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WIRE BONDING APPARATUS, CONTROL DEVICE, AND CONTROL METHOD

Abstract

According to one embodiment, a wire bonding apparatus includes a bonding tool configured to feed a wire, a driver configured to drive the bonding tool, and a controller. The controller performs a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point. The controller further performs a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point. The controller determines a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, the detected value being prescribed.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS
[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2024-018071, filed on Feb. 8, 2024; the entire contents of which are incorporated herein by reference.
FIELD
[0002] Embodiments of the invention generally relate to a wire bonding apparatus, a control device, and a control method.
BACKGROUND
[0003] used in Wire bonding apparatuses are widely manufacturing processes of semiconductor devices. A wire bonding apparatus forms a bump, bonds a wire, etc. There is a need for wire bonding apparatus technology that can determine the goodness of the bump bonding at an earlier timing.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0004] FIG. **1** is a schematic view schematically showing a wire bonding apparatus according to an embodiment;
[0005] FIG. **2** is a schematic view schematically showing a portion of the wire bonding apparatus according to the embodiment;
[0006] FIGS. **3**A to **3**C are schematic views showing an example of a wire bonding process;
[0007] FIG. **4** is a schematic view showing an example of a bump bonding process;
[0008] FIG. **5** is a schematic view showing the change of the Z-position of a bonding tool;
[0009] FIG. **6**A is a schematic view showing the state of a bump when the bonding is good, and FIG. **6**B is a schematic view showing the state of the bump when the bonding is defective;
[0010] FIG. **7** is a schematic view showing another example of the bump bonding process;
[0011] FIG. **8** is a schematic view showing the change of the Z-position of the bonding tool;
[0012] FIG. **9** is a schematic view showing an example of the bump bonding process;
[0013] FIG. **10** is a schematic view showing the change of the load on the bonding tool;
[0014] FIG. **11** is a schematic view showing the change of the Z-position of the bonding tool; and
[0015] FIG. **12** is a schematic view illustrating a hardware configuration.
DETAILED DESCRIPTION
[0016] According to one embodiment, a wire bonding apparatus includes: a bonding tool configured to feed a wire; a driver configured to drive the bonding tool; and a controller configured to control the bonding tool and the driver. The controller performs a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point. The controller further performs a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool

toward the first bonding point. The controller determines a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, the detected value being prescribed.

[0017] Embodiments of the invention will now be described with reference to the drawings. The drawings are schematic or conceptual; and the relationships between the thicknesses and widths of portions, the proportions of sizes between portions, etc., are not necessarily the same as the actual values thereof. The dimensions and/or the proportions may be illustrated differently between the drawings, even in the case where the same portion is illustrated. In the drawings and the specification of the application, components similar to those described thereinabove are marked with like reference numerals, and a detailed description is omitted as appropriate.

[0018] Embodiments of the invention relate generally to a wire bonding apparatus, a control device controlling the apparatus, and a control method of the apparatus. For example, the wire bonding apparatus is used in a manufacturing process of a semiconductor device and uses a wire, which is a fine metal wire, to connect between a pad, which is an electrode of a semiconductor chip, and a lead, which is an electrode of a leadframe.

First Embodiment

[0019] FIG. **1** is a schematic view schematically showing a wire bonding apparatus according to an embodiment.

[0020] As shown in FIG. **1**, the wire bonding apparatus **100** according to the embodiment includes a bonding head **10**, a position detecting part **10***a*, an X-Y stage **20**, a bonding stage **30**, a load sensor **40**, a camera device **50**, and a controller **60**.

[0021] The bonding head **10** includes a bonding tool **11**, an ultrasonic horn **12**, a bonding arm **13**, and a driver **14**.

[0022] The bonding tool **11** feeds a wire **3** as a bonding material. The bonding tool **11** is, for example, a bonding capillary. The wire **3** is, for example, an aluminum wire, a gold wire, a silver wire, a copper wire, etc. The bonding tool **11** causes the wire **3** to contact a bonding portion **2** of a workpiece **1** placed on the bonding stage **30**, and applies a load to the bonding portion **2**. According to the embodiment, the bonding portions **2** include a first bonding point P**1** or a second bonding point P**2** which are described below.

[0023] The position detecting part **10***a* detects the Z-direction position of the bonding tool **11**. For example, an origin is defined at a prescribed position; and the position detecting part **10***a* detects the vertical-direction position of the bonding tool **11** from the origin. The position detecting part **10***a* is communicably connected with the controller **60**.

[0024] The ultrasonic horn **12** generates an ultrasonic vibration. The ultrasonic horn **12** includes an ultrasonic vibrator that generates the ultrasonic vibration. The ultrasonic horn **12** supports the bonding tool **11**. The ultrasonic vibration that is generated from the ultrasonic horn **12** is transferred to the wire **3** via the bonding tool **11**. The wire **3** is bonded to the bonding portion **2** by the ultrasonic vibration being transferred to the wire **3** in a state in which the wire **3** contacts the bonding portion **2**. The ultrasonic horn **12** is electrically connected with the controller **60**.

[0025] The bonding arm **13** supports the ultrasonic horn **12**. That is, the bonding arm **13** supports the bonding tool **11** via the ultrasonic horn **12**. The bonding arm **13** is rotatable around an axis part **13***a*.

[0026] The driver **14** drives the bonding arm **13** in a Z-direction with the axis part **13***a* as the center. The driver **14** is, for example, a linear motor. The bonding tool **11** and the ultrasonic horn **12** that are supported by the bonding arm **13** are moved in the Z-direction by moving the bonding arm **13** in the Z-direction. By moving the bonding tool **11** in the Z-direction, the wire **3** can be caused to contact the first bonding point P**1** or the second bonding point P**2** described below; and the load can be applied from the bonding tool **11**. The driver **14** is communicably connected with the controller **60**.

[0027] In this specification, the direction that connects the bonding tool **11** and the workpiece **1** is taken as the Z-direction. A direction orthogonal to the Z-direction is taken as an X-direction. A direction orthogonal to the Z-direction and X-direction is taken as a Y-direction. For example, the Z-direction is parallel to the vertical direction. The X-direction and the Y-direction are parallel to the horizontal plane. Herein, the direction from the bonding tool **11** toward the workpiece **1** is called “down”, and the opposite direction of down is called “up”.

[0028] The bonding head **10** is mounted to the X-Y stage **20**. The X-Y stage **20** is movable in the X-direction and Y-direction. The bonding head **10** is moved in the X-direction and Y-direction by moving the X-Y stage **20** in the X-direction and Y-direction. That is, the X-Y stage **20** functions as a positioning part that positions the bonding tool **11** and the like included in the bonding head **10** in the X-direction and Y-direction. The X-Y stage **20** is communicably connected with the controller **60**.

[0029] The bonding stage **30** supports the workpiece **1**, which is the object of the wire bonding. For example, the bonding stage **30** supports the workpiece **1** by suction. The workpiece **1** is a substrate or a semiconductor chip such as an IC chip, etc.

[0030] The load sensor **40** continuously detects the load applied from the bonding portion **2** of the workpiece **1** to the bonding tool **11**. The load sensor **40** includes, for example, a strain gauge. In the illustrated example, the load sensor **40** is mounted to the bonding arm **13**. The load sensor **40** is communicably connected with the controller **60**. The load sensor **40** outputs data of the detected load to the controller **60**.

[0031] The camera device **50** images the ball formed at the tip of the bonding tool **11**. Parameters of the ball can be calculated based on the image acquired by the camera device **50**.

[0032] The controller **60** controls operations of the bonding tool **11**, the ultrasonic horn **12**, the driver **14**, and the X-Y stage **20**. For example, the controller **60** controls the feeding of the wire by the bonding tool **11** and the supply rate of the wire. The controller **60** controls the output of the ultrasonic vibration generated from the ultrasonic horn **12**.

[0033] The controller **60** can move the bonding tool **11** by operating the driver **14**. More specifically, the controller **60** can control the Z-direction position of the bonding tool **11** by driving the bonding arm **13** in the Z-direction by controlling the driver **14**. As a result, the controller **60** can control the magnitude of the load applied from the bonding tool **11** to the bonding portion **2**.

[0034] The position detecting part **10***a* acquires the Z-direction position of the bonding tool **11** driven by the driver **14**. The position detecting part **10***a* may be included in the controller **60**. For example, the position detecting part **10***a* includes an encoder. When a motor of the driver **14** is operated, the position detecting part **10***a* detects the rotational direction and rotational position of the motor. The position detecting part **10***a* calculates the Z-direction position of the bonding tool **11** based on the detected rotational direction and position.

[0035] The controller **60** can move the bonding tool **11** by operating the X-Y stage **20**. More specifically, the controller **60** can control the positions of the bonding tool **11** in the X-direction and Y-direction by driving the bonding head **10** in the X-direction and Y-direction by controlling the X-Y stage **20**.

[0036] FIG. **2** is a schematic view schematically showing a portion of the wire bonding apparatus according to the embodiment.

[0037] As shown in FIG. **2**, a bump **2***a* is formed at the bonding portion **2** of the workpiece **1**; and the wire **3** is bonded to the bump **2***a*. The wire bonding apparatus **100** forms the bump **2***a*, bonds the wire **3** to the bump **2***a*, etc. For example, the wire bonding apparatus **100** bonds the wire **3** to the bonding portion **2** by generating an ultrasonic vibration from the ultrasonic horn **12** in a state in which the wire **3** is fed from the bonding tool **11** and pressed onto the bonding portion **2**.

[0038] A series of processes of bonding the wire **3** will now be described. FIGS. **3**A to **3**C are schematic views showing an example of a wire bonding process.

[0039] As shown in FIGS. **3**A to **3**C, the wire bonding process includes the three processes of a bump bonding process (FIG. **3**A), a first bonding process (FIG. **3**B), and a second bonding process

(FIG. **3**C). In the illustrated example, a chip C is located on a substrate BA. The first bonding point P**1** is on the chip C; and the second bonding point P**2** is on the substrate BA. The substrate BA on which the chip C is located is an example of the workpiece **1**. The first bonding point P**1** and the second bonding point P**2** each are examples of the bonding portion **2**. Bumps B**1** and B**2** are formed at the first and second bonding points P**1** and P**2**; and the wire **3** is bonded to the bumps.
[0040] First, as shown in FIG. **3**A, the bump bonding process is performed to form the bump B**1** at the first bonding point P**1**. Specifically, the bonding tool **11** moves above the first bonding point P**1** of the chip C. The wire **3** is inserted into the bonding tool **11**; and the tip of the wire **3** is pre-formed into a ball. For example, the tip of the wire is melted by generating an electrical discharge at the tip of the wire by applying a voltage to the wire. A ball is formed by the molten metal rounding into a sphere due to surface tension and then solidifying. The bonding tool **11** is lowered toward the first bonding point P**1**; and the ball at the tip of the wire **3** contacts the first bonding point P**1**. An ultrasonic wave is applied to the bonding tool **11** in a state in which a load is applied to the wire **3**. As a result, the ball at the tip of the wire **3** is deformed into the bump B**1** on the chip C; and the bump B**1** is bonded with the first bonding point P**1**. Subsequently, the wire **3** is cut by an ultrasonic wave; and the bump B**1** remains on the chip C. Then, the bonding tool **11** moves above the second bonding point P**2** from the first bonding point P**1**.
[0041] After forming the bump B**1**, the first bonding process is performed as shown in FIG. **3**B. A ball is pre-formed at the tip of the wire **3**. The bonding tool **11** is lowered toward the second bonding point P**2**; and the ball at the tip of the wire **3** contacts the second bonding point P**2**. An ultrasonic wave is applied to the bonding tool **11** in a state in which a load is applied to the wire **3**. As a result, the ball at the tip of the wire **3** is deformed into the bump B**2** on the substrate BA; and the bump B**2** is bonded with the second bonding point P**2**. After forming the bump B**2**, the wire **3** is not cut; and the state in which the wire **3** is connected with the bump B**2** is maintained.
[0042] After forming the bump B**2**, the second bonding process is performed as shown in FIG. **3**C. The bonding tool **11** moves upward for a prescribed distance in the state in which the bump B**2** and the wire **3** are connected. Subsequently, the bonding tool **11** bends the wire **3** and moves toward the first bonding point P**1** from the second bonding point P**2**. The wire **3** is bonded with the bump B**1** on the chip C. Then, the wire **3** is cut by an ultrasonic vibration; and the wire **3** is bonded to the chip C and the substrate BA. The procedure described above is an example of wire bonding.
[0043] The procedure is not limited to the illustrated example; the first bonding point may be positioned on the substrate BA; and the second bonding point may be positioned on the chip C. In such a case, the bump B**1** is formed on the substrate BA, then the bump B**2** is formed on the chip C, and the wire **3** is bonded from the bump B**2** to the bump B**1**.
[0044] The bump bonding process will now be described in more detail. FIG. **4** is a schematic view showing an example of the bump bonding process.
[0045] As shown in FIG. **4**, the bump bonding process includes a search process R**1**, a bonding process R**2**, a reverse process R**3**, a lowering process R**4**, a tail formation process R**5**, a tail cut process R**6**, and a spark process R**7**.
[0046] In the search process R**1**, a ball BO that is formed at the tip of the wire **3** inserted into the bonding tool **11** is caused to contact the surface of the chip C. In the bonding process R**2**, the ball BO is mashed and bonded to the surface of the chip C by applying a load and an ultrasonic vibration to the ball BO. In the reverse process R**3**, after the bonding tool **11** is raised a prescribed distance, the position of the bonding tool **11** in the horizontal direction is changed. In the lowering process R**4**, the height of the bump B**1** is determined by lowering the bonding tool **11**. In the reverse process R**3** and the lowering process R**4**, the wire remains connected with the bump. In the tail formation process R**5**, the bonding tool **11** is raised to a prescribed position to form a tail. The tail cut process R**6** cuts the tail away from the bump B**1** by applying an ultrasonic vibration while raising the bonding tool **11**. As a result, the bump B**1** is formed on the chip C. In the following spark process R**7**, a ball is formed at the tip of the wire **3** by melting the tip of the wire **3** by

generating a spark at the tip of the wire **3**.
[0047] FIG. **4** also shows the vibration state of the ultrasonic vibration (US) and the detection state of the Z-position of the bonding tool **11** in the processes R**1** to R**7**. In FIG. **4**, h**1** illustrates the Z-direction position when the bonding tool **11** is lowered most in the bonding process R**2**. For example, in the bonding process R**2**, the bonding tool **11** is lowered until a prescribed load on the bonding tool **11** is detected. Or, the bonding tool **11** is lowered until the lowering rate of the bonding tool **11** reaches or drops below a prescribed value. h**2** illustrates the Z-position when the bonding tool **11** is lowered until a prescribed load is applied to the bonding tool **11** in the lowering process R**4**, or the Z-position when the bonding tool **11** is lowered until the lowering rate of the bonding tool **11** reaches or drops below a prescribed value in the lowering process R**4**.
[0048] In the bump bonding process, the controller **60** determines whether or not the bonding of the bump B**1** to the chip C is good. The Z-position h**1** and the Z-position h**2** shown in FIG. **4** are used to determine the goodness of the bump bonding B**1**. The bonding of the bump B**1** being good refers to the bump B**1** being bonded to the chip C with a sufficient bonding strength. The bonding of the bump B**1** being defective refers to the state in which the bonding strength between the bump B**1** and the chip C is insufficient. For example, when the bonding of the bump B**1** is defective, the bump B**1** easily detaches from the surface of the chip C.
[0049] A specific determination method of the goodness will now be described. FIG. **5** is a schematic view showing the change of the Z-position of the bonding tool.
[0050] In FIG. **5**, the horizontal axis is time, and the vertical axis is the Z-position of the bonding tool **11**. The solid line illustrates the change of the Z-position when the bonding of the bump is good. The broken line illustrates the change of the Z-position when the bonding of the bump is defective.
[0051] In the example shown in FIG. **5**, when the bonding of the bump B**1** is good, the bonding tool **11** is lowered to a Z-position h**2**.sub.1 in the lowering process R**4**. When the bonding of the bump B**1** is defective, the bonding tool **11** is lowered to a Z-position h**2**.sub.2 in the lowering process R**4**. The bonding tool **11** is lowered until the prescribed load is detected. That is, the inventors of the application found that the Z-position of the bonding tool **11** when the prescribed load is detected in the case where the bonding is defective is lower than the Z-position of the bonding tool **11** when the prescribed load is detected in the case where the bonding is good. It is considered that the Z-position difference is caused by the difference between the state of the bump B**1** in the lowering process R**4** when the bonding is good and the state of the bump B**1** in the lowering process R**4** when the bonding is defective.
[0052] Or, the bonding tool **11** may be lowered at a constant speed; and the lowering rate may be detected at that time. When the output of the driver **14** is constant when lowering the bonding tool **11**, the lowering rate of the bonding tool **11** decreases when the bonding tool **11** contacts the bump B**1**. The controller **60** acquires the Z-position of the bonding tool **11** when the lowering rate of the bonding tool **11** reaches or drops below a prescribed value in the lowering process. When the Z-position is acquired based on the lowering rate, the Z-position changes according to the goodness of the bonding. It is considered that the Z-position difference also is caused by the difference between the state of the bump B**1** in the lowering process R**4** when the bonding is good and the state of the bump B**1** in the lowering process R**4** when the bonding is defective.
[0053] FIG. **6**A is a schematic view showing the state of the bump when the bonding is good. FIG. **6**B is a schematic view showing the state of the bump when the bonding is defective.
[0054] As shown in FIG. **6**A, in the reverse process R**3** after the bonding process R**2**, the bonding tool **11** is raised and then moved a preset distance in a preset direction. For example, the bonding tool **11** moves a preset X-direction distance. The movement direction of the bonding tool **11** may be oblique to the horizontal plane. When the bonding is good, the position of the bump B**1** bonded to the chip C in the reverse process R**3** does not change despite the movement in the X-direction of the bonding tool **11**. In the following lowering process R**4**, the bonding tool **11** is lowered, and the

lower end of the bonding tool **11** contacts the seam between the bump B**1** and the wire **3**. At this time, a load is applied to the bonding tool **11**. The prescribed load is detected by the load sensor **40**; and the lowering of the bonding tool **11** is stopped. Or, the lowering rate of the bonding tool **11** is reduced when a load is applied to the bonding tool **11**. The driver **14** stops lowering the bonding tool **11** when the lowering rate falls below a prescribed value.

[0055] On the other hand, the bump B**1** easily detaches from the chip C when the bonding is defective. Therefore, as shown in FIG. **6**B, it is considered that the position of the bump B**1** changes according to the movement in the X-direction of the bonding tool **11** in the reverse process R**3**. Subsequently, when the bonding tool **11** is lowered in the lowering process R**4**, the lower end of the bonding tool **11** contacts the side portion of the bump B**1** instead of the seam between the bump B**1** and the wire **3**. When the bonding tool **11** contacts the side portion of the bump B**1**, a load is applied to the bonding tool **11**. The lowering of the bonding tool **11** is stopped based on one of the load on the bonding tool **11** or the lowering rate of the bonding tool **11**. Therefore, the Z-position at which the bonding tool **11** stops is lower than the position when the bonding tool **11** contacts the seam between the bump B**1** and the wire **3**.

[0056] The controller **60** determines the goodness of the bump bonding B**1** by utilizing the change of the Z-position corresponding to the goodness of the bonding. Specifically, the controller **60** calculates the difference between the Z-position h**1** detected in the bonding process R**2** and the Z-position (h**2**.sub.1 or h**2**.sub.2) detected in the lowering process R**4**. It can be seen from FIG. **5** that the difference between the Z-position h**1** and the Z-position h**2**.sub.2 is less than the difference between the Z-position h**1** and the Z-position h**2**.sub.1. The controller **60** compares the calculated difference to a preset threshold. The threshold is set to a value that is greater than the difference between the Z-position h**1** and the Z-position h**2**.sub.2 and less than the difference between the Z-position h**1** and the Z-position h**2**.sub.1. When the difference is not less than the threshold, the controller **60** determines that the bonding of the bump B**1** is good. When the difference is less than the threshold, the controller **60** determines that the bonding of the bump B**1** is defective.

[0057] When the bonding of the bump B**1** is determined to be defective, the controller **60** stops the wire bonding process. The specific timing of the stop is arbitrary. For example, the controller **60** may stop the wire bonding process immediately when the bonding of the bump B**1** is determined to be defective. Or, the controller **60** may stop the wire bonding process after the processes up to the tail cut process R**6** are performed. In any case, the subsequent first bonding process is not performed. When the bonding of the bump B**1** is determined to be good, the controller **60** performs the subsequent first bonding process and second bonding process.

[0058] Advantages of the first embodiment will now be described.

[0059] When the bonding of the bump is defective, the bump detaches easily. As a result, a conduction defect or the like of the workpiece occurs. It is therefore desirable to determine the goodness of the bonding after the bump is bonded. The following two methods may be considered as reference examples to determine the goodness of the bonding.

[0060] In a first method, the electrical resistance between the bump and the workpiece or the electrostatic capacitance of the workpiece is measured when bonding the bump. When the bonding of the bump is good, the electrical resistance or the electrostatic capacitance changes. The goodness of the bump bonding can be determined based on the change.

[0061] In a second method, the Z-position of the bonding tool in the second bonding process is used. The wire contacts the bump in the second bonding process when the bonding of the bump is good and the bump remains at the surface of the chip. If the bonding of the bump is insufficient and the bump does not remain at the surface of the chip, the wire contacts the surface of the chip. In other words, the Z-position of the bonding tool in the second bonding process changes according to the goodness of the bump bonding. Therefore, the goodness of the bump bonding can be determined based on the Z-position of the bonding tool in the second bonding process.

[0062] However, in the first method, the goodness of the bump bonding cannot be determined

when the workpiece is not conductive or when the electrostatic capacitance of the workpiece is small. In the second method, the goodness of the bonding is determined when bonding the wire after the bump is formed. When the bonding is determined to be defective, a person inspects the bonding of the bump with the naked eye. When the inspection with the naked eye also determines the bonding to be defective, the wire is cut so that the workpiece will be reliably determined to be defective in a subsequent test of the electrical characteristics. Therefore, a task is necessary when a bonding defect occurs.
[0063] For these problems, according to the first embodiment, the controller **60** calculates, when bonding the bump B**1**, the difference between the first position when the bonding tool **11** is lowered most in the bonding process R**2** and the second position when the prescribed load is applied to the bonding tool **11** in the lowering process R**4**. Then, the controller **60** determines the goodness of the bump bonding based on the difference. According to this method, the goodness of the bump bonding can be determined regardless of the electrical characteristics of the workpiece. Also, the goodness of the bump bonding can be determined based on only information obtained in the bump bonding process. In other words, the determination result is obtained at a timing that is earlier than the second bonding process. Therefore, according to the determination result, the first bonding process and the second bonding process can be stopped. Because the first bonding process and the second bonding process are not performed, it is unnecessary to cut the wire before performing the test of the electrical characteristics, and so the task that was necessary when the bonding was defective can be eliminated.
[0064] According to the first embodiment, the goodness of the bump bonding can be determined at an earlier timing, regardless of the electrical characteristics of the workpiece.
Modifications
[0065] FIG. **7** is a schematic view showing another example of the bump bonding process.
[0066] The bump bonding process may include multiple reverse processes R**3** and multiple lowering processes R**4**. In the example shown in FIG. **7**, the bump bonding process includes a reverse process R**3***a*, a lowering process R**4***a*, a reverse process R**3***b*, and a lowering process R**4***b*. That is, the reverse process R**3** and the lowering process R**4** are alternately repeated twice.
[0067] In the reverse process R**3***a*, the bonding tool **11** is raised, and then the position of the bonding tool **11** in the horizontal direction (e.g., the X-direction) is changed. In the lowering process R**4***a*, the bonding tool **11** is lowered until the prescribed load is applied to the bonding tool **11**. In the reverse process R**3***b*, the bonding tool **11** is raised and then moved in the −X direction. The horizontal direction in which the bonding tool **11** moves in the reverse process R**3***b* is the opposite of the horizontal direction in which the bonding tool **11** moves in the reverse process R**3***a*. Subsequently, in the lowering process R**4***b*, the bonding tool **11** is lowered until the prescribed load is applied to the bonding tool **11**. Thereafter, the tail formation process R**5**, the tail cut process R**6**, and the spark process R**7** are performed similarly to the example shown in FIG. **4**.
[0068] When multiple lowering processes are performed, the Z-position is detected in each of the lowering processes. For example, as shown in FIG. **7**, the Z-position h**2** is detected in the lowering process R**4***a*; and a Z-position h**3** is detected in the lowering process R**4***b*.
[0069] When the bonding of the bump B**1** is insufficient, the bump B**1** also moves according to the movement in the horizontal direction of the bonding tool **11** as shown in FIG. **5**. Therefore, the Z-position of the bonding tool **11** when the prescribed load is applied to the bonding tool **11** in the lowering processes R**4***a* and R**4***b* changes according to the goodness of the bump bonding B**1**.
[0070] FIG. **8** is a schematic view showing the change of the Z-position of the bonding tool.
[0071] In FIG. **8**, the horizontal axis is time and the vertical axis is the Z-position of the bonding tool **11**. The solid line illustrates the change of the Z-position when the bonding of the bump is good. The broken line illustrates the change of the Z-position when the bonding of the bump is defective. For example, as shown in FIG. **8**, when the bonding is good, the Z-position h**2**.sub.1 is detected in the lowering process R**4***a*; and a Z-position h**3**.sub.1 is detected in the lowering process

R**4***b*. When the bonding is defective, the Z-position h**2**.sub.2 is detected in the lowering process R**4***a*; and a Z-position h**3**.sub.2 is detected in the lowering process R**4***b*. The Z-position h**2**.sub.2 is positioned lower than the Z-position h**2**.sub.1; and the Z-position h**3**.sub.2 is positioned lower than the Z-position h**3**.sub.1.

[0072] The controller **60** calculates a first difference between the Z-position h**1** detected in the bonding process R**2** and the Z-position (h**2**.sub.1 or h**2**.sub.2) detected in the lowering process R**4***a*. The controller **60** also calculates a second difference between the Z-position h**1** and the Z-position (h**3**.sub.1 or h**3**.sub.2) detected in the lowering process R**4***b*.

[0073] The controller **60** determines the bonding of the bump B**1** to be good when the first difference is not less than a prescribed threshold and the second difference is not less than the threshold. The controller **60** determines the bonding of the bump B**1** to be defective when the first difference is less than the threshold or when the second difference is less than the threshold.

[0074] Or, the controller **60** may determine the bonding of the bump B**1** to be good when the first difference is not less than a prescribed threshold and the second difference is not less than a threshold. The controller **60** determines that the bonding of the bump B**1** is defective when the first difference is less than the threshold and the second difference is less than the threshold.

[0075] When multiple reverse processes R**3** and multiple lowering processes R**4** are performed, the accuracy of the determination can be further increased by using the Z-positions of the lowering processes R**4** to determine the goodness of the bump bonding B**1**.

Second Embodiment

[0076] FIG. **9** is a schematic view showing an example of the bump bonding process.

[0077] FIGS. **4** and **7** show the Z-position detected in the bump bonding process. In contrast, FIG. **9** shows the load detected in the bump bonding process.

[0078] As shown in FIG. **9**, a load is applied to the bonding tool **11** in a portion of the search process R**1**, in the bonding process R**2**, and in the lowering process R**4**. The load that is applied to the bonding tool **11** is detected by the load sensor **40**. According to the second embodiment, the goodness of the bump bonding B**1** is determined based on the load on the bonding tool **11** detected in the lowering process R**4**.

[0079] Specifically, in the lowering process R**4** according to the first embodiment, the bonding tool **11** is lowered until the prescribed load is detected. In the lowering process R**4** according to the second embodiment, the bonding tool **11** is lowered until the bonding tool **11** reaches a prescribed Z-position. When the bonding of the bump B**1** is good, the prescribed Z-position is set to a position such that the bonding tool **11** contacts the bump B**1**. As shown in FIG. **5**, the bonding tool **11** contacts the bump B**1** at a higher position when the bonding of the bump B**1** is good than when the bonding of the bump B**1** is defective. That is, when states are compared in which the bonding tool **11** is at the same Z-position, the load on the bonding tool **11** when the bonding of the bump B**1** is good is greater than the load on the bonding tool **11** when the bonding of the bump B**1** is defective.

[0080] FIG. **10** is a schematic view showing the change of the load on the bonding tool.

[0081] In FIG. **10**, the horizontal axis is time, and the vertical axis is the load on the bonding tool **11**. The solid line illustrates the change of the load when the bonding of the bump is good. The broken line illustrates the change of the load when the bonding of the bump is defective. In the example shown in FIG. **10**, a load L**1** is detected in the lowering process R**4** when the bonding tool **11** reaches the prescribed Z-position when the bonding of the bump B**1** is good. A load L**2** is detected in the lowering process R**4** when the bonding tool **11** reaches the prescribed Z-position when the bonding of the bump B**1** is defective. The load L**2** is less than the load L**1**.

[0082] The controller **60** compares the load detected in the lowering process R**4** to a prescribed threshold. The threshold is set to a value between the load L**1** and the load L**2**. When the detected load is not less than the threshold, the controller **60** determines the bonding to be good. When the detected load is less than the threshold, the controller **60** determines the bonding to be defective. When the bonding of the bump B**1** is determined to be defective, the controller **60** stops the wire bonding process.

[0083] According to the second embodiment, similarly to the first embodiment, the goodness of the bump bonding can be determined at an earlier timing, regardless of the electrical characteristics of the workpiece.

Third Embodiment

[0084] In the lowering process R**4** according to a third embodiment of the invention, the period (the length of time) from the start of the lowering of the bonding tool **11** until the prescribed load is applied to the bonding tool **11** is detected. The controller **60** determines the goodness of the bump bonding B**1** based on the period.

[0085] FIG. **11** is a schematic view showing the change of the Z-position of the bonding tool.

[0086] In FIG. **11**, similarly to FIG. **5**, the horizontal axis and the vertical axis are respectively the time and the Z-position. The solid line and the broken line illustrate the change of the Z-position when the bonding of the bump is respectively good and defective. In the example shown in FIG. **11**, when the bonding of the bump B**1** is good, the length of time from the start of the lowering of the bonding tool **11** in the lowering process R**4** until the prescribed load on the bonding tool **11** is detected is a period p**1**. When the bonding of the bump B**1** is defective, the length of time from the start of the lowering of the bonding tool **11** in the lowering process R**4** until the prescribed load on the bonding tool **11** is detected is a period p**2**. The period p**2** is greater than the period p**1**.

[0087] The controller **60** compares the detected period to a prescribed threshold. The threshold is set to a value between the period p**1** and the period p**2**. The controller **60** determines the bonding to be good when the detected period is less than the threshold. When the detected period is not less than the threshold, the controller **60** determines the bonding to be defective. The controller **60** stops the wire bonding process when the bonding of the bump B**1** is determined to be defective.

[0088] According to the third embodiment, similarly to the first embodiment, the goodness of the bump bonding can be determined at an earlier timing, regardless of the electrical characteristics of the workpiece.

[0089] A bump bonding process such as that shown in the modification of the first embodiment in which multiple reverse processes R**3** and multiple lowering processes R**4** are performed also is applicable to the second embodiment or third embodiment above.

[0090] According to the embodiments of the invention described above, the controller **60** can determine the goodness of the bump bonding at the first bonding point based on the prescribed detected value detected in the lowering process R**4**.

[0091] According to the first embodiment, “the prescribed detected value” is the second position of the bonding tool **11** when the prescribed load is applied to the bonding tool **11** in the lowering process R**4**. The controller **60** acquires the first position of the bonding tool **11** when the bonding tool **11** is lowered most in the bonding process R**2**. The controller **60** determines the goodness of the bump bonding B**1** by comparing the difference between the first position and the second position to a preset threshold.

[0092] According to the second embodiment, “the prescribed detected value” is the load on the bonding tool **11** when the bonding tool **11** is lowered to the prescribed position in the lowering process R**4**. The controller **60** determines the goodness of the bump bonding B**1** by comparing the load to the preset threshold.

[0093] According to the third embodiment, “the prescribed detected value” is the period from the start of the lowering process R**4** until the prescribed load is applied to the bonding tool **11**. The controller **60** determines the goodness of the bump bonding B**1** by comparing the period to the preset threshold.

[0094] FIG. **12** is a schematic view illustrating a hardware configuration.

[0095] For example, a computer **90** shown in FIG. **12** is used as the controller **60**. The computer **90** includes a CPU **91**, ROM **92**, RAM **93**, a storage device **94**, an input interface **95**, an output interface **96**, and a communication interface **97**.

[0096] The ROM **92** stores programs controlling operations of the computer **90**. The ROM **92** stores programs necessary for causing the computer **90** to realize the processing described above. The RAM **93** functions as a memory region into which the programs stored in the ROM **92** are loaded.
[0097] The CPU **91** includes a processing circuit. The CPU **91** uses the RAM **93** as work memory to execute the programs stored in at least one of the ROM **92** or the storage device **94**. When executing the programs, the CPU **91** executes various processing by controlling configurations via a system bus **98**.
[0098] The storage device **94** stores data necessary for executing the programs and/or data obtained by executing the programs.
[0099] The input interface (I/F) **95** can connect the computer **90** and an input device **95***a*. The input I/F **95** is, for example, a serial bus interface such as USB, etc. The CPU **91** can read various data from the input device **95***a* via the input I/F **95**.
[0100] The output interface (I/F) **96** can connect the computer **90** and an output device **96***a*. The output I/F **96** is, for example, an image output interface such as Digital Visual Interface (DVI), High-Definition Multimedia Interface (HPMI (registered trademark)), etc. The CPU **91** can transmit data to the output device **96***a* via the output I/F **96** and cause the output device **96***a* to display an image.
[0101] The communication interface (I/F) **97** can connect the computer **90** and a server **97***a* outside the computer **90**. The communication I/F **97** is, for example, a network card such as a LAN card, etc. The CPU **91** can read various data from the server **97***a* via the communication I/F **97**.
[0102] The storage device **94** includes at least one selected from a hard disk drive (HDD) and a solid state drive (SSD). The input device **95***a* includes at least one selected from a mouse, a keyboard, a microphone (audio input), and a touchpad. The output device **96***a* includes at least one selected from a monitor, a projector, a printer, and a speaker. A device such as a touch panel that functions as both the input device **95***a* and the output device **96***a* may be used.
[0103] The processing that is performed by the controller **60** may be realized by one computer **90** and may be realized by collaboration of multiple computers **90**.
[0104] The processing of the various data described above may be recorded, as a program that can be executed by a computer, in a magnetic disk (a flexible disk, a hard disk, etc.), an optical disk (CD-ROM, CD-R, CD-RW, DVD-ROM, DVD+R, DVD+RW, etc.), semiconductor memory, or another non-transitory computer-readable storage medium.
[0105] For example, the information that is recorded in the recording medium can be read by a computer (or an embedded system). The recording format (the storage format) of the recording medium is arbitrary. For example, the computer reads a program from the recording medium and causes a CPU to execute the instructions recited in the program based on the program. In the computer, the acquisition (or the reading) of the program may be performed via a network.
[0106] The embodiments of the invention include the following features.
Feature 1
[0107] A wire bonding apparatus, including: [0108] a bonding tool configured to feed a wire; [0109] a driver configured to drive the bonding tool; and [0110] a controller configured to control the bonding tool and the driver, [0111] the controller performing at least [0112] a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point, and [0113] a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, [0114] the controller determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, [0115] the detected value being prescribed.
Feature 2

[0116] The wire bonding apparatus according to feature 1, in which [0117] the detected value includes at least one selected from: [0118] a position of the bonding tool when a prescribed load is applied to the bonding tool in the lowering process; [0119] a position of the bonding tool when a lowering rate of the bonding tool changes to be not more than a prescribed value in the lowering process; [0120] a load on the bonding tool when the bonding tool is lowered to a prescribed position in the lowering process; and [0121] a period from a start of the lowering process until a prescribed load is applied to the bonding tool.

Feature 3

[0122] The wire bonding apparatus according to feature 1, in which [0123] the controller acquires a first position when the bonding tool is lowered most in the bonding process, [0124] the detected value includes a second position of the bonding tool when a prescribed load is applied to the bonding tool in the lowering process, and [0125] the controller determines that the bonding of the bump is defective in the case where a difference between the first position and the second position is less than a preset threshold.

[0126] The wire bonding apparatus according to any one of features 1 to 3, in which

Feature 4

[0127] in the case where the bonding of the bump is determined to be good, the controller performs at least a first bonding process of moving the bonding tool above a second bonding point, lowering the bonding tool with a ball formed at the tip of the wire, and causing the ball to contact the second bonding point, and [0128] in the case where the bonding of the bump is determined to be defective, the controller does not perform the first bonding process.

Feature 5

[0129] A control device configured to control a wire bonding apparatus, [0130] the wire bonding apparatus including: [0131] a bonding tool configured to feed a wire; and [0132] a driver driving the bonding tool, [0133] the control device being configured to cause the wire bonding apparatus to perform at least: [0134] a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point; and [0135] a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, [0136] the control device determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, [0137] the detected value being prescribed.

Feature 6

[0138] A control method of a wire bonding apparatus, [0139] the wire bonding apparatus including: [0140] a bonding tool configured to feed a wire; and [0141] a driver configured to drive the bonding tool, [0142] the control method including causing the wire bonding apparatus to perform at least: [0143] a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point; and [0144] a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, [0145] the control method further including determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, [0146] the detected value being prescribed.

[0147] According to the embodiments above, a wire bonding apparatus is provided that can determine the goodness of the bump bonding at an earlier timing, regardless of the electrical characteristics of the workpiece. Also, by performing the determination method of the goodness of the bonding described above in the bump bonding process, the controller (the control device) can determine the goodness of the bump bonding at an earlier timing, regardless of the electrical characteristics of the workpiece. According to the control method performed by the controller described above, the goodness of the bump bonding can be determined at an earlier timing, regardless of the electrical characteristics of the workpiece.

[0148] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention. Moreover, above-mentioned embodiments can be combined mutually and can be carried out.

Claims

1. A wire bonding apparatus, comprising: a bonding tool configured to feed a wire; a driver configured to drive the bonding tool; and a controller configured to control the bonding tool and the driver, the controller performing at least a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point, and a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, the controller determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, the detected value being prescribed.

2. The wire bonding apparatus according to claim 1, wherein the detected value includes at least one selected from: a position of the bonding tool when a prescribed load is applied to the bonding tool in the lowering process; a position of the bonding tool when a lowering rate of the bonding tool changes to be not more than a prescribed value in the lowering process; a load on the bonding tool when the bonding tool is lowered to a prescribed position in the lowering process; and a period from a start of the lowering process until a prescribed load is applied to the bonding tool.

3. The wire bonding apparatus according to claim 1, wherein the controller acquires a first position when the bonding tool is lowered most in the bonding process, the detected value includes a second position of the bonding tool when a prescribed load is applied to the bonding tool in the lowering process, and the controller determines that the bonding of the bump is defective in the case where a difference between the first position and the second position is less than a preset threshold.

4. The wire bonding apparatus according to claim 1, wherein in the case where the bonding of the bump is determined to be good, the controller performs at least a first bonding process of moving the bonding tool above a second bonding point, lowering the bonding tool with a ball formed at the tip of the wire, and causing the ball to contact the second bonding point, and in the case where the bonding of the bump is determined to be defective, the controller does not perform the first bonding process.

5. A control device configured to control a wire bonding apparatus, the wire bonding apparatus including: a bonding tool configured to feed a wire; and a driver driving the bonding tool, the control device being configured to cause the wire bonding apparatus to perform at least: a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point; and a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, the control device determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, the detected value being prescribed.

6. A control method of a wire bonding apparatus, the wire bonding apparatus including: a bonding tool configured to feed a wire; and a driver configured to drive the bonding tool, the control method comprising causing the wire bonding apparatus to perform at least: a bonding process of causing a ball formed at a tip of the wire to contact a first bonding point, deforming the ball into a bump, and bonding the bump to the first bonding point; and a lowering process of raising the bonding tool while the bonding tool holds the wire connected with the bump, changing a position of the bonding tool in a horizontal direction, and subsequently lowering the bonding tool toward the first bonding point, the control method further comprising determining a goodness of the bonding of the bump to the first bonding point based on a detected value detected in the lowering process, the detected value being prescribed.