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Klaerner et al.

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(54) **CLEANING SYSTEMS FOR WIRE BONDING TOOLS, WIRE BONDING MACHINES INCLUDING SUCH SYSTEMS, AND RELATED METHODS**

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B08B 1/20 (2024.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B08B 1/12*** (2024.01); ***B08B 1/20*** (2024.01); ***B08B 1/34*** (2024.01); ***B08B 3/02*** (2013.01);
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(58) **Field of Classification Search**
CPC H01L 2224/7801; H01L 24/78; H01L 2224/78343; H01L 2224/78621;
(Continued)

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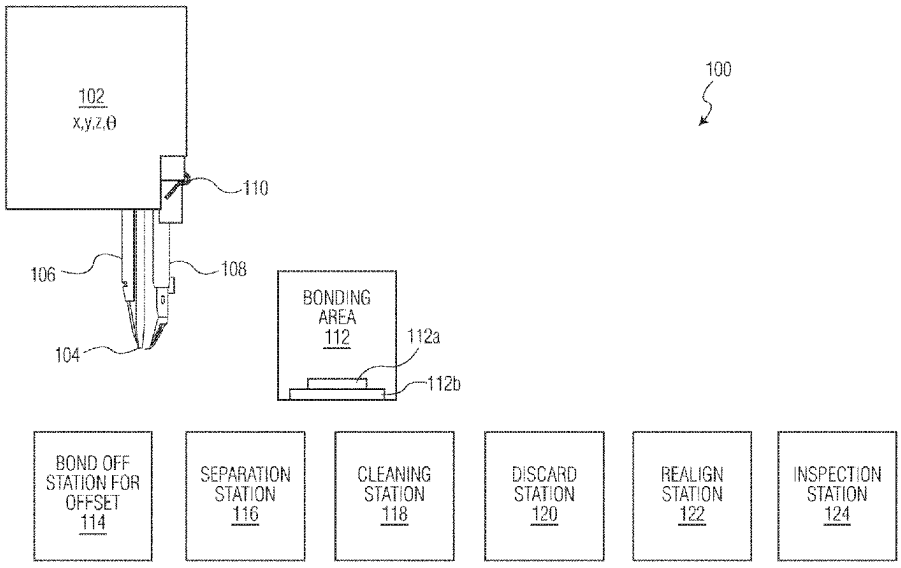
Primary Examiner — Douglas Lee
(74) *Attorney, Agent, or Firm* — Christopher M. Spletzer, Sr.

(57) **ABSTRACT**

A method of cleaning a tip of a wire bonding tool on a wire bonding machine is provided. The method includes the steps of: (a) moving a wire away from the wire bonding tool such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine; and (b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a).

22 Claims, 28 Drawing Sheets



(51) **Int. Cl.**

B08B 1/34	(2024.01)
B08B 3/02	(2006.01)
B08B 7/00	(2006.01)
B23K 37/00	(2025.01)
H01L 23/00	(2006.01)

(52) **U.S. Cl.**

CPC ***B08B 7/0028*** (2013.01); ***B08B 7/0035*** (2013.01); ***B08B 7/0042*** (2013.01); ***B23K 37/00*** (2013.01); ***H01L 24/78*** (2013.01); *H01L 2224/7801* (2013.01); *H01L 2224/78343* (2013.01); *H01L 2224/78621* (2013.01); *H01L 2224/78756* (2013.01)

(58) **Field of Classification Search**

CPC . H01L 2224/78756; B08B 1/002; B08B 1/02; B08B 1/04; B08B 3/02; B08B 7/0028; B08B 7/0035; B08B 7/0042; B23K 20/005; B23K 20/007; B23K 20/233; B23K 20/26; B23K 2101/42; B23K 31/125; B23K 37/00

See application file for complete search history.

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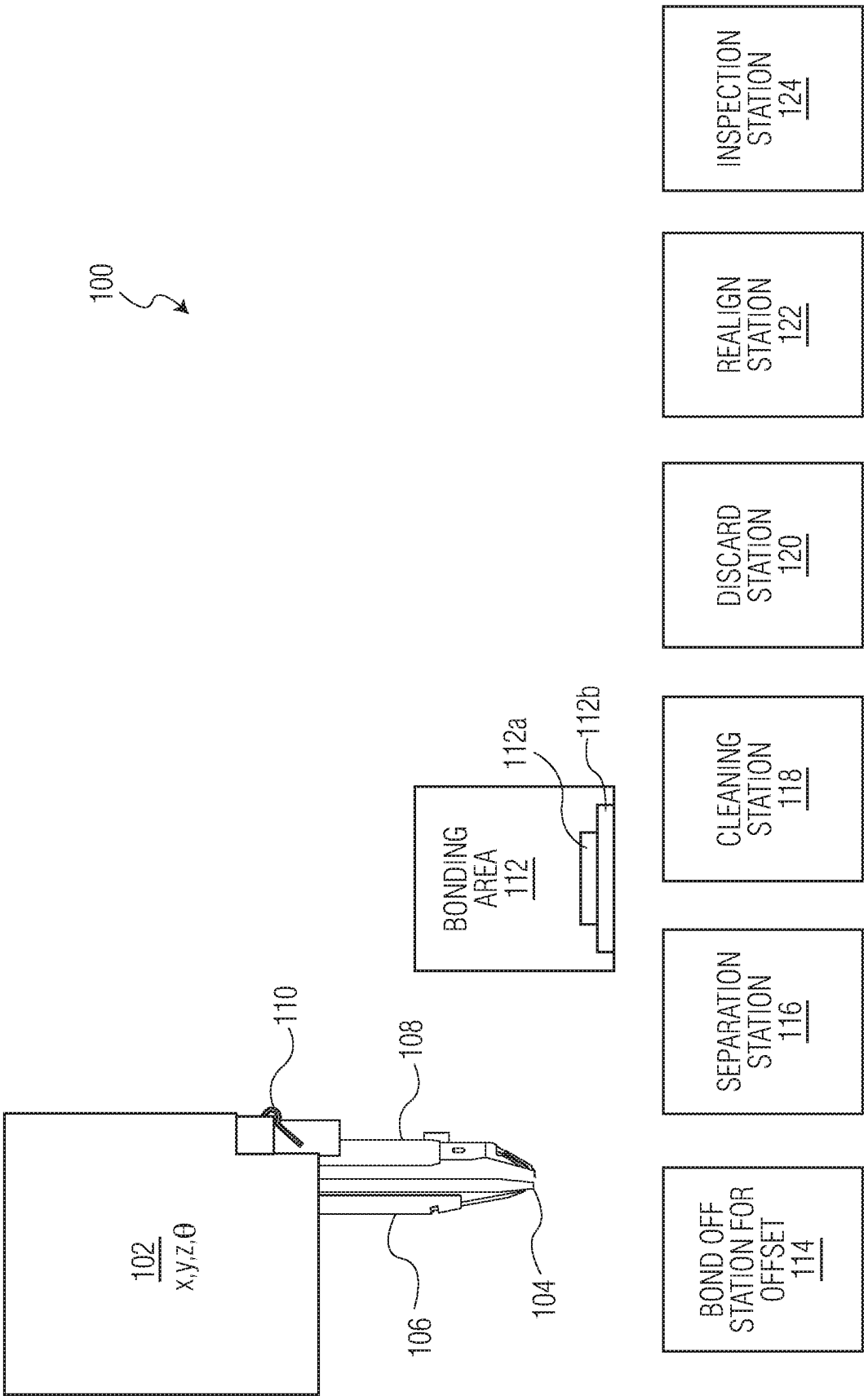

100
102
x,y,z,θ
104
106
108
110
BONDING AREA 112
112a
112b
BOND OFF STATION FOR OFFSET 114
SEPARATION STATION 116
CLEANING STATION 118
DISCARD STATION 120
REALIGN STATION 122
INSPECTION STATION 124

FIG. 1

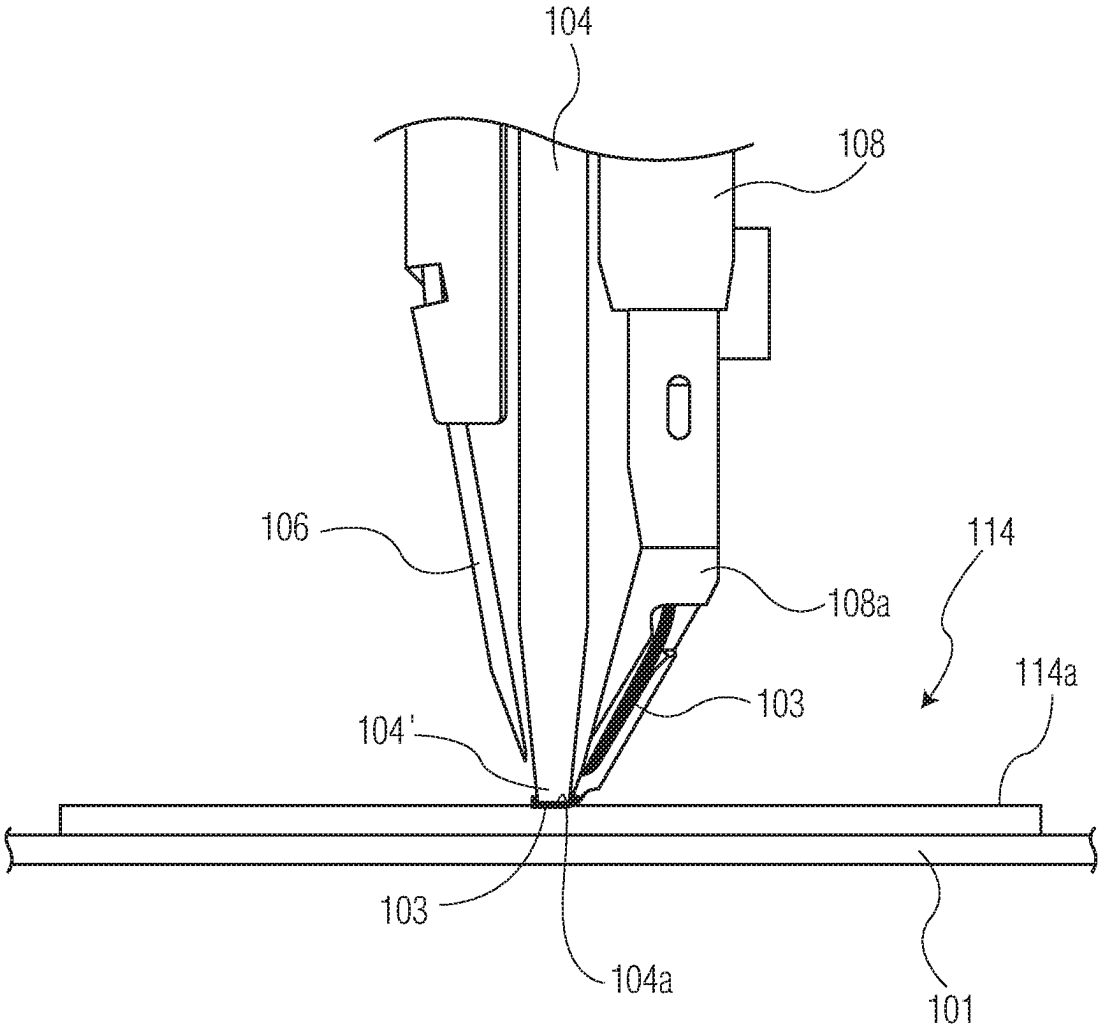


FIG. 2A

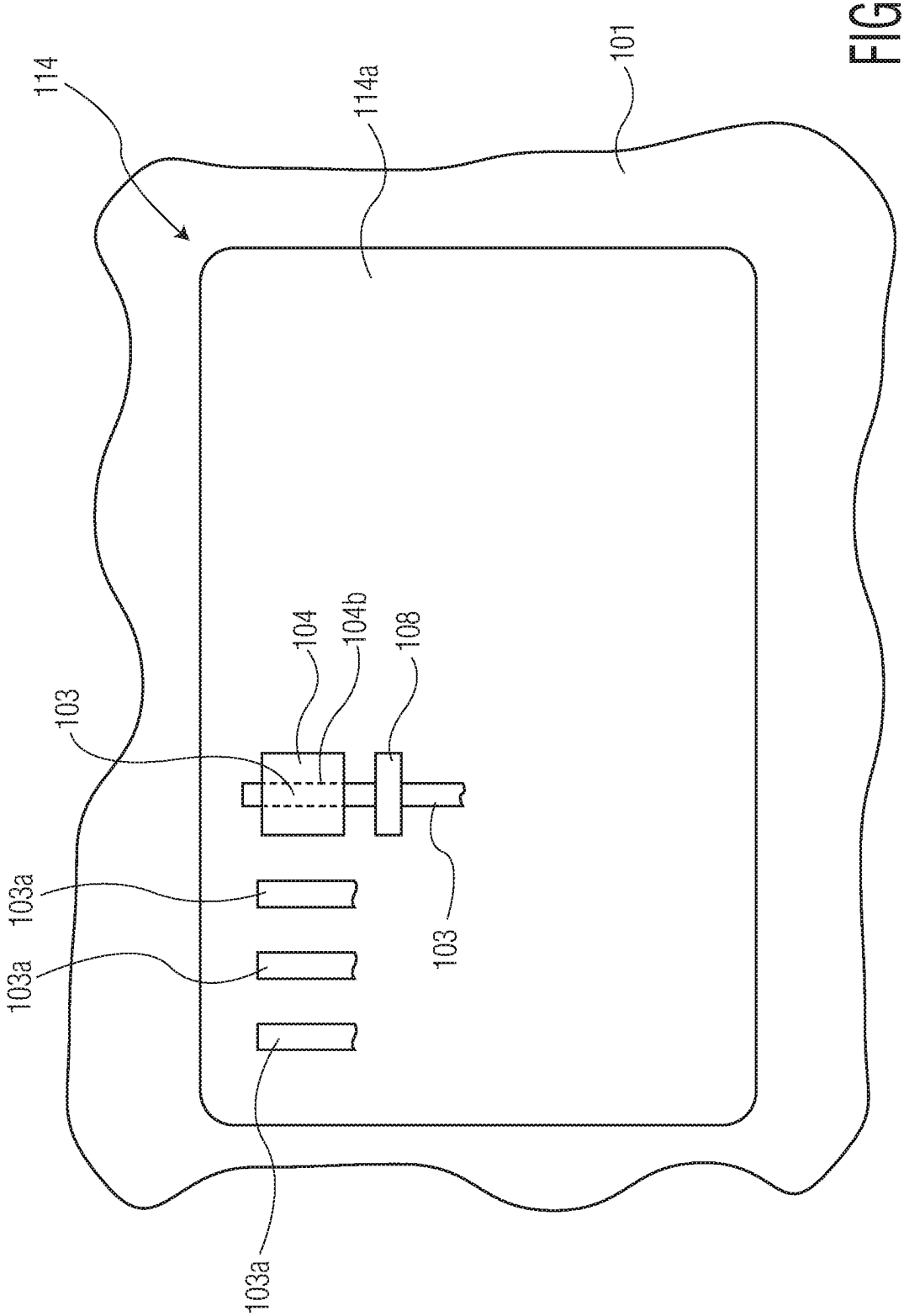


FIG. 2B

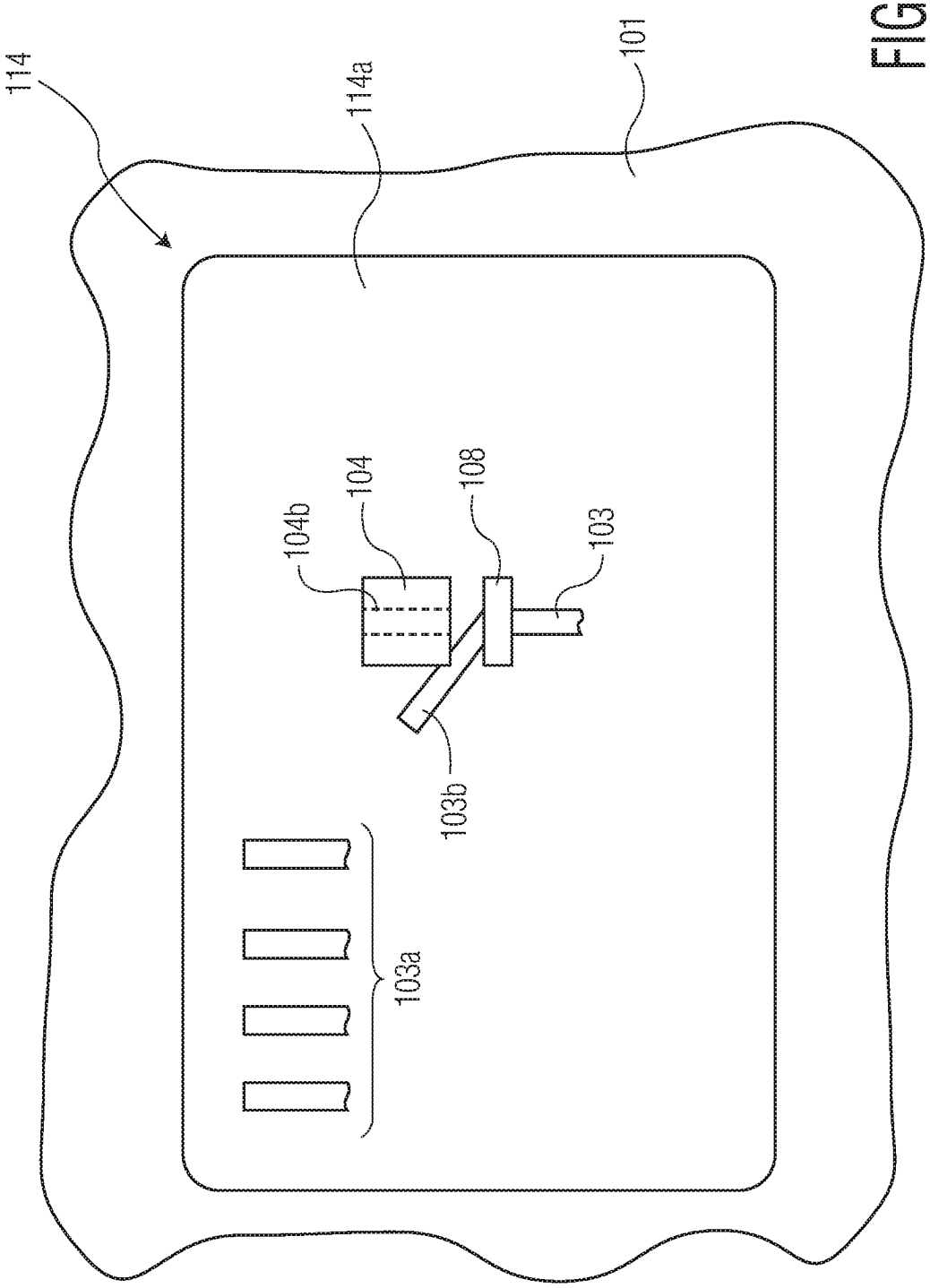


FIG. 2C

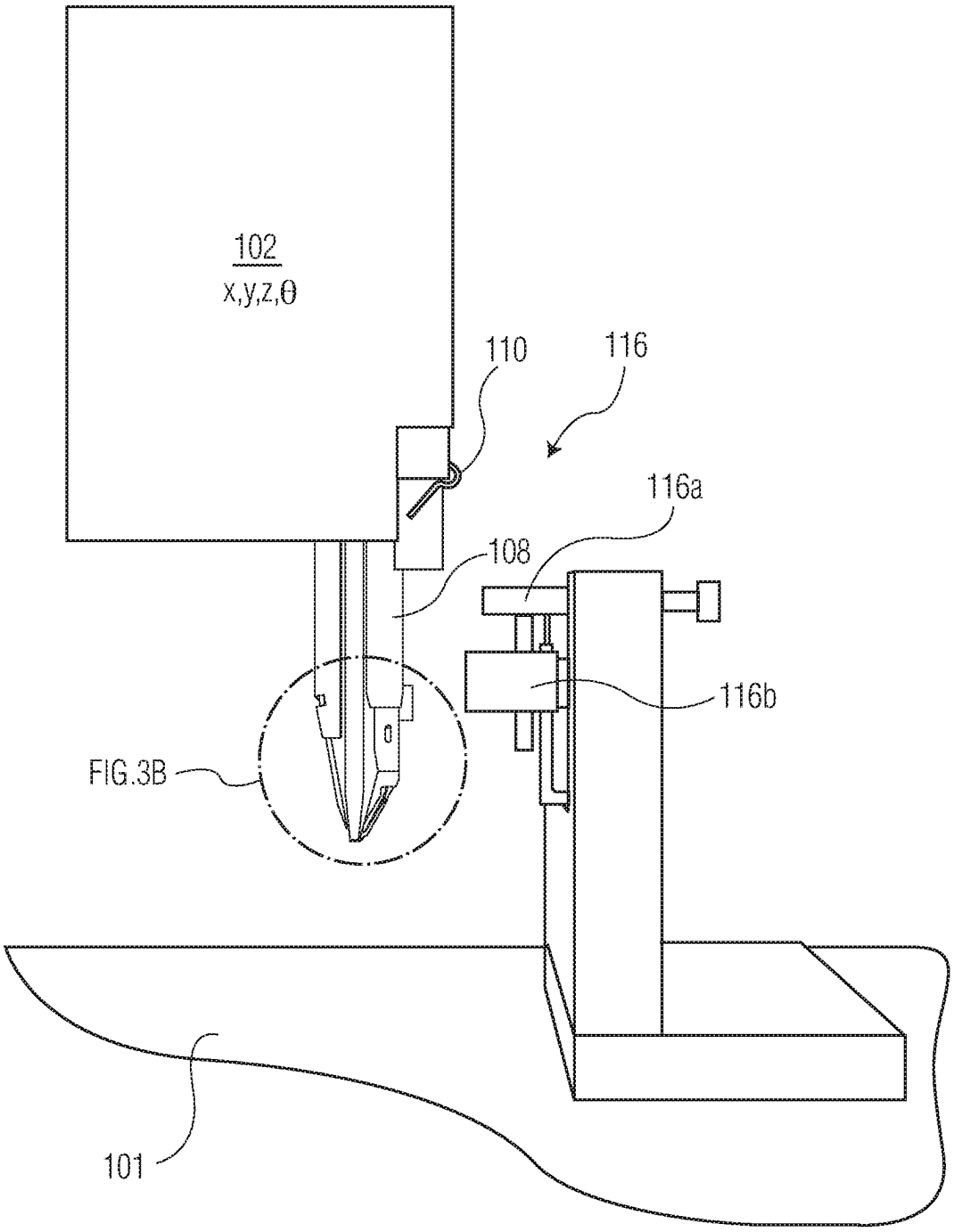


FIG. 3A

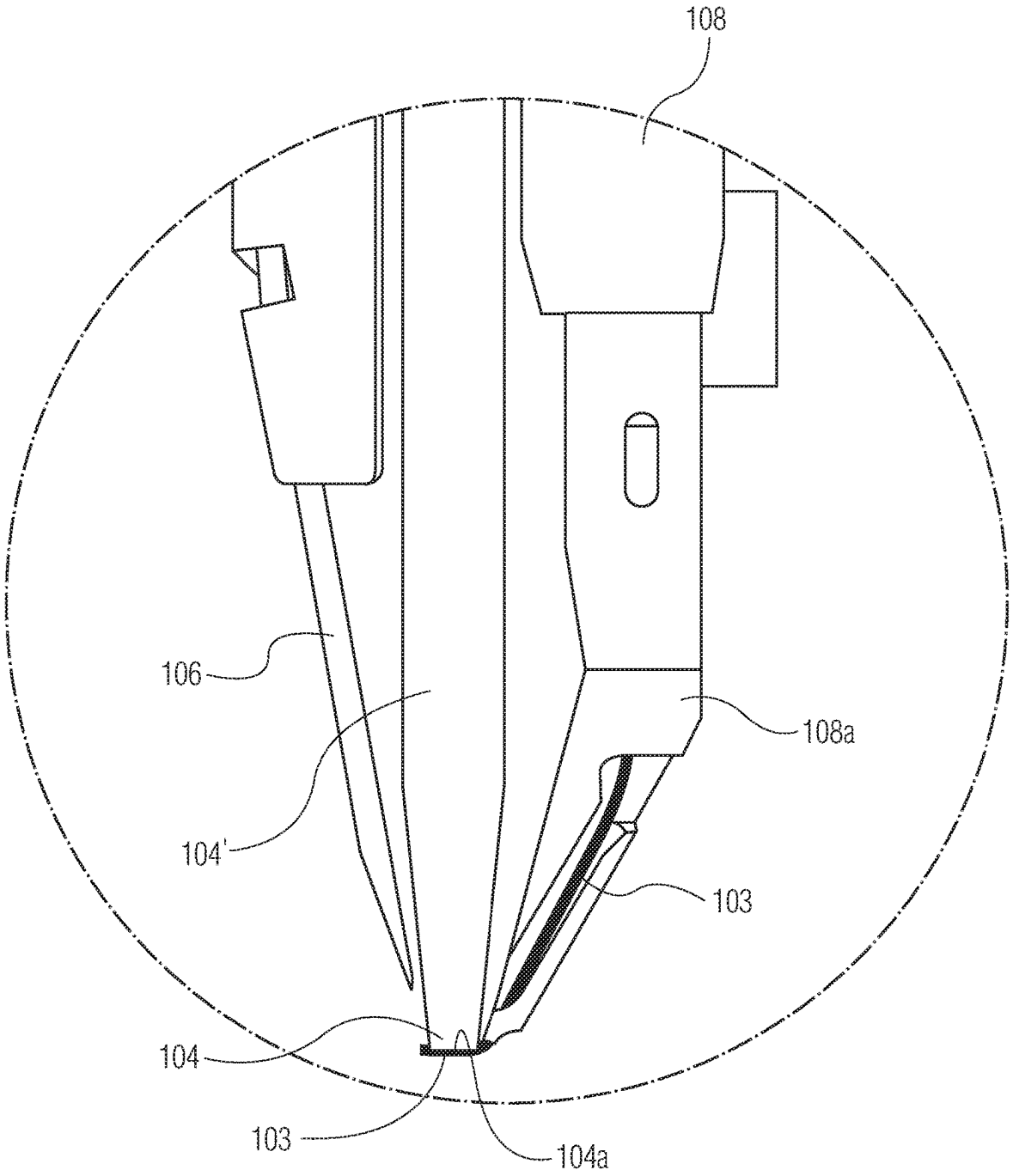


FIG. 3B

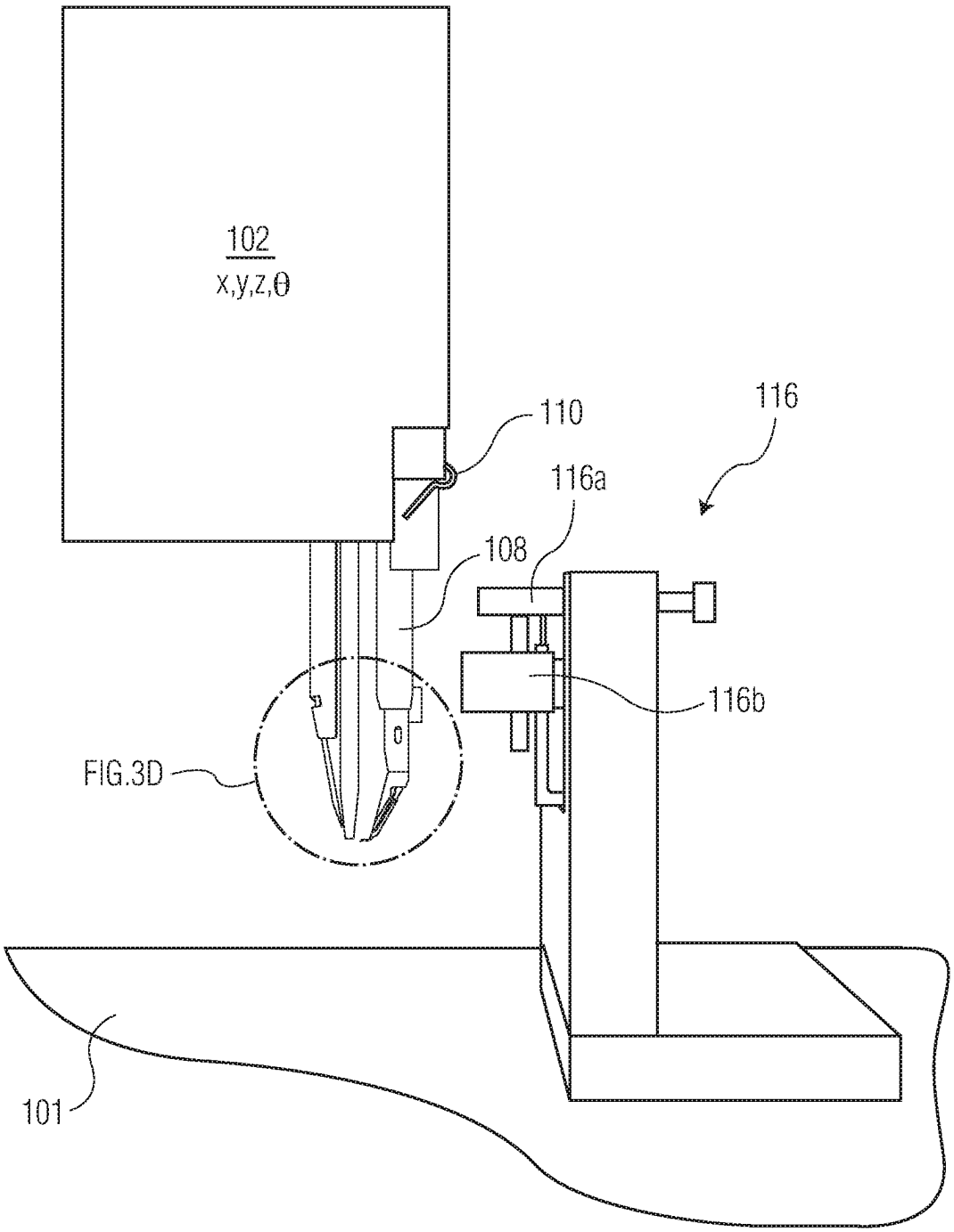


FIG. 3C

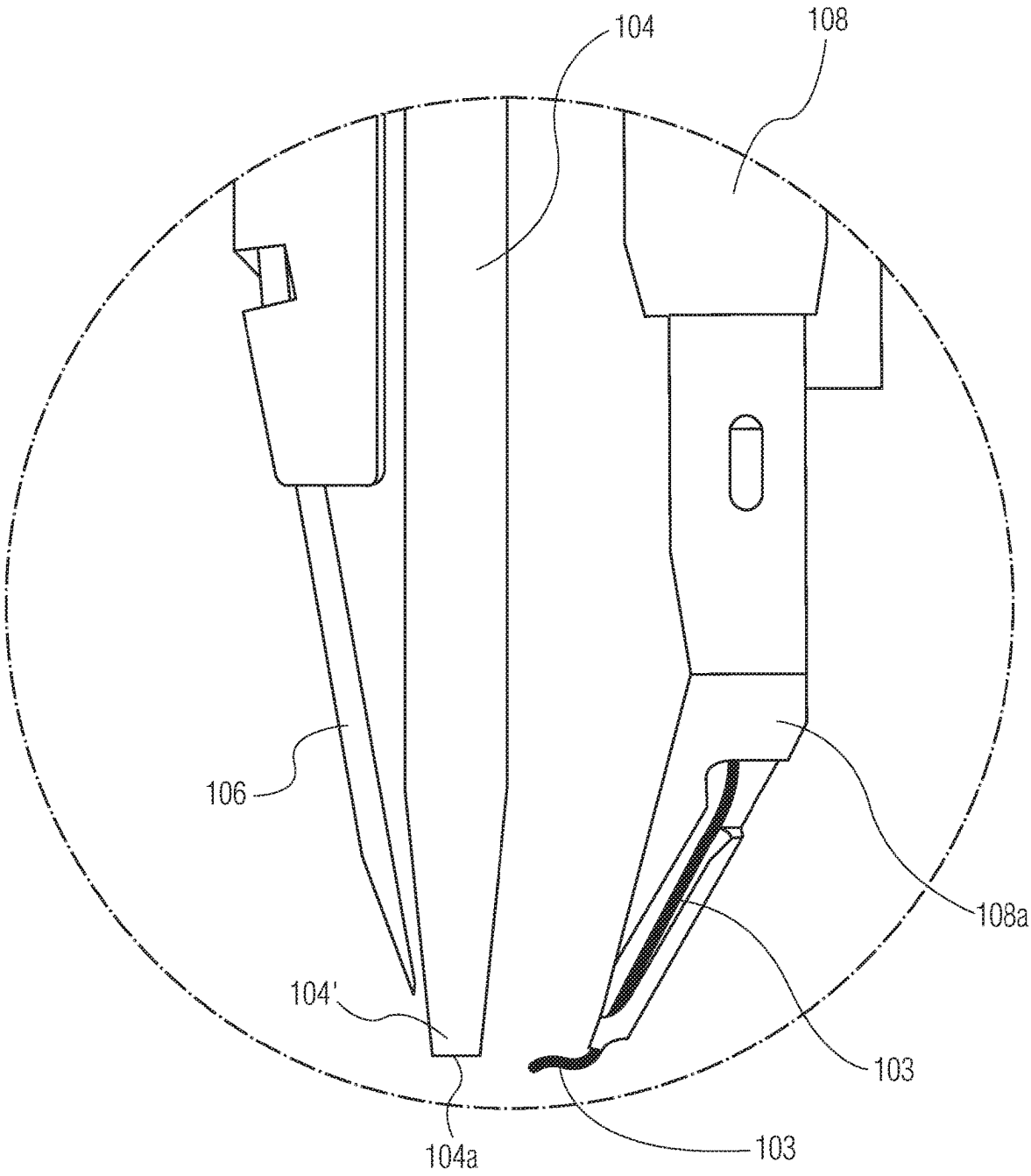
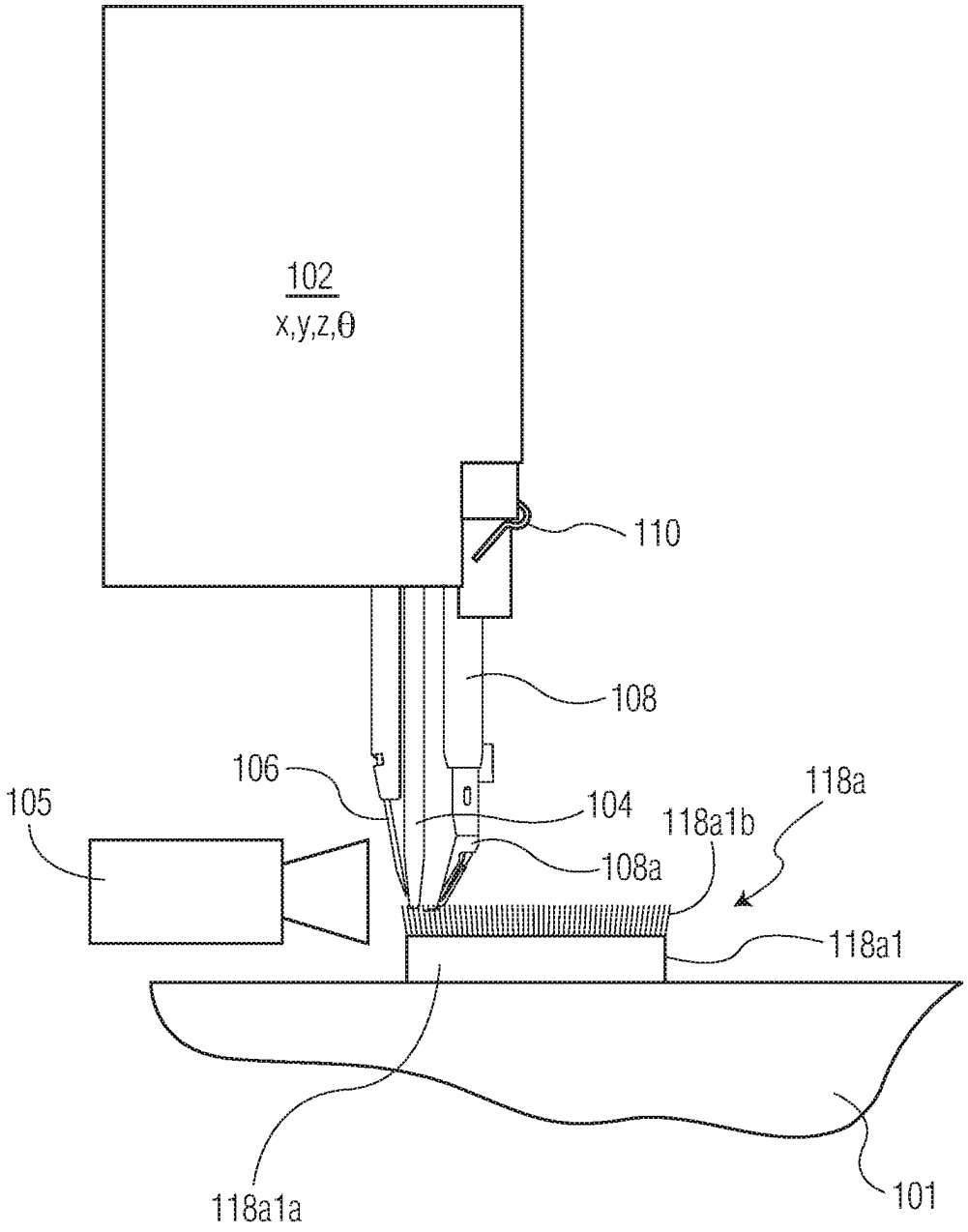


FIG. 3D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x,y,z,θ
110
108
106
105
104
118a
118a1b
108a
118a1
118a1a
101

FIG. 4A

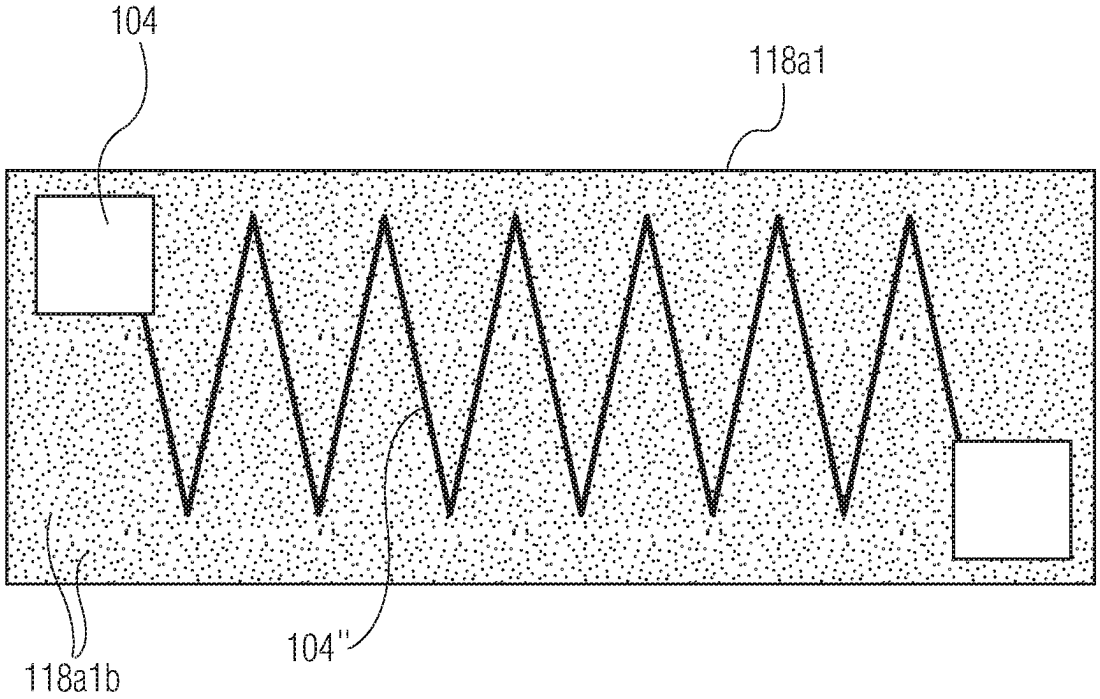
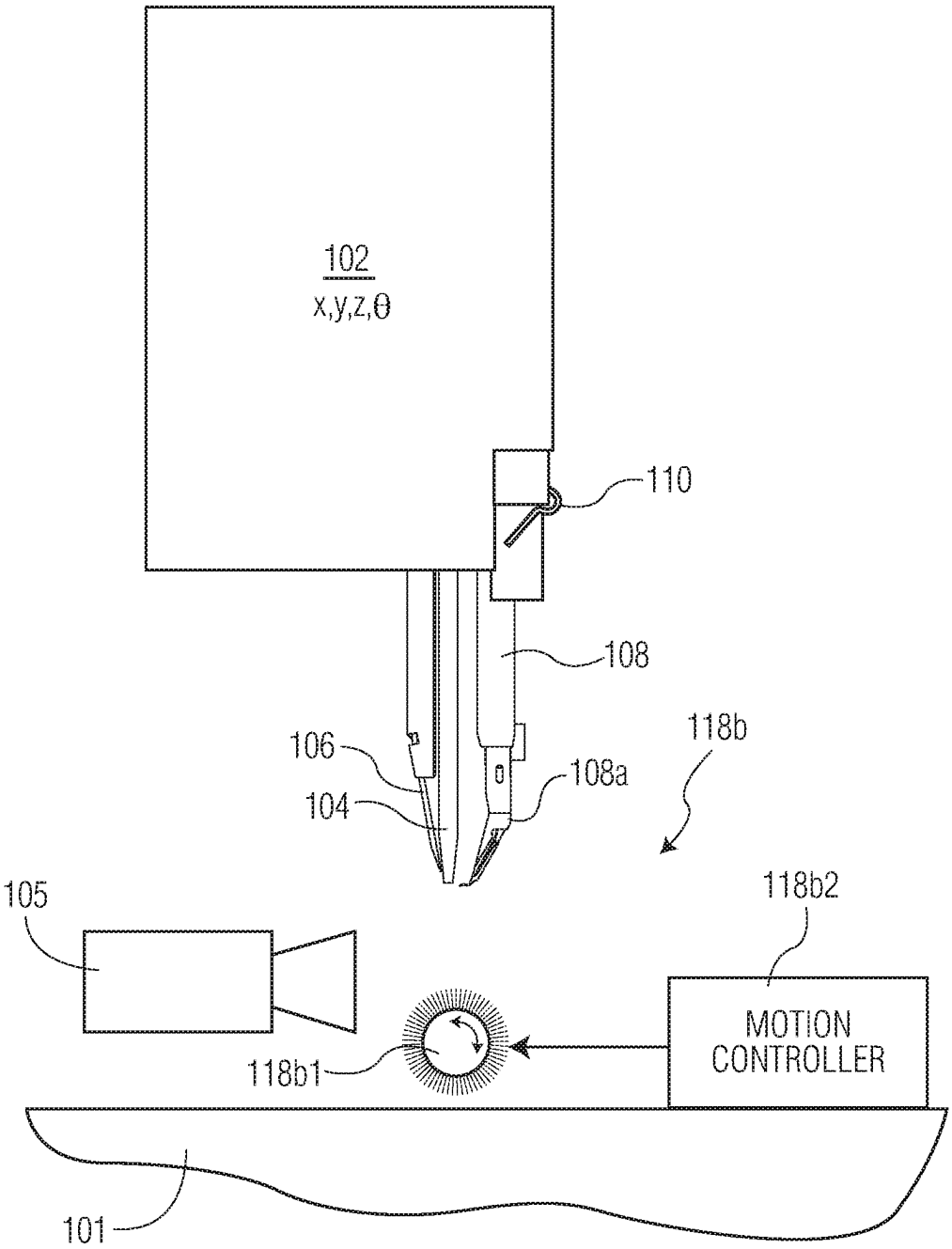


FIG. 4B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x,y,z,θ
110
108
106
104
108a
118b
105
118b2
MOTION CONTROLLER
118b1
101

FIG. 5A

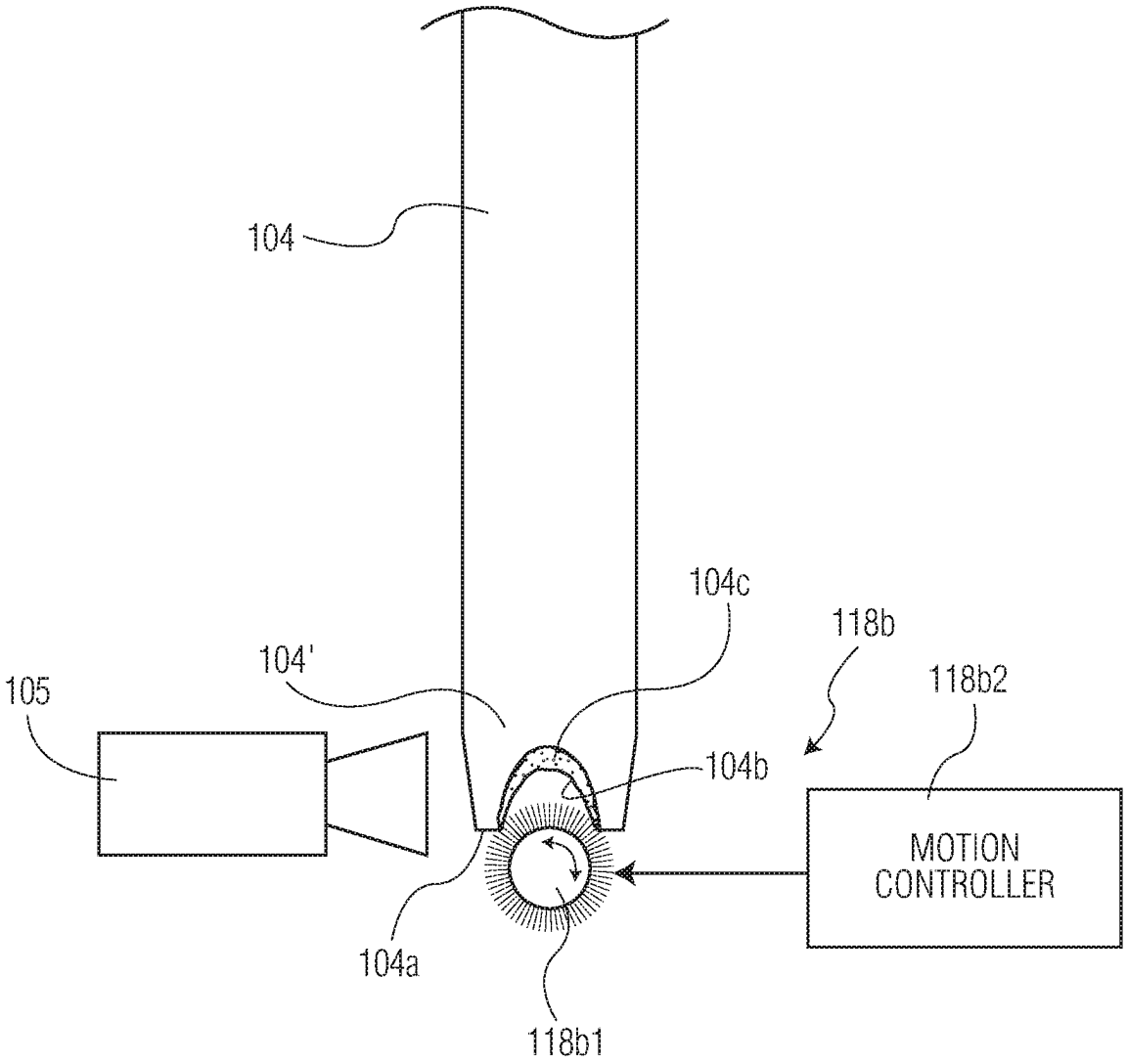

104
104c
118b
104'
118b2
105
104b
MOTION CONTROLLER
104a
118b1

FIG. 5B

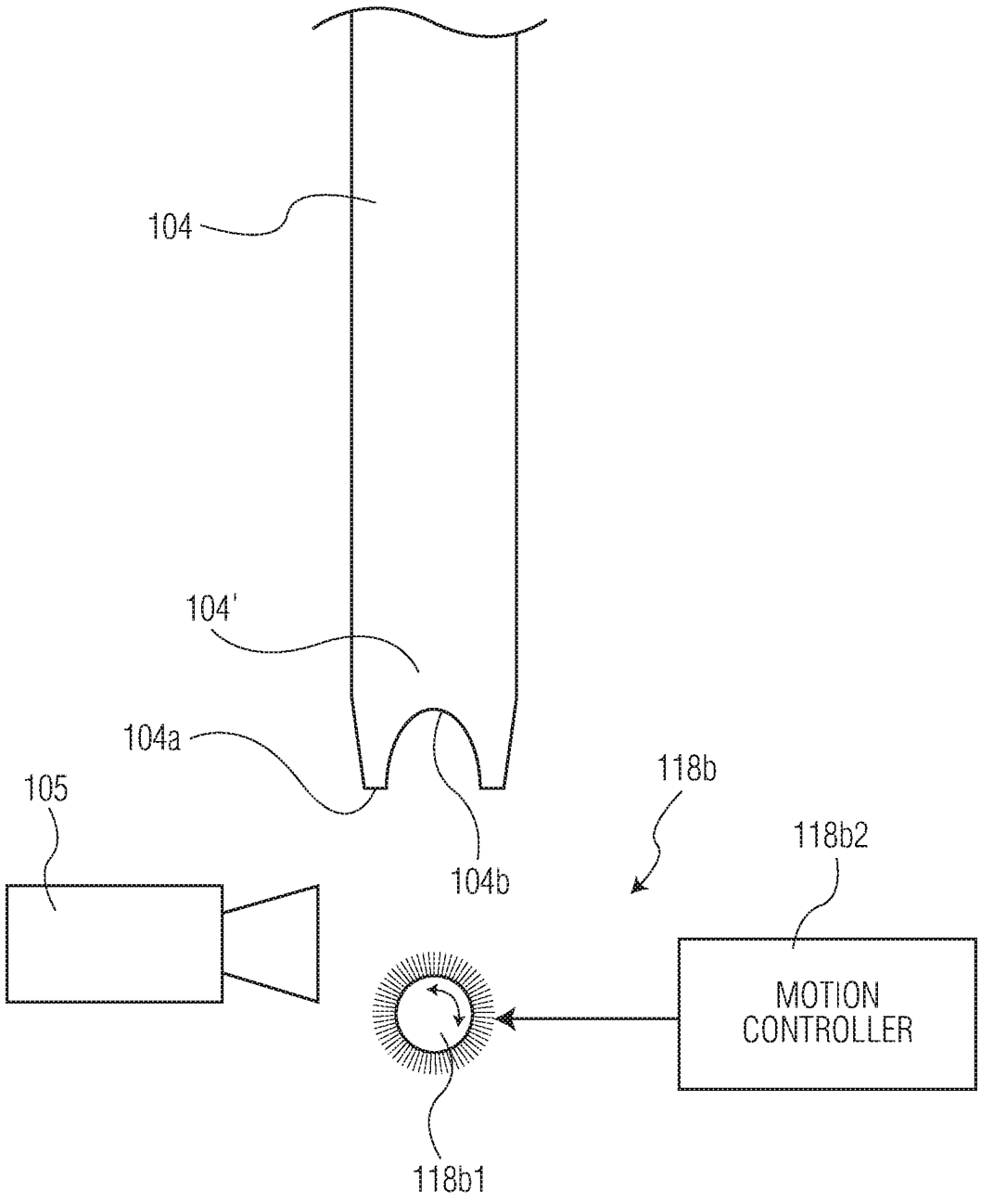


FIG. 5C

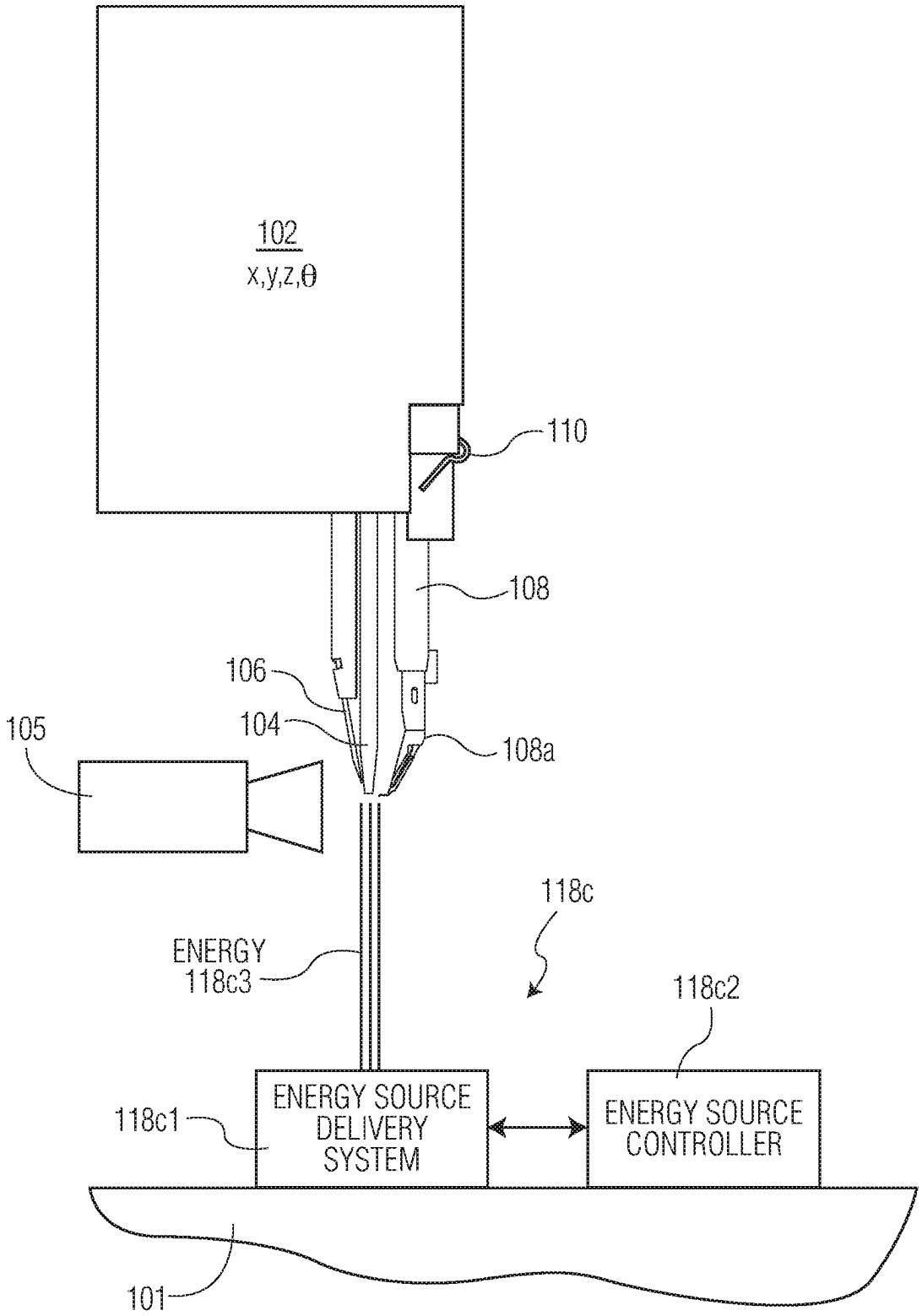

102
x,y,z,θ
110
108
106
104
105
108a
118c
ENERGY
118c3
118c2
118c1
ENERGY SOURCE DELIVERY SYSTEM
ENERGY SOURCE CONTROLLER
101

FIG. 6

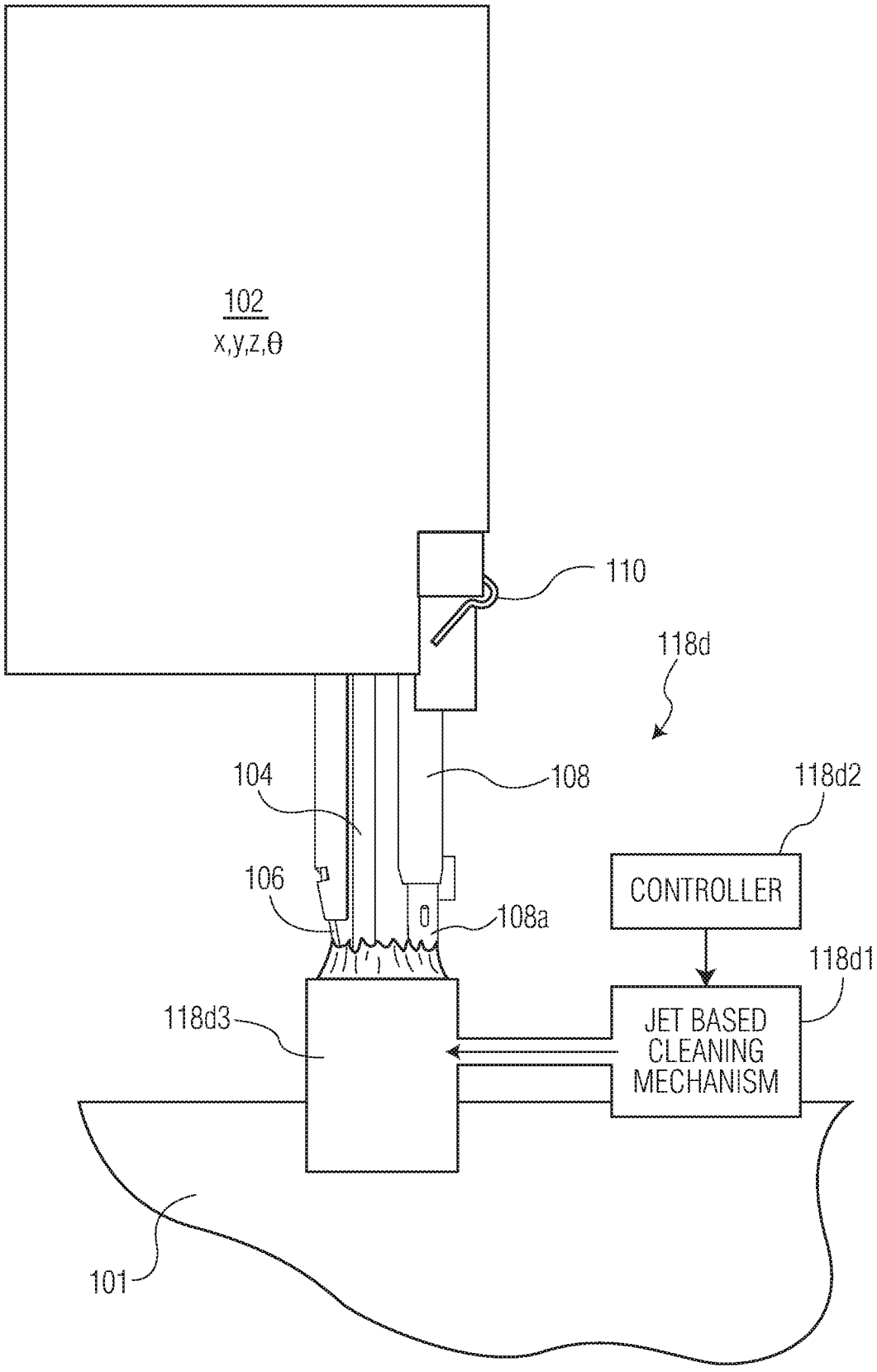

102
x,y,z,θ
110
118d
104
108
118d2
106
CONTROLLER
108a
118d1
118d3
JET BASED
CLEANING
MECHANISM
101

FIG. 7

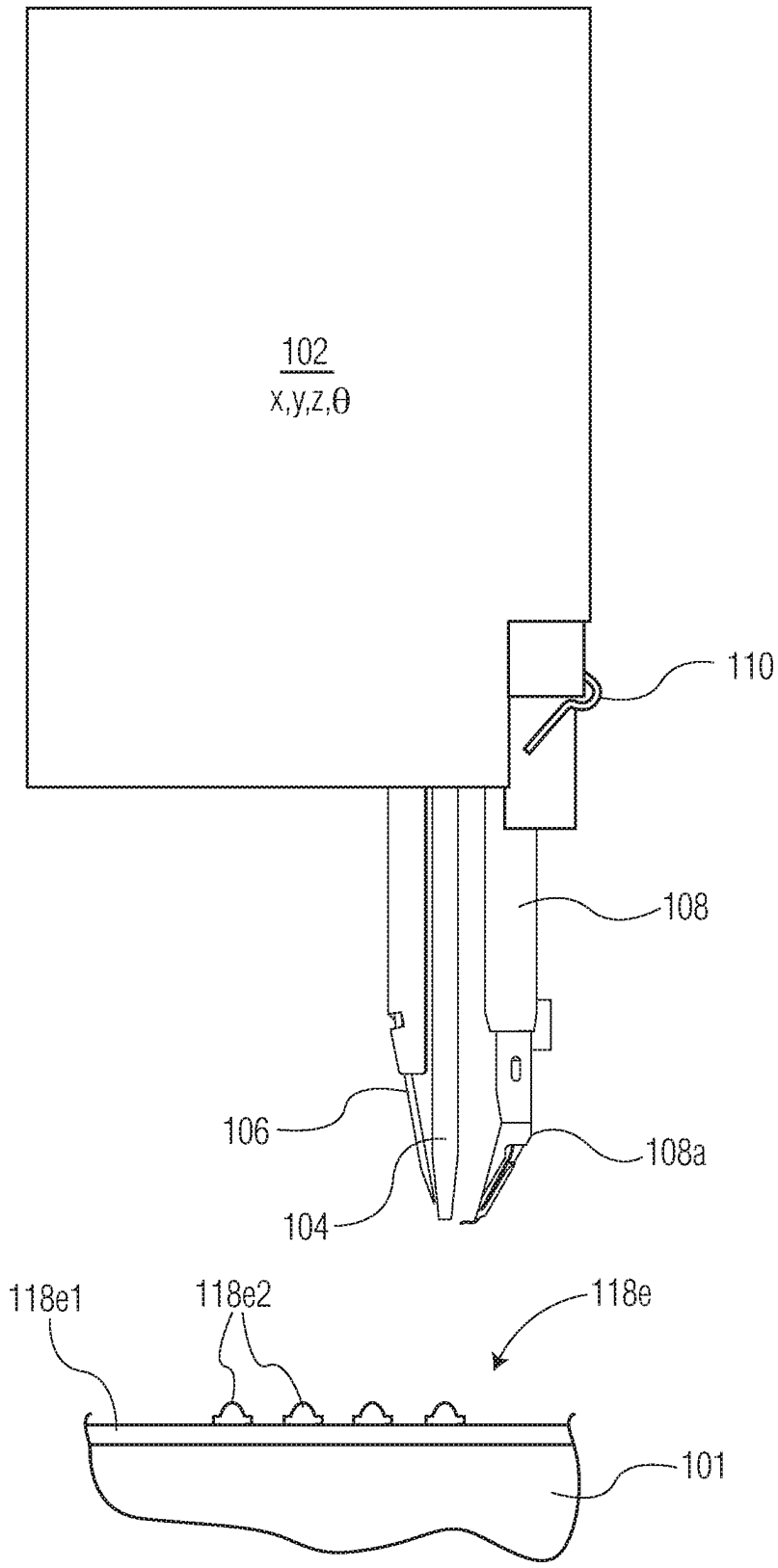


FIG. 8A

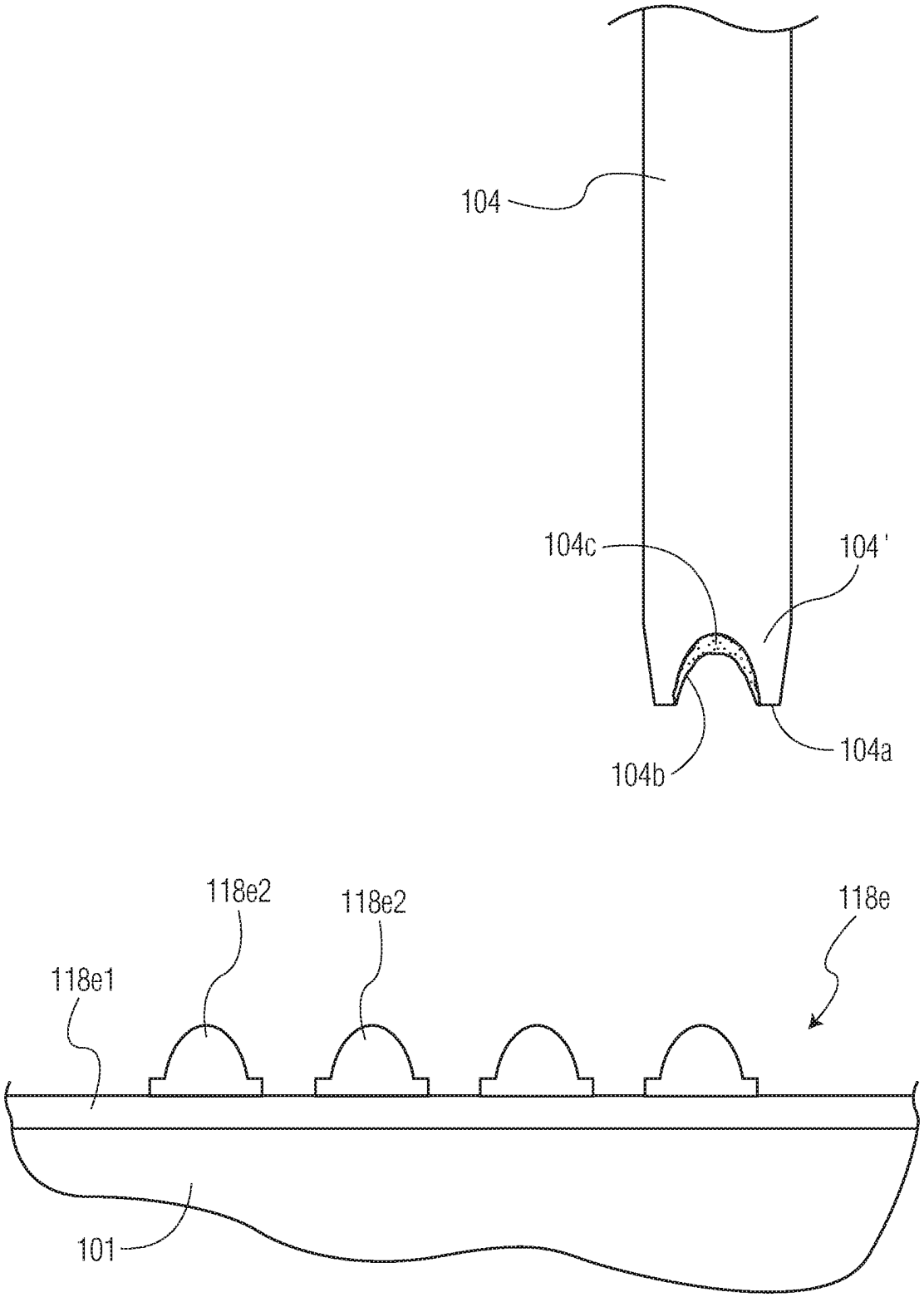


FIG. 8B

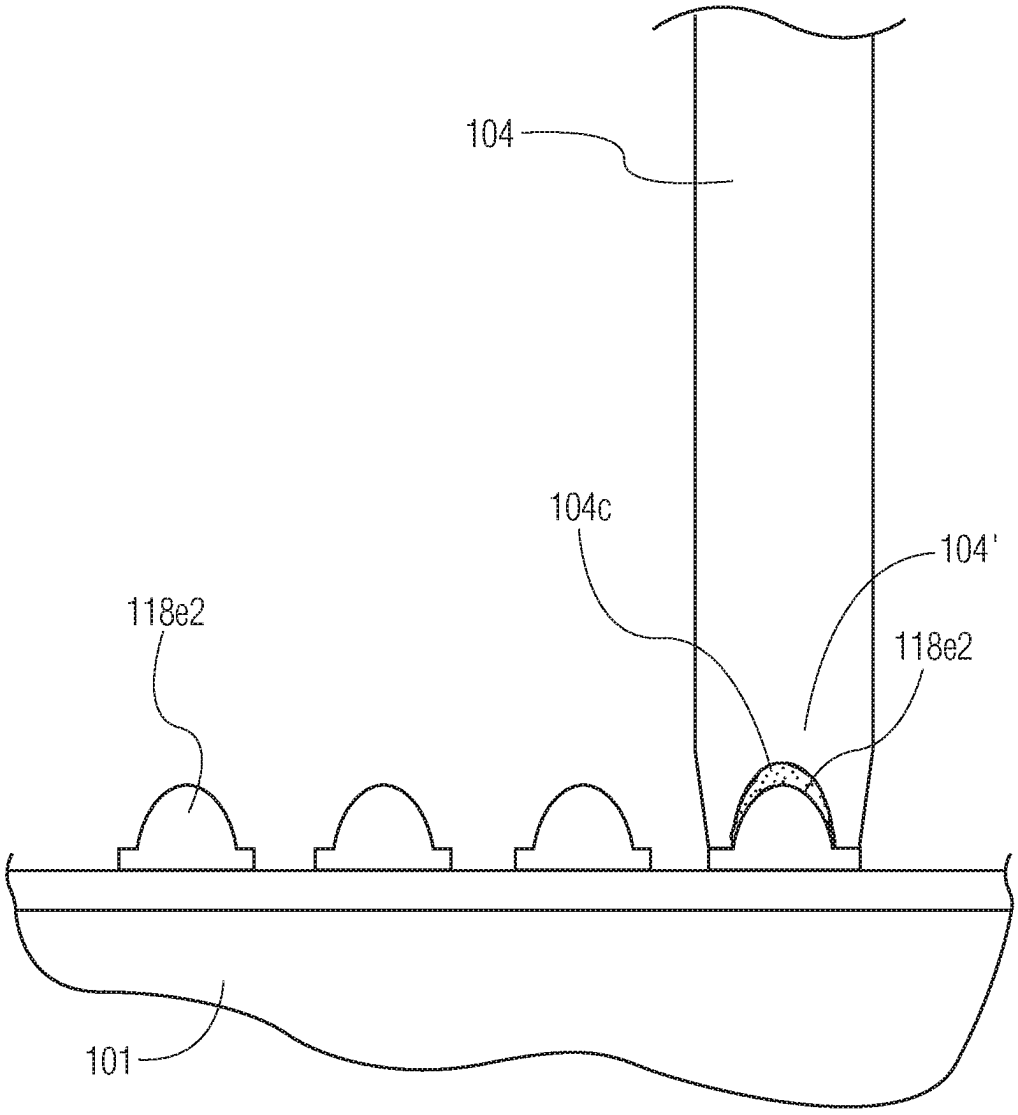


FIG. 8C

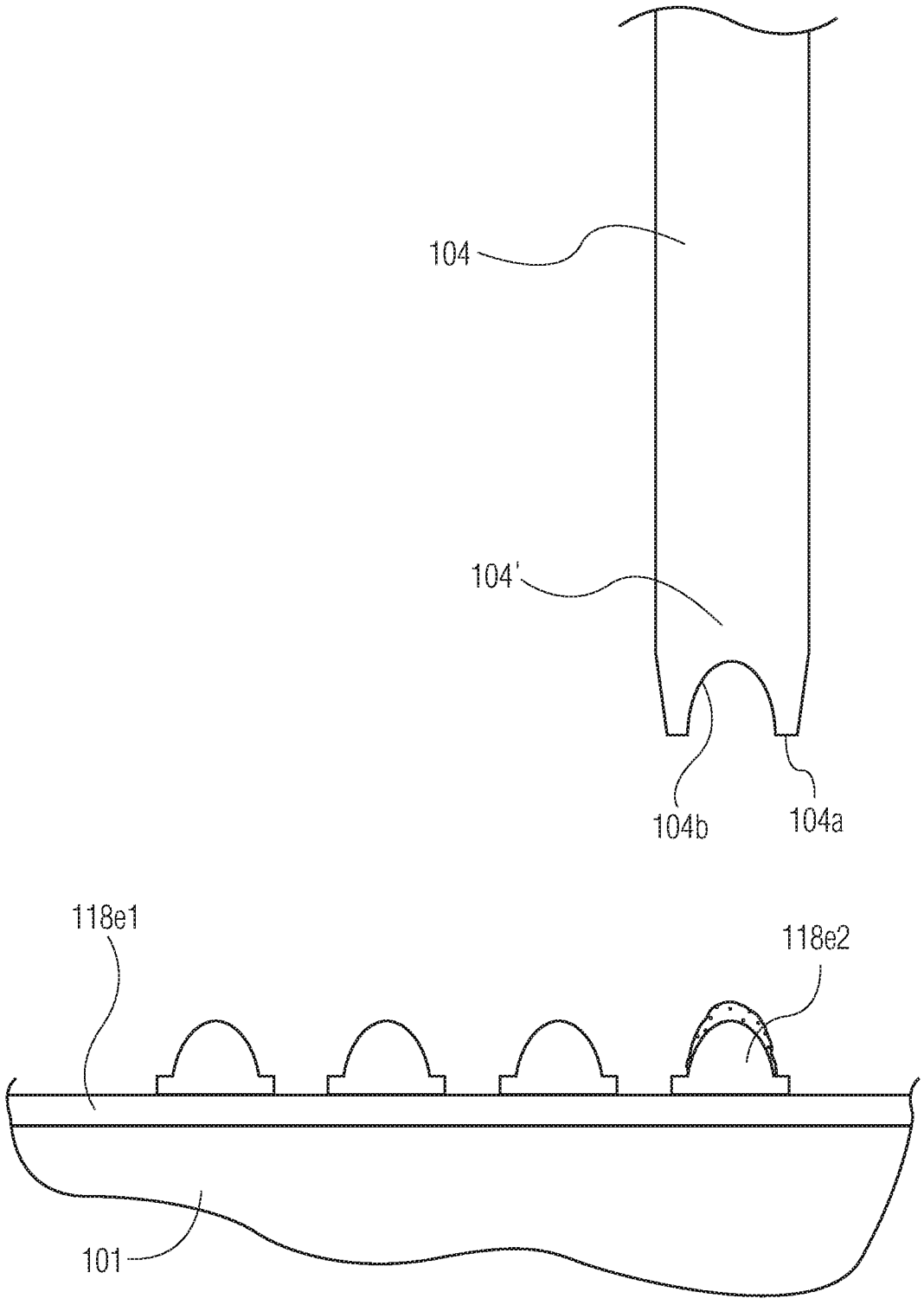


FIG. 8D

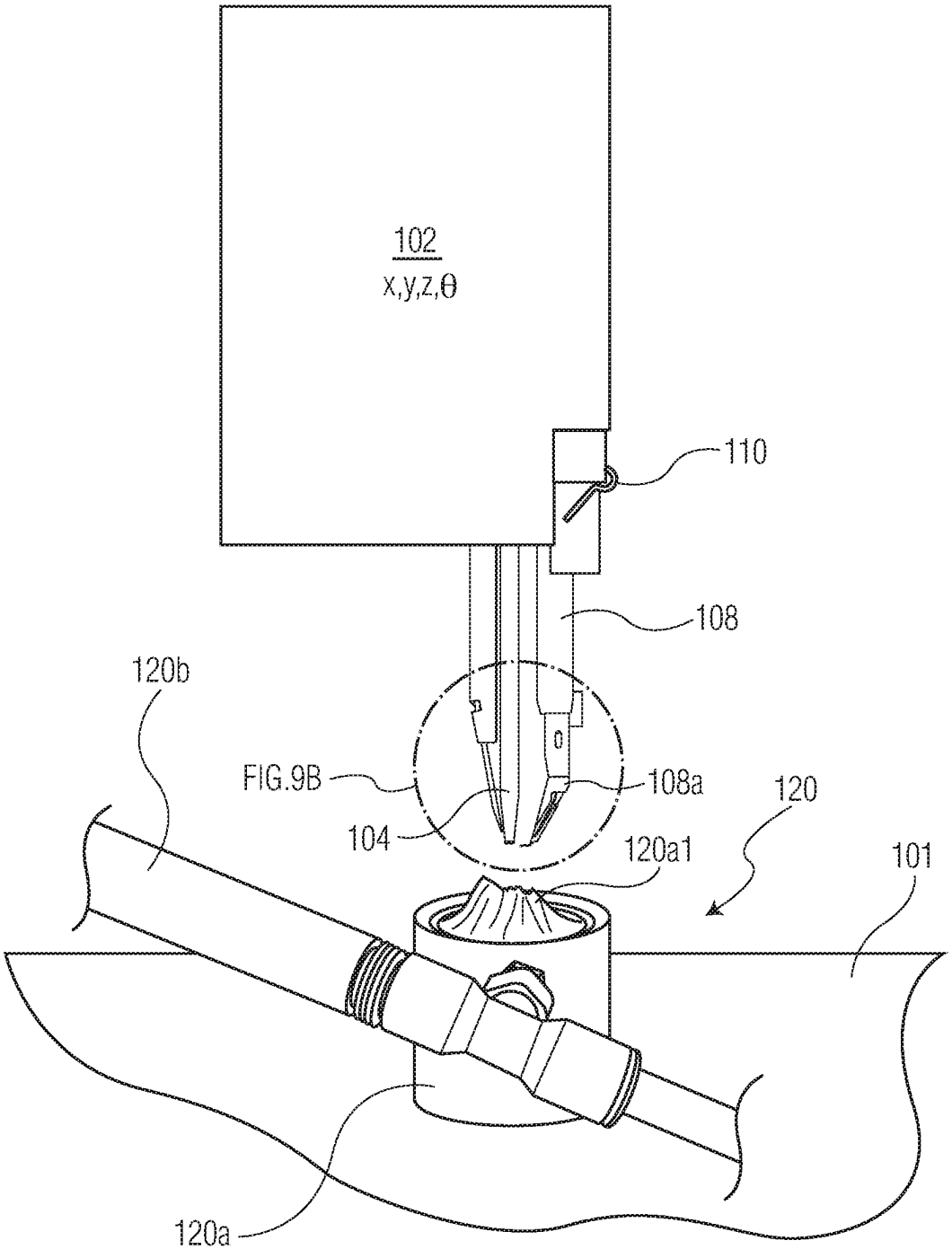


FIG. 9A

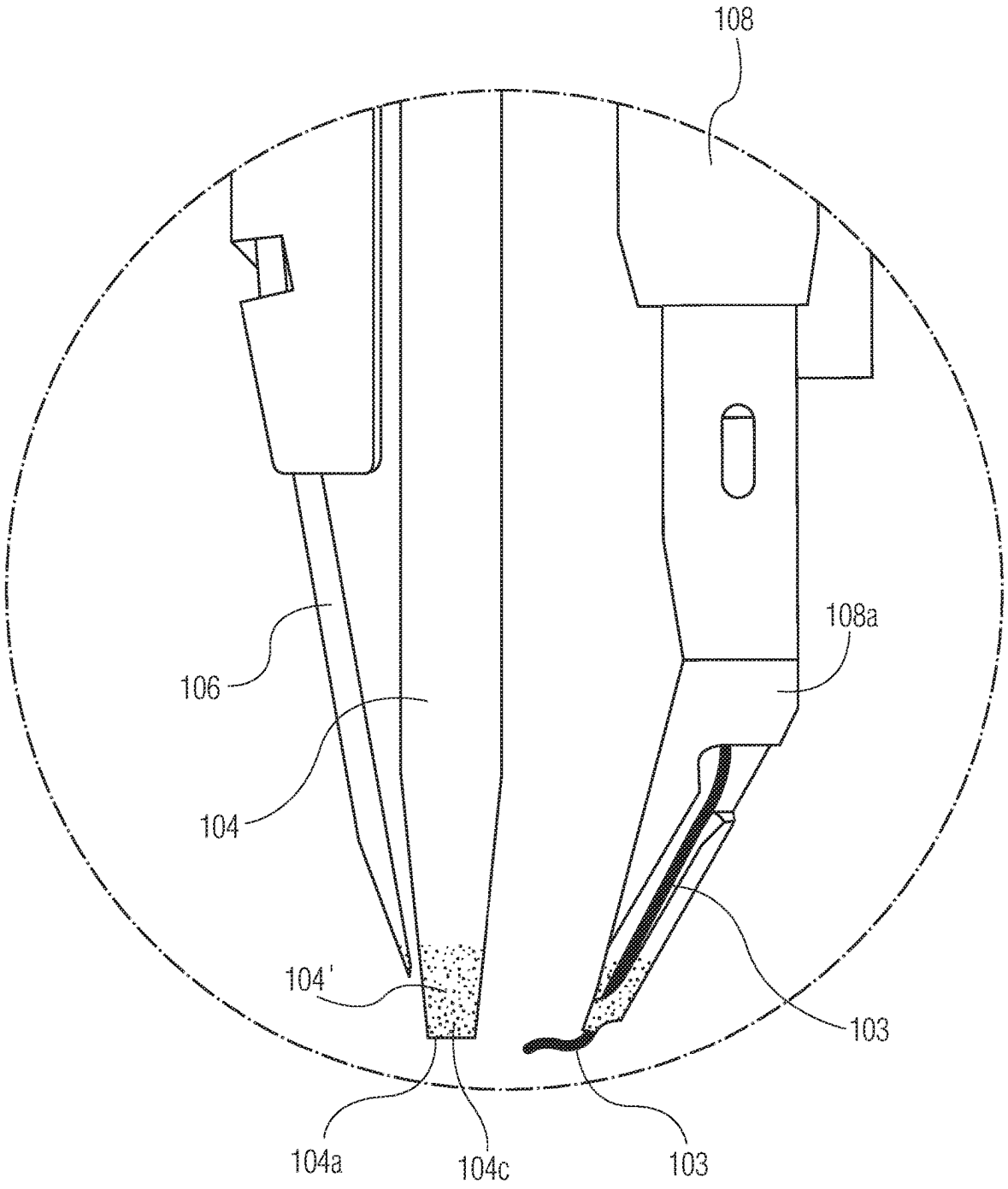


FIG. 9B

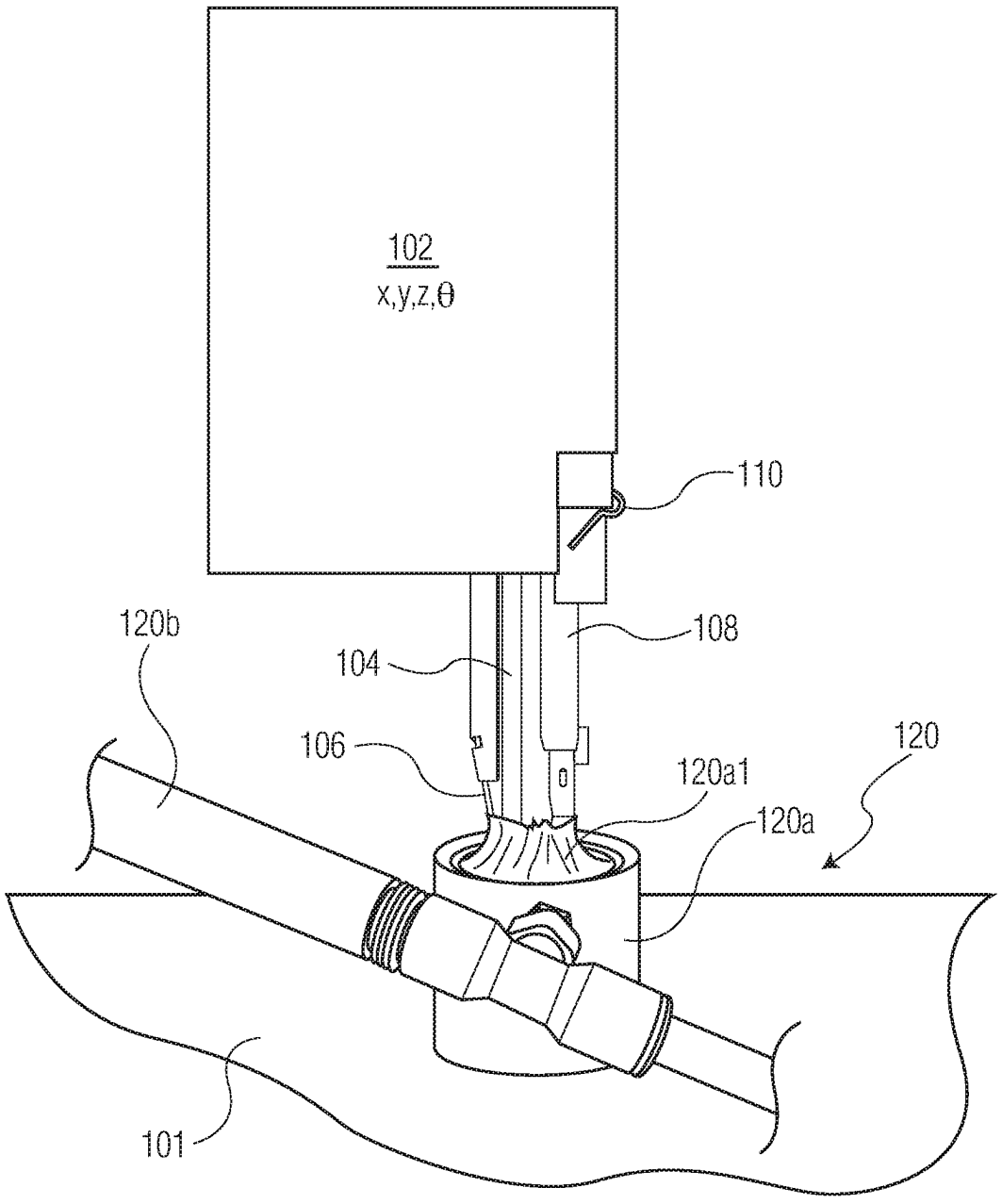


FIG. 9C

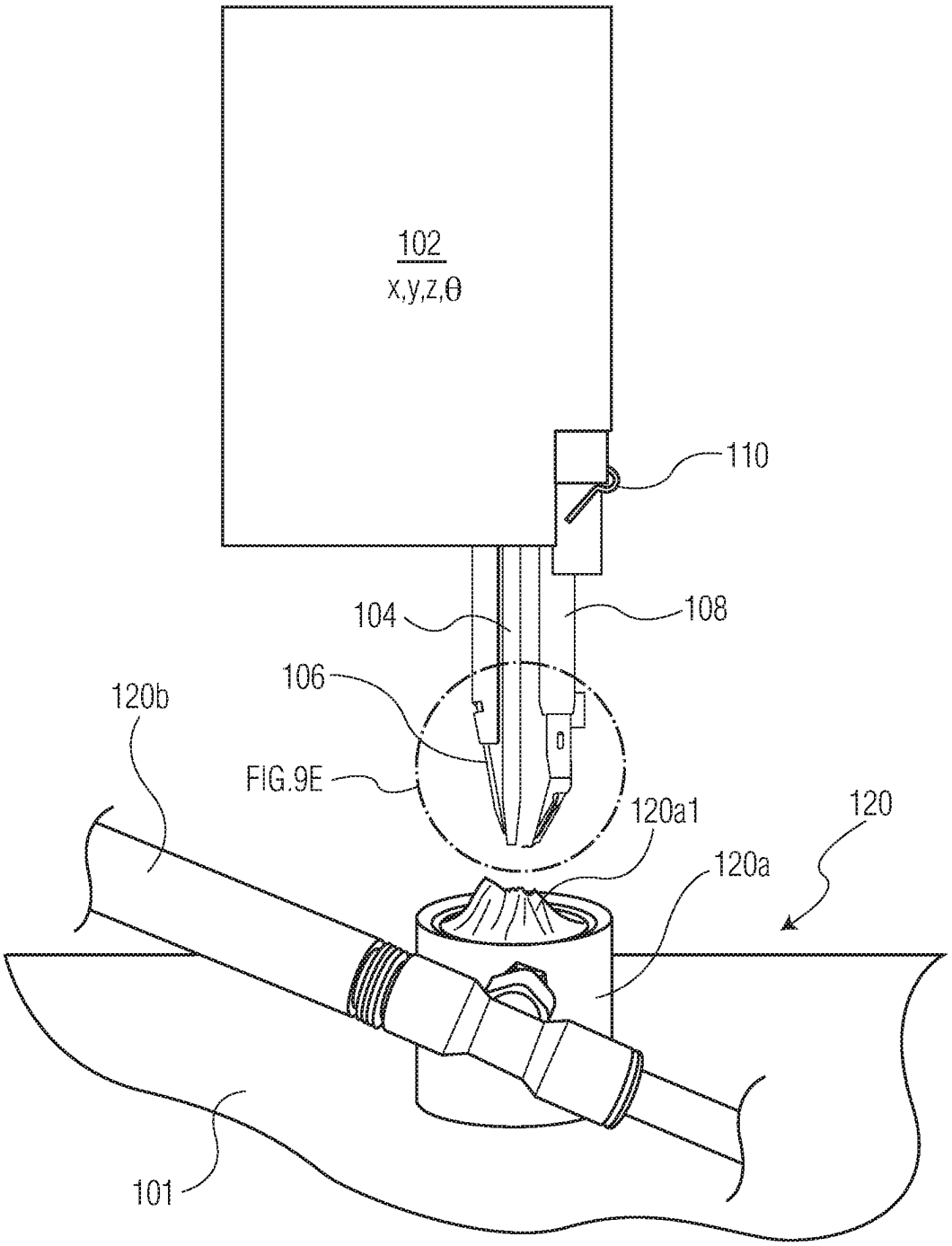


FIG. 9D

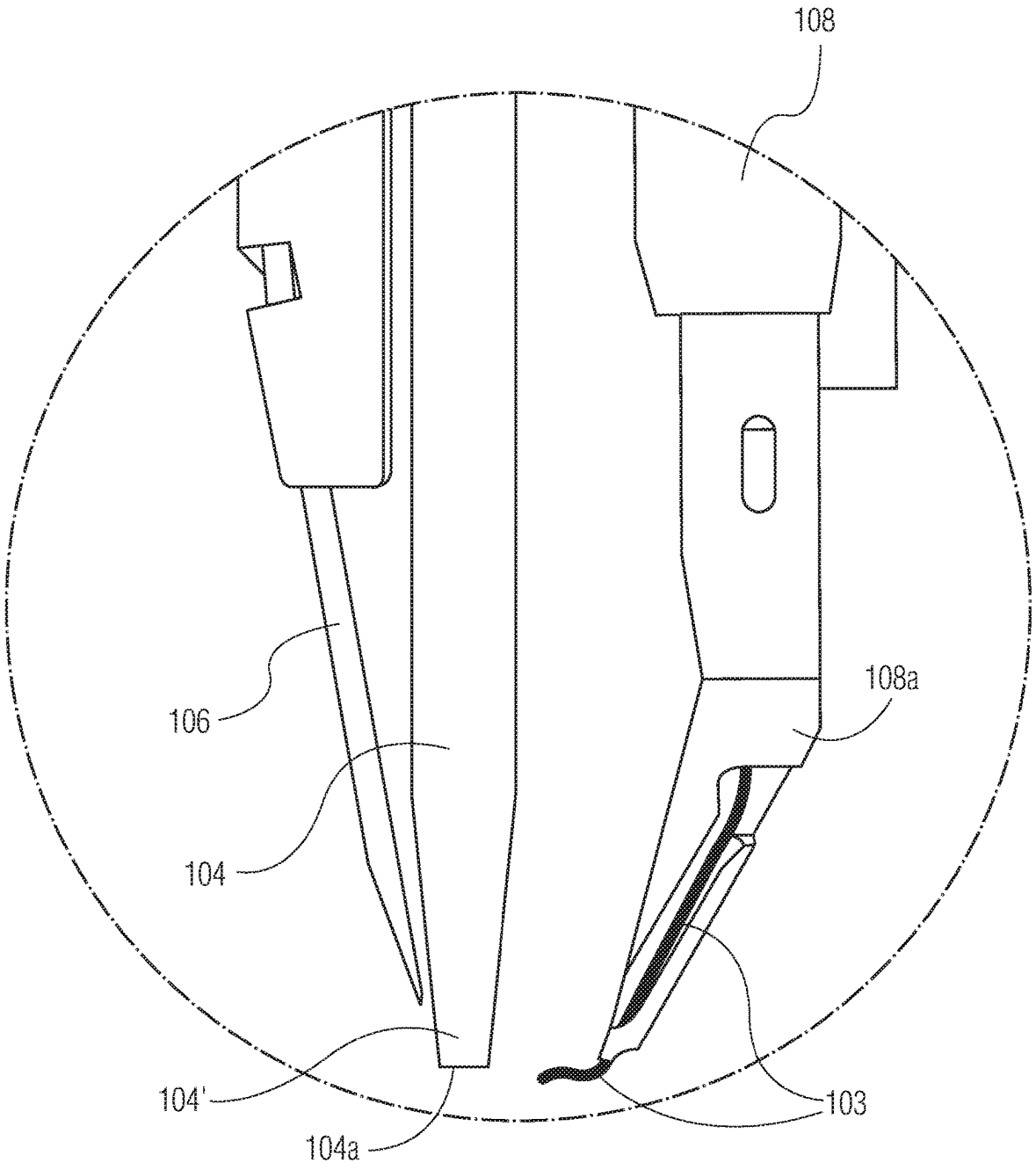


FIG. 9E

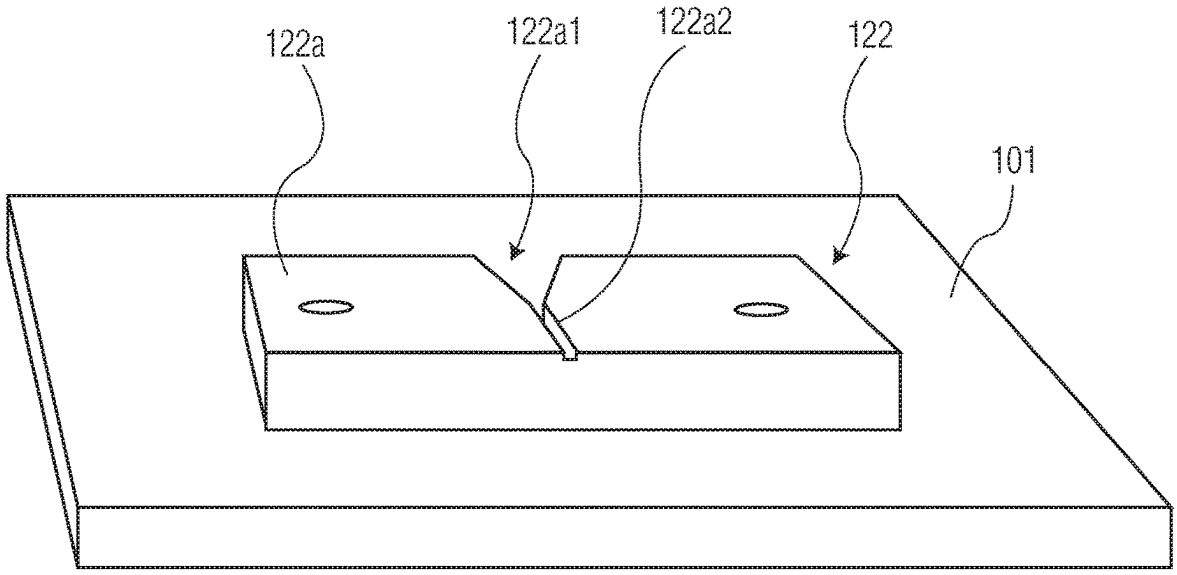


FIG. 10A

FIG. 10B

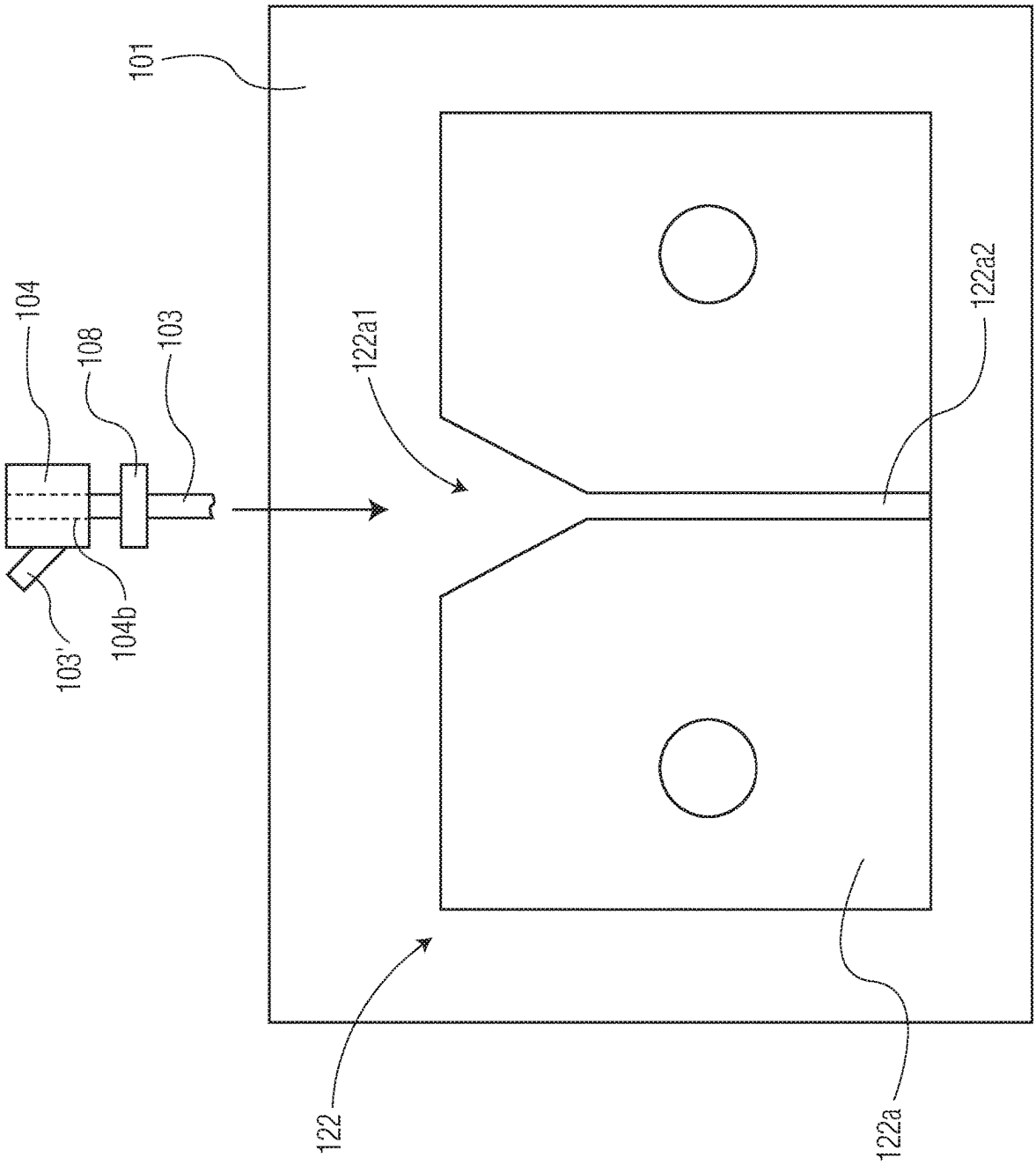


FIG. 10C

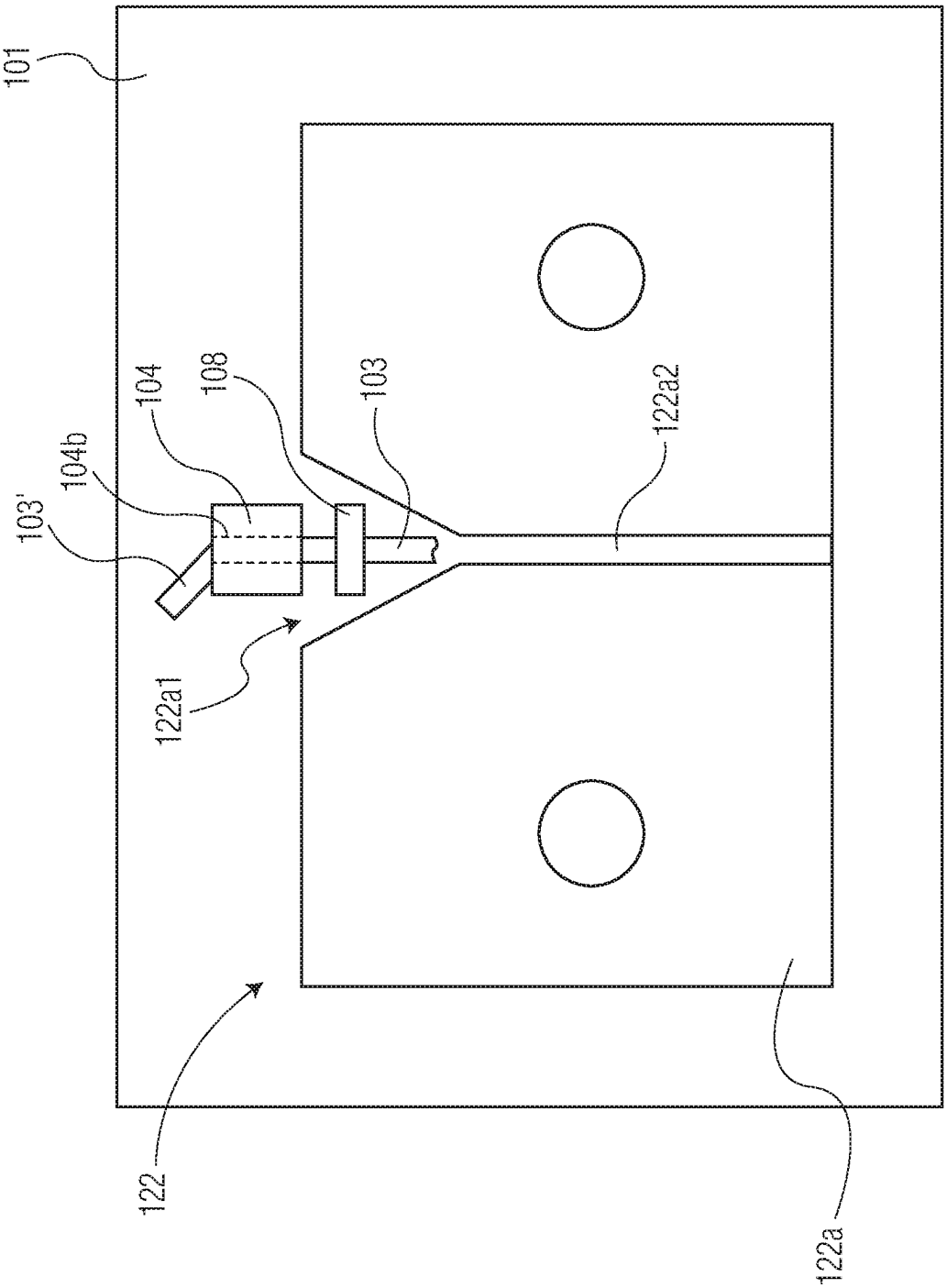
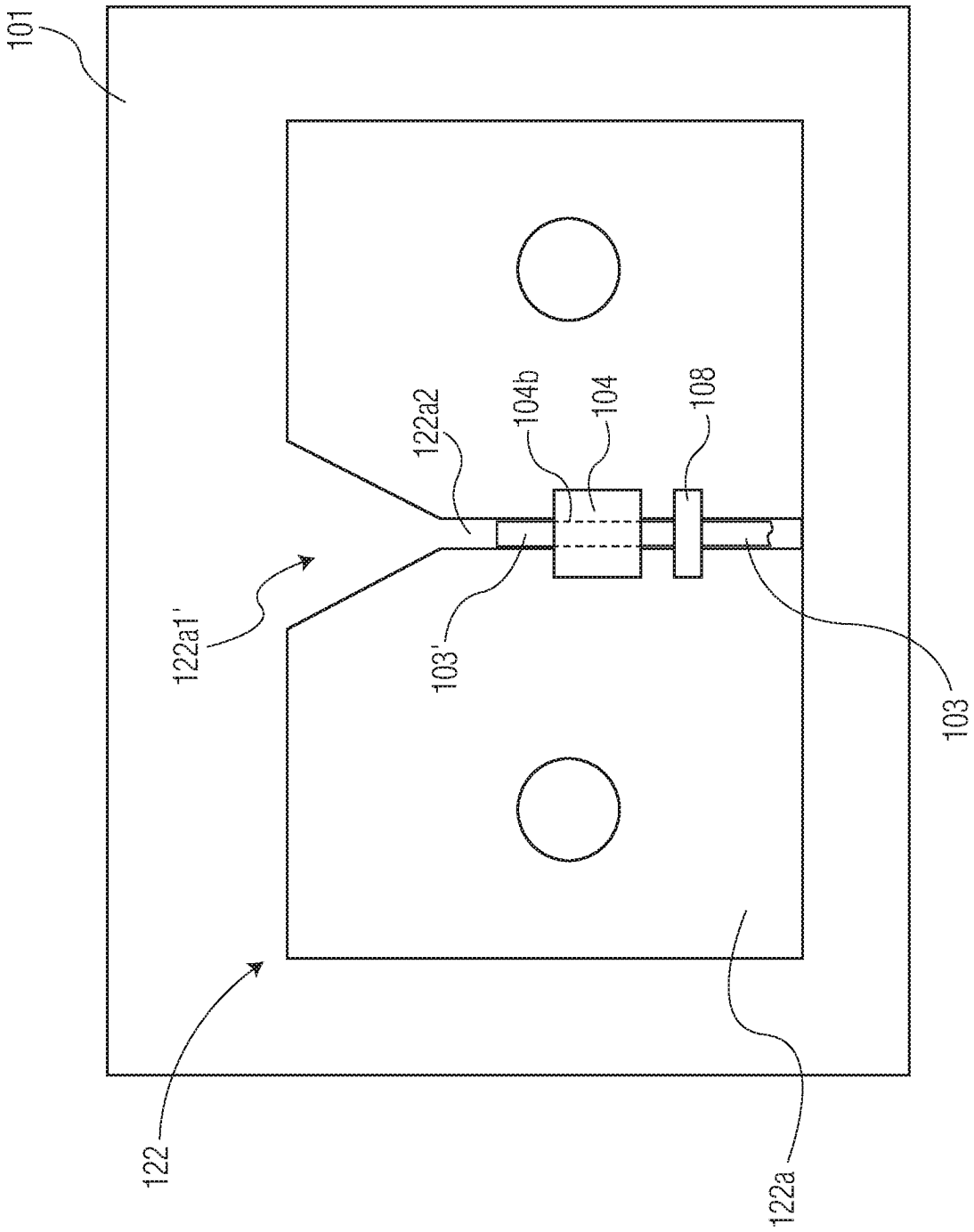


FIG. 10D



CLEANING SYSTEMS FOR WIRE BONDING TOOLS, WIRE BONDING MACHINES INCLUDING SUCH SYSTEMS, AND RELATED METHODS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 62/624,037 filed on Jan. 30, 2018, the content of which is incorporated herein by reference.

FIELD

The invention relates to the cleaning of wire bonding tools, and more particularly, to improved systems and methods for cleaning wire bonding tools on wire bonding machines.

BACKGROUND

In the semiconductor packaging industry, and other industries requiring electrical interconnection, wire and ribbon bonding are widely adopted technologies using a wire bonding machine. In connection with wire and ribbon bonding operations, various types of energy (e.g., ultrasonic energy, thermosonic energy, thermocompressive energy, etc.) are used to bond an end portion of wire/ribbon to a first bonding location. After a first bond is formed at the first bonding location, a length of wire/ribbon is extended to second bonding location, and then a second bond is formed at the second bonding location.

Exemplary conductive materials used for the wire/ribbon in conventional wire bonding (e.g., ball bonding, wedge bonding, ribbon bonding, etc.) include aluminum, copper, gold, among others.

A challenge in wire bonding is contamination of the wire bonding tool used in the wire bonding operation. For example, in wedge and ribbon bonding operations, the tool may become contaminated with bits of wire (e.g., aluminum wire). This contamination has an impact on the effectiveness of the wire bonding operation. Replacement and/or cleaning of the tool may result in operational delay and excessive costs.

Thus, it would be desirable to provide improved cleaning systems for wire bonding tools on wire bonding machines, improved wire bonding machines including such cleaning systems, and ribbon bonding tools, and improved methods of cleaning wire bonding tools on a wire bonding machines.

SUMMARY

According to an exemplary embodiment of the invention, a wire bonding machine is provided. The wire bonding machine includes: (a) a wire bonding tool; (b) a wire guide for guiding a wire to a position beneath a bonding surface of the wire bonding tool, the wire guide being configured for movement between (i) an engagement position with respect to the wire bonding tool (e.g., see FIG. **3**B) and (ii) a non-engagement position with respect to the wire bonding tool (see FIG. **3**D); and (c) a cleaning station for cleaning at least a portion of a tip of the wire bonding tool when the wire guide is in the non-engagement position. The engagement position is a position whereby the wire guide guides an end portion of wire to the position beneath the bonding (working) surface of the wire bonding tool. The non-engagement position is a position whereby the wire guide has been moved away from (e.g., swiveled away from) the engagement position.

According to another exemplary embodiment of the invention, a wire bonding machine is provided. The wire bonding machine includes: (a) a wire bonding tool; and (b) a cleaning station for cleaning the wire bonding tool, the cleaning station including at least one brush, wherein the at least one brush includes a stationary brush on the wire bonding machine, and wherein the wire bonding tool is configured to be moved such that a tip of the wire bonding tool is in contact with the stationary brush during a cleaning operation.

According to yet another exemplary embodiment of the invention, a method of cleaning a tip of a wire bonding tool on a wire bonding machine is provided. The method includes the steps of: (a) moving a wire away from the wire bonding tool such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine; and (b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a).

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawings. It is emphasized that, according to common practice, the various features of the drawings are not to scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawings are the following figures:

FIG. **1** is a block diagram view of elements of a wire bonding machine in accordance with an exemplary embodiment of the invention;

FIGS. **2**A-**2**C are block diagrams illustrating a bond off station of a wire bonding machine in accordance with an exemplary embodiment of the invention;

FIGS. **3**A-**3**D are block diagrams illustrating a separation station of a wire bonding machine in accordance with an exemplary embodiment of the invention;

FIGS. **4**A-**4**B are block diagrams illustrating a cleaning station of a wire bonding machine in accordance with an exemplary embodiment of the invention;

FIGS. **5**A-**5**C are block diagrams illustrating another cleaning station of a wire bonding machine in accordance with another exemplary embodiment of the invention;

FIG. **6** is a block diagram illustrating yet another cleaning station of a wire bonding machine in accordance with another exemplary embodiment of the invention;

FIG. **7** is a block diagram illustrating yet another cleaning station of a wire bonding machine in accordance with another exemplary embodiment of the invention;

FIGS. **8**A-**8**D are block diagrams illustrating yet another cleaning station of a wire bonding machine in accordance with another exemplary embodiment of the invention;

FIGS. **9**A-**9**E are block diagrams illustrating a discard station of a wire bonding machine in accordance with an exemplary embodiment of the invention; and

FIGS. **10**A-**10**D are block diagrams illustrating a realignment station of a wire bonding machine in accordance with an exemplary embodiment of the invention.

DETAILED DESCRIPTION

As used herein, the term "wire bonding tool" may refer to any type of tool used to bond a portion of wire against a workpiece. Exemplary wire bonding tools include wedge

bonding tools (sometimes referred to as wedge tools, or wedges), ball bonding tools (sometimes referred to as capillary tools or capillaries), and ribbon bonding tools. Thus, the term "wire bonding machine", as recited herein, may refer to wedge bonding machines, ball bonding machines, ribbon bonding machines, stud bumping machines, etc.

In accordance with exemplary aspects of the invention, tool buildup (e.g., debris, contaminants, etc.) may be removed from the tool tip of a wire bonding tool by one of plurality of exemplary inventive cleaning sequences. Such a cleaning sequence may be automatic (e.g., triggered by the occurrence of a predetermined event, such as completion of a predetermined time interval or a predetermined number of operations or triggering of process signals). Alternatively, the cleaning sequence may be user-triggered.

A specific exemplary sequence is as follows: the bonding tool is moved (e.g., using the bond head assembly) to a wire handling location; the wire is moved away from the wire bonding tool (e.g., either manually or automatically); and the wire bonding tool is moved to a cleaning station of the wire bonding machine (e.g., where the cleaning station may include one or more brushes, a laser, a pre-form, among other mechanisms). At the cleaning station, a portion of the wire bonding tool (e.g., the tip portion, including the working surface of the wire bonding tool) is cleaned using the cleaning station.

In the case of a brush, the wire bonding tool may be moved to a location on top of the brush. The wire bonding machine may determine a "first touch" position. After determining the "first touch" position, the wire bonding tool is is lowered in the Z-direction by a certain distance or until a certain force is measured. The wire bonding machine performs brushing motions of the tool against the brush (e.g., zig-zag motions or some other predetermined motion profile), for example, until a certain time or number of brush moves have been completed. It is noteworthy that the motions may be completed by the wire bonding tool, the brush, or both.

After cleaning (and regardless of which type of cleaning station is used), the wire bonding tool may be moved to an inspection location on the wire bonding machine where the level of cleanliness of the wire bonding tool tip may be evaluated (e.g., manually by an operator, automatically using a vision system and a computer, etc.).

After cleaning, and optional inspection, the wire bonding tool may then move to a wire handling location, and the wire is moved back in position in connection with the wire bonding tool (e.g., under the tool tip or working face of the wire bonding tool). A manual or automated bond off (e.g., a single-bond including a pull-test) may be performed at a bond-off location of the wire bonding machine. If it is determined that the wire bonding tool has been properly cleaned (or if no check inspection is completed) the wire bonding machine may then return to production.

Throughout the various drawings, like reference numerals refer to the like elements, except where explained herein.

Referring specifically to FIG. **1**, a block diagram of a wire bonding machine **100** is provided. Wire bonding machine **100** is exemplary in nature, and the invention is not limited to the details shown in FIG. **1**. For example, FIG. **1** illustrates a specific type of wire bonding tool (a wedge bonding tool for ultrasonic wedge bonding) and bond head elements; however, the invention is not limited to this specific type of wire bonding tool or bond head elements. Further, FIG. **1** illustrates a plurality of "stations" of wire bonding machine **100**. It is understood that the invention does not require each of these stations. Rather, selected ones of these stations (or other stations or mechanisms within the scope of the invention) may be selected for a given application. Further, the stations are not limited to use in the order shown. Rather, a station (e.g., an inspection station) may be used at any time during the proces as desired.

Wire bonding machine **100** includes a bond head assembly **102**. Bond head assembly **102** carries wire bonding tool **104**, cutter **106** (for cutting wire), and wire guide assembly **108** (including wire guide **108***a*, shown, for example, in FIG. **2**A). Wire **103** (e.g., see FIG. **2**A) is guided by wire guide assembly **108** to a position beneath a bonding surface of wire bonding tool **104**. Bond head assembly **102** also carries locking mechanism **110** (explained in greater detail below). Bond head assembly **102** is configured for motion along the x-axis of wire bonding machine **100**, along the y-axis of wire bonding machine **100**, along the z-axis of wire bonding machine **100**, and about the theta axis of wire bonding machine **100**. Thus, wire bonding tool **104** may be moved along (and about) these axes as is desired in connection with the cleaning operations (and related operations) described herein.

Wire bonding machine **100** includes bonding area **112**. At bonding area **112**, wire bonding tool **104** bonds wire **103** (e.g., see FIG. **2**A) to provide electrical interconnections for the given application. In the example shown in FIG. **1**, bonding wire **103** will be bonded between first workpiece **112***a* (e.g., a semiconductor element, such as a semiconductor die) and second workpiece **112***b* (e.g., a substrate, such as a leadframe, another semiconductor element, etc.).

As shown in FIG. **1**, wire bonding machine **100** includes bond off station **114**, separation station **116**, cleaning station **118**, discard station **120**, realign station **122**, and inspection station **124**. Examples of various of these "stations" are provided throughout the subsequent drawings. It will be appreciated that the term "station" shall be broadly defined as an area of the wire bonding machine adapted for a specific function/operation.

Referring now to FIGS. **2**A-**2**C, a "bond off process" is illustrated. In connection with the cleaning of a wire bonding tool, it is desirable to have access to the bonding surface at the tip of the wire bonding tool. So the wire needs to be moved away from the working surface. An exemplary approach to this process is described in connection with FIGS. **3**A-**3**D. However, sometimes additional clearance between the working surface of the tip and the end portion of the wire is desirable. This specifics of this additional clearance depend on the specific type of cleaning operation. For example, it may be desirable to have the end portion of the wire bent to one side or the other of the working surface. In another example, it may be desirable to have the end portion of the wire bent downward away from the working surface. In any event, it may be desirable to establish some additional level of clearance between the working surface of the tip of the wire bonding tool and the end portion fo the wire. In accordance with exemplary aspects of the invention, use of bond off station **114** may be used to provide such additional clearance.

In connection with bond off station **114**, an end portion of wire is "bonded" (e.g., ultrasonically bonded) to a substrate provided at the bond off station **114**. Then, after the bonding, the wire is torn (or otherwise separated) from the bonded end portion of the wire. The motions of bond head assembly **102**, in connection with this tearing operation, will establish a bend (or other change) in the end portion of the wire carried by wire guide assembly **108**. Referring specifically to FIG. **2**A, bond off subtrate **114***a* of bond off station **114** is carried by wire bonding machine support structure **101**. Bond off

substrate **114***a* may be considered a consummable substrate, in that after a number of "bond off" operations, bond off substrate **114***a* may be replaced.

Again referring to FIG. **2**A, an end portion of wire **103** is being ultrasonically bonded to bond off substrate **114***a*. FIG. **2**B is a simplified top view of this ultrasonic bonding (with certain elements removed for clarity). After the bonding shown in FIGS. **2**A-**2**B, wire **103** is torn (or otherwise separated) from the last bonded end portion **103***a*, based on the motions of bond head assembly **102**. The result is that, in FIG. **2**C, there is another separate bonded end portion **103***a* (now there are 4 bonded end portions **103***a*, as opposed to 3 bonded end portions **103***a* in FIG. **2**B), and a bent end portion **103***b* carried by wire guide assembly **108**. As shown in FIG. **2**C, because bent end portion **103***b* is offset from supply of wire **103** (and offset from groove **104***b* of wire bonding tool **104**, see FIG. **5**C for example of groove **104***b*), additional clearance toward the working surface of wire bonding tool **104** is provided. As mentioned above, the bond off process accomplished at bond off station **114** may result in the wire being bent (or otherwise offset from the supply of wire **103** from wire guide assembly **108**) in any direction desired given the specifics of the cleaning operation.

Regardless of whether bond off station **114** is utilized as in FIGS. **2**A-**2**C, it may be desirable to provide separation between an end portion of wire **103** and working surface **104***a* (e.g., see FIGS. **3**B and **3**D) of wire bonding tool **104**. FIGS. **3**A-**3**D illustrate an example of an exemplary separation station **116**. In order to provide separation between the end portion of wire **103** and working surface **104***a*, wire bonding machine **100** may be provided with a moveable (e.g., swivel based) wire guide assembly **108**. More specifically, wire guide assembly **108** may be swiveled away from wire bonding tool **104** to provide the desired separation. The action of wire guide assembly **108** may be automatic (or automated) or may be manual. In the case of automated movement of wire guide assembly **108** away from wire bonding tool **104**, the movement may be provided by a mechanical interlock, a motion system (e.g., a motor, a cylinder, etc), etc. In the example shown in FIGS. **3**A-**3**D, an automated mechanical interlock is shown. Locking mechanism **110** locks wire guide assembly **108** in position with respect to wire bonding tool **104**. In order to enable the swivel action of wire guide assembly **108**, locking mechanism **110** must be actuated to the "unlock" position. Block portions **116***a* and **116***b* are provided in separation station **116**. Through movements of bond head assembly **102**, locking mechanism **110** is actuated through engagement with one or both of block portions **116***a* and **116***b*. Thus, by mechanical engagement of locking mechanism **110** with block portion **116***a* and/or **116***b* (through the motion of bond head assembly **102**), locking mechanism **110** is unlocked, and wire guide assembly **108** may move (e.g., swivel) away from wire bonding tool **104** (e.g., see FIGS. **3**C-**3**D). By mechanical re-engagement of locking mechanism **110** with block portion **116***a* and/or **116***b* (through the motion of bond head assembly **102**), locking mechanism **110** is re-locked, locking wire guide assembly **108** to its operational position with respect to wire bonding tool **104** (e.g., see FIGS. **3**A-**3**B). Of course, FIGS. **3**A-**3**D illustrate just one type of separation station **116**; alternative configurations are contemplated within the scope of the invention.

After the operations of bond off station **114** and/or separation station **116**, a tip portion **104'** (also referred to herein as a "tip" or "tool tip") of wire bonding tool **104** may be ready for cleaning at cleaning station **118** (e.g., see FIG. **1**). In accordance with the invention, various different types of cleaning stations **118** may be utilized. FIGS. **4**A-**4**B illustrate cleaning station **118***a*; FIGS. **5**A-**5**C illustrate cleaning station **118***b*; FIG. **6** illustrate cleaning station **118***c*; FIG. **7** illustrate cleaning station **118***d*; and FIGS. **8**A-**8**D illustrate cleaning station **118***e*. Any of cleaning stations **118***a*, **118***b*, **118***c*, **118***d*, and **118***e* (and any other cleaning station within the scope of the invention) may be used as cleaning station **118** in FIG. **1**.

Referring specifically to FIG. **4**A, cleaning station **118***a* includes at least one brush **118***a***1**. Brush **118***a***1** may be a stationary brush (as described below), or may be a moveable brush (moved with a motion system, not shown). Brush **118***a***1** includes bristles **118***a***1***b* held together by bound portion **118***a***1***a*. Brush **118***a***1** is supported by wire bonding machine support structure **101**. Cleaning station **118***a* also includes debris collection system **105**. For example, debris collection system **105** may be a vacuum based system for collecting debris (e.g., debris released from wire bonding tool **104**, debris resulting from broken bristles **108***a***1***b*, etc.) resulting from cleaning of wire bonding tool **104** at cleaning station **118***a*. Alternative types of debris collection systems (e.g., magnetic systems for attracting ferrous debris, vessels for at least partially surrounding the cleaning operation for collecting debris, etc.) are contemplated within the scope of the invention.

Bond head assembly **102** moves wire bonding tool **104** into a position such that working surface **104***a* of tip **104'** of wire bonding tool **104** is in contact with bristles **118***a***1***b* of brush **118***a***1**. While tip **104'** of wire bonding tool **104** is in contact with bristles **118***a***1***b* of brush **118***a***1**, bond head assembly **102** follows a predetermined motion profile for moving tip **104'** of wire bonding tool **104** with respect to brush **108***a***1**. For example, FIG. **4**B illustrates (from a simplified top view perspective) a predetermined motion profile including a zig-zag motion path **104"**. Of course, alternative predetermined motion profiles are contemplated within the scope of the invention.

In connection with a cleaning operation of tip **104'** of wire bonding tool **104** at cleaning station **118***a*, it may be desirable to use force control (e.g., closed loop control). Specifically, a force sensor (e.g., a load cell, etc., not shown) may be provided as part of bond head assembly **102**, or in relation to (e.g., below) brush **118***a***1**. Such a force sensor may be used to measure a force during the cleaning operation. Force data from the force sensor may be provided to a controller or other computer of wire bonding machine **100**. Thus, adjustments may be made to the cleaning operation in a closed loop force control mode, using the force data.

Referring specifically to FIG. **5**A, cleaning station **118***b* includes at least one brush **118***b***1**. Brush **118***b***1** is a rotary brush (e.g., a motor driven brush configured to be actuated in connection with a cleaning operation of wire bonding tool **104**), and is driven by motion controller **118***b***2**. FIG. **5**B illustrates wire bonding tool **104** rotated 90 degrees with respect to the position shown in FIG. **5**A (this change is arbitary, and is not required within the scope of the invention). FIG. **5**B illustrates debris **104***c* deposited within groove **104***b* of tip **104'** of wire bonding tool **104**. Brush **118***b***1** (including the illustrated bristles) is rotated and used to loosen debris **104***c* (see clean tool **104**, substantially without debris **104***c* in groove **104***b*, shown in FIG. **5**C). Debris collection system **105** is provided in cleaning station **118***b*. Debris collection system **105** may be a vacuum based system, or other type of collection system, for collecting debris (e.g., debris released from wire bonding tool **104**,

debris resulting from broken bristles of brush **118***b***1**, etc.) resulting from cleaning of wire bonding tool **104** with cleaning station **118***b*.

In connection with a cleaning operation of tip **104'** of wire bonding tool **104** at cleaning station **118***b*, it may be desirable to use force control (e.g., closed loop control). Specifically, a force sensor (e.g., a load cell, etc., not shown) may be provided as part of bond head assembly **102**, or in relation to (e.g., below) brush **118***b***1**. Such a force sensor may be used to measure a force during the cleaning operation. Force data from the force sensor may be provided to a controller or other computer of wire bonding machine **100**. Thus, adjustments may be made to the cleaning operation in a closed loop force control mode, using the force data.

Referring now to FIG. **6**, an energy based cleaning system **118***c* is illustrated. Cleaning station **118***c* includes an energy source delivery system **118***c***1** (e.g., a laser light source, another light source, a plasma source, a heat source, etc.), and an energy source controller **118***c***2** for controlling operation of energy source delivery system **118***c***1**. Through the operation of energy source delivery system **118***c***1**, energy **118***c***3** (e.g., laser light energy, other light energy, plasma energy, heat energy, etc.) is directed toward the working surface **104***a* of tip **104'** of wire bonding tool **104**. Debris collection system **105** is included in cleaning station **118***c*. Debris collection system **105** may be a vacuum based system, or other type of collection system, for collecting debris (e.g., debris released from wire bonding tool **104**, etc.) resulting from cleaning of wire bonding tool **104** with cleaning station **118***c*.

Referring now to FIG. **7**, an jet based cleaning system **118***d* is illustrated. Cleaning station **118***d* includes a jet based cleaning mechanism/source **118***d***1** (e.g., a gas pressure based cleaning mechanism for cleaning wire bonding tool **104**, a CO_2 based cleaning mechanism for cleaning wire bonding tool **104**, a sand blasting based cleaning mechanism for cleaning wire bonding tool **104**, a bead blasting based cleaning mechanism for cleaning wire bonding tool **104**, etc.), and a controller **118***d***2** for controlling operation of jet based cleaning mechanism/source **118***d***1**. Cleaning station **118***d* also includes vessel **118***d***3**. Through motions of bond head assembly **102**, a portion of wire bonding tool **104** (and perhaps other bond head elements such as a portion of wire guide assembly **108** and/or blade **106**) are brought into vessel **118***d***3** through an aperture thereof. Through the operation of jet based cleaning mechanism **118***d***1**, a jet (see the arrow-headed line pointing out of jet based cleaning mechanism **118***d***1**) (e.g., a gas jet such as an air jet, a CO_2 jet, a jet of sand blasting material, a jet of bead blast material, etc.) is directed toward tip **104'** of wire bonding tool **104** within vessel **118***d***3** for cleaning debris from tip **104'** of wire bonding tool **104** (and/or the other bond head elements within vessel **118***d***3**).

Referring now to FIGS. **8**A-**8**D, a cleaning system **118***e* is provided. Cleaning station **118***e* includes a plurality of pre-form structures **118***e***2** on substrate **118***e***1**. Pre-form structures **118***e***2** may have a shape corresponding to at least a portion of tip **104'** of the wire bonding tool **104** (e.g., groove **104***b* of tip **104'**). Pre-form structures **118***e***2** are configured to remove debris **104***c* from wire bonding tool **104**. The cleaning operation of cleaning station **118***e* may utilize an ultrasonic generator carrying wire bonding tool **104**, where the ultrasonic generator is part of bond head assembly **102** (such ultrasonic generators are well known to be included in bond head assemblies of wire bonding machines, for ultrasonically bonding wire to a bonding location). FIG. **8**B illustrates wire bonding tool **104** rotated 90 degrees with respect to the position shown in FIG. **8**A (this change is arbitary, and is not required within the scope of the invention). FIG. **8**B illustrates debris **104***c* deposited within groove **104***b* of tip **104'** of wire bonding tool **104**. FIG. **8**C illustrates groove **104***b* engaging one of pre-form structures **118***e***2** (e.g., through the motion of bond head assembly **102**). Ultrasonic energy may be applied (e.g., using an ultrasonic generator included in bond head assembly **102**), and then wire bonding tool **104** is raised (e.g., through the motion of bond head assembly **102**) above pre-form structure **118***e***2** as shown in FIG. **8**D. Debris **104***c* has been transferred to the right-most pre-form structure **118***e***2**, and channel **104***b* is shown substantially free from debris **104***c*. In a specific exemplary case, pre-form structures **118***e***2** may be copper structures (e.g., formed of copper wire or the like) which are particularly suited for removal of, for example, aluminum debris from groove **104***b* of wire bonding tool **104**.

Substrate **118***e***1** of cleaning station **118***e* may be considered a consummable substrate, in that after a number of cleaning operations (e.g., one cleaning operation per pre-form structure **118***e***2** included on substrate **118***e***1**), substrate **118***e***1** may be replaced.

Of course, other shapes (e.g., different than shapes corresponding to the groove of the wire bonding tool) may be utilized in connection with transferring debris using ultrasonic energy. For example, a flat plate or substrate (e.g., a ceramic plate, a plate with suitable surface roughness, etc.) may be contacted by working surface **104***a* of wire bonding tool **104**, and then ultrasonic energy (and/or a motion profile provided by bond head assembly **102**) may be applied to remove certain debris from tip **104'** of wire bonding tool **104**.

After a cleaning operation (e.g., using any of cleaning stations **118***a*, **118***b*, **118***c*, **118***d*, **118***e*, or any other cleaning station within the scope of the invention), an additional step in cleaning may be utilized at a discard station **120** (e.g., see FIG. **1**). Such a discard station may be used to remove (e.g., using a forced gas such as air, or vacuum, or other systems) debris from tip **104'** of wire bonding tool **104**. Such debris may be (i) debris released from wire bonding tool **104** during the previously described cleaning operations, (ii) debris resulting from broken bristles of a brush in applications where the cleaning station includes at least one brush, etc.), etc. FIGS. **9**A-**9**D illustrate an example of such a discard station **120**. Discard station **120** includes a vessel **120***a* (including a lid **120***a***1**), and gas/vacuum source **120***b* (e.g., air piping, gas piping, vacuum piping, etc). FIG. **9**B illustrates debris **104***c* on tip **104'**, wire guide **108***a*, and blade **106**. As shown in FIG. **9**C, through motions of bond head assembly **102**, a portion of wire bonding tool **104** (and perhaps other bond head elements such as a portion of wire guide assembly **108** and/or blade **106**) have been brought into vessel **120***a* through an aperture of lid **120***a***1**. Through the operation of gas/vacuum source **120***b* (e.g., air or other gas forced into vessel **120***a* from gas/vacuum source **120***b*), debris **104***c* is removed from tip **104'**, wire guide **108***a*, and blade **106** (see FIGS. **9**D-**9**E, where such elements are free from debris **104***c* as compared to FIG. **9**B). Of course, alternative discard stations **120** are contemplated (as opposed to the illustrated forced gas/vacuum based systems), such as, for example, magnetic based systems for attracting ferrous based debris.

After the cleaning operation (e.g., performed at one of the inventive cleaning stations, with or without further cleaning at discard station **120**) is complete, realignment of the end portion of the wire **103** may be desired, for example, to

perform further wire bonding operations. The end portion of wire **103** may be out of position because of the operations at bond off station **114** and/or separation station **116**. Further, cleaning and other operations as described herein may result in misalignment of the end portion of wire **103**. Thus, it may be desirable to realign the end portion of wire **103** using realign station **122** (e.g., see FIG. **1**). FIGS. **10**A-**10**D illustrate an exemplary realign station **122**.

Realign station **122** includes block **122***a* supported by wire bonding machine support structure **101**. Block **122***a* defines v-shaped groove **122***a***1** which extends into linear groove **122***a***2**. FIGS. **10**B-**10**C are top views illustrating a process of re-aligning an end portion of wire **103** (e.g., to be in line with groove **104***b* of tip **104'** of wire bonding tool **104**). As shown in FIG. **10**B, through motions of bond head assembly **102** (not shown), wire **103** (including the "bent" end portion **103'**) is engaged in v-shaped groove **122***a***1**, and then into linear groove **122***a***2** (see FIGS. **10**C-**10**D). As shown in FIG. **10**D, the end portion **103'** of wire **103** is now realigned to be in line with groove **104***b* of tip **104'** of wire bonding tool **104**.

After cleaning (and any other processes as desired herein, such as realignment), inspection station **124** (see FIG. **1**) may be used to inspect various elements. For example, inspection station **124** may be used to confirm that wire bonding tool **104** (e.g., tip **104'** of wire bonding tool **104**) is now clean. Further, inspection station **124** may be used to determine that the end portion of wire **103** is properly aligned for entry into groove **104***b* of tip **104'** of wire bonding tool **104**. Inspection station **124** may include one or more vision system elements (e.g., cameras, optical elements such as lenses, mirrors, etc.) to image the desired elements. Inspection station **124** may be in communication with a computer of wire bonding machine **104**, for example, to allow for image processing of images generated by vision system elements of inspection station **124**. Through this image processing, determinations may be made regarding such as, for example: whether tip **104'** of wire bonding tool **104**) is now clean; whether tip **104'** of wire bonding tool **104**) needs cleaning in the first place; whether the end portion of wire **103** is properly aligned for entry into groove **104***b* of tip **104'**; etc. While inspection station **124** is shown downstream of realign station **122** in FIG. **1**, it is understood that inspection station **124** may be used at any time. For example, inspection station **124** may be used to determine that realignment of end portion of wire **103** is needed—thereby initiating the realignment at realignment station **122**. In another example, inspection station **124** may be used to determine that a further cleaning operation (e.g., at discard station **120**) should be performed.

In accordance with any of the cleaning operations described herein, an ultrasonic generator (e.g., carrying the wire bonding tool, and included as part of the bond head assembly, as known to those skilled in the art) may be used to provide ultrasonic motion to the tip of the wire bonding tool during at least a portion of such cleaning operations at any of the cleaning stations, or at any of the other stations of wire bonding machine **100** (see FIG. **1**).

After cleaning, and inspection, and any other desired processes as described herein, the wire guide may now desirably be returned to the engagement position. For example, this maybe accomplished by reversing the process described above with respect to FIGS. **3**A-**3**D. That is, locking mechanism **110** may be actuated as described above to lock the wire guide assembly **108** back into the engagement position. Following this action, and any other desired checks (e.g., a bond off prior to resuming wire bonding, a pull test of the bond off prior to resuming wire bonding, etc.), the wire bonding machine may now be ready to resume wire bonding operations.

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is claimed:

1. A method of cleaning a tip of a wire bonding tool on a wire bonding machine, the method comprising the steps of:

(a1) performing a bond off process at a bond off station of the wire bonding machine to bend an end portion of a wire away from a working surface of the wire bonding tool, the wire being engaged with a bond head assembly of the wire bonding machine, the bond off process including steps of (i) ultrasonically bonding the end portion of the wire to a bond off substrate of the bond off station, and (ii) tearing the wire from a bonded portion of the end portion of the wire by moving the bond head assembly to bend the end portion of the wire away from the wire bonding tool while tearing the wire;

(a2) moving the end portion of the wire further away from the working surface of the wire bonding tool through the action of a moveable wire guide assembly of the bond head assembly such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine;

(b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a1) and step (a2), wherein the cleaning station includes at least one brush, the cleaning of step (b) being automatically triggered by the occurrence of a predetermined event;

wherein, during step (b), while the tip of the wire bonding tool is in contact with the at least one brush, the bond head assembly of the wire bonding machine follows a predetermined motion profile for moving the tip of the wire bonding tool with respect to the at least one brush; and

(c) realigning the end portion of the wire with a realignment station such that the end portion of the wire is realigned with a groove of the tip of the wire bonding tool after step (b).

2. The method of claim **1** wherein the moveable wire guide assembly is provided on the wire bonding machine for guiding the wire to a position beneath a bonding surface of the wire bonding tool, wherein step (a2) includes moving the moveable wire guide assembly from (i) an engagement position with respect to the wire bonding tool to (ii) a non-engagement position with respect to the wire bonding tool, and wherein step (b) includes the cleaning of at least the portion of the tip of the wire bonding tool when the wire guide is in the non-engagement position.

3. The method of claim **1** wherein the predetermined motion profile includes a zig-zag motion path.

4. The method of claim **1** wherein the bond head assembly carries the wire bonding tool and is configured to move the wire bonding tool along a plurality of axes.

5. The method of claim **4** wherein in connection with step (b) the bond head assembly moves the wire bonding tool into a position such that the tip of the wire bonding tool is in contact with the at least one brush for the cleaning of at least the portion of the tip.

6. The method of claim **1** further comprising a step of inspecting the tip of the wire bonding tool after step (b).

7. The method of claim 1 further comprising a step of collecting debris resulting from the cleaning of at least the portion of the tip of the wire bonding tool with the cleaning station using a debris collection system.

8. The method of claim 1 wherein a level of cleanliness of the wire bonding tool is determined at an inspection location after step (b).

9. The method of claim 1 wherein a force sensor is used to measure a force during the cleaning.

10. The method of claim 1 wherein, during step (a2), the wire bonding machine uses the moveable wire guide assembly to provide a desired separation of the end portion of the wire and the working surface of the wire bonding tool.

11. The method of claim 1 wherein, during step (a2), the wire is moved using the movable wire guide assembly to provide a desired separation of the end portion of the wire and the working surface of the wire bonding tool, the movement of the moveable wire guide assembly being provided by at least one of a mechanical interlock and a motion system.

12. The method of claim 11 wherein the movement of the movable wire guide assembly is a swivel action.

13. The method of claim 1 further comprising a step of determining a first touch position by moving the wire bonding tool to a location on top of the at least one brush, prior to step (b).

14. A method of cleaning a tip of a wire bonding tool on a wire bonding machine, the method comprising the steps of:

(a1) performing a bond off process at a bond off station of the wire bonding machine to bend an end portion of a wire away from a working surface of the wire bonding tool, the wire being engaged with a bond head assembly of the wire bonding machine, the bond off process including steps of (i) ultrasonically bonding the end portion of the wire to a bond off substrate of the bond off station, and (ii) tearing the wire from a bonded portion of the end portion of the wire by moving the bond head assembly to bend the end portion of the wire away from the wire bonding tool while tearing the wire;

(a2) moving the end portion of the wire further away from the working surface of the wire bonding tool through the action of a moveable wire guide assembly of the bond head assembly such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine;

(b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a1) and step (a2), wherein the wire bonding machine includes the moveable wire guide assembly for guiding the wire to a position beneath the working surface of the wire bonding tool, the moveable wire guide assembly being configured for automated movement between (i) an engagement position with respect to the wire bonding tool and (ii) a non-engagement position with respect to the wire bonding tool, wherein the cleaning station includes at least one brush, the cleaning of step (b) being automatically triggered by the occurrence of a predetermined event;

wherein, during step (b), while the tip of the wire bonding tool is in contact with the at least one brush, the bond head assembly of the wire bonding machine follows a predetermined motion profile for moving the tip of the wire bonding tool with respect to the at least one brush; and

(c) realigning the end portion of the wire with a realignment station such that the end portion of the wire is realigned with a groove of the tip of the wire bonding tool after step (b).

15. The method of claim 14 wherein a level of cleanliness of the wire bonding tool is determined at an inspection location after step (b).

16. The method of claim 14 wherein a force sensor is used to measure a force during the cleaning.

17. The method of claim 14 wherein, during step (a2), the wire bonding machine uses the moveable wire guide assembly to provide a desired separation of the end portion of the wire and the working surface of the wire bonding tool.

18. The method of claim 14 wherein, during step (a2), the wire is moved using the movable wire guide assembly to provide a desired separation of the end portion of the wire and the working surface of the wire bonding tool, the movement of the moveable wire guide assembly being provided by at least one of a mechanical interlock and a motion system.

19. The method of claim 18 wherein the movement of the movable wire guide assembly is a swivel action.

20. The method of claim 14 further comprising a step of determining a first touch position by moving the wire bonding tool to a location on top of the at least one brush, prior to step (b).

21. A method of cleaning a tip of a wire bonding tool on a wire bonding machine, the method comprising the steps of:

(a1) performing a bond off process at a bond off station of the wire bonding machine to bend an end portion of a wire away from a working surface of the wire bonding tool, the wire being engaged with a bond head assembly of the wire bonding machine, the bond off process including steps of (i) ultrasonically bonding the end portion of the wire to a bond off substrate of the bond off station, and (ii) tearing the wire from a bonded portion of the end portion of the wire by moving the bond head assembly to bend the end portion of the wire away from the wire bonding tool while tearing the wire;

(a2) moving the end portion of the wire further away from the working surface of the wire bonding tool through an action of a moveable wire guide assembly of the bond head assembly such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine; and

(b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a1) and step (a2), wherein the cleaning station includes at least one brush, the cleaning of step (b) being automatically triggered by the occurrence of a predetermined event; and

(c) realigning the end portion of the wire with a realignment station such that the end portion of the wire is realigned with a groove of the tip of the wire bonding tool after step (b),

wherein, during step (b), while the tip of the wire bonding tool is in contact with the at least one brush, the bond head assembly of the wire bonding machine follows a predetermined motion profile for moving the tip of the wire bonding tool with respect to the at least one brush,

wherein, during step (b), a debris collection system is used including at least one of (i) a magnetic system for attracting ferrous debris and (ii) a vessel for at least partially surrounding a cleaning operation for collecting debris.

22. A method of cleaning a tip of a wire bonding tool on a wire bonding machine, the method comprising the steps of:

(a1) performing a bond off process at a bond off station of the wire bonding machine to bend an end portion of a wire away from a working surface of the wire bonding tool, the wire being engaged with a bond head assembly of the wire bonding machine, the bond off process including steps of (i) ultrasonically bonding the end portion of the wire to a bond off substrate of the bond off station, and (ii) tearing the wire from a bonded portion of the end portion of the wire by moving the bond head assembly to bend the end portion of the wire away from the wire bonding tool while tearing the wire;

(a2) moving the end portion of the wire further away from the working surface of the wire bonding tool through an action of a moveable wire guide assembly of the bond head assembly such that the tip of the wire bonding tool is accessible to a cleaning station of the wire bonding machine;

(b) cleaning at least a portion of the tip of the wire bonding tool with the cleaning station after step (a1) and step (a2), wherein the wire bonding machine includes the moveable wire guide assembly for guiding the wire to a position beneath the working surface of the wire bonding tool, the moveable wire guide assembly being configured for automated movement between (i) an engagement position with respect to the wire bonding tool and (ii) a non-engagement position with respect to the wire bonding tool, wherein the cleaning station includes at least one brush, the cleaning of step (b) being automatically triggered by the occurrence of a predetermined event; and

(c) realigning the end portion of the wire with a realignment station such that the end portion of the wire is realigned with a groove of the tip of the wire bonding tool after step (b),

wherein, during step (b), while the tip of the wire bonding tool is in contact with the at least one brush, the bond head assembly of the wire bonding machine follows a predetermined motion profile for moving the tip of the wire bonding tool with respect to the at least one brush,

wherein, during step (b), a debris collection system is used including at least one of (i) a magnetic system for attracting ferrous debris and (ii) a vessel for at least partially surrounding a cleaning operation for collecting debris.

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