – 10.1.9.

10.3 *Method C—Referee Method (To be done with a manual pull tester and full operator participation):*

10.3.1 Measure and record the horizontal distance *(d)* between the two bonds, the vertical distance *(H)* between the two bonds, and the loop height *(h)* as shown in Fig. 2. Use the same unit of measurement for *d, h,* and *H*.

10.3.2 Use either Method A or Method B, whichever is appropriate.

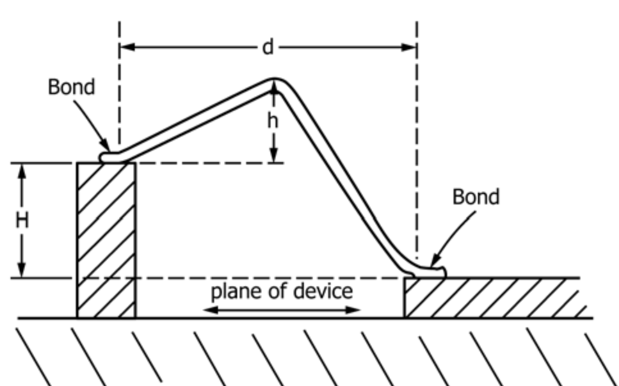

FIG. 2 Diagram of a Typical Wire Bond

10.3.3 If Method B is used, read and record the tip angle (the angle through which the device has been tipped from the horizontal) to within 2°.

11. Calculation (for Method C)

11.1 If the substrate was tipped from the horizontal, calculate the force in grams-force (or millinewtons) in the wire at failure.

11.1.1 If failure occurs at the higher of the two bond sites, calculate the force in the wire as follows:[2]

$$F_{hi} = F \frac{\sqrt{1+\left(\frac{d}{2h}\right)^2}}{\left(1+\frac{H}{2h}\right)} \left[\frac{1}{2}\cos\varphi + \left(\frac{h+H}{d}\right)\sin\varphi\right]$$

where:

F_{hi} = force in the wire on the high side, gf (or mN),
F = corrected applied pull force, gf (or mN),
d = horizontal distance between the two bonds along a parallel to plane of device,
H = vertical distance between the two bond sites along a perpendicular to plane of device,
h = loop height as defined in Fig. 2, and
φ = angle through which device has been tipped.

11.1.2 If failure occurs at the lower bond site, calculate the force in the wire as follows:

$$F_{lo} = \frac{\left(1+\frac{H}{h}\right)}{\left(1+\frac{H}{2h}\right)} \sqrt{1+\left[\frac{d}{2\,(H+h)}\right]^2} \left[\frac{1}{2}\cos\varphi - \frac{h}{d}\sin\varphi\right]$$

where F_{lo} = force in the wire at the low side in grams-force (or millinewtons) and the other symbols are as indicated in 11.1.1.

11.2 If the device was not tipped from the horizontal, calculate F_{hi} and F_{lo} as follows:

$$F_{hi} = F \frac{\sqrt{1+\left(\frac{d}{2h}\right)^2}}{\left(2+\frac{H}{h}\right)}$$

$$F_{lo} = F \frac{\left(1+\frac{H}{h}\right)}{\left(2+\frac{H}{h}\right)} \sqrt{1+\left[\frac{d}{2(H+h)}\right]^2}$$

where the symbols have the same meaning as in 11.1.1 and 11.1.2.

12. Report

12.1 *Method A*—The report for Method A shall contain the following:

12.1.1 Name of the person performing the test,

12.1.2 Date of the test,

12.1.3 Identification of the wire-bond pull tester,

12.1.4 Identification of the device,

12.1.5 Identification of each wire bond,

12.1.6 Corrected force in grams-force (or millinewtons) required to break the wire bond, and

12.1.7 Location of failure.

12.2 *Method B*—In addition to that required by 12.1, the report for Method B shall contain the angle through which the device was tipped.

12.3 *Method C*—In addition to that required by 12.1, the report for Method C shall contain the following:

12.3.1 Measured values of *d, H,* and *h*, in the same units,

12.3.2 Angle through which device was tipped, if Method B was used, and

12.3.3 Calculated force in the wire in grams-force (or millinewtons).

13. Precision and Bias

13.1 An interlaboratory evaluation of these test methods was carried out as follows:

13.1.1 Six laboratories participated, including the originating laboratory.

13.1.2 Aluminum ultrasonic wedge bonds were used employing Al-1 % Si wire 0.001-in. (25.4-μm) diameter.

13.1.3 Each test specimen prepared by the originating laboratory contained groups of bonds with three different mean pull strengths: high-quality bonds, approximately 10 gf (98 mN); average-quality bonds, approximately 7.5 gf (74 mN); and low-quality (overly deformed) bonds, approximately 4.0 gf (39 mN).

13.2 The wire-bond pull test is destructive, and different test samples do not necessarily represent bonds from the same statistical population. Therefore, the results from test samples in the interlaboratory round robin are compared after normalizing the values with results from the originating laboratory.

13.2.1 The selected estimate of precision for each group is given by the relation:

$$\text{Estimate of precision, \%} = \frac{200\,S_{\bar{x}}}{G}$$

where:

$S_{\bar{x}}$ = sample standard deviation of the normalized mean values obtained by each cooperating laboratory for the given group, and
G = nominal group pull strength given in 13.1.3.

13.2.2 The group precision values are for wire bonds of high quality, 8.0 %; average quality, 10.4 %; and low quality, 27.2 %.

14. Keywords

14.1 microelectronic wire bonds; pull strength; wire bonds