

METHOD AND APPARATUS FOR WIRE BONDING CHARACTERIZATION IN INTEGRATED CIRCUITS

PRIORITY CLAIM

[0001] The present application claims priority from Singapore Patent Application 10202251001K, filed 14 September 2022.

TECHNICAL FIELD

[0002] The present invention generally relates to semiconductor packaging, and more particularly relates to methods, apparatuses and systems for wire bonding characterization in packaging semiconductor integrated circuits.

BACKGROUND OF THE DISCLOSURE

[0003] The quality of integrated circuits is critical due to their wide usage in both consumer and industrial products. As such one hundred per cent of integrated circuit (IC) chips undergo final off-line electrical tests before being shipped to customers. However, it is currently no viable methods to achieve reasonable coverage for testing of the mechanical strength of wire bond. A weak wire bond cannot be detected by the final electrical test. It can lead to potential failure in applications with vibration, temperature cycles, and voltage/current loading. Mechanical failure may also cause catastrophic failures in applications

[0004] There is currently no electrical and mechanical in-line testing capability in wire bonding machines. Conventional mechanical strength validation is carried out with off-line testers by taking samples from the bonded IC chips and subjecting the bonds to a series of mechanical pulling as well as microscopic examination. Such conventional

wire bond mechanical strength testing, however, is destructive, meaning that the IC chips that have gone through such mechanical testing can no longer function.

[0005] Thus, there is a need for methods and apparatuses for non-destructive testing of wire bond strength that overcomes the drawbacks of prior methods and provides a scalable in-line device and process for efficient use during semiconductor backend manufacturing. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[0006] According to at least one aspect of the present embodiments, an apparatus for sensing operation of a wire bonding tool is provided. The apparatus includes a first plurality of sensing elements, a second plurality of sensing elements, and a base. The first plurality of sensing elements is configured to sense displacement of the wire bonding tool during its operation and the second plurality of sensing elements configured to sense force of the wire bonding tool during its operation. The base is coupled to the first plurality of sensing elements and the second plurality of sensing elements and is configured to forward information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

[0007] According to another aspect of the present embodiments, a wire bonding quality monitoring system is provided. The system includes a wire bonding tool, a first plurality of sensing elements, a second plurality of sensing elements, and a base. The first plurality of sensing elements is configured to sense displacement of the wire bonding tool during its operation and the second plurality of sensing elements configured to sense force of the wire bonding tool during its operation. The base is

coupled to the first plurality of sensing elements and the second plurality of sensing elements and is configured to forward information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

[0008] According to yet a further aspect of the present embodiments, a method for determining a quality of a wire bonding process is provided. The method includes determining a wire diameter of a wire being used by a wire bonding tool during the wire bonding process and defining an alarm threshold for displacement of a wire bonding tool in response to the wire diameter. The method further includes detecting displacement of the wire bonding tool by capacitance change based on relative positions of the wire bonding tool and one or more of a first plurality of sensing elements and determining a position of the wire bonding tool in a three-dimensional Cartesian coordinate system in response to the detected displacement of the wire bonding tool. And then the method includes generating an alert in response to the position of the wire bonding tool in the three-dimensional Cartesian coordinate system and the alarm threshold for displacement of the wire bonding tool.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with present embodiments.

[0010] FIG. 1 depicts a diagram of a wire bond quality detection system in accordance with the present embodiments.

[0011] FIG. 2 depicts a perspective view of a force and displacement sensing unit in accordance with present embodiments.

[0012] FIG. 3 depicts an image of bonding tool for xyz-axis displacement sensing in accordance with the present embodiments.

[0013] FIG. 4 depicts a circuit diagram of an equivalent circuit for displacement sensing in accordance with the present embodiments.

[0014] And FIG. 5 depicts an image of bonding tool for xyz-axis force sensing in accordance with the present embodiments.

[0015] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale nor in full detail.

DETAILED DESCRIPTION

[0016] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. It is the intent of present embodiments to address to provide a device, process and system for in-line wire bond monitoring to determine the mechanical strength of wire bonds during semiconductor packaging. More specifically, a method and an apparatus are developed to monitor wire bonds to determine the key wire bond parameters related to the quality of formed intermetallic compound (IMC), normal force and shear force, thereby enabling characterization of the quality and strength of the wire bond.

[0017] The embodiments disclosed herein are method and apparatus for the characterization of wire bonding mechanical strength in integrated circuits (ICs) measured as the IC die is wire bonded to its packaging as a backend semiconductor

process in forming the IC package. In accordance with present embodiments, the novel apparatus directly measures bonding tool behaviors during the actual bonding process. The measurements include measuring forces and displacements in three dimensions as functions of time. Direct time-domain measurement of the key parameters of the wire bonding process (i.e., the xyz-forces and the xyz-displacements) enables real-time measurement of wire bond strength (i.e., calibrating the quality of formed intermetallic compound, measuring normal force, shear force) as the wire bond is formed.

[0018] In accordance with the present embodiments, methods are proposed to compare the measurement data against a baseline of wire bond measurements to provide in-line wire bond quality determination. The wire bonding operator will be alerted for process optimization or correction if the values are out of the pre-defined range around a predetermined baseline. The method and apparatus in accordance with the present embodiments advantageously replaces offline wire bond testers and thereby reduce yield loss in IC mass production and, more importantly, reducing catastrophic incidents in end-user applications.

[0019] Referring to FIG. 1, a diagram 100 depicts a wire bonding system 110 and a wire bond monitoring system 120 in accordance with the present embodiments. The wire bonding system 110 includes a bonding tool 112 driven by an ultrasonic transducer 114. A piezoelectric stack 116 acting under control of an ultrasonics transducer control system 118 generates displacement for the transducer 114.

[0020] The wire bond monitoring system 120 includes a sensing unit 122 to measure displacements and forces of the bonding tool 112 during wire bonding of the integrated circuit die. A data processing unit 124 is coupled to the sensing unit 122 to collect and analyze measurement data obtained by the sensing unit 122.

[0021] During operation, the data processing unit 124 receives wire bonding signals in real-time and communicates control signals to the ultrasonics transducer control system for control of the wire bonding system 110. In addition, there is communication between the data processing unit 124 and the ultrasonics transducer control system 118 for synchronization between the wire bonding system 110 and the wire bond monitoring system 120. Upon detection of abnormalities in the wire bonding by the sensing unit 122, the wire bonding monitoring system will alert 126 a user for process optimization or correction.

[0022] The sensing unit 122 is both a force and a displacement sensing unit in that the main function of the sensing unit 122 is to measure displacements and forces along the x-axis, the y-axis and the z-axis in a synchronized manner (i.e., to measure xyz displacements and xyz forces in a synchronized manner). Referring to FIG. 2, a perspective view 200 depicts the sensing unit 122 having a base 202, displacement sensing elements 204a-204h and force sensing elements 206a-206e. The base 202 supports sensing elements 204a-204h, 206a-206e and is coupled to the data processing unit 124 (FIG. 1) to send measured sensing signals to the data processing unit 124 in accordance with the present embodiments.

[0023] The xyz-axis displacement sensing elements 204a-204h are a group of capacitance sensors positioned at optimal distances from the bonding tool 112 (FIG. 1). The position of the bonding tool 112 can be detected by the capacitance change in the displacement sensing elements 204a-204h and displacement along the x-axis, the y-axis and the z-axis is determined by the data processing unit 124 based on the capacitance change in each of the displacement sensing elements 204a-204h.

[0024] The xyz-axis force sensing elements 206a-206e are arranged such that force sensing elements 206a and 206b are sensors for measuring x-axis force, force sensing

elements 206c and 206d are sensors for measuring y-axis force, and force sensing element 206e is a sensor for measuring z-axis force. In addition to serving as the sensor for z-axis force, the force sensing element also serves as a support base for the displacement sensing elements 204a-204h.

[0025] Wedges 208a-208d secure and pre-load the displacement sensing elements 204a-204h and the force sensing elements 206a-206e. As all of the sensed signals are generated by the sensing elements 204a-204h, 206a-206e on the sensing unit 122, the sensing unit 122 sends measured sensing signals to the data processing unit 124 for processing in accordance with the present embodiments.

[0026] Referring to FIG. 3, an image 300 depicts displacement sensing of the bonding tool 112 in accordance with the present embodiments. The bonding tool 112 displacement is sensed by capacitance change based on relative positions of the bonding tool to the eight displacement sensing elements 204a-204h. When the bonding tool 112 is close enough to one or more of the displacement sensing elements 204a-204h, the displacement sensing elements 204a-204h together can detect the xyz location of the bonding tool 112 with good resolution.

[0027] The relative displacement range the displacement sensing elements 204a-204h can measure is between 0.1 to 5 times the wire diameter that the wire bonding tool 112 is bonding. A 0.6 mil bonding wire has an expected displacement measurement range between 1.5 μm and 75 μm , thus the sensing range of the displacement sensing elements 204a-204h can determine whether the bonding tool is within the bonding wire expected displacement measurement range. During the wire bonding process, the 3-dimensional displacement information is provided to and recorded by the data processing unit 124. The wire bonding tool operator can define an alarm threshold (e.g., 15% variation from displacement baseline) for displacement, and the data processing unit 124 analyses the

3-dimensional displacement information to determine if it is within the defined threshold. When the displacement information is outside the defined threshold, the wire bonding tool operator can stop production to prevent yield loss and adjust the wire bonding tool 112 to be within the defined threshold.

[0028] FIG. 4 depicts a circuit diagram 400 of an equivalent circuit for xyz displacement sensing in accordance with the present embodiments. The equivalent circuit includes capacitive sensing elements C0-C7 corresponding to displacement sensing elements 204a-204h. The eight displacement sensing elements 204a-204h can be grouped into four pairs of capacitors. The displacement of the bonding tool 112 will change the capacitance of each capacitor as seen in the circuit diagram 400.

[0029] The symmetric arrangement of the displacement sensing elements 204a-204h and the division of the eight displacement sensing elements 204a-204h into four capacitive sensing groups advantageously provides benefits of higher signal to noise ratio and stronger noise immunity. For example, an increase in the capacitance values for all four groups of capacitors indicates movement downward of bonding tool 112 in the z-axis. Alternatively, an increase in the capacitance of the capacitor group of C0 and C1 while the capacitance of the capacitor group of C2 and C3 decreases is indicative of the axis of the bonding tool 112 moving toward the direction of C0 and C1. Thus, by comparing time-domain capacitance measurements for the values of all four groups, the data processing unit 124 can determine the xyz position of the bonding tool 112 and, therefore, determine whether the bonding tool 112 is creating wire bonds within the defined displacement threshold.

[0030] Referring to FIG. 5, an image 500 depicts xyz force sensing of the bonding tool 112 in accordance with the present embodiments. In the image 500, the displacement sensing elements 204a-204h have been removed to illustrate the force

sensing. During the bonding process, the bonding tool 112 carries bonding wire with a free-air ball of gold, copper, or other conductive metal or alloy. When the ball touches the z-axis force sensing platform 206e, by moving along the z-axis, the force will be sensed by the force sensing elements 206a-206d. And when the bonding tool moves in the xyz plane, the shear force will be measured in the x-direction by the force sensing elements 206a and 206b and in the y-direction by the force sensing elements 206c and 206d. The sensing elements 206a-206d are made of piezoelectric materials to measure the shear force applied. In order to sense the forces for wire bonding with different wire diameters, the load range of the force sensing elements 206a-206d can measure up to 1 N with a resolution 1 mN. In general, the shear force should be about 50 mN/mil². For a sensitive application with 0.6mil wire, the shear force can be approximately 65 mN/mil². For a large wire application such as a 2 mil wire, the shear force is about 720 mN/mil². The z-axis bond force can be in the range of 50 mN to 800 mN depending on the application and the wire size. Thus, with the force sensing elements 206a-206d, the wire bonding operator can verify the wire bonding system against its specifications.

[0031] A typical wire bonding backend semiconductor process includes multiple wire bonding tools operating simultaneously. The data processing unit 124 would be coupled to all of the wire bonding tools and have the specifications for each as well as information on the operations being performed by each and the defined threshold of operational parameters within which each bonding machine tool should operate. Upon collecting data from each wire bonding tool, the data processing unit 124 will compare the data from each tool with the baseline for that tool. If the operating parameters are out of range (e.g., 15% variation), the wire bonding tool operator is alerted for process optimization or correction. This helps the operators of wire bonding tools to improve the semiconductor package quality and prevent yield loss.

[0032] Thus, it can be seen that the present embodiments provide systems, devices and processes for in-line wire bond monitoring to determine the mechanical strength of wire bonds during semiconductor packaging. In accordance with the present embodiments, a method and an apparatus are developed to monitor wire bonds to determine the key wire bond parameters related to the quality of formed intermetallic compound (IMC), normal force and shear force, thereby enabling characterization of the quality and strength of the wire bond. The system includes both displacement sensing elements and force sensing elements provided at the point of wire bonding. When operated at optimized conditions, the method in accordance with the present embodiments provides improved yield with improved devices having reliable wire bonds.

[0033] While exemplary embodiments have been presented in the foregoing detailed description of the present embodiments, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, operation, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing exemplary embodiments of the invention, it being understood that various changes may be made in the structure of the reactor and/or the system described in the exemplary embodiments or the function and arrangement of steps and method of operation described in the exemplary embodiments without departing from the scope of the invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. An apparatus for sensing operation of a wire bonding tool, the apparatus comprising:

a first plurality of sensing elements configured to sense displacement of the wire bonding tool during its operation;

a second plurality of sensing elements configured to sense force of the wire bonding tool during its operation; and

a base coupled to the first plurality of sensing elements and the second plurality of sensing elements and configured to forward information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

2. The apparatus in accordance with Claim 1 further comprising a data processing unit for receiving the information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

3. The apparatus in accordance with Claim 2 wherein the data processing unit is configured to generate an alert when the information on the sensed displacement and the sensed force of the wire bonding tool indicate that the bonding tool is operating outside defined parameter thresholds.

4. The apparatus in accordance with any of Claims 1 to 3 further comprising one or more wedges coupled to the first plurality of sensing elements, the second plurality of sensing elements and the base in a manner to secure the second plurality of

sensing elements to the base and pre-load the first plurality of sensing elements and the second plurality of sensing elements.

5. The apparatus in accordance with any of Claims 1 to 4 wherein the first plurality of sensing elements comprise capacitance sensors positioned at locations around the wire bonding tool, wherein the capacitance sensors are configured to determine a position of the wire bonding tool in a three-dimensional Cartesian coordinate system in response to a capacitance change of one or more of the capacitance sensors.

6. The apparatus in accordance with Claim 5 wherein the capacitance sensors are positioned at locations equidistant from the wire bonding tool.

7. The apparatus in accordance with Claim 5 or Claim 6, wherein the first plurality of sensing elements are configured to sense xyz-axis displacements in the three-dimensional Cartesian coordinate system within a displacement range between 0.1 to 5 times a diameter of a wire being bonded by the wire bonding tool.

8. The apparatus in accordance with any of Claims 1 to 7 wherein the second plurality of sensing elements comprise piezoelectric sensors located in relation to the wire bonding tool to sense forces along an x-axis, a y-axis and a z-axis.

9. A wire bonding quality monitoring system comprising:
a wire bonding tool;

a first plurality of sensing elements configured to sense displacement of the wire bonding tool during its operation;

a second plurality of sensing elements configured to sense force of the wire bonding tool during its operation; and

a base coupled to the first plurality of sensing elements and the second plurality of sensing elements and configured to forward information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

10. The wire bonding system in accordance with Claim 9 further comprising a data processing unit for receiving the information on the sensed displacement and the sensed force of the wire bonding tool during its operation.

11. The wire bonding system in accordance with Claim 10 wherein the data processing unit is configured to generate an alert when the information on the sensed displacement and the sensed force of the wire bonding tool indicate that the bonding tool is operating outside defined parameter thresholds.

12. The wire bonding system in accordance with any of Claims 9 to 11 further comprising one or more wedges coupled to the first plurality of sensing elements, the second plurality of sensing elements and the base in a manner to secure the second plurality of sensing elements to the base and pre-load the first plurality of sensing elements and the second plurality of sensing elements.

13. The wire bonding system in accordance with any of Claims 9 to 12 wherein the first plurality of sensing elements comprise capacitance sensors positioned at

locations around the wire bonding tool, wherein the capacitance sensors are configured to determine a position of the wire bonding tool in a three-dimensional Cartesian coordinate system in response to a capacitance change of one or more of the capacitance sensors.

14. The wire bonding system in accordance with Claim 13 wherein the capacitance sensors are positioned at locations equidistant from the wire bonding tool.

15. The wire bonding system in accordance with Claim 13 or Claim 14, wherein the first plurality of sensing elements are configured to sense xyz-axis displacements in the three-dimensional Cartesian coordinate system within a displacement range between 0.1 to 5 times a diameter of a wire being bonded by the wire bonding tool.

16. The wire bonding system in accordance with any of Claims 9 to 15 wherein the second plurality of sensing elements comprise piezoelectric sensors located in relation to the wire bonding tool to sense forces along an x-axis, a y-axis and a z-axis.

17. A method for determining a quality of a wire bonding process, comprising:
determining a wire diameter of a wire being used by a wire bonding tool during the wire bonding process;

defining an alarm threshold for displacement of a wire bonding tool in response to the wire diameter;

detecting displacement of the wire bonding tool by capacitance change based on relative positions of the wire bonding tool and one or more of a first plurality of sensing elements;

determining a position of the wire bonding tool in a three-dimensional Cartesian coordinate system in response to the detected displacement of the wire bonding tool;
and

generating an alert in response to the position of the wire bonding tool in the three-dimensional Cartesian coordinate system and the alarm threshold for displacement of the wire bonding tool.

18. The method in accordance with Claim 17, wherein defining the alarm threshold comprises defining the alarm threshold for displacement of the wire bonding tool at greater than 15% variation from a displacement baseline, and wherein the displacement baseline comprises a displacement in a range of 0.1 to 5 times the wire diameter.

19. The method in accordance with Claim 17 or Claim 18 further comprising:
defining an alarm threshold for measured force of a wire bonding tool; and
detecting a force of the wire bonding tool by piezoelectric change in one or more of a second plurality of sensing elements receiving force during operation of the wire bonding tool,
wherein generating the alert further comprises generating the alert in response to the force of the wire bonding tool during operation thereof and the alarm threshold for measured force of the wire bonding tool.